Environmental Monitoring Report for the Point Lepreau, N.B., Nuclear Generating Station -1984

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Les rapports techniques peuvent être cités comme des publications complètes. Le titre exact paraît au-dessus du résumé de chaque rapport. Les rapports techniques sont résumés dans la revue *Résumés des sciences aquatiques et halieutiques*, et ils sont classés dans l'index annuel des publications scientifiques et techniques du Ministère.

Les rapports techniques sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre. Les rapports épuisés seront fournis contre rétribution par des agents commerciaux.

Les établissements des Sciences et levés océaniques dans les régions et à l'administration centrale ont cessé de publier leurs diverses séries de rapports en décembre 1981. Une liste complète de ces publications figure dans le volume 39, Index des publications 1982 du *Journal canadien des sciences halieutiques et aquatiques*. La série actuelle a commencé avec la publication du rapport numéro 1 en janvier 1982.

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ENVIRONMENTAL MONITORING REPORT FOR THE POINT LEPREAU, N.B., NUCLEAR GENERATING STATION - 1984

by

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ABSTRACT

Nelson, R.W.P., Ellis, K.M., and Smith, J.N. 1986. Environmental monitoring report for the Point Lepreau, N.B., nuclear generating station - 1984. Can. Tech. Rep. Hydrogr. Ocean Sci. No. 75: vi + 154 p.

The Point Lepreau Environmental Monitoring Program (PLEMP) has been established within the Department of Fisheries and Oceans to assess the environmental impact of radioactive, thermal, and chemical releases from the Point Lepreau, N.B. Nuclear Generating Station (NGS) located on the Bay of Fundy. This report contains the results for the second year of the operational phase of the monitoring program. Emphasis has been placed on those areas where effects from the NGS operation were expected to be observed.Further studies were carried out on the characterization of the thermal plume during several pre-arranged tritium releases. Attention was given to tritium levels at the outfall, in the atmosphere and in biological samples. An initial attempt was made to relate the distribution of tritium in the Point Lepreau area in various phases to local meteorological conditions. Radionuclide levels in lichen, including, for the first time, aerial lichen on a regular basis, an efficient accumulator of atmospheric particulates were monitored. In addition, radionuclide measurements were made on samples collected during the pre-operational phase from the major environmental reservoirs and these radioactivity levels were compared to previous measurements to assess the impact of the operation of the NGS. The purpose of this program is to provide government with a comprehensive scientific basis upon which to assess the environmental implications of the operation of nuclear reactors in coastal regions.

RÉSUMÉ

Nelson, R.W.P., Ellis, K.M., and Smith, J.N. 1986. Environmental monitoring report for the Point Lepreau, N.B., nuclear generating station - 1984. Can. Tech. Rep. Hydrogr. Ocean Sci. No. 75: vi + 154 p.

On a créé, au sein du ministère des Pêches et des Océans, le Programme de surveillance écologique de Pointe Lepreau afin d'évaluer les répercussions environnementales des rejets radioactifs, thermiques et chimiques par la centrale nucléaire de Pointe Lepreau située sur la baie de Fundy (Nouveau-Brunswick). Le rapport contient les résultats de la deuxième année d'activité de la phase opérationnelle du programme. On s'est intéressé de façon toute particulière aux secteurs où les effets étaient le plus susceptibles de se manifester. On a poursuivi les études pour caractériser le panache thermique produit par plusieurs rejets expérimentaux de tritium. On s'est penché plus particulièrement sur les concentrations de tritium au point d'évacuation, dans l'atmosphère et dans les échantillons biologiques. On a tenté d'établir un rapport entre la distribution du lithium dans la région de Pointe Lepreau, dans diverses phases, aux conditions météorologiques locales. On a mesuré la concentration de radionucléides dans les lichens, y compris, pour la première fois, dans les lichens aériens, puisque ces organismes accumulent efficacement les particules en suspension dans l'atmosphère. De plus, durant la phase précédant la mise en exploitation, on a mesuré la concentration de radionucléides dans des échantillons prélevés dans les principaux réservoirs environnementaux pour ensuite les comparer avec celles relevées précédemment, afin d'evaluer toute répercussion de l'exploitation de la centrale. Le programme a pour but de fournir aux gouvernement une solide base de données scientifiques qui permettra d'évaluer les répercussions environnementales de l'exploitation de réacteurs nucléaires dans les zones côtières.

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1.0 INTRODUCTION

The first nuclear power generating facility built in the Atlantic Provinces is situated at Point Lepreau, New Brunswick, approximately 40 km southwest of the city of Saint John (Fig. 1). The Point Lepreau Nuclear Generating Station (NGS) houses a CANDU 600 reactor which is cooled using a "once through" seawater cooling system with an off-shore intake and discharge directly to the Bay of Fundy. The NGS attained criticality in July of 1982 and has been operating at full power since March of 1983. In response to the unique environmental constraints posed by the proximity of the NGS to the ocean, the Point Lepreau Environmental Monitoring Program (PLEMP) has been established within the Department of Fisheries and Oceans to assess the long term environmental impact of the operation of the Point Lepreau NGS.

PLEMP has been designed to provide a broad understanding of the distribution processes affecting radioactivity released from the NGS into the surrounding environment. The sampling program includes the major environmental reservoirs such as seawater, sediments, atmospheric gases and particulates and marine flora and fauna. Measurements of radioactivity made on these samples, combined with the determination of other oceanographic and ecological parameters, are being used to identify transport pathways for radionuclides through various environmental media and to determine fluxes of radionuclides along specific pathways.

The responsibility for maintaining PLEMP has been assigned to the Atlantic Environmental Radiation Unit (AERU) which is a section of the Chemical Oceanography Division of the Atlantic Oceanographic Laboratory, Department of Fisheries and Oceans located at the Bedford Institute of Oceanography, Dartmouth, Nova Scotia. In addition, a working group on environmental radioactivity, composed of scientists in various disciplines and departments in the Atlantic region (Appendix 1), has been established to ensure that the concerns and responsibilities of different agencies with respect to Point Lepreau are addressed in a co-ordinated manner by PLEMP. The working group advises AERU on field activities, reviews reports produced during this program and members of the working group act as scientific authorities for contracts administered by AERU.

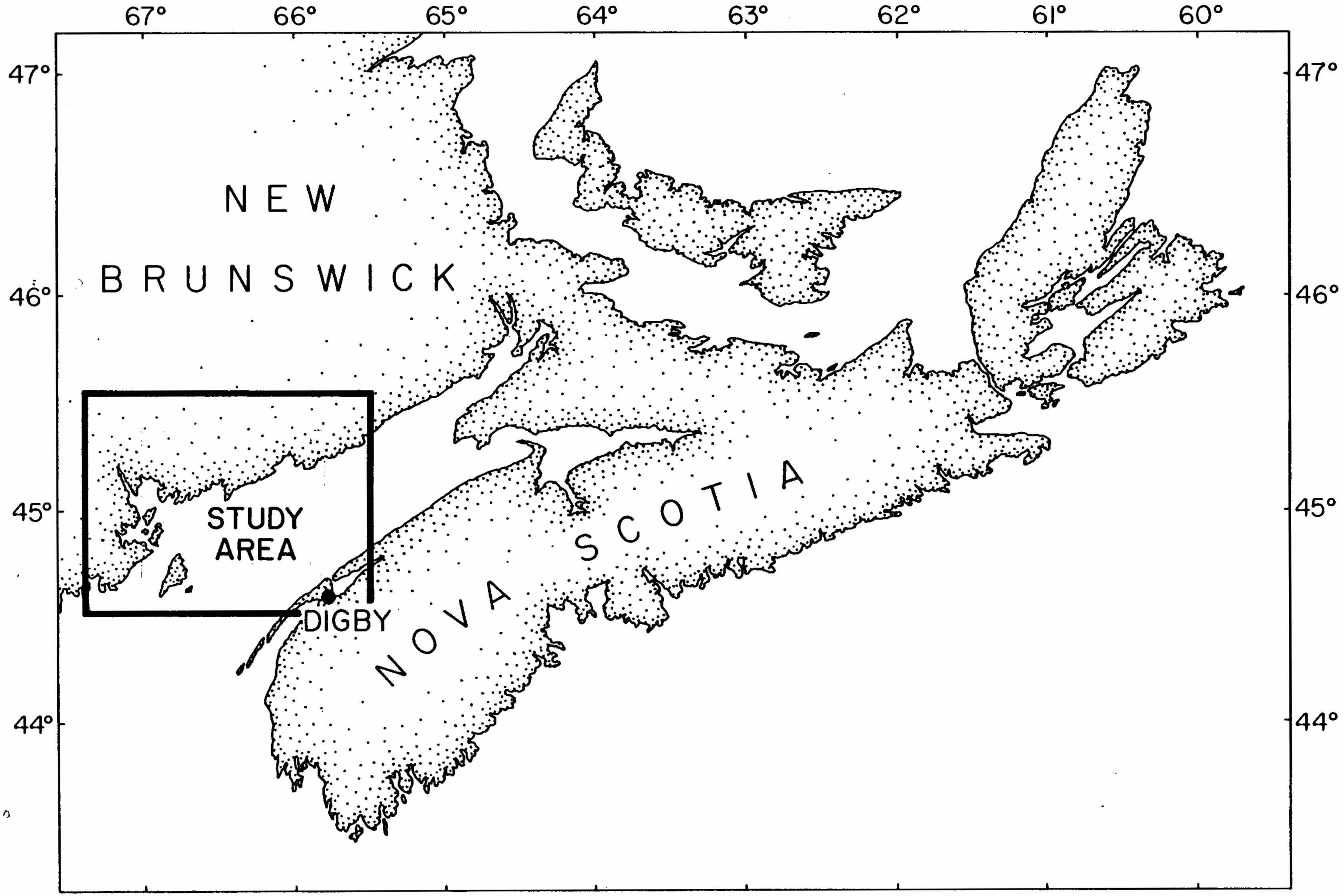

Figure 1. Location of the Point Lepreau study area in the Bay of Fundy.

PLEMP has been designed and carried out in two phases. The pre-operational program was started in 1979 and was designed to characterize the natural and fallout radioactivity background in the Point Lepreau area and investigate the predominant transport processes at work in the region. Pre-operational data are summarized in Bishop *et al.* (1980), Smith *et al.* (1981,82) and Ellis *et al.* (1984).

The operational phase of PLEMP began in 1983 with the ultimate goal of providing the government with a sound scientific basis upon which to assess the environmental implications of the operation of nuclear reactors in coastal environments. The results for the first year of the operational program 1983 are summarized in Nelson *et al.* (1985). 1984 marks the second full year for the operational monitoring program. Results from 1983 (Nelson *et al.* 1985) indicated areas for which impacts from the operation of the NGS were apparent and efforts have been directed towards these areas. Of particular interest were the thermal plume produced in the Bay of Fundy as a result of the discharge of waste heat from the cooling water outfall, tritium levels in biota and the atmosphere in the immediate vicinity of the NGS, and radionuclide levels in lichen, a known accumulator of atmospheric material. In addition, activity measurements have continued for samples collected from the major environmental reservoirs and levels compared with those observed during previous years to document the environmental impact associated with the operation of the NGS.

This report, the sixth in a series of annual monitoring reports for the Point Lepreau NGS, describes work carried out during 1984 and is the second in a series covering the operational phase of PLEMP.

2.0 MARINE ENVIRONMENT

2.1 Water Circulation

Water circulation patterns in the Bay of Fundy are dominated by a cyclonic, anti-clockwise 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 et al. 1965). Water movement in the Bay of Fundy is characteristic of simple estuarine circulation. Low salinity water dominated by inputs from the Saint John River (from which up to 60% of the freshwater input originates) flows out at the surface, while denser shelf and slope waters mix across the shelf break and enter the Bay of Fundy at depths predominantly below 100 meters.

Salinity-depth profiles have been constructed along a series of three transects, A, B and C, as in previous reports, from data collected July 10-16, 1984, during cruise 84-025 (Fig. 2), to illustrate the predominant characteristics of water circulation in the Point Lepreau area.

Three transects (shown in Figure 2) were chosen to approximate those examined during previous cruises. This is the first summer cruise for which salinity-depth diagrams were constructed and several features of summer water circulation in the Bay of Fundy are illustrated. In Figure 3, the salinity-depth diagram for transect A, which runs approximately east/west, indicates that the freshwater plume moves around Grand Manan Island to the east with little or no freshwater flowing between the Island and the mainland of New Brunswick. This differs from earlier cruises in the spring and winter where the fresh water plume splits around Grand Manan Island with lower salinity water moving both to the west and east of Grand Manan Island. Along transect C, which runs parallel to theNew Brunswick shore, the strongest effect of the freshwater plume is observed at stations 12 and 14 (Figure 4), further offshore than has been observed in previous cruises. The salinity-depth diagram, shown in Figure 5, for transect B, which runs northeast/southwest further serves to illustrate the offshore nature of the freshwater plume from the Saint John River.

The salinity - depth profiles constructed for Cruise 84-025 indicate that the summer is a time of reduced freshwater input and therefore stratification of the water column in the vicinity

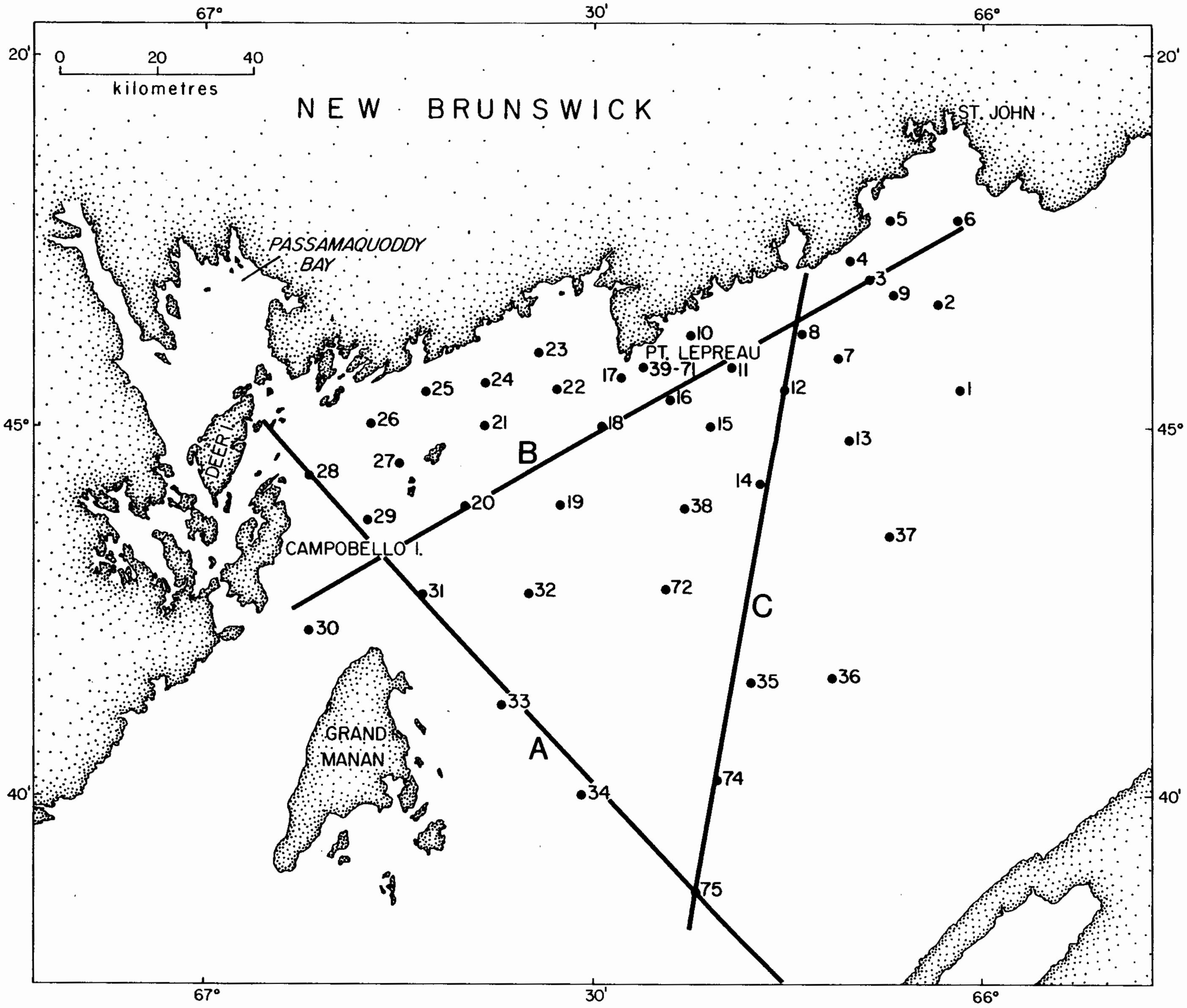

Figure 2. Station locations for cruise 84-025 and transect lines used for salinity depth profiles shown in Figures 3,4, and 5.

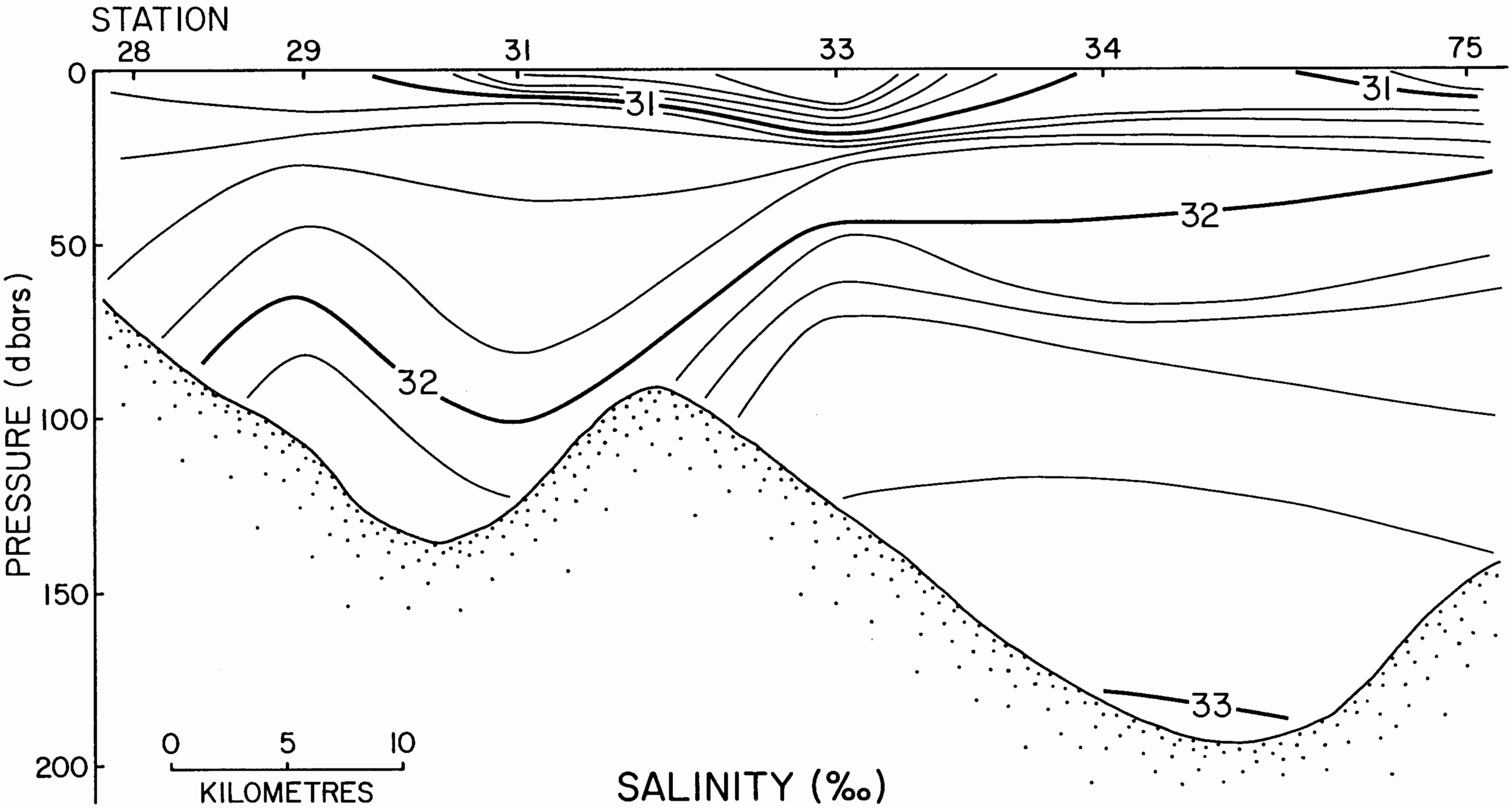

Figure 3. Salinity depth profile for transect A,shown in Figure 2.

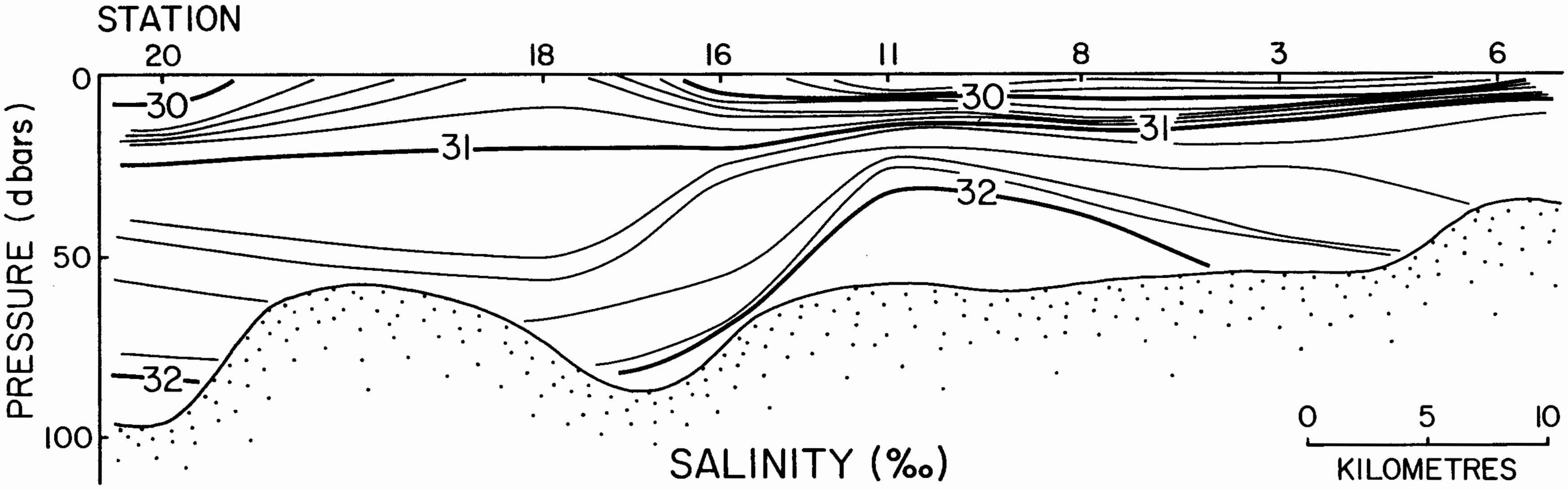

Figure 4. Salinity depth profile for transect B,shown in Figure 2.

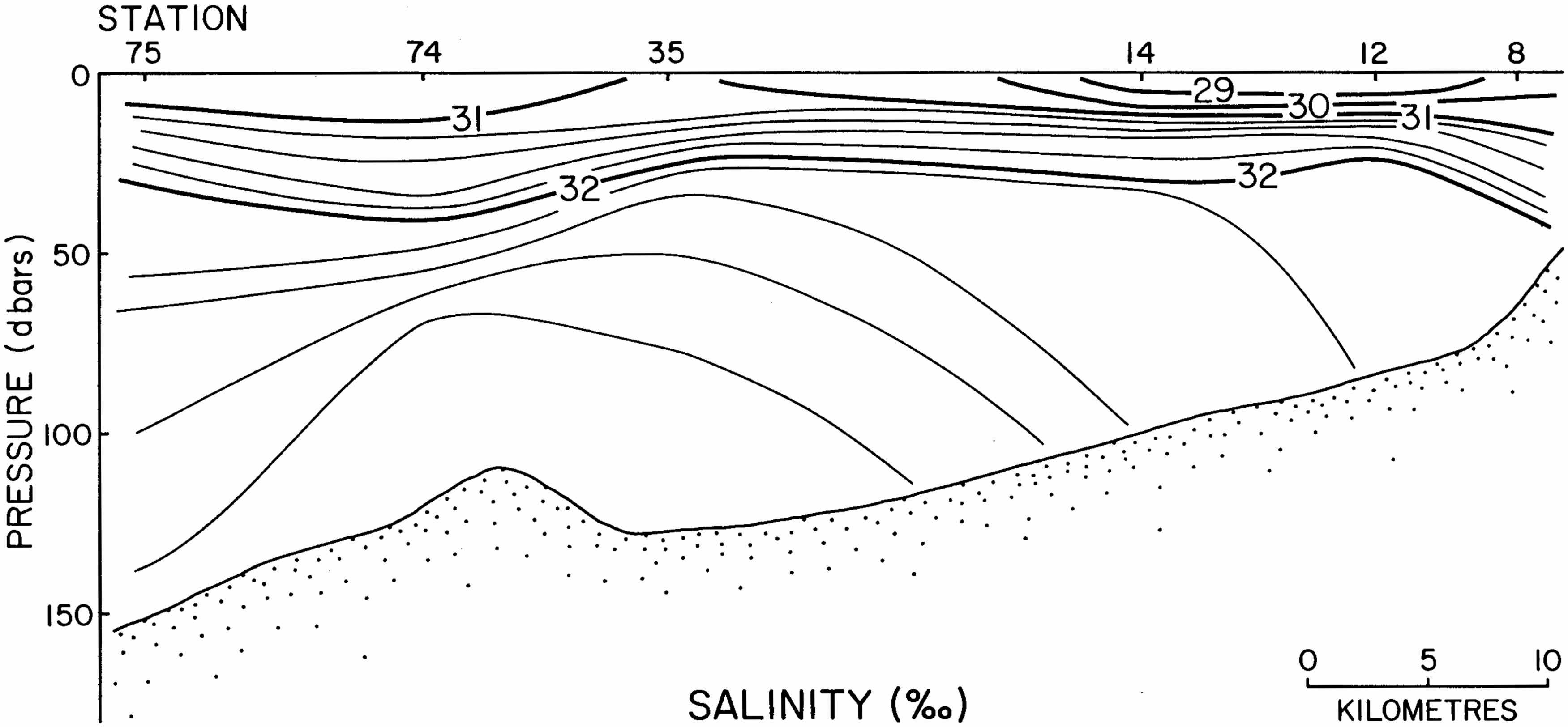

Figure 5. Salinity depth profile for transect C,shown in Figure 2.

of Point Lepreau is reduced. The freshwater plume travels further from shore than observed at other times of year and because of this, does not split around Grand Manan Island but stays to the west of the Island as it flows out of the Bay of Fundy.

In general, water circulation patterns in the Bay of Fundy are seasonal in nature and are largely controlled by the amount of freshwater input. The major portion of the freshwater plume originates from the Saint John River and moves along the New Brunswick coast at a varying distance offshore and then splits around Grand Manan Island. The spring is a time of high river runoff and of increased stratification and reduced vertical mixing. The summer is a period of reduced freshwater input where vertical mixing is not inhibited by the large freshwater surface layer present at times of high river runoff. The nature and extent of circulation patterns prevalent in the Bay of Fundy will be dependent on the magnitude and duration of freshwater input from the spring melt.

2.2 Effluent Releases

The release of radioactive materials to the environment is an inevitable consequence of the use of nuclear energy. Radionuclides may be discharged or released as a result of various processes involved in producing nuclear power, (e.g. neutron activation of deuterium which produces tritium and neutron activation of reactor support and encasement material creating activation products), to either the atmosphere or the marine environment. The effects that these releases have on a regional and global scale depend on several factors. The activity of the radionuclides released, the half life, the residence time of the nuclide in the transport medium and the possibility of resuspension and subsequent enrichment of radionuclides in the medium are all important factors governing the availability of released radionuclides. Thus a thorough knowledge of the source term for the input of radioactive waste to the environment is an essential facet of a monitoring program.

Emissions from the Point Lepreau NGS are closely monitored at the source under the Liquid Effluent Monitoring Program (LEM) conducted by the New Brunswick Electric Power

Commission (NBEPC). The liquid effluent monthly summary from the Point Lepreau NGS is presented in Table 1. Releases are reported as a percent of the Derived Emission Limit (DEL) that has been calculated for each radionuclide. The average emission rate for all nuclides declined from 1.5 x 10^{-3}% DEL in 1983 to 6 x 10^{-4}% DEL in 1984. There was, however, a change in the patterns of release for individual radionuclides. Releases of I-131 and Ru-103 decreased by two orders of magnitude. The emission rates for all other radionuclides have increased including Mn-54, by 800 fold, Co-60 by a factor of 35 and tritium and Cr-51 by approximately an order of magnitude. The LEM program provides for the proper characterization of liquid effluent releases, which in turn can provide detailed information to aid in the determination of concentration factors, critical pathways and radionuclide migration.

2.3 Chemical Oceanography

Radionuclides discharged into the ocean by the nuclear industry are generally point source releases into coastal waters. Releases may be in the form of primary or secondary cooling waters, treated low level wastes, or accidental discharges (cooling water spills, ruptured fuel elements etc.). Speciation plays an important role in the fate of artificial radionuclides released into the oceans. Radionuclides discharged from nuclear generating stations often enter the oceans in different chemical forms from those of their stable analogues present in the receiving waters. If the attainment of equilibrium is slow, radionuclides and their stable analogues in the marine biosphere may exhibit significant behavioral differences. In addition, chemical forms and equilibrium situations may be different in biologically-active coastal water as compared to 'clean' open ocean water.

The chemical oceanography section of PLEMP was designed to help characterize the general water column chemistry of the western Bay of Fundy and to establish baseline levels of radionuclides and their stable analogues in order to predict the transport properties of radionuclides released from the Point Lepreau NGS. The operational phase of PLEMP continues to include the measurement of important hydrographic parameters,such as temperature, salinity,

Table 1. Liquid Effluent Monthly Summary for 1984 from Point Lepreau NGS.

	Monthly DEL (Bq)	% Monthly DEL												Total Bq Released This Year	Average % DEL To Date	Total Bq Released 1983
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec			
H-3	4E+18	1E-04	6E-05	4E-05	3E-05	8E-05	9E-05	8E-05	4E-04	3E-04	1E-04	6E-05	3E-04	6.8E+13	1.5E-04	9.1E+12
Cr-51	2E+15	3E-06	4E-06	9E-08	1E-06	6E-07	4E-07	2E-07	9E-07	4E-04	1E-04	1E-06	1E-05	1.1E+10	4.7E-05	7.7E+08
Mn-54	2E+13	--------	2E-06	--------	8E-07	2E-06	7E-07	--------	3E-06	6E-04	4E-04	5E-06	4E-05	2.7E+08	9.2E-05	3.4E+05
Co-58	7E+13	--------	--------	--------	--------	--------	--------	--------	--------	8E-06	4E-06	--------	--------	9.0E+06	1.0E-06	------------
Fe-59	1E+13	3E-05	1E-04	2E-06	8E-06	--------	--------	4E-06	8E-06	2E-04	8E-06	3E-06	5E-04	8.2E+07	7.2E-05	1.8E+07
Co-60	3E+13	1E-06	2E-05	5E-06	1E-06	8E-06	3E-06	4E-07	3E-06	4E-04	4E-04	2E-05	6E-05	2.6E+08	8.1E-05	7.5E+06
Zn-65	9E+12	--------	--------	--------	2E-06	--------	--------	--------	--------	--------	3E-06	--------	--------	4.6E+05	4.1E-07	------------
Zr-95	6E+13	1E-05	2E-05	1E-05	4E-05	2E-04	3E-05	3E-05	2E-05	3E-05	8E-06	2E-05	2E-05	2.8E+08	3.9E-05	5.3E+07
Nb-95	6E+13	3E-05	4E-05	3E-05	7E-05	4E-05	7E-05	5E-05	3E-05	6E-05	2E-05	3E-05	4E-05	5.1E+08	7.1E-05	8.4E+07
Ru-103	1E+14	--------	--------	--------	--------	--------	7E-08	--------	--------	--------	--------	--------	--------	7.5E+04	5.7E-09	6.1E+06
Ru-106	2E+13	6E-06	--------	--------	--------	--------	7E-06	--------	3E-06	--------	--------	--------	--------	3.6E+06	1.3E-06	------------
Ag-110m	1E+13	--------	--------	--------	--------	--------	--------	1E-04	9E-07	--------	--------	--------	--------	1.1E+05	7.3E-08	2.8E+05
I-131	1E+13	--------	--------	--------	--------	--------	--------	4E-07	2E-04	6E-05	4E-06	--------	7E-06	4.8E+07	3.4E-05	2.1E+09
Cs-134	4E+13	--------	--------	--------	--------	--------	--------	--------	--------	5E-06	2E-05	7E-07	4E-06	1.1E+07	2.3E-06	1.8E+07
Cs-137	7E+13	--------	--------	--------	2E-06	4E-06	--------	--------	--------	2E-05	5E-05	9E-06	1E-05	6.1E+07	7.6E-06	------------
Ba-140	2E+14	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	------------	------------	------------
La-140	2E+14	--------	--------	--------	--------	--------	--------	--------	1E-07	--------	--------	--------	--------	2.0E+05	1.1E-08	6.4E+05
Ce-141	2E+14	--------	--------	--------	--------	--------	--------	--------	--------	1E-07	--------	--------	--------	3.0E+05	1.1E-08	7.0E+05
Ce-144	2E+13	--------	--------	6E-06	--------	--------	4E-06	--------	--------	--------	--------	--------	--------	1.9E+06	8.1E-07	8.0E+06

nutrients, and suspended particulate matter, and, in addition, monitors the levels of Cs-137, H-3, and plutonium in particular and gamma-emitting radionuclides, in general, both in the water column and sediments. The information collected in the post-operational phase of the program can be compared to pre-operational data to assess any post-operational releases of radioactivity. In addition, information on water circulation patterns, dispersion rates and particle transport processes in the Point Lepreau region is being continually updated.

2.3.1 Radionuclides - Water Column

The July 1984 cruise, 84-025, was the second in a series of post-operational cruises conducted by AERU. The seawater sampling procedures and the analytical methods used at the AERU laboratory have been described previously (Ellis *et al.* 1984). Briefly, 50 litre water samples were collected at surface and bottom water depths and the seawater samples were passed through columns consisting of: (1) a 0.3 micrometre pore size filter to remove particulates; (2) chelex-100 ion exchange resin to adsorb activation products, such as Co-60 and Mn-54; and (3) a KCFC column (potassium cobalt ferrocyanide) that absorbs Cs-137 (Figure 6). Samples were also collected and analyzed for nutrients, salinity and tritium. In addition, thermal plume studies were undertaken to determine the effects, if any, of thermal releases from the Point Lepreau NGS. The sampling matrices and nuclear instrumentation used in this program are summarized in Table 2.

2.3.1.1 Cs-137 Activity in Seawater

Cs-137 is a relatively long lived ($t_{1/2} = 30.2$ years) fission product which originates mainly from nuclear weapons testing programs and nuclear power production. Cesium is present in seawater primarily as Cs^{+1} and is expected to be found almost entirely in its dissolved ionic state (Coughtrey *et al.* 1983). In addition, it is one of the few fission products that is present in readily detectable quantities in the ocean today that will be released from the NGS.

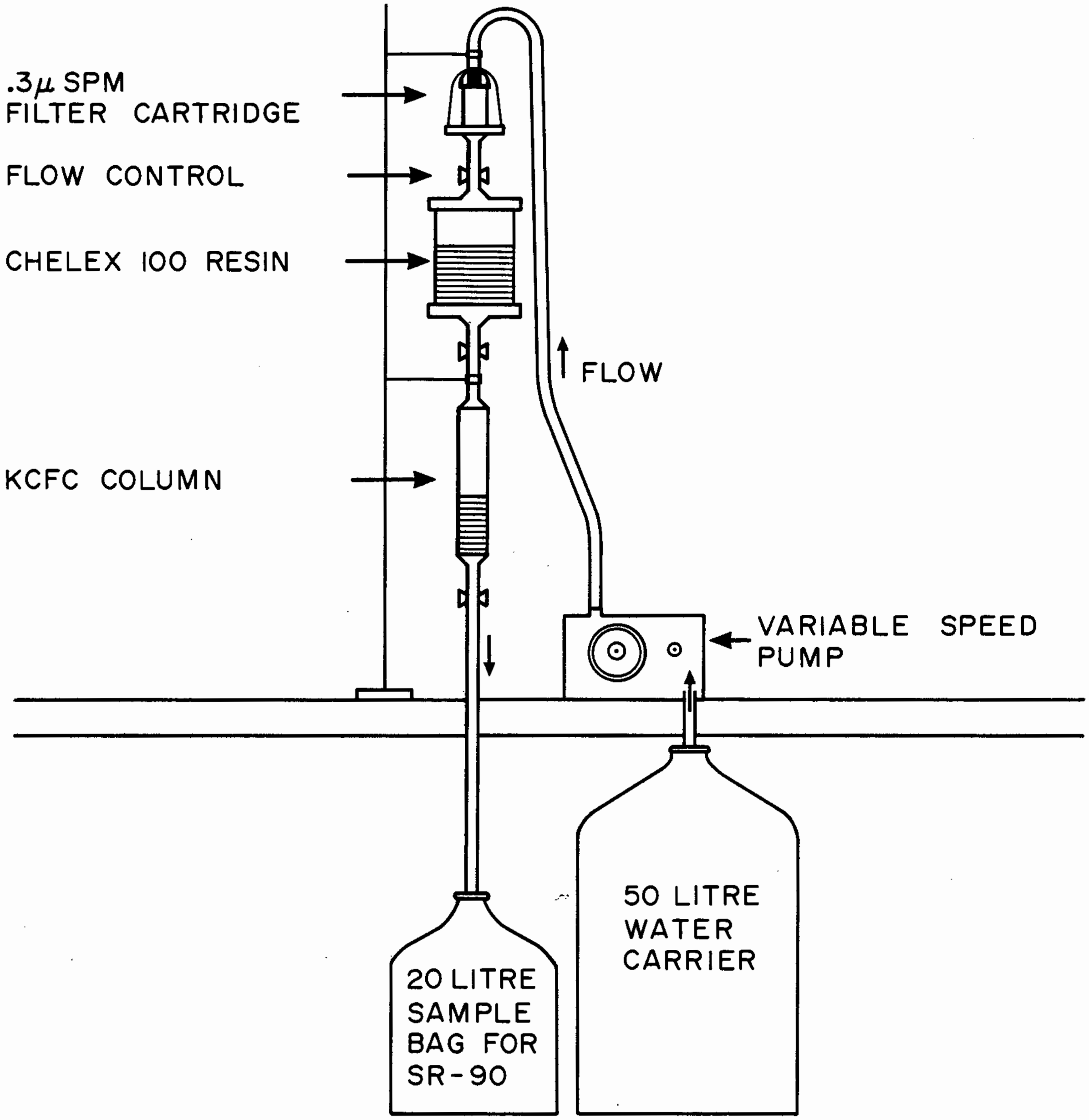

Figure 6. Schematic diagram of column used to concentrate radionuclides from seawater.

Table 2. Summary of nuclear instrumentation used in the AERU Laboratory.

Nuclide	Environmental Phase	Counting Matrix	Detection System
Cs-137	Seawater	KCFC	Ge and NaI Detectors
Cs-137	SPM	Filter Cartridge (0.3 µm)	Ge Detector
Cs-137	Sediment	Dried Bulk Sediment	Ge and NaI Detectors
Sr-90	Seawater, SPM, and Sediment	Y-90 on Filter Paper	Alpha/Beta Counter
Gamma emitters	Seawater	Chelex-100 Eluate	Ge Detector
Gamma emitters	SPM	Filter Cartridge (0.3 µm)	Ge Detector
H-3	Seawater	Gel (Water/Cocktail)	Liquid Scintillation Counter
Pb-210 (Po-210)	SPM, Sediments	Ag,Ni Discs	Alpha Spectrometer (Surface Barrier Detectors)
Pu-239,240	Sediment	Steel Disc	Alpha Spectrometer
Ra-226	Sediment	Ra-222 Gas	Gas Phase Scintillation Counter
Ra-226	Sediment	Bi-214 in Dried Bulk Sediment	Ge Detector

Cs-137 results for sea water samples collected during the summer 1984 cruise, 84-025 are presented in Table 3. Activity measurements are reported in Becquerels (Bq) which are defined as a disintegration per second. Conversion factors for non-SI units of radioactivity are listed in Appendix 2. The mean Cs-137 activity found in sea water for all stations excluding the anchor station was 2.99 ± 0.50 mBq/ℓ (n = 28), with a range of 1.21 to 3.66 mBq/ℓ. Levels of Cs-137 found during cruise 84-025 fall within the range of Cs-137 activities measured during both the pre-operational and post-operational monitoring programs (Table 4). There was no strong correlation observed between Cs-137 activity and water depth, geographical location or salinity, a fact that is indicative of efficient tidal mixing in the Bay of Fundy.

Several of the filter cartridges were analysed for Cs-137. Less than 5% of the total Cs-137 in seawater is expected to be associated with suspended particulate matter (Kupferman *et al.* 1979) and the distribution coefficient, K_D for Cs-137, estimated from the following equation,

$$K_D = \frac{\textit{Activity on particles } (Bq/g)}{\textit{Activity in solution } (Bq/ml)}$$

is 3 x 10^3 with a range of 10^2 to 2 x 10^4 (IAEA 1985). Levels of particulate Cs-137 were generally below the detection limit of 0.4 mBq/ℓ corresponding to less than 10% of the Cs-137 associated with particles and a K_D of less than 5 x 10^4. One measured value of particulate Cs-137 of 0.50 ± 0.33 mBq/ℓ was made for sample 84-2130. This corresponds to a total Cs-137 activity of 3.94 ± 0.60 mBq/ℓ and a K_D of 3.4 ± 2.3 x 10^4, in good agreement with the upper estimates of K_D's for coastal areas.

A designated anchor station was occupied for a 36 hour period (Stations 39-71, each cast was represented as a separate station) at a point located several hundred metres off the cooling water outfall at Point Lepreau (Fig. 2). Samples were collected at surface and bottom water depths and analyzed for Cs-137, salinity and SPM (suspended particulate material). The results of these analysis are presented in Figures 7 and 8. Salinity results are similar to those observed during cruise 80-018 which took place in the late spring of 1980 (Ellis *et al.* 1984). Both surface and bottom water salinities lie within narrow salinity ranges (31 to 32 ‰ at bottom, 30.3

Table 3. Soluble Cs-137, H-3, SPM and Nutrient results for selected stations sampled during Cruise 84-025.

Sample Ident.	Station	Depth (m)	Salinity ‰	Temp. °C	Silicate µG-At/ℓ	Phosphate µG-At/ℓ	Nitrate µG-At/ℓ	SPM mg/ℓ	Cs-137 mBq/ℓ	Tritium Bq/ℓ
84-2103	2	75	31.992	7.78	4.68	0.92	5.81	3.72	3.44±0.57	-
84-2104	2	1	25.831	11.70	10.58	0.58	5.69	1.80	2.39±0.68	-
84-2105	3	47	31.772	7.90	4.32	0.84	5.56	-	3.07±0.67	-
84-2106	3	1	29.037	10.55	5.28	0.70	5.33	1.81	2.42±0.45	-
84-2119	9	30	31.634	8.30	4.36	0.78	5.59	4.10	3.04±0.57	<2.1
84-2120	9	1	30.064	9.78	5.08	0.71	5.70	1.46	3.06±0.58	2.8±2.6
84-2121	10	40	31.261	9.82	3.62	0.76	5.32	19.30	3.29±0.52	<2.1
84-2122	10	1	30.590	8.84	4.00	0.66	5.24	1.24	3.07±0.60	<2.1
84-2125	12	77	32.190	7.53	5.66	1.12	6.00	1.09	2.50±0.87	-
84-2126	12	1	23.346	12.61	13.50	0.67	6.08	2.47	2.40±0.32	-
84-2135	17	31	31.005	8.90	4.18	0.76	5.34	2.35	3.34±0.68	<1.5
84-2136	17	1	30.298	10.06	4.18	0.87	5.20	1.99	3.06±0.50	<1.5
84-2137	18	65	31.590	8.12	4.40	0.84	6.11	1.91	3.39±0.43	<1.5
84-2138	18	1	30.564	9.60	3.40	0.62	3.91	1.37	3.66±0.50	<1.5
84-2139	19	73	32.230	6.97	6.56	0.96	8.30	4.01	2.74±0.47	3.6±1.7
84-2140	19	3	30.304	10.18	3.69	0.58	3.72	1.27	1.21±0.50	2.4±1.7
84-2151	23	24	31.113	8.65	3.92	0.76	5.31	2.28	3.39±0.50	<2.0
84-2152	23	1	29.710	10.33	2.88	0.46	0.96	2.65	2.76±0.50	5.4±2.5
84-2157	25	31	31.606	7.57	6.14	1.14	6.87	3.37	3.27±0.50	-
84-2158	25	1	30.405	10.28	2.18	0.55	0.53	2.23	3.01±0.48	-
84-2163	28	99	31.980	7.41	5.24	0.91	7.04	1.87	3.46±0.35	-
84-2164	28	1	31.286	8.86	3.24	0.69	4.31	1.28	2.92±0.52	-
84-2170	30	93	31.937	7.47	5.25	0.86	7.14	1.14	3.16±0.38	-
84-2171	30	1	31.431	8.43	4.41	0.83	5.68	1.17	3.34±0.50	-
84-2178	34	181	33.039	6.62	10.48	1.28	2.46	1.62	2.79±0.43	-
84-2179	34	2	31.103	10.19	1.28	0.43	0.62	1.21	3.56±0.45	-
84-2190	39	35	32.682	9.08	3.56	0.74	5.16	2.06	3.79±0.50	-
84-2193	40	1	30.710	9.32	3.78	0.63	4.18	1.92	2.09±0.38	-
84-2194	41	34	31.601	8.18	5.12	0.80	5.95	4.83	3.69±0.54	-

Table 3. Continued

Sample Ident.	Station	Depth (m)	Salinity ‰	Temp. °C	Silicate µG-At/ℓ	Phosphate µG-At/ℓ	Nitrate µG-At/ℓ	SPM mg/ℓ	Cs-137 mBq/ℓ	Tritium Bq/ℓ
84-2197	42	1	30.711	9.54	4.06	0.64	4.48	2.57	3.44±0.30	-
84-2198	43	41	31.487	8.37	4.95	0.78	5.92	4.79	3.89±0.52	-
84-2301	44	1	30.552	9.74	4.13	0.58	4.46	6.69	3.51±0.53	-
84-2303	45	37	31.672	8.22	4.44	0.68	5.26	3.81	3.81±0.50	-
84-2306	46	1	30.559	10.57	5.31	0.62	4.92	1.28	3.44±0.50	-
84-2307	47	36	31.588	8.50	3.78	0.79	4.93	2.65	3.62±0.42	3.0±1.7
83-2310	48	2	30.872	10.45	4.18	0.72	5.28	1.45	3.49±0.50	<2.0
84-2311	49	35	31.211	9.07	3.78	0.74	5.28	2.74	3.52±0.55	5.4±1.8
84-2314	50	1	30.801	10.22	3.98	0.70	5.20	1.18	3.56±0.48	-
84-2315	52	44	31.097	9.23	3.80	0.76	5.24	2.04	3.27±0.35	-
84-2320	54	39	31.478	8.51	4.45	0.82	5.74	4.70	3.66±0.50	-
84-2323	55	1	30.807	9.42	4.11	0.64	4.62	1.79	3.61±0.50	-
84-2342	56	40	31.649	7.98	4.94	1.18	6.31	5.66	3.81±0.52	-
84-2327	57	2	30.903	9.30	3.71	0.65	4.62	1.65	2.92±0.48	-
84-2328	58	40	31.860	7.89	4.22	0.66	5.16	6.10	3.57±0.53	-
84-2331	59	1	30.845	9.56	4.19	0.65	4.61	1.27	3.44±0.28	-
84-2332	60	40	31.554	8.51	3.60	0.72	4.87	3.20	4.02±0.47	-
84-2335	61	2	30.579	9.80	3.88	0.61	4.66	1.30	3.81±0.47	-
84-2336	62	31	31.255	9.09	3.50	0.68	4.88	2.87	3.57±0.40	-
84-2339	63	1	30.759	9.49	3.55	0.66	4.84	1.23	3.24±0.50	-
84-2340	64	32	31.057	9.31	3.32	0.65	4.76	1.64	3.37±0.48	-
84-2343	65	1	30.306	10.21	3.99	0.70	4.90	1.49	3.34±0.52	-
84-2344	66	35	31.620	8.34	4.44	0.88	5.75	2.80	3.21±0.45	-
84-2347	67	1	31.094	9.18	3.59	0.62	4.67	2.58	3.26±0.48	-
84-2348	68	40	31.536	8.46	4.40	0.76	5.56	2.92	3.54±0.48	-
84-2353	69	1	31.124	8.97	4.70	0.88	5.70	2.79	3.57±0.48	-
84-2354	70	35	31.546	8.28	4.30	0.63	5.34	5.56	3.82±0.45	-
84-2358	71	1	30.335	10.51	4.23	0.45	4.59	1.37	3.36±0.30	-

Table 4. Average radionuclide values measured in the water column for all cruises.

Cruise No.	Date	Radionuclide Concentrations			
		Cs-137 (Particulate) mBq/ℓ	Cs-137 Dissolved) mBq/ℓ	Sr-90 mBq/ℓ	H-3 mBq/ℓ
Pre-operational					
79-007	May 1-6, 1979	-	3.8* ± 0.7**, n=28	3 ± 1, n=13	2700 ± 3000
79.027	Oct 24-28, 1979	-	2.6 ± 0.8 , n=24	-	1700 ± 2700
80-018	Jun 9-14, 1980	<0.8	4.2 ± 0.3 , n=43	-	<2300
81-500	Feb 23-26, 1981	<1.5	4.4 ± 0.5 , n=20	-	2840 ± 1200
81-010	Apr 14-21, 1981	<1.2	3.5 ± 0.3 , n=33	-	2210 ± 0580
Post-operational					
83-003	Apr 12-18, 1983	-	3.3 ± 0.6 , n=30	-	2525 ± 0910
84-025	Jul 10-16, 1984	<0.4	3.0 ± 0.5 , n=28		2933 ± 0611

* Mean radionuclide values calculated using a single mean from the anchor station data.

** Error reported is the statistical error for mean value.

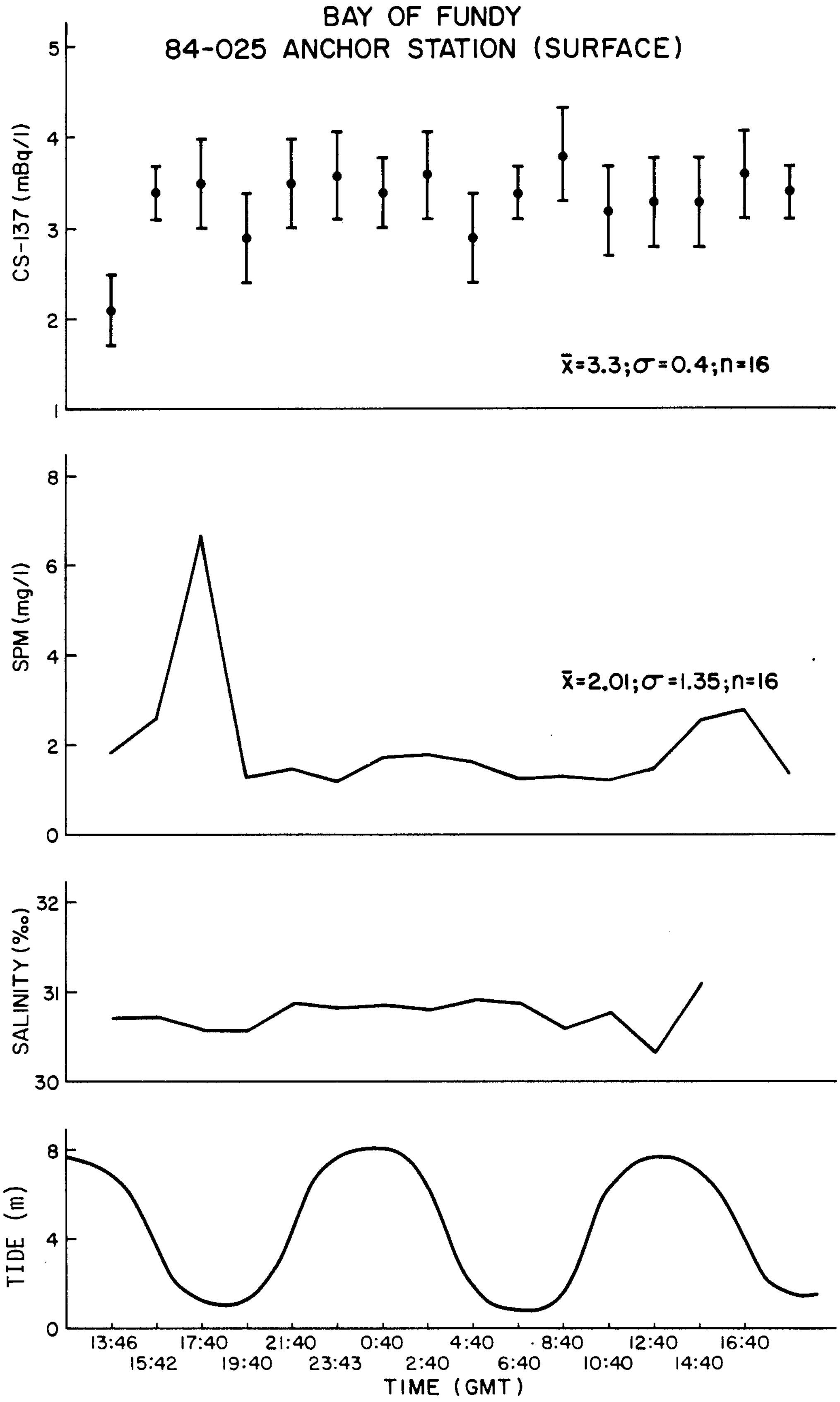

Figure 7. Cs-137, SPM, and salinity plotted as a function of time for surface water samples collected at the anchor station during cruise 84-025.

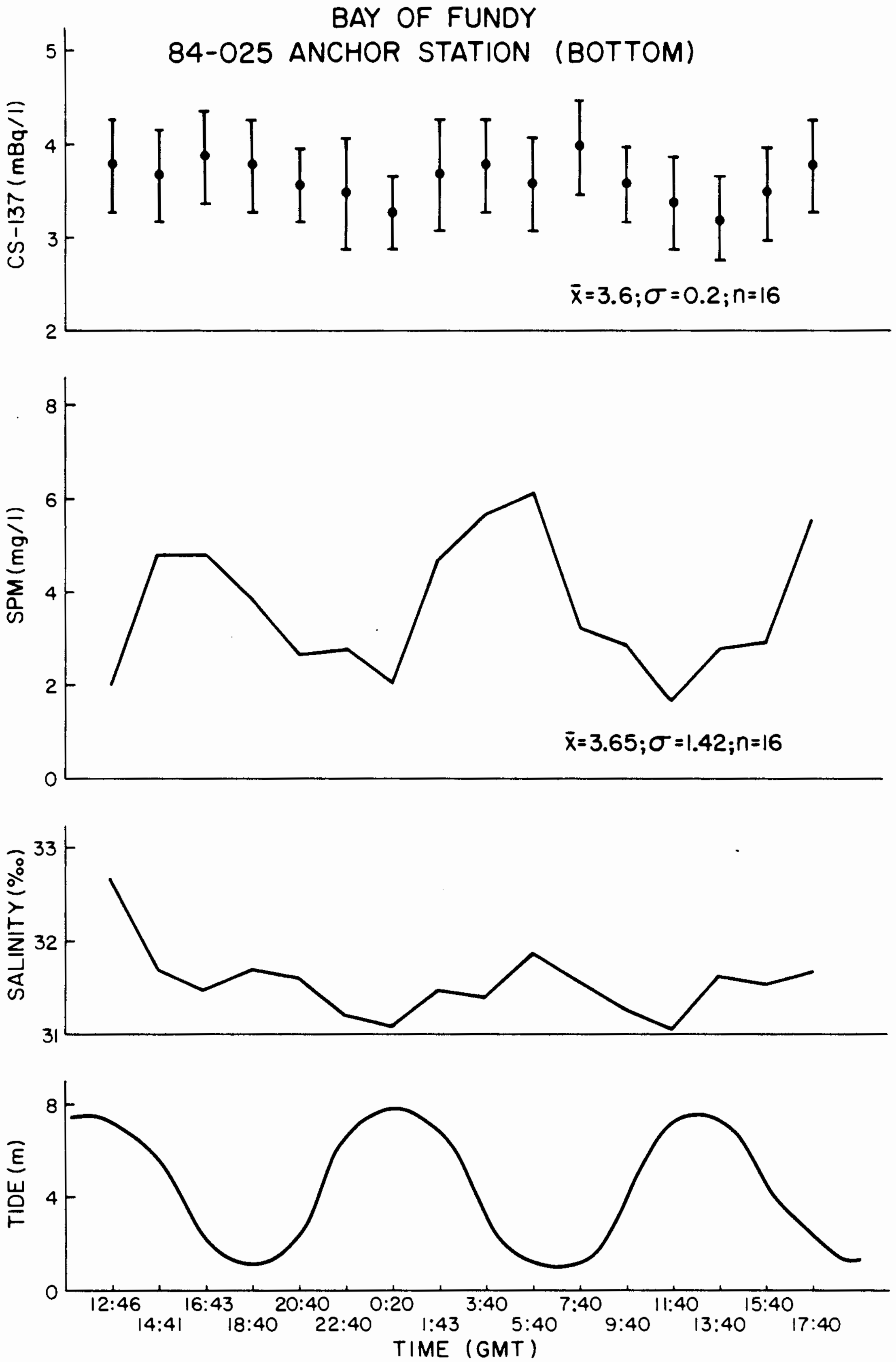

Figure 8. Cs-137, SPM, and salinity plotted as a function of time for bottom water samples collected at the anchor station during cruise 84-025.

to 31‰ at surface) and the high, surface water, salinities reflect the reduced freshwater input from the Saint John River in the vicinity of the anchor station. SPM values for bottom water samples ranged from 2.06 to 6.10 mg/ℓ (average of 3.65 ± 1.40, n = 16) and for surface water samples ranged from 1.18 to 6.69 mg/ℓ (average of 2.04 ±.140, n = 15). SPM values are lower than those observed during previous cruises and reflect the absence of the freshwater plume in the area of the anchor station. Higher SPM concentrations (up to 35 mg/ℓ) measured during cruise 83-003, for which salinities as low as 27‰ were observed at the anchor station during a time of high spring runoff, indicate that the reduction in SPM values observed during cruise 84-025 is related to the reduced freshwater input during the summer.

During cruise 84-025, water samples were collected and filtered using both a filter cartridge (pore size ~ 0.3 µm) processing 50ℓ of water and a nuclepore filter (pore size = 0.4 µm) processing 250 ml of water. The filter cartridge has a much larger capacity for particle collection while the nuclepore filters allow for more complete filtration and have a larger but more exact pore size. The results for both sets of data are compared in Figure 9 and a correlation coefficient of 0.66 (n=14) is obtained. At low SPM concentrations, there is excellent agreement between filter cartridge and Nuclepore filter results which become more scattered as the SPM concentration increases. Higher values measured for SPM using Nuclepore filters (2.65 to 13.40 mg/ℓ with an average of 8.39 ± 3.43 mg/ℓ, n=14) are related to several factors; the large errors associated with filtering small volumes (only 250 ml), incomplete filtering associated with the large 50ℓ water samples and the settling of particulate matter during the lengthy filtering times (≈6-8 hours per 50ℓ sample). During the next cruise in this series, this experiment will be repeated using a larger volume of seawater in an effort to reduce these errors.

Current meters were deployed at the anchor station at depths of 5 (surface), 15 (mid-water) and 35 (bottom) metres to monitor current velocity and direction in the vicinity of the reactor outfall. As in previous cruises, current velocities ranged from 0 to 1.0 m/sec with maximum current velocities being observed with falling tides. The low current velocities of 0.1 to 0.2 m/sec were associated with tidal reversal and low SPM concentrations. The SPM peaks

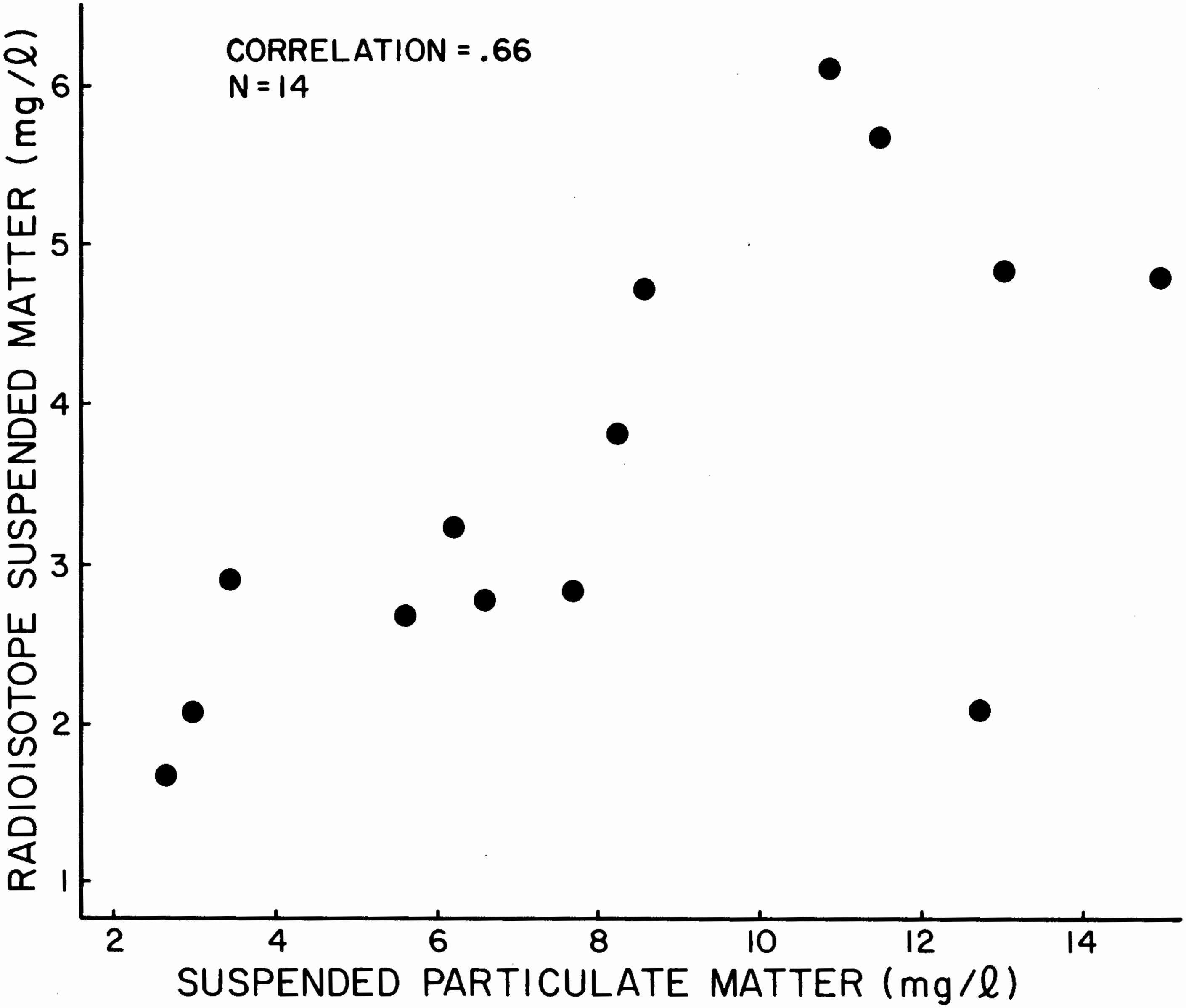

Figure 9. Comparison of suspended particulate matter (using nuclepore filters) and radioisotope suspended matter (using filter cartridges) for samples collected during cruise 84-025.

illustrated in Figure 8 were slightly out of phase with flood tide conditions and current velocities of 0.6 to 0.9 m/sec. In general, current meter data indicate that the resuspension of bottom material, due to changing current conditions and subsequent transport with the rising tide during periods of maximum current velocity may be a possible mechanism to explain peak SPM concentrations observed in bottom waters at the anchor station.

The Cs-137 results for samples collected at the anchor station are illustrated in Figures 7 and 8 and in Table 4. Average bottom water values of 3.6 ± 0.2 mBq/ℓ are higher than surface water activities of 3.3 ± 0.4 mBq/ℓ but fall within statistical uncertainties. The range in Cs-137 activities 2.09 ± 0.38 to 4.02 ± 0.47 mBq/ℓ at the anchor station is similar to that found over the entire sampling area (1.21 to 3.66 mBq/ℓ). Cs-137 activities measured at the anchor station show a weak ($r = 0.48$, $n = 15$) correlation with bottom water SPM (cartridge technique). It is also interesting to note that although the nuclepore SPM values differed from the AERU SPM values, a similar correlation with Cs-137 levels was observed ($r = 0.54$, $n = 14$). Stanners and Aston (1982), observed that Cs-137 and Cs-134 from reprocessing effluents are to some extent reversibly adsorbed onto particulate matter, inferring some form of ion-exchange mechanism as a possible explanation for the correlation of Cs-137-SPM concentrations.

2.3.1.2 Gamma-Emitting Radionuclides

Neutron activation products of transition metals present in reactor support and encasement materials, such as Zn-65, Co-60, and Mn-54, are environmentally important radionuclides resulting from both nuclear weapons fallout and effluents from reactor facilities. The stable element analogues are physiologically essential to marine organisms and concentration factors of 10^3 to 10^5 from seawater have been observed (IAEA 1985).

For analysis, the gamma-emitting radionuclides listed in Table 5 are concentrated from seawater by adsorption onto Chelex-100 (with the exception of I-131 and Cs-137). The average retention efficiency of 90% was determined using an NBS mixed gamma radionuclide

Table 5. Comparison of detection limits for radionuclides in dissolved and particulate phases.

Nuclide	Half life (Days, years)	Detection limit		Expected Activities**	
		Suspended matter (mBq/ℓ)	Dissolved (mBq/ℓ)	Suspended matter (mBq/ℓ)	Dissolved (mBq/ℓ)
Ag-110m	250.40 d	0.84	2	0.000002	0.0002
Ce-141	33.00 d	72	5	0.0005	0.00003
Ce-144	284.40 d	3.3	12	0.003	0.0002
Co-58	71.20 d	4.9	3	0.01	0.006
Co-60	5.27 y	0.60	3	0.3	0.2
Cr-51	27.70 d	1494	30	6.0	14.0
Cs-134	2.06 y	0.51	3	0.0005	0.02
Cs-137	30.00 y	0.47	-	0.002	0.1
I-131	8.06 d	-	-	0.000002	0.009
Mn-54	321.60 d	0.80	3	0.3	0.2
Nb-95	35.20 d	-	4	0.8	0.2
Ru-103	39.40 d	31	4	-	0.0001
Ru-106	368.00 d	6.6	23	0.0002	0.007
Zn-65	244.10 d	2.0	5	0.0001	0.0007
Zr-95	65.00 d	11	7	0.5	0.05
H-3	12.30 y	-	1500	-	-

* Calculation based on seawater volume of 50 ℓ, SPM concentration of 8.5 mg/l, and counting time of 1500 min one month after sample collection.

** Radionuclide concentration expected at the cooling water outfall. Calculated from liquid effluent monthly summary (Table 2) and coastal partition coefficients compiled by IAEA, (IAEA 1985).

standard. The detection limits in Table 5 are based on an assumed water volume of 50 litres with eluted samples counted for 1500 minutes, one month after the sample collection.

Radionuclide concentrations expected at the cooling water outfall have been calculated using NBEPC liquid effluent data (Table 2) and recommended values for coastal water partition coefficients (IAEA 1985), using the following equation.

$$\frac{Total\ Activity\ released/year}{Volume\ of\ Water\ released/year} = Act_{sol} + Act_{part} = Act_{sol}(1 + K_D\ [SPM])$$

where K_D is the partition coefficient, for a SPM concentration of 8.5×10^{-6} g/ml and for a yearly effluent volume of $5.5 \times 10^{11} \ell$. Although actual releases are intermittant and the waste is pumped out as the waste tanks become full, radionuclide concentrations expected at the outfall have been estimated assuming a constant release rate. This allows the calculation of expected concentrations for both dissolved and particulate radionuclide species being released from the Point Lepreau NGS. A comparison of AERU detection limits with expected activities for dissolved species indicates that, even before dilution in the receiving waters of the Bay of Fundy, the concentration of radionuclides released were below AERU detection limits.

As expected, all gamma-emitting radionuclides were below detection limits for all samples analysed. Radioecological studies of activation products released from two boiling water reactors in Sweden found that Co-60 was first detected in seawater after three years of two-unit operation. Seawater concentrations of 1.3 to 5.4 mBq/ℓ were found at sampling sites 5 km from the cooling water outfall (Nilsson *et al.* 1984). This suggests that all of the radionuclides routinely released from the Point Lepreau NGS probably will remain below AERU detection limits for several years.

2.3.1.3 Plutonium in Seawater

The majority of plutonium entering marine systems originates from nuclear weapons testing. Accidential releases of Pu-238 to the environment have also occurred as a result of the reentry burnup of the nuclear powered SNAP-9A satellite in 1964. Plutonium-239 has also been released from accidents related to weapons uses of plutonium.

Isotopes of plutonium, namely Pu-238 ($t_{1/2}$ = 86.4 y), Pu-239 ($t_{1/2}$ = 24,400 y), Pu-240 ($t_{1/2}$ = 6000 y) and Pu-241 ($t_{1/2}$ = 13 y), because of their long half-lives and high chemical and radiotoxicity, are the important transuranic radionuclides in fallout. Plutonium is considered to be particle reactive and oceanic plutonium is distributed approximately 30% dissolved and 70% particulate. Plutonium is depleted from surface waters rapidly compared with Cs-137 and Sr-90 and downward transport of Pu in fast settling zooplankton fecal pellets is an important component in the vertical transport of plutonium (NRCC. 1983).

Levels of soluble plutonium (Pu-239,240, Pu-238) in seawater were determined using a ferrous hydroxide precipitation technique on 100ℓ water samples collected in the Bay of Fundy during cruise 84-025. The results are presented in Table 6. Soluble levels of Pu-239,240 and Pu-238 are comparable to those measured during cruise 81-010 (Ellis *et al.* 1984) by D. Nelson (personal communication).

A mean fallout activity ratio of 0.012 was estimated by Harley (1975) for Pu-239, 240/Cs-137 from measurements conducted on air particulate samples collected during the early 1960s. Plutonium-239,240/Cs-137 inventory ratios in the Bay of Fundy sediments (average of 0.37) are greater than fallout ratios by an order of magnitude (Ellis *et al.*, 1984), as a result of larger K_D values for plutonium. The average Pu-239,240/Cs-137 ratio in water in the Bay of Fundy in 1984 is 0.004, much less than the fallout activity ratio. This low ratio is consistent with preferential adsorption of plutonium onto particles, followed by particle settling.

An average Pu-238/Pu-239,240 activity ratio of 0.087 was found for water samples collected in the Bay of Fundy. This ratio is much lower than the fallout activity pre-SNAP 9A ratio of 0.025 (Hardy *et al.*, 1973), although large errors are associated with the determined ratios.

Table 6. Radionuclide results for plutonium in water samples collected during cruises 81-010 and 84-025

Sample No.	Station	Depth	Particulate Pu-239,240 (mBq/ℓ)	Soluble Pu-239,240 (mBq/ℓ)	Total Pu-239,240 (mBq/ℓ)	Pu-238 (mBq/ℓ)	Ratio Pu-238/Pu-239,240
81-7962	23	66	0.013 ± 0.001	0.020 ± 0.001	0.033 ± 0.001	-	-
81-7982	30	125	0.004 ± 0.001	0.019 ± 0.001	0.023 ± 0.001	-	-
81-8063	62	37	0.052 ± 0.004	0.018 ± 0.006	0.070 ± 0.004	-	-
84-2107	3	1	-	0.009 ± 0.001	-	0.0012 ± 0.0005	0.14 ± 0.06
84-2141	19	3	-	0.101 ± 0.002	-	0.0010 ± 0.0005	0.10 ± 0.05
84-2153	23	1	-	0.010 ± 0.001	-	0.0005 ± 0.0002	0.05 ± 0.02
84-2302	44	1	-	0.009 ± 0.001	-	0.0003 ± 0.0002	0.04 ± 0.03
84-2315	50	4	-	-	0.010 ± 0.002	0.0014 ± 0.0008	0.14 ± 0.08
84-2364	74	1	-	-	0.013 ± 0.002	0.0006 ± 0.0004	0.05 ± 0.03

2.3.1.4 Tritium in Seawater

The major tritium inputs into the environment in the past have been associated with fallout from nuclear weapons tests, in addition to the naturally occurring input from cosmogenic interactions in the upper atmosphere. Environmental releases of tritium from the Point Lepreau NGS will be substantially greater than those for any other radionuclide under normal operating conditions due to the use of heavy water (D_20) as the moderator and coolant and elevated levels of tritium associated with reactor releases are likely to be detectable in a range of environmental phases.

Water samples collected for tritium analysis in the Bay of Fundy were distilled under vacuum and counted for 500 or 1000 minutes in a liquid scintillation counter using methods outlined in previous reports (Ellis *et al.*, 1984). The results for cruise 84-025 are given in Table 3. The range in tritium values for cruise 84-025 was <2.0 to 3.6 Bq/ℓ and the majority of seawater samples analyzed were below the detection limit. Tritium values for this cruise are comparable with those found during the pre-operational program (Table 4) indicating that no measurable increase in the overall seawater tritium activity occurred in the Bay of Fundy.

Water samples were collected for tritium analysis at the surface and bottom during the July cruise 1984 as part of a thermal plume study conducted at that time. A detailed discussion of these results is presented in Section 2.4.1.

2.3.2 Nutrients

The oceans, and particularly coastal waters, are inhomogeneous mixtures with regard to chemical composition. In the majority of coastal waters, precipitation and freshwater runoff exceed evaporation from the ocean's surface. The less dense freshwater mixes in the surface layers and moves away from the coast, being replaced by a subsurface input of more saline deep water. This process adds to the chemical inhomogeneity of coastal waters by replenishing chemicals lost from the surface layer by particulate settling and biological action, and the replenishment of depleted surface waters with nutrient-rich bottom water is vital to the high primary productivity characteristic of shelf seas.

Water samples for nutrients and salinity determinations were collected at selected water depths using 12-litre Niskin bottles. Nutrient samples were drawn directly from the Niskin bottles and stored frozen for subsequent analysis by standard auto-analysis techniques. Unfiltered water samples were also collected for salinity determinations. Selected results for nutrient analysis for cruise 84-025 are presented in Table 3 and the values measured are within the ranges of values previously measured. The inverse silicate-salinity relationship present during previous cruises is again evident for cruise 84-025 ($r = -0.55$, $n = 30$) but weaker than that observed during the May cruise in 1979 (79-007; $r = 0.998$, $n = 49$). This difference is probably due to the narrower range in salinity and silicate values measured during cruise 84-025.

2.3.3 Sediment Studies

Radionuclides released from the Point Lepreau NGS will be partitioned between soluble and suspended particulate matter to an extent dependent on their respective particle-water distribution coefficients. The more particle-reactive radionuclides such as Co-60 and Zn-65 will follow the transport pathways for particulate matter through the water column and will deposit in the sediments. Sites of net sediment deposition within the western Bay of Fundy warrant investigation because they may record the historical record of particle-reactive radionuclide releases from the Point Lepreau NGS. Further, knowledge of radionuclide sediment inventories is critical to the determination of the availability of these radionulcides for uptake by bottom dwelling organisms and to assess the importance of post-depositional remobilization of radionuclides by particle resuspension, bioturbation and diffusion. Finally, the sediment inventory of radionuclides may represent a significant fraction of the total budget for radionuclide releases from the Point Lepreau NGS which must be determined in order to estimate net radionuclide fluxes through different environmental phases.

Classification of the sediments on the basis of their relative sand and mud content gives the distribution pattern for the western Bay of Fundy indicated in Figure 10 (Loring 1979). The finest grained sediments are found in the Quoddy region, west of Point Lepreau and extending in a lobe south of Grand Manan Island, a pattern that is generally consistent with the distribution pattern of LaHave clays (Fader *et al.* 1977). Particle size is the main factor controlling trace metal concentrations in the Bay of Fundy because the adsorption of metals onto the detrital host mineral particles increases with the particle surface area. Therefore, the finer offshore sediments in the Quoddy regions are a sink and an enrichment area for trace metals as well as particle-reactive radionuclides introduced from both natural and industrial sources such as the St. Croix drainage basin, coastal industries and offshore dredge disposal sites (Loring 1982).

Sediment cores have been collected at various stations in the western Bay of Fundy from 1979 to 1983 using box and Lehigh gravity core devices. The cores were subsampled at 1 cm intervals, freeze-dried and analysed for Pb-210 and Ra-226 (as well as Cs-137, Pu-239,240 and Pu-238) using methods outlined in Smith *et al.* (1982).

Pb-210 ($t_{1/2}$ = 22.3 yr) is a naturally-occurring member of the U-238 decay series which is introduced into coastal waters at a relatively constant rate as a result of the radioactive decay of Rn-222 in the atmosphere. Pb-210 is rapidly scavenged by particulate matter in the water column and accumulates as an unsupported excess in the sediments.

The measurements of Pb-210 and Ra-226 were used to construct a map of the excess Pb-210 inventory, $I_{Pb\text{-}210_{ex}}$ (integrated quantity of excess Pb-210 in a core) in the western Bay of Fundy. $I_{Pb\text{-}210_{ex}}$ is proportional to the total flux of excess Pb-210 to the sediments, which, in turn, is a function of the sedimentation rate of fine-grained particulate material. The inventories obtained for five box cores collected during cruise 84-025 are used to provide a more complete description of Pb-210 distributions in the sediments and the results are presented in Figure 11. The excess Pb-210 inventories in the western Bay of Fundy can be regionally characterized by low ($<$30 dpm cm^{-2}), medium (30-100 dpm cm^{-2}), high (100-200 dpm cm^{-2}) and very high ($>$200 dpm

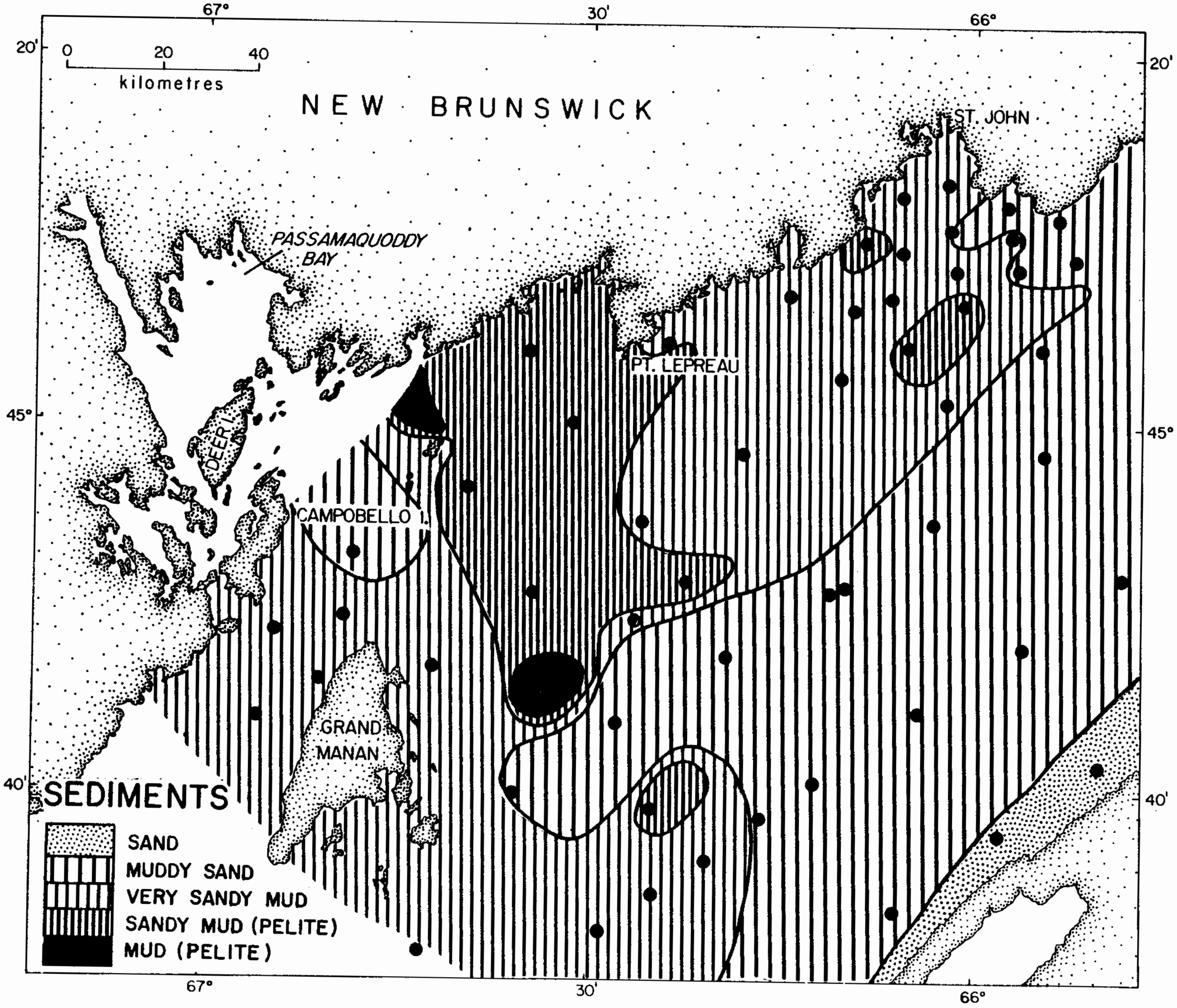

Figure 10. Particle size distribution of sediments in the western Bay of Fundy. Reproduced from Loring (1979).

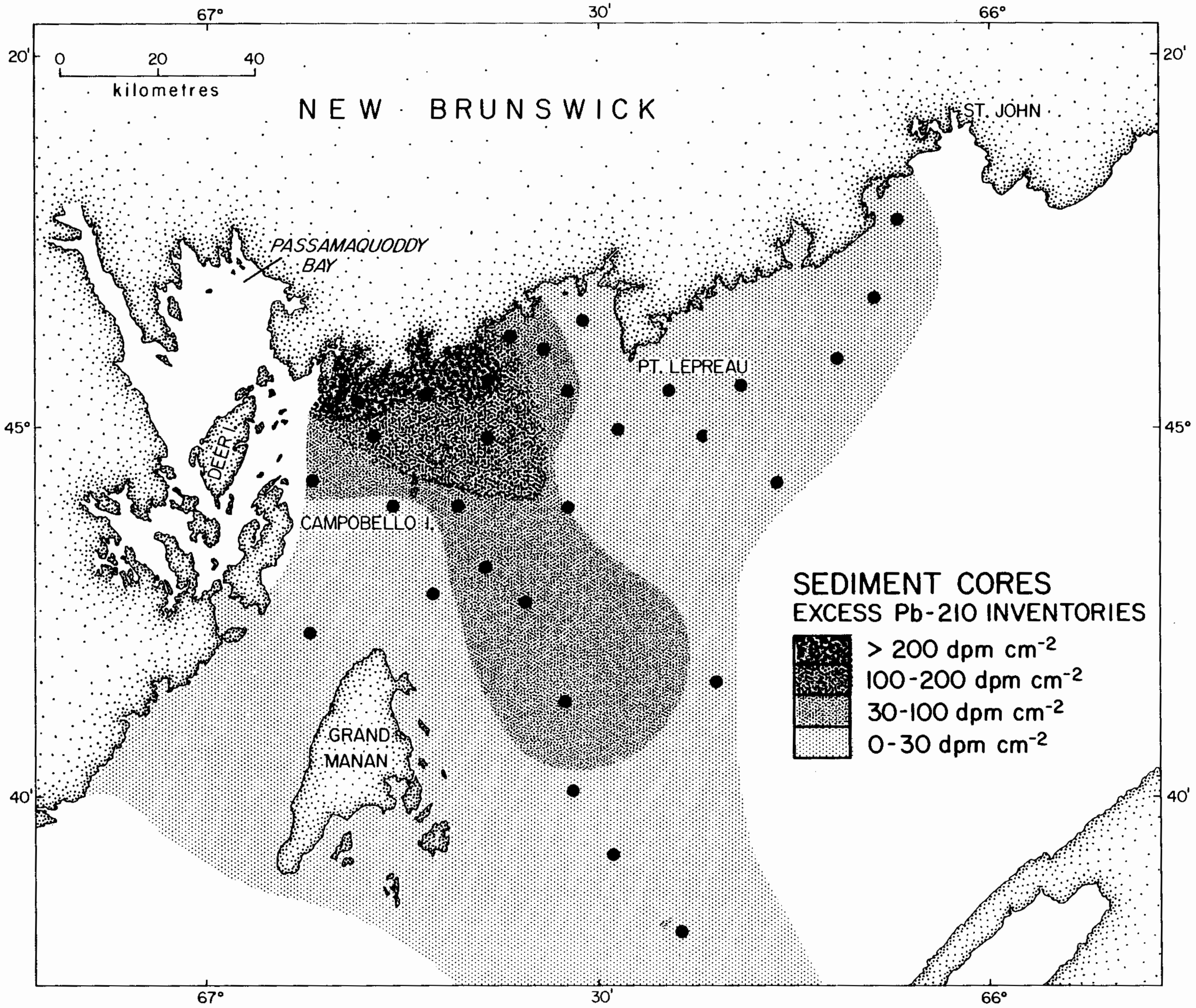

Figure 11. Excess Pb-210 inventories in sediment cores (filled circles) in the western Bay of Fundy.

cm^{-2}) excess Pb-210 inventories. The highest Pb-210 inventories are found in the Quoddy region, near the northern approaches to Passamaquoddy Bay, where the sediments consist of fine-grained muds (Figure 10). The fine-grained sediments in this region constitute a net depositional sink, both for Pb-210 and other particle reactive radionuclides, in addition to particle-reactive trace metals such as Zn and Hg (Loring 1982). In contrast, the sediments in the immediate vicinity of Point Lepreau, which grade into sandy muds, are characterized by lower inventories of Pb-210. This latter relationship is consistent with the inhibition of deposition of fine-grained material as the result of the strong residual bottom currents in this region. Although particle-reactive radionuclides released from the Point Lepreau NGS may temporarily reside in sediment regimes near Point Lepreau, the final repository for these substances is the fine-grain sediment regime of the Quoddy region.

2.4 Thermal Plume Study

The generation of electricity by all thermal processes is accompanied by the production of waste heat that must constantly be removed by means of a cooling water stream and ultimately dispersed into the surrounding environment. The Point Lepreau NGS has chosen the "once through" cooling system with offshore intake and discharge designed to take advantage of the rapid mixing present in the Bay of Fundy to disperse waste heat.

Temperature affects both the physical and chemical properties of water. Its variation causes changes in density, vapour pressure, viscosity, surface tension and gas solubility and diffusion and affects chemical reactions. These changes result in a complex chain of events involving hydrodynamics, heat and mass transfer, biological and ecological factors (Miller *et al.*, 1984).

Even a small reduction in density, as little as 0.2%, as a result of a typical temperature increase can have a dramatic effect on the hydrodynamics of cooling water discharges. Of particular importance is the suppression of turbulance by buoyancy forces: warm water displaced downwards in turbulant eddies tends to rise, while lower temperature water displaced upward tends to sink, resulting in a suppression of turbulance in the interface area. The initial inertia of a thermal discharge causes turbulent mixing with the main body of water, but as flow moves away from the point of discharge, velocities decrease and density differences suppress vertical mixing. When the receiving waters are marine, salinity gradients may complicate the issue, the resulting density gradients tending to further suppress mixing. This phenomenon has been observed in spring in the Lepreau area (Nelson *et al.*, 1985). If, away from the immediate point of entry, only forces due to buoyancy were present, thermal plumes would cover large surface areas. In practice, receiving water bodies are always in motion, the strength of which effects gross plume behavior as well as being the cause of turbulance which erodes plumes (Miller *et al.*, 1984). The Bay of Fundy tides are an especially vigorous example.

Many of the effects of thermal discharges are associated with the resulting increases in temperature of the receiving water. The most important consequence of increased temperature is the decreased solubility of oxygen, as dissolved oxygen is necessary for many forms of aquatic life. In addition, the rate of chemical reactions is approximately doubled for each 10°C temperature rise (Clark *et al.*, 1973) and because of changes in the properties of water, changes in flocculation and ion exchange will occur, so that sedimentation may be increased. Numerous site specific biological and ecological events giving rise to concern about thermal discharges have been documented. However, no serious impacts have been observed in any large aquatic ecosystem.

Ultimately the impact of thermal pollution on the environment will depend on the extent and duration of the thermal plume. The ensuing dispersal of heat through the receiving waters and into the atmosphere is controlled by current velocity, turbulance, temperature difference between air and water, the humidity of the air and the speed and direction of the wind.

Thermal Plume Field Work

The 1984 thermal plume survey was conducted over July 13 and 14 as part of CSS Dawson cruise 84-025. The Dawson's launch was used to perform four separate surveys timed so that each survey began at a distinct stage of the tide; low water, 1/2 tide rising, high water and 1/2 tide falling. During each survey, vertical profiles of temperature and salinity were obtained using a Guildline portable CTD system and water samples were collected at the surface and at depth for tritium analysis. The NGS undertook controlled liquid waste pumpouts, with tritium activities ranging from 110 to 6000 Bq/ℓ, to coincide with the beginning of each survey (Table 7). The use of Loran-C for launch navigation permitted estimation of surface current vectors by fixing the position of the launch at the beginning and end of each station. Very little wind was encountered during the surveys, so that launch drift was felt to be representative of surface currents.

The waters of the Bay of Fundy well away from the effects of the thermal plume exhibited a complicated thermal structure with a warm surface mixed layer ranging in depth from 10 to 20 metres. Surface temperatures ranged from over 12°C to below 9.5°C. This structure in the ambient waters of the bay made it difficult to determine the characteristics of the waters

Table 7. Details of liquid waste pumpouts for 1984 thermal plume survey (J. O'Donnell NBEPC, Health Physics Department, personal communication)

Start of Pumpout GMT		Outfall Concentration (Bq/ℓ)	Outfall Temperature (°C)
84.07.13	1300	350	-
84.07.13	1901	180	23.7
84.07.14	1020	110	22.2
84.07.14	1640	6000	22.7

with which the heated effluent was mixing. This makes delineation of the plume and calculation of parameters such as effluent dilution rather uncertain in some cases.

The dilution factor at a specific location is defined as the inverse of the fraction of effluent detected relative to that emitted at source. If background values of a particular pollutant in the surrounding waters are negligible, this is the number by which the outfall concentration would be divided to give the concentration at a particular place. In terms of temperature or tritium this may be written

$$\left[D = \frac{T_o - T_a}{T_m - T_a}\right]$$

where D is the dilution factor, T_0 the outfall temperature (tritium), T_a the ambient temperature (tritium) and T_m the measured value. In the presence of thermal structure in the ambient water T_a is taken to be the temperature averaged from the surface to the approximate depth of the outfall discharge (15m) at a station considered to be unaffected by the plume. Some results of the surveys are presented below. Observations are described in an order different than that in which they were taken in order to facilitate description of the plume and currents near the outfall through a tidal cycle. Salinity gradients in the area of the outfall were found to be negligible at this time of year.

Survey #3 (Low Water - 1/2 hour → Low Water + 2 hours)

Station locations and surface temperature contours are shown in Figure 12. The temperature-depth profile (Figure 13) along the transect illustrated in Figure 12, indicates the extent of the thermal plume at this stage of the tide. The plume is seen to extend in a north-easterly direction into Duck Cove (Figure 12). This is in response to the currents illustrated in Figure 14 which, as shown by observations at CSS Dawson, were turning from going out of the bay to setting into the bay with the rising tide. Also shown on Figure 14 are approximate dilution contours, assuming that station 42 is representative of the waters with which the plume is mixing. Tritium observations obtained during this survey are displayed in Figure 15 in the form

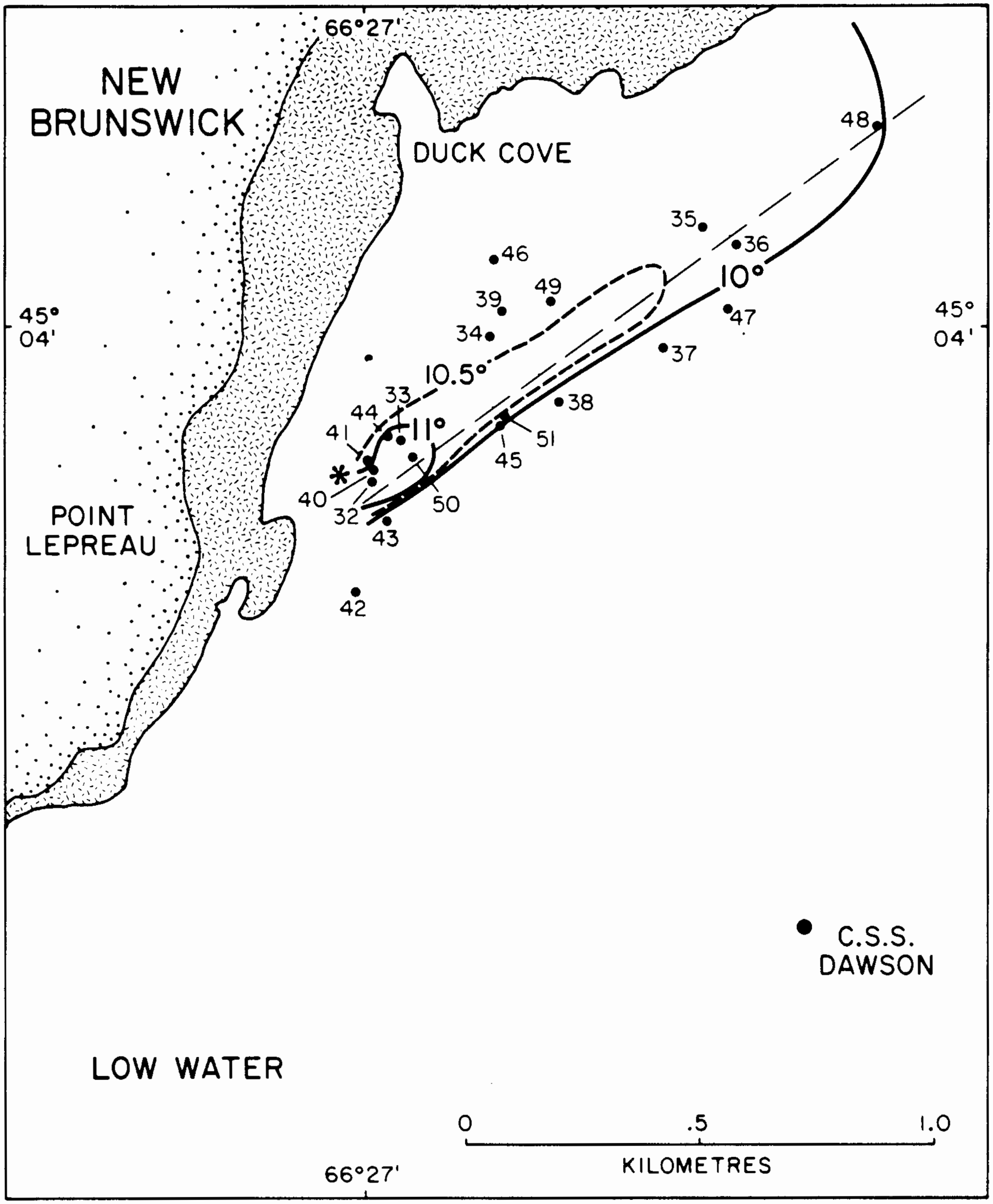

Figure 12. Station locations and surface temperatue contours for survey # 3. The dashed line shows the position of the vertical temperature section shown in Figure 13.

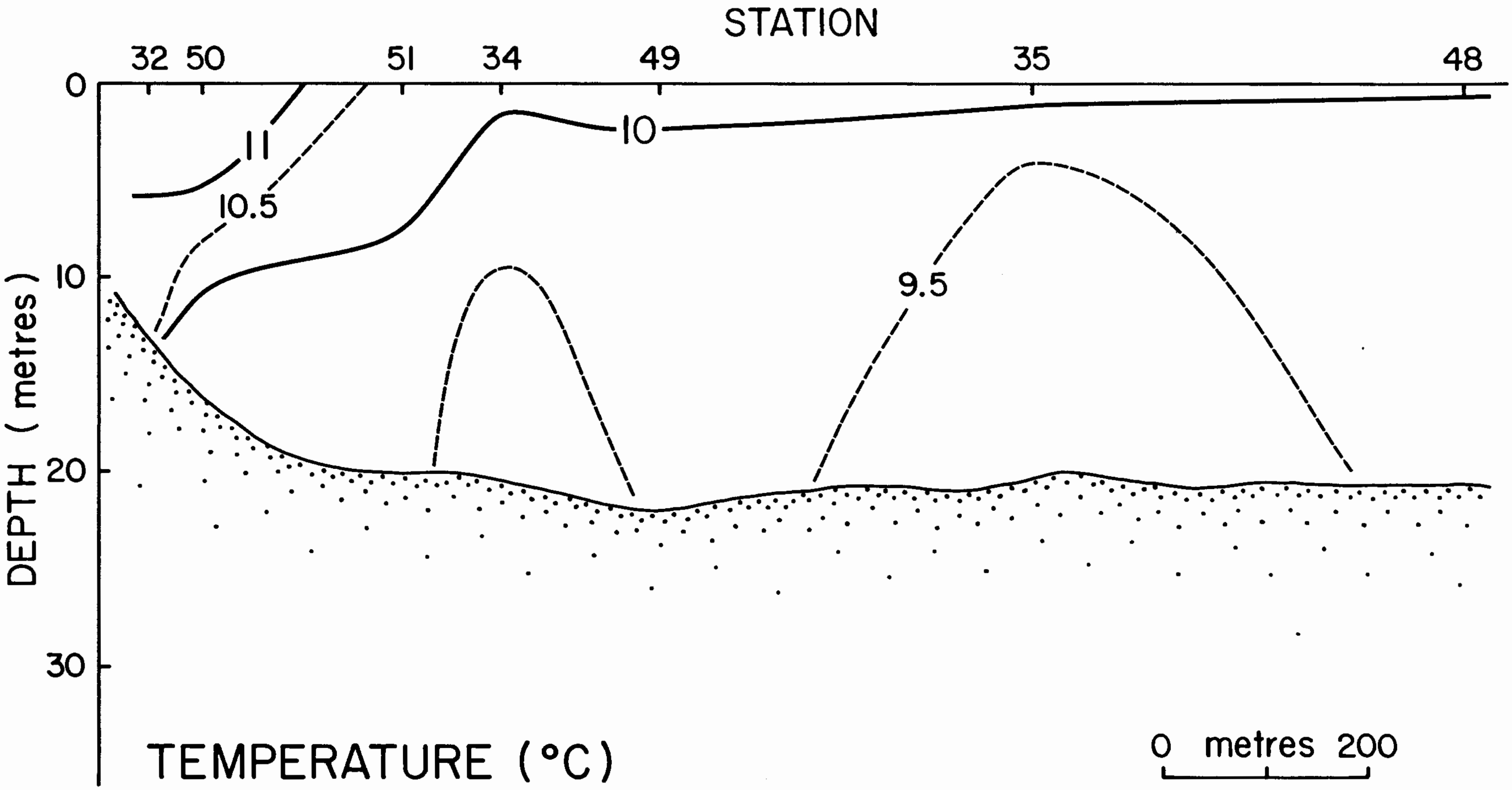

Figure 13. Vertical temperature section along the approximate plume axis for survey # 3.

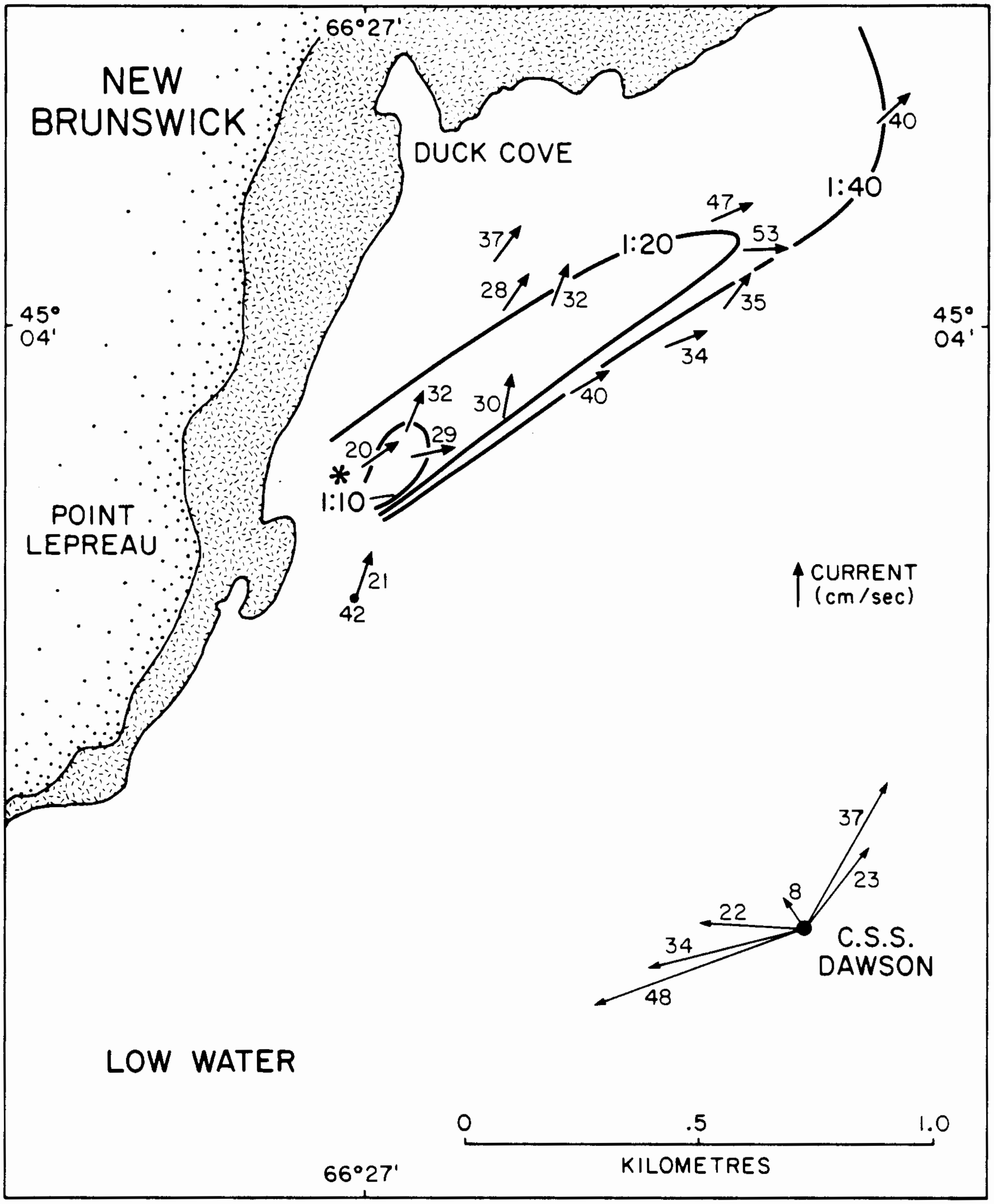

Figure 14. Surface current vectors and approximate dilution contours for survey # 3 (see text). Also shown are 1/2 hour averaged currents observed at CSS Dawson during the course of the launch survey.

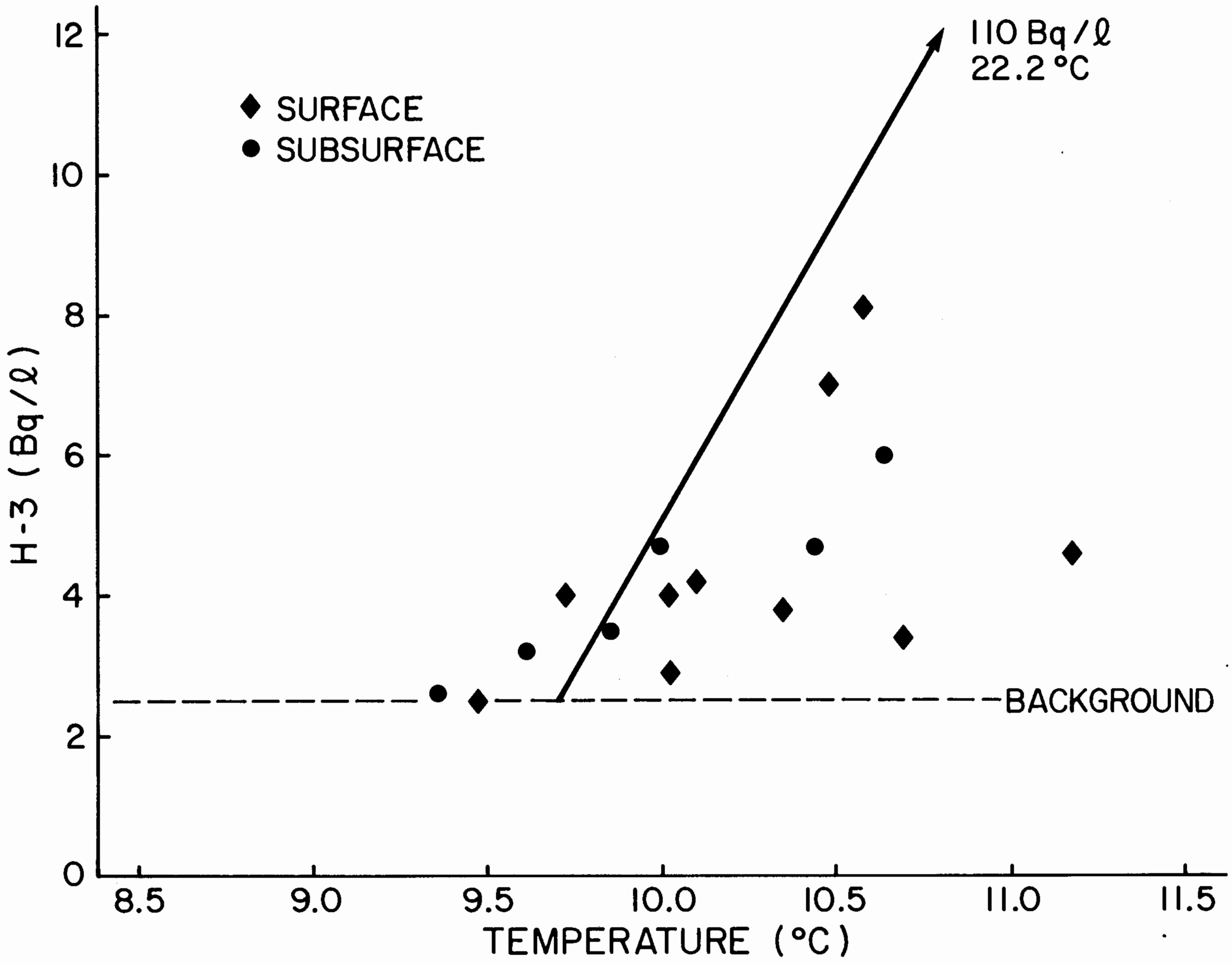

Figure 15. Temperature - H-3 mixing diagram for survey # 3 (see text).

of a temperature - H-3 mixing diagram. Because of the relatively low activity of H-3 of this pumpout, observed tritium activity levels are generally close to background level (estimated to be 2.5 Bq/ℓ). Agreement is fairly good but the fact that most observations lie below the mixing line between ambient Bay of Fundy water and the outfall mixing member seems to suggest that quite a bit of mixing is occuring between thermal plume water from the liquid waste pumpout and waters discharged before the pumpout began which would produce water which would exibit elevated temperatures, but background tritium levels. This type of mixing leads to reduced tritium activities without a corresponding reduction in temperature. The short duration of the pumpout does not allow any sort of steady state to be reached, thus making interpretation of the tritium results difficult in this and other cases.

Survey #1 (High Water - 3 hours → High Water + 1/2 hour)

Station locations and temperature contours are given in Figure 16 for the 1/2 tide rising conditions. The thermal plume is larger, less concentrated and extends further off shore than during survey #3. The temperature-depth distributions are shown for the two transects illustrated in Figure 16. In Figure 17, the temperature distribution is given for the downstream transect and shows the extent of the thermal plume. The distribution of temperature along the upstream transect (Figure 18) indicates that the thermal plume in this direction is only in the surface water.

As the ingoing tide continues to increase in the outer bay, current velocities increase and flow separation occurs at Point Lepreau resulting in the formation of a back eddy on the eastern side of the point large enough to affect the current at CSS Dawson. Therefore the outfall plume is swept in a southwesterly direction and the remnants of the plume which had been transported in a northeasterly direction are now bent around by the changing current and transported back past the outfall further offshore (Figures 16 and 19). Dilution contours on Figure 19 are again based on station #42 (Survey #3) representing the ambient waters. Tritium observations from the survey were generally very near to background (Figure 20). This is due to

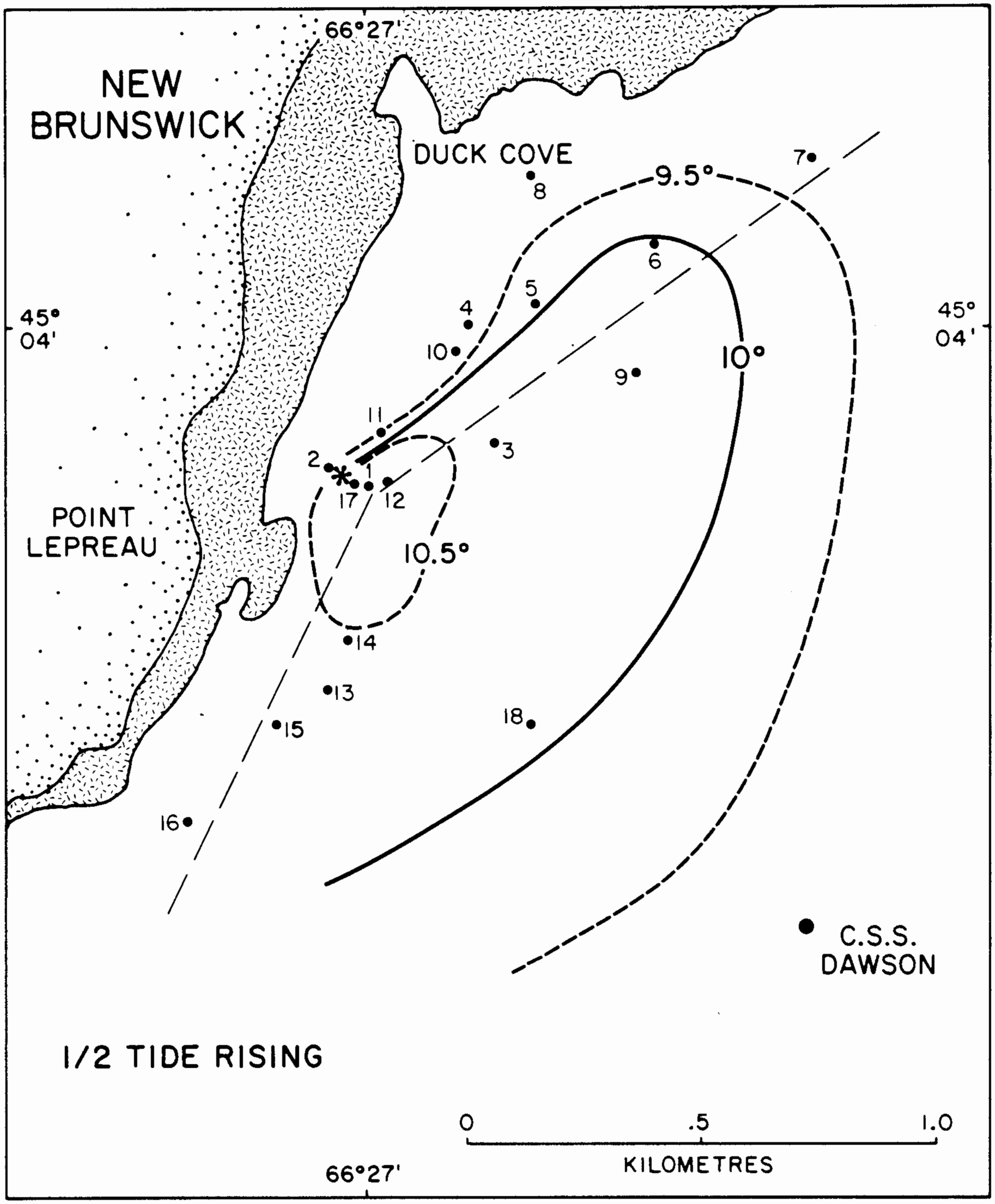

Figure 16. Station locations and surface temperature contours for survey # 1. The dashed lines indicate the positions of the vertical temperature sections shown in Figures 17 and 19.

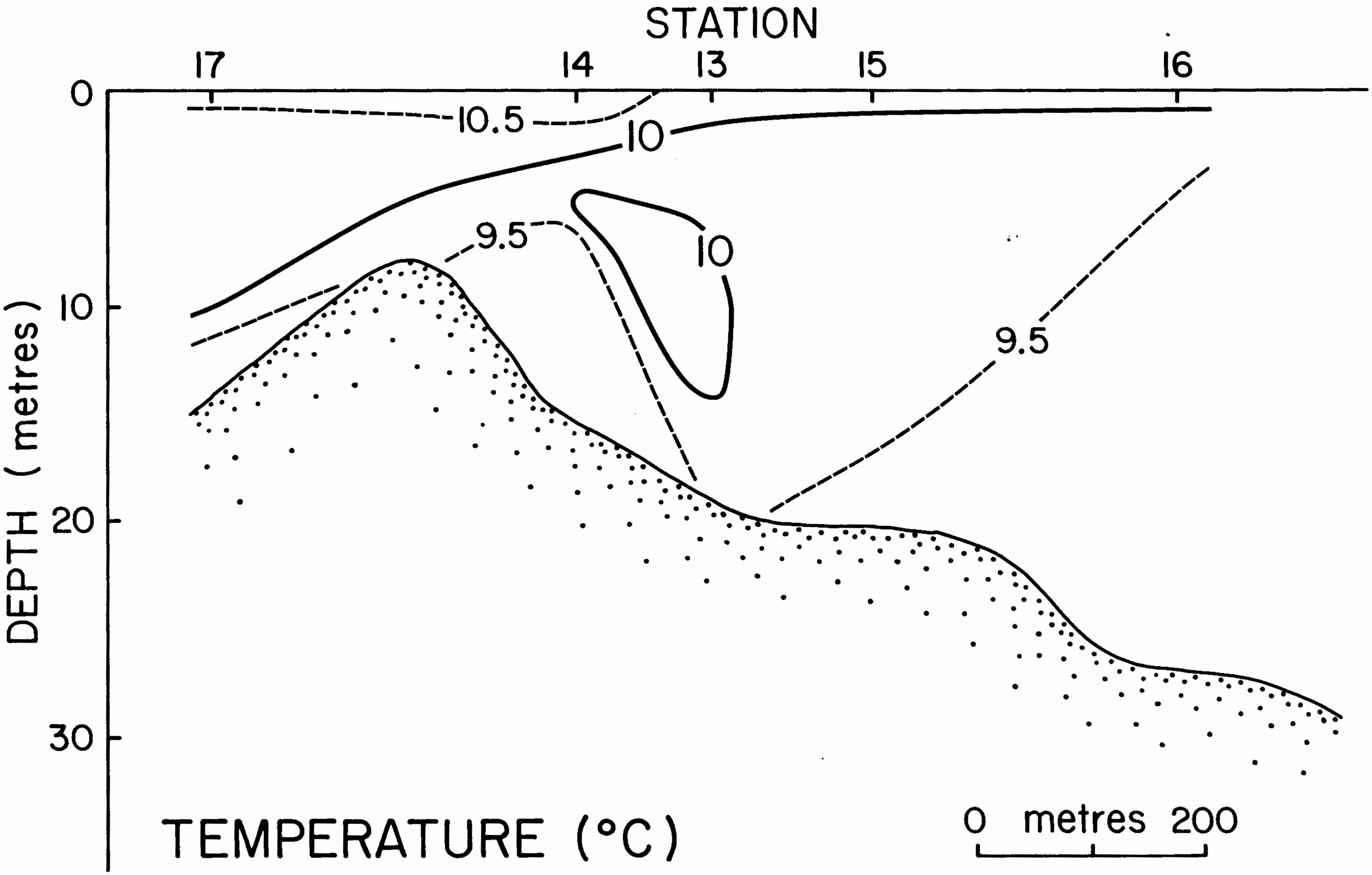

Figure 17. Vertical temperature section in a southwesterly direction for survey # 1.

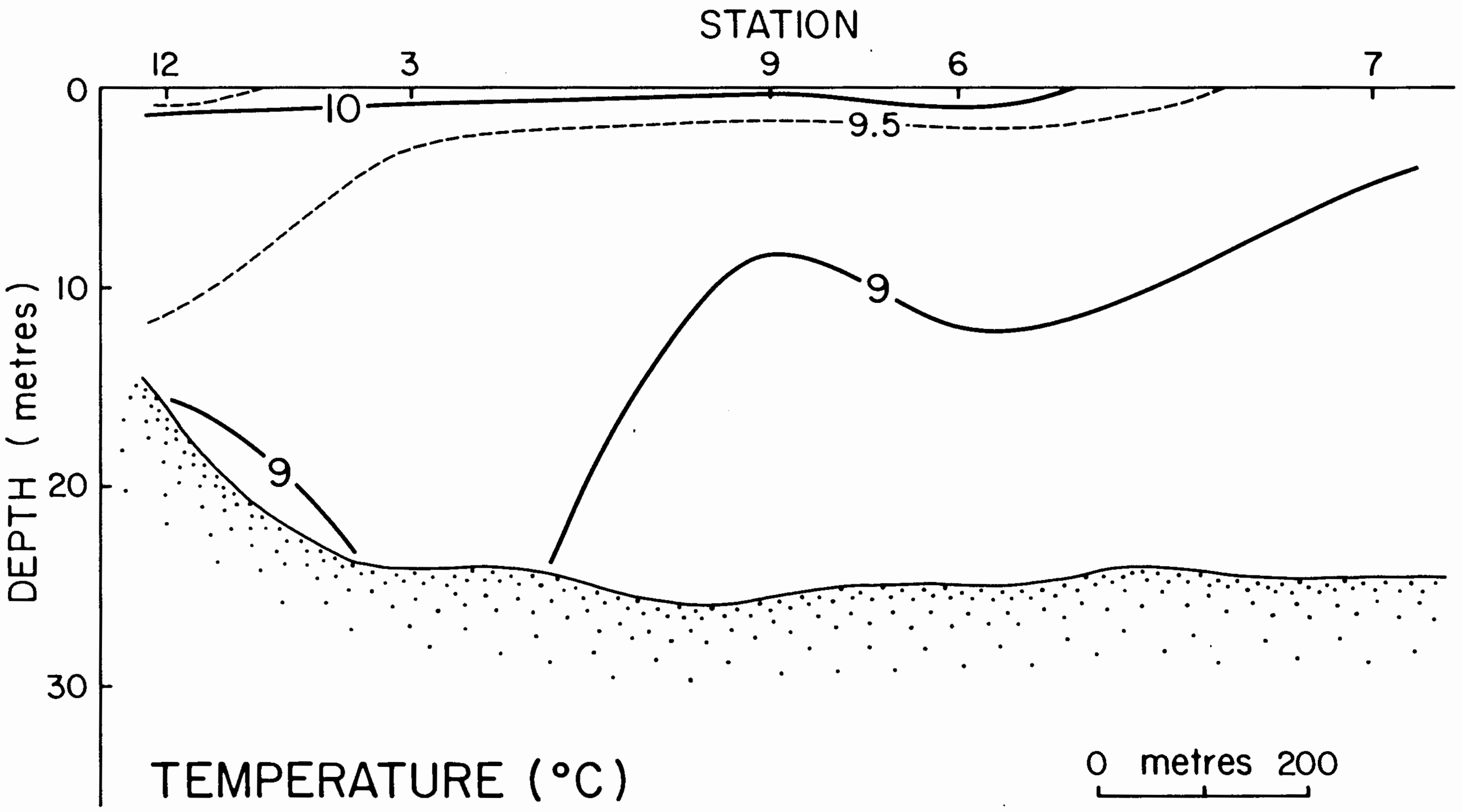

Figure 18. Vertical temperature section in a northwesterly direction for survey # 1.

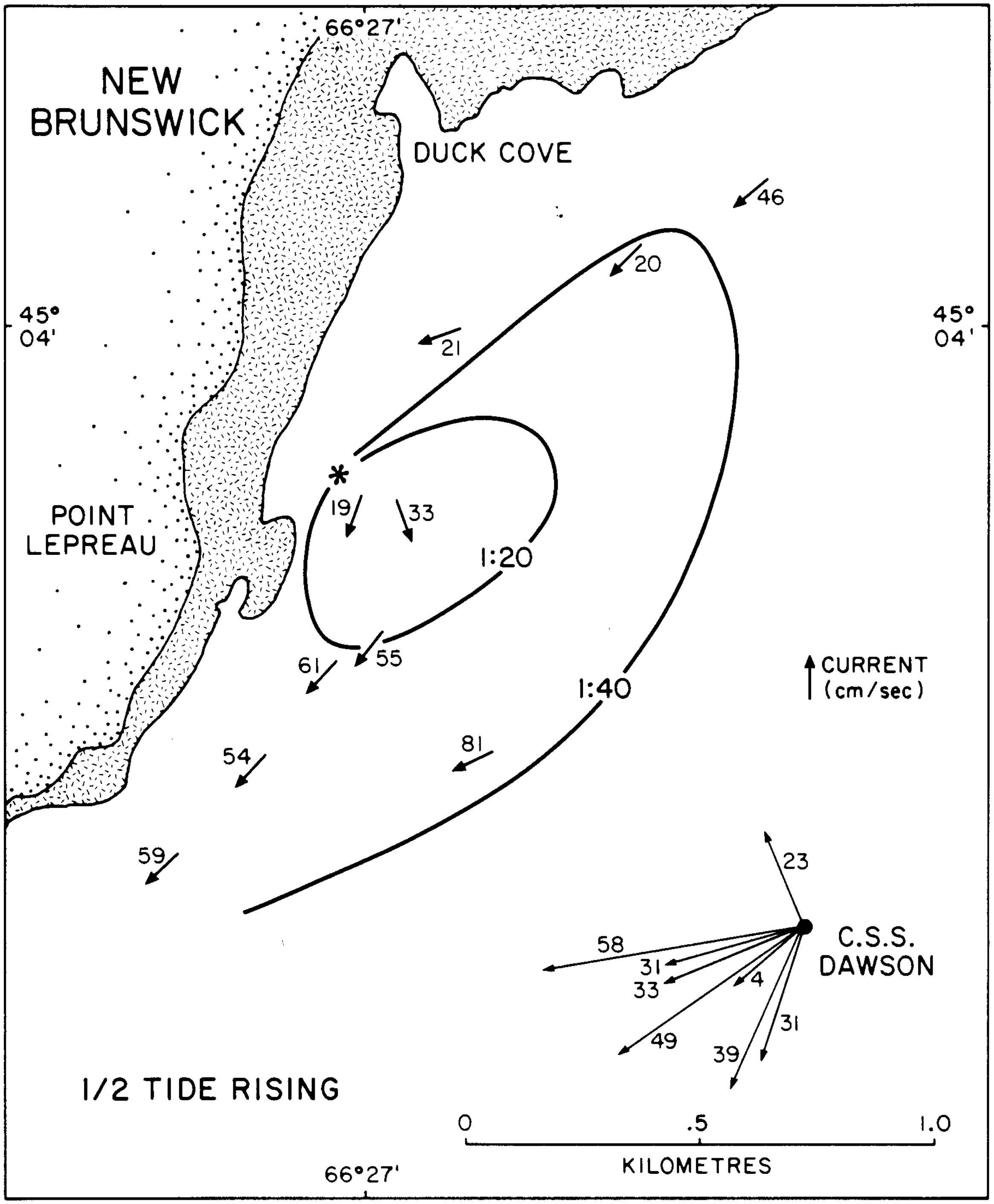

Figure 19. Surface current vectors and approximate dilution contours for survey # 1. 1/2 hour average currents at CSS Dawson during the course of the survey are also shown.

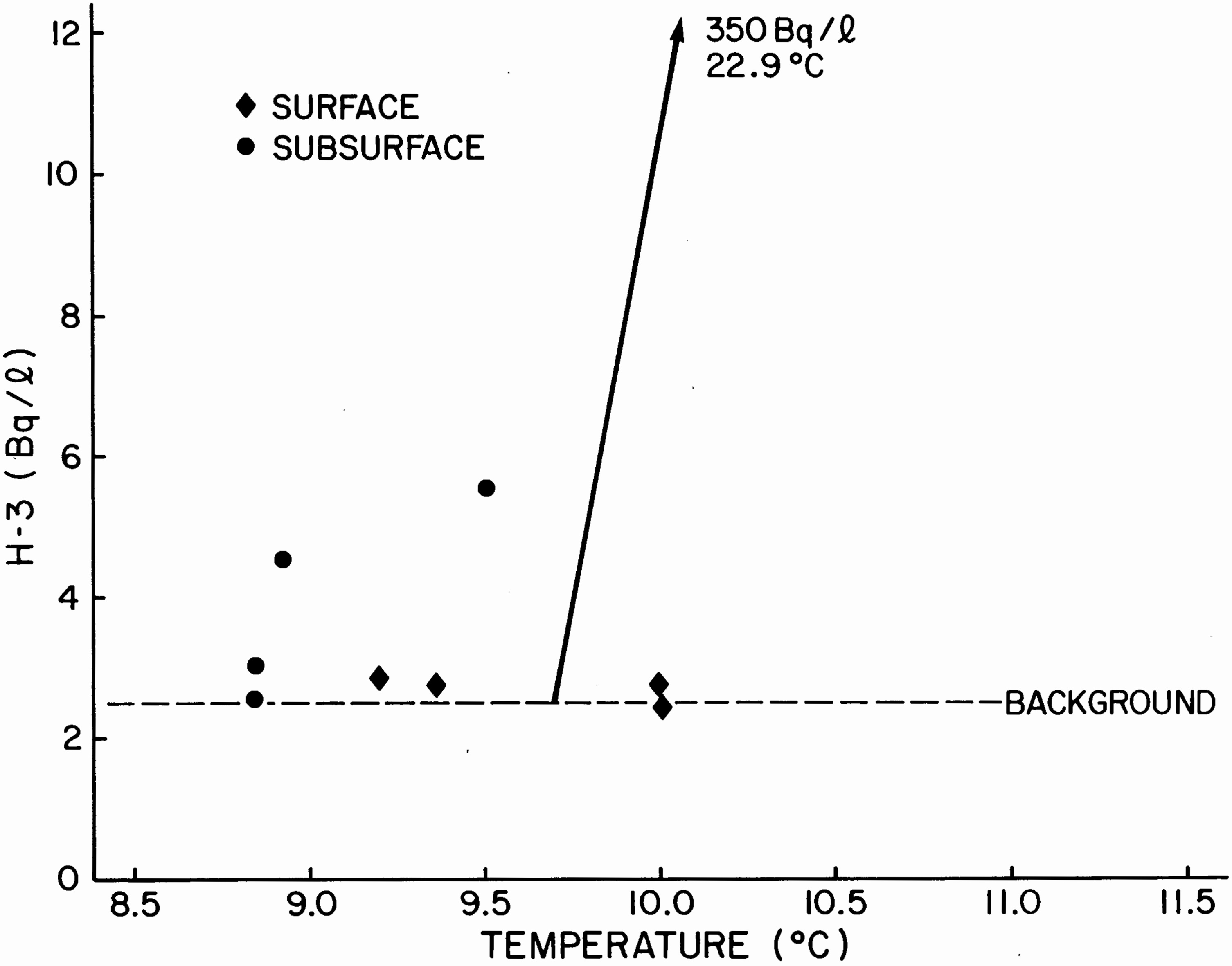

Figure 20. Temperature - H-3 mixing diagram for survey # 1.

the fact that most stations occupied at the time of the pumpout were located upstream of the southwesterly flowing plume.

Survey #4 (High Water - 1/2 hour → High Water + 1 hour)

Most station locations during the high water survey were located southwest of the outfall (Figure 21). Surface temperatures from this survey displayed no coherent spatial picture, probably as a result of the vigorous mixing occuring so that temperature contours were not constructed for Figure 21 . The temperature depth profile is given in Figure 22.

Currents during this survey were setting strongly toward the southwest (Figure 23) in response to the remnants of the eddy set up by the incoming tide and the begining of the ebb tide. It was felt that some portion of the diluted effluent was flowing shoreward of the rock outcrop known locally as The Gillmore, but shoal water and brisk currents prevented sampling in this area.

The tritium activity in the release during this survey was easily detectable (6000 Bq/ℓ) and allowed the measurement of tritium in most samples, surface and bottom, taken downstream from the outfall (Table 8). In this case, the tritium activity can be used to determine dilution factors and allow a comparison with dilution factors calculated using temperature variations. For example, surface tritium concentrations decreased from 505 Bq/ℓ to 392 Bq/ℓ to 42 Bq/ℓ at stations 56, 57 and 58 which correspond to 0.2, 0.4 and 0.6 km downstream of the outfall location.

Dilution factors calculated from both the temperature and tritium values (assuming station #55 to be representative of ambient conditions) ranged from 8 to almost 30 generally increasing with distance from the outfall. Good agreement for dilution factors were obtained between those using only temperature or only tritium activity, each being within 30% of the other.

Tritium observations in the form of a tritium-temperature mixing diagram are given in Figure 24. Good agreement of tritium concentration measured compared to that predicted by the

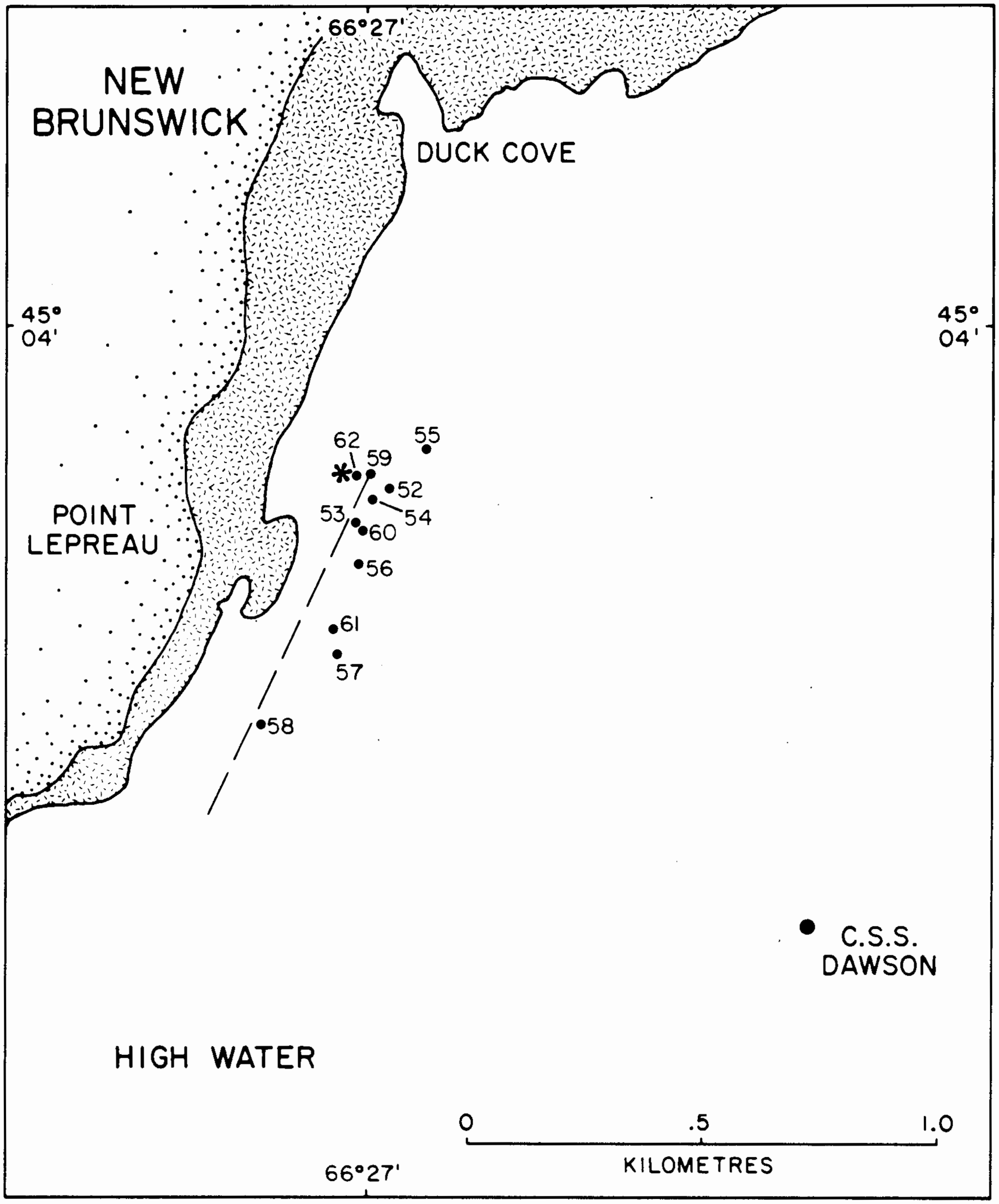

Figure 21. Station locations for survey # 4 .The dashed line indicates the position of the vertical section displayed in Figure 23.

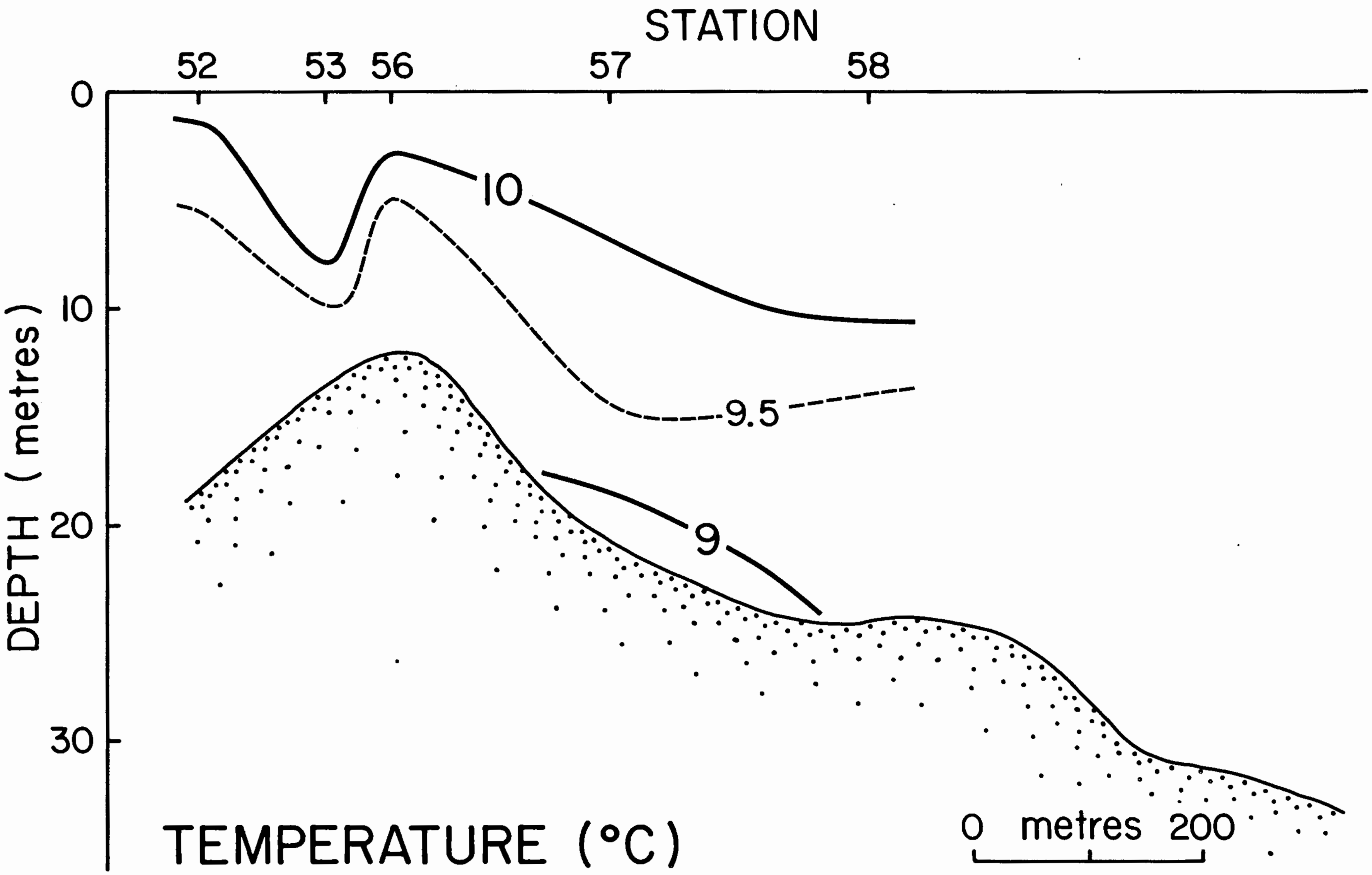

Figure 22. Vertical temperature section in a southwesterly direction for survey # 4.

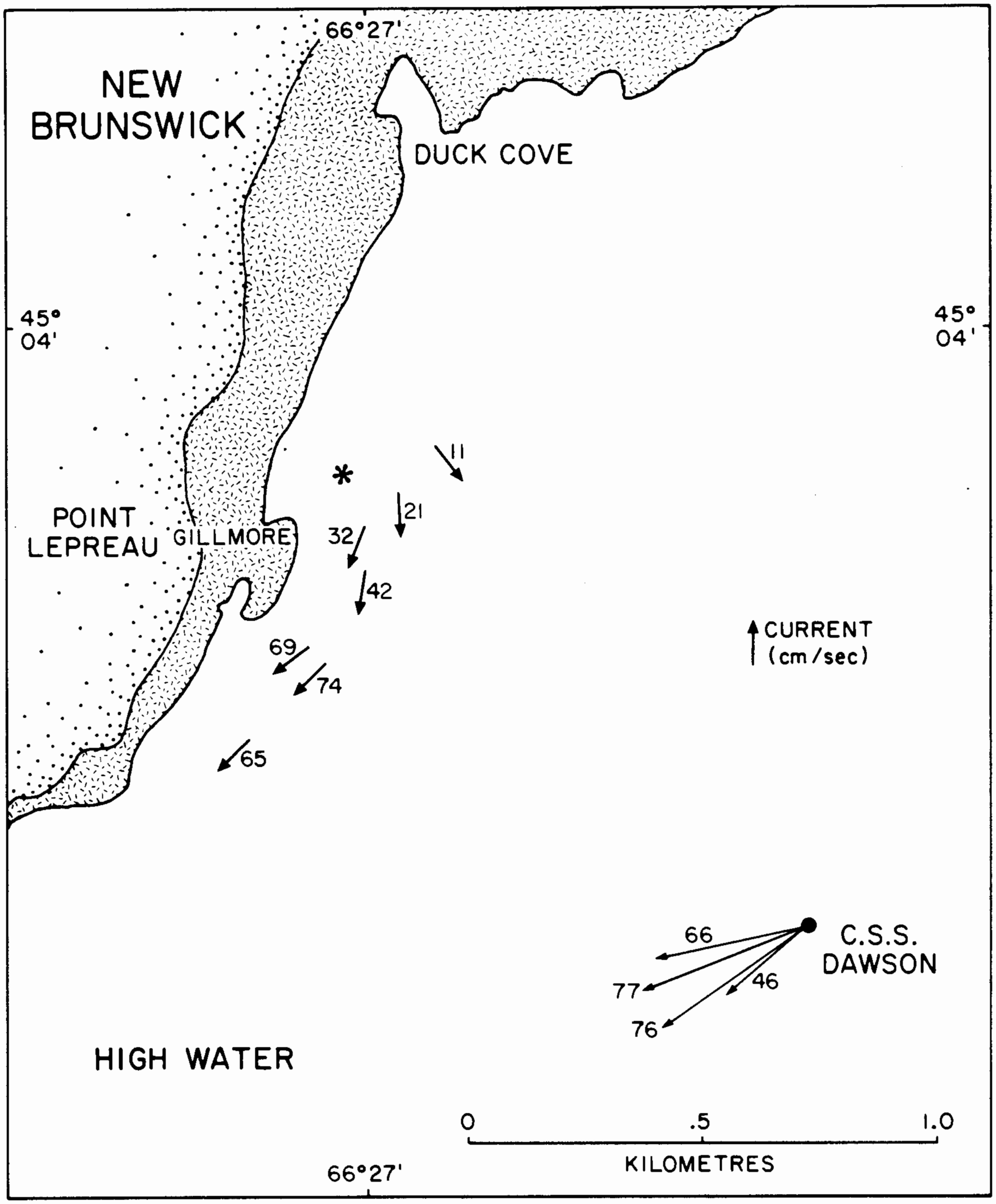

Figure 23. Current vectors for survey # 4.

Table 8. Station locations, depths and times for stations occupied during launch survey.

Sample ID	Station	Depth	Sample Depth	H-3	Salinity	T°C	Latitude	Longitude	GMT	Date
84-02201	1	16.5	1	<1.4	30.35	10.34	45°3.82N	66°17.02W	12:57	13/7/84
2202			14.3	"	30.80	13.90				
2203	2	16.5	1	"	30.44	10.35	45°3.83N	66°27.08W	13:06	13/7/84
2204			15.3	"	–	9.80				
2205	3	27.4	1	"	29.98	10.46	45°3.87N	66°26.82W	13:18	13/7/84
2206			25.1	1.8 ± 1.7	31.13	9.10				
2207	4	20.1	1	<1.4	30.55	9.49	45°4.00N	66°26.75W	13:28	13/7/84
2208			17.5	"	31.05	9.10				
2209	5	23.8	1	"	30.59	9.47	45°4.03N	66°26.75W	13:42	13/7/84
2210			18.6	"	31.14	9.10				
2211	6	25.6	1	2.4 ± 1.7	30.48	10.01	45°4.10N	66°26.56W	14:02	13/7/84
2212			22.2	<1.4	31.21	8.90				
2213	7	25.6	1	"	31.01	9.28	45°4.20N	66°26.30W	14:23	13/7/84
2214			22.3	3.0 ± 1.7	31.26	8.85				
2215	8	9.1	1	2.7 ± 1.7	30.86	9.36	45°4.18N	66°26.76W	14:35	13/7/84
2216			8.1	<1.4	31.12	9.08				
2217	9	32.9	1	<1.4	30.67	9.92	45°3.95N	66°26.58W	14:45	13/7/84
2218			27.5	2.5 ± 1.7	31.29	8.84				
2219	10	22.0	1	2.8 ± 1.7	31.06	9.20	45°3.98N	66°26.88W	14:56	13/7/84
2220			20.0	4.5 ± 1.7	31.20	8.93				
2221	11	22.0	1	<1.4	30.92	9.43	45°3.87N	66°27.00W	15:04	13/7/84
2222			18.5	"	31.19	8.92				
2223	12	24.0	1	"	31.04	10.55	45°3.82N	66°26.99W	15:10	13/7/84
2224			18.2	"	31.22	8.84				
2225	13	29.0	1	"	30.15	9.91	45°3.58N	66°27.09W	15:19	13/7/84
2226			24.0	"	31.22	8.85				
2227	14	29.0	1	"	30.72	10.32	45°3.64N	66°27.06W	15:39	13/7/84
2228			24.0	5.5 ± 1.7	31.04	9.51				
2229	15	29.0	1	2.7 ± 1.7	30.82	10.00	45°3.53N	66°27.18W	15:47	13/7/84

Table 8. Continued.

Sample ID	Station	Depth	Sample Depth	H-3	Salinity	T°C	Latitude	Longitude	GMT	Date
84-02230			26.6	<1.4	31.04	9.33				
2231	16	29.0	1	"	30.85	10.07	45°3.42N	66°27.33W	15:55	13/7/84
2232			25.9	"	31.05	9.23				
2233	17	20.0	1	"	30.89	10.40	45°3.82N	66°27.03W	16:11	13/7/84
2234			17.2	"	30.88	9.40				
2235	18	46.0	1	"	30.47	10.15	45°3.53N	66°26.77W	16:24	13/7/84
2236			41.3	"	31.46	8.45				
2237	19	16.5	1	<1.4	30.94	10.61	45°3.83N	66°27.00W	18:43	13/7/84
2238			15.0	"	31.46	8.63				
2239	20	22.0	1	"	30.74	10.05	45°3.88N	66°26.95W	18:51	13/7/84
2240			19.5	"	31.48	8.64				
2241	21	22.0	1	2.4 ± 1.8	30.69	10.21	45°3.94N	66°26.09W	18:58	13/7/84
2242			19.2	1.9 ± 1.8	31.47	8.63				
2243	22	27.0	1	<1.4	30.65	10.24	45°4.08N	66°26.57W	19:07	13/7/84
2244			22.0	<1.4	31.47	8.68				
2245	23	27.0	1	3.0 ± 1.8	30.90	10.42	45°4.18N	66°26.12W	19:16	13/7/84
2246			24.2	2.3 ± 1.8	31.40	8.78				
2247	24	22.0	1	2.8 ± 1.8	30.69	10.48	45°4.14N	66°26.43W	19:29	13/7/84
2248			20.2	7.1 ± 1.9	31.41	8.73				
2249	25	18.0	1	2.9 ± 1.8	30.82	10.31	45°4.04N	66°26.81W	19:38	13/7/84
2250			16.5	5.0 ± 1.9	31.45	8.66				
2251	26	11.0	1	1.6 ± 1.8	31.20	10.47	45°3.94N	66°26.93W	19:47	13/7/84
2252			9.4	22.4 ± 2.0	31.36	8.90				
2253	27	20.0	1	3.2 ± 1.8	31.12	10.76	45°3.85N	66°26.98W	19:53	13/7/84
2254			18.0	<1.5	31.37	9.23				
2255	28	16.0	1	"	31.03	9.50	45°3.71N	66°27.06W	20:01	13/7/84
2256			12.5	"	31.13	9.25				
2257	29	27.0	1	"	30.94	9.61	45°3.35N	66°27.49W	20:30	13/7/84
2258			21.2	"	31.17	9.14				

Table 8. Continued.

Sample ID	Station	Depth	Sample Depth	H-3	Salinity	T°C	Latitude	Longitude	GMT	Date
84-02259	30	24.0	1	2.2 ± 1.7	31.01	9.58	45°3.74N	66°27.00W	20:22	13/7/84
2260			-	<1.5	31.07	-				
2261	31	15.0	1	3.4 ± 2.6	31.15	10.44	45°3.90N	66°26.95W	20:30	13/7/84
2262			13.2	2.3 ± 2.6	31.18	9.52				
2263	32	13.0	1	<2.0	31.00	11.28	45°3.85N	66°27.00W	10:04	14/7/84
2264			7.0	"	30.92	11.10				
2265	33	20.0	1	"	30.89	11.08	45°3.87N	66°26.97W	10:11	14/7/84
2266			12.9	"	30.92	9.68				
2267	34	18.0	1	"	30.89	10.32	45°3.99N	66°26.82W	10:20	14/7/84
2268			15.5	"	30.94	9.48				
2269	35	18.0	1	"	30.97	9.82	45°4.12N	66°26.47W	10:29	14/7/84
2270			15.5	2.6 ± 2.6	31.03	9.36				
2271	36	24.0	1	<2.0	30.92	10.38	45°4.09N	66°26.43W	10:36	14/7/84
2272			21.1	"	31.07	9.29				
2273	37	26.0	1	"	31.01	9.39	45°3.97N	66°26.54W	10:45	14/7/84
2274			22.2	"	31.06	9.32				
2275	38	26.0	1	2.5 ± 2.6	30.92	9.48	45°3.91N	66°26.71W	10:54	14/7/84
2276			22.6	<2.0	30.97	9.43				
2277	39	15.0	1	7.0 ± 2.6	30.86	10.49	45°4.02N	66°26.81W	11:02	14/7/84
2278			12.0	<2.0	30.85	9.53				
2279	40	15.0	1	8.1 ± 2.6	30.80	10.59	45°3.83N	66°27.01W	11:10	14/7/84
2280			12.1	4.7 ± 2.6	30.86	10.45				
2281	41	15.0	1	3.4 ± 2.5	30.87	10.70	45°3.85N	66°27.02W	11:20	14/7/84
2282			12.9	6.0 ± 2.5	30.86	10.65				
2283	42	18.0	1	<2.0	30.49	9.91	45°3.69N	66°27.04W	11:29	14/7/84
2284			15.4	29.3 ± 2.7	30.83	9.55				
2285	43	22.0	1	<2.0	30.48	9.94	45°3.78N	66°26.99W	11:36	14/7/84
2286			18.0	"	30.73	9.67				
2287	44	16.0	1	4.6 ± 2.5	30.86	11.19	45°3.87N	66°26.99W	11:42	14/7/84

Table 8. Continued.

Sample ID	Station	Depth	Sample Depth	H-3	Salinity	T°C	Latitude	Longitude	GMT	Date
84-02288			13.8	4.7 ± 2.5	30.84	10.00				
2289	45	24.0	1	2.9 ± 2.5	30.37	10.03	45°3.90N	66°26.80W	11:49	14/7/84
2290			21.6	<2.1	30.79	9.58				
2291	46	13.0	1	4.2 ± 2.5	30.50	10.11	45°4.08N	66°26.82W	11:57	14/7/84
2292			11.5	<2.1	30.88	9.95				
2293	47	27.0	1	4.0 ± 2.5	30.72	9.73	45°4.02N	66°26.43W	12:05	14/7/84
2294			24.3	<2.1	30.87	9.53				
2295	48	22.0	1	4.0 ± 2.5	30.49	10.03	45°4.23N	66°26.19W	12:14	14/7/84
2296			19.1	3.5 ± 2.5	30.77	9.86				
2297	49	20.0	1	<2.1	30.64	10.34	45°4.03N	66°26.72W	12:25	14/7/84
2298			17.4	"	30.81	9.73				
2299	50	24.0	1	"	30.79	11.30	45°3.85N	66°26.95W	12:33	14/7/84
2300			20.8	3.2 ± 2.5	30.79	9.62				
2401	51	24.0	1	3.8 ± 2.5	30.50	10.36	45°3.89N	66°26.81W	12:44	14/7/84
2402			21.6	<2.1	30.71	9.60				
2403	52	27.0	1	<2.1	30.73	10.21	45°3.82N	66°26.99W	16:24	14/7/84
2404			24.3	"	31.06	9.17				
2405	53	16.0	1	"	30.84	10.40	45°3.77N	66°27.05W	16:34	14/7/84
2406			9.2	<2.2	30.91	9.42				
2407	54	20.0	1	"	30.81	10.26	45°3.81N	66°27.02W	16:42	14/7/84
2408			18.0	"	30.95	12.10				
2409	55	27.0	1	"	31.00	9.38	45°3.86N	66°26.93W	16:51	14/7/84
2410			24.2	"	31.28	8.88				
2411	56	22.0	1	505.1 ± 6.4	31.09	10.49	45°3.73N	66°27.04W	17:00	14/7/84
2412			19.1	<2.2	31.17	8.94				
2413	57	26.0	1	391.8 ± 5.7	31.08	10.27	45°3.63N	66°27.08W	17:06	14/7/84
2414			23.4	17.4 ± 2.8	31.27	8.89				
2415	58	26.0	1	41.5 ± 3.1	30.76	10.38	45°3.54N	66°27.21W	17:12	14/7/84
2416			23.1	11.0 ± 2.7	31.20	9.04				
2417	59	18.0	1	< 2.2	31.03	10.01	45°3.83N	66°27 03W	17:24	14/7/84

Table 8. Continued.

Sample ID	Station	Depth	Sample Depth	H-3	Salinity	T°C	Latitude	Longitude	GMT	Date
84-02418			15.8	301.5 ± 5.1	31.24	9.92				
2419	60	24.0	1	419.2 ± 5.9	31.13	9.96	45°3.76N	66°27.04W	17:31	14/7/84
2420			21.6	<2.2	31.40	8.74				
2421	61	20.0	1	236.0 ± 4.7	31.22	9.93	45°3.66N	66°27.08W	17:38	14/7/84
2422			17.5	7.0 ± 2.6	31.16	9.19				
2423	62	20.0	1	<2.2	30.78	10.08	45°3.83N	66°27.04W	17:48	14/7/84
2424			17.1	<2.2	31.34	8.83				

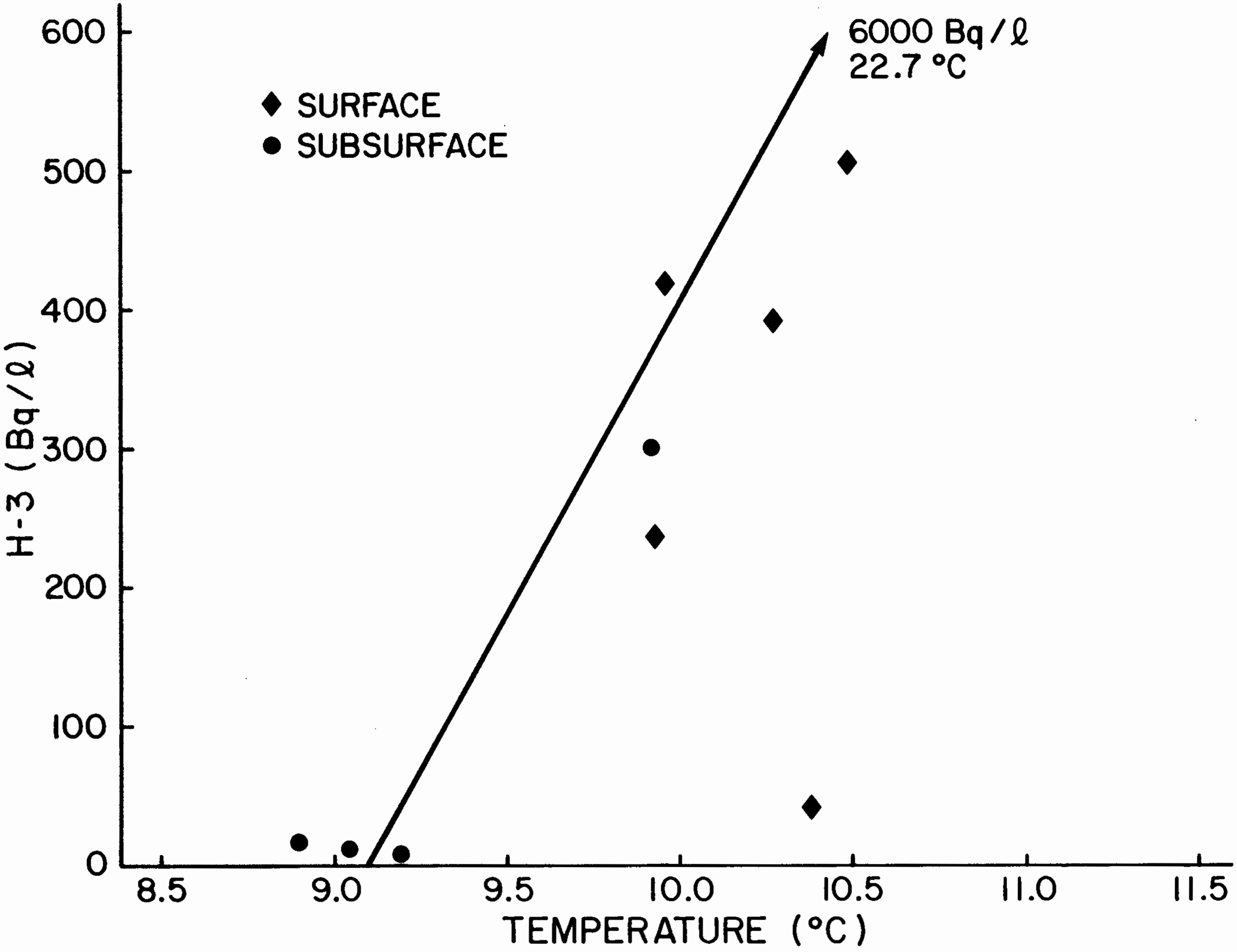

Figure 24. Temperature - H-3 mixing diagram for survey # 4.

temperature were obtained. This is largely a result of the strong currents and higher activity levels of tritium measured.

Survey #2 (Low Water - 3 1/2 hour →Low Water - 1 1/2 hour)

Station locations for the half tide falling condition of the second survey are given in Figure 25. As the outgoing tidal current continues to increase, flow separation again occurs resulting in a back eddy in Duck Cove. Separation appears to occur just south of the cooling water outfall causing reactor effluent to flow in a northeasterly direction as illustrated for temperature in Figure 26 for the transect in Figure 25. Although the western limit of this eddy is not well defined by this survey, examination of Figure 27, which shows the temperature-depth profile with time at CSS Dawson at the anchor station, reveals warmer water at the position of CSS Dawson near this stage of the tide. Low levels of tritium were generally measurable in water samples taken down stream of the outfall (Stations 21-27, Table 8). Several measurements of tritium were also made from samples taken from CSS Dawson at anchor. These measurements were made only during times of half tide falling. For example sample 84-2307 had a tritium concentration of 3.0 Bq/ℓ, 84-2314 of 5.4 Bq/ℓ and 84-2358 of 5.0 Bq/ℓ (Table 3). These findings give further support to the conclusion that the anchor station location of CSS Dawson is within the influence of the eddy. Dilution contours shown in Figure 28 are again based on station #42. The temperature-tritium mixing diagram displayed in Figure 29 presents a rather confused picture, again due to the low level release and the short duration of the pumpout.

Summary

Improvement in launch navigation technique coupled with the lack of wind during this survey permitted the determination of surface currents in greater detail than previously available. The observed currents agree well with with those obtained in 1975 as part of the environmental assessment process (MacLaren Atlantic Ltd., 1977). Observed temperature rises are well within those predicted, however the surface extent of the plume which reaches maximums in the

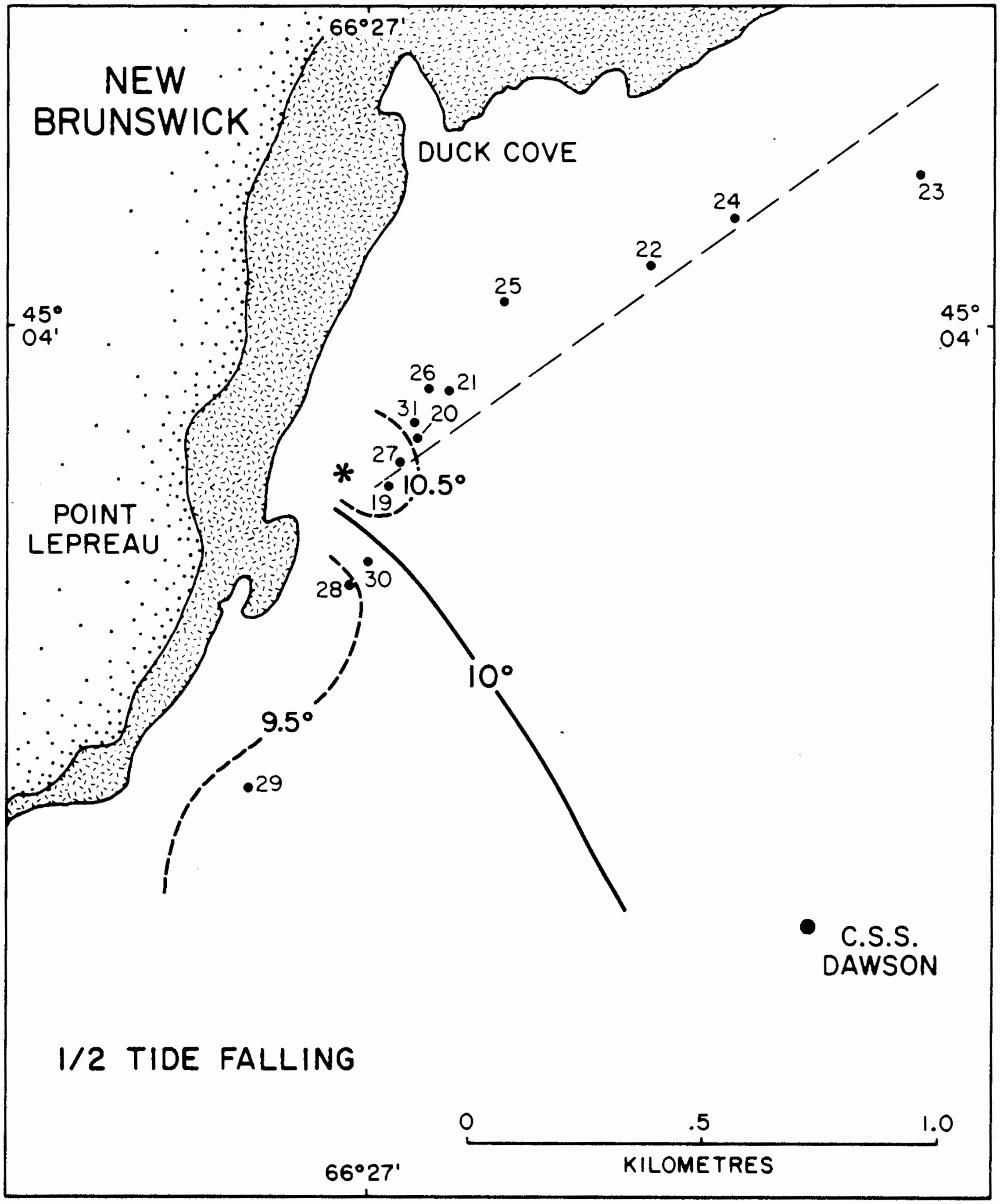

Figure 25. Station locations and surface temperature contours for survey # 2.The dashed line indicates the position of the vertical temperature section shown in Figure 26.

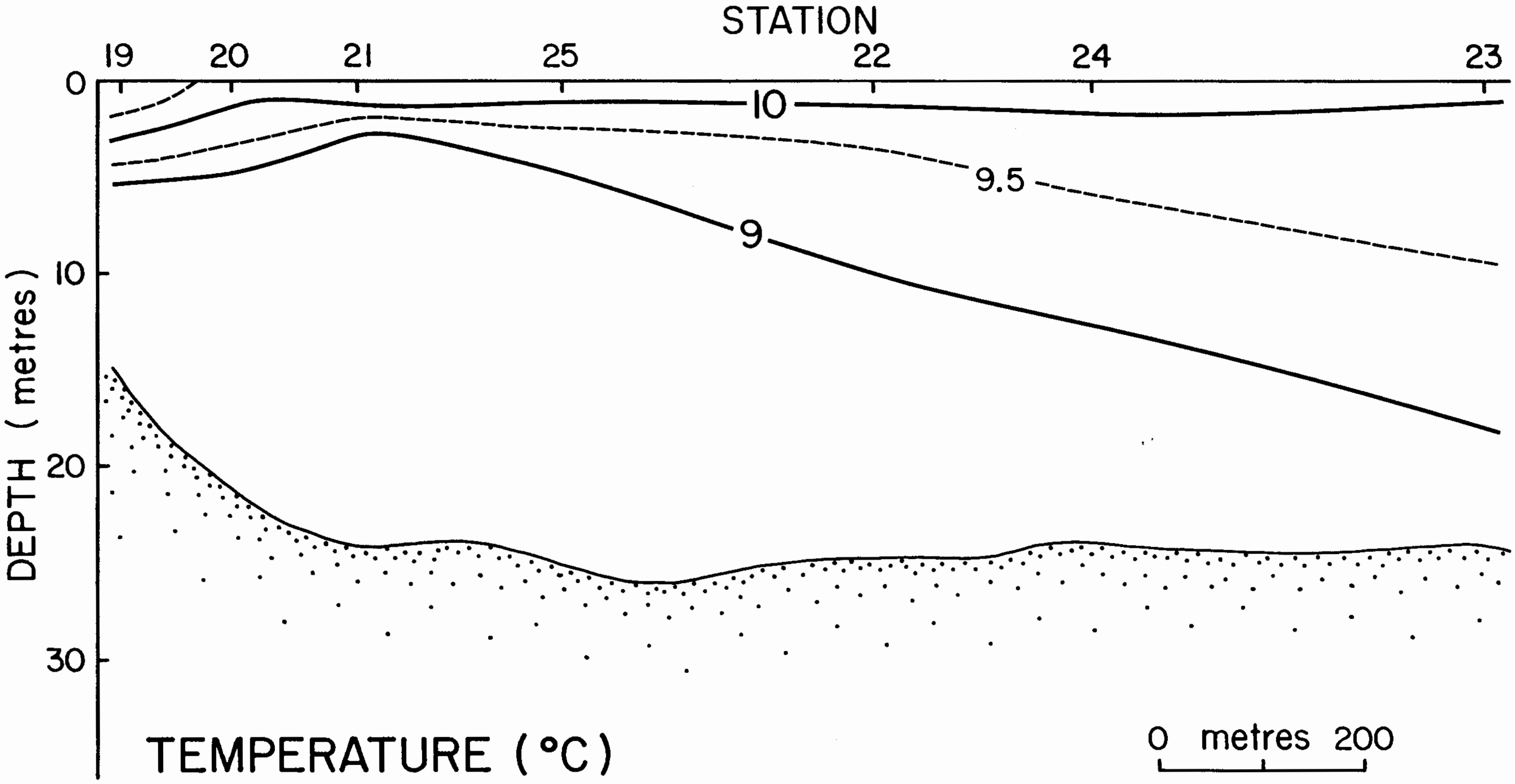

Figure 26. Vertical temperature section in a north westerly direction for survey # 2.

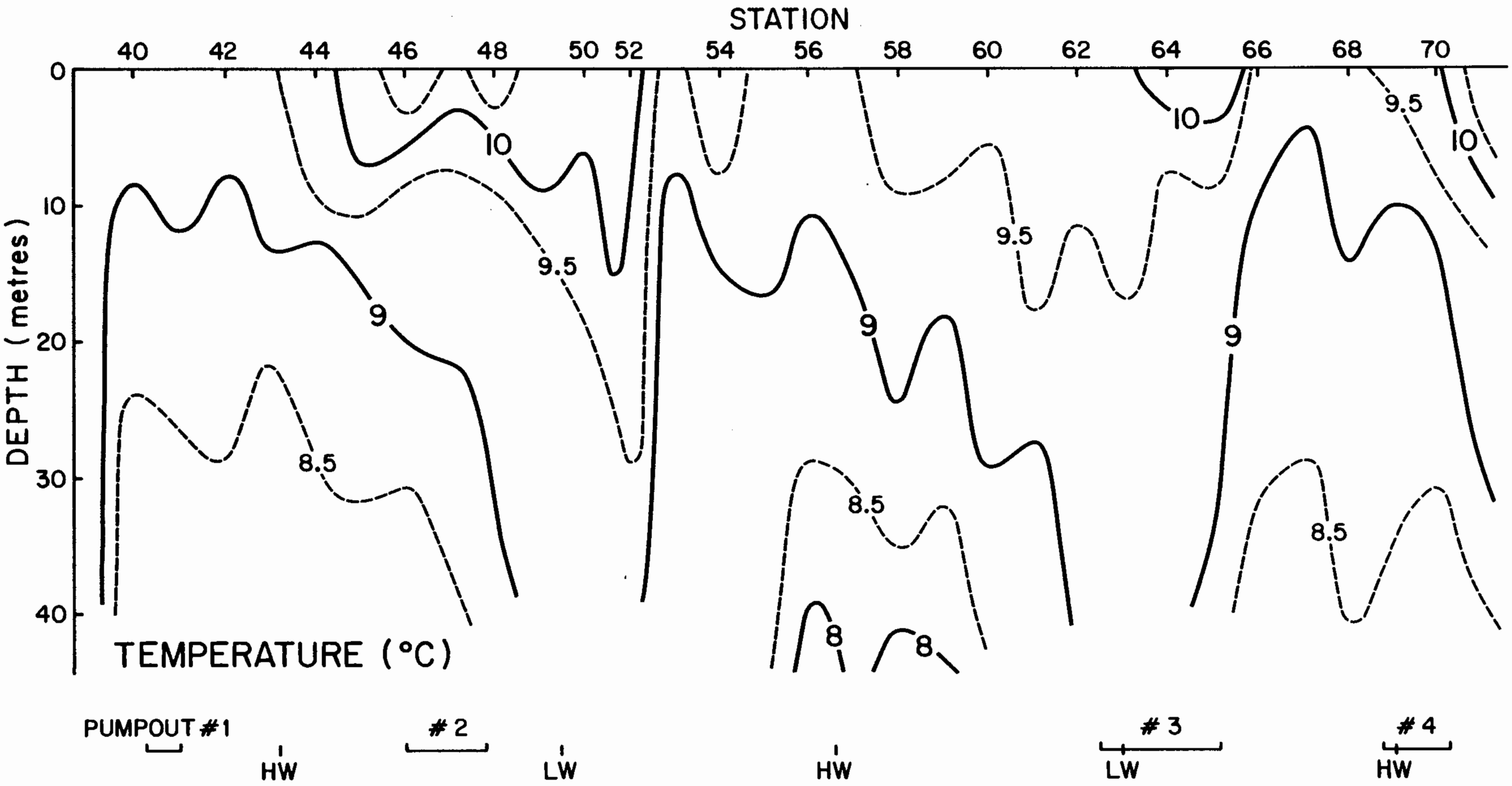

Figure 27. Time series section of temperature versus depth at CSS Dawson during the course of the thermal plume surveys.

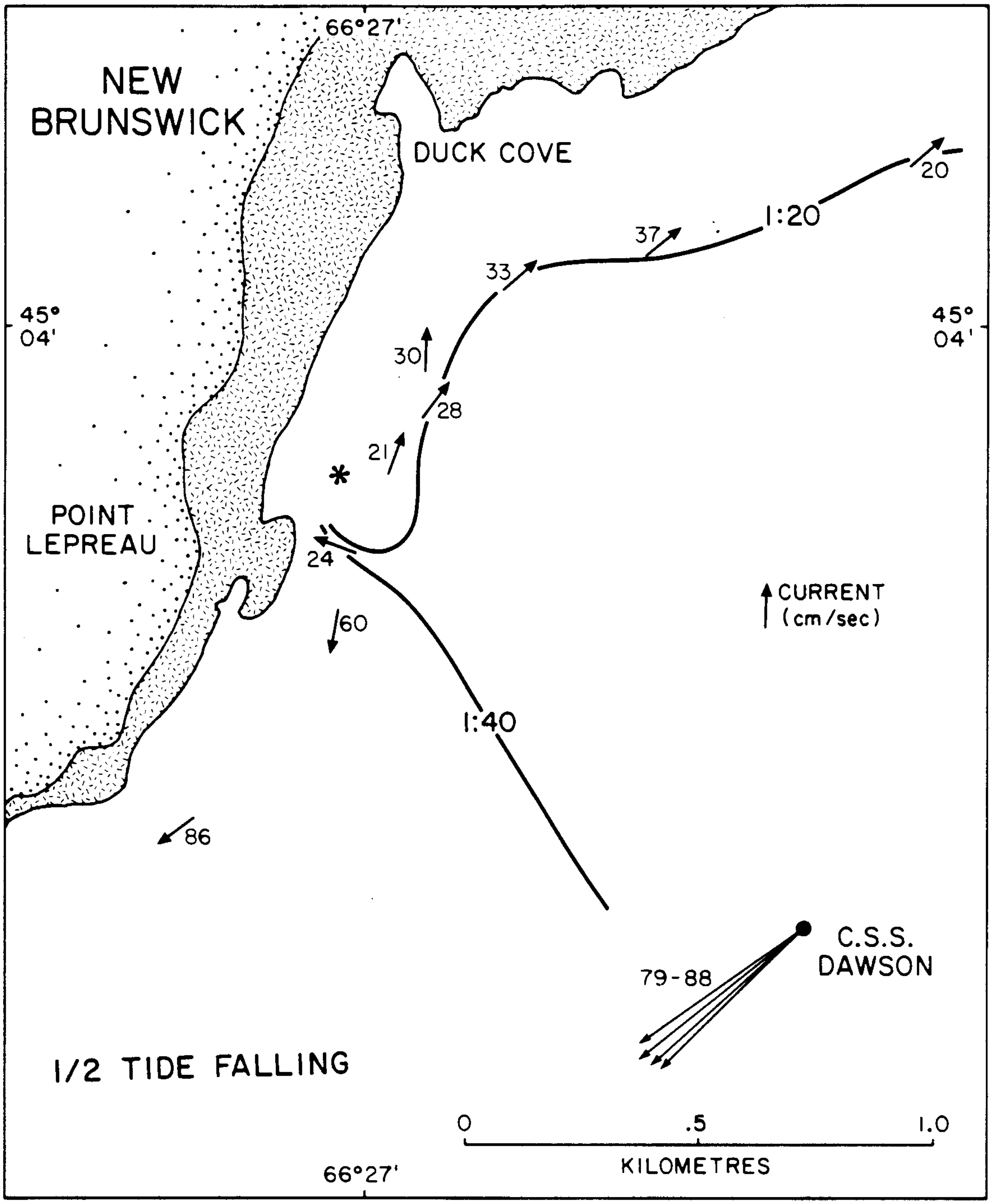

Figure 28. Current vectors and dilution contours for survey # 2.

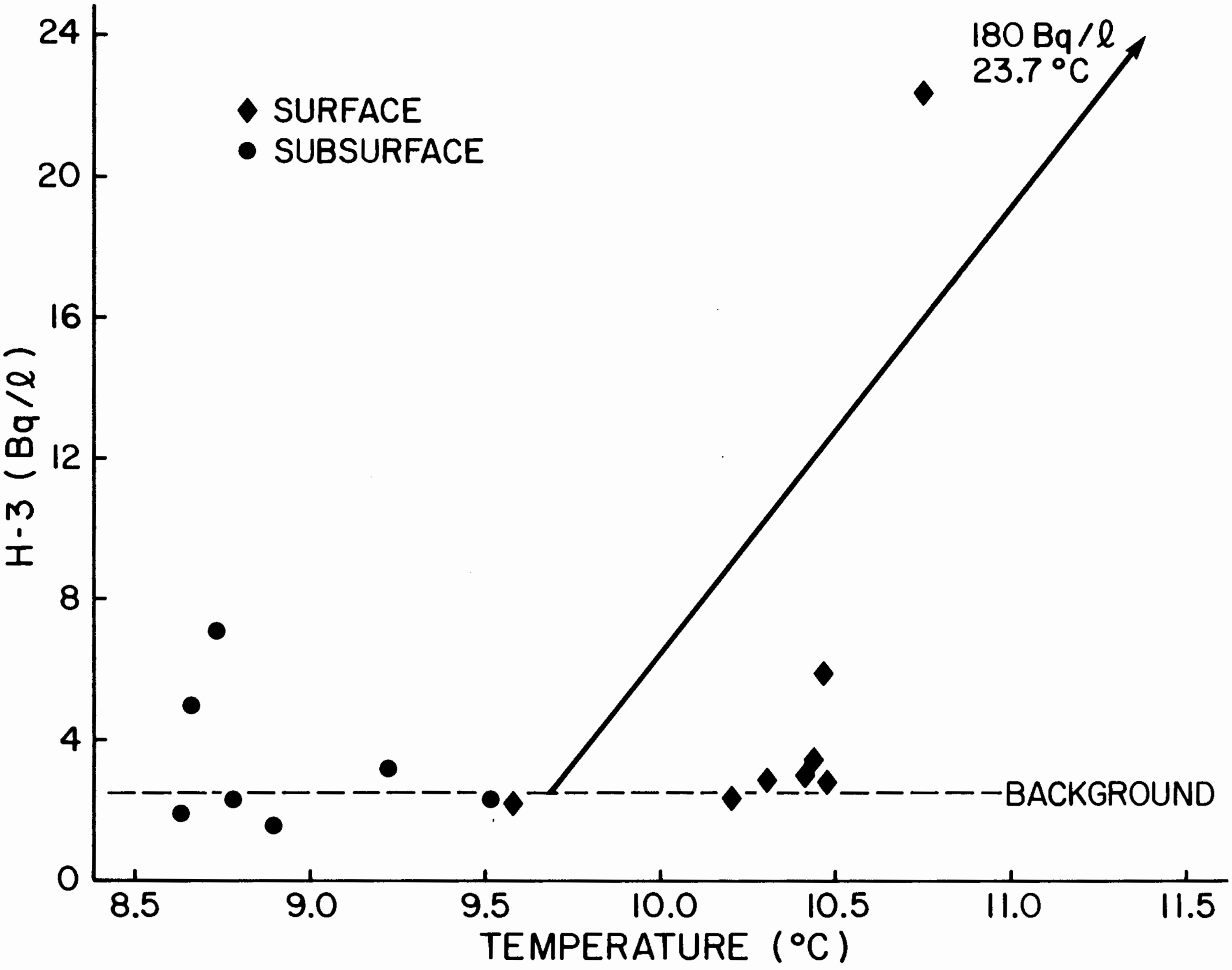

Figure 29. Temperature - H-3 mixing diagram for survey # 2.

eddies set up at half tide rising and falling is slightly larger than might have been anticipated from previously available information. However, the ambient thermal structure in the Bay of Fundy which existed at the time of the survey made it difficult to judge what was heated effluent and what was simply warmer water advected from other parts of the bay.

The duration of the liquid waste pump-outs (approximately 40 minutes in each case) was too short to allow any sort of steady state to be reached. This prevented extensive use of tritium values as a plume tracer, a procedure which would have been useful in separating the thermal effluent from the Bay of Fundy waters. In general, the tritium values were useful in some cases, verifing the dilution values derived from the temperature measurements. Salinity gradients in the receiving waters had a negligible effect on plume dynamics at this time of year.

Characterizing the thermal plume in terms of tidal conditions is critical to understanding the distribution of the plume. Under certain conditions (ie. half tide rising and high water) the thermal plume is swept away from the area while under other tidal conditions (ie. low tide and half tide falling) the plume becomes trapped in back eddies and remain in the vicinity of the outfall for longer periods. In addition, the pattern of the thermal plume for any tidal condition is strongly influenced by the previous tidal condition.

3.0 ATMOSPHERIC MONITORING

The atmosphere is the most dynamic environmental medium for the transport of gaseous and particulate emissions from nuclear power generating facilities. Effective dispersion of gaseous or finely divided material released into the atmosphere near the ground depends on various natural mixing processes. Mainly, this mixing is a direct consequence of turbulent and convective motions generated in the boundary layer itself. Mixing in the boundary layer is dependent partly on the aerodynamic friction of the underlying surface and on the density stratification of the air which results from differences in surface and air temperature. Temperature differences arise over land primarily in the course of the daily cycle of radiative heating and cooling of the ground but may also arise from the influx of air from warmer or cooler regions of the earth (Pasquill *et al.* 1983). The dispersion of radionuclides released via stack gas emissions follows several pathyways; direct deposition, transport via air movement and subsequent exchange with surface water and transfer to various media via precipitation of airborne particulates.

The two principal components of the atmospheric monitoring program at Point Lepreau are (1) the on going compilation of a meteorological data base for the Point Lepreau region which can be applied in the projection of the transport of airborne pollutants under diverse weather conditions and in atmospheric transport models and (2) the collection of atmospheric water vapour and air particulate samples for radionuclide analysis.

3.1 Meteorological Data Collection

The meteorological data collection station was established in 1978 at Hall's Lake Siding but in 1983 was moved 3 km east to the New Brunswick Department of Transport depot at Musquash, N.B. to facilitate equipment maintenance. The station consists of (1) U2A wind equipment to measure wind speed and direction 10 meters above ground level, (2) Fisher and Porter precipitation gauge and (3) a thermohydrograph to record temperature and relative humidity.

The Atmospheric Environment Service abstracted the temperature, relative humidity and wind data for 1984. The wind speed and direction data are summarized in Table 9. The mean wind

Table 9. Mean speed (knots) and percent frequency of wind direction from U2A wind sensor at Point Lepreau, N.B. during 1984. Station located at Musquash, N.B.

Direction	January - March		April - June		July - September		October - December		Annual	
	% Frequency	Wind Speed	% Frequency	Wind Speed	% Frequency	Wind Speed	% Frequency	Wind Speed	% Frequency	Wind Speed
N	3.9	4.5	2.7	4.0	2.7	2.2	5.7	3.1	4.0	3.4
NNE	8.0	4.9	3.5	4.1	0.9	1.9	5.3	3.1	4.9	3.5
NE	5.6	6.5	1.2	2.6	0.9	0.9	1.9	2.2	2.6	3.0
ENE	1.9	6.2	2.7	3.6	1.5	1.0	0.9	2.0	1.7	3.2
E	1.4	5.5	3.1	2.4	1.2	1.6	1.7	2.8	1.8	3.1
ESE	1.1	5.9	2.3	1.3	1.3	1.7	0.9	3.3	1.4	3.0
SE	0.6	3.4	2.9	3.2	1.1	2.0	2.4	3.3	1.7	3.0
SSE	1.3	5.2	5.6	3.2	12.8	3.4	2.9	3.4	5.2	3.8
S	3.0	6.5	12.2	4.3	11.5	3.0	5.5	4.0	7.5	4.4
SSW	4.1	6.0	5.5	4.6	13.3	3.1	5.0	4.6	6.7	4.6
SW	2.9	5.5	7.0	3.1	8.1	2.1	6.7	3.6	6.0	3.6
WSW	2.7	4.4	3.2	3.9	4.9	2.0	8.6	2.8	4.9	3.3
W	6.2	3.5	4.8	4.0	4.6	2.5	8.4	3.7	6.3	3.4
WNW	7.1	5.0	5.7	3.7	2.4	2.4	3.5	3.8	4.6	3.7
NW	4.2	4.3	2.9	4.0	1.5	0.8	2.6	2.4	2.8	2.9
NNW	3.5	3.4	1.8	2.6	1.9	3.0	2.4	2.6	2.5	2.9
Calm	42.5	0.0	33.1	0.0	29.2	0.0	35.7	0.0	35.4	0.0
Mean Speed 1984		3.6		4.2		2.3		2.4		3.1
Mean Speed 1983		-		4.5		2.5		4.7		3.9

speed for the three month sampling periods is lower than in 1984, 3.4 knots compared with 3.9 knots and the percent calm days has increased from 32% to 35%. These changes may be the result of annual variations in wind patterns or may be a result of the changing of the site of the meteorological station. In general, wind speed data for 1984 reflects the past patterns in air flow in the Point Lepreau region. Wind speeds tend to be lower in the summer with a higher percentage of calm days during the summer and winter months.

Rainfall data has been collected at both the Musquash and Saint John airport stations and the results are presented in Table 10. In general, less rain falls (6% less in 1984), at Musquash than at Saint John as has been previously noted (Nelson *et al.* 1985).

3.2 Air Monitoring Results

Five air monitoring stations, previously described in Bishop *et al.* (1980) and deployed in the Point Lepreau region at the sites indicated in Figure 30, are illustrated schematically in Figure 31. The stations located at the Point Lepreau lighthouse (#3), Dipper Harbour (#2), and Mace's Bay (#4) are situated close to stations owned and operated by the New Brunswick Electric Power Commission (NBEPC) and others operated by Health and Welfare Canada allowing for a comparison of data. The fourth station is located in Musquash, 15 km north of Point Lepreau NGS and is used as a background station. A fifth station has been located at Digby, N.S., to assess the magnitude of airborne radionuclide transport from Point Lepreau across the Bay of Fundy.

Air samples are drawn through a 47 mm diameter type 'A' glass fibre filter (to remove particulates), a cartridge of activated coconut shell carbon (to remove I-131) and a molecular sieve 'bomb' which absorbs water vapour. Sieve air flow rates are regulated according to estimates of seasonal variation in absolute humidity. This ensures that the water sample collected is within the sieve's retention capacity.

The approximate detection limits, which vary depending on sampling and instrumental parameters, are 4×10^{-5} Bq m^{-3} for particulate Cs-137, 3×10^{-5} Bq m^{-3} for I-131, and 1 to 7×10^{-2} Bq

Table 10. Comparison in millimeters of monthly precipitation at stations located in Saint John and Musquash, New Brunswick.

Month	Saint John	Musquash
January	142.0	129.5
February	147.1	149.9
March	120.9	165.1
April	148.1	137.2
May	134.1	139.7
June	241.3	228.6
July	165.9	154.9
August	56.6	33.0
September	70.9	50.8
October	49.0	35.6
November	48.0	40.6*
December	167.1	132.1
Yearly Totals	1491.0	1397.0**

* Data missing from November 5 - 16, estimated from Coleson Cove Data.

** Includes estimated amounts.

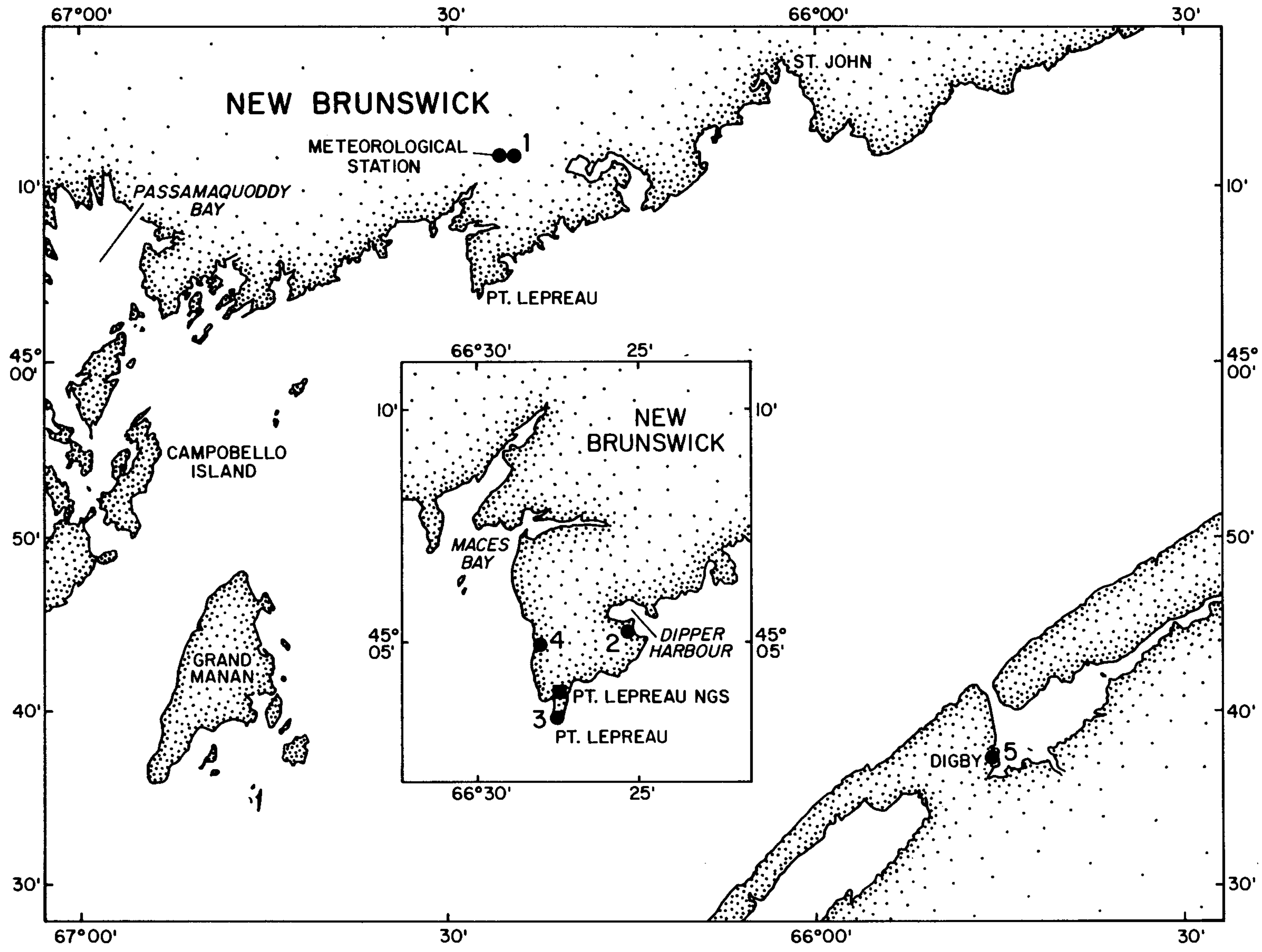

Figure 30. Air monitoring station locations.

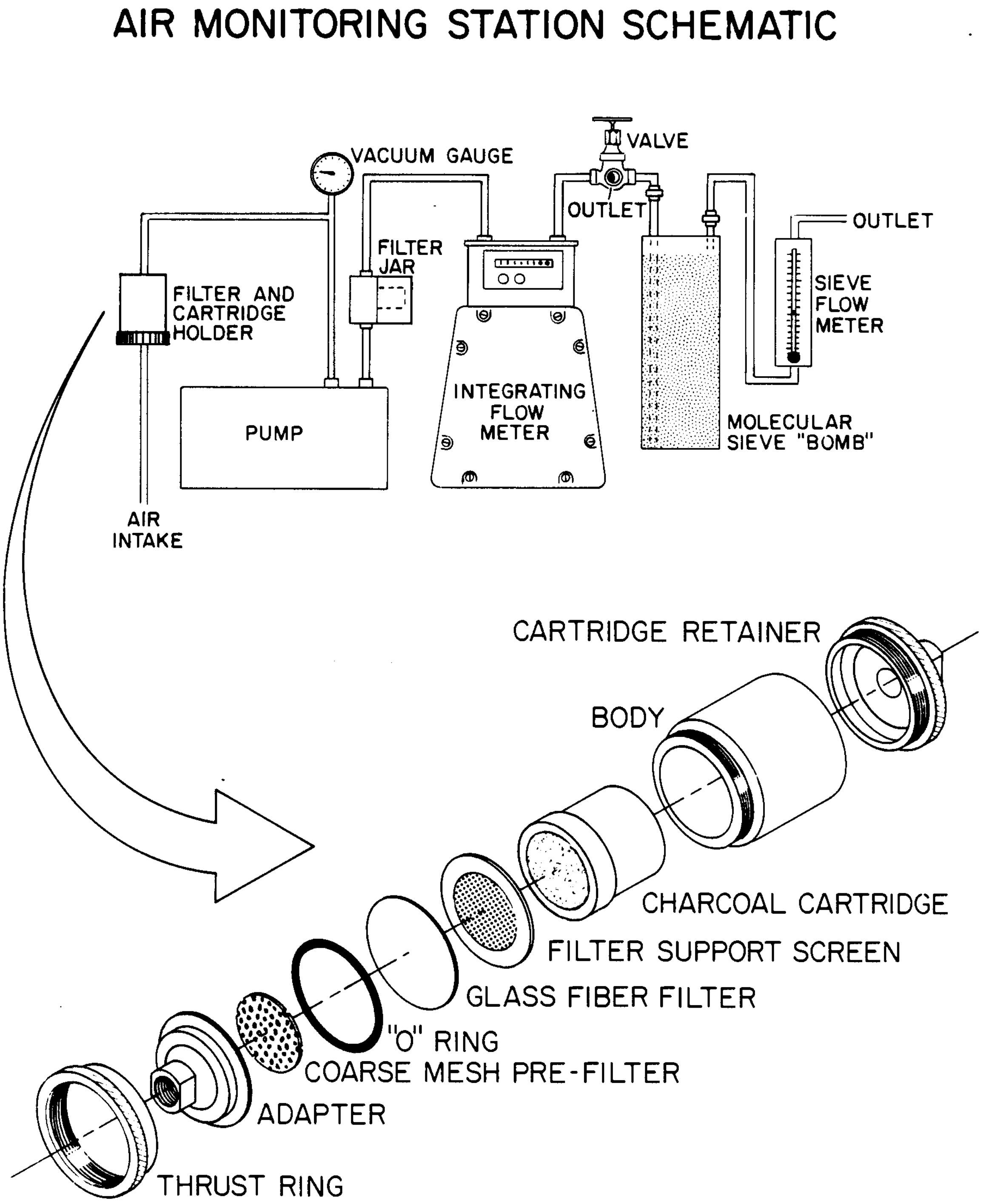

Figure 31. Schematic diagram of air monitoring station used in the field to collect water vapour (on molecular sieve), particulates (glass fiber filter), and I-131 (on charcoal cartridge).

m^{-3} for H-3 in water vapour. These detection limits assume a decay interval between sampling and analysis of 10 days.

Relative humidity and temperature data are available from the meteorological station at Musquash (Figure 30) and are used as a check for absolute humidities calculated from sieve water recovery data. There is excellent agreement between calculated and observed absolute humidities (Figure 32). Absolute humidity increases during the summer months due to the increase in air temperature.

3.2.1 Tritium Results

The five air monitoring stations have been operating satisfactorily through 1984. Sampling periods ranged from 6 to 18 days per month and an average of 907 cubic meters of air was drawn through the filters. Water was distilled from the molecular sieve material and analysed for tritium following the procedures outlined in Bishop *et al.* (1980).

The results of tritium activity measurements for samples collected at the five air monitoring stations in 1984 are presented in Figures 33-37 and Table 11. The vertical error bars represent the two sigma counting uncertainty and the horizontal bars the sampling period. Tritium activity is reported both in terms of Bq/ℓ of atmospheric moisture (Figure 33, 34 and 35) and in terms of Bq m^{-3} of air volume (Figure 36 and 37).

Tritium activity calculated in terms of atmospheric moisture is presented in Figure 33 for all five air monitoring stations for 1982, 1983 and 1984. The increase in the range and median tritium activities during the air monitoring program is apparent. During the preoperational program in 1982, a mean tritium activity of 6 ± 2 Bq/ℓ (< 2 to 15 Bq/ℓ) was measured. The average yearly tritium activity for all five air monitoring stations has been steadily increasing. In 1983, the mean yearly tritium activity was 18 ± 30 Bq/ℓ (range of 2 to 149 Bq/ℓ) which has increased to 31 ± 61 Bq/ℓ (range of 2.5 to 364 Bq/ℓ) in 1984 so that in each successive year there has been an increase in the range of tritium activities measured.

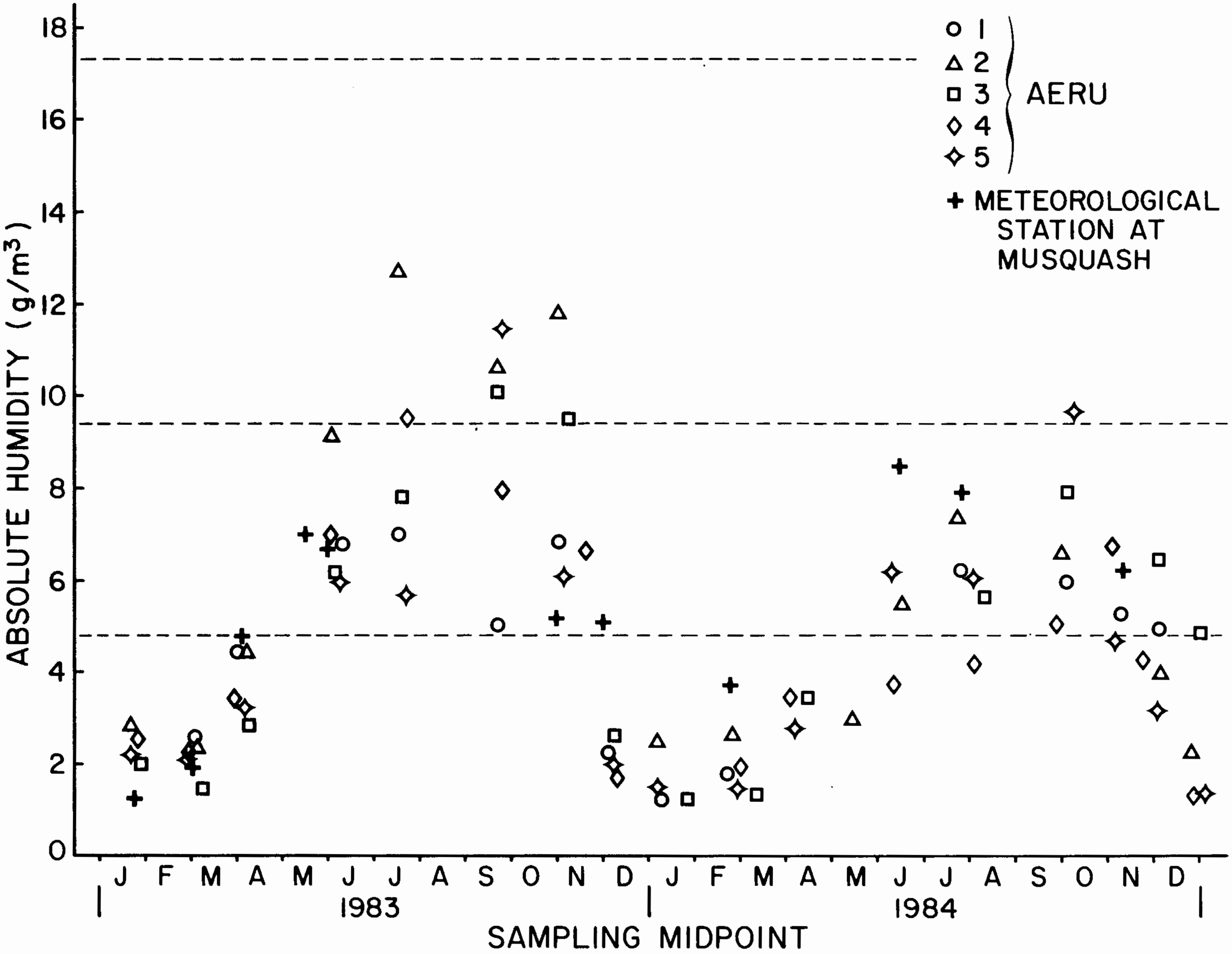

Figure 32. Absolute humidities for tritium sampling periods. Dashed lines correspond to theoretical absolute humidities at different temperatures: 0°C, 100% RH = 4.8, 10°C, 100% RH = 9.4, and 20°C, 100% RH = 17.3.

Table 11. Tritium results for air monitoring stations identified by location numbers shown in Fig. 23.

Sample		Julian Sampling Date MPt	Vol. Air (m^3) Through Sieve	H-3 (Bq m^{-3})
Number	Station			
x 1981	All Stns.	-	11.5	0.07
x 1982	All Stns.	-	11.9	0.04
x 1983	All Stns.	-	14.1	0.08
83-1649	1	11.5	32.6	0.003 ± 0.002
83-1650	2	6.9	21.6	0.003 ± 0.004
83-1651	3	26.1	48.8	0.164 ± 0.003
83-1653	5	7.6	27.7	0.009 ± 0.003
84-0901	1	53.0	22.9	0.011 ± 0.003
84-0902	2	56.2	20.2	0.036 ± 0.005
84-0903	3	71.6	46.5	0.123 ± 0.003
84-0904	4	59.5	22.7	0.023 ± 0.003
84-0905	5	57.4	25.4	0.009 ± 0.003
84-0906	1	126.2	18.7	-
84-0907	2	134.2	14.9	0.217 ± 0.007
84-0908	3	104.5	17.0	1.204 ± 0.012
84-0909	4	95.3	13.6	0.085 ± 0.006
84-0910	5	96.9	14.4	0.021 ± 0.004
84-0912	2	168.2	6.7	0.139 ± 0.011
84-0914	4	162.5	12.7	0.067 ± 0.007
84-0915	5	159.9	6.9	0.002 ± 0.011
84-0916	1	204.6	11.0	0.049 ± 0.011
84-0917	2	202.5	6.6	0.196 ± 0.014
84-0918	3	220.1	14.2	0.146 ± 0.011
84-0919	4	215.6	11.3	0.044 ± 0.007
84-0920	5	211.9	7.0	0.034 ± 0.011
84-0921	1	274.7	10.8	0.034 ± 0.011
84-0922	2	271.9	6.6	0.129 ± 0.013
84-0923	3	275.5	9.6	0.359 ± 0.017
84-0924	4	269.6	7.9	0.039 ± 0.007
84-0925	5	279.5	4.0	0.005 ± 0.002
84-0926	1	310.1	11.7	0.027 ± 0.010
84-0927	2	302.9	6.1	0.199 ± 0.014
84-0928	3	333.6	11.5	0.332 ± 0.013
84-0929	4	324.9	8.0	0.016 ± 0.007
84-0930	5	307.9	7.5	0.007 ± 0.003
84-0931	1	333.7	12.5	0.041 ± 0.009
84-0932	2	336.1	10.3	0.057 ± 0.007
84-0933	3	361.1	13.9	0.254 ± 0.040
84-0934	4	358.4	27.1	0.017 ± 0.002
84-0935	5	335.0	10.5	0.018 ± 0.005
84-0937	2	356.1	19.1	0.023 ± 0.004
84-0940	5	360.1	22.7	0.008 ± 0.003

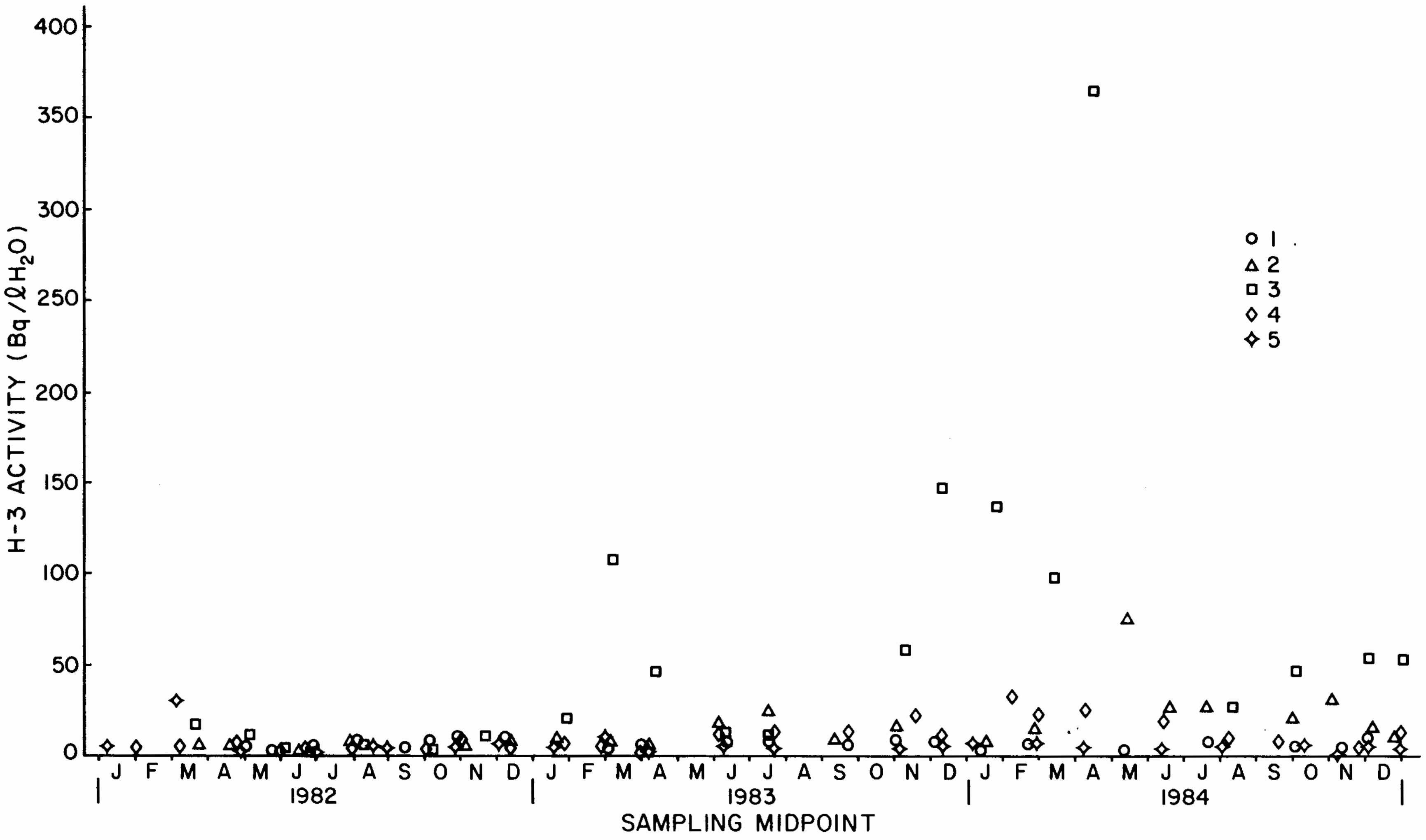

Figure 33. Tritium activities (Bq/l) for different air monitoring stations as a function of sampling date 1983, 1984.

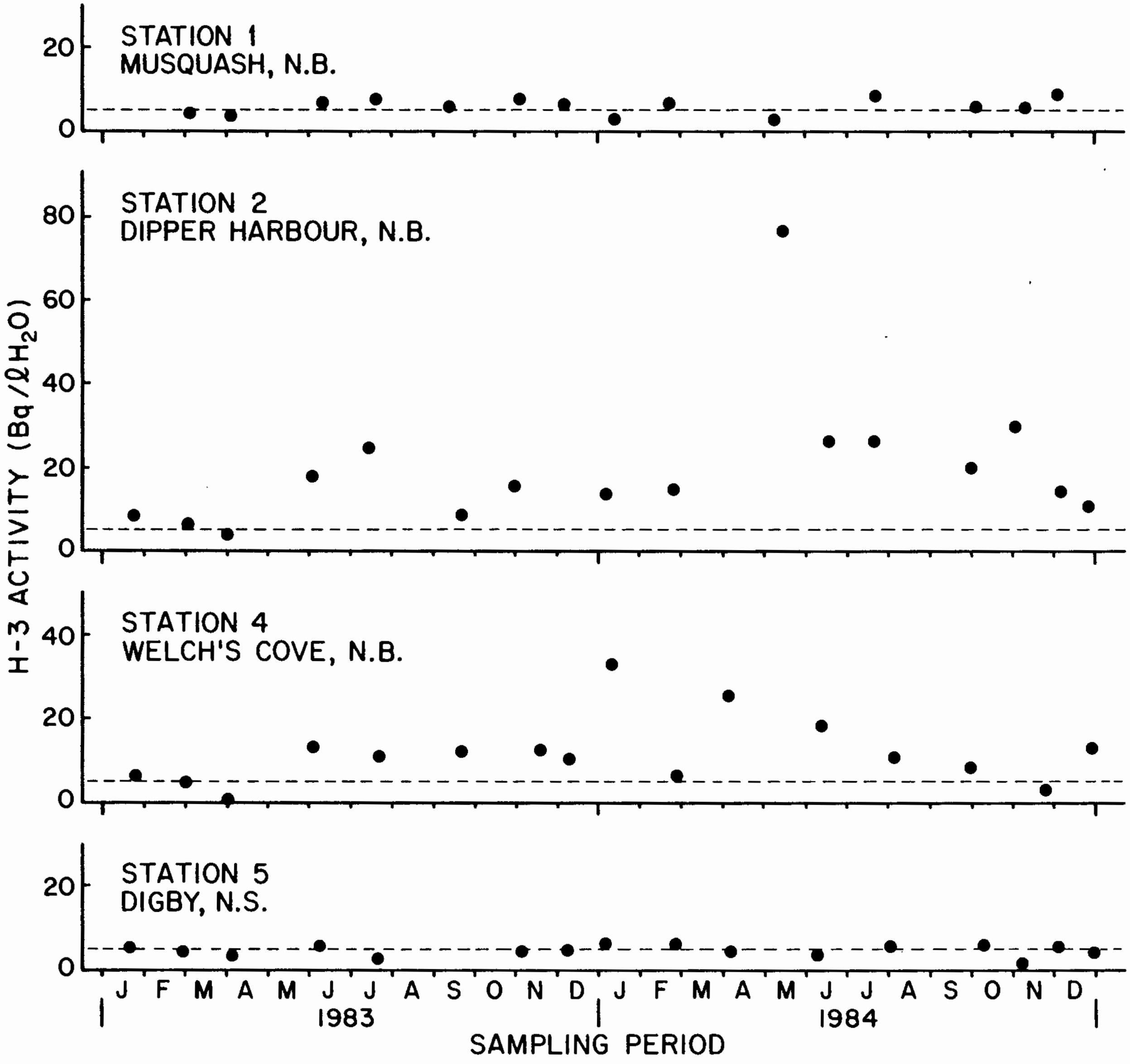

Figure 34. Tritium activity (Bq/l) as a function of sampling date for stations 1,2,4, and 5.

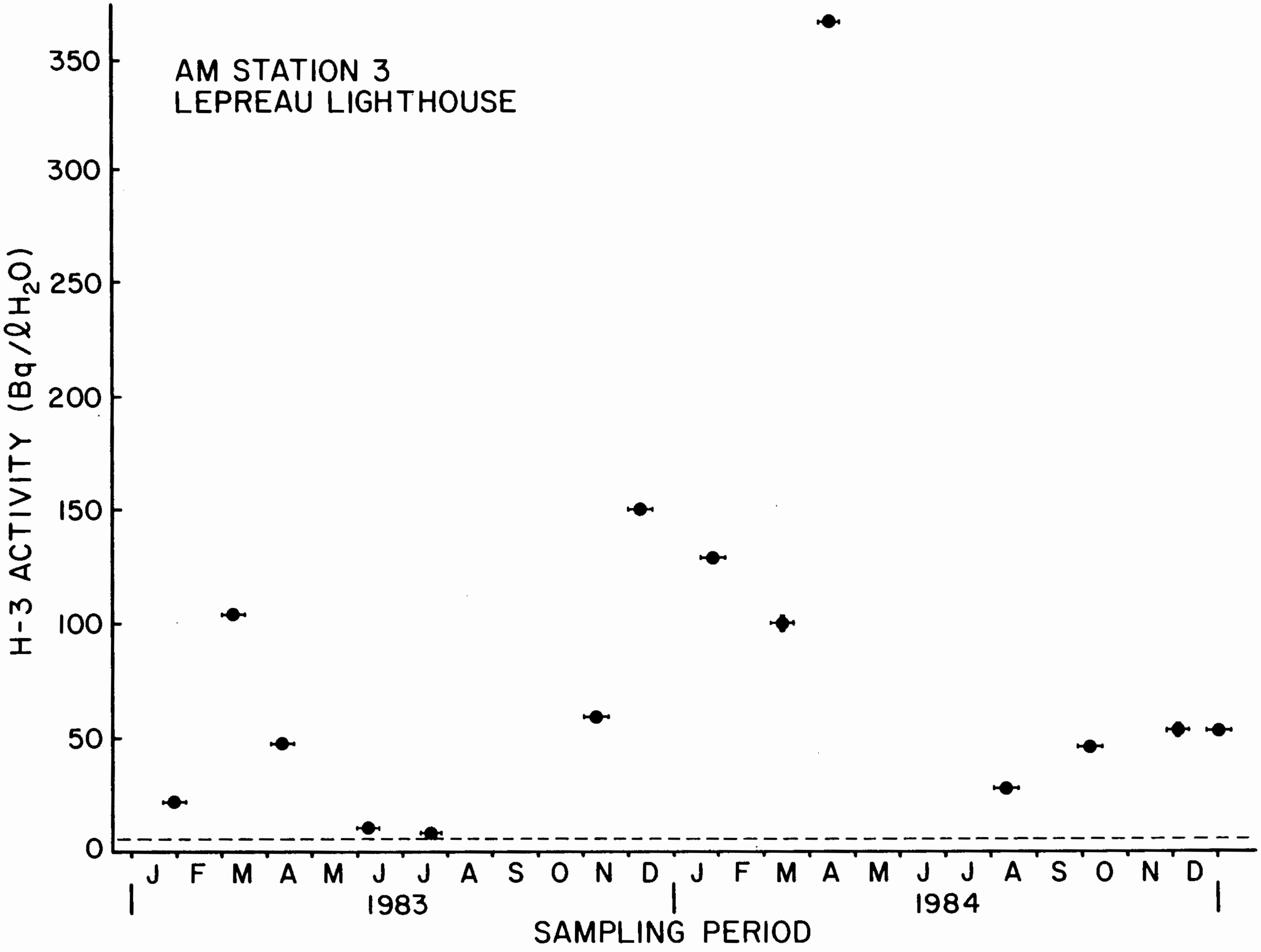

Figure 35. Tritium activity (Bq/l) as a function of sampling date for station 3.

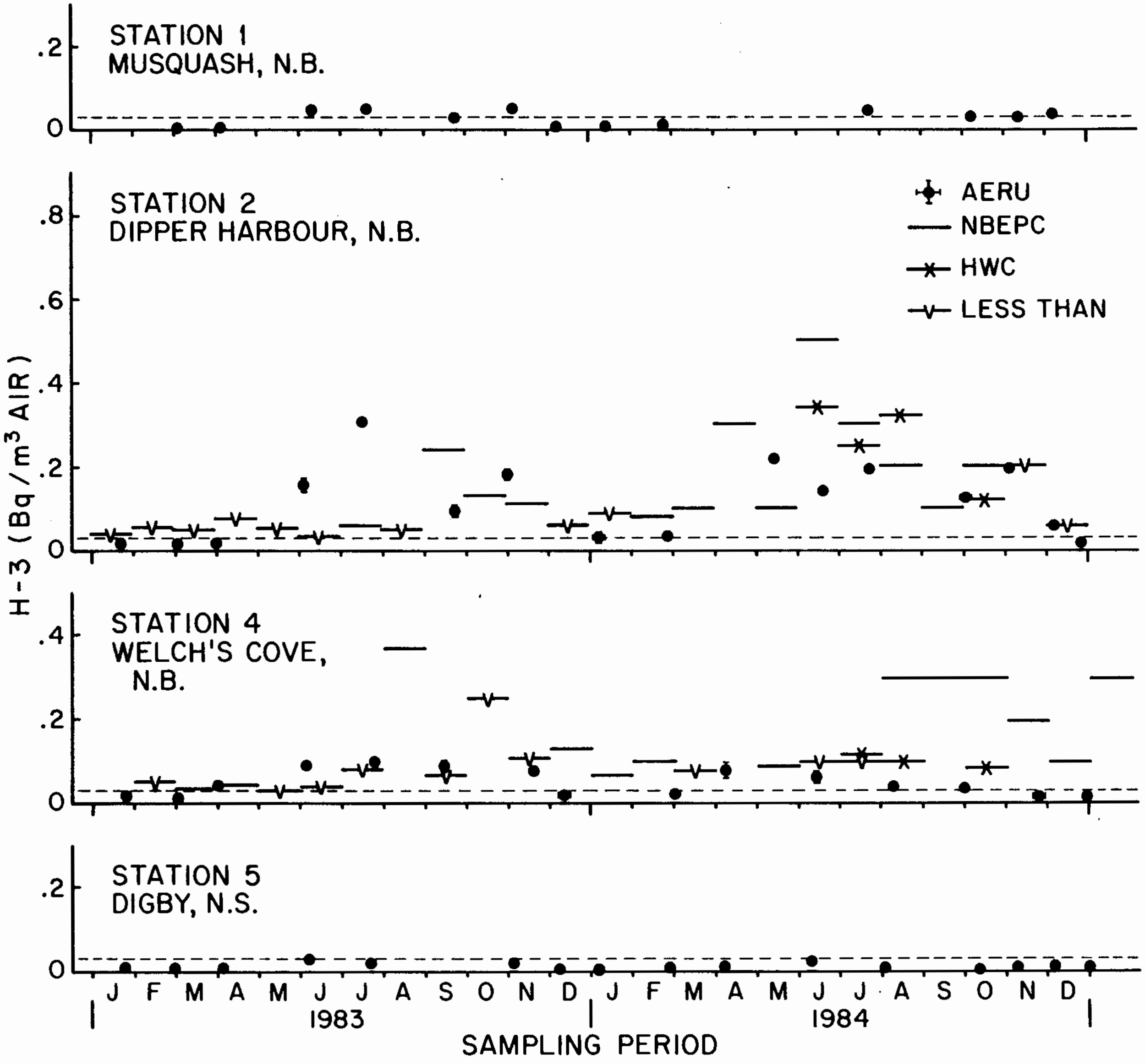

Figure 36. Tritium activities (Bq/m^3) as a function of air volume for stations 1, 2, 4, and 5. Comparison with NBEPC and HWC for stations at the same locations.

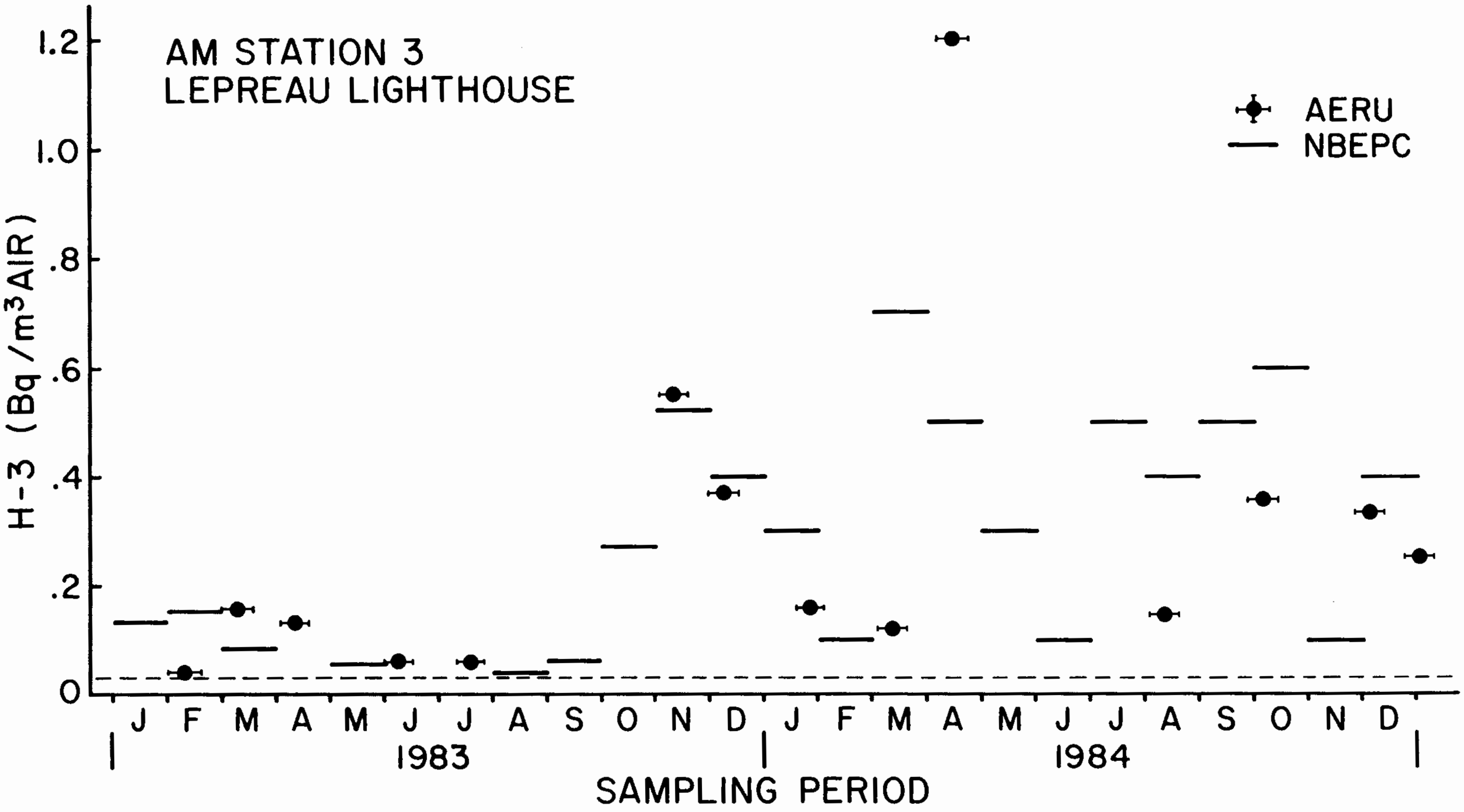

Figure 37. Tritium activities (Bq/m^3) as a function of air volume for station 3.

The tritium activities for the individual air monitoring stations plotted as a function of atmospheric moisture and sampling period are illustrated in Figure 34 for stations 1, 2, 4 and 5 and in Figure 35 for station 3. The baseline pre-operational tritium activity of 5 Bq/ℓ is marked as a dashed line. Air monitoring stations #1 (located at Musquash 15 km north of the NGS) and #5 (located at Digby, Nova Scotia) have shown no increase in the tritium concentration measured for 1984 and serve as background indicators for the air monitoring program. The summer increase in tritium activity in Bq/ℓ (Figures 33, 34 and 35) that has been observed previously, is again evident in 1984 and is partially a result of the increase in absolute humidity during the summer months. Converting the tritium concentration from units of Bq/ℓ to Bq m^{-3} removes the effect of atmospheric moisture. The tritium data, in units of Bq m^{-3}, is presented in Figures 36 and 37 and illustrates the 'real' increase in the tritium activity in 1984. A measureable increase in tritium activity was observed at stations 2, 3 and 4 (those situated closest to the NGS) while no increase was measured at stations 1 and 5. The decrease in tritium activity as a function of distance from the reactor indicates that the primary input source for atmospheric tritium in the Point Lepreau area is the NGS.

In addition to AERU, NBEPC operates air monitoring stations at eight locations, 3 of which are at Lepreau lighthouse, Dipper Harbour and Welch Cove (Sutherland, 1985) and Health and Welfare Canada operates stations at Welch Cove and Dipper Harbour (D. Meyerhoff, personal communication). All three sets of data are plotted in Figures 36 and 37. Where sampling periods are not known, their tritium activities have been plotted as a monthly average. Good correlation is observed for all three sets of data.

Data collected in 1983 (Nelson *et al.* 1985) and in 1984 indicate that the Point Lepreau NGS is the source of elevated levels of atmospheric tritium. Because the dispersion of an airborne pollutant depends on the nature of the terrain and on the meteorological conditions prevalent during the time of release (Pasquill *et al.* 1983), it should be possible to relate airborne tritium activities observed at the individual air monitoring stations to wind conditions in the Point Lepreau area.

Figures 38, 39, 40 and 41 show the average tritium activities at each air monitoring station for three month periods with the corresponding wind roses for 1984. The period January to March is

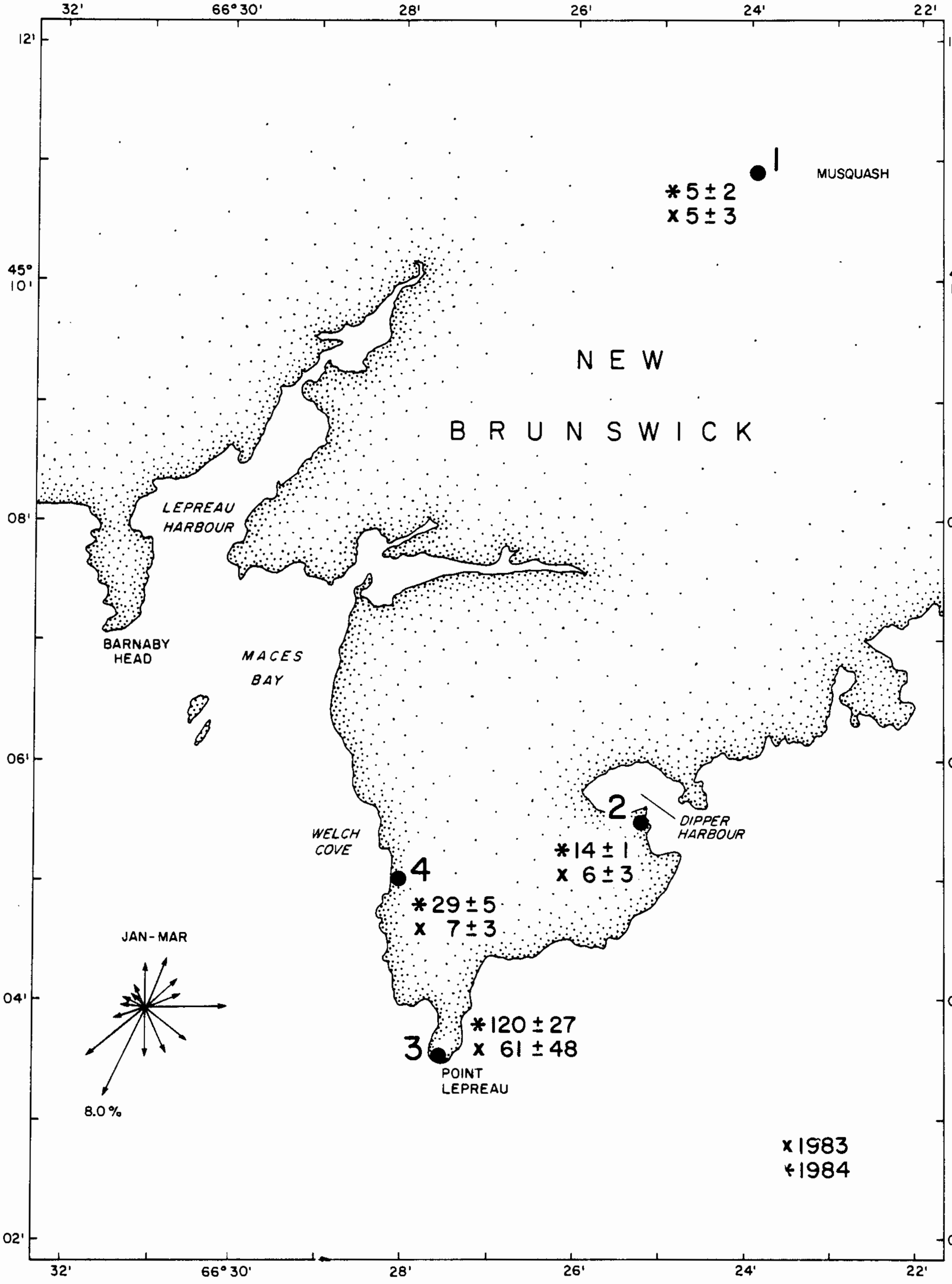

Figure 38. Relationship between atmospheric tritium distribution (Bq/l) and wind direction for the period Jan - March 1984.

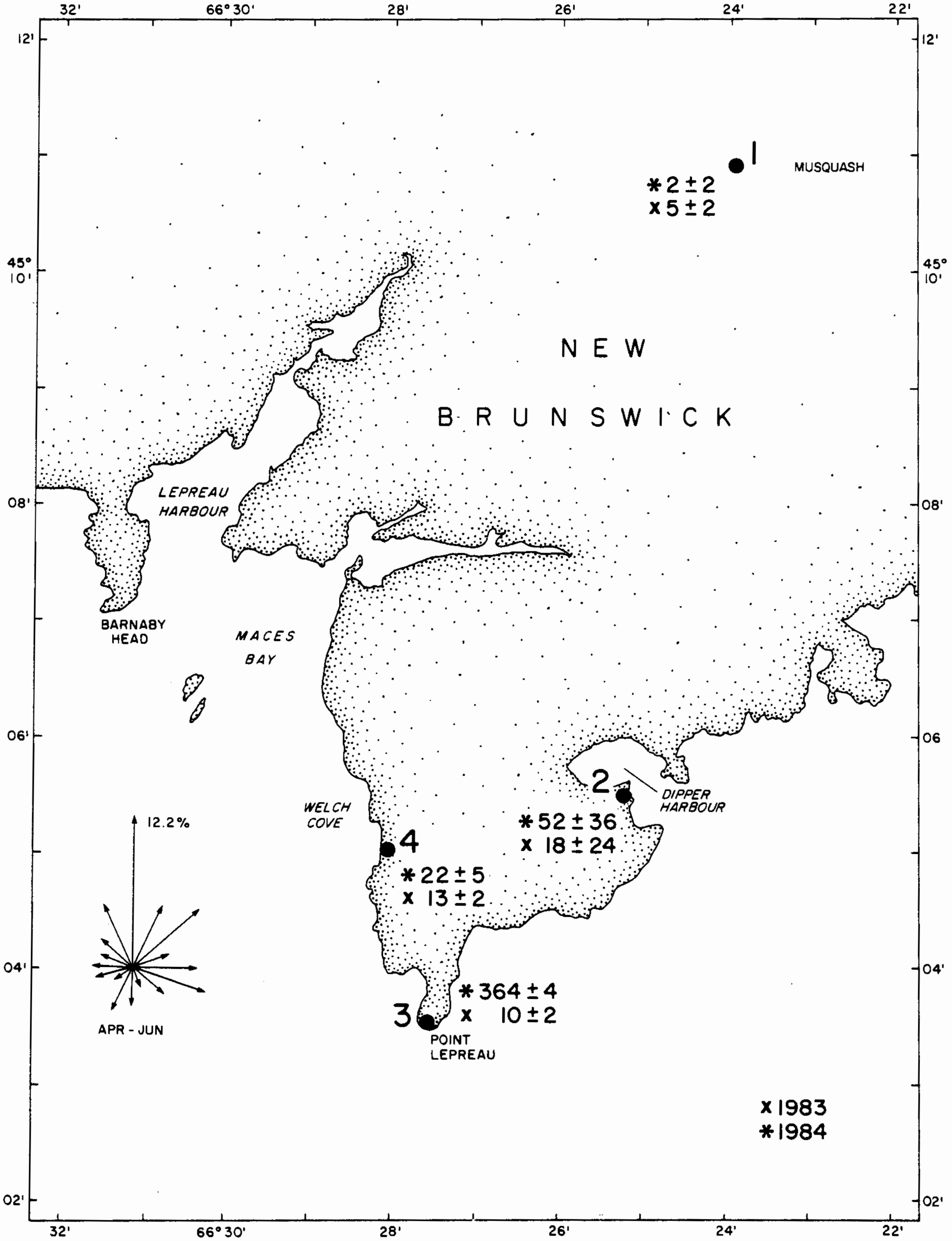

Figure 39. Relationship between atmospheric tritium distribution (Bq/l) and wind direction for the period April - June 1984.

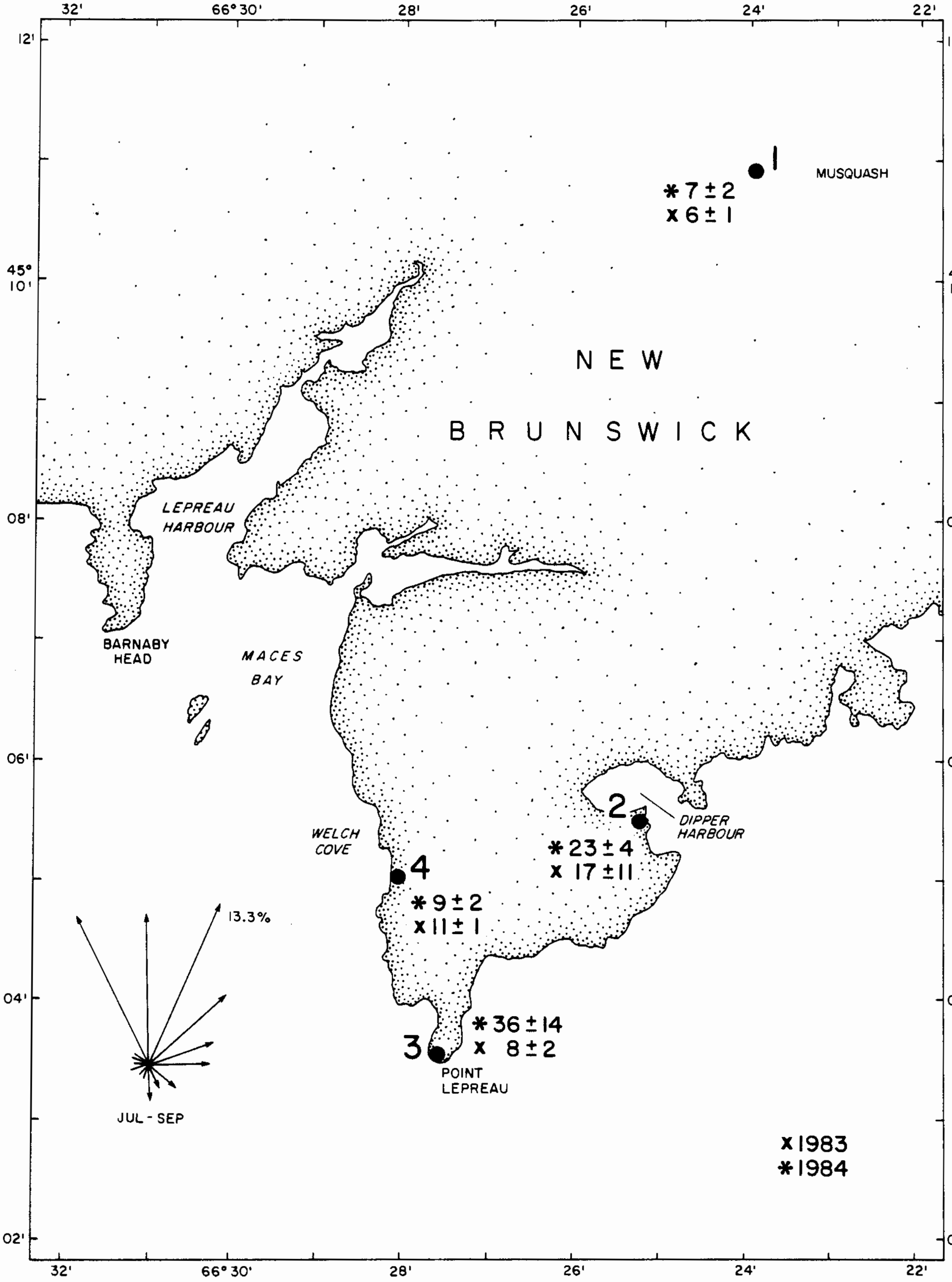

Figure 40. Relationship between atmospheric tritium distribution (Bq/l) and wind direction for the period July - Sept 1984.

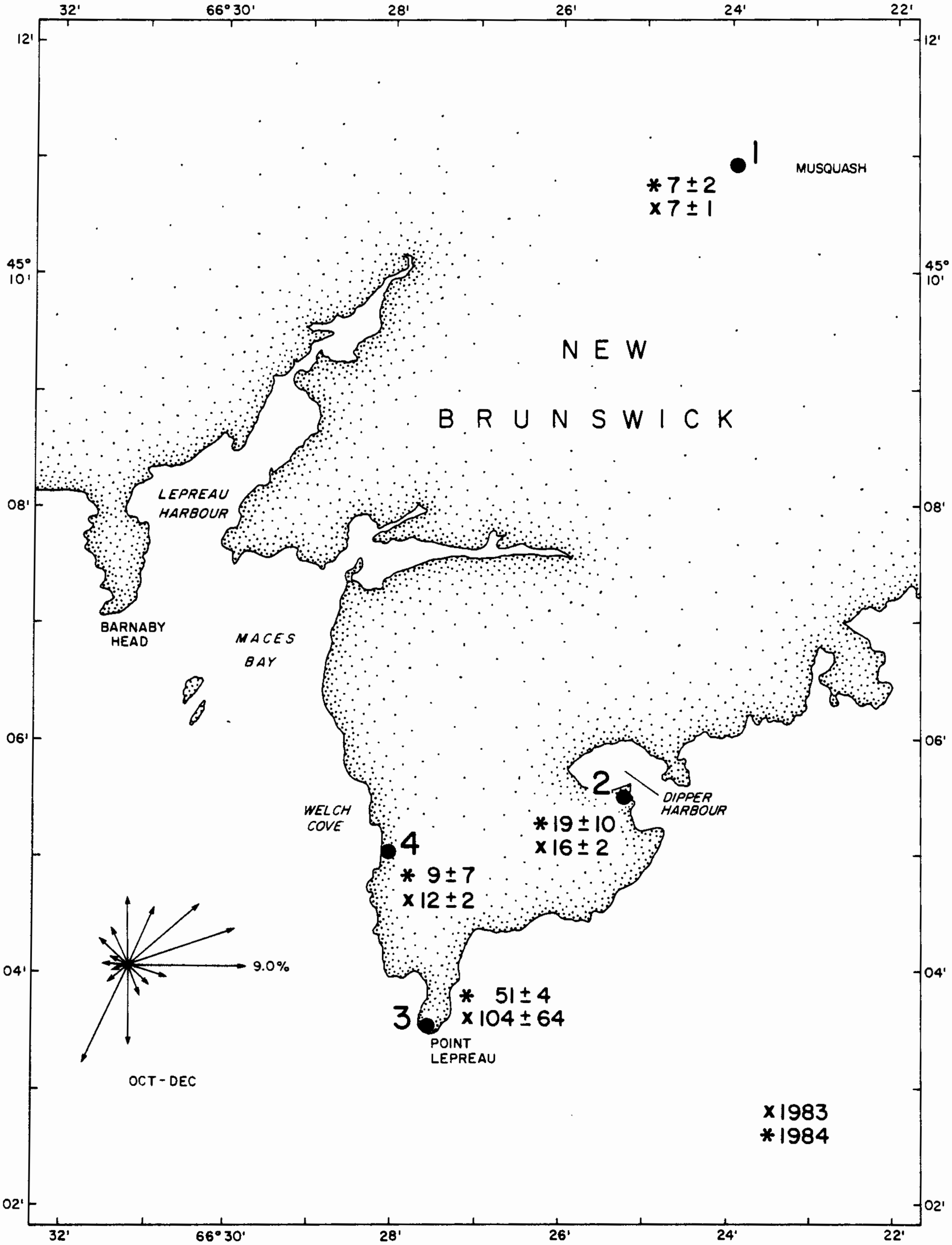

Figure 41. Relationship between atmospheric tritium distribution (Bq/l) and wind direction for the period Oct - Dec 1984.

marked by a high percentage of calm days with winds blowing from the northeast and the west (Figure 38). As expected for these conditions, the highest tritium signal is observed at the Lepreau Lighthouse (air monitoring station #3) the station closest to the NGS and situated in the path of the prevailing winds. Both the air monitoring stations at Welch Cove (#4) and Dipper Harbour (#2) show an increase in tritium activity over previous years. The higher signal at Welch's cove is due to its relative proximity to the NGS (it is located only 1.5 km from the NGS).

The period from April to June shows a strong component of wind from the south (Figure 39) and as would be expected, both air monitoring stations #4 and #2 which are located to the NNW and NE respectively show elevated tritium signals. The higher tritium activity signal observed at air monitoring station #3 is related to its proximity to the NGS.

Figure 40 indicates a strong southerly component in the wind direction during July to September. This is consistent with the relatively low tritium signal observed at air monitoring station 3 during this period. The wind rose indicates that both air monitoring stations 2 and 4 should show a tritium signal elevated above background. This is the case for station 2 but the increase in tritium activity at air monitoring station 4 is smaller than expected. The wind conditions illustrated in Figure 40 led to the lowest tritium activity observed during the four sampling periods.

The final wind rose illustrated in Figure 41 is for the period October to December. During this period the most frequent winds were from the west and N to NNE. The tritium activity at station 4 is expected to be lower than station #3 and a higher activity is expected at AMS #3. Figure 41 shows that the distribution of the tritium activity follows the pattern expected from the wind rose.

In general, there has been a measurable increase in the tritium concentration in air in the area surrounding the Point Lepreau NGS. The three air monitoring stations located close to the NGS reflect this. Air monitoring stations 1, at Musquash, and 5, in Digby, (see Figure 30), are located a greater distance from the NGS and show no significant increase in tritium activity over the pre-operational baseline. Although the average tritium activity for all stations has increased each year, the increase is localized and measurable only at those AMS located close to the NGS.

3.2.2 Radionuclides in Atmospheric Particulates

Air filters containing airborne particulate matter were analyzed for gamma-emitting radionuclides by direct counting of samples on hyper-pure Ge detectors. The results are presented in Table 12 for station locations illustrated in Figure 30. Be-7 was the only radionuclide present in measurable quantities and it is a naturally produced cosmogenic tracer. The NBEPC, which also analyzes air filters for air particulates, also detected Be-7 in the particulate samples (Sutherland 1985).

3.2.2.1 Beryllium-7

Beryllium-7 is a naturally occurring radionuclide which is the product of the cosmic ray fragmentation of atmospheric nitrogen and oxygen which takes place in the upper stratosphere. Be-7, because of its high specific activity, short half-life (53 days), lack of dilution by stable beryllium and its particle affinity, has been extensively used to estimate the residence time of aerosols in the upper troposphere. Furthermore, because of its particle reactive characteristics Be-7 is useful as a particle tracer for rapid processes in the marine and aquatic environments (Krishnaswami *et al.* 1980).

The Be-7 results for 1984 are presented in Figure 42 and Table 12. The range of Be-7 values measured in 1984 was 0.2 to 8.8 mBq m^{-3} with an average value of 1.7 mBq m^{-3}. The average Be-7 activity is comparable to the 1983 Be-7 activity of 1.6 mBq m^{-3} but lower than the pre-operational Be-7 activity of 2.4 mBq m^{-3}. Rainfall in 1984 of 1397 mm was similar to that of 1983 (1359 mm) which was a significant increase over the amount of rainfall, 932 mm, in 1982. The Be-7 air concentration is a function of the input of Be-7 from the upper atmosphere and the removal of Be-7 to the earth's surface so that an increase in rainfall should cause a decrease in the air concentration of Be-7. Figure 43 shows the monthly average Be-7 concentration plotted with the average monthly rainfall for 1984. In general, high Be-7 concentrations tend to follow lower rainfall with the exception of the summer months.

Table 12. Radionuclide results for air particulate material collected on air filters at air-monitoring stations identified by location numbers shown in Fig. 23.

Sample #	Station #	Julian Date	Vol (m^3)	Cs-137 (mBq/m^3)	Be-7 (mBq/m^3)
83-1649	1	12 ± 5	1407.4	< 0.02	0.58 ± 0.05
83-1650	2	9 ± 3.5	243.5	<0.09	0.45 ± 0.17
83-1651	3	26 ± 7.5	926.0	<0.03	1.60 ± 0.10
83-1653	5	8 ± 4.0	835.9	<0.03	1.87 ± 0.11
84-0901	1	53 ± 3.5	889.0	<0.02	1.33 ± 0.08
84-0903	3	72 ± 9.0	1690.0	<0.01	0.77 ± 0.06
84-0904	4	60 ± 3.0	758.9	<0.03	0.79 ± 0.09
84-0905	5	57 ± 3.0	755.8	<0.03	0.87 ± 0.10
84-0908	3	105 ± 4.0	733.4	<0.06	1.27 ± 0.20
84-0910	5	97 ± 3.5	736.8	<0.03	1.89 ± 0.13
84-0911	1	167 ± 4.0	894.8	<0.02	3.18 ± 0.12
84-0912	2	168 ± 3.5	781.5	<0.03	0.50 ± 0.06
84-0914	4	163 ± 5.0	654.8	<0.04	3.38 ± 0.16
84-0916	1	205 ± 5.0	1081.7	<0.02	2.76 ± 0.11
84-0917	2	203 ± 4.0	863.7	<0.03	0.22 ± 0.07
84-0918	3	220 ± 7.5	1251.6	<0.02	1.24 ± 0.09
84-0919	4	216 ± 3.0	1161.0	<0.03	1.27 ± 0.14
84-0920	5	212 ± 3.5	770.8	<0.03	1.58 ± 0.13
84-0921	1	275 ± 4.0	968.4	<0.04	2.82 ± 0.17
84-0922	2	272 ± 3.5	758.9	<0.03	0.25 ± 0.06
84-0923	3	276 ± 5.0	875.0	<0.02	0.78 ± 0.08
84-0924	4	270 ± 4.0	880.7	<0.02	0.92 ± 0.08
84-0925	5	280 ± 4.0	3628.5	<0.01	0.39 ± 0.02
84-0926	1	310 ± 4.5	1081.7	<0.02	8.83 ± 0.32
84-0927	2	303 ± 3.5	716.4	<0.02	0.60 ± 0.06
84-0928	3	334 ± 6.0	1059.1	<0.02	0.78 ± 0.08
84-0929	4	325 ± 3.5	770.2	<0.03	0.80 ± 0.13
84-0930	5	308 ± 3.5	742.5	<0.07	5.78 ± 0.40
84-0931	1	334 ± 4.0	906.1	<0.02	2.24 ± 0.14
84-0932	2	336 ± 3.5	809.9	<0.03	0.28 ± 0.11
84-0933	3	361 ± 6.5	1257.3	<0.02	1.49 ± 0.08
84-0934	4	359 ± 5.0	1090.2	<0.02	2.58 ± 0.08
84-0935	5	335 ± 3.5	724.6	<0.02	2.58 ± 0.09
84-0936	1	368 ± 15.5	3253.6	<0.01	2.88 ± 0.06
84-0937	2	356 ± 3.5	798.5	<0.03	0.37 ± 0.09
84-0940	5	360 ± 3.5	775.6	<0.03	2.77 ± 0.14

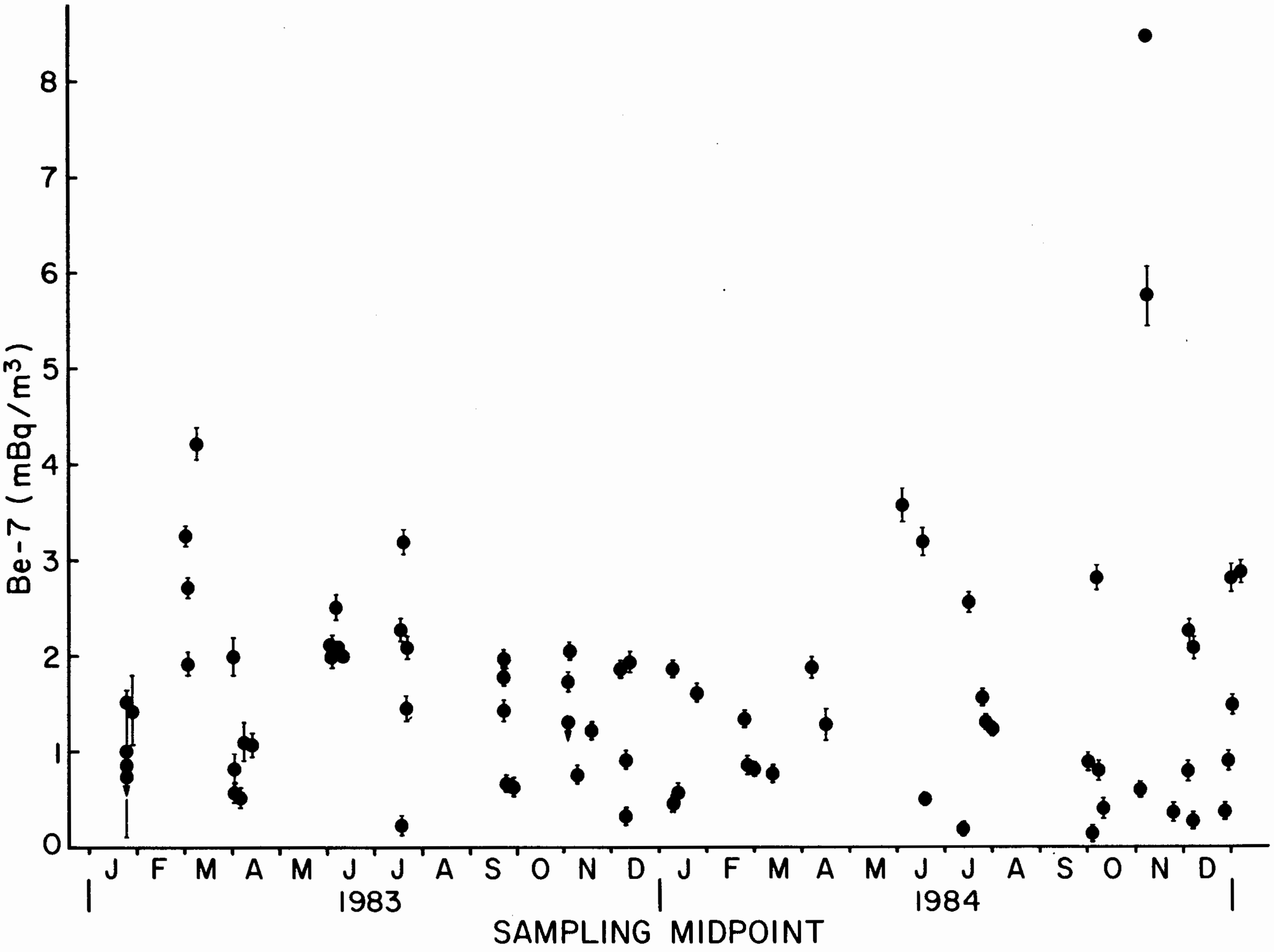

Figure 42. Be-7 activity measured in air particulate material for 1983 and 1984.

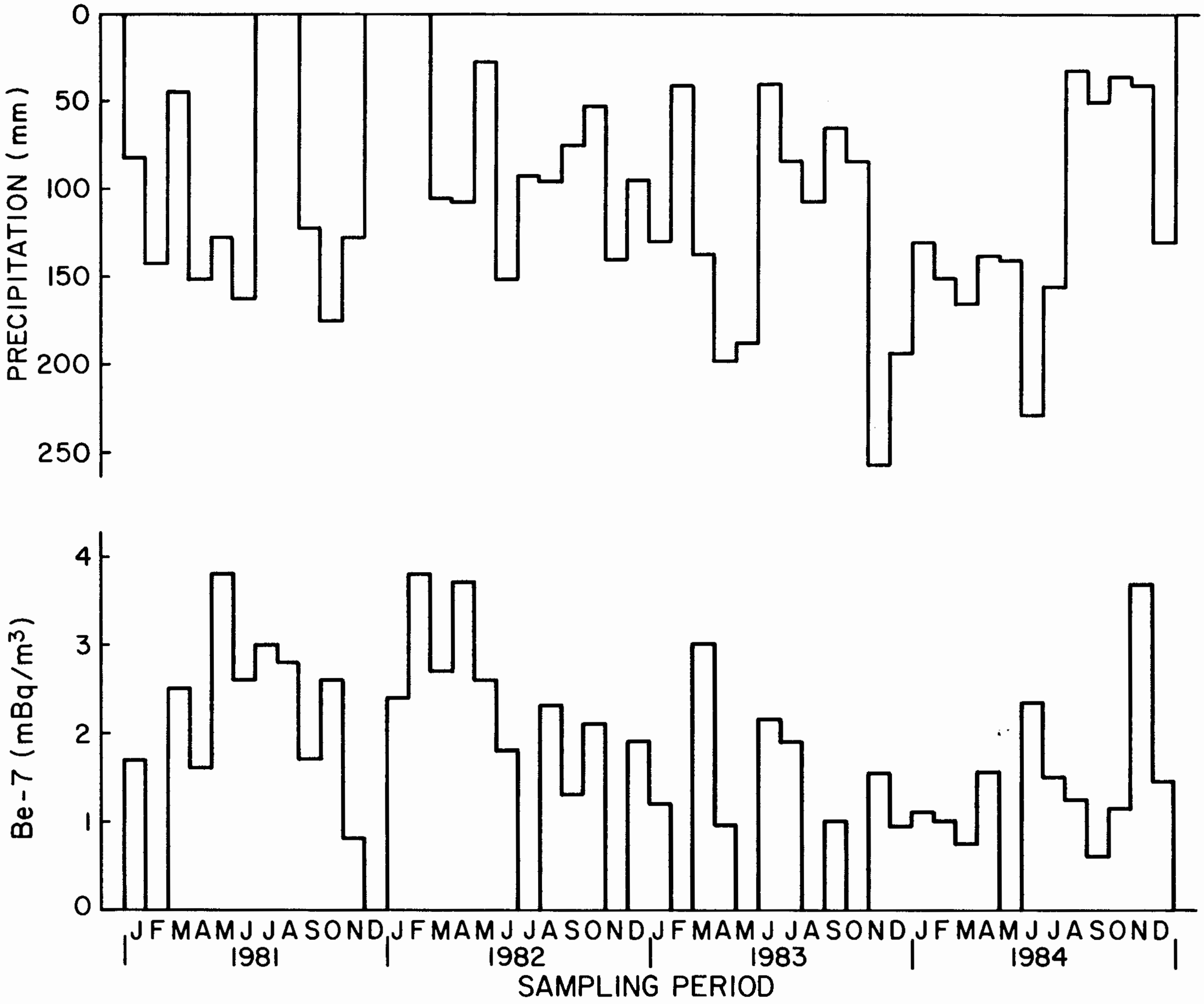

Figure 43. Average monthly Be-7 activity measured in air particulate material versus average monthly rainfall measured at Musquash for 1983 and 1984.

Be-7 data from NBEPC have shown a decrease in activity from a value of 3.1 mBq m^{-3} in 1981 to 2.4 Bq m^{-3} in 1984. Although the absolute Be-7 values for AERU and NBEPC measurements are not identical due to different sampling periods, both laboratories have observed a drop of similar magnitude in the Be-7 signal over the last several years.

3.2.2.2 Radioactive Fallout

The history of nuclear weapons tests was clearly reflected in the historical record of Sr-90 deposition for New York City (EML, 1984) illustrated in Figure 44. The first major nuclear test was conducted in 1952 with maximum testing in 1958-1959 and in 1961-1963. Fallout deposition has declined since the 1960s with smaller peaks in the 1970s occurring as the result of tests carried out by India, France, England and the People's Republic of China. Much of the bomb-produced radioactivity is initially injected into the stratosphere where the residence time of particle reactive radionuclides is of the order of 1 to 2 years compared to a tropospheric residence time of the order of months. Enhanced mixing of stratospheric and tropospheric air masses during the spring and summer months produces the yearly maxima evident in the fallout record.

Cs-137 is a relatively long lived ($t_{1/2} = 30.2$ y) fission product which, along with Sr-90, contributes most of the fallout exposure to present generations. Cs-137 is monitored at the atmospheric monitoring stations indicated in Figure 30 and activities were below AERU detection limits for 1984.

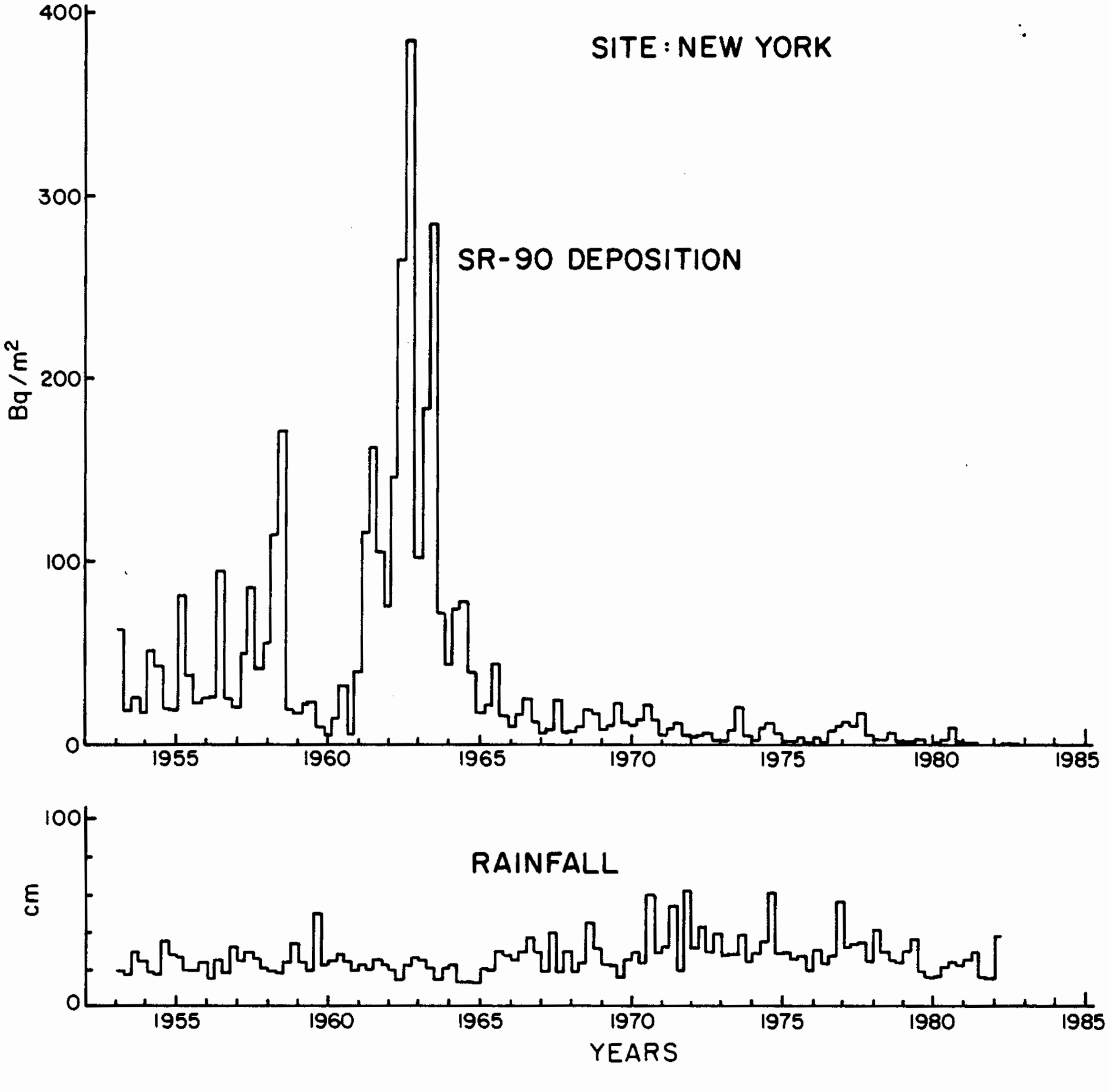

Figure 44. Quarterly fallout record of Sr-90 for New York city measured by Environmental Measurements Laboratory (1983).

4.0 BIOLOGICAL OCEANOGRAPHY

Over seventy percent of the earth's surface is covered by the oceans, which consist of a single body of water containing dissolved salts and suspended solids. The oceans are in constant motion, the scale of movement ranges from Brownian movement of molecules, through various turbulent eddies, to the large-scale circulation associated with the major ocean current systems. The physical dispersion of substances, including radionuclides, in sea water is controlled by two types of processes; advection and turbulent diffusion. Advection involves the physical displacement, or movement of water and results from relatively large scale transport of water in currents. Turbulent mixing results from shear forces between water bodies and transport occurs in a manner analogous to diffusion.

The dissolved constituents of sea water are a complex mixture of salts and organic compounds, derived principally from the input of continental weathering products and the biological activity in the oceans respectively. The major elements of seawater, chlorine, sodium, magnesium, etc. are referred to as conservative, i.e. their concentration is proportional to the salinity. In addition to the major components, many other elements and their compounds exist in sea water at very low concentrations. Despite their low concentrations, this group of constituents is of interest because they are both geochemically and biologically "reactive".

The oceans may be divided into two basic regions: the open ocean, comprising the vast majority of the marine environment and has average water depths of 4000 to 6000 m; and secondly the shallower coastal zone which consists of the nearshore and continental shelf. The waters of the open ocean are more stably stratified, vertical mixing is less intense and the chemical composition is less influenced by local inputs (natural and man-made) than nearshore waters.

Both currents and mixing processes are more intense in coastal waters. In the nearshore zone, currents from major ocean circulation patterns, winds and tidal motions combine, following the general trend of the coastline and giving rise to flows tangential to it. Although mixing is relatively strong, the shallow depths of this region restrict the quantities of water available for the dilution of land discharged pollutants. The physical boundary of the shoreline also restricts the directions in which dispersion can occur. The nearshore zone is influenced by river run-off, relatively high suspended matter loads due to the remobilization of local sediments, the presence of intertidal areas, the contrasting nature of shorelines, which can range from base rocks to extensive muddy flats, tidal cycles, seasonal variability of physical and biological phenomena and the occurrence of man-made constructions and pollutant discharges (IAEA 1985).

The degree of dispersion of radionuclides released into coastal waters will depend upon the physical characteristics of the receiving water mass and the chemical properties of the element. Phenomena such as currents, turbulent diffusion, isotopic dilution and biological transport act to dilute and disperse radionuclides. Simultaneously, chemical and physical forces such as absorption, ion exchange, flocculation and sedimentation, and the passage of radionuclides through the food chain act as concentrating mechanisms (Rice *et al.* 1974). The release of radioactivity into the marine environment from an NGS is effectively a point source input that can lead to relatively high activities in localized areas. However, the overall extent of the contamination is generally confined and the activity is only rarely distinguishable from background at distances greater than a few hundred kilometers from the point of discharge.

4.1 Biological Uptake of Radioactivity

The availability of radionuclides to marine organisms depends on the chemical and physical properties of the radionuclide and on complex interactions involving environmental and biological factors. With the exception of tritium, most of the radionuclides released from nuclear generating stations are non-conservative elements (i.e., they do not follow water circulation patterns directly) and their biological uptake is generally higher than that of conservative elements. Marine organisms can accumulate and redistribute radionuclides independently of other physico-chemical processes resulting in the potential 'concentration' of radio-activity throughout different levels of the food chain. The term concentration factor (C.F.) has been used to describe the biological uptake of a chemical species and is defined as the activity of the nuclide per unit fresh weight of the organism divided by the activity of the same nuclide per unit volume of water (Coughtrey *et al.* 1983):

$$C.F. = (100 - \%\ H_2O)\ A_{Cs\text{-}137}\ \text{sample}/100\ A_{Cs\text{-}137}\ \text{water}$$

where % H_2O is the percent water per sample wet weight, $A_{Cs\text{-}137}$ sample is the Cs-137 activity in the sample dry weight, and $A_{Cs\text{-}137}$ water is the mean Cs-137 activity in sea water. The mean sea water Cs-137 activity is 3.3 mBq/l in the lower Bay of Fundy. Concentration factors defined in this manner are of limited value for higher trophic levels where organisms ingest radionuclides from a variety of sources and for infaunal marine organisms which ingest large amounts of sediment along with organic detritus. Despite these deficiencies, concentration factors do provide a semi-quantitative description of radionuclide accumulation in the marine environment.

Biological half-life is another concept useful in describing the uptake of radionuclides in marine systems. The biological half-life is defined as the time required for an organism to exchange half its total inventory of an element. The shorter the biological half-life, the faster an organism will reach a steady state with respect to seawater radionuclide concentrations. This concept is important in water masses where radionuclide activities vary as a function of time, such as with releases from nuclear installations. Higher trophic levels with long biological half-lives may never attain a steady state radionuclide concentration with respect to a changing environmental concentration. Conversely, primary producers, such as plankton, often have turnover rates on the order of hours and effectively mirror changing environmental levels.

A third factor which plays an important role in understanding the biological uptake of radioactivity is the physico-chemical interactions that take place between radionuclides and marine organisms. Goldberg (1957) showed that the ability of marine organisms to concentrate metals from the sea paralleled the order of the strength of metal-organo-ligand complexes and Szabo (1967) observed that mixed plankton accumulated alkaline earths in the same sequence as cation exchangers such as Dowex -50. Alkali metals (K, Na, Ru, and Cs) may be incorporated into bottom sediments as the result of ion-exchange reactions with clay minerals and it has been proposed that similar ion-exchange reactions may occur at the surfaces of marine organisms. More recently, the presence of specific metal binding proteins such as metallothionein, a low molecular weight, sulfur containing metal-binding protein has been correlated with elevated levels of trace metals in marine invertebrates such as oysters, blue crab and lobster (Engel *et al.* 1984). Metallothionein acts to bind trace metals and remove them from circulation to storage in various organs. In mammals for example, cadmium-metallothionein complexes are stored in the kidney (Ridlington *et al.* 1981). These proteins have been viewed as inducible (i.e., synthesized in response to the presence of toxic metals, (Cherian *et al.* 1978) and play an important role in the sequestration of elevated levels of trace metals in various organisms.

The relationship between the concentration of a radionuclide in a living organism and the ambient seawater is a dynamic one. Rates of uptake and excretion are affected by body size, growth rate, temperature, light (in the case of algae), salinity, etc. Several elements that are accumulated by some organisms are not eliminated, a variable fraction being incorporated into parts of the body structure. Skeletal tissues may act as depositories for a number of elements particularly multivalent cations. Some elements become incorporated into granules, probably as a means of detoxification, which may or may not be subsequently excreted. Crustaceans, which grow by a process of moulting may lose absorbed material in cast moults as well as by resorption, before moulting, certain elements which are then re-incorporated into the new exoskeleton.

Added to these factors is the continuing change in the concentration of some radionuclides over short periods of time. It is to be expected, therefore, that real differences exist between some CF values even for the same element and species and that the range of values derived reflects true environmental fluctuations in any one area (IAEA 1985).

4.2 Processing and Analysis of Biological Materials

An assessment of environmental effects associated with the biological uptake of radioactivity requires a surveillance program consistent with local and regional marine energetics, the nature of the food web, water circulation and zones of productivity. Sampling sites have been chosen for the collection of representative species as outlined in Table 13. Biological samples have been

Table 13. Representative species for different marine sampling regimes near Point Lepreau.

Species	Embayment, Estuary	Intertidal Zone	Subtidal Zone	Pelagic Zone
Plants		Rockweed, Irish moss dulse, Fucus	Laminaria	
Grazers		Periwinkle	Sea urchin	
Detritus Feeders		Gammarus		
Suspension Feeders	Soft shelled clams	Blue Mussel	Horse Mussel Scallop	
Predators and Scavengers	Sandshrimp	Green Crab Hermit Crab	Rock Crab Lobster	Rock Crab
Fish		Flounder		Herring
Birds	Purple sandpiper	Eider Duck	Cormorant, Herring Hull	
Mammals			Harbour Seal	
Planktonic Forms				Bulk Samples Phyto- and Zooplankton

collected from the major marine habitats in the Point Lepreau region and these samples have been analysed for radioactivity in the AERU laboratory. In general, species which have been selected for surveillance occur abundantly in most of the major habitats and play a significant role in the food web. All trophic levels are represented and any trends in the transport and accumulation of radioactivity within these communities should become apparent at some level within the sampling assemblage. Sampling methods, criteria and frequency have been noted in Bishop *et al.* (1980), although these procedures have been modified to some extent.

The processing of marine biological samples has been described previously (Ellis *et al.* 1984). The tritium content of marine biological samples, terrestrial samples and soils was determined using an azeotropic distillation method (Moghissi *et al.* 1973). Freeze-dried, homogenized samples were analysed for gamma-emitting radionuclides using two 25% efficient hyper pure germanium detectors. A gamma spectra for each sample was automatically analysed using a PDP-11-04 computer which identified and quantified radionuclide peaks of interest. Samples were analysed using one of five standard counting geometries, corresponding to sample volumes of 500 ml, 300 ml, 100 ml, 50 ml and 20 ml. Detection limits (Bq/kg) for each radionuclide of interest are given in Appendices 3 and 4 for the five counting geometries. A more detailed discussion of AERU counting procedures is given in Ellis *et al.* (1984).

4.3 Radionuclide Results - Plankton

Plankton occupy a critical position at the base of the food chain. Their rapid growth rates and large surface area make plankton an excellent fast-response indicator species for changes in radioactivity levels in sea water. Phytoplankton are primary producers that accumulate radionuclides by both adsorption which is the predominant mechanisim and absorption which is particularily important for essential trace elements. Zooplankton accumulate radionuclides by both processes as well as consumption of phytoplankton. In the contaminated waters of the Adriatic sea (Jelisaveic, 1979) and near Cap de la Hague, France (Germain *et al.* 1979) plankton have been shown to accumulate Ce-141,144, Ru-106 and Zr-95 at levels up to 3500 Bq/kg. Elevated levels of

Cs-137, Co-60, Zn-65, Sb-125, Fe-59 and Mn-54 were also observed. Levels of radionuclides in zooplankton are generally lower than those in phytoplankton owing to their relatively inefficient assimilation of radionuclides across the gut wall (Smith *et al.* 1981).

The radionuclide activities expected to be found in plankton samples collected from the vicinity of the cooling water outflow of the Point Lepreau NGS have been calculated from the monthly effluent release data from Table 1 and concentration factors for phytoplankton (IAEA, 1985) and are presented in Table 14.

Expected activities are calculated from LEM data, the total amount of a radionuclide released each year divided by the total volume of water passed through the cooling system gives the average expected activity at the outfall. This number is then used to calculate the expected activity in phytoplankton using concentration factors compiled by IAEA (IAEA 1985) and assuming a dilution factor of 1/50 for a distance 300 m from the outfall. (G. Bugden, personal communication; MacLaren Atlantic Ltd., 1977). In all cases, the expected activities are below AERU detection limits.

The results of radionuclide analysis for phytoplankton samples collected in 1984 are presented in Table 15. The sampling locations for phytoplankton are shown in Figure 45. Samples collected in 1984 were analyzed according to mesh size and in one sample Cs-137 was detected but at a level similar to that found in preoperational samples. Radionuclide levels in phytoplankton show no increase over pre-operational levels.

4.4 Marine Algae

Marine algae are primary producers located at the base of the food web. Benthic algae are coated with a mucus that provides a slippery surface to minimize wear and tear and help prevent water loss during exposure at low tide. The coating also provides an excellent surface for the adsorption of a large range of radionuclides and the concentrations of radionuclides in algae frequently exceed those of the surrounding water (Pentreath 1980). This factor, combined with their sessile nature, make benthic algae an excellent site-specific monitor for marine radioactivity and

Table 14. Comparison of calculated expected activities in plankton and AERU detection limits for samples collected 300 m from the Point Lepreau outfall for 1984.

Radionuclide	Half Life (Days, Years)	Calculated Activity[1] at Outfall (mBq/ℓ)	Concentration* Factor	Calculated Activity[2] in Organism (mBq/kg)	AERU Detection Limit (mBq/kg)
Ce-141	33.00 d	0.00003	$9x10^4$	0.054	30,300
Ce-144	284.40 d	0.0002	$9x10^4$	0.36	1,000
Co-58	71.20 d	0.006	$5x10^3$	0.6	1,900
Co-60	5.27 y	0.20	$5x10^3$	20.0	74
Cr-51	27.70 d	14.0	$2x10^3$	560.0	50,000
Cs-137	30.00 y	0.10	$2x10^1$	0.04	63
I-131	8.10 d	0.009	$1x10^3$	0.18	-
Mn-54	321.60 d	0.20	$6x10^3$	24.0	140
Nb-95	35.20 d	0.20	$1x10^3$	4.0	10,000
Ru-103	39.40 d	0.001	$2x10^5$	4.0	31,000
Ru-106	368.00 d	0.007	$2x10^5$	28.0	1,000
Zn-65	244.10 d	0.0007	$3x10^4$	0.42	370
Zr-95	65.00 d	0.05	$6x10^4$	60.0	4,900

* IAEE 1985

[1] Calculated assuming a continuous release of radionuclides. (Total Bq released in 1984 [from Table 1]/Total volume released in 1984).

[2] Calculated assuming a 1/50 dilution factor for effluent entering the Bay of Fundy at 300 m from the outfall.

Table 15. Radionuclide results for plankton and marine plant samples collected near Point Lepreau.

Sample	Date	Sample No.	Component	Sample					Range
				Site	Wt(g)	Geom.	% H_2O	Cs-137 Bq/kg	
Plankton	1980-1982	-	Total; n=9	P-1 - P-7	-	-	-	2.3 ± 1.8	<1.0 to 2.3 ± 1.8
	1983	83-1633	Total	-	247.98	1	-	<0.6	-
	17-4-84	84-1006	253μ mesh	I-6	24.83	3	96.0	1.4 ± 1.3	
	"	"	64 μ mesh	I-6	22.93	4	94.0	<2	
	"	"	253μ mesh	I-6	6.65	5	93.0	<5	
	"	"	64 μ mesh	I-6	5.07	5	97.0	<6	
Rockweed	1980-1982	-	Total	I-4, 6, 8	-	-	74.7	0.4 ± 0.1	0.3 ± 0.1 to 0.5 ± 0.4
(*Ascophyllum nodosum*)	1983	-	Total	I-6	-	-	72.2	<0.5	-
	17-5-84	84-1026	Total	I-6	150.36	1	84.0	<2	
Fucus vesiculosus	1981-1982	-	Total	I-6	-	-	77.4	0.3 ± 0.1	0.2 ± 0.1 to 0.4 ± 0.4
	1983	-	Total	I-6	-	-	78.6	<1	
	17-5-84	84-1027	Total	I-6	231.36	1	85	<1	
Kelp	1980-1982	-	Total	I-2, 3, 6, 9	-	-	80.5	0.9 ± 0.5	0.5 ± 0.3 to 1.2 ± 0.7
(*Laminaria sp.*)	1983	83-1663	Total	I-6	88.72	1	-	<1.3	-
	17-5-84	84-1028	Total	I-6	85.21	1	88	<3	-

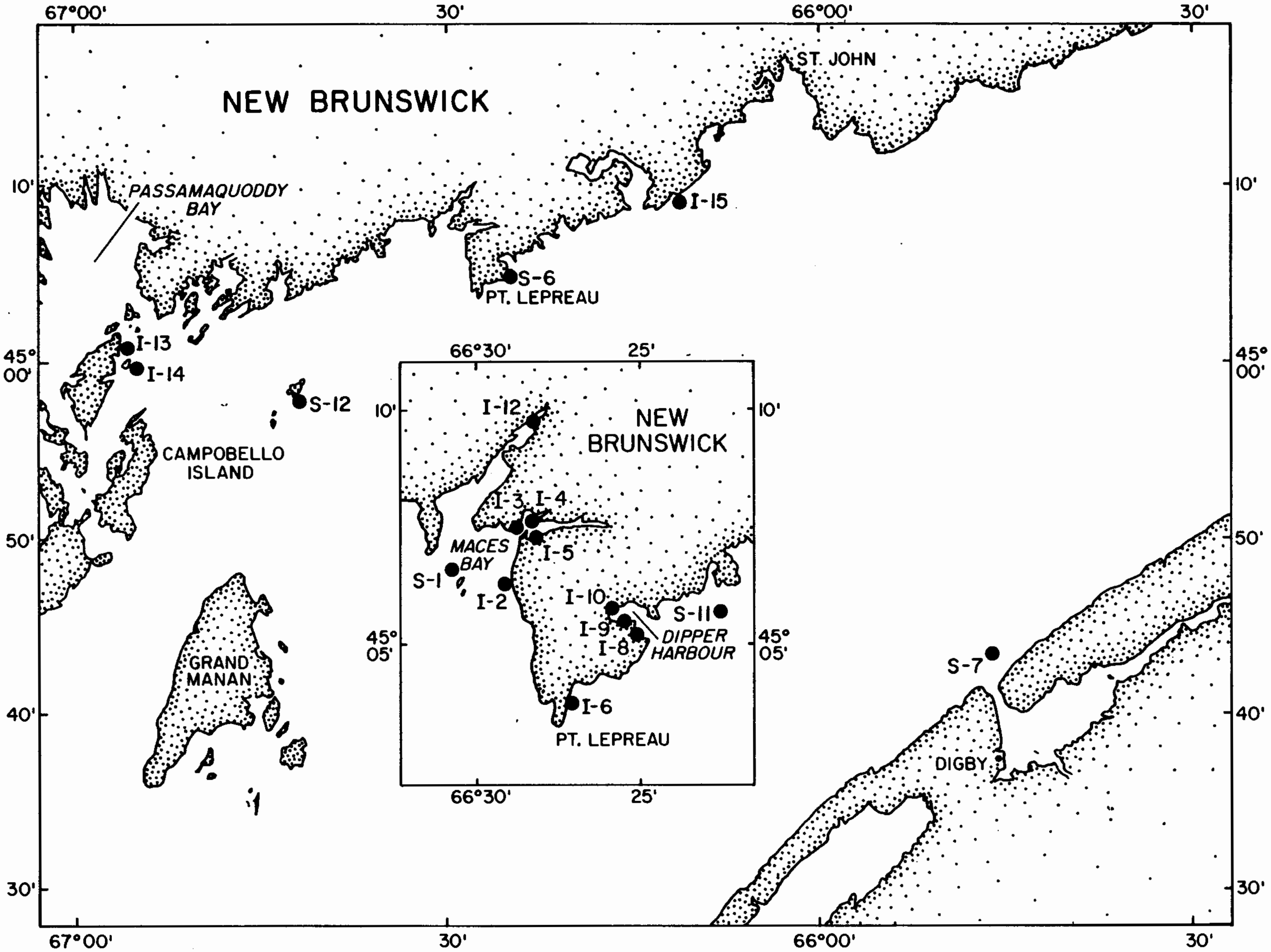

Figure 45. Marine biological sampling sites in the Bay of Fundy.

trace elements. The degree of accumulation of radionuclides varies from species to species but most are suitable as indicators of radioactive releases to the marine environment.

Marine plants selected as monitoring species at the Point Lepreau NGS include the brown algae; *Ascophyllum nodosum, Fucus vesiculosis* and *Laminaria sp.* and the red algae; *Chondrus crispus* and *Rhodymenia palmata.*

The use of marine algae as bio-indicators for radionuclides in the marine environment is well documented. The NKA, (Nordic Liaison Committee for Atomic Energy) bio-indicator study identified the algae *Fucus vesiculosus* as being available in all parts of the North Atlantic region and for many radionuclides studied showed accumulation factors from seawater on the order of 10^3 and higher. Other useful algae mentioned included *Ascophyllum nodosum, Fucus serratus* and *Laminaria sp.* (Aarkrog *et al.* 1985). Guimaraes *et al.* (1985) followed the uptake, accumulation and loss of Cs-137, Co-60 and I-125 discharged from the Angra dos Reis nuclear power plant located in Angra dos Reis county in Brazil using the seaweed species *Saragassum filipendula, Padina vickersaie* and *Acanthophora spicifera.* They found that fast uptake, high bio-accumulation factors (ranging from 50 to 5000) and long biological half-lives make algae important monitors for radionuclide releases.

The predicted levels of radionuclides in marine algae (calculated from IAEA concentration factors and effluent release data) are all below AERU detection limits (Table 16). The marine algae species selected for monitoring in 1984 are presented in Table 15 and no fission or fallout radionuclides were found in any of the 1984 marine algae samples analyzed.

4.5 Marine Molluscs

Bivalve molluscs are largely filter-feeders that display a remarkable ability to concentrate a wide range of radionuclides. Radionuclides are concentrated directly from seawater, by ingestion of contaminated food and by ingestion of contaminated silt particles or detritus. Digestion can occur both intracellularly, within the cells of the distal tubules, and extrocellularly within the stomach. Radionuclides are generally stored in the hepatopancreas (Schelske 1973) but other organs, such as

Table 16. Comparison of calculated expected activities in macro-algae and AERU detection limits for samples collected 300 m from the Point Lepreau outfall for 1984.

Radionuclide	Half Life (Days, Years)	Calculated Activity[1] at Outfall (mBq/ℓ)	Concentration* Factor	Calculated Activity[2] in Organism (mBq/kg)	AERU Detection Limit (mBq/kg)
Ce-141	33.00 d	0.00003	5x10^3	0.003	30,300
Ce-144	284.40 d	0.0002	5x10^3	0.02	1,000
Co-58	71.20 d	0.006	1x10^4	1.2	1,900
Co-60	5.27 y	0.20	1x10^4	40.0	74
Cr-51	27.70 d	14.0	2x10^3	560.0	50,000
Cs-137	30.00 y	0.10	2x10^1	0.04	63
I-131	8.10 d	0.009	1x10^3	0.18	-
Mn-54	321.60 d	0.20	6x10^3	24.0	140
Nb-95	35.20 d	0.20	3x10^3	12.0	10,000
Ru-103	39.40 d	0.001	2x10^3	0.04	31,000
Ru-106	368.00 d	0.007	2x10^3	0.28	1,000
Zn-65	244.10 d	0.0007	2x10^1	0.28	370
Zr-95	65.00 d	0.05	3x10^3	3.0	4,900

* IAEE 1985

[1] Calculated assuming a continuous release of radionuclides (Total Bq released in 1984 [from Table 1]/Total volume released in 1984).

[2] Calculated assuming a 1/50 dilution factor for effluent entering the Bay of Fundy at 300 m from the outfall.

kidneys, may specifically accumulate certain radionuclides. Scallops (*Pecten maximus*) concentrate manganese in the kidney, oysters concentrate zinc and mussels selectively concentrate iron in preference to manganese and zinc. The iron in mussels is particularly highly concentrated in the hepatopancreas but appears to be excreted through the production of byssus threads (Pentreath 1980).

Work done during the NKA bio-indicator study singled out the blue mussel, *Mytilus edulis* as a particularly useful species because of its availability and the high accumulation factors (up to 10^3) demonstrated for several radionuclides (Aarkrog *et al.* 1985).

The results for gamma emitting radionuclides in marine molluscs collected at sites shown in Figure 45 are presented in Table 17. Radionuclide levels found in samples collected in 1984 were below AERU detection limits. Table 18 shows the expected concentrations in marine molluscs for various radionuclides and in all cases, calculated levels were below AERU detection limits.

4.6 Marine Crustacea

Benthic crustacea, such as crabs and lobsters, also display a remarkable ability to concentrate certain elements. In crustaceans, most of the absorption from food takes place in the midgut and normally the digestive diverticula are not a primary store for radionuclides. Moreover, the exoskeleton, which often forms a secondary store, is moulted at various periods during the life-cycle and this process can represent a significant route for the transfer of accumulated activity back to the environment if the exoskeleton is not consumed by the animal (Coughtrey 1983). Crustaceans form an important part of the decomposition cycle in marine habitats with many representatives in the decomposer fauna.

The crustacea selected for use in the Point Lepreau monitoring program include *Carcinus maenas*, the green crab; *Cancer sp.*, rock crab; *Pagurus sp.*, hermit crab; *Crangon septemspinosus*, sandshrimp; and *Gammarus oceanicus*, amphipods. The hepatopancreas from the *Homarus americanus*, the lobster, was added to the monitoring program in 1983. Samples were collected from Dipper Harbour and off the coast of Nova Scotia, at Digby.

Table 17. Radionuclide results for marine molluscs and marine crustacea collected near Point Lepreau.

Sample	Date	Sample No.	Component	Sample					Range
				Site	Wt(g)	Geom.	% H_2O	Cs-137 Bq/kg	
Horse muscle	1980-1982	-	Flesh	S-1, I-8,6	-	-	77.0	1.7 ± 1.2	<1 to 1.7 ± 1.2
(*Modiolus modiolus*)	1980-1982	-	Shell	S-1, I-8,6			18.8	0.12 ± 0.07	0.07 ± 0.05 to 0.17 ± 0.15
	1983	-	Flesh	I-6	-	-	85.4	<3	-
	1983		Shell	I-6	-	-	13.2	<0.2	-
	17-5-84	84-1032	Flesh	I-6	177.57	1	83.0	<1	-
	17-5-84	84-1033	Shell	I-6	492.87	1	18.0	<1	-
	17-5-84	84-1034	Shell	I-6	533.22	1	22.0	<1	-
	1981-1982	-	Flesh	I-6	-	-	75.4	<3	-
Periwinkle	1981-1982	-	Shell	I-6	-	-	3.7	<0.2	-
(*Littorina littorea*)									
	1983	-	Flesh	I-6	-	-	64.5	<1	
	1983	-	Shell	I-6	-	-	4.8	<0.3	
	17-5-84	84-1030	Flesh	I-6	123.34	1	70.0	<1	
	17-5-84	84-1031	Shell	I-6	499.54	1	4.1	<0.3	
	17-5-84	84-1013	Flesh	I-6	87.22	2	81.0	0.4 ± 0.1	
Scallop	17-5-84	84-1017	Shell	I-6	574.38	1	8.0	<0.2	
	1980-1981	-	Flesh	I-6, I-8	-	-	69.2	<6	
Green Crab	1980-1981	-	Shell	I-6, I-6	-	-	60.2	<3	
Carinus sp.	1980-1981	-	Hepatopancreas	I-6, I-6	-	-	74.6	<10	
	1982	-	Total	I-8	-	-	71.5	<2	

Table 17. (Continued)

Sample	Date	Sample No.	Component	Sample					Range
				Site	Wt(g)	Geom.	% H_2O	Cs-137 Bq/kg	
	1983	-	Flesh	I-6	-	-	70.1	<0.8	
	1983	-	Shell	I-6	-	-	63.3	<0.2	
	17-5-84	84-1003	Total	I-6					
	17-5-84	84-1004	Total	I-6					
	17-5-84	84-1015	Total	I-6	61.6	3	71.0	<2	
Lobster (*Homarus americanus*)	1983	84-1033	Hepatopancreas	I-6	-	-	55.8	<0.6	
	27-06-84	84-2518	Hepatopancreas	I-7		2	81.0	0.4 ± 0.1	
	27-06-84	84-2519	Hepatopancreas	I-6		1	8.0	<0.2	
Sand Shrimp (*Crangon sp.*)	1980	-	Total	I-3		-	59.6	0.8 ± 0.5	
	1983	-	Total	I-6		-	79.4	<1	
	17-5-84	84-1013	Total	I-6	105.83	2	80.0	<2	
	17-5-84	84-1017	Total	I-6	42.01	3	75.0	<3	
Sea Urchin	17-5-84	84-1010	Total	I-6	272.59	1	71.0	<1	

Table 18. Comparison of calculated expected activities in marine molluscs and AERU detection limits for samples collected 300 m from the Point Lepreau outfall for 1984.

Radionuclide	Half Life (Days, Years)	Calculated Activity[1] at Outfall (mBq/ℓ)	Concentration* Factor	Calculated Activity[2] in Organism (mBq/kg)	AERU Detection Limit (mBq/kg)
Ce-141	33.00 d	0.00003	5x10^3	0.003	30,300
Ce-144	284.40 d	0.0002	5x10^3	0.02	1,000
Co-58	71.20 d	0.006	5x10^3	0.6	1,900
Co-60	5.27 y	0.20	5x10^3	20.0	74
Cr-51	27.70 d	14.0	8x10^2	224.0	50,000
Cs-137	30.00 y	0.10	3x10^1	0.06	63
I-131	8.10 d	0.009	1x10^1	0.0018	-
Mn-54	321.60 d	0.20	5x10^3	20.0	140
Nb-95	35.20 d	0.20	1x10^3	4.0	10,000
Ru-103	39.40 d	0.001	2x10^3	0.04	31,000
Ru-106	368.00 d	0.007	2x10^3	0.28	1,000
Zn-65	244.10 d	0.0007	3x10^3	0.042	370
Zr-95	65.00 d	0.05	5x10^3	5.0	4,900

* IAEA 1985

[1] Calculated assuming a continuous release of radionuclides. (Total Bq released in 1984 [from Table 1]/Total volume released in 1984).

[2] Calculated assuming a 1/50 dilution factor for effluent entering the Bay of Fundy at 300 m from the outfall.

The levels of radionuclides that might be expected to be found in marine crustacea from the Point Lepreau area have been calculated from effluent release data and CF (IAEA, 1985) and are presented in Table 19. In all cases, expected levels are below AERU detection limits and only Co-60 and Mn-54 predicted activities are within an order of magnitude of AERU detection limits and should be the first radionuclides to be measured from the NGS effluent.

The levels of gamma-emitting radionuclides measured in marine crustacea samples collected at sites shown in Figure 45 and presented in Table 17. Cs-137 was measured in one sample of scallop flesh but at levels very close to AERU detection limits. All other radionuclides were below AERU detection limits as has been observed in previous years.

4.7 Marine Vertebrates

In general, marine vertebrates are less suitable as indicator species because of their mobility and their inefficient accumulation of radionuclides compared to other organisms. But, because of their commercial importance and their vital position in the food web relative to man, marine vertebrates remain important monitoring species. The primary route for nutrient uptake in fish is through the mouth, with a secondary route occurring through the gills. The uptake of radionuclides through outer body surfaces is minimal because they are generally impermeable to ions. The accumulation of radionuclides in marine fish is dependent on size (the rate of intake decreases with increasing body size), excretion rates and growth rate.

Marine vertebrates selected for monitoring near Point Lepreau include the following: harbour seal, *Phoca vitulina*; harbour porpoise, *Phocoena phocoena*, when available; *Pleudopleuronectes americanus*, the winter flounder; and *Clupea harengus*, the atlantic herring.

One sample of winter flounder was analyzed in 1984 and there were no radionuclides detected above AERU detection limits (Table 20). Comparison of calculated expected activities in fish and AERU detection limits (Table 21) show that for the radionuclides released all are expected to be below AERU detection limits. Because of the mobile nature of fish species, it is hard to predict

Table 19. Comparison of calculated expected activities in marine crustaceans and AERU detection limits for samples collected 300 m from the Point Lepreau outfall for 1984.

Radionuclide	Half Life (Days, Years)	Calculated Activity[1] at Outfall (mBq/ℓ)	Concentration* Factor	Calculated Activity[2] in Organism (mBq/kg)	AERU Detection Limit (mBq/kg)
Ce-141	33.00 d	0.00003	1x10^{3}	0.0006	30,300
Ce-144	284.40 d	0.0002	1x10^{3}	0.004	1,000
Co-58	71.20 d	0.006	5x10^{3}	0.6	1,900
Co-60	5.27 y	0.20	5x10^{3}	20.0	74
Cr-51	27.70 d	14.0	5x10^{2}	140.0	50,000
Cs-137	30.00 y	0.10	3x10^{1}	0.06	63
I-131	8.10 d	0.009	1x10^{1}	0.0018	-
Mn-54	321.60 d	0.20	1x10^{4}	40.0	140
Nb-95	35.20 d	0.20	2x10^{2}	0.8	10,000
Ru-103	39.40 d	0.001	1x10^{2}	0.002	31,000
Ru-106	368.00 d	0.007	1x10^{2}	0.014	1,000
Zn-65	244.10 d	0.0007	5x10^{4}	0.7	370
Zr-95	65.00 d	0.05	2x10^{32}	0.2	4,900

* IAEA 1985

[1] Calculated assuming a continuous release of radionuclides. (Total Bq released in 1984 [from Table 1]/Total volume released in 1984).

[2] Calculated assuming a 1/50 dilution factor for effluent entering the Bay of Fundy at 300 m from the outfall.

Table 20. Radionuclide results for marine vertebrated collected near Point Lepreau.

Sample	Date	Sample No.	Component	Sample					Others
				Site	Wt(g)	Geom.	% H_2O	Cs-137 Bq/kg	
Winter flounder (*Pseudopleuronectes americanus*)	1980	-	Flesh	S-11	-	-	72.9	<2	
	1982	-	Flesh	I-6	-	-	79.4	1.0 ± 0.2	
	1982	-	Remains	I-6	-	-	76.6	0.4 ± 0.1	
	1982	-	Skin	I-6	-	-	75.6	<2	
	1983		Rlesh	S-7	-	-	76.3	<0.9	
	1983		Remains	S-7	-	-	81.1	<0.7	
	1983		Skin	S-7	-	-	77.3	<2	
	17-5-84	84-1009	Total	I-6	105.34	1	79.0	<2	

Table 21. Comparison of calculated expected activities in surface water fish and AERU detection limits for samples collected 300 m from the Point Lepreau outfall for 1984.

Radionuclide	Half Life (Days, Years)	Calculated Activity[1] at Outfall (mBq/ℓ)	Concentration* Factor	Calculated Activity[2] in Organism (mBq/kg)	AERU Detection Limit (mBq/kg)
Ce-141	33.00 d	0.00003	$5x10^{1}$	0.00003	30,300
Ce-144	284.40 d	0.0002	$5x10^{1}$	0.0002	1,000
Co-58	71.20 d	0.006	$1x10^{3}$	1.12	1,900
Co-60	5.27 y	0.20	$1x10^{3}$	4.0	74
Cr-51	27.70 d	14.0	$2x10^{2}$	56.0	50,000
Cs-137	30.00 y	0.10	$1x10^{2}$	0.2	63
I-131	8.10 d	0.009	$1x10^{1}$	0.0018	-
Mn-54	321.60 d	0.20	$4x10^{2}$	1.6	140
Nb-95	35.20 d	0.20	$3x10^{1}$	0.12	10,000
Ru-103	39.40 d	0.001	$2x10^{0}$	0.00004	31,000
Ru-106	368.00 d	0.007	$2x10^{0}$	0.0003	1,000
Zn-65	244.10 d	0.0007	$1x10^{3}$	0.014	370
Zr-95	65.00 d	0.05	$2x10^{1}$	0.008	4,900

* IAEA 1985

[1] Calculated assuming a continuous release of radionuclides. (Total Bq released in 1984 [from Table 1]/Total volume released in 1984).

[2] Calculated assuming a 1/50 dilution factor for effluent entering the Bay of Fundy at 300 m from the outfall.

amount of time spent in the effluent plume. As a result, lower radionuclide concentrations in fish species may be expected.

4.8 Tritium in Marine Organisms

It is generally believed that tritium freely exchanges with hydrogen and that the bioconcentration of tritium is negligible in marine organisms. However, studies on natural ecosystems have revealed levels of tritium incorporated into organic matter at concentrations 20 times higher than those in the surrounding water (IAEA 1981). These seemingly anomalously high levels were due to the presence of tritiated organic compounds in the effluent that were readily absorbed and only slowly exchanged with tritium in the environment (IAEA 1981).

Most of the tritium released from nuclear reactors is in two forms: molecular tritium gas, released to the atmosphere via stack gas discharges and tritiated water (HTO) both in vapor and liquid form. Molecular tritium is converted into HTO by either exchange or oxidative reactions. The HTO interacts with living organisms via two pathways - exposure of organisms to water contaminated with HTO and the ingestion by organisms of foods contaminated with tritium.

Tritium incorporated by marine and aquatic organisms can exist as tissue-free water and tissue-bound water (i.e. incorporated into organic molecules) and incorporation is dependent on the physico-chemical state of the tritium in the liquid effluent. Tritiated water, HTO, is exchanged with free tissue water very quickly and can represent up to 95% of the tritium in the organism (IAEA 1981). Tritium can also be incorporated into organic compounds by the exchange reaction with hydrogen in organic compounds. This fraction consists of two components, a rapidly exchanged fraction with a biological half-life on the order of hours or days and a slowly exchangeable fraction with a $t_{1/2}$ on the order of 300 days (IAEA 1981). Thus, it would appear that the physico-chemical state of the tritium is a sensitive parameter of particular importance for predicting and evaluating the environmental behavior of tritium.

The effects of tritium incorporation on plants and animals results from mass difference, beta-particle emission or the properties of the decay product He-3, which differ vastly from the properties of hydrogen. Vig and McFarlane (1975) have identified genetic effects in soybean plants when the seeds were germinated in water containing as little as 370 Bq/ml of tritium.

Tritium levels found in marine systems near the Point Lepreau NGS are given in Table 22. Samples collected in 1984 for various species of marine algae show an average H-3 activity of 3.8 ± 0.6 Bq/ℓ, lower than algae samples collected near the outfall in 1983 which had an average tritium activity of 5.2 ± 1.3 Bq/ℓ but higher than levels found in 1982 (average of 2.9 Bq/ℓ). The decrease in H-3 activity from 1983 to 1984 is indicative of the difference in distance from the outfall for the two sets of samples. Samples of marine crustacea were collected in 1984 and both shell and flesh were analyzed for tritium. The average activity of tritium in water from shell material was 7.2 ± 0.6 Bq/ℓ compared to 4.2 ± 2.6 Bq/ℓ in tissue water. The enhanced tritium signal observed in shell material in previous years, (1982 = 6.3 ± 1.8 Bq/ℓ; 1983 = 7.1 ± 1.9 Bq/ℓ) is again present in 1984.

Table 22. Tritium levels found in marine systems.

Species	Date	Sample No.	Site No.	H-3 (Bq/ℓ)
Water	1982	-	-	avg. 2.31
Water	1983	-	-	avg. 2.53
Water	1984	-	-	avg. 2.93
Algae	1982	-	-	2.3 ± 1.8 to 3.2 ± 1.6 avg. 2.9 ± 0.5
	1983	-	-	4.3 ± 1.7 to 6.1 ± 1.9 avg. 5.2 ± 1.3
Fucus vesiculosus	17-5-84 17-5-84	84-1027 84-2403	I-6 I-6	4.4 ± 2.7 <2.1
Ascophyllum nodosum	17-5-84	84-1026	I-6	3.4 ± 1.9
Laminaria sp.	17-5-84	84-1028	I-6	3.5 ± 2.7
Crustacea	1982	Flesh Shell	- -	2.4 ± 1.7 6.3 ± 1.8
Littorina littorea	1983	Shell	-	7.1 ± 1.9
Scallop	84-1013 84-1017	Flesh Shell	I-6 I-6	<2 7.6 ± 2.8
Neptunium sp.	84-1004	Flesh Shell	I-6 I-6	8.6 ± 2.8 7.0 ± 2.8
Carinus sp.	84-1015	Flesh Shell	I-6 I-6	4.5 ± 2.7 7.6 ± 2.8
Homarus americanus	84-1024	Shell	I-6	7.6 ± 2.8
Sea Urchin	84-1010	Meat	I-6	3.6 ± 2.7
Crangon sp.	84-1014	Whole	I-6	7.4 ± 2.8
Pseudopleuronectes americanus	84-1008	Flesh	I-6	<4

5.0 TERRESTRIAL AND AQUATIC ENVIRONMENTAL PHASES

The complex interrelationship between the terrestrial and aquatic environmental phases is illustrated in Figure 46. Radionuclides are injected into the system via two primary pathways: (1) the atmosphere, from stack discharges at nuclear generating stations and from above ground nuclear tests, and (2) from effluent releases in the cooling water outflow. In both cases, molecular and turbulent diffusion processes take effect immediately and generally act to reduce radionuclide concentration as a function of distance from the source. At the same time, the radionuclides are subject to depositional phenomena, including gravitational settling, precipitation scavenging, impaction, chemical adsorption and exchange. The high particle reactivity of some radionuclides leads to their rapid removal from the air-water continuum and plays an important role in their subsequent availability for biological uptake.

Radionuclides in the abiotic phases of the environment can enter the food chain at any trophic level. Plants, which are at the base of the grazing food chain, accumulate radionuclides from the soil, from atmospheric deposition, and by sorption from water. At higher trophic levels, mechanisms such as the inhalation of aerosol particles can play an important role for some insoluble radionuclides, as well as the standard plant-herbivore-carnivore cycles.

Radionuclides tend to accumulate in 'sinks' composed of deeper strata of soils, sediments and their associated deposits of organic detritus where radionuclides are tightly bound and have negligible contact with biological components. The environmental distribution of radioactivity is as much a function of physiological partitioning within the biotic compartments as it is a function of the physical and chemical interactions between the biotic and abiotic compartments. The rates at which radionuclides are distributed throughout an ecosystem determine the speed with which their steady state distribution is reached and the final distribution patterns that are obtained.

The operational monitoring program for the Point Lepreau NGS emphasizes the early detection and monitoring of reactor-derived radionuclides, while continuing to stress an ecosystem approach to the understanding of radionuclide transport. During the initial stages of the reactor operation, activity levels in most biotic and abiotic phases are expected to remain at background

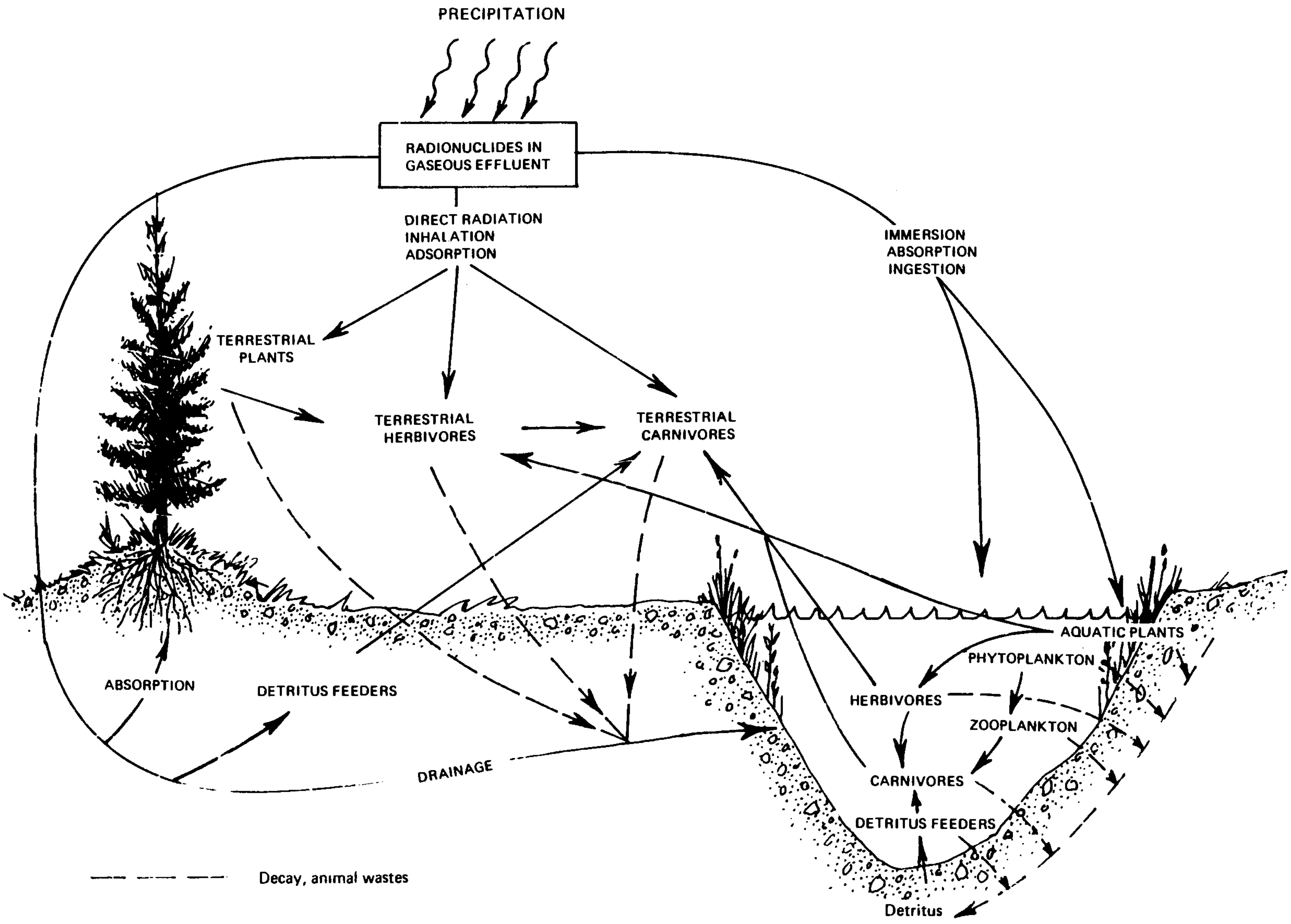

Figure 46. Illustration of transport pathways for radionuclides in aquatic and terrestrial environments.

levels. Table 1, section 2.2, gives the activities of radionuclides released by the reactor during 1984, but because of the rapid mixing of waters within the Bay of Fundy, none of the radionuclides released were detected except in the immediate vicinity of the reactor outfall. On the other hand, elevated tritium signals were observed at several of the air monitoring stations operated by AERU, pointing out the importance of selecting species which directly intercept atmospheric deposition for analysis. Emphasis during the initial years of post-operational program has been placed on those biotic and abiotic compartments which have exhibited, in the pre-operational phase, properties that make them useful environmental monitors. Plant species, such as lichen, blueberry leaves and alder leaves and animal species such as muskrat and frogs have been sampled in 1984. Soil and fresh water sediments, which act as radionuclide sinks, are part of the long range sampling program and will be studied later in the operational program.

5.1 Aquatic Systems

The major dispersion and transfer pathways occurring in a generalized aquatic environment are illustrated in Figure 46. The movement of pollutants through aquatic systems will, in general, be at low concentrations and may be influenced by the presence of other materials, both inorganic and organic, in the water. This includes dissolved ions, variations in pH, suspended particulate matter and silt and clay particles. Physical transport processes include currents, sedimentation, resuspension and turbulent and convective mixing. At the same time, chemical transport processes including absorption, adsorption, dissolution and ion exchange all affect the transport of radionuclides in aquatic systems. In general, the fate of radionuclides in aquatic systems has been studied using long-lived biologically important radionuclides such as Sr-90, and Cs-137. Tracy and Prantl (1983) found that, although bottom sediments acted as a sink for Cs-137, it was distributed throughout the ecosystem with concentration factors from 400 to 6000. In experiments involving artificially contaminated lakes, concentration factors for most radionuclides were found to range over many orders of magnitude for biological materials and values from 100 to 25,000 have been reported in the literature (Polikarpov 1966). The magnitude of the concentration factor varies depending on the radionuclide, the organism in question and even the ecosystem. Concentration factors for H-3 are generally less than one for most organisms (IAEA 1981) while concentration factors of up to 300,000 have been measured for P-32 in algae (Kornberg and Davies 1966). Commonly lakes which are oligotrophic (low nutrient levels, comparatively high dissolved oxygen) are inhabited by organisims having higher radionuclide levels than those found in eutrophic lakes.

The five sampling sites, T-1 to T-5, selected for collecting aquatic samples are located as illustrated in Figure 47. Two of the sites (T-2 and T-4) are small lakes and the remaining sites are stream locations. The experimental methodology for the preparation of biological, sediment and water samples and subsequent analysis using nuclear instrumentation are similar to procedures discussed earlier in this report (section 4.2). The principal difference is that the analytical problems associated with the high salt content of marine samples are not encountered in freshwater samples.

5.1.2 Aquatic Plants and Animals

The factors that affect the uptake of radioactivity by marine organisms include water temperature, redox conditions and pH and the degree and rate of sedimentation. The predominant mechanisms for the accumulation of radionuclides in aquatic plants and invertebrate animals are adsorption and absorption, generally leading to a more direct equilibration with air and water. Vertebrate animals, on the other hand, accumulate radionuclides mainly by ingestion, resulting in slower response times to changes in environmental levels of radioactivity.

Aquatic plant species sampled during 1984 included *Equisetum sp.*, *Iris veriscolor* and *Typha sp.* Aquatic vertebrates sampled during 1984 included the fish species *Salvelinus fontinalis*, *Rhinichtyhys atratulus* and *Semotilus atromaculatus* and several frog species including *Rana sylvatica* and *Rana catesbyiana.*

Radionuclide results for aquatic plant samples collected at sites shown in Figure 47 are presented in Table 23. During 1984, Cs-137 was measured in three samples of wild iris (Cs-137 range = 4 to 85 Bq/kg, avg = 33 Bq/kg) and in one sample of equisetum (Cs-137 = 6 ± 2 Bq/kg).

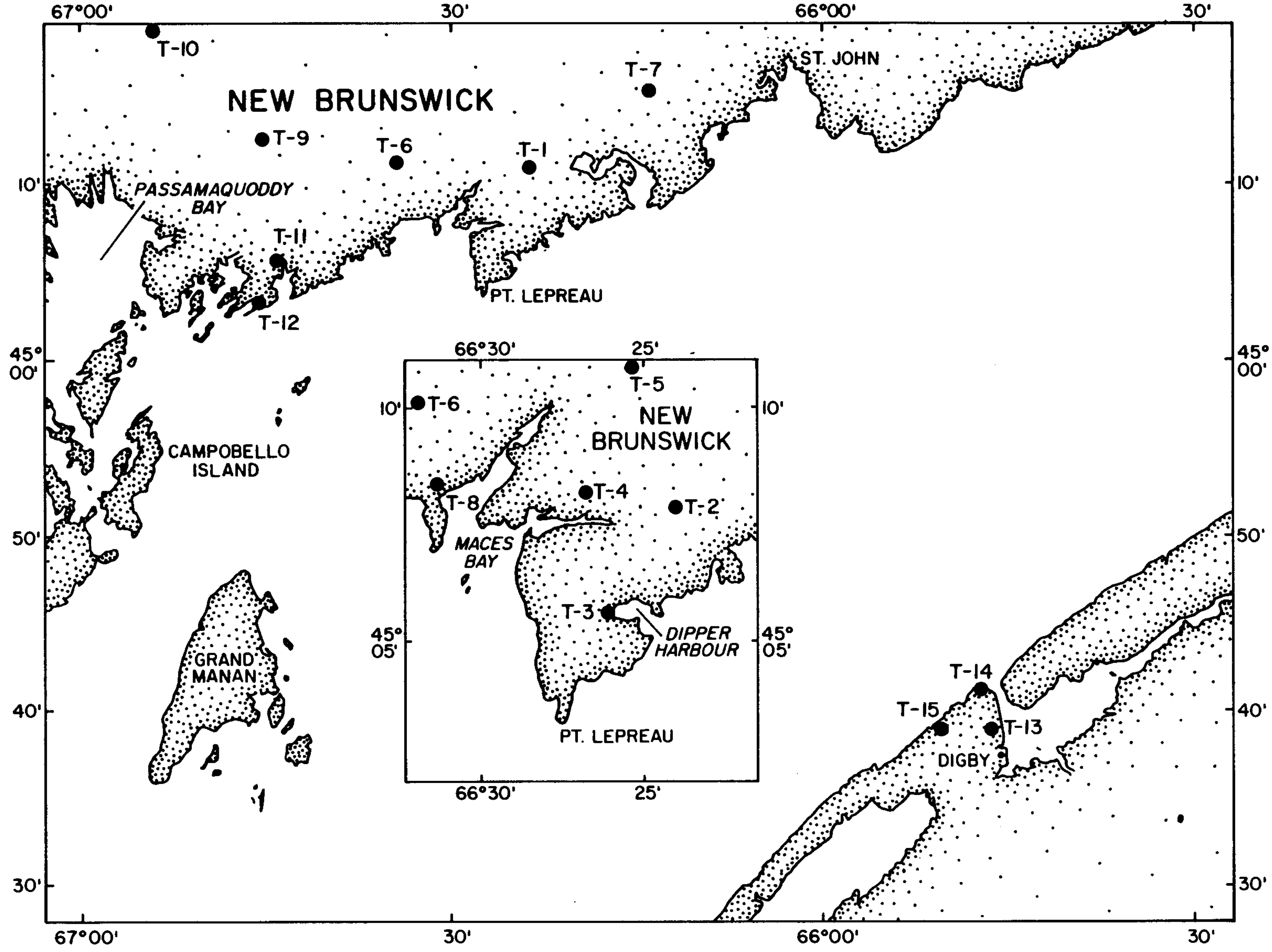

Figure 47. Aquatic and terrestrial sampling sites in the Point Lepreau area.

Table 23. Radionuclide results for aquatic plants collected near Point Lepreau.

Sample	Date	Sample No.	Component	Sample					Range (Bq/kg)
				Site	Wt(g)	Geom.	% H_2O	Cs-137 Bq/kg	
Horsetail *Equisetum sp.*	1981-1982	-	Total	T-1, T-5	-	-	78.9	56 ± 80	<2 to 230 ± 8
	27-6-84	84-1044	Total	1	25.76	2	76.0	6 ± 2	-
	27-6-84	84-2502	Total	4	10.99	3	74.0	<6	-
	27-6-84	84-2516	Total	5	11.49	3	76.0	<9	-
Wild Iris *Iris versicolor*	1981-1982	-	Total	T-1, T-5	-	-	79.8	15 ± 20	3 ± 1 to 55 ± 7
	27-6-84	84-1036	Total	3	26.22	2	80.0	4 ± 2	-
	27-6-84	84-1055	Total	8	17.78	2	91.0	85 ± 6	-
	27-6-84	84-1100	Total	2	20.43	2	86.0	11 ± 2	-
Cat tail *Typha sp.*	1981	-	Total	T-3	-	-	88.0	<13	-
	1983	-	Head	T-3	-	-	61.5	<1	-
			Leaves	T-3, T-4	-	-	73.5	<2	-
	27-6-84	-	Total	T-4	48.88	1	68.8	<2	
Fish	1981	-	Total	T-1 to 5	-	-	87.4	11 ± 8	5 ± 4 to 17 ± 4
	1983	-	Total	T-1 to 5	-	-	76.8	26 ± 12	<6 to 34 ± 3
	17-7-84	84-2547	Total	1	26.11	3	83.0	11 ± 1	
Frog. *Rana sp.*	1981	-	Total	T-1 to 5	-	-	81.3	35 ± 12	24 ± 3 to 49 ± 9
	1983	-	Total	T-1 to 5	-	-	80.7	39 ± 32	15 ± 5 to 95 ± 20
	28-6-84	84-1062	Total	4	1.45		80.0	48 ± 15	
	28-6-84	84-1065	Total	3	8.46	3	80.0	50 ± 5	
	28-6-84	84-1066	Total	2	10.74	4	82.0	51 ± 4	
	27-6-84	84-2504	Total	3	1.39	5	80.0	256 ± 19	

The Cs-137 level of the iris sample from site T-8 was above the range of pre-operational Cs-137 values but was probably a function of the variable levels of Cs-137 found in plant samples. Levels of Cs-137 were below AERU detection limits for samples of *Typha sp.* collected in 1984.

Radionuclide results for aquatic vertebrates sampled during 1984 are presented in Table 24. The Cs-137 activity in the fish sample (11 ± 1 Bq/kg) was within the range of pre-operational measurements. Several samples of frog were also analyzed and the Cs-137 activity ranged from 48 ± 15 Bq/kg to 256 ± 19 Bq/kg. As was observed in 1983 (Nelson *et al.*, 1985), the Cs-137 activities in frog samples were consistantly higher than in fish samples as a result of their respective habitats. Fish live in freshwater with relatively lower Cs-137 activities compared to frogs which spend a significant amount of time in higher activity sediments.

The absorption, distribution and retention of Cs-137 differs widely between species, genera and animal groups as well as with a variety of physical factors. In general, Cs-137 is concentrated rapidly by aquatic organisms and equilibrium is attained within a few days to a few weeks (Coughtrey *et al.* 1983).

5.2 Terrestrial Systems

Greater variability in radionuclide levels is generally observed in terrestrial compared to aquatic systems. The residence times of most radionuclides in air are much shorter than their residence times in water, and as a result, a steady state in radionuclide levels can be established throughout the different components of an aquatic system more rapidly and efficiently than throughout a terrestrial ecosystem. Physiography, microterrain and microclimate variables which control processes within the ecosystem, and the properties of radionuclide transport within these systems are important factors governing the nature of terrestrial ecosystems. Biological uptake of fallout radionuclides is generally more efficient in the terrestrial environment, compared to aquatic and marine ecosystems, because of the absence of a diluting medium such as water. The end result is the accumulation of higher levels of fallout radionuclides in land-based plants and animals as illustrated in pre-operational data (Ellis *et al.* 1984).

Table 24. Radionuclide results for aquatic vertebrates collected near Point Lepreau.

Sample	Date	Sample No.	Component	Sample					Range
				Site	Wt(g)	Geom.	% H_2O	Cs-137 Bq/kg	
Fish	1981	-	Total	T-1 to 5	-	-	87.4	11 ± 8	5 ± 4 to 17 ± 4
	1983	-	Total	T-1 to 5	-	-	76.8	26 ± 12	<6 to 34 ± 3
	17-7-84	84-2547	Total	1	26.11	3	83.0	11 ± 1	
Frog. *Rana sp.*	1981	-	Total	T-1 to 5	-	-	81.3	35 ± 12	24 ± 3 to 49 ± 9
	1983	-	Total	T-1 to 5	-	-	80.7	39 ± 12	15 ± 5 to 95 ± 20
	28-6-86	84-1062	Total	4	1.45	5	80.0	48 ± 15	
	28-6-86	84-1065	Total	3	8.46	3	80.0	50 ± 5	
	28-6-86	84-1066	Total	2	10.74	4	82.0	5 ± 4	
	27-6-86	84-2504	Total	3	1.39	5	80.0	256 ± 19	

5.2.1 Terrestrial Plants

The input of radionuclides to plant surfaces may take place via wet and dry deposition and direct irrigation. A proportion of this input may be lost through processes of resuspension and it is often difficult to differentiate those losses which are attributable to leaching during rainfall from those due to abscission, mortality and resuspension. Seasonal factors have a major influence on these processes, affecting the surface area and physical characteristics of plant parts for particle capture, the degree of root uptake and translocation and the magnitude of losses via mortality and abscission. In this regard, it should be noted that all processes of uptake and loss from plants can be expected to be related not only to the maturity of the plant but also to the temperature, surface wetting, humidity, chemical form of the substance concerned and general nutritional status (Coughtrey *et al.* 1983). Radionuclides adsorbed onto plant surfaces may become incorporated into plant tissue through stomates or outer epidermal layers, but in many plants much of the radioactivity is simply adsorbed onto surface layers and can be removed by leaching (Takashima *et al.* 1978).

The plant species selected for monitoring at Point Lepreau for the second year of the operational monitoring program include alder leaves, blueberry leaves, lichen, including a species of lichen living above ground on trees, *Usnea sp.*, which derives all its nutrient needs from the air.

Alder and Blueberry Leaves:

Alnus rugosa (speckled alder) is found predominantly in drainage areas and is considered to be a good indicator of water-borne radionuclides. The alder is at the base of the food chain and, although not a primary browse species, it is utilized by insects which in turn are consumed by amphibians, birds, mammals, and reptiles. Radionuclide results for alder samples collected at the terrestrial sampling sites indicated in Figure 47, are presented in Table 25. Only Cs-137 was detected in the samples analysed and values ranged from 25 to 70 Bq/kg (avg = 57 Bq/kg). Radionuclide results for blueberry leaves are included in Table 25. Only Cs-137 was detected and values ranged from 20 ± 2 Bq/kg to 164 ± 9 Bq/kg (avg = 70 ± 65 Bq/kg). All Cs-137 levels in

Table 25. Radionuclide results for terrestrial plant samples collected near Point Lepreau.

Sample	Date	Sample No.	Component	Sample					Range
				Site	Wt(g)	Geom.	% H_2O	Cs-137 Bq/kg	
Alder (*Alnus rugosa*)	1980	-	Buds	T-1,2	-	-	-	21 ± 8	16 ± 2 to 27 ± 3
			Branches	T-1,2	-	-	-	4 ± 1	3 ± 2 to 6 ± 2
	1982		Leaves	T-1 to 5	-	-	59.1	22 ± 13	<2 to 35 ± 2
	1983		Leaves	T-1 to 5	-	-	55.2	16 ± 13	<1 to 32 ± 3
	27-6-84	84-1041	Leaves	T-3	26.69	2	73.0	<5	
	27-6-84	84-1050	Leaves	T-5	38.04	2	65.0	70 ± 2	
	27-6-84	84-1079	Leaves	T-8	14.00	3	65.0	44 ± 7	
Blueberry	1981	-	Leaves	T-1 to T-12	-	-	-	96 ± 76	15 ± 3 to 253 ± 7
	1982	-	Leaves	T-1 to T-12	-	-	62.4	63 ± 56	14 ± 2 to 197 ± 5
	1983	-	Leaves	T-1 to T-12	-	-	51.1	27 ± 32	4 ± 2 to 74 ± 9
	27-6-84	84-1037	Leaves	T-3	11.84	3	70.0	115 ± 8	
	27-6-84	84-1045	Leaves	T-4	20.01	2	75.0	25 ± 2	
	27-6-84	84-1052	Leaves	T-3	12.37	3	73.0	164 ± 9	
	28-6-84	84-1058	Leaves	T-2	26.47	2	62.0	28 ± 1	
	27-6-84	84-2505	Leaves	T-1	30.00	2	71.0	20 ± 2	
Moss (*Sphagnum sp.*)	1980	-	Total	T-1 to 5	-	-	78.0	74 ± 58	24 ± 7 to 165 ± 5
	1982	-	Total	T-1 to T-4	-	-	51.1	275 ± 280	4 ± 4 to 930 ± 11
	28-6-84	84-1064	Total	T-4	17.66	2	72.0	13 ± 2	
	28-6-84	84-1076	Total	T-8	21.29	1	91.0	20 ± 3	
	27-6-84	84-1091	Total	T-3	19.35	2	87.0	104 ± 4	
	27-6-84	84-1099	Total	T-5	39.35	1	67.0	171 ± 4	
	27-6-84	84-2506	Total	T-2	47.39	1	73.0	189 ± 16	
	27-6-84	84-2509	Total	T-1	151.92	1	71.0	15 ± 1	
Ferns	27-6-84	84-1075	Total	T-8	38.28	2	79.8	28 ± 1	

alder and blueberry leaves were within the range of Cs-137 activities observed during the pre-operational program. In 1984, the Cs-137 results for blueberry leaves and alder leaves showed a wide intra-species variability for plants sampled from the same site. Remmenga and Whicker (1979) observed Cs-137 activities four to seven times higher in blueberry leaves than aspen leaves at sites 10 metres apart.

In addition, several samples of sphagnum moss were collected and analyzed in 1984. Radionuclide results are presented in Table 25. Cesium-137 was detected only, ranging from 13 ± 2 to 189 ± 16 Bq/kg (avg 85 ± 81 Bq/kg). Pre-operational results for Cs-137 in sphagnum ranged from 4 to 930 Bq/kg and operational results are within this range. The uptake of radionuclides by plant species depends on the degree of fallout entrapment, plant surface characteristics, age, and the physiological demand for the radionuclide or stable analogue and these factors are responsible for the wide inter- and intra- species variability in radionuclide accumulation by plants.

Lichen

Lichen communites have long been recognized as a reservoir of natural and artificial radionuclides. The accumulation of radionuclides in lichen is enhanced by several factors; the persistance of aerial parts (plants with persistent aerial parts contain 2-10 times greater amounts of fallout materials than seasonal plants, Hanson, 1967), slow growth rate, long life span, high ratio of surface to mass and foliar absorption of nutrients. These morphological and physiological characteristics of lichen, which have evolved to enable these organisms to exist in environmental extremes, serve to make them an excellent indicator of contaminant fallout. Work by Hanson *et al.* (1966) has shown that lichen retain approximately 10% of the fallout deposition. Their value as fallout indicators around industrial installations is well documented and it is widely recognized that there is a qualitiative and quantitative improvement in lichen flora and a decrease in pollutant content of thalli as distance increases from the source of contamination (Goyal and Seaward, 1981).

The uptake of radionuclides by lichen is complicated by environmental factors. The influence of habitat is very pronounced; lichens from pine forests contained 925 Bq/kg Cs-137, from tundra 815 Bq/kg and from deciduous forest 740 Bq/kg (Kwapulinski *et al.*, 1985). Hanson and Eberhardt (1971), found that Cs-137 content in lichens followed a seasonal cycle with maximum values in the summer and minimum values in mid winter. Work carried out by Kwapulinski *et al.* (1985), should that accumulation of Cs-137 by lichen was influenced by altitude and that the coefficient of accumulation rose with increasing altitude. The uptake of radionuclides in lichen follows the series Cs-137 > Sr-90 > Fe-55 > Co-60 and different lichen types accumulate radionuclides with varying degrees of effectiveness. For example Cs-137 uptake can be summarized as terricolous lichens > epilithic lichens > epiphytic lichens and for Sr-90 the order changes to epiphytic lichens > terricolous lichens > epilithic lichens, (Kwapulinski *et al.*, 1985).

Two species of lichen were collected in 1984 - *Cladonia arbuscula*, a ground lichen sampled in previous years and *Usnea sp*, which is an aerial lichen commonly referred to as spanish moss or 'old man's beard'. The aerial lichen was added as a new sampling species as a result of its abundance in the vicinity of Point Lepreau and its ease of sampling during all times of year. Samples were collected at almost all the terrestrial sites as well as at three sites in the Digby, Nova Scotia area.

The results of analysis of *C. arbuscula* are given in Table 26. Cesium-137 and K-40 were the only nuclides routinely measured above the detection limit. Due to problems in the detection system which lead to long time periods between sample collection and analysis, levels of short-lived nuclides could not be determined in most cases.

The Cs-137 distribution in *C. arbuscula*, shown in Figure 48, varies greatly with geographical distribution, ranging from 14 Bq/kg near Digby to 344 Bq/kg at site T-6. The average activity found in New Brunswick was 119 Bq/kg and the variation found is reflected in the high standard deviation of 72 Bq/kg. The highest levels are found on land surrounding Maces Bay and levels found on the peninsula of Point Lepreau are generally higher than levels found at inland sites, as has been observed in pre-operational years (Ellis *et al.*, 1984). These differences are a result of existing environmental conditions rather than as a result of reactor releases.

The activities of the lichen measured in 1984 are slightly higher than levels measured in *C. arbuscula* in 1983, where an average level of 93 Bq/kg was found, and lower than the average level

Table 26. Radionuclide results for lichen collected near Point Lepreau.

Sample	Date	Sample No.	Component	Sample					Range
				Site	Wt(g)	Geom.	% H_2O	Cs-137 Bq/kg	
Lichen (*C. arbuscula*)	1981	-	Total	T-7	-	-	12.0	265 ± 10	33 ± 1 to 156 ± 3
	1983	-	Total	T-1,6,14	-	-	10.0	85 ± 42	
	27-6-84	84-1038	Total	T-3	4.25	5	77.0	134 ± 5	
	27-6-84	84-1039	Total	T-10	3.76	5	83.0	99 ± 8	
	27-6-84	84-1040	Total	T-3	4.26	5	77.0	143 ± 11	
	27-6-84	84-1059	Total	T-3	7.35	4	76.0	157 ± 7	
	27-6-84	84-1060	Total	T-15	15.98	3	57.0	63 ± 3	
	28-6-84	84-1067	Total	T-12	33.02	2	55.0	164 ± 12	
	28-6-84	84-1068	Total	T-2	11.11	4	59.0	96 ± 7	
	27-6-84	84-1080	Total	T-6	7.22	4	77.0	344 ± 4	
	28-6-84	84-1085	Total	T-2	35.57	1	57.0	68 ± 5	
	27-6-84	84-1086	Total	T-5	9.20	4	75.0	90 ± 12	
	27-6-84	84-1087	Total	T-14	43.77	1	65.0	22 ± 3	
	27-6-84	84-1094	Total	T-13	12.63	4	69.0	14 ± 3	
	27-6-84	84-1097	Total	T-1	8.51	4	71.0	109 ± 6	
	27-6-84	84-2501	Total	T-8	8.20	4	71.0	219 ± 7	
	27-6-84	84-2513	Total	T-4	8.33	4	76.0	285 ± 12	
	27-6-84	84-2514	Total	T-7	4.43	5	83.0	92 ± 6	
	27-6-84	84-2515	Total	T-9	5.46	5	75.0	32 ± 4	
	27-6-84	84-2517	Total	T-11	8.07	4	71.0	91 ± 9	
	15-8-84	84-2530	Total	T-1	11.41	4	-	57 ± 6	
	17-7-84	84-2531	Total	T-1	17.36	3	46.0	71 ± 6	
	12-9-84	84-2001	Total	T-1	4.23	5	73.0	56 ± 7	
	18-10-84	84-2004	Total	T-1	16.47	3	34.0	63 ± 5	
	19-11-84	84-2007	Total	T-1	13.31	4	54.0	45 ± 3	
	17-12-84	84-2010	Total	T-1	19.59	3	55.0	91 ± 2	

Table 26. Continued

Sample	Date	Sample No.	Component	Sample					Range
				Site	Wt(g)	Geom.	% H_2O	Cs-137 Bq/kg	
Lichen (*Usnea sp.*)	28-6-84	84-1070	Total	T-8	16.29	3	30.0	34 ± 5	
	28-6-84	84-1077	Total	T-2	18.72	3	21.0	54 ± 4	
	28-6-84	84-1083	Total	T-1	15.60	3	24.0	14 ± 3	
	28-6-84	84-1084	Total	T-5	32.03	2	25.0	33 ± 1	
	15-8-84	84-2521	Total	T-3	21.46	2	36.0	60 ± 3	
	15-8-84	84-2522	Total	T-1	15.19	3	29.0	37 ± 3	
	17-7-84	84-2530	Total	T-1	13.46	3	52.0	110 ± 4	
	12-9-84	84-2002	Total	T-1	6.10	4	36.0	94 ± 7	
	12-9-84	84-2003	Total	T-8	10.93	3		12 ± 3	
	18-10-84	84-2005	Total	T-1	8.75	4	28.0	8 ± 2	
	18-10-84	84-2006	Total	T-8	15.78	3	17.0	10 ± 2	
	19-11-84	84-2009	Total	T-8	10.66	3	14.0	21 ± 2	
	17-12-84	84-2011	Total	T-1	8.47	3	-	24 ± 5	
	17-12-84	84-2012	Total	T-8	15.79	3	-	<7	
	27-6-84	84-1056	Total	T-3	29.19	1	86.0	29 ± 2	
	28-6-84	84-1081	Total	T-8	19.77	3		14 ± 2	

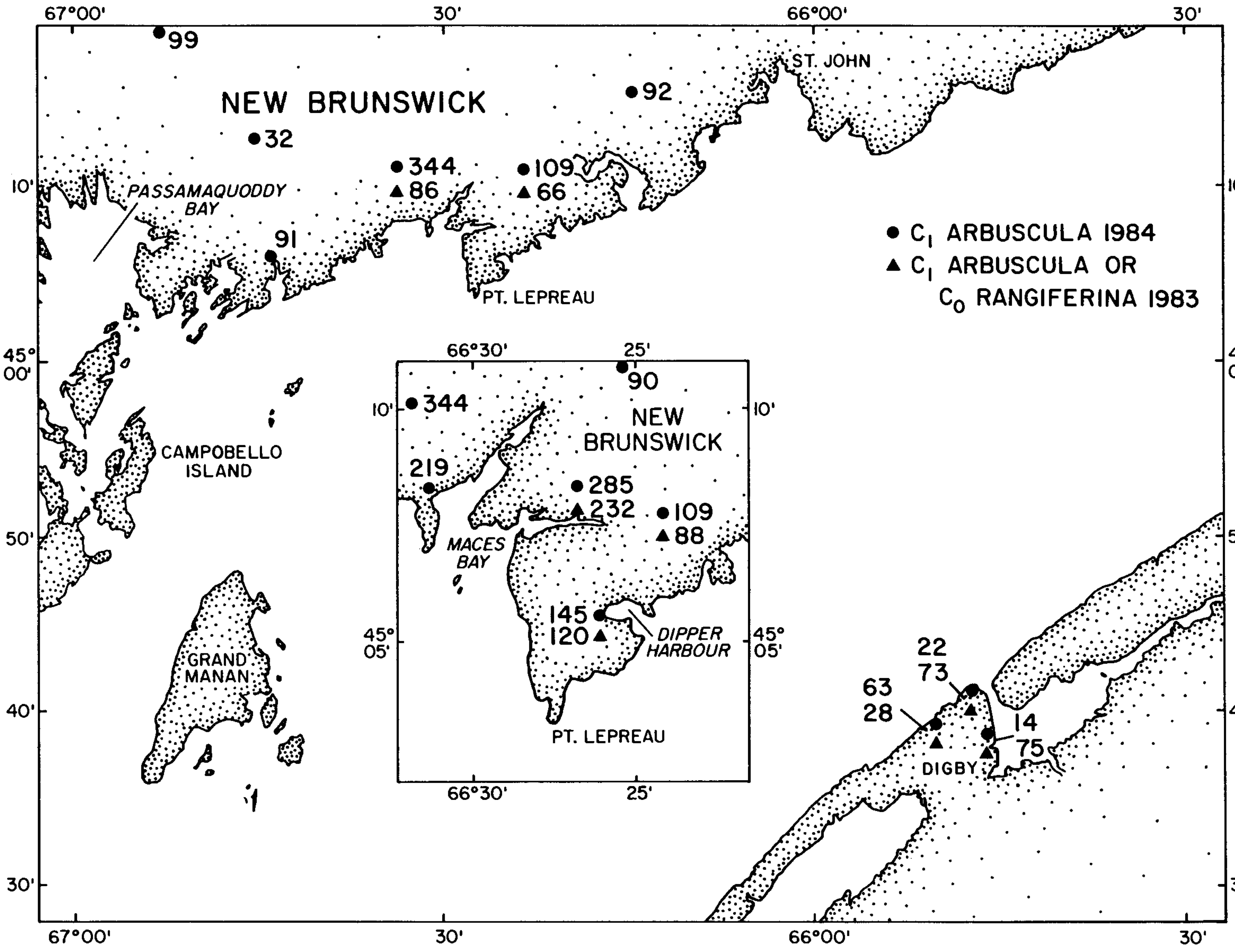

Figure 48. Geographical distribution of Cs-137 in lichen.

of 130 Bq/kg found in *C. rangiferina*, a similar lichen species, in 1983. The Cs-137 activity in lichen appears to become relatively constant so that the amount of Cs-137 taken up by the lichen is equal to that eliminated.

Lichen samples were collected from three sites in the Digby, Nova Scotia area, starting in 1983. These sites were established in order to monitor the movement of radionuclides across the Bay of Fundy from Point Lepreau to Nova Scotia and would complement measurements of air collected at Digby since 1981. The average Cs-137 activities in lichen at Digby were lower than those collected at Point Lepreau for both 1983 and 1984. An average value of 45 Bq/kg was found at Digby compared to the average of 108 Bq/kg at Point Lepreau in 1983 and for 1984, the average level at Digby of 33 Bq/kg were again less than Point Lepreau average of 119 Bq/kg. A decrease in Cs-137 activity was observed at Digby from 1983 to 1984, but this decrease is within sample variability.

Levels of radionuclides found in *Usnea sp.* are given in Table 26. The average Cs-137 activity, 35 Bq/kg, is much lower than the average level of 119 Bq/kg found in *C. arbuscula*. The Cs-137 activities for samples of these two lichen collected at the same time and location are plotted against each other in Figure 49. The average *Usnea* level of 43 Bq/kg is less than half that of *C. arbuscula* (101 Bq/kg) for these samples. There appears to be no strong correlation between the Cs-137 contents in these lichen, although, in most cases, higher levels in one species are reflected in the other. The differences in these species is probably a function of their different habitats. The ground lichen is able to trap rainwater and as a result is able to extract more nutrients. The aerial lichen hanging from tree limbs is unable to trap rainwater and must obtain most of its nutrients and moisture from the atmosphere directly. In addition, the aerial lichen is probably younger and would contain a smaller inventory of fission products from nuclear tests during the 1950s and 1960s compared to ground lichen which is typically 30-45 years old (Hale, 1973) and would have a large inventory of fission products. Kwapulinski *et al.* (1985) also found that Cs-137 uptake was greater for terricolous lichen such as *C. arbuscula* than for epiphytic lichen such as the aerial lichen, *Usnea*.

Samples of *C. arbuscula* were collected at site T-1 at monthly intervals where possible during 1983 and 1984. The activities are illustrated in Figure 50 and are compared with the

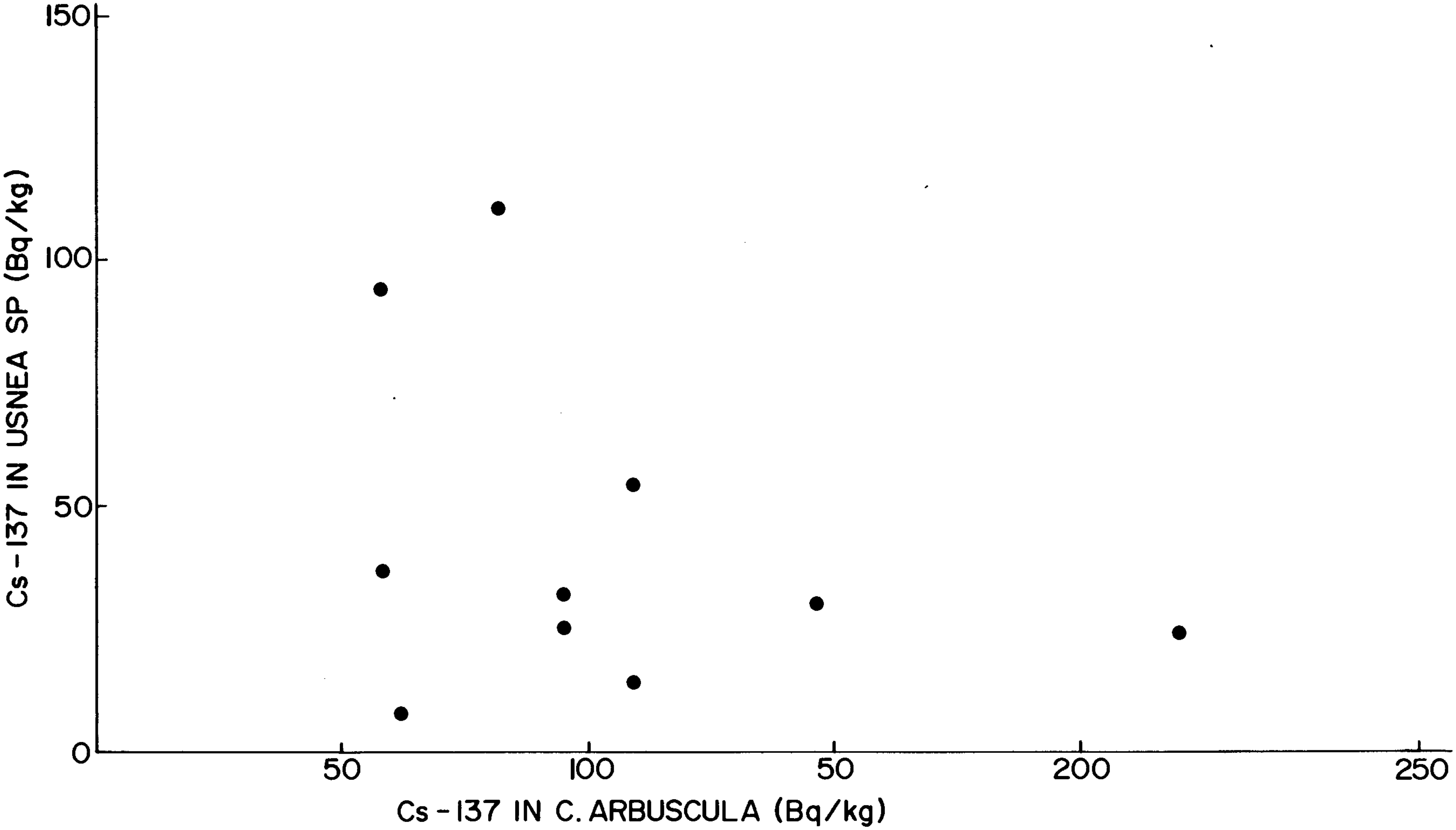

Figure 49. Cs-137 in aerial lichen *Usnea sp*. versus Cs-137 in ground lichen *C. arbuscula*.

monthly rainfall for the same period. Cesium-137 levels in *Usnea sp.* collected during the second half of 1984 are also included. There is excellent agreement between the level of Cs-137 in *C. arbuscula* and rainfall for 1983 and 1984. A correlation coefficient of 0.64 is obtained and indicates that rainfall is an important variable in radionuclide uptake in *C. arbuscula* as mentioned earlier. There does not appear to be any relationship between the Cs-137 content of *Usnea sp.* and rainfall, as is expected since aerial lichen is unable to trap rainfall and therefore is less affected by the amount of rainfall.

In previous years, the isotopic ratio of Ce-144/Cs-137 has been studied (Ellis *et al.* 1984, Nelson *et al.* 1985). A steady decrease in the ratio has been observed since 1981, when large amounts of Cs-137 and Ce-144 were introduced into the atmosphere as a result of the 25th Chinese nuclear test (Smith *et al.* 1982), at a rate which corresponds to the relative decay ratio of these two isotopes. It was concluded from this that cerium and cesium are eliminated from lichen at the same rate. This year, the level of Ce-144 was, in all cases, below our detection limit and the consistancy of the ratio could not be ascertained.

The relationship between Cs-137 and K-40 was studied for *C. arbuscula* again and for *Usnea sp.* (Figure 51). In previous years, we have found a negative correlation between Cs-137 and K-40 (Ellis *et al.* 1984) which supports postulation that Cs-137 was taken up as a substitute for potassium (Davis 1963).

Samples collected in 1983 did not show this correlation (Nelson *et al.* 1985) and again this year there is no correlation for either species. *Usnea sp.* have a much higher K-40 activity than *C. arbuscula* (174 Bq/kg vs 99 Bq/kg), which may explain the lower Cs-137 levels found in *Usnea sp.*

In summary, the average Cs-137 level found in New Brunswick in *C. arbuscula* was 119 Bq/kg, a similar activity to the previous years. Highest activities were found in the Maces Bay area, as was observed previously and is unrelated to reactor releases, while lowest levels were found in the Digby, Nova Scotia area. *Usnea sp.*, an aerial lichen collected for the first time this year, has lower levels of Cs-137. A direct correlation is observed between the Cs-137 content of *C. arbuscula* and

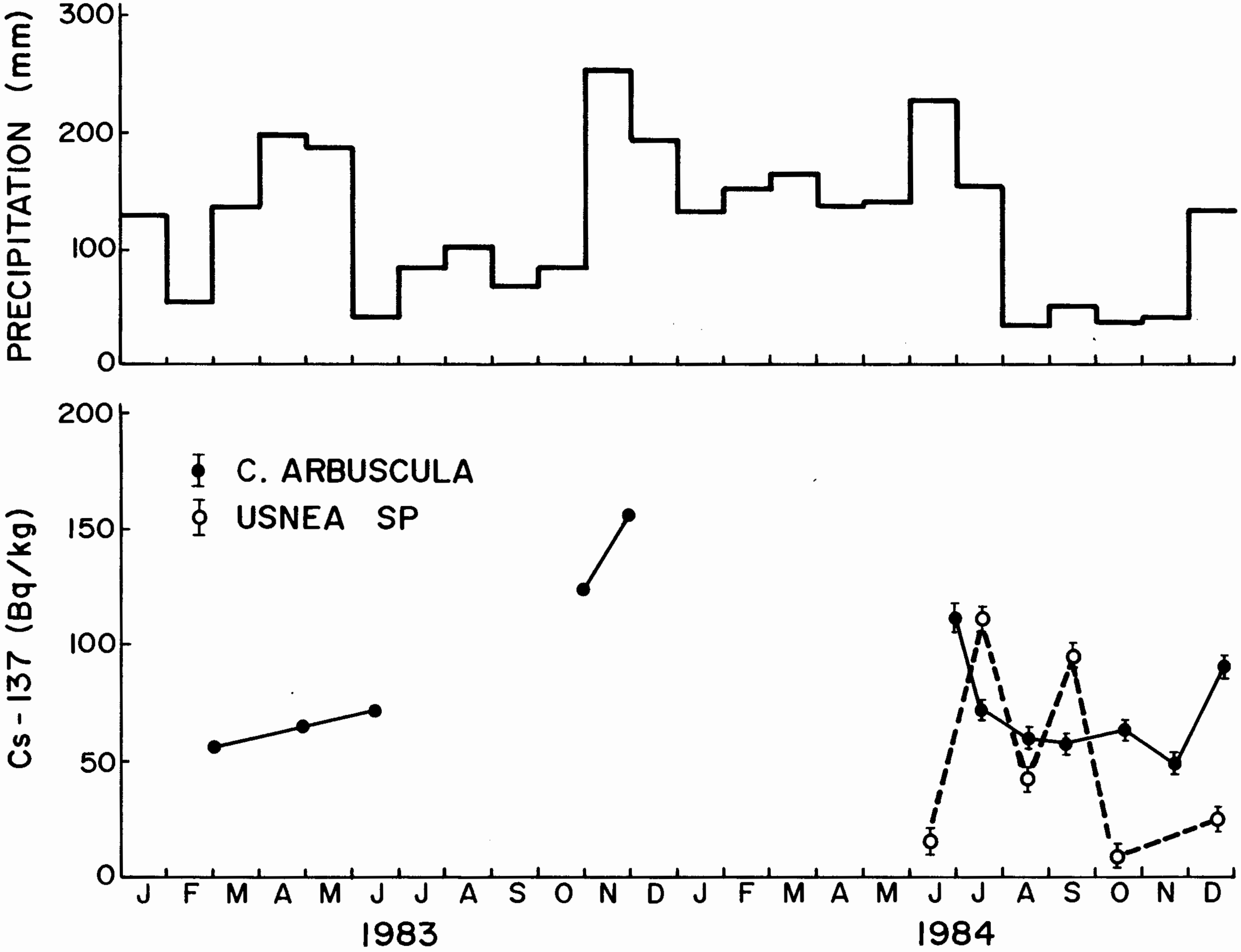

Figure 50. Time series for terrestrial sampling site 1, Cs-137 and rainfall.

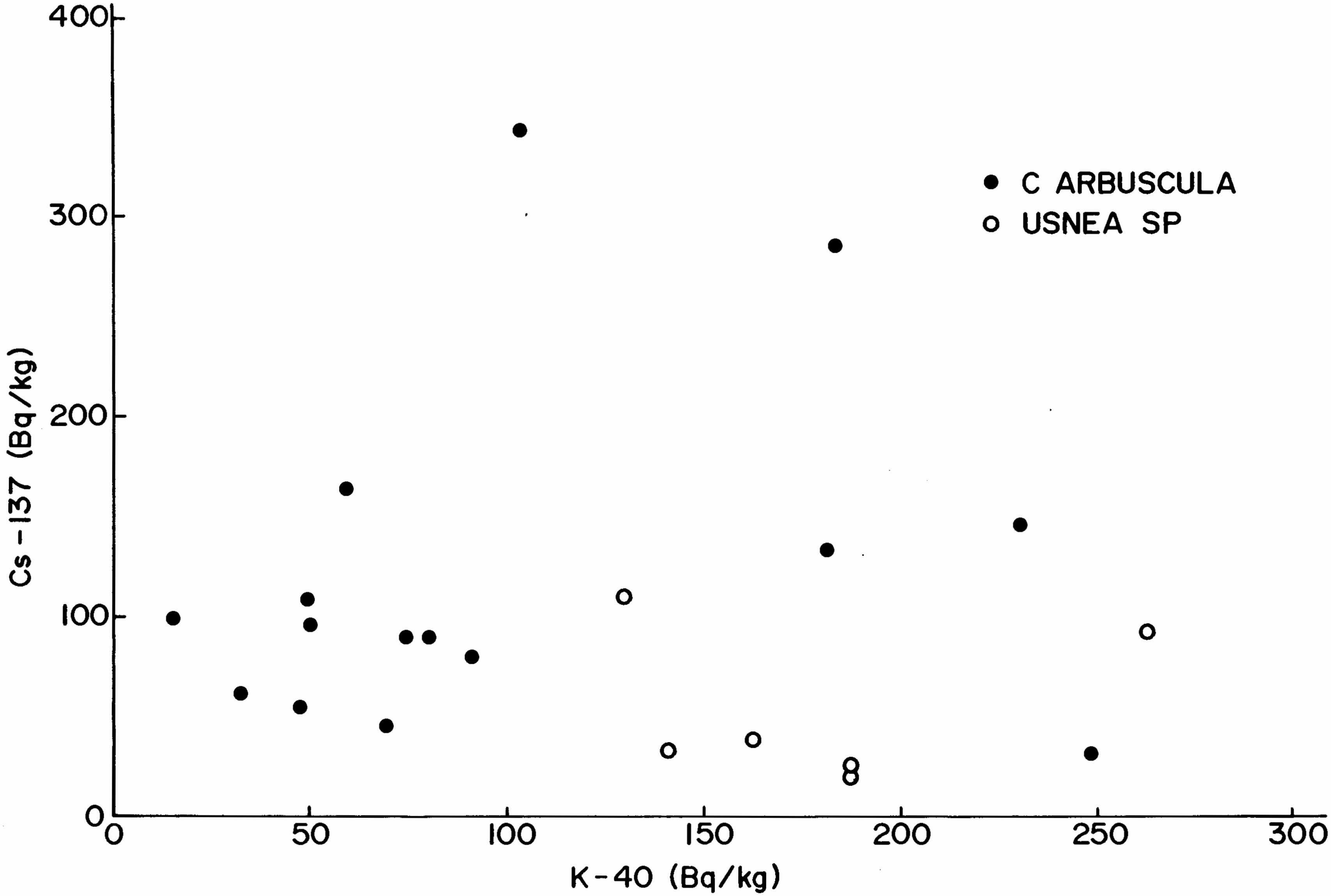

Figure 51. K-40 versus Cs-137 in lichen collected in 1984.

rainfall that is not observed for *Usnea sp.* No correlation was found between Cs-137 and K-40 content in lichen, although levels of K-40 are higher in *Usnea sp.* than in *C. arbuscula.*

5.2.2 Terrestrial Animals

Terrestrial animals can receive inputs of contaminants via surface deposition to their skin, inhalation of particulates or gases, ingestion of contaminated drinking water and plant and animal material, as well as, supplementary intakes of soil particles (particularly during winter months). The main routes of loss from the animal involve excretion and to a limited extent exhalation.

The three principal herbivore species monitored for radioactivity at Point Lepreau over the course of the monitoring program have been the muskrat (*Ondatra zibethicus*), varying hare (*Lupus americanus*), meadow vole (*Microtus pennsylvanicus*) and, when available, white tailed deer (*Odocileus virginianus*).

In 1984, muskrat samples were collected at sites T1, to T5 and were dissected into muscle, bone, liver, and brain. Muskrats feed on readily available emergent vegetation, cattail, water lily and other pond weeds as well as fresh water muscles and occasionally frogs and small turtles. During the pre-operational phase of the program only Cs-137 was detected in muskrat samples and activities were found to be highly variable.

Results for muskrats collected in 1984 are given in Table 27, and continue to show great variability in activities. The range of Cs-137 activity measured in muskrat muscle in 1984 was <4 Bq/kg to 84 ± 2 Bq/kg and falls within the range of Cs-137 activities measured during the pre-operational program. Cs-137 was found in muscle and liver in muskrats collected at sites T-2 and T-3, but was below the detection limits at sites 1, 4 and 5. Cs-137 activities in samples collected in previous years showed a similar variability. For instance in 1983, at site 3, 239 ± 13 Bq/kg of Cs-137 was measured in muskrat muscle while at site 5 no Cs-137 was detected.

Several samples of insects were also collected in 1984 and the results are presented in Table 27. The Cs-137 activities measured are comparable to those determined during the pre-operational program.

Table 27. Radionuclide results for vertebrate animals and insects collected near Point Lepreau.

Sample	Date	Sample No.	Component	Sample					Range
				Site	Wt(g)	Geom.	% H_2O	Cs-137 Bq/kg	
Muskrat	1980-1982	-	Muscle	T-1 to 5	-	-	73.6	44 ± 68	2 ± 0.7 to 173 ± 15
(*Ondatra zeibenthicus*)		-	Bone	T-1 to 5	-	-	32.8	5 ± 2	<3 to 5 ± 2
			Liver	T-1 to 5	-	-	70.8	60 ± 45	<3 to 108 ± 5
		-	Brain	T-1 to 5	-	-	74.4	<5	-
	1982	-	Stomach	T-1 to 5	-	-	78.9	4 ± 2	2 to 4 ± 2
	1983	-	Muscle	T-3,5	-	-	73.8	239 ± 13	-
			Bone	T-3,5	-	-	47.1	35 ± 4	-
			Liver	T-3,5	-	-	72.5	101 ± 9	-
			Brain	T-3,5	-	-	77.7	60 ± 22	-
	17-07-84	Composite	Brain	T-1 t T-5	3.32	5	82.0	<18	
	17-07-84	Composite	Bone	T-1 t T-5	33.36	4	34.0	8 ± 1	
	17-07-84	84-2014	Liver	T-1	4.69	5	75.0	<13	
	17-07-84	84-2015	Muscle	T-1	10.64	4	73.0		
	17-07-84	84-2018	Liver	T-2	7.19	5	72.0	64 ± 4	
	17-07-84	84-2019	Muscle	T-2	13.26	4	74.0	84 ± 2	
	17-07-84	84-2022	Liver	T-3	4.24	5	73.0	66 ± 5	
	17-07-84	84-2023	Muscle	T-3	13.39	4	70.0	54 ± 5	
	17-07-84	84-2026	Liver	T-4	3.80	5	76.0	<4	
	17-07-84	84-2027	Muscle	T-4	10.64	4	73.0	<6	
	17-07-84	84-2030	Liver	T-5	6.12	5	73.0	<7	
	17-07-84	84-2031	Muscle	T-5	14.47	4	71.0	<6	
Insects	1981	-	Total	T-1, T-5	-	-	55.0	31 ± 55	3 to 143
	29-06-84	84-2508	Total	T-5	7.57	3	66.0	13 ± 5	
	29-06-84	84-2511	Total	T-1	0.99	5	60.0	<36	
	29-06-84	84-2512	Total	T-4	6.75	3	66.0	<0.6	

5.3 Tritium in Aquatic and Terrestrial Systems

The importance of the distribution of tritium in ecosystems in general and in food chains in particular has increased with the increase in the use of atomic energy for peaceful purposes. Tritium enters the hydrosphere in the form of HTO and the atmosphere in the form of HTO vapour and HT gas. The elemental form is partly oxidized in the atmosphere and joins the overall water cycle (Krishnamoorthy *et al.* 1975). The processes of dispersion, wet and dry deposition, and ecosystem water cycling are dominant in producing the patterns of tritium activities observed in the environment (Murphy *et al.* 1975).

Tritiated water behaves much like ordinary water in most environmental systems and has been used extensively to trace water movement. HTO can move directly from the atmosphere into vegetation via exchange processes. Uptake or loss of HTO in leaves is very fast under conditions that promote stomatal opening (high light intensity, low moisture stress). Soil equilibrates with atmospheric HTO more slowly than does vegetation. However, once HTO is in the soil, it is readily absorbed by plant roots and is cycled back to the atmosphere via evapotranspiration. HTO can also re-enter the atmosphere directly by evaporation or move through the soil by diffusion and displacement (Sweet *et al.* 1983).

Atmospheric molecular tritium can also enter soil and vegetation. Micro-organisms in soil readily oxidize HT to HTO in various soils and under a wide range of environmental conditions. Direct oxidation of HT in leaves also takes place, but the amount of HTO formed in this way is small compared to the amount formed in the soil under the canopy (Sweet *et al.* 1983).

A release of HTO to the atmosphere results in higher tritium levels in vegetation relative to the atmospheric activity than a release of HT. However, tritium levels in the atmosphere and in vegetation resulting from an HT release are maintained for a much longer time. The half-life for HT rainout varies from 96 to 136 months (Crawley 1984). Sweet *et al.* found that tritiated water could be detected in pine needles up to 30 days after a release of HT compared to tritium levels that approached background in only 3 days after a comparable release of HTO (Sweet et al. 1983). This may be due to the slower evaporation of deposited HTO from mineral soil.

The movement of tritium through ecological systems is complex and dependent on the medium in which the tritium is fixed. In general, the levels of tritium found in biological systems mirror tritium activities in the surrounding media and concentration factors normally range from zero to slightly larger than one. Adams *et al.* (1979) reported that tritium levels in a contaminated freshwater marsh ecosystem generally followed marsh water tritium levels. Harrison *et al.* (1971) found that both cattails *Typha angustfolia* and filamentous algae *Pithophora sp.* grown in a contaminated pool reached tritium levels from 70 to 100% of the original pool water but no concentration effects were observed.

Tritium levels found in the terrestrial and aquatic environments in 1984 are presented in Table 28. The results indicate that an increase in the tritium activity has been observed in several plant species collected near the NGS. Figure 52 shows tritium activities of samples collected, and the prevailing wind patterns and tritium activities measured at the air monitoring stations in the area for that time of year (June-July). The wind rose indicates that emissions from the NGS would travel in a north northeasterly direction and results from both AMS and biological samples collected show that this occurs. Biological samples collected show tritium activities approaching those measured in the air during the sampling dates, but do not exceed them. Figure 53 shows that the influence of emissions from the NGS does not extend as far as AMS #1 where both the biological samples collected and the AMS data indicated background levels of tritium.

Table 28. Comparison of tritium levels found in aquatic and terrestrial systems.

Species	Date	Sample No.	Component	Site No.	H-3 Bq/ℓ
Pre-operational					
Water	1980-82	-	Water	-	7.5 ± 2.5
Air	1982-82	-	Air	-	6 ± 2
Plants					
Equisetum sp.	1982	-	Total	T-4	4.5 ± 1.6
Iris verisicolor	1982	-	Total	T-5	5.4 ± 1.6
C. rangiferna	1982	-	Total	T-1	3.6 ± 2.2
Sphagnum sp.	1982	-	Total	T-2	6.0 ± 1.6
Alnus rugosa	1982	-	Total	T-5	3.7 ± 1.6
Vaccinium sp.	1982	-	Total	T-10,T-12	4.2 ± 1.3
Post-operational					
Water	1983	-	Water	-	4.2 ± 1.8
Air	1983	-	Air	-	18 ± 1.8
Plants					
Vaccinium sp.	-	-	Total	T-4	7.5 ± 1.8
Typha sp.	-	-	Head	T-3	36.9 ± 2.0
	-	-	Leaves	T-3	17.3 ± 1.8
Golden rod	-	-	Total	T-8	14.2 ± 2.0
	1984				
Water	-	-	Water	-	-
Air	-	-	Air	-	31 ± 61
Plants					
Equisetum sp.	27-06-84	84-1047	Total	T-3	9.5 ± 1.9
	27-06-84	84-1092	Total	T-2	<2
Iris versicolor	27-06-84	84-1042	Total	T-5	4.5 ± 1.9
		84-1098	Total	T-1	<1
Sphagnum sp.	27-06-84	84-1091	Total	T-3	25.6 ± 2.9
	27-06-84	84-1088	Total	T-4	<2
Vaccinium sp.	27-06-84	84-1035	Total	T-4	2.6 ± 1.8
Alnus rugsa		84-1048	Leaf	T-10	<1.5
		84-1089	Leaf	T-4	<1
		84-1049	Leaf	T-2	3.8 ± 1.9
		84-1093	Leaf	T-1	<2
Usnea sp.		84-2507	Total	T-4	9.7 ± 2.6
Animals					
Rana sp.		84-2541	Total	T-5	<3
Fish		84-2546	Total	T-5	<3
Trout		84-2543	Total	T-3	15.8 ± 3

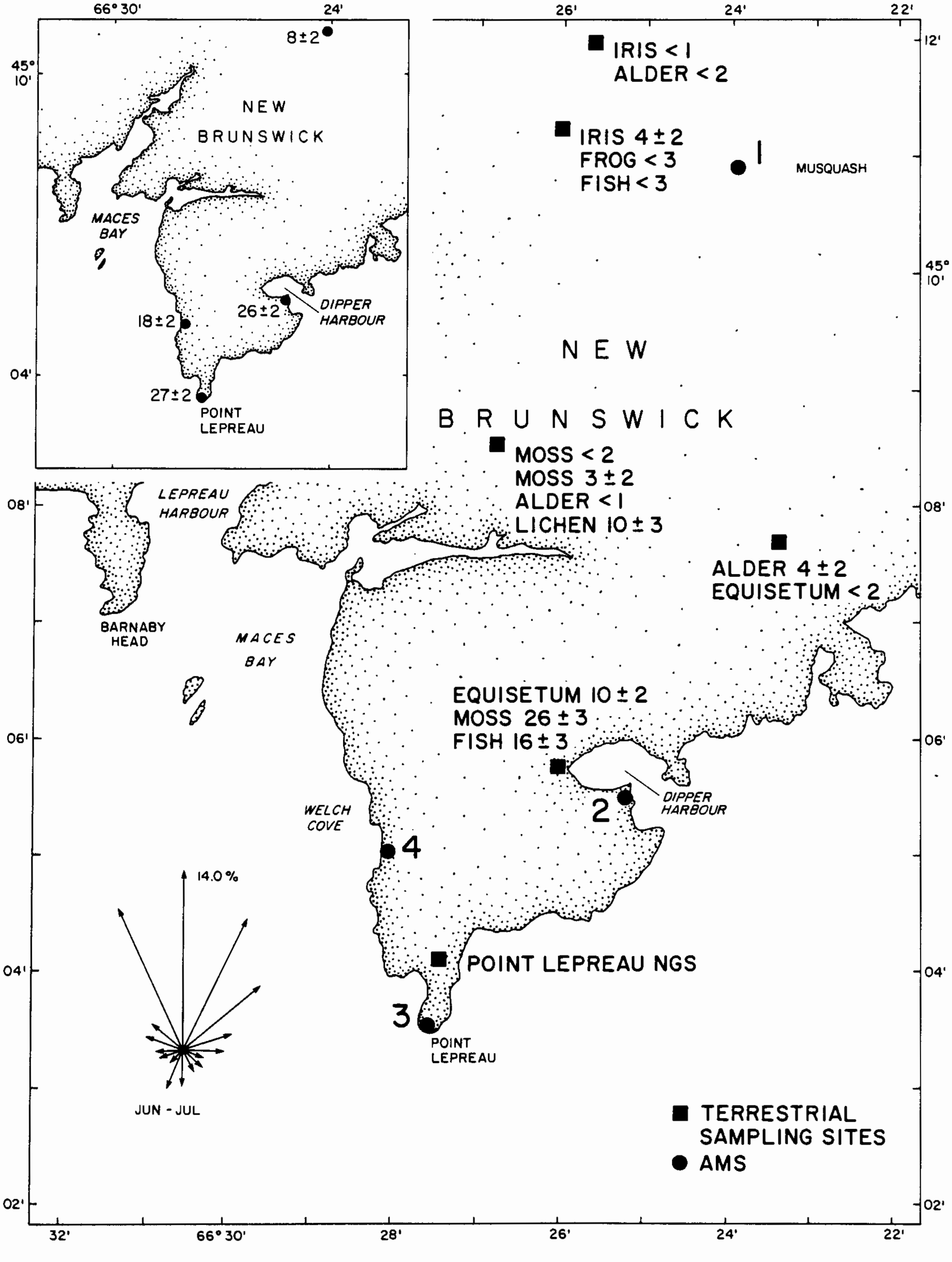

Figure 52. Tritium activities measured in plant samples in the Point Lepreau region.

6.0 LABORATORY INTERCOMPARISON PROGRAM

The AERU laboratory participates in a "blind" laboratory intercomparison study provided by United States Environmental Protection Agency (EPA) in order to maintain a check on the laboratory's analytical precision and accuracy in radionuclide results (Laboratory #IA). The wide range of radionuclide material provided by the EPA is matched for each geometry and matrix used to ensure routine check on all analytical results. This material is also used to check on the internally used standards and blanks. The results of the program are published and distributed to participants throughout United States and Canada by the EPA.

The AERU results for the period 1979 to 1982, are reported in Ellis *et al.* (1984) and Nelson *et al.* (1985). The AERU results for 1984 are listed in Table 29. Values determined by AERU are generally within 2 standard deviation of the EPA's reported values. Tritium in water, Cs-137 in air filters, Sr-90 and I-131 in water are consistently in good agreement with EPA values. As a result of postal delays, some of the short-lived radioisotopes in the mixed gammas in water were below detection limits. However, longer lived radioisotopes showed good results in the same medium. The analysis of Pu-239 and Ra-226 in water was added in 1984 as a result of new analysis carried out in the AERU laboratory. Radium-226 results agreed well with EPA values. The initial Pu-239 analysis revealed a tracer calibration error, which had lead to a low value of Pu-239 in water. This error was corrected and the subsequent analysis gave excellent agreement with the EPA value. The results indicate that there has been no significant problems existing with experimental procedures in operations and values determined by AERU are generally in good agreement with EPA values.

Table 29. Results of AERU Laboratory intercomparison experiments with the Environmental Protection Agency.

Sample Matrix	Collection Date	Nuclide	EPA Value	AERU Value	All Labs Grand Mean	SD AERU Expt.	SD All Labs	AERU/EPA
Water	09-12-83	H-3	2389 pCi/ℓ	2329 pCi/ℓ	2341 pCi/ℓ	36	62	0.97
Water	10-02-84	H-3	2383 pCi/ℓ	2575 pCi/ℓ	2366 pCi/ℓ	47	247	1.08
Water	12-10-84	H-3	2742 pCi/ℓ	2742 pCi/ℓ	2814 pCi/ℓ	83	213	0.98
Air Filter	25-11-83	Cs-137	20 pCi/filter	20 pCi/filter	24 pCi/filter	1	5	1.0
Air Filter	23-03-84	Cs-137	10 pCi/filter	11 pCi/filter	12 pCi/filter	1	3	1.1
Air Filter	24-08-84	Cs-137	15 pCi/filter	15 pCi/filter	17 pCi/filter	1	4	1.0
Air Filter	23-11-84	Cs-137	10 pCi/filter	10 pCi/filter	11 pCi/filter	1	3	1.0
Water	07-12-84	I-131	36 pCi/filter	37 pCi/filter	-	-	-	1.03
Water	06-01-84	Sr-90	24 pCi/ℓ	24 pCi/ℓ	23 pCi/ℓ	1	3	1.00
Water	18-02-84	Sr-90	30 pCi/ℓ	28 pCi/ℓ	28 pCi/ℓ	3	3	0.93
Water	03-03-84	Cs-137	16 pCi/ℓ	12 pCi/ℓ	16 pCi/ℓ	3	3	0.75
Water	01-06-84	Cs-137	37 pCi/ℓ	31 pCi/ℓ	37 pCi/ℓ	1	4	0.84
Water	05-10-84	Cs-137	24 pCi/ℓ	25 pCi/ℓ	25 pCi/ℓ	2	3	1.04
Water	03-02-84	Cs-134	31 pCi/ℓ	26 pCi/ℓ	29 pCi/ℓ	1	3	0.84
Water	01-06-84	Cs-134	47 pCi/ℓ	37 pCi/ℓ	47 pCi/ℓ	2	2	0.79
Water	05-10-84	Cs-134	31 pCi/ℓ	27 pCi/ℓ	29 pCi/ℓ	3	3	0.87
Water	03-02-84	Co-60	10 pCi/ℓ	9 pCi/ℓ	11 pCi/ℓ	2	2	0.90
Water	01-06-84	Co-60	31 pCi/ℓ	27 pCi/ℓ	31 pCi/ℓ	3	4	0.87
Water	05-10-84	Co-60	20 pCi/ℓ	26 pCi/ℓ	20 pCi/ℓ	3	3	1.30
Water	03-02-84	Zn-65	50 pCi/ℓ	41 pCi/ℓ	50 pCi/ℓ	4	8	0.82
Water	01-06-84	Zn-65	62 pCi/ℓ	56 pCi/ℓ	63 pCi/ℓ	3	9	0.89
Water	05-10-84	Zn-65	146 pCi/ℓ	146 pCi/ℓ	149 pCi/ℓ	12	12	1.00
Water	13-07-84	Pu-239	12.5 pCi/ℓ	10.0 pCi/ℓ	11.3 pCi/ℓ	0.1	2.1	0.80
Water	11-01-85	Pu-239	15.7 pCi/ℓ	15.0 pCi/ℓ	15.2 pCi/ℓ	0.1	1.2	0.96
Water	09-03-84	Ra-226	4.1 pCi/ℓ	4.0 pCi/ℓ	3.8 pCi/ℓ	0.3	0.7	0.98
Water	15-06-84	Ra-226	3.5 pCi/ℓ	3.0 pCi/ℓ	3.2 pCi/ℓ	0.4	0.5	0.86
Water	04-09-84	Ra-226	4.9 pCi/ℓ	4.7 pCi/ℓ	4.7 pCi/ℓ	0.2	0.7	0.96

7.0 CONCLUSIONS

(1) 1984 was the second year of the operational program for the Point Lepreau NGS. The overall activity of all nuclides in liquid effluent declined in 1984 from 1.5 x 10^{-3} % DEL to 6 x 10^{-4} % DEL. Releases of I-131 and Ru-103 were reduced by two orders of magnitude while emission rates for Mn-54, Co-60, H-3 and Cr-51 all increased.

(2) The average Cs-137 activity was 3.3 ± 0.6 mBq/ℓ in seawater in the summer of 1984. Tritium activities ranged from <1.5 to 3.0 ± 1.7 Bq/ℓ (avg 2.9 ± 0.6 Bq/ℓ). There was no evidence of increased Cs-137 or tritium activity in the Bay of Fundy due to the Point Lepreau NGS with the exception of tritium close to the outfall during release experiments.

(3) There were no enhanced levels of radionuclides detected in marine sediments sampled in the Point Lepreau area.

(4) A thermal plume study was conducted during the summer of 1984 under various tidal conditions and including planned releases. Results indicate the existance of a back eddy set up during the rising tide that transports effluents into Duck Cove and then out of the Bay of Fundy. Observed temperature increases were within those predicted, however the surface extent of the plume, which reaches maximums in the eddies set up at half tide rising and falling is slightly larger than might have been anticipated from previously available information.

(5) Average tritium levels in air moisture on the peninsula of Point Lepreau increased for the second year, up to 31 Bq/ℓ (range 2.5 to 36.4 Bq/ℓ) from 18 Bq/ℓ in 1983. This increase in the tritium signal observed in the Point Lepreau area occurs only at those sites close to the NGS. At sites located further away, tritium activities remained at background levels. Comparison of AERU results with those from NBEPC and Health and Welfare Canda showed good agreement.

(6) Levels of fallout radionuclides measured in air particulate material were below AERU detection limits for 1984.

(7) Levels of radionuclides found in marine systems showed no increase over pre-operational levels. Tritium levels in shell material were again found to be 2 to 3 times higher than water tritium activities. Estimated radionuclide concentrations in marine organisms using effluent release data, approximate dilution factors and K_D values for various marine organisms indicate that radionuclides released from the NGS should be below AERU detection limits in the major groups of marine organisims sampled.

(8) Levels of radionuclides measured in aquatic and terrestrial animal and plant samples show no increase over pre-operational levels. Radionuclide levels in *C. Arbucula* showed little change from 1983. Aerial lichen *Usnea sp.* was sampled for the first time and showed consistantly lower levels of Cs-137 than *C. arbuscula*. A direct correlation was observed between Cs-137 content in *C. arbuscula* and rainfall, but was not observed for *Usnea sp.*

(9) An increase in tritium levels in several vegetation samples located close to the NGS was observed. Tritium levels in several samples approached those measured in the atmosphere when plant samples were collected but did not exceed them. The influence of atmospheric tritium releases on tritium levels in flora was localized and did not extend as far AMS #1 located in Musquash.

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Appendix 1

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Appendix 2

Conversion factors for different radioactivity units.

1 Becquerel (Bq) = 2.7 x 10^{-11} Curies (Ci)

1 Bq = 27 pCi

1 Bq = 60 dpm

1 Bq/l = 8.3 Tritium Units (TU)

1 Ci = 3.7 x 10^{10} Bq

1 mCi = 3.7 x 10^{7} Bq

1 psCi = 3.7 sx 10^{-2} Bq

1 dpm = 0.0167 Bq

1 dpm = 0.45 pCi

1 TU = 0.12 Bq/l

1 TU = 7.2 dpm/l

1 TU = 3.2 pCi/l

Appendix 3

Detection limits (Bq/kg) for each radionuclide and geometry assuming a counting time of 10^5 s for analyses performed one month subsequent to sample collection. Detection limit for specific sample is determined by choosing detection limit for a radionuclide for the appropriate geometry and dividing by the sample weight. These estimates are approximate and will vary depending upon the specific counting times and delay between sample collection and analysis.

Nuclide	Half-life	Geometry 1	Geometry 2	Geometry 3	Geometry 4	Geometry 5
Ag-110 m	253.0 d	150	94	95	95	47
Ba-140	12.8 d	1700	1700	1000	1000	490
Be-7	53.6 d	1100	1200	690	670	370
Ce-141	32.4 d	280	330	170	140	110
Ce-144	284.0 d	780	900	460	400	200
Co-56	77.0 d	130	140	90	90	40
Co-57	270.0 d	110	130	63	54	35
Co-58	71.0 d	130	140	77	78	39
Co-60	5.26 y	120	120	65	69	35
Cr-51	28.0 d	1700	1800	1100	1001	570
Cs-134	2.07 y	110	120	69	69	33
Cs-137	30.2 y	107	100	62	60	31
Eu-152	12.5 y	660	690	410	410	200
Eu-155	1.81 y	300	340	160	160	69
Fe-59	44.6 y	340	330	190	200	89
I-131	8.06 d	1200	1400	780	750	410
La-140	40.2 h	510	510	340	360	190
Mn-54	313.0 d	110	110	67	65	31
Nb-95	35.1 d	180	180	110	110	54
Ru-103	39.6 d	150	160	93	92	46
Ru-106	1.0 y	900	940	540	550	250
Sb-124	60.2 d	18	20	11	11	6
Sb-125	2.7 y	240	260	150	147	73
Zn-65	244.0 d	290	260	140	150	73
Zr-95	64.0 d	140	240	150	150	70

Appendix 3

Detection limits (Bq/kg) for each radionuclide and geometry assuming a counting time of 10^5 s for analyses performed one year subsequent to sample collection.

Nuclide	Half-life	Geometry 1	Geometry 2	Geometry 3	Geometry 4	Geometry 5
Ag-110 m	253.0 d	380	410	240	240	120
Ba-140	12.8 d	-	-	-	-	-
Be-7	53.6 d	-	-	-	-	-
Ce-141	32.4 d	-	-	-	-	-
Ce-144	284.0 d	1700	2000	1000	890	660
Co-56	77.0 d	2600	2800	1600	1600	750
Co-57	270.0 d	250	300	150	140	82
Co-58	71.0 d	3400	3400	1900	1900	980
Co-60	5.26 y	130	130	74	78	40
Cr-51	28.0 d	-	-	-	-	-
Cs-134	2.07 y	150	160	93	940	45
Cs-137	30.2 y	110	110	63	61	32
Eu-152	12.5 y	700	720	440	430	200
Eu-155	1.81 y	420	480	220	230	98
Fe-59	44.6 y	57000	56000	32000	30000	15000
I-131	8.06 d	-	-	-	-	-
La-140	40.2 h	-	-	-	-	-
Mn-54	313.0 d	230	230	140	135	65
Nb-95	35.1 d	-	-	-	-	-
Ru-103	39.6 d	49000	53000	31000	3000	15000
Ru-106	1.0 y	1700	1800	1000	1000	470
Sb-124	60.2 d	800	880	500	490	250
Sb-125	2.7 y	300	330	180	180	91
Zn-65	244.0 d	730	680	370	383	190
Zr-95	64.0 d	7900	8200	4900	4900	2400