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A survey of tritium in sea water in Tees Bay, July 1986

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SUMMARY

A survey of tritium in sea water in Tees Bay in July 1986 is described. The survey was carried out by taking one litre water samples from shoreline and offshore positions after a discharge had taken place from the Hartlepool nuclear power station. The concentrations decreased quickly in time and the peak value measured is shown to be insignificant in terms of radiation exposure of the public. The prevailing wind conditions had a significant effect on the dispersion of tritium.

1. INTRODUCTION

This report describes the methods and results from a survey of tritium in sea water in Tees Bay in July 1986. Tritium is of particular interest in this area because of discharges into the sea from the nuclear power station at the mouth of the River Tees (see Figure 1). Hartlepool nuclear power station is an Advanced Gas-Cooled Reactor (AGR) which is authorised to dispose of up to 1850 TBq of tritium to sea each year. In numerical terms, this is a relatively large quantity of activity and can be compared with the authorisations of 4 and 7.5 TBq per year for 'total activity excluding tritium and sulphur-35' and 'sulphur-35' respectively at the same site. However, such comparisons are misleading in isolation because they do not reflect the radiological significance of the discharges. In the case of tritium, the consequences of discharge are minor because of the very low radiotoxicity of the nuclide. This subject is taken up in more detail in Section 5 of this report.

The report begins with a section providing details of the survey methods which involved water sampling at shoreline and offshore positions throughout the Bay over a three-day period. The analytical method is described briefly and followed by the results of the survey including maps of the distribution of tritium as a function of time. Consideration of how the measured values agree with predictions based on a simple tidal dispersion model is included in Section 5.

2. FIELD SURVEY

The bulk of tritium requiring disposal to sea from AGRs is collected on site from cooling gas driers. It is collected in its liquid form as water in tritiated water storage tanks (TWSTs) and discharged periodically. The periodicity will vary according to the power of the reactors, because tritium waste is generated whilst the reactors are producing power. As an approximation, however, it can be assumed that a tritium discharge will be made every month or so.

The discontinuous nature of the discharge dictates that special monitoring techniques are required to assess the effects of releases. The results of infrequent monitoring would be susceptible to large random fluctuations in environmental processes, in particular to the weather, which could be difficult to interpret. For this reason, it was thought necessary to extend our normal monitoring programme for the site and to focus on one discharge event for this radionuclide. The normal programme and its results are described by Hunt (1989).

Arrangements were made with the site operators, the Central Electricity Generating Board (CEGB), to give us prior notice of the requirement to make a TWST discharge. A survey team of four staff was assembled and equipped with an inflatable boat with outboard motor, a seawater temperature and depth measuring device, a Nansen sampling device, VHF radios and one-litre collection bottles.

It was recognised, at the outset, that the fate of the radionuclide discharged would be difficult to predict with any certainty because of variable environmental conditions, and that wind speed and direction would be important factors influencing the dispersion pattern. Nevertheless, a rough idea of the likely extent of the movement of the patch of tritium was derived from tidal velocity data from Admiralty Chart 2567 (Hydrographer of the Navy, 1978).

The two nearer tidal stations are shown in Figure 2 and tidal cycle progressive vector diagrams are plotted in Figure 3 for spring and neap conditions at both stations. Tidal stream data are reproduced in Table 1. These suggest that the extent of movement of the patch of tritium in the early days after release would be likely to be within the confines of Tees Bay. Given that the discharge would be taking place shortly after high water when the tidal stream would be approximately NNW, a pattern of sampling stations was devised running from approximately 3 km south of the release point. The release point is on Ordnance Survey 1:50 000 series sheet 93 at 539 (easting) 290 (northing)(Ordnance Survey, 1988). The stations sampled from the boat were within the Bay on an approximately 1 kilometre grid and shoreline stations stretched from Hartlepool town in the north to the inner Tees mouth in the south. The sampling stations used during the survey are numbered and shown in Figure 4.

Staff travelled to Hartlepool on 14 July 1986 to prepare for a release expected after high water at about midday on 16 July. Shoreline stations were visited and ease of access was confirmed during the afternoon and evening of 14 July. The tide times over the three-day survey period are shown in Table 2. During this period there were neap tides.

2.1 15 July 1986

The following day, offshore stations were fixed and marked, where necessary, with Dahn buoys. Offshore positions were generally established using protractor bearings read from fixed shoreline positions. However, the more distant offshore stations proved difficult to position when mist obscured the boat from the shoreline. In these cases, compass bearings were taken from the boat on conspicuous landmarks to establish positions. Existing channel buoys and a reef buoy were used for stations 18, 23 and 26.

One-litre surface water samples were collected from five offshore stations to establish whether there was any measurable background of tritium prior to the discharge. Throughout the survey and during subsequent storage prior to analysis, glass bottles were used to minimise the possibility of tritium egress. When sampling, care was taken to avoid cross-contamination due to splashing and, after sampling, each bottle was sealed inside a polythene bag before storage. A log of sample number, depth, time and position was kept and each bottle was clearly labelled. Results of samples taken throughout the three-day period are recorded in Table 3. All times in this report refer to British Summer Time unless stated otherwise.

The VHF radio communications with the power station staff were tested and earlier arrangements for prior notification of the exact time of release were confirmed.

2.2 16 July 1986

Communications with the power station staff were checked at 0900 h and found to be satisfactory.

The day's sampling from the boat began at about 1100 h (high water) directly above the discharge point immediately before the discharge was to take place. This was repeated at approximately fifteen-minute intervals until the release was expected to have cleared itself from the pipeline. Samples were taken at this station (27) in surface waters and at 1 m above the sea bed and, at the same time, shoreline samples were collected close to the outfall (stations 6-9).

At about 1230 h, both the offshore and shoreline staff began to move throughout the survey area, sampling surface sea water at the pre-arranged stations and taking bottom water samples at a few locations (stations 27, 24, 30). The latter were collected 1 m above the sea bed using a Nansen reversing bottle with messenger triggering. Sampling continued until 1830 h (one hour after low water) and, during this period, three 'sweeps' of the boat and shoreline stations were made at about high-, mid- and low- water periods.

2.3 17 July 1986

Sampling commenced at midday (high water) and was repeated at low water, finishing at about 2100 h.

2.4 18 July 1986

All offshore gear was retrieved and multiple bearings were taken at each station, as additional positional checks to be charted on return to the laboratory. The gear was packed and a 900 ml sample of the effluent discharged from the TWST was collected from the power station.

3. SAMPLE ANALYSIS

The glass bottles containing the sea-water samples were returned to the Lowestoft laboratory of The Directorate of Fisheries Research for analysis of their tritium content. Because of the pressure of work from the aftermath of the contemporary Chernobyl accident, some of the samples were not analysed. Of the 169 samples taken, 41 were not analysed.

The method used to analyse the sea-water samples was to double distil and count using a liquid scintillant. The steps are, briefly, as follows:

a) approximately half fill a 250 ml boiling flask with sea water and add anti-bump granules;

b) distil to dryness and collect the distillate;

c) add small quantities of 'hold back carriers' (sodium hydroxide, sodium metabisulphite and sodium iodide) to the distillate;

d) distil to dryness and collect the distillate;

e) add 9 ml of the second distillate to 10 ml of the liquid scintillant LUMAGEL;

f) count for 500 minutes on an INTERTECHNIQUE SL30 liquid scintillation spectrometer using a calibration standard.

The limit of detection of the method is approximately 4 Bq l^{-1}.

4. RESULTS

The measured concentrations of tritium in sea water are given in Table 3 with their associated counting errors. Tritium was not detected in the majority of the samples analysed, including the 'background' samples taken on the day before the discharge took place. If we neglect the effect of previous discharges from the power station, we can expect that the true background concentration would be significantly less than 1 Bq l^{-1} in this area, because concentrations in 1980/81 were about this level (Wedekind, 1982) and the combined inputs from fallout from weapons testing, natural production and nuclear industry discharges had decreased by 1986.

Thirty four of the 128 samples analysed contained tritium at concentrations ranging from 4 Bq l^{-1} to over 100 000 Bq l^{-1}. However, the majority of those samples with detectable levels of tritium were at concentrations below 100 Bq l^{-1}.

5. DISCUSSION

The details of the quantities discharged and times of disposal, as provided by the CEGB, are shown in Table 4. The TWST discharge began at 1110 h and finished 20 minutes later. The power station was 'off-load' at the time and the discharge was, therefore, at ambient temperature. In addition to the TWST discharge, there was also a tritium discharge from the Final Monitoring and Delay Tank (FMDT) immediately after completion of TWST emptying. The quantity of tritium discharged from the FMDT was trivial and will not be considered further.

The concentration of TWST tritium in the cooling water would have been about 3 10^5 Bq l^{-1} assuming continuous and uniform mixing in the cooling water. The results of the sea-water analyses (Table 3) show that there was no detectable tritium in bottom water at the outfall before 1137 h and in surface water before 1134 h. The release was first detected at 1155 h at a sea-water concentration of 1.25 10^5 Bq l^{-1}. Thus, it appears that there was no significant dilution in sea water at the outfall whilst the discharge was taking place.

The time dependence of the tritium concentrations is shown on maps of Tees Bay in Figure 5(a-c) for the following three time periods:

i) Figure 5 (a): 1100-1500 h on 16 July 1986, i.e. from high water to three hours before low water (before, during and following the discharge);

ii) Figure 5 (b): 1500-1900 h on 16 July 1986, i.e. from three hours before to one hour after low water; and

iii) Figure 5 (c): 1145-2100 h on 17 July 1986, i.e. from one hour before high water to two hours after low water.

All of the results shown are for surface samples except those marked with 'B'; the latter were taken from 1 m above the sea bed. Seven out of eleven bottom water samples contained concentrations similar to those of surface waters collected at about the same time. However, the data are limited and do not offer strong evidence for the presence, or absence, of vertical mixing in the Bay during the experiment. The distinct difference between samples from station 27 collected at 1208 h in surface waters and 1212 h in bottom waters (3.8m) immediately after the discharge, could have been due to the spreading of the patch horizontally.

Figures 6 and 7 show progressive vector diagrams for neap tides beginning at 1200 h on 16 July 1986, i.e. immediately following completion of the discharge. The progression starts at the outfall and the vectors are plotted for three consecutive tides taking the plot to low water at 1758 h on 17 July 1986. Two plots are provided, one for the mean of tidal data for stations A and B and the other for station B on its own. Station B is nearest to the outfall. Both sets of tidal data are normalised in direction such that the dominant flow direction is parallel to the coast at the outfall.

The plots for the two sets of data are similar, showing an 'elliptical' range of about 5 km in the coastal direction (approximately NNW) with a small (less than 2 km) minor axis at 90° to the coast.

It is interesting to compare the observed spreading of the tritium patch with the predicted movement from the tidal plots. The initial spread of the patch is shown in Figure 5 and can be seen to be limited to the immediate vicinity of the outfall, with the exception of the results for stations 1 and 4 which indicate a possible south-easterly streak. The errors on these data are 46% and 41% respectively and they do not, therefore, provide a firm basis from which to draw conclusions. With the exception of the data for stations 1 and 4, the results are in good agreement with the predictions within the constraints of the survey grid and timing.

As the day progressed, it can be seen that the patch spread northwards from the outfall and by low water was north of Tees Bay. The northward progression of the patch was approximately twice as far as the tidal data would suggest.

On 17 July 1986, from the beginning of high water up until low water on the third tide after release, the levels of tritium were low, at no more than 25 Bq l^{-1} and were spread extensively to the east. Indeed, it is possible that higher concentrations could have been present outside the sampling area.

The prevailing wind conditions shown in Table 5 offer an explanation for the movement of the patch, which was more extensive than that predicted by the tidal data. Whilst calm conditions existed on 15 July, the wind freshened on 16 July and on 17 July was significantly above average for the eastern seaboard. The winds were mainly from the south-west but varied from 200° at the time of release on 16 July to 280° (i.e. offshore) for much of the period of the 'third tide' on 17 July.

5.1 Radiological impact

Tritium is a low energy electron emitter with a low toxicity of 1.7 10^{-11} Sv Bq^{-1} ingested (Kendall *et al.*, 1987). If an individual were at the outfall at the time when the discharge was taking place he/she would have had to drink over 2 000 litres of sea water in order to receive the ICRP dose limit of 5 mSv $year^{-1}$. In the extremely unlikely event that fish were in dynamic equilibrium with sea water at this concentration, then a similar quantity of fish would have to be consumed to reach the same level of dose rate.

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TABLE 1. Tidal stream data from Admiralty Chart 2567 (Hydrographer of the Navy, 1978).

	Time	Station 'A' 54°46.5'N 1°14.6'W			Station 'B' 54°41.3'N 1°10.0'W		
		Direction	Speed Spring	Knots Neap	Direction	Speed Spring	Knots Neap
Hrs before HW	6	346	0.3	0.1	- - - - - - - Slack - - - -		
	5	40	0.1	0.1	163	0.2	0.1
	4	165	0.2	0.1	198	0.6	0.3
	3	165	0.5	0.2	200	1.0	0.5
	2	163	0.6	0.3	194	0.8	0.4
	1	161	0.5	0.2	179	0.5	0.2
	HW	152	0.3	0.1	123	0.2	0.1
Hrs after HW	1	- - - - - - - Slack - - - -			53	0.3	0.2
	2	348	0.2	0.1	17	0.4	0.2
	3	335	0.4	0.2	12	0.6	0.3
	4	331	0.6	0.3	5	0.6	0.3
	5	336	0.6	0.3	353	0.6	0.3
	6	339	0.4	0.2	321	0.3	0.1

TABLE 2. Tide times at Middlesborough, 15-17 July 1986 (Anon, 1985).

Tide	Time GMT*	Date
Low	1537	15 July 1986
High	2157	"
Low	0355	16 July 1986
High	1010	"
Low	1645	"
High	2304	"
Low	0509	17 July 1986
High	1126	"
Low	1758	"

*To convert to BST add one hour.

TABLE 3. Results from the Hartlepool tritium survey, July 1986.

Stn.	Position		Concen-	LSN	Sample	Bottle	Time 1	Time 2	Date
	Latitude	Longitude	tration (Bql^{-1})		depth				
1	54 38.1 0	01 07.2 1	6.4+/-46%	6742	S	57	38.33	14.20	16
1	54 38.1 0	01 07.2 1	0.0	6747	S	62	40.85	16.51	16
1	54 38.1 0	01 07.2 1	0.0	6751	S	66	42.02	18.01	16
1	54 38.1 0	01 07.2 1	0.0	6830	S	206	61.17	13.10	17
1	54 38.1 0	01 07.2 1	0.0	6835	S	211	67.25	19.15	17
2	54 38.8 0	01 08.1 1	0.0	6741	S	56	37.78	13.47	16
2	54 38.8 0	01 08.1 1	0.0	6746	S	61	40.25	16.15	16
2	54.38.8 0	01 08.1 1	0.0	6750	S	65	41.45	17.27	16
2	54 38.8 0	01 08.1 1	0.0	6828	S	204	60.40	12.24	17
2	54 38.8 0	01 08.1 1	0.0	6833	S	209	66.77	18.46	17
3	54 38.8 0	01 08.2 1	0.0	6740	S	55	37.85	13.51	16
3	54 38.8 0	01 08.2 1	0.0	6745	S	60	40.37	16.22	16
3	54 38.8 0	01 08.2 1	0.0	6749	S	64	41.60	17.36	16
3	54 38.8 0	01 08.2 1	0.0	6829	S	205	60.67	12.40	17
3	54 38.8 0	01 08.2 1	0.0	6834	S	210	66.87	18.52	17
4	54 38.4 0	01 08.4 1	7.3+/-41%	6739	S	54	37.50	13.30	16
4	54 38.4 0	01 08.4 1	0.0	6744	S	59	39.88	15.53	16
4	54 38.4 0	01 08.4 1	0.0	6748	S	63	41.20	17.12	16
4	54 38.4 0	01 08.4 1	0.0	6827	S	203	60.35	12.21	17
4	54 38.4 0	01 08.4 1	0.0	6832	S	208	66.53	18.32	17
5	54 37.7 0	01 09.0 1	0.0	6743	S	58	39.13	15.08	16
5	54 37.7 0	01 09.0 1	0.0	6752	S	67	42.58	18.35	16
5	54 37.7 0	01 09.0 1	0.0	6831	S	207	62.03	14.02	17
5	54 37.7 0	01 09.0 1	0.0	6836	S	212	68.05	20.03	17
6	54 38.9 0	01 09.4 1	0.0	6686	S	2	35.40	11.24	16
6	54 38.9 0	01 09.4 1	0.0	6688	S	4	35.68	11.41	16
6	54 38.9 0	01 09.4 1	0.0	6690	S	6	35.98	11.59	16
6	54 38.9 0	01 09.4 1	0.0	6692	S	8	36.30	12.18	16
6	54 38.9 0	01 09.4 1	0.0	6795	S	115	40.15	16.09	16
6	54 38.9 0	01 09.4 1	0	6790	S	110	41.33	17.20	16
6	54 38.9 0	01 09.4 1	0	6716	S	32	60.27	12.16	17
6	54 38.9 0	01 09.4 1	0	6840	S	228	66.80	18.48	17
7	54 38.9 0	01 09.7 1	0.0	6685	S	1	35.22	11.13	16
7	54 38.9 0	01 09.7 1	0.0	6687	S	3	35.55	11.33	16
7	54 38.9 0	01 09.7 1	0.0	6689	S	5	35.83	11.50	16
7	54 38.9 0	01 09.7 1	0.0	6691	S	7	36.13	12.08	16
8	54 38.9 0	01 09.8 1	0.0	6698	S	14	35.32	11.19	16
8	54 38.9 0	01 09.8 1	0.0	6700	S	16	35.50	11.30	16
8	54 38.9 0	01 09.8 1	0.0	6702	S	18	35.78	11.47	16
8	54 38.9 0	01 09.8 1	0.0	6704	S	20	36.02	12.01	16
8	54 38.9 0	01 09.8 1	0.0	6706	S	22	36.28	12.17	16
8	54 38.9 0	01 09.8 1	0.0	6708	S	24	36.52	12.31	16
9	54 39.0 0	01 10.0 1	0.0	6897	S	13	35.25	11.15	16
9	54 39.0 0	01 10.0 1	0.0	6699	S	15	35.42	11.25	16
9	54 39.0 0	01 10.0 1	0.0	6701	S	17	35.67	11.40	16
9	54 39.0 0	01 10.0 1	20.5+/-14%	703	S	19	35.92	11.55	16
9	54 39.0 0	01 10.0 1	7.7+/-38%	6705	S	21	36.17	12.10	16
9	54 39.0 0	01 10.0 1	7.3+/-41%	6707	S	23	36.42	12.25	16
9	54 39.0 0	01 10.0 1	0.0	6794	S	114	40.10	16.06	16
9	54 39.0 0	01 10.0 1	0.0	6787	S	107	41.12	17.07	16
9	54 39.0 0	01 10.0 1	9.5+/-24%	6693	S	9	60.30	12.18	17
9	54 39.0 0	01 10.0 1	11.8+/-2.3%	6837	S	225	66.63	18.38	17

TABLE 3. Continued.

Stn.	Position		Concen-tration (Bql^{-1})	LSN	Sample depth	Bottle	Time 1	Time 2	Date
	Latitude	Longitude							
10	54 39.5 0	01 10.7 1	0.0	6709	S	25	37.25	13.15	16
10	54 39.5 0	01 10.7 1	6.9+/-43%	6713	S	29	39.87	15.52	16
10	54 39.5 0	01 10.7 1	11.8+/-25%	6717	S	33	41.38	17.23	16
10	54 39.5 0	01 10.7 1	0	6729	S	42	59.77	11.46	17
10	54 39.5 0	01 10.7 1	0	6725	S	38	66.67	18.40	17
11	54 39.7 0	01 10.8 1	0	6710	S	26	37.57	13.34	16
11	54 39.7 0	01 10.8 1	0	6714	S	30	40.25	16.15	16
11	54 39.7 0	01 10.8 1	0	6718	S	34	41.73	17.44	16
11	54 39.7 0	01 10.8 1	0	6728	S	41	61.15	13.09	17
11	54 39.7 0	01 10.8 1	0	6724	S	37	66.97	18.58	17
12	54 40.8 0	01 11.8 1	0	6711	S	27	38.00	14.00	16
12	54 40.8 0	01 11.8 1	0	6715	S	31	40.50	16.30	16
12	54 40.8 0	01 11.8 1	0	6719	S	35	42.00	18.00	16
12	54 40.8 0	01 11.8 1	0	6727	S	40	61.40	13.24	17
12	54 40.8 0	01 11.8 1	0	6730	S	43	67.28	19.17	17
13	54 41.3 0	01 11.5 1	0	6712	S	28	38.53	14.32	16
13	54 41.3 0	01 11.5 1	0	6720	S	36	42.57	18.34	16
13	54 41.3 0	01 11.5 1	0	6726	S	39	61.65	13.39	17
13	54 41.3 0	01 11.5 1	0	6331	S	44	67.62	19.37	17
14	54 41.5 0	01 10.3 1	0.0	6776	S	96	38.50	14.30	16
14	54 41.5 0	01 10.3 1	0	6798	S	118	61.83	13.50	17
14	54 41.5 0	01 10.3 1	0	6857	S	245	68.53	20.32	17
15	54 41.4 0	01 09.9 1	0.0	6774	S	94	38.28	14.17	16
15	54 41.4 0	01 09.9 1	167.0+/-1.6%	6813	S	133	42.63	18.38	16
15	54 41.4 0	01 09.9 1	0.0	6815	S	136	61.63	13.38	17
15	54 41.4 0	01 09.9 1	0	6856	S	244	68.42	20.25	17
16	54 41.4 0	01 09.3 1	0.0	6775	S	95	38.40	14.24	16
16	54 41.4 0	01 09.3 1	0	6799	S	119	61.73	13.44	17
16	54 41.4 0	01 09.3 1	0	6855	S	243	68.23	20.14	17
17	54 40.8 0	01 10.6 1	0.0	6734	S	49	18.00	18.00	15
17	54 40.8 0	01 10.6 1	0.0	6777	S	97	38.63	14.38	16
17	54 40.8 0	01 10.6 1	0.0	6786	S	106	40.83	16.50	16
17	54 40.8 0	01 10.6 1	0.0	6812	S	132	42.55	18.33	16
17	54 40.8 0	01 10.6 1	21.1+/-9.5%	6824	S	200	61.93	13.56	17
17	54 40.8 0	01 10.6 1	0	6858	S	246	68.67	20.40	17
18	54 40.8 0	01 09.8 1	0.0	6773	S	93	38.22	14.13	16
18	54 40.8 0	01 09.8 1	564.0+/-0.7%	6785	S	105	40.77	16.46	16
18	54 40.8 0	01 09.8 1	97.2+/-2.7%	6810	S	131	42.47	18.28	16
18	54 40.8 0	01 09.8 1	0.0	6821	S	142	61.52	13.31	17
18	54 40.8 0	01 09.8 1	0	6853	S	241	67.97	19.58	17
19	54 40.8 0	01 08.8 1	0	6854	S	242	68.03	20.02	17
20	54 40.2 0	01 10.6 1	0.0	6772	S	92	38.08	14.05	16
20	54 40.2 0	01 10.6 1	31.0+/-7.6%	6783	S	103	40.65	16.39	16
20	54 40.2 0	01 10.6 1	22.6+/-8.9%	6811	S	130	42.20	18.12	16
20	54 40.2 0	01 10.6 1	24.2+/-8.4%	6825	S	201	61.43	13.26	17
20	54 40.2 0	01 10.6 1	0	6852	S	240	67.85	19.51	17
21	54 40.2 0	01 09.7 1	0.0	6771	S	91	38.03	14.02	16
21	54 40.2 0	01 09.7 1	0.0	6784	S	104	40.70	16.42	16
21	54 40.2 0	01 09.7 1	0.0	6809	S	129	42.00	18.00	16
21	54 40.2 0	01 09.7 1	12.0+/-19%	6695	S	11	61.28	13.17	17
21	54 40.2 0	01 09.7 1	0	6851	S	239	67.78	19.47	17
22	54 40.4 0	01 09.0 1	0.0	6770	S	90	37.97	13.58	16

TABLE 3. Continued.

Stn.	Position		Concen-tration (Bql^{-1})	LSN	Sample depth	Bottle	Time 1	Time 2	Date
	Latitude	Longitude							
22	54 40.4 0	01 09.0 1	0.0	6805	S	125	41.70	17.42	16
22	54 40.4 0	01 09.0 1	7.5+/-26%	6814	S	135	61.20	13.12	17
22	54 40.4 0	01 09.0 1	0	6850	S	238	67.72	19.43	17
23	54 39.8 0	01 07.6 1	0.0	6769	S	89	37.87	13.52	16
23	54 39.8 0	01 07.6 1	0.0	6780	S	100	40.38	16.23	16
23	54 39.8 0	01 07.6 1	0.0	6804	S	124	41.60	17.36	16
23	54 39.8 0	01 07.6 1	10.7+/-18%	6818	S	139	61.05	13.03	17
23	54 39.8 0	01 07.6 1	0	6849	S	237	67.52	19.31	17
24	54 39.7 0	01 09.7 1	0	6738	S	53	18.00	18.00	15
24	54 39.7 0	01 09.7 1	0.0	6765	S	85	37.57	13.34	16
24	54 39.7 0	01 09.7 1	5.0+/-42%	6766	B	86	37.63	13.38	16
24	54 39.7 0	01 09.7 1	0.0	6782	S	102	40.57	16.34	16
24	54 39.7 0	01 09.7 1	0.0	6807	B	127	41.90	17.54	16
24	54 39.7 0	01 09.7 1	0.0	6808	S	128	41.92	17.55	16
24	54 39.7 0	01 09.7 1	15.4+/-15%	6800	S	120	60.75	12.45	17
24	54 39.7 0	01 09.7 1	15.0+/-13%	6819	B	140	60.80	12.48	17
24	54 39.7 0	01 09.7 1	0	6845	S	233	67.17	19.10	17
24	54 39.7 0	01 09.7 1	0	6846	B	234	67.22	19.13	17
25	54 39.6 0	01 08.8 1	0.0	6767	S	87	37.72	13.43	16
25	54 39.6 0	01 08.8 1	0.0	6781	S	101	40.48	16.29	16
25	54 39.6 0	01 08.8 1	0.0	6806	S	126	41.82	17.49	16
25	54 39.6 0	01 08.8 1	15.8+/-13	6817	S	138	60.93	12.56	17
25	54 39.6 0	01 08.8 1	0	6847	S	235	67.32	19.19	17
26	54 39.4 0	01 08.1 1	0.0	6768	S	88	37.78	13.47	16
26	54 39.4 0	01 08.1 1	0.0	6779	S	99	40.33	16.20	16
26	54 39.4 0	01 08.1 1	0.0	6803	S	123	41.55	17.33	16
26	54 39.4 0	01 08.1 1	22.1+/-9.1%	6822	S	143	60.98	12.59	17
26	54 39.4 0	01 08.1 1	0	6848	S	236	67.42	19.25	17
27	54 39.2 0	01 09.8 1	0.0	6735	S	50	18.00	18.00	15
27	54 39.2 0	01 09.8 1	0.0	6753	S	73	35.23	11.14	16
27	54 39.2 0	01 09.8 1	0.0	6754	S	74	35.42	11.25	16
27	54 39.2 0	01 09.8 1	0.0	6755	S	75	35.57	11.34	16
27	54 39.2 0	01 09.8 1	0.0	6756	B	76	35.62	11.37	16
27	54 39.2 0	01 09.8 1	125000.0+/-0.0%	6757	S	77	35.92	11.55	16
27	54 39.2 0	01 09.8 1	2160.0+/-0.4%	6758	S	78	36.13	12.08	16
27	54 39.2 0	01 09.8 1	266.0+/-2.4%	6759	B	79	36.20	12.12	16
27	54 39.2 0	01 09.8 1	81.0+/-3.1%	6760	S	80	36.42	12.25	16
27	54 39.2 0	01 09.8 1	0.0	6793	S	113	40.03	16.02	16
27	54 39.2 0	01 09.8 1	0.0	6788	S	108	41.17	17.10	16
27	54 39.2 0	01 09.8 1	0.0	6789	B	109	41.27	17.16	16
27	54 39.2 0	01 09.8 1	0.0	6696	S	12	60.33	12.20	17
27	54 39.2 0	01 09.8 1	6.9+/-29%	6816	B	137	60.42	12.25	17
27	54 39.2 0	01 09.8 1	0.0	6838	S	226	66.68	18.41	17
27	54 39.2 0	01 09.8 1	0.0	6839	B	227	66.77	18.46	17
28	54 39.0 0	01 09.4 1	0.0	6736	S	51	18.00	18.00	15
28	54 39.0 0	01 09.4 1	4.4+/-47%	6761	S	81	36.92	12.55	16
28	54 39.0 0	01 09.4 1	0.0	6796	S	116	40.18	16.11	16
28	54 39.0 0	01 09.4 1	4.2+/-46%	6820	S	141	60.48	12.29	17
28	54 39.0 0	01 09.4 1	0	6841	S	229	66.85	18.51	17

TABLE 3. Continued.

Stn.	Position		Concen-tration (Bql^{-1})	LSN	Sample depth	Bottle	Time 1	Time 2	Date
	Latitude	Longitude							
29	54 39.3 0	01 09.2 1	0	6737	S	52	8.00	18.00	15
29	54 39.3 0	01 09.2 1	5.0+/-42%	6764	S	84	37.50	13.30	16
29	54 39.3 0	01 09.2 1	0.0	6778	S	98	40.28	16.17	16
29	54 39.3 0	01 09.2 1	0.0	6792	S	112	41.38	17.23	16
29	54 39.3 0	01 09.2 1	7.3+/-30%	6694	S	10	60.67	12.40	17
29	54 39.3 0	01 09.2 1	0	6844	S	232	67.07	19.04	17
30	54 39.1 0	01 08.7 1	0.0	6762	S	82	37.35	13.21	16
30	54 39.1 0	01 08.7 1	0.0	6763	B	83	37.43	13.26	16
30	54 39.1 0	01 08.7 1	0.0	6797	S	117	40.23	16.14	16
30	54 39.1 0	01 08.7 1	0.0	6801	B	121	41.45	17.27	16
30	54 39.1 0	01 08.7 1	0.0	6802	S	122	41.48	17.29	16
30	54 39.1 0	01 08.7 1	5.4+/-36%	6823	S	144	60.53	12.32	17
30	54 39.1 0	01 08.7 1	0.0	6826	B	202	60.58	12.35	17
30	54 39.1 0	01 08.7 1	0	6842	S	230	66.88	18.53	17
30	54 39.1 0	01 08.7 1	0	6843	B	231	66.93	18.56	17

Notes

1. Latitude/longitude is in degrees and decimal minutes. Trailing 0 = N or E. Trailing 1 = S or W.
2. Concentration of tritium in unfiltered sea water and percentage 1 sigma counting error: A '0' indicates that the sample was not analysed (see text); A '0.0' indicates that the sample was analysed and that no tritium was detected.
3. 'LSN' is the laboratory sample number.
4. For sample depth: S=surface; B=bottom - 1 metre.
5. 'Bottle' is the laboratory bottle number.
6. 'Time 1' is the time in decimal hours after midnight on 14 July 1986.
7. 'Time 2' is the time (24 hour clock) in hours and minutes.

TABLE 4. Details of the tritium discharge.

Power station status	Shut down
Cooling water pumps	2 operational, 30,000 m^3 hour^{-1} pump^{-1}
Starting time for draining TWST$^+$	1110 h on 16 July 1986
Finishing time for draining TWST	1130 h " " " "
Starting time for draining FMDT*	1130 h " " " "
Finishing time for draining FMDT	1245 h " " " "
Tritium discharged from TWST	5.5 TBq
Tritium discharged from FMDT	18 MBq

$^+$Tritium waste storage tanks
*Final monitoring and delay tanks

TABLE 5. Meteorological anemographic data for South Shields.

Date (July 1986)	Mean wind speed (knots)
9	8.8
10	3.9
11	2.6
12	1.5
13	2.2
14	7.0
15	0.7
16	8.5
17	15.7
18	7.2

Hour	15 July Direction*	Mean wind speed (knots)	16 July Direction*	Mean wind speed (knots)	17 July Direction*	Mean wind speed (knots)
00	0	0	140	1	230	3
01	0	0	190	1	240	7
02	0	0	210	4	240	10
03	0	0	210	1	240	12
04	0	0	180	1	250	14
05	220	1	170	1	250	11
06	230	1	170	2	260	15
07	240	1	180	2	270	17
08	0	0	180	5	270	19
09	260	1	190	10	270	24
10	60	1	200	10	270	20
11	0	0	210	15	260	20
12	0	0	200	14	270	23
13	270	3	210	12	280	20
14	280	3	210	13	280	22
15	280	1	230	13	290	21
16	0	0	240	15	280	20
17	0	0	220	15	280	20
18	140	1	230	13	280	16
19	140	2	230	17	280	14
20	150	1	220	15	270	10
21	0	0	220	5	270	12
22	0	0	250	9	270	13
23	0	0	250	10	270	13

*Direction from which the wind is coming, expressed as the veer from north in degrees true. (Overing 1988).

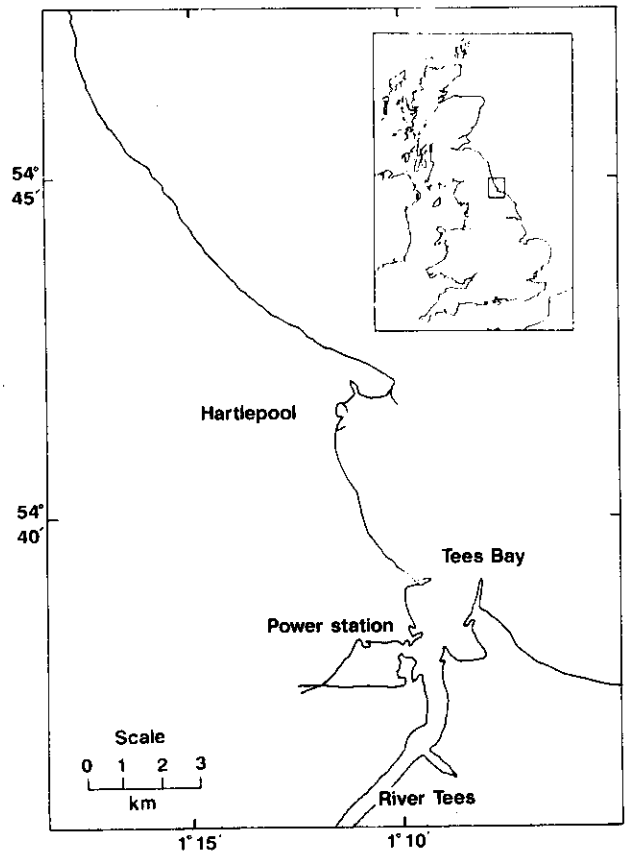

FIGURE 1. The location of Hartlepool nuclear power station

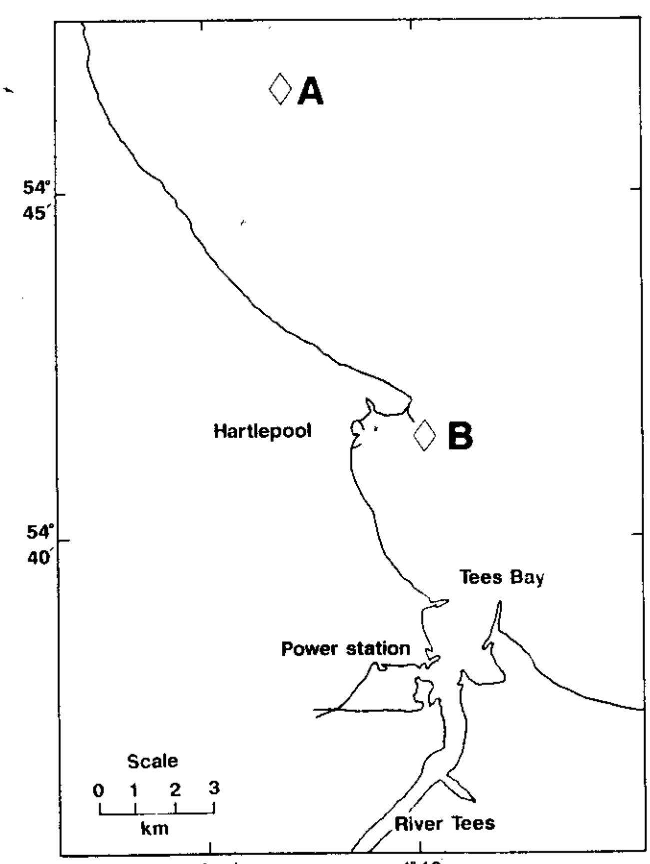

FIGURE 2. The location of tidal stream stations on Admiralty Chart 2567 (Hydrographer of The Navy, 1978)

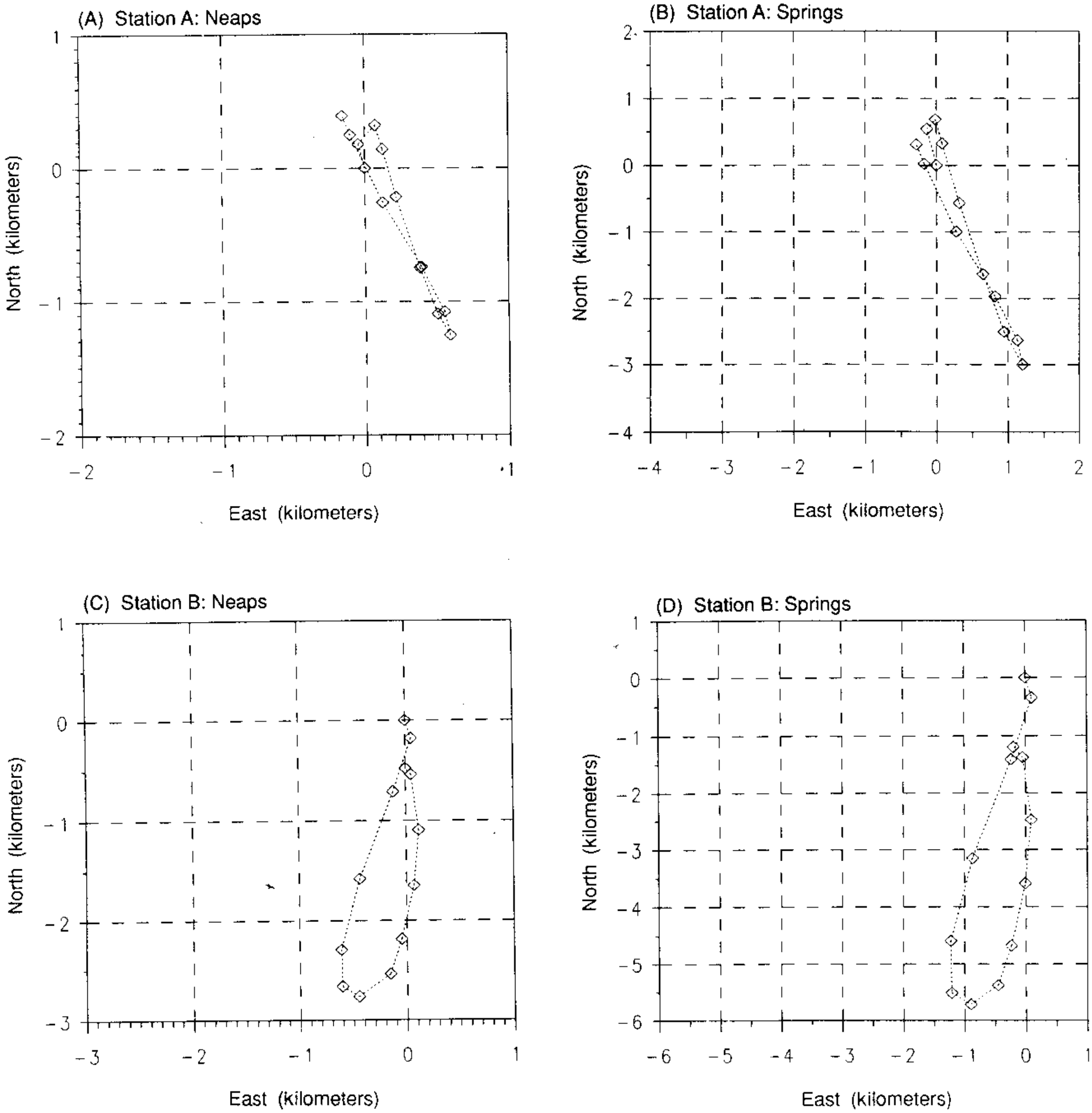

FIGURE 3. Progressive vector diagram for a tidal cycle at Stations A and B on Admiralty Chart 2567 (Hydrographer of the Navy, 1978)

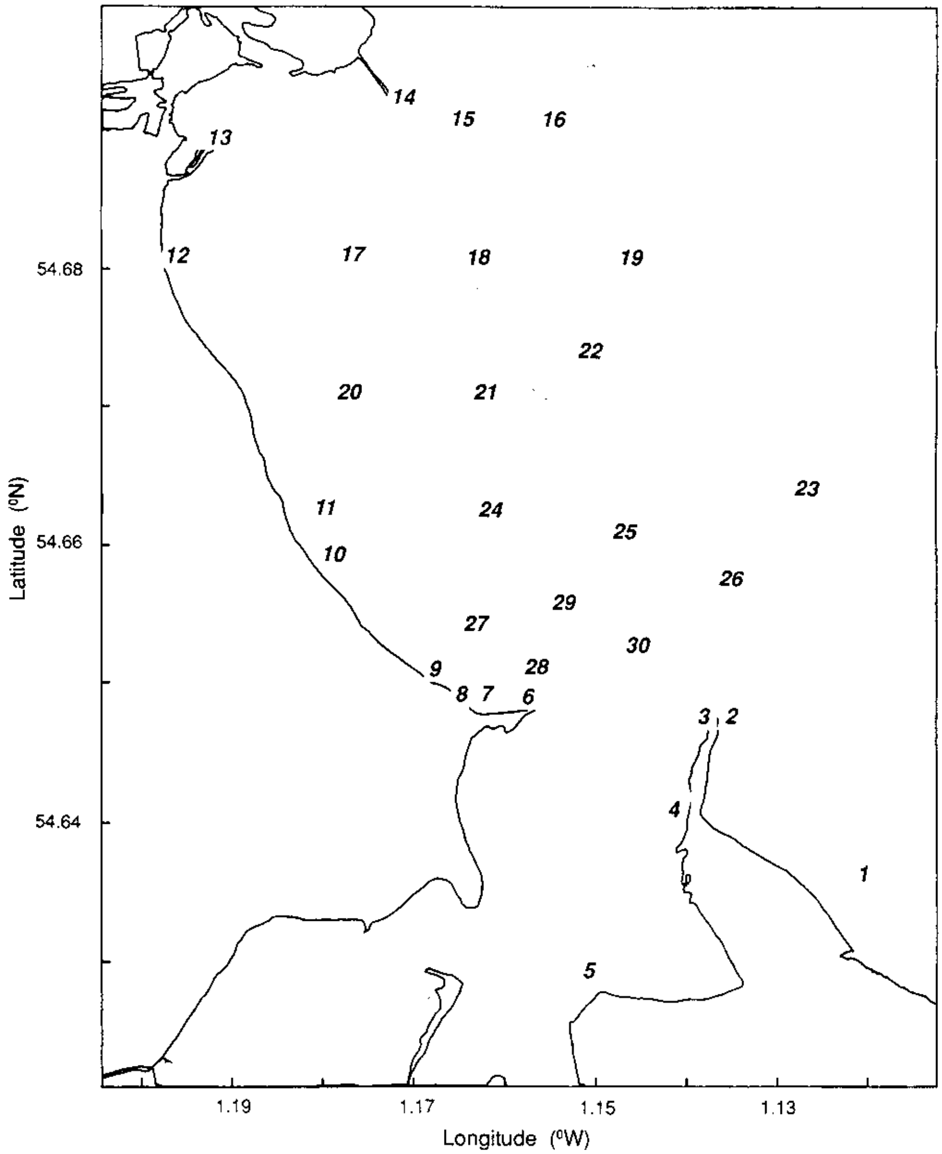

FIGURE 4. The location of sampling stations used during the survey

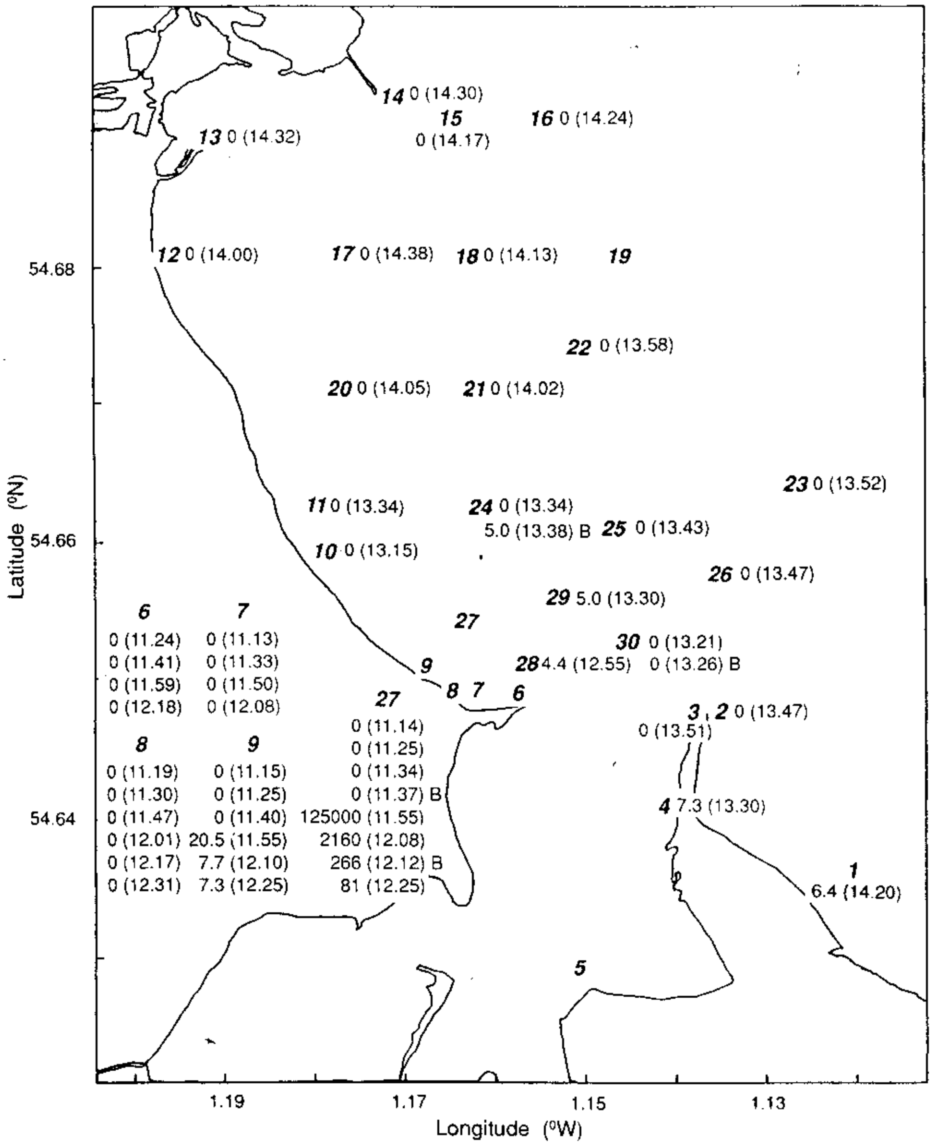

FIGURE 5(a). Concentration (Bq l^{-1}) of tritium in sea water in Tees Bay: 1100-1500h, 16 July 1986

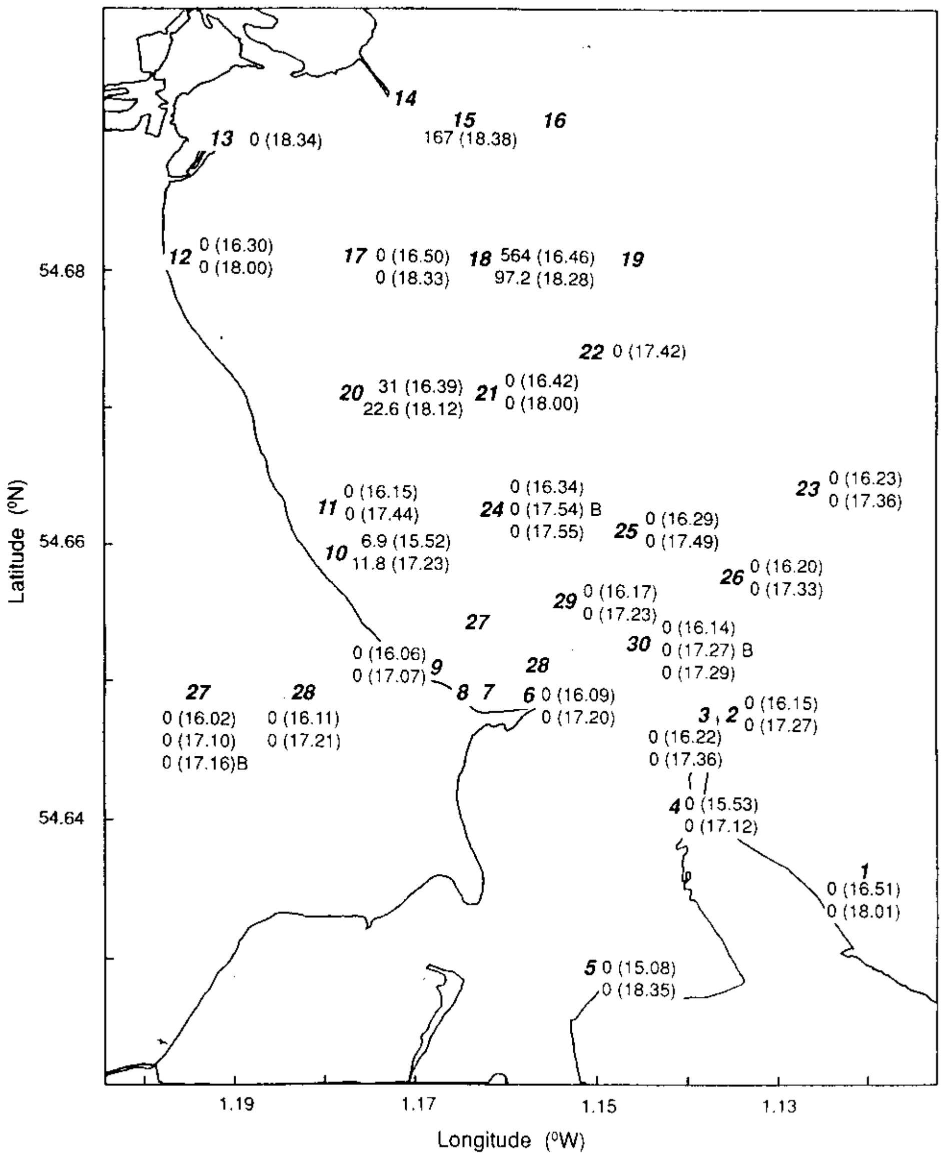

FIGURE 5(b). Concentration (Bq l^{-1}) of tritium in sea water in Tees Bay: 1500-1900h, 16 July 1986

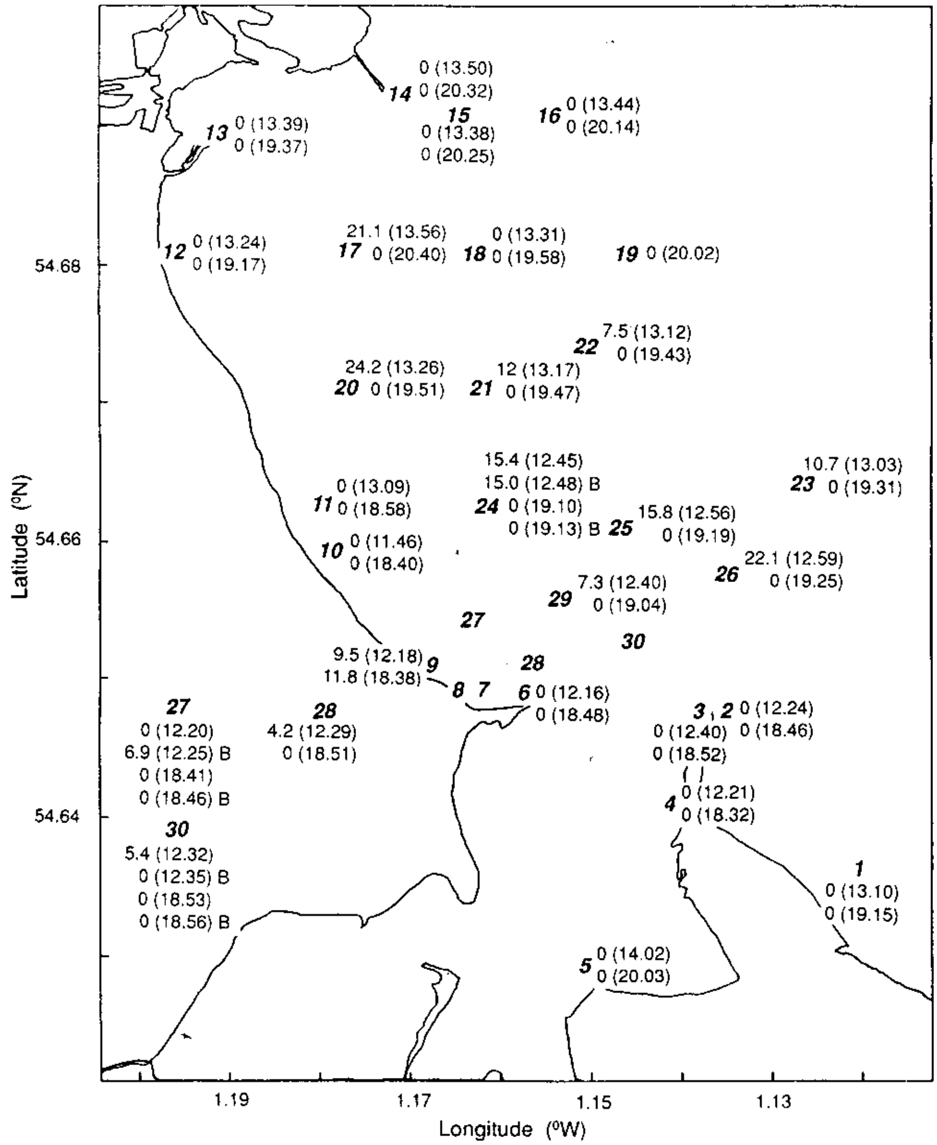

FIGURE 5(c). Concentration (Bq l⁻¹) of tritium in sea water in Tees Bay: 1145-2100 h, 17 July 1986

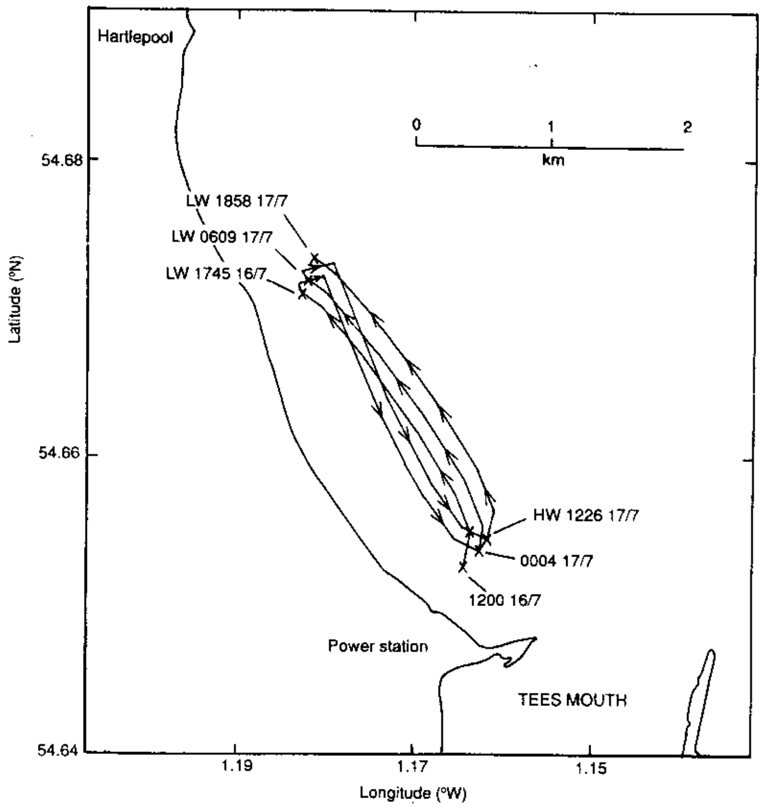

FIGURE 6. The predicted movement of the centre of the patch of tritium using tidal stream data for Stations A and B combined

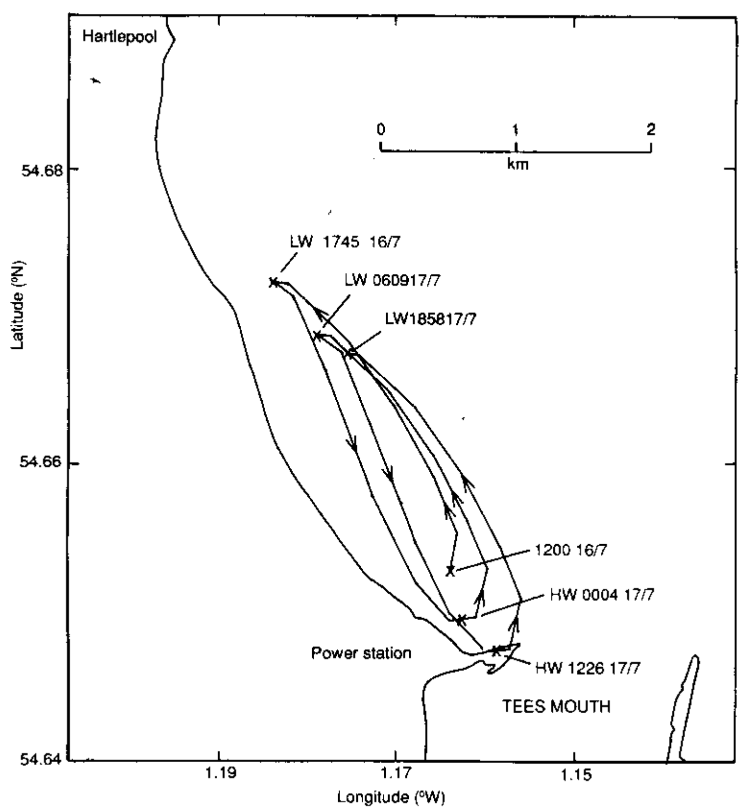

FIGURE 7. The predicted movement of the centre of the patch of tritium using tidal stream data for Station B