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## The Radionuclide Content of Seaweeds and Seagrasses Around the Coast of Oman and the United Arab Emirates

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The ability of seaweeds to concentrate the very low levels of radionuclides in seawater was one of the driving forces in their early use in the 1960s as biomonitors (Phillips and Rainbow, 1994). Seaweeds have been used extensively since then in monitoring programmes for radioactive discharges (Cross and Day, 1981; Druehl *et al.*, 1988; Hunt, 1980; Mattsson *et al.*, 1980; Raisbeck *et al.*, 1995; Thompson *et al.*, 1982; Woodhead, 1984). Seagrasses have also occasionally been included in such studies; for example, Manjón *et al.* (1995) measured the radioactivity in seaweed and seagrass samples from the Andalucía coast in Spain. Routine monitoring of seaweed, fish and shellfish occurs around the British Isles to monitor discharges from the Sellafield Reprocessing Plant and also from La Hague Reprocessing Plant in France.

In the Arabian Gulf region, Kureishy (1991) analysed heavy metal concentrations in seaweeds and one unidentified seagrass around the coast of Qatar. Along the Arabian Sea coast of India, Bhat *et al.* (1981) analysed the radionuclide content, including <sup>137</sup>Cs, of seaweeds found near a nuclear power station. To date, no study

has been reported on the radionuclide content of seaweeds and seagrasses in Oman.

Seaweed and seagrass samples were collected from various sites along the coast of Oman. Most samples were picked fresh from the rocks, whilst the others were collected off the beach. Where possible, the wet samples were air dried before returning to the laboratory. The location of sampling was recorded and a sub-sample was taken for taxonomic identification. Each sample was dried at 90°C for 24 h and then ground and sieved through a 250 µm mesh. The majority of samples had a mass of about 45 g when dried and sealed in a petri dish. Some of the larger samples were about 200 g in weight and were sealed in 1 l Marinelli beakers. Each sample was counted on an EGG Ortec high purity germanium detector system for 60 000 s. The gamma spectroscopy system was calibrated every day against a standard multigamma source with a calibration certificate issued by the National Physical Laboratory, UK. The spectra were quantitatively analysed for both manmade and naturally occurring radionuclides.

The position of the sampling locations is shown in Fig. 1. The predominance of samples collected in the south reflects the greater abundance of seaweeds along the southern coast. The majority of samples were collected during and after the Kharif (monsoon) season when seaweed growth is greatest.

Table 1 lists the mean minimum detectable activity (MDA) based on an average sample size of 45 g. The larger samples of about 200 g exhibited MDAs which were less than half of these values. Each sample was analysed for all of these radionuclides.

Table 2 lists the samples by region, and their radionuclide content by dry weight. Twelve of the natural radionuclides are listed. Potassium-40 is a primordial radionuclide that occurs naturally. Its specific activity is proportional to the total quantity of potassium in a sample. Thus, the high levels of <sup>40</sup>K in some of the darker weeds indicate that these are rich in potassium. The remaining natural radionuclides are from the three decay series, <sup>238</sup>U, <sup>235</sup>U and <sup>232</sup>Th. They appear in many organic samples, including foods.

The only man-made radionuclide found was <sup>137</sup>Cs. Fig. 2 shows the locations of these samples, with the area of the circles proportional to the <sup>137</sup>Cs concentra-

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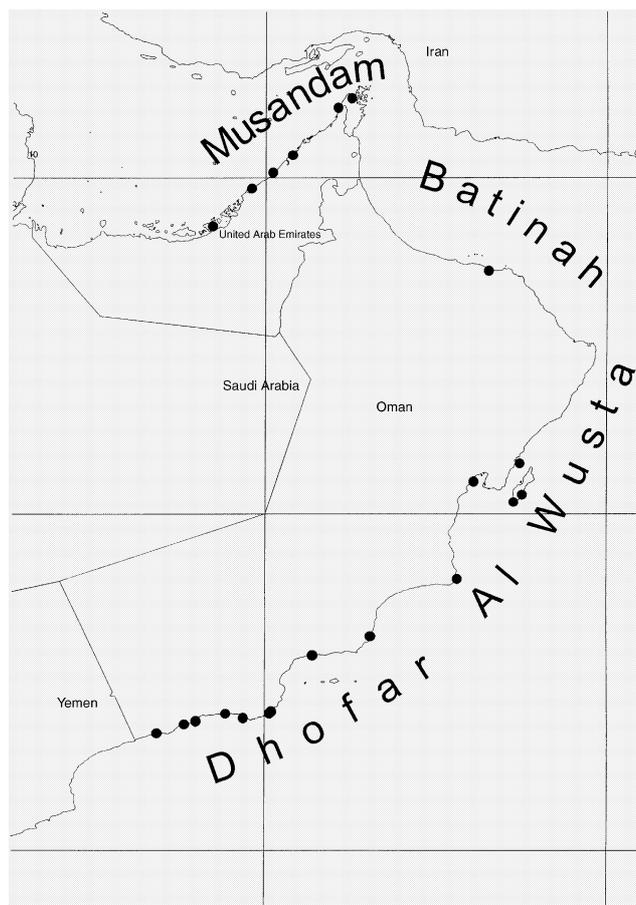


Fig. 1 Seaweed sampling locations.

tion. Levels were highest in the green intertidal seaweeds *Enteromorpha* spp. and *Chaetomorpha* spp. in Musandam. The concentrations of  $^{137}\text{Cs}$  in Omani seaweeds were up to  $3.9 \text{ Bq kg}^{-1}$  dry weight, which led to further samples being collected further down the Musandam peninsula towards Abu Dhabi. The maximum concentration of  $7.5 \text{ Bq kg}^{-1}$  dry weight was found in *Chaetomorpha brachygona* from Umm Al Qawayn, 20 km north of Dubai.

All samples from the Batinah and Al Wusta areas exhibited  $^{137}\text{Cs}$  levels below the detection limits. In Dhofar, concentrations of  $^{137}\text{Cs}$  of up to  $2.1 \text{ Bq kg}^{-1}$  dry weight were found. The mean activity concentrations of five radionuclides for each region were calculated as shown in Table 3. Samples with activity concentrations below the MDA were ignored in the calculation of mean values. The mean  $^{137}\text{Cs}$  concentration in Musandam was  $3.2 \text{ Bq kg}^{-1}$ , as compared to  $1.4 \text{ Bq kg}^{-1}$  in Dhofar.

Green seaweeds are known to concentrate  $^{137}\text{Cs}$  more than brown varieties (Manjón *et al.*, 1995). The results shown in Table 4 agree with this: the mean  $^{137}\text{Cs}$  concentration in Chlorophyta was  $3.3 \text{ Bq kg}^{-1}$  and in Phaeophyta was  $1.8 \text{ Bq kg}^{-1}$ . Similar levels of  $^{137}\text{Cs}$ , up to  $2.9 \text{ Bq kg}^{-1}$  dry weight, were found by Manjón *et al.* (1995) along the Mediterranean and Atlantic coasts of Spain, and were attributed to fallout. In the South and

TABLE 1

Minimum detectable activity (MDA) for man-made and naturally occurring radionuclides in  $\text{Bq kg}^{-1}$  dry weight.

Radionuclide	MDA ( $\text{Bq kg}^{-1}$ )
<i>Man-made radionuclides</i>	
Mn54	1.1
Co58	1.0
Co60	1.9
Zn65	3.0
Zr95	1.8
Ag110m	0.8
Cs134	0.7
Cs137	0.7
Ce144	3.1
Cr51	5.1
<i>Naturally occurring radionuclides</i>	
Th234	40
Pa234	2.2
Th230	440
Ra226	8.0
Pb214	1.9
Bi214	2.9
Pb210	250
U235	0.5
Th231	3800
Pa231	3300
Th227	5.1
Ra223	3.5
Rn219	5.3
Ac228	6.6
Th228	49
Ra224	20
Pb212	1.3
Bi212	1.3
Tl208	1.5
K40	13

North polar regions, values of  $0.4$  and  $1.8 \text{ Bq kg}^{-1}$  have been reported in *Fucus* species (Holm, 1991).

The results from the Batinah and Al Wusta regions indicate that the  $^{137}\text{Cs}$  concentrations are below the MDA level of  $0.7 \text{ Bq kg}^{-1}$  and hence closer to the levels found at the South Pole. The higher concentration in the Dhofar samples, particularly those from the Sadh area, are believed to be due to the strong upwelling along the Mirbat peninsula (Savidge *et al.*, 1990). The mean concentration of  $^{137}\text{Cs}$  in this area of  $1.4 \text{ Bq kg}^{-1}$  reflects the increased flow of seawater, and the activities are considered to be principally from fallout. However, the higher and localised concentration of  $^{137}\text{Cs}$  in samples from Musandam is unlikely to be due to fallout.

The nuclear power plants in the region (Fig. 3) constitute a possible source of radionuclides. Reynolds (1993) reported a schematic of surface currents in the Arabian Gulf and the upper Gulf of Oman obtained during the NOAA survey of the Gulf war oil spill, in 1992. Considering the Gulf first, there is a general counter-clockwise pattern of currents, with a westerly flow to a mid-point along the Iranian coast being met by a significant southerly flow from the north-east Gulf towards Qatar, and then an easterly return flow towards the Strait of Hormuz. Further data in the same cruise using hydrodynamic modelling showed coastal jets in

TABLE 2  
Radionuclide analysis of seaweeds (Bq kg<sup>-1</sup>).

Sam ID	Date	Latitude	Longitude	Location	Weed type	Division	Drift	Mass (g)	Th234	Th230	Ra226	Pb214	Bi214	Pb210	U235	Ac228	Pb212	Bi212	Tl208	K40	Cs137
Musandam																					
24	13-Jan-1999	26°12'34"	56°15'46"	Khasab fort in front of	<i>Enteromorpha flexuosa</i> (Wulfen ex Roth) J. Agardh	C		182	<20	272	18.3	11.0	9.7	<124	<0.2	7.0	7.2	<7.0	2.3	638	2.9
25	15-Jan-1999	26°12'34"	56°15'46"	Khasab fort in front of	<i>Chaetomorpha brachygona</i> Harvey	C		218	62	<200	<3.6	14.4	11.6	<114	1.8	6.7	<0.6	6.1	2.0	417	3.1
65	16-Mar-2000	26°05'42"	56°19'58"	Khawr Najd	<i>Rosenvingea intricata</i> (J. Agardh) Borgesen	P	D	38	457	<479	<8.7	60.8	82.5	<272	30.9	106.1	51.4	<15.2	24.0	5443	3.1
66	16-Mar-2000	26°11'52"	56°15'06"	Khasab fort in front of	<i>Enteromorpha instestinalis</i> (Linnaeus) Link (?)	C		88	112	431	16.5	19.6	12.1	<179	<0.4	13.3	6.6	18.0	2.7	1203	<0.5
67	16-Mar-2000	26°11'52"	56°15'06"	Khasab fort in front of	<i>Chaetomorpha brachygona</i> Harvey	C		91	238	579	<5.6	18.6	22.3	<176	17.8	19.8	2.3	31.5	4.9	1330	3.9
68	16-Mar-2000	26°12'03"	56°14'47"	Khasab, picknick spot	<i>Ulva fasciata</i> Delile	C		20	150	975	<12.0	9.0	4.4	<375	<0.8	18.4	<2.0	48.6	<2.3	1414	3.2
70	17-Mar-2000	26°05'41"	56°06'38"	Bukha-Tibat road	<i>Sargassum angustifolium</i> C. Agardh	P	D	95	319	523	21.0	6.6	3.3	<172	<0.3	<4.5	0.8	<9.6	0.7	186	1.1
71	17-Mar-2000	25°33'34"	55°39'27"	nr Umm Al Qaywayn	<i>Chaetomorpha brachygona</i> Harvey	C		26	<53	<579	<10.5	<2.5	13.8	<329	<0.7	17.6	6.4	<18.4	3.0	2276	7.5
72	17-Mar-2000	25°08'09"	55°11'08"	Jamera Beach, Dubai	<i>Sargassum boveanum</i> J. Agardh (var. <i>atterimum</i> ?)	P	D	120	107	<269	<4.9	7.5	4.7	<153	<0.3	7.4	1.6	7.8	0.6	1305	1.2
73	18-Mar-2000	24°58'54"	55°00'46"	Jebal Ali Beach	<i>Sargassum boveanum</i> J. Agardh	P	D	72	86	1073	48.2	13.2	21.5	<198	<0.4	<5.2	3.0	<11.1	2.9	3651	<0.6
76	11-Apr-2000	24°28'00"	54°22'00"	Abu Dhabi, boat peir	<i>Chetomorpha? and Halophila stipulacea</i>	C		4	<134	<1476	<26.8	<6.4	20.0	<839	<1.7	<22.1	<4.4	<47.0	<5.0	4444	<2.3
77	8-Apr-2000	24°28'00"	54°22'00"	Abu Dhabi, beach	<i>Cladophora and Halodule urinervis</i>	C		38	296	<479	<8.7	31.8	38.6	<272	<0.5	30.4	<1.4	<15.2	4.7	831	2.8
Batinah																					
17	1-Nov-1998	23°37'14"	58°17'00"	Civil Aviation beach	<i>Sargassum</i> sp.	P	D	12	234	<852	<15.5	22.8	<5.6	<484	<1.0	<12.8	<2.5	<27.1	<2.9	2821	<1.4
18	8-Nov-1998	23°37'14"	58°17'00"	Civil Aviation beach	<i>Sargassum</i> sp.	P	D	33	178	269	<9.3	<2.2	<3.4	<292	<0.6	5.0	<1.5	<16.3	<1.8	874	<0.8
23	1-Jan-1999	23°37'00"	58°17'00"	Civil Aviation beach	<i>Halophila ovalis</i> (R. Brown) Hook. f.	A	D	160	93	1129	<4.2	15.6	17.5	<133	<0.3	9.5	7.6	1.8	2.8	1908	<0.4
27	24-Sep-1999	23°37'14"	58°17'00"	Civil Aviation beach	<i>Chaetomorpha crassa</i> (Ag.) Kützing	C	D	36	59	<492	<8.9	4.9	2.6	<280	<0.6	<7.4	2.0	<15.7	<1.7	772	<0.8
28	28-Sep-1999	23°37'14"	58°17'00"	Civil Aviation beach	<i>Chaetomorpha crassa</i> (Ag.) Kützing	C	D	37	<44	<485	<8.8	<2.1	<3.2	<276	<0.6	<7.3	<1.4	<15.4	<1.7	1445	<0.8
29	5-Oct-1999	23°37'14"	58°17'00"	Civil Aviation beach	<i>Halodule uninervis</i> (Forssk.) Aschers.	A	D	31	<48	<530	<9.6	<2.3	16.2	<301	<0.6	<8.0	<1.6	<16.9	<1.8	4085	<0.8
30	12-Oct-1999	23°37'14"	58°17'00"	Civil Aviation beach	<i>Halodule uninervis</i> (Forssk.) Aschers.	A	D	41	<42	<461	<8.4	9.1	14.4	<262	1.7	<6.9	1.1	<14.7	<1.6	2811	<0.7
31	14-Oct-1999	23°37'14"	58°17'00"	Civil Aviation beach	<i>Halodule uninervis</i> (Forssk.) Aschers.	A	D	18	286	2289	<12.6	14.6	<4.6	<395	5.5	<10.4	<2.1	<22.1	2.7	2897	<1.1
74	1-Apr-2000	23°37'14"	58°17'00"	Civil Aviation beach	<i>D.dichotoma</i> (Huds) J.V. Lamour var. <i>intricata</i> (C. Agardh)	P		71	143	586	19.7	11.6	8.7	<199	<0.4	11.6	1.2	32.1	2.2	<10	<0.6
75	1-Apr-2000	23°37'14"	58°17'00"	Civil Aviation beach	<i>Ceramium</i>	R		55	204	996	19.1	12.7	11.1	<226	<0.5	23.4	8.3	<12.7	5.0	1700	<0.6
Al Wusta																					
13	13-Oct-1998	19°01'50"	57°48'53"	Ras Madrakra	<i>Melanothamnus somalensis</i> Bornet et Falkenberg	R		48	<39	<426	<7.7	<1.8	6.6	<242	<0.5	<6.4	<1.3	<13.6	<1.5	2458	<0.7
14	13-Oct-1998	19°01'50"	57°48'53"	Ras Madrakra	<i>Jolya laminarioides</i> Guimaraes in Guimaraes et al.	P		35	<45	<499	<9.1	11.5	<3.3	<283	<0.6	<7.5	<1.5	<15.9	<1.7	<15	<0.8
15	15-Oct-1998	20°29'09"	58°04'01"	Khaluf	<i>Padina tetrastromatica</i> Hauck	P	D	25	<54	430	<10.7	<2.5	2.3	<335	<0.7	6.0	<1.7	<18.8	1.1	687	<0.9
16	15-Oct-1998	20°29'09"	58°04'01"	Khaluf	<i>Syringodium isoetifolium</i> (Aschers.) Dandy	A	D	26	<53	<579	<10.5	13.5	<3.8	<329	<0.7	<8.7	<1.7	<18.4	2.0	<17	<0.9
19	28-Nov-1999	20°10'16"	58°39'34"	Sinfah, Masirah	<i>Syringodium isoetifolium</i> (Aschers.) Dandy	A		42	<41	<455	<8.3	<2.0	2.3	<259	<0.5	<6.8	<1.3	<14.5	<1.6	2737	<0.7
20	28-Nov-1999	20°17'13"	58°46'39"	nr Arf	<i>Jolya laminarioides</i> Guimaraes in Guimaraes et al.	P	D	27	<52	<568	<10.3	<2.5	<3.7	<323	<0.6	<8.5	1.0	<18.1	<1.9	328	<0.9
21	29-Nov-1999	20°45'00"	58°44'27"	Shannah, w	<i>Sargassum</i> sp.	P	D	29	49	800	<10.0	<2.4	5.5	362	1.4	13.7	2.2	<17.4	<1.9	3050	<0.9
22	29-Nov-1999	20°45'00"	58°44'27"	Shannah, w	<i>Enteromorpha</i> sp.	C	D	27	<52	<568	<10.3	<2.5	5.6	<323	<0.6	<8.5	4.4	<18.1	1.8	2182	<0.9
60	29-Oct-1999	20°12'43"	58°43'08"	Ras Zarri, Masirah	<i>Porphyra</i> sp.	R		15	<69	<762	<13.9	<3.5	<5.0	<433	9.2	3.8	0.7	19.2	<2.6	462	<1.2
61	5-Nov-1999	20°26'58"	58°02'42"	Khaluf	<i>Melanothamnus somalensis</i> Bornet et Falkenberg	R		30	<49	<539	<9.8	<2.3	<3.6	<306	<0.6	<8.1	<1.6	<17.1	<1.8	<16	<0.9
62	6-Nov-1999	20°31'30"	58°04'29"	Pink beach, Khaluf	<i>Padina tetrastromatica</i> Hauck	P	D	36	<45	<492	<8.9	<2.1	11.5	<280	<0.6	<7.4	<1.5	<15.7	2.5	125	<0.8
63	6-Nov-1999	20°31'30"	58°04'29"	Pink beach, Khaluf	<i>Stoechospermum marginatum</i> (C. Agardh) Kützing	P	D	9	<89	<984	<17.9	42.3	<6.5	<559	<1.1	46.0	<2.9	133.9	<3.4	647	<1.6
64	6-Nov-1999	20°31'30"	58°04'29"	Pink beach, Khaluf	<i>Bryopsis pennata</i> Lamouroux	C	D	5	<120	1017	<24.0	11.0	12.7	<750	<1.5	61.8	6.0	<42.0	<4.5	270	<2.1
Dhofar																					
4	7-Oct-1998	17°03'48"	55°05'39"	Khawr Murir	<i>Stoechospermum marginatum</i> (C. Agardh) Kützing	P		251	331	<186	<3.4	2.7	2.4	<106	0.6	<2.8	3.3	<5.9	1.2	2234	<0.3
5	7-Oct-1998	17°03'48"	55°05'39"	nr Sadh	<i>Ulva fasciata</i> Delile	C		18	65	<698	<12.7	<3.0	1.8	<396	<0.8	4.4	<2.1	<22.2	1.0	162	<1.1
6	8-Oct-1998	16°55'31"	53°59'25"	Raysut port	<i>Ulva fasciata</i> Delile	C		27	<52	<569	<10.3	<2.5	1.7	<323	<0.6	5.0	0.9	<18.1	<1.9	429	<0.9
7	8-Oct-1998	16°55'31"	53°59'25"	Raysut port	<i>Jolya laminarioides</i> Guimaraes in Guimaraes et al.	P		28	<51	<558	<10.1	<2.4	<3.7	<317	<0.6	<8.4	<1.6	<17.7	<1.9	2000	<0.9
8	8-Oct-1998	16°45'07"	53°25'10"	Rakhyut	<i>Ulva fasciata</i> Delile	C		20	<60	<660	<12.0	<2.9	<4.4	<375	4.2	<9.9	<2.0	<21.0	<2.3	793	<1.1
9	9-Oct-1998	16°53'14"	53°49'08"	Mughsayl	<i>Codium dwarkense</i> Borgesen	C		54	<37	<402	<7.3	7.4	5.8	<228	1.8	<6.0	<1.2	<12.8	<1.4	445	<0.6
10	9-Oct-1998	16°53'14"	53°49'08"	Mughsayl	<i>Solieria robusta</i> (Grev.) Kylin	R		27	<52	594	<10.3	<2.5	7.0	<323	<0.6	<8.5	3.9	<18.1	3.1	1044	<0.9
11	11-Oct-1998	17°54'07"	55°42'10"	Fararah	<i>Ulva fasciata</i> Delile	C		24	<55	<602	<11.0	<2.6	<4.0	<342	<0.7	<9.0	<1.8	<19.2	<2.1	640	<1.0
12	11-Oct-1998	17°54'07"	55°42'10"	Fararah	<i>Melanothamnus somalensis</i> Bornet et Falkenberg	R		43	<41	<450	<8.2	<1.9	<3.0	<256	<0.5	14.6	<1.3	<14.3	<1.5	3726	<0.7
26	26-Mar-1999	18°11'12"	56°32'49"	Sawqrah	<i>Sargassum</i> sp.	P	D	32	42	<523	<9.5	21.0	15.3	<297	<0.6	<7.8	1.2	<16.6	<1.8	573	<0.8
32	20-Oct-1999	17°02'02"	54°31'31"	Taqah	<i>Ulva fasciata</i> Delile	C		26	42	<579	<10.5	<2.5	<3.8	279	<0.7	<8.7	<1.7	14.7	0.5	185	<0.9
33	20-Oct-1999	17°02'02"	54°31'31"	Taqah	<i>Sargassum</i> sp. No. 2	P	D	35	79	<499	<9.1	<2.2	3.3	<283	7.6	<7.5	1.7	<15.9	2.8	398	<0.8
34	20-Oct-1999	17°02'53"	55°04'31"	Sadh, East harbour side	<i>Prilophora</i> sp.	R		28	<51	<558	<10.1	<2.4	2.3	<317	1.7	<8.4	<1.6	22.5	<1.9	1967	<0.9

TABLE 2 (CONTINUED)

Sam ID	Date	Latitude	Longitude	Location	Weed type	Division	Drift	Mass (g)	Th234	Th230	Ra226	Pb214	Bi214	Pb210	U235	Ae228	Pb212	Bi212	Tl208	K40	Cs137
35	20-Oct-1999	17°02'53"	55°04'31"	Sadh, East harbour side	<i>Hypnea flagelliformis</i> Grev.	R		26	93	698	<10.5	2.7	6.3	366	<0.7	5.0	<1.7	22.5	<2.0	1094	1.0
36	20-Oct-1999	17°02'53"	55°04'31"	Sadh, East harbour side	<i>Melanothamnus somalensis</i> Bornet et Falkenberg	R		53	<37	<405	8.2	<1.8	2.0	238	<0.5	2.4	0.9	17.1	2.4	4373	<0.6
37	20-Oct-1999	17°02'53"	55°04'31"	Sadh, East harbour side	<i>Ulva fasciata</i> Delile	C		36	<45	<492	<8.9	<2.1	3.9	159	<0.6	8.2	0.6	<15.7	<1.7	879	0.9
38	20-Oct-1999	17°02'53"	55°04'31"	Sadh, East harbour side	<i>Codium dworkense</i> Borgesen	C		26	<53	<579	<10.5	6.1	4.1	612	2.5	<8.7	<1.7	<18.4	2.2	4195	1.9
39	20-Oct-1999	17°02'53"	55°04'31"	Sadh, East harbour side	<i>Sargassum</i> sp. No. 5	P	D	37	242	824	20.1	8.1	7.5	375	<0.6	<7.3	5.2	<15.4	1.9	4637	1.4
40	20-Oct-1999	17°02'53"	55°04'31"	Sadh, East harbour side	<i>Sargassum</i> sp. No. 6	P	D	34	252	697	<9.2	3.5	<3.3	<288	1.4	12.8	2.1	<16.1	1.2	1543	<0.8
41	20-Oct-1999	17°02'51"	55°04'21"	Sadh, West harbour side	<i>Codium dworkense</i> Borgesen	C		32	28	<522	<9.5	2.0	<3.4	<296	<0.6	<7.8	<1.5	17.8	<1.8	341	<0.8
42	20-Oct-1999	17°02'51"	55°04'21"	Sadh, West harbour side	<i>Nizamuddinina zanardini</i> (Schiffner) P. Silva, <i>comb. nov.</i>	P		50	944	6533	<7.6	84.7	61.6	<237	1.8	<6.3	<1.2	<13.3	<1.4	4512	<0.7
43	20-Oct-1999	17°03'41"	55°05'34"	East of Sadh by 5 km	<i>Ptilophora</i> sp.	R		38	<44	150	<8.7	<2.1	<3.2	<272	<0.5	<7.2	<1.4	10.6	<1.6	523	1.3
44	20-Oct-1999	17°03'41"	55°05'34"	East of Sadh by 5 km	<i>Melanothamnus somalensis</i> Bornet et Falkenberg	R		54	<37	159	<7.3	<1.7	<2.6	<228	5.2	<6.0	0.6	<12.8	0.5	2316	<0.6
45	20-Oct-1999	17°03'41"	55°05'34"	East of Sadh by 5 km	<i>Sargassum</i> sp. No. 6	P		32	182	<522	<9.5	2.9	4.6	547	<0.6	<7.8	2.1	37.5	1.3	2999	1.9
46	20-Oct-1999	17°03'41"	55°05'34"	East of Sadh by 5 km	<i>Ulva fasciata</i> Delile	C		29	<50	223	<10.0	<2.4	2.2	158	<0.6	<8.2	0.6	<17.4	<1.9	125	<0.9
47	20-Oct-1999	16°55'51"	53°59'46"	Raysut, port Salalah	<i>Codium arabicum</i> Kützing	C		22	24	305	<11.4	1.3	3.7	84	<0.7	<9.4	1.4	6.1	0.7	241	<1.0
48	20-Oct-1999	16°55'51"	53°59'46"	Raysut, port Salalah	<i>Hypnea flagelliformis</i> Grev.	R		27	<52	<568	<10.3	3.6	<3.7	124	<0.6	1.6	<1.7	<18.1	0.9	278	0.3
49	20-Oct-1999	16°55'51"	53°59'46"	Raysut, port Salalah	<i>Laurencia elata</i> (C. Ag.) Harvey	R		14	67	<789	<14.3	<3.4	5.7	<448	<0.9	11.4	1.1	<25.1	<2.7	805	<1.3
50	20-Oct-1999	16°55'51"	53°59'46"	Raysut, port Salalah	<i>Ptilophora</i> sp.	R		32	<47	<522	<9.5	<2.3	<3.4	<296	<0.6	6.1	<1.5	<16.6	0.3	500	1.3
51	20-Oct-1999	16°55'51"	53°59'46"	Raysut, port Salalah	<i>Plocamium</i> sp.	R		12	130	<852	2.9	<3.7	<5.6	<484	<1.0	12.6	<2.5	<27.1	<2.9	811	<1.4
52	20-Oct-1999	16°52'36"	53°46'13"	Mughsayl	<i>Ptilophora</i> sp.	R		36	<45	<492	4.1	<2.1	3.0	<280	<0.6	<7.4	<1.5	17.0	<1.7	490	<0.8
53	20-Oct-1999	16°52'36"	53°46'13"	Mughsayl	<i>Melanothamnus somalensis</i> Bornet et Falkenberg	R		25	<54	<590	<10.7	<2.5	<3.9	<335	<0.7	60.8	<1.7	<18.8	<2.0	2720	<0.9
54	20-Oct-1999	16°53'15"	53°49'21"	Mughsayl, east	<i>Ptilophora</i> sp.	R		33	<47	<514	<9.3	32.3	30.0	<292	<0.6	34.3	8.3	<16.3	6.7	603	1.8
55	21-Oct-1999	17°01'53"	54°26'22"	Khawr Rawri	<i>Melanothamnus somalensis</i> Bornet et Falkenberg	R		46	<40	<435	<7.9	5.2	<2.9	<247	<0.5	<6.5	<1.3	<13.8	<1.5	3770	1.9
56	21-Oct-1999	16°58'43"	54°41'30"	Mirbat	<i>Nizamuddinina zanardini</i> (Schiffner) P. Silva, <i>comb. nov.</i>	P		34	<46	<506	<9.2	6.7	<3.3	<288	<0.6	<7.6	<1.5	<16.1	<1.7	1827	2.1
57	21-Oct-1999	16°58'43"	54°41'30"	Mirbat	<i>Ulva fasciata</i> Delile	C		33	<47	<514	<9.3	8.7	<3.4	<292	<0.6	<7.7	<1.5	<16.3	<1.8	163	<0.8
58	21-Oct-1999	16°58'43"	54°41'30"	Mirbat	<i>Sargassum duplicatum</i> Bory	P		23	<56	<615	<11.2	13.8	<4.1	<350	<0.7	<9.2	<1.8	<19.6	<2.1	4755	<1.0
59	22-Oct-1999	16°52'45"	53°46'31"	Mugsayl	<i>Ulva reticulata</i> Forsskäl	C		41	<42	<461	<8.4	<2.0	5.8	<262	<0.5	<6.9	1.7	<14.7	<1.6	100	<0.7
3 bis	7-Oct-1998	17°03'48"	55°05'39"	Khawr Murir	<i>Ulva fasciata</i> Delile	C		24	<55	<602	<11.0	1.4	<4.0	<342	0.7	<9.0	<1.8	<19.2	<2.1	621	<1.0

*A. anthophyta**C. chlorophyta**P. phaeophyta**R. rhodophyta*

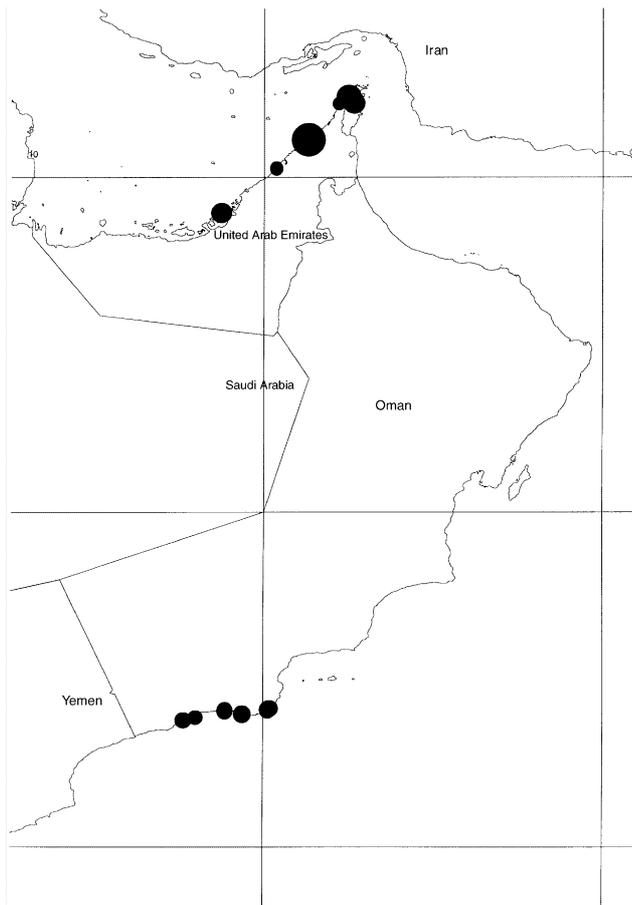


Fig. 2 Cs137 concentrations: the area of the spot indicates the concentration.

June running towards the southeast from the Iranian coast near Bushehr, and linking up with strong easterly surface flows ( $12\text{--}15\text{ cm s}^{-1}$ ) towards Musandam (Lardner *et al.*, 1993). A drifting buoy released by the NOAA vessel near the Bushehr region travelled due south some 150 km in 22 days (see Fig. 2 in Al-Rabeh *et al.*, 1993).

From these data, it would seem that  $^{137}\text{Cs}$  could travel from Bushehr in surface currents to Khasab in Musandam, resulting in the accumulation seen in the seaweeds. It should be emphasised that the levels of  $^{137}\text{Cs}$  found here are in trace quantities. Levels of up to  $500\text{ Bq kg}^{-1}$  dry weight of  $^{137}\text{Cs}$  were reported in the red seaweed *Jania* sp. by Bhat *et al.* (1981) and levels of  $80\text{--}700\text{ Bq kg}^{-1}$  of  $^{137}\text{Cs}$  have been reported in seaweeds in the vicinity of power stations (Manjón *et al.*, 1995).

It may also be possible (but is less likely), that radioactive wastes could be carried to Musandam from facilities along the Pakistan and Indian coasts. Thus Shetye *et al.* (1994) and McCreary *et al.* (1996) reported surface currents running along these coasts to the north and northwest during December and January, in the Northeast Monsoon.

Data are sparse in the Gulf of Oman. Flagg and Kim (1998) reported a tendency for northerly currents along the Ras Al Hadd to Muscat area from approximately January–July. ASA (1996) reported strong east to west flows across Mina Al Fahal, Muscat in January/February. The situation is complex further up the Gulf of Oman. Reynolds (1993) shows a double gyre with upwellings off the Iranian coast, involving a counter-clockwise gyre to the east and a clockwise gyre to the west. It is known that currents along this northern Batinah coast of Oman run strongly in a northwest direction towards Musandam. Thus, despite the complexities, it seems possible that pollutants could travel from the Arabian Sea coast of India and Pakistan, up to the Musandam area. However, the much greater distances and strong outflows through the Strait of Hormuz make this a much less likely source of the  $^{137}\text{Cs}$  than that proposed from within the Gulf.

The very low concentrations of  $^{137}\text{Cs}$  make further analysis difficult. No consistent relationship was found between species and activities. Insufficient weed grows naturally round the coast to obtain reliable comparisons within a species.

TABLE 3

Mean radionuclide concentrations by region ( $\text{Bq kg}^{-1}$ ).

	No. of Samples	Ra226	U235	Ac228	K40	Cs137
Musandam	12	26.0	16.8	25.2	1928	3.2
Batinah	12	19.4	3.6	12.4	2146	<0.7
Al Wusta	13	< 8.0	5.3	26.2	1295	<0.7
Dhofar	38	8.8	2.7	13.8	1534	1.4

TABLE 4

Mean radionuclide content by division ( $\text{Bq kg}^{-1}$ ).

Division	No. of samples	Ra226	U235	Ac228	K40	Cs137
Anthrophyta	6	< 12.1	3.6 (1.7–5.5)	9.5 (9.5–9.5)	2888 (1908–4085)	< 1.1
Chlorophyta	24	17.4 (16.5–18.3)	5.6 (1.8–17.8)	16.2 (4.4–61.8)	1045 (100–4444)	3.3 (0.9–7.5)
Phaeophyta	25	25.6 (19.1–48.2)	7.3 (0.6–30.9)	26.2 (5.0–106)	2049 (125–5443)	1.8 (1.1–3.1)
Rhodophyta	18	5.1 (2.9–8.2)	5.3 (1.7–9.2)	15.3 (1.6–60.8)	1643 (278–4373)	1.3 (0.3–1.9)

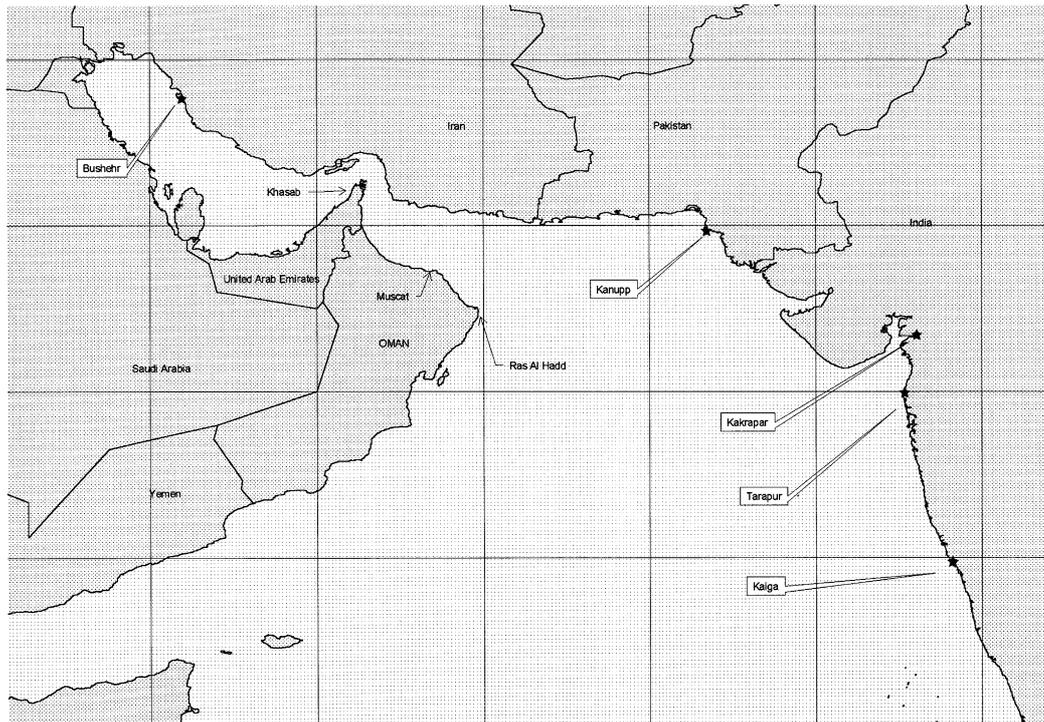


Fig. 3 Location of nuclear power facilities in the region.

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