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Wholebody-to-muscle radionuclide activity concentration conversion ratios for marine biota: data update 2026

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Summary

This data report provides an expanded compilation of wholebody-to-muscle conversion ratios for radionuclide activity concentrations in marine biota. These ratios support a variety of models and calculations used in assessing radionuclide accumulation in marine organisms and in exposures to humans who may consume these organisms as seafood. The ratios presented here are for five common categories of marine organisms and seventeen naturally occurring and anthropogenic radionuclides of principal concern under typical background conditions in marine systems worldwide. They were derived from worldwide range of peer reviewed science papers and government reports that were accessed after initial review of data in the IAEA Marine Radioactivity Information System (MARIS). The statistically summarised ratios (Table 1) cover 12 elements, representing 17 radionuclides of concern across the five marine biota categories of bivalves, cephalopods, crustaceans, fish, gastropods. These ratios are intended to be useful for a wide range of applications and to be relevant for many years into the future.

Background

The accumulation of radionuclides in various tissues of marine organisms depends on the organism's metabolism and physiology, as well as the physico-chemical characteristics of the radionuclides [1][2, 3]. For example, Cs-137 readily accumulates in the muscle tissue of fish, whereas Sr-90 does not and instead preferentially accumulates in bones [4]. As a result, activity concentrations generally differ between the wholebody and specific tissues. For many radionuclides, wholebody activity concentrations typically exceed muscle levels by factors of about 2–5, although the ratios between the two can span two orders of magnitude including some that are <1 for radionuclides such as Cs-137 and K-40 [1].

For marine biota globally, radionuclide activity concentration data are often reported for the muscle/edible-flesh portion because many monitoring studies focus on seafood as an exposure pathway for humans consuming these parts [5]. However, other data are reported as wholebody activity concentrations, especially for smaller organisms but also because dose assessments for marine biota require the wholebody activity concentrations which integrate across all tissues (e.g., organs, skin, and other body

components). When considering global data, in some biota-radionuclide categories only wholebody data are available [5].

When needed, muscle/edible-flesh activity concentrations can be estimated from wholebody data using wholebody-to-muscle conversion ratios. Previously, the most comprehensive source of conversion ratios relating tissue-specific and wholebody data was Yankovich et al. (2010) [1] , which compiled ratios for a range of terrestrial, freshwater, and marine biota. These data were subsequently included in IAEA TRS 479 [6].

The present report uses the compiled data from IAEA TRS 479/Yankovich et al. (2010) as a starting point and expands on these data to address key gaps and improve the statistical robustness of estimates for key categories. This update provides 60 wholebody-to-muscle conversion ratios for use in future studies. These ratios are statistically summarised from 202 underlying ratios extracted from publications reporting sufficient tissue-specific and wholebody measurements. The 60 summary ratios cover 12 elements, representing 17 radionuclides of concern for dose assessment, across five marine biota categories: bivalves, cephalopods, crustaceans, fish, gastropods [7].

Methods

The primary data source was the IAEA Marine Radioactivity Information System (MARIS)[5] from which data from more than 181 studies were initially evaluated. Generally, only a small proportion of studies include the data required to derive conversion ratios. Needed are the activity concentration measurements in both wholebody and muscle/edible tissues for the same species at the same location, or a sufficient range of tissue-specific measurements to derive wholebody activity concentrations. Of the studies evaluated, 42 were found to contain suitable data for deriving the wholebody-to-muscle conversion ratios reported here. A list of source studies is provided in Table 2.

The data cover 17 radionuclides, comprising 11 naturally occurring and six anthropogenic radionuclides. These were selected after screening 63 radionuclides for their relative contributions to typical doses to marine organisms under background conditions (Table 3). Some radionuclides originate from both natural and anthropogenic sources and are classified according to their dominant source. For example, C -14 is grouped with the naturally occurring radionuclides because an estimated 90–95% of C -14 in coastal marine systems is of cosmogenic origin, with only 5–10% attributable to weapons testing [3].

Table 1. Wholebody-to-muscle activity concentration conversion ratios. Conversion ratios are summarised geometric means from underlying published data (except when N<3, for which they are the arithmetic means). N indicates the number of underlying data gathered from references listed in Table 2. The radionuclides are grouped as natural and anthropogenic, and arranged from left to right according to their importance in contributing to radiation dose in marine organisms in general background conditions. Table cells highlighted in magenta identify data gaps and the indicated values are estimates that have been approximated from the closest analogue element (closest in chemical/physiological behaviour) and/or the closest analogue biota category (see specific footnotes).

Radionuclide (Natural)	**Po-210**		**Pb-210**		**K-40**		**Ra-224, 226, 228**		**Th-230, 232**		**U-234, 238**		**C-14**	
Taxonomic Group	*Ratio*	*N*	*Ratio*	*N*	*Ratio*	*N*	*Ratio*	*N*	*Ratio*	*N*	*Ratio*	*N*	*Ratio*	*N*
Bivalves	0.37	17	0.50	1	1.30	1	0.37[a]	-	0.33[b]	-	0.24	3	1.00	2
Cephalopods	0.22	10	0.45	3	1.05	3	0.40	3	0.55[c]	-	0.47	3	1.00[e]	-
Crustaceans	0.27	18	0.25	1	1.21	1	1.03	1	0.41[d]	-	0.33	2	1.00[e]	-
Fish	0.28	15	0.28	7	1.25	7	0.38	3	0.57	2	0.51	1	1.00[e]	-
Gastropods	0.20	8	0.25	7	1.10	1	0.69	2	0.73	2	0.77	2	1.00[e]	-

Radionuclide (Anthropogenic)	**Cs-137**		**Sr-90**		**Tc-99**		**Ag-110m**		**Pu-239,240**	
Taxonomic Group	*Ratio*	*N*	*Ratio*	*N*	*Ratio*	*N*	*Ratio*	*N*	*Ratio*	*N*
Bivalves	0.51	2	0.28	3	0.40[g]	-	0.20[h]	-	0.13	6
Cephalopods	1.13	6	0.33[f]	-	0.48[g]	-	0.06	3	0.17[i]	-
Crustaceans	1.10	1	0.40	2	0.50	2	0.13	1	0.12	1
Fish	1.13	17	0.06	6	0.53[g]	-	0.27[h]	-	0.03	6
Gastropods	1.19	1	0.37[f]	-	0.61[g]	-	0.29[h]	-	0.16[i]	-

Where no published data were available (magenta cells), approximate ratio estimates were derived as follows:

[a] The Ra-bivalve ratio was estimated from N-weighted data for Ra in gastropods and Sr in bivalves.

[b] The Th-bivalve ratio was estimated from N-weighted data for Th in gastropods and U in bivalves.

[c] The Th-cephalopod ratio was estimated from N-weighted data for Th in gastropods and U in cephalopods.

[d] The Th-crustacean ratio was estimated from N-weighted data for Th in fish and U in crustaceans.

[e] Suggest applying the same ratio as for bivalves.

[f] The indicated values for Sr in gastropods and cephalopods are from N-weighted data for Sr in bivalves and U data from the same organism type.

[g] The indicated values for Tc in fish, bivalves, gastropods and cephalopods are from N-weighted data for Tc in crustaceans and best available U or Th data from same organism type.

[h] The indicated values for Ag in fish, bivalves and gastropods are from N-weighted data for Ag in crustaceans and best available U or Th data from same organism type.

[i] The indicated values for Pu in gastropods and cephalopods are from N-weighted data for Pu in bivalves and best available U or Th data from the same organism type.

The summarised values are calculated from underlying data sets derived from published measurements of muscle tissue and wholebody activity concentrations. Specifically, for each underlying data point, the reported wholebody activity concentration was divided by the corresponding muscle (edible-flesh) activity concentration measured in the same sample or sample group. Multiple measurements for the same species within a given study were grouped. The summarised conversion ratios are geometric means. The geometric mean provides the most representative measure of central tendency. Where sufficient data were available, the underlying distributions were tested for lognormality using the Kolmogorov–Smirnov test on log-transformed data. In most cases, the hypothesis of lognormality was accepted, and where it was not, the data remained more consistent with a lognormal distribution than with alternative distribution models. Additional summary statistics (arithmetic mean, standard deviation, geometric standard deviation, median, minimum, and maximum), are provided in Table 4.

Wholebody definition. In practice, the term "wholebody" is used differently by various researchers. Here, we use the same definition of "wholebody" as in Yankovich et al. 2010 [1] described as:

- For fish, crustaceans and cephalopods, wholebody means all tissues (including skin, bones, exoskeleton, organs). The ratios were intended to be calculated from data that did not include the contents of the stomach or GI tract. These contents should be removed before analysis as they are not integrated into tissues. Ideally, the source publication provided a clear definition of which tissues were assessed including removal of stomach and GI tract contents. However, in practice, the wholebody data are often vaguely defined in publications. In some instances, data from substantive and representative portions were provided (while lacking minor portions) and these data were used along with their appropriate mass proportions to derive wholebody estimates. Data were not used when significant tissue types were omitted, for example when the liver and other organs were omitted.
- For bivalves and gastropods, wholebody means all soft tissues without the shell or byssus filaments. The reported conversion ratios compare muscle data vs whole soft-tissue data. For most radionuclides, this is adequate because most radionuclide accumulation is accounted for as the greatest accumulation is in the soft tissues, especially digestive/hepatopancreas organs, not in the shells. This suggests the current approach is adequate. However, a more ideal approach for bivalves and gastropods would include the radionuclides accumulated in shells as appropriately weighted according to their dose contributions. Gamma and beta emitting radionuclides located in the shell tissues will contribute proportionally to organism dose whereas most alpha emissions originating in shell material would be self-shielded within the shell. In the current work, we examined available shell data

and, for marine organisms, it appears that the addition of shell data would not greatly alter potential dose rates (excepting perhaps beta emitters such as Sr-90) although these complexities could be further considered using 3D voxel modelling to reduce uncertainties.

The five marine biota categories mainly reflect the available data types which in turn mainly come from seafood monitoring programs. Categorisation also reflects physiological differences—molluscs are divided into subcategories because cephalopods typically lack the shells that are present on bivalves and gastropods. Bivalves and gastropods are listed separately as their feeding behaviours lead to differing radionuclide accumulation. In addition, most seafood consumers eat all (or most) of the soft tissues of bivalves including the GI tract, whereas they typically do not with other seafoods (most fish, cephalopods) although exceptions occur for smaller organisms (sardines). Conversion ratios for marine mammals are not provided due to sparse wholebody data. Conversion factors for plants (i.e. seaweed) were not determined due to insignificant differences in activity concentrations between leaf, stem, roots etc.

The current data are not sufficient to support a rigorously detailed taxonomic analysis, and this could be done in the future when more data become available. Within the categories, the limited conversion ratio data suggest some differences between species/genera likely owing to physiological differences. However, these do not appear to be large differences. For example, the interspecies variation in wholebody-to-muscle ratios appears to be far less than that which is exhibited in uptake factors (concentration ratios, CRs)[2]. This makes sense in that CRs reflect the *amount* of a radionuclide taken up which can vary widely between species depending on differing feeding behaviours, whereas the distribution of the radionuclides among tissue types does not depend on the amount being taken up.

A total of 42 reference studies contributed 202 underlying ratios to the final compilation with the specific references for each ratio are listed in Table 2. The literature search was extensive and relied primarily on manual examination of PDF journal articles assembled during IAEA projects. Note that laboratory uptake/biokinetic study data were considered but not used here as their wholebody-to-muscle ratios are (by design in pulse-chase studies) not steady state or representative of chronic exposure conditions. The pulse-chase laboratory data we evaluated varied greatly depending on study durations (usually days) and were distinctly different than the field/chronic data. From a given source publication, the reported muscle (edible flesh) activity concentration was divided by the corresponding wholebody activity concentration as measured for the same sample or sample group. Repeats for the same species within a given study were grouped.

Because the Table 1 values represent typical background marine conditions (not specific site releases) it does not therefore include some radionuclides that could be of concern in local areas or of short-lived concern. For example, I-131 and H-3 were both considered in the initial screening because they may be important dose contributors in localised or dynamic conditions [8]. However, owing to their relatively short half-lives and/or rapid environmental dispersion, their activity concentrations under typical background conditions are too low to make a substantial contribution to chronic background radiation dose[9].

For future efforts to improve the coverage of wholebody-to-muscle ratios, we suggest that additional data may be found in studies reporting on elemental concentrations in seafood and also in government reports, national marine monitoring programmes or environmental monitoring reports associated with nuclear facilities. These sources were accessed in this work, but only to a limited degree as this effort focused mainly on peer-reviewed science publications containing radionuclide measurements.

Table 2. publication references supporting the values in Table 1.

[10],[11],[12],[13],[14],[15],[16],[17],[18],[19],[20],[21],[22],[23],[24],[25],[26],[27],[28],[29],[30],[31],[32],[33],[34],[35],[36],[37],[38],[39],[40],[41],[42],[43],[44],[45],[46],[47],[1],[48]

	Po-210	Pb-210	K-40	Ra-224, 226, 228	Th-230, 232	U-234, 238	C-14		Cs-137	Sr-90	Tc-99	Ag-110m	Pu-239, 240
Fish	[1] [15], [16], [18], [23], [29], [31]	[15], [16], [1]	[35], [36]	[1] [11]	[10], [17]	[10]			[34], [35], [36]	[1], [35], [39], [42]			[13], [34], [35], [36]
Crustaceans	[1], [15], [16], [27], [28], [31], [33], [41]	[1], [16], [27], [28]	[1], [38]	[38]		[45]			[46]	[49]	[30]	[19]	[46]
Bivalves	[1], [14], [18], [20], [21], [22], [32], [40], [47]	[1], [22], [40], [47]	[1], [35]			[49]	[25]		[32]				[34], [35], [36]
Gastropods	[1], [18], [28], [47]	[1], [28], [47]	[47]	[47]	[47]	[47]			[47]				
Cephalopods	[12], [15], [16], [24], [27], [43]	[15], [16], [27]	[48]	[48]		[48]			[48]			[48]	

Table 3. Radionuclides screened for inclusion in this study. Carried forward were the 11 naturally-occurring radionuclides and 5 anthropogenic radionuclides that, in their respective categories, are of most consequence for imparting dose in typical background marine conditions [7].

Ac-228	Eu-154	Pb-214	Sc-46
Ag-110m	Eu-155	Po-210	Sn-113
Am-241	Eu-156	Pu-238	Sn-117m
Ba-140	Fe-59	Pu-239	Sr-89
Be-7	Gd-153	Pu-240	Sr-90
Bi-214	H-3	Pu-241	Tc-99
C-14	I-129	Pu-242	Te-129m
Ce-141	I-131	Ra-223	Th-227
Ce-144	K-40	Ra-224	Th-228
Co-57	La-140	Ra-226	Th-230
Co-58	Mn-54	Ra-228	Th-232
Co-60	Na-22	Rb-86	Th-234
Cs-134	Nb-95	Rb-87	U-234
Cs-137	Pa-234m	Ru-106	U-235
Cr-51	Pb-210	Sb-124	U-238
Eu-152	Pb-212	Sb-125	

Table 4. Summary statistics on the wholebody-to-muscle activity concentration conversion ratios. GM it the geometric mean, GSD is the geometric standard deviation, AM is the arithmetic mean, SD is the standard deviation, N is the number of underlying published data.

Radionuclide	Taxonomic group	GM	GSD	Median	AM	SD	Min	Max	N
Ag-110m	Bivalve								
	Cephalopods	0.06	1.80	0.04	0.06	0.04	0.04	0.11	3
	Crustaceans				*0.13*				*1*
	Fish								
	Gastropod								
C-14	Bivalve				*1.00*	*0.01*	*0.99*	*1.01*	*2*
	Cephalopods								
	Crustaceans								
	Fish								
	Gastropod								
Cs-137	Bivalve				*0.51*	*0.01*	*0.51*	*0.52*	*2*
	Cephalopods	1.13	1.10	1.17	1.13	0.11	1.00	1.24	6
	Crustaceans				*1.10*				*1*
	Fish	1.12	1.18	1.14	1.14	0.17	0.71	1.39	15
	Gastropod				*1.19*				*1*
K-40	Bivalve	1.30	1.09	1.24	1.30	0.11	1.23	1.43	3
	Cephalopods	1.05	1.03	1.06	1.05	0.03	1.01	1.07	3
	Crustaceans				*1.15*	*0.09*	*1.09*	*1.21*	*2*
	Fish	1.25	1.09	1.22	1.25	0.10	1.08	1.39	7
	Gastropod				*1.10*				*1*
Pb-210	Bivalve	0.50	1.82	0.52	0.58	0.34	0.24	1.13	6
	Cephalopods	0.45	2.25	0.53	0.54	0.27	0.11	0.82	5
	Crustaceans	0.25	1.79	0.24	0.28	0.13	0.08	0.50	9
	Fish	0.28	2.54	0.23	0.43	0.51	0.07	1.72	9
	Gastropod	0.25	2.28	0.29	0.32	0.21	0.08	0.58	7
Po-210	Bivalve	0.37	1.98	0.38	0.45	0.28	0.06	1.08	17
	Cephalopods	0.22	2.78	0.32	0.32	0.24	0.03	0.81	12
	Crustaceans	0.27	1.81	0.29	0.32	0.17	0.09	0.69	18
	Fish	0.28	1.85	0.30	0.33	0.18	0.09	0.66	15
	Gastropod	0.20	1.64	0.21	0.23	0.11	0.10	0.44	8
Pu-239,240	Bivalve	0.13	3.50	0.11	0.22	0.24	0.02	0.62	6
	Cephalopods								
	Crustaceans				*0.12*				*1*
	Fish	0.03	2.23	0.02	0.04	0.03	0.01	0.10	6
	Gastropod								
Ra-224,226,228	Bivalve								
	Cephalopods	0.36	1.97	0.50	0.41	0.22	0.17	0.57	3

Radionuclide	Taxonomic group	GM	GSD	Median	AM	SD	Min	Max	N
	Crustaceans				*1.03*				*1*
	Fish	0.38	1.15	0.39	0.38	0.05	0.32	0.43	3
	Gastropod				*0.69*	*0.06*	*0.65*	*0.73*	*2*
Sr-90	Bivalve	0.34	2.28	0.28	0.43	0.36	0.17	0.83	3
	Cephalopods								
	Crustaceans				*0.59*	*0.46*	*0.26*	*0.91*	*2*
	Fish	0.06	3.65	0.04	0.11	0.13	0.01	0.32	6
	Gastropod								
Tc-99	Bivalve								
	Cephalopods								
	Crustaceans				*0.55*	*0.30*	*0.33*	*0.76*	*2*
	Fish								
	Gastropod								
Th-230,232	Bivalve								
	Cephalopods								
	Crustaceans								
	Fish				*0.57*	*0.10*	*0.50*	*0.64*	*2*
	Gastropod				*0.73*	*0.13*	*0.64*	*0.82*	*2*
U-234,238	Bivalve	0.28	2.05	0.26	0.33	0.23	0.14	0.59	3
	Cephalopods	0.44	1.50	0.47	0.47	0.18	0.29	0.65	3
	Crustaceans				*0.33*	*0.03*	*0.31*	*0.35*	*2*
	Fish				*0.51*				*1*
	Gastropod				*0.77*	*0.00*	*0.76*	*0.77*	*2*

Where there are only 2 data, the AM, SD and min and max are provided. Where there is only 1 data, that value is provided as the AM.

Blank cells indicate data gaps, see table 1 for suggested conversion ratios derived using an analogue species and/or radionuclides.

Authorship

This data report was prepared by Mathew P. Johansen (mathew.johansen@ansto.gov.au) and Francesca Gissi (Francesca.gissi@ansto.gov.au) Australian Nuclear Science and Technology Organisation, Sydney Australia.

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