Additional Comparative Levels of Radionuclides in Marine Biota

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Concentrations of radionuclides within marine biotic systems can be influenced by a number of factors, including the type of biota, its source, the radionuclide, and specific characteristics of the sampled specimens (age, gender) and the marine environment (salinity, etc.). The bioconcentration factor (BCF) for a marine organism is the ratio of the concentration of a radionuclide in that organism to the concentration found in its marine water environment – under conditions of equilibrium. BCFs have been estimated for various indicator species with respect to a number of radionuclides (FASSET, Deliverable 5, Appendix 2, 2003). For example phytoplankton species have 100,000 fold BCFs for plutonium and Americium isotopes and can obviously represent very sensitive indicator organisms for the early detection of contamination by these radionuclides. Technetium contamination can be monitored by assessing macroalgae, which concentrates the substance 10,000 to 100,000 fold. Macroalgae and zooplankton are strong indicator organisms (1,000 to 10,000 BCF) for detecting a suite of radionuclides, including iodine 129/131, Americium-241 and the plutonium isotopes. In contrast, there do not appear to be high CFs for strontium uptake, with none of the marine indicator organisms (fish, crustaceans, mollusks, zooplankton, macroalgae or phytoplankton) demonstrating a CF as high as 10.

FISH

There are variations in concentrations of a given radionuclide within a common indicator organism (i.e., fish), based upon marine body of water and subtype of organism (i.e, species/genus). The specific reasons for such variations are likely to be multifactorial, based partly upon resident locations of the organisms, their diets, metabolisms, excretory patterns, longevity, types of exposures, etc. Table AD1 lists the cesium-137 concentrations found in a variety of types of fish sampled from the Barents, North, and Norwegian Seas, and Skagerrak in 2000 through 2003 by - or for - the Norwegian Radiation Protection Authority. The average fish concentrations are very consistent within the Barents, North and Norwegian Seas (ranging from 0.24 to 0.35 Bq/kg-ww), while a somewhat higher value was noted from the Sagerrak (1.08 Bq/kg-ww). The overall average concentration of Cesium-137 in the 146 pooled samples (representing over 4,400 fish) is 0.32 Bq/kg. A large number of fish demonstrate concentrations very close to the overall average – including the Atlantic Salmon, Blue Whiting, Cod, Dab, Lemon sole, Long rough dab, Rabbitfish, Saithe, Spotted catfish and Torsk. Cod was also the most commonly retrieved type of fish, and appears to be a good indicator species (represents average values and is obtained in high numbers) – at least in northern European seas. Some fish demonstrated lower concentrations - with at least 50% lower concentrations (often based on small sample sizes) seen in Cat-fish, European plaice, Golden redfish, Greater argentine, Haddock, Lumpsucker, Mackerel, Norway pout, Norway redfish, Round ray, and Witch. Increased cesium-137 concentrations, 50% or greater than the overall average, were noted for the Atlantic Herring, Black-mouthed dogfish, Horse mackerel, Ling, Sprat and Whiting.

Table AD-1
Pooled Fish Samples Analyzed by the Norwegian Radiation Protection Authority. Number of Pooled Samples by Sea, Average Concentration, and % Non-detect Cesium-137 measured in Bq/kg

						Weighted	
	Barents	*North*	*Norwegian*	*Skagerrak*	*Total #*	*Ave Conc**	*% nd*
Atlantic Salmon	2		2		4	0.28	0%
Atlantic Herring	2		2	3	7	0.62	0%
Blue Whiting			3		3	0.27	67.00%
Blackmouthed dogfish			1		1	0.69	0%
Cat-fish	1		1		2	0.13	100%
Cod	47	2	12		61	0.3	0%
Dab		1		1	2	0.25	0%
European plaice	1		1		2	0.15	50%
Golden redfish	1				1	0.09	0%
Greater argentine			1		1	0.14	100%
Haddock	10	2	1	1	14	0.16	0%
Horse mackerel				1	1	2.2	0%
Lemon sole	1	1	1		3	0.21	33%
Ling			1		1	0.65	0%
Lumpsucker		1			1	0.1	100%
Long rough dab	5				5	0.25	0%
Mackerel			2		2	0.14	50%
Norway pout		1	4		5	0.15	80%
Norway redfish		2	1		3	0.15	33%
Rabbitfish			2		2	0.2	100%
Round ray			1		1	0.15	100%
Saithe	7	1	4		12	0.3	16%
Spotted catfish		1			1	0.2	0%
Sprat	1	2		1	4	0.7	0%
Torsk			2		2	0.28	0%
Whiting		1	2	1	4	0.9	0%
Witch			1		1	0.13	100%
Total # Sample Pools	78	17	43	8	146		
Wtd. Concen. Bq/kg	0.27	0.24	0.35	1.08	0.32		
% Non-detects	5.10%	5.40%	34.90%	0%	13.70%		

Note: the 146 pooled samples contained 4379 fish. Eleven other pooled samples with undefined number of fish were not included in this summary.

Reference: Data extracted and analyzed from: Gafvert T, Foyn L, Brungot AL, et al. Radioactivity in the Marine Environment 2000 and 2001, Norwegian Radiation National Monitoring Programme, 2003.

Table AD2 describes a larger (n=298 pooled samples) set of data from United Kingdom sampling (RIFE 8, 9) as well as recent Norwegian data (RAME-2003). The overall average concentration of Cs-137 is nearly identical the value found in table AD1 (0.3 vs 0.32). Those bodies of water represented both in tables AD1 and AD2 and having double-digit sample sizes in each table (Barents, North, Norwegian Seas) maintain very similar average concentrations (Barents: 0.27 vs 0.28; North: 0.24 vs 0.28; Norwegian: 0.35 vs 0.28). The Skagerrak average concentration moderated somewhat from table AD1 (1.08, based upon 8 pooled samples) to table AD2 (0.62, based upon 25 pooled samples), as the number of samples increased. Data from the North Atlantic (0.31) was essentially identical with the overall average fish concentration, and the Channel values were lower (0.16) – highly influenced by lower concentrations in plaice.

Table AD2
Average Fish Cs-137 Concentrations of Less Contaminated N. European Seas Concentration in Bq/kg-ww

	Barents	Norwegian	North	N. Atlantic	Channel	Skagerrak	Totals
Cod							
Ave conc	0.29	0.32	0.38	0.51	0.2	0.31	0.31
# pooled	53	20	21	3	8	6	111
Plaice							
Ave conc	0.18		0.21	0.36	0.06		0.16
# pooled	1		19	3	16		39
Haddock							
Ave conc	0.2	0.17	0.2	0.47		0.1	0.23
# pooled	10	1	10	3		1	25
Herring							
Ave conc	0.75	0.28	0.37	0.25		0.45	0.41
# pooled	2	2	9	3		12	28
Mackerel							
Ave conc		0.14		0.09	0.19		0.15
# pooled		4		5	8		17
Other							
Ave conc	0.17	0.3	0.23		0.31	1.35	0.36
# pooled	18	34	12		8	6	78
Total							
Ave conc	0.28	0.29	0.28	0.31	0.16	0.62	0.3
# pooled	84	61	71	17	40	25	298

Data derived from RIFE 8, RIFE 9, RAME (2003). No data for flounder were identified from the noted bodies of water and state databases.

MOLLUSKS

Radionuclide concentrations in mollusks in the Irish Sea – by type of mollusk and type of radionuclide – are summarized in table AD-3. It appears that scallops and squid are not strong concentrators of any of the noted radionuclides – with concentrations either lower than the mda (mean detectable activity) or values much lower than other members of the mollusk family. For example, the Cs-137 concentration in scallops (0.16 Bq/kg-ww, n = 27) is only about 2% of that noted for winkles (6.69 Bq/kg-ww, n = 111), and 14% of the mollusk with the next lowest concentration - whelks (1.13 Bq/kg-ww, n = 16). It also should be noted that certain radionuclides are not easily detected in mollusks of the Irish Sea. Both Cm-242 and Ce-144 were rarely detected within any mollusk form studied - with typical concentrations lower than the mda. In contrast, Tc-99 - very highly concentrated in mollusks – was found in winkles and mussels at values between 600 and 900 Bq/kg-ww, respectively. Irish Sea mussels and winkles also have concentrations of Pu-241 at average values between 61 and 114 Bq/kg-ww.

Table AD-3
Radionuclides in Irish Sea Mollusks by type of biota. Concentrations in Bq/kg-ww. 2002 and 2003 data. Selected Beta or Gama Radionuclides.

		Cockles	Limpets	Mussels	Whelks	Winkles	Scallops	Squid
Co-60								
ave		3.58	3.45	3.22	4.06	7.25	<mda	<mda
range		0.14-16	2.9-4.4	<0.04-10	<0.10-14	<1.5 - 14	<0.05-<.10	<0.05
# tests		50	16	80	20	111	27	2
Sr-90								
ave				0.76		3.84		
range				0.47-1.7		0.3-7.9		
# tests				24		63		
Tc-99								
ave				900.3		599.8		
range				30-2000		<1.6-980		
# tests				44		71		
Ru-106								
ave				14.39		24.3		
range				<0.33-65		<1.4-65		
# tests				86		111		
Cs-137								
ave		3.69	7.15	2.4	1.13	6.69	0.16	0.75
range		1.5-5.2	0.61-1.9	nd-4.6	0.61-1.90	<0.21-16	<0.17-.31	.60-1.90
# tests		50	16	91	16	111	27	2
Ce-144								
ave				<mda		<mda		
range				<0.22-3.4		<0.3-6.7		
# tests				86		111		
Pu-238								
ave		0.67	1.8	1.4	0.25	1.78	0.011	
range		0.11-2.1	1.4-2.4	0.016-2.7	0.056-.47	0.02-4.8	0.007-.014	
# tests		23	4	25	6	29	6	
Pu-239,40								
ave		3.48	8.73	6.52	1.29	0.33	0.056	
range		0.64-9.7	6.3-12	0.097-12	0.31-2.3	0.16-22	0.036-.008	

Table AD-3 (continued)

# tests		23	4	25	6	27	6	
Pu-241								
ave		42.31	73	60.55	13.07	113.65		
range		22-100	72-74	20-98	2.6-25	10-260		
# tests		13	2	11	6	26		
Am-241								
ave		9.66	1.7	9.35	2.65	17.6	<mda	<mda
range		1.8-28	24-Nov	<mda-24	0.4-7.4	0.19-39	<mda-.065	<mda
# tests		23	4	38	10	39	10	2
Cm-242								
ave		<mda	0.04	<mda	<mda	<mda	<mda	
range		nd-0.063	nd-0.65	<mda	<mda-0.17	<mda-.17	<mda-.0002	
# tests		23	4	12	6	26	6	

Data derived from RIFE 8, RIFE 9, RAME (2003)

A comparison of radionuclide concentrations for mollusks in the Irish Sea vs the North Sea and the English Channel is shown in table AD-4. Where data are available for mollusks in both marine environments, the contrast in values is rather dramatic. The Irish Sea concentrations are much higher, regardless of radionuclide measured. For example, the Tc-99 concentration in mussels in the Irish Sea average about 900 Bq/kg-ww, while a concentration over 500 times lower (1.67 Bq/kg-ww) is seen in the North Sea. Mussels and cockles display similar comparative concentration ratios in discerning Pu-238 and Pu-239,240 differences between the Irish and North Seas (ratios of about 250 for both mussels and cockles in the Irish vs North Seas). Thus, either of these two organisms should be effective indicators for plutonium uptake in marine environments.

Table AD-4: Radionuclide concentration comparison – by type of radionuclide, marine mollusk and body of water.

	Cockles		*Mussels*		*Scallops*	
	Irish Sea	**North Sea**	**Irish Sea**	**North Sea**	**Irish Sea**	**Channel**
Co-60						
ave	3.58	<mda	3.22	<mda	<mda	<mda
range	0.14-16	<.04-<.12	<0.04-10	<.03-<.06	<0.05-<.1	<.05-<.12
#	50	8	80	12	27	16
Sr-90						
ave			0.76			
range			0.47-1.7			
#			24			
Tc-99						
ave		1.07	900.3	1.67		
range		0.12-1.55	30-2000	1.6-1.7		
#		3	44	8		
Ru-106						
ave		<mda	14.39	<mda		<mda
range		<.23-<.90	<0.33-65	<.30-<.63		<.43-<1.1
#		8	86	12		16
Cs-137						
ave	3.69	0.13	2.4	<mda	0.16	<mda
range	1.5-5.2	<.16-0.18	<mda-4.6	<mda-0.11	<0.17-0.31	<mda-.08
#	50	8	91	12	27	16
Pu-238						
ave	0.67	0.0025	1.4	0.005	0.011	0.0004
range	0.11-2.11	.0017-.003	0.016-2.7	.0015-.013	0.007-.014	8-20E-4
#	23	4	25	4	6	4
Pu-239,40						
ave	3.48	0.0143	6.52	0.026	0.056	0.0032
range	0.64-9.7	.007-.021	0.097-12	.0068-.064	0.036-.078	.002-.004
#	23	4	25	4	6	4
Pu-241						
ave	42.31		60.55			
range	22-100		20-98			
#	13		11			
Am-241						
ave	9.66	0.012	9.35	0.35	<mda	0.0014
range	1.8-28	.0086-.019	<mda-24	.0051-0.12	<mda-.065	9-22E-04
#	23	4	38	4	10	4

Note: Ce-144 and Cm-242 were not found above the mda in any of the samples. Data derived from RIFE 8, RIFE 9, RAME 2002, RPII.

MARINE ALGAE

Algal radionuclide concentrations vary considerably, by both type of algae and type of radionuclide. Recent work (Toshiaki Ishii et al, 2005) has focused on the identification of specific marine algae that have the ability to hyper-accumulate radioisotopes, that is, maintain concentrations of at least 100 times that of a reference organism in the same environment. An assessment of fifty marine algae demonstrated that *Bryopsis maxima* is a hyperaccumulator of Ra-226, Sr-90 and Re-185&187. Its concentration of 0.27 Bq/kg-ww of Sr-90 was the highest of all 50 marine algae tested from the Japanese coast. Compared to the index marine green algae, *Ulva pertusa*, *Bryopsis maxima* concentrated Re-185+187 at a level 22,000 times higher.

References for Appendix 11D:

RIFE 8: CEFAS (The Centre for Environment, Fisheries and Aquaculture Science) – for the Environment Agency, Environment and Heritage Service, Food Standards Agency, and the Scottish Environment Protection Agency: “Radioactivity in Food and the Environment, 2002”, October, 2003.

RIFE 9: CEFAS (The Centre for Environment, Fisheries and Aquaculture Science) – for the Environment Agency, Environment and Heritage Service, Food Standards Agency, and the Scottish Environment Protection Agency: “Radioactivity in Food and the Environment, 2003”, October, 2004.

RAME 2002: Norwegian Radiation Protection Authority. Radioactivity in the Marine Environment 2002, Results from the Norwegian Marine Monitoring Programme (RAME), Stralevern Rapport 2004:10, 2004.

FASSET (Framework for Assessment of Environmental Impact). Deliverable 5: Handbook for Assessment of the Exposure of Biota to Ionising Radiation from Radionuclides in the Environment. (Edited by J Brown, P Strand, A. Hosseini and P Borretzen). October, 2003.

Ishii T, H Shigeki, T. Watabe et al. Hyperaccumulation of Radioisotopes in Marine Algae. Report (2005) of the Laboratory for Radioecology, Nakaminato, Japan.