Assessment of doses to biota in the Baltic Sea

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Abstract. The Baltic Sea is one of the most contaminated sea areas with respect to ^{137}Cs and ^{90}Sr. Due to the slow exchange of water between the Baltic Sea and the North Sea and the relatively rapid sedimentation rates, radionuclides have prolonged residence times in the Baltic Sea. To assess the doses to biota resulting from exposure to radionuclides from anthropogenic sources in the Baltic Sea, the ERICA assessment tool was applied. ERICA Tool allows the estimation of dose rates to biota for different ecosystems for a set of default reference organisms or a user-defined organism. The input data on radionuclide concentrations in biota, water and sediment were obtained from the HELCOM-MORS database complemented by additional measurements carried out by STUK. The assessment was carried out for the major anthropogenic radionuclides, ^{137}Cs and ^{90}Sr. However, the dose resulting from the most important natural radionuclides, such as ^{210}Po, was also considered for comparison. The assessment was performed for the most contaminated areas of the Baltic Sea: the Gulf of Finland and the Bothnian Sea. The species considered included seaweed, fish and bottom living crustacean. The assessment was carried out for the present situation and also for the time of the Chernobyl accident. The results revealed that the dose rates to the studied species were clearly below the screening level of 10µGy/h, indicating no significant impact due to the anthropogenic radionuclides on these species. Regarding the radionuclides assessed, ^{210}Po contributed the highest dose.

KEYWORDS: (Baltic Sea, biota, dose, polonium)

INTRODUCTION

International standards and national legislation of many countries have until recently had the statement that the environment or non-human species are protected from the harmful effects of ionising radiation if humans are protected. Upcoming new editions of international standards, such as the EU or IAEA Basic Safety Standards, and the existing ICRP Publication 108 include new requirements and recommendations for safety and protection of non-human species or the total environment.

It is important to demonstrate that both humans and biota are protected against the effects of industrial pollutants and also radionuclides. Usually different levels of protection are applied for humans and for biota. Regarding humans every individual should be protected, while for non-human species protection on a population level is sufficient with some exceptions. Therefore, in many cases the assumption that non-human species are protected when humans are protected could be applied. However, there are environments where humans are not present whereas biota is under the impact of ionising radiation permanently. Such an environment is the Baltic Sea.

The origin of artificial radionuclides in the Baltic Sea is the Chernobyl fallout in 1986, nuclear weapons tests fallout from the 1940s to the 60s as well as routine and continuous discharges from licensed facilities. The Baltic Sea biota received the most important contribution of its activity concentrations from the Chernobyl accident in 1986, predominantly from ^{137}Cs and ^{134}Cs. Certain radionuclides occurring in water and sediment are gradually accumulated to organisms mainly through nutrient uptake or via food chains. The potential harmful effects of radiation to biota include, for instance, increased mortality and reduced reproductive success of a population. These effects are addressed in environmental risk assessment methods, whereas factors such as variation in radiosensitivity between species and individuals, interactions between species and adaptation of populations to radiation exposure are omitted due to inadequate scientific knowledge.

Various tools exist that can be used for assessment of risk caused by ionizing radiation to biota. Some of them, for example the ERICA Tool or RESRAD-BIOTA, are freely accessible, while many others, such as AECL, Dmax, ECOMOD, Lietdos and LakeCo are not. Intercomparisons of different tools have shown wide variability of the results (e.g. Beresford et al., 2008; Vives I Batlle et al., 2007, 2010; Yankovich et al., 2010). The main reason for this variability is the parameterisation of the transfer components of the models. Therefore, the availability and use of site-specific data instead of generic transfer factors lead to higher accuracy and smaller uncertainties of the estimated doses to biota.

This paper presents the outcome of a radiological impact assessment of biota in the Gulf of Finland and the Bothnian Sea, representing areas which contain the highest activity concentrations found in the Baltic Sea.

DATA USED IN RADIOLOGICAL IMPACT ASSESSMENT FOR BIOTA IN THE BALTIC SEA

Existing database produced under the HELCOM/MORS programme (HELCOM MORS, 2010) was used to estimate dose rates to biota in the Baltic Sea. The data from the HELCOM-MORS database was supplemented with some ^{90}Sr and ^{239,240}Pu data (Ilus et al., 2008; Ikäheimonen et al., 2006 a,b) and with previously unpublished Po and Pb measurements carried out at STUK. Dose estimations were carried out for two sub-basins in the Baltic Sea: the Gulf of Finland and the Bothnian Sea. These are the two sea areas that received the highest ^{137}Cs deposition and subsequent runoff from the catchment areas of the Baltic Sea. The assessment was carried out for the present situation and also for the year of the Chernobyl accident, 1986. The present situation covers mainly the period of 2006-2010. For certain sample types and radionuclides a longer time period (2000-2010) was considered due to lack of data.

The average activity concentrations of ^{137}Cs, ^{40}K, ^{90}Sr, ^{210}Po, ^{210}Pb, and $^{234,\ 240}$Pu were calculated from the data for surface water, sediment (top 5 cm), macroalgae (*Fucus vesiculosus*), crustacean (*Saduria entomon*), and pike (*Esox lucius*). In addition, the dose rates from ^{137}Cs to *Fucus vesiculosus*, *Saduria entomon* and Baltic herring (*Clupea harengus membras*) were estimated from the data obtained in 1986. These average activity concentrations (Tables 1-2) represent the best estimate values for the Gulf of Finland and the Bothnian Sea in the studied time periods.

Table 1. Average activity concentrations of ^{137}Cs, ^{40}K, ^{90}Sr, ^{210}Po, ^{210}Pb, $^{234,\ 240}$Pu in surface water (Bq/l), sediment (Bq/kg dry weight) and biota (Bq/kg fresh weight, whole organism) at present.

Sampling site	Sample	^{137}Cs	^{40}K	^{90}Sr	^{210}Po	^{210}Pb	^{239,240}Pu
Gulf of Finland	Water (Bq/l)	0.0249	1.74	0.00963	0.00195	0.00695	0.0000016
	Sediment (Bq/kg d.w.)	240	714	3.51	696	464	**1.50**
	Fucus v. (Bq/kg f.w.)	5.28	146	1.65	3.42	1.00	0.0139
	Saduria e. (Bq/kg f.w.)	2.78	47.9	2.58	16.5	1.70	0.00417
	Esox lucius (Bq/kg f.w.)	10.3	87.0	0.437	3.078	0.0855	0.00076*
Bothnian Sea	Water (Bq/l)	0.0426	1.94	0.009	0.00178	0.00215	0.0000016
	Sediment (Bq/kg d.w.)	726	1030	2.36	-	333	2.01
	Fucus v. (Bq/kg f.w.)	4.31	120	1.24	2.02	0.643	0.00944
	Esox lucius (Bq/kg f.w.)	16.5	80.6	0.678	1.43	0.0490	-

*Value is an average value for fish (several species) from the whole Baltic Sea area

Table 2. Average activity concentrations of ^{137}Cs in surface water (Bq/l), sediment (Bq/kg dry weight) and biota (Bq/kg fresh weight) in the Gulf of Finland and the Bothnian Sea in 1986.

Sampling site	Sample	^{137}Cs
Gulf of Finland	Water	0.461
	Sediment	378
	Saduria entomon	121
	Clupea harengus membras	56.6
	Fucus vesiculosus	147
Bothnian Sea	Water	0.477
	Sediment	305
	Clupea harengus membras	56.1
	Fucus vesiculosus	63

ESTIMATION OF DOSE RATES TO BIOTA USING THE ERICA TOOL

The ERICA Assessment Tool (Brown et al., 2008), version May 2009, was used to estimate the dose rates to biota. In the ERICA Tool, Tier 2 of the three available tiers was applied in this assessment. The first tier intended to screen out sites of negligible concern with a high degree of confidence was not used since a comparison of the performance of three models, including the ERICA Tool, showed that the outputs of the screening tiers vary considerably between the models (Beresford et al., 2010).

The site-specific measured activity concentrations of ^{137}Cs, ^{40}K, ^{90}Sr, ^{210}Po, ^{210}Pb and $^{239, 240}$Pu in biota, water and sediment (Tables 1-2) were used as input data in the model. The default reference organisms were used for the geometries and dimensions of biota (Table 3). The default occupancy factors for the reference organisms provided in the Tool were used in the model calculations (Table 3). The use of the default occupancy factors will result in maximal dose rates to biota (Oughton et al., 2008). Also a default uncertainty factor of three was used to account for the uncertainties involved in the assessment method (Oughton et al., 2008).

The Tool performs dose rate calculations using the input data by applying dose conversion coefficients (µGy/h per Bq/kg fresh weight, see Ulanovsky et al., 2008) and weighting factors for different components of radiation (10 for alpha, 3 for low energy beta and 1 for beta, gamma radiation). At Tier 2 the results are given as total, internal and external weighted whole body absorbed dose rates (Brown et al., 2008).

Currently there are no internationally agreed legally binding criteria or standards for dose rates to biota that must be met in accordance with regulation. Several dose rate values have been suggested to be used as a screening value, which means that if this value is exceeded further investigation is needed to better understand and quantify the risk. In this study a screening value 10 µGy/h was used. The derivation of this value is based on examination of the available data on dose-effect relationships for various organisms obtained in laboratory or field experiments, and has been presented in Andersson et al. (2009) and Garnier-Laplace et al. (2008). The total (internal and external summed) dose rates estimated are compared directly to the selected screening dose rate to enable the assessment of risk to biota.

Table 3. Reference organisms for marine environment provided in the ERICA Tool, samples corresponding to reference organisms and default occupancy factors.

Reference organism	Sample	Occupancy factor (percentage of time spent in given locations)
Crustacean	*Saduria entomon*	100% on sediment surface
Macroalgae	*Fucus vesiculosus*	100% on sediment surface
Pelagic fish	*Esox lucius* *Clupea harengus membras*	100% in water column

RESULTS AND DISCUSSION

Currently the total dose rate from ^{137}Cs varies from 0.002 to 0.1 µGy/h for the studied species in the most contaminated sea areas of the Baltic Sea, the Gulf of Finland and the Bothnian Sea (Table 4). The lowest dose rates were associated with fish and the highest with seaweed. The results of ^{137}Cs are in line with Hosseini et al. (2011) indicating the highest external and total doses to sediment-associated organisms. For those species not associated with sediment, such as pelagic fish, the internal doses exceeded the external doses of ^{137}Cs.

Table 4. Average dose rate (internal, external and total dose rate) to biota in the Baltic Sea given as µGy/h from various radionuclides at present.

Sampling site	Sample		^{137}Cs	^{40}K	^{90}Sr	^{210}Po	^{210}Pb	^{239,240}Pu
Gulf of Finland	*Fucus vesiculosus*	Internal	6,87E-04	3,29E-02	7,42E-04	1,06E-01	2,08E-04	4,16E-04
		External	4,08E-02	5,95E-02	3,52E-04	1,71E-06	1,09E-02	3,39E-07
		Total	4,14E-02	9,24E-02	1,09E-03	1,06E-01	1,11E-02	4,17E-04
	Saduria entomon	Internal	5,00E-04	1,45E-02	1,62E-03	5,13E-01	4,24E-04	1,25E-04
		External	3,48E-02	3,15E-02	4,05E-05	1,50E-06	1,04E-03	8,76E-08
		Total	3,53E-02	4,60E-02	1,67E-03	5,13E-01	1,47E-03	1,25E-04
	Esox lucius	Internal	1,85E-03	2,62E-02	2,71E-04	9,54E-02	2,13E-05	2,25E-05*
		External	7,22E-06	1,57E-04	2,60E-07	8,58E-12	3,41E-08	2,083E-13*
		Total	1,86E-03	2,64E-02	2,71E-04	9,54E-02	2,14E-05	2,25E-05*
Bothnian Sea	*Fucus vesiculosus*	Internal	5,61E-04	2,72E-02	5,59E-04	6,26E-02	1,34E-04	2,83E-04
		External	1,23E-01	8,54E-02	2,37E-04	1,71E-06	7,83E-03	4,54E-07
		Total	1,24E-01	1,13E-01	7,96E-04	6,26E-02	7,96E-03	2,84E-04
	Esox lucius	Internal	2,97E-03	2,43E-02	4,20E-04	4,20E-02	1,22E-05	-
		External	1,24E-05	1,75E-04	2,43E-07	7,81E-12	1,05E-08	-
		Total	2,99E-03	2,45E-02	4,21E-04	4,42E-02	1,22E-05	-

*Value is an average value for various fish species sampled from the whole Baltic Sea area

Table 5. Average dose rate (internal, external and total dose) to biota in the Baltic Sea given as μGy/h in 1986 from Cs-137

Sampling site	Sample	Dose	^{137}Cs
Gulf of Finland	*Fucus vesiculosus*	Internal	1,91E-02
		External	6,43E-02
		Total	8,34E-02
	Saduria entomon	Internal	2,18E-02
		External	5,49E-02
		Total	7,66E-02
	Clupea harengus membras	Internal	1,02E-02
		External	1,34E-04
		Total	1,03E-02
Bothnian Sea	*Fucus vesiculosus*	Internal	8,19E-03
		External	5,19E-02
		Total	6,01E-02
	Clupea harengus membras	Internal	1,01E-02
		External	1,38E-04
		Total	1,02E-02

In the year of the Chernobyl accident, 1986, the dose rate from ^{137}Cs varied from 0.01 to 0.08 µGy/h for biota (Table 5). Within 25 years the total dose rates from ^{137}Cs to fish have decreased by a factor of ten while those to macroalgae and crustacean have decreased by a factor of two, except in the Bothnian Sea where the total dose rate to seaweed has increased due to the higher external dose rate from sediments there (Fig. 1). Most of the ^{137}Cs originating from the Chernobyl deposition and subsequent runoff from the catchment areas have settled into the bottom sediments. However, total amounts of ^{137}Cs in sediments are not yet showing any signs of decrease (Ikäheimonen et al., 2009). Any loss of ^{137}Cs due to physical decay is counterbalanced by the settling of ^{137}Cs from water into sediments that still continues to a lesser degree.

The other Cs isotope, ^{134}Cs, which was released from Chernobyl accident, is not considered here. Due to its shorter half-life (2 years) it is not anymore present in the Baltic Sea, though back in 1986 it contributed to the dose.

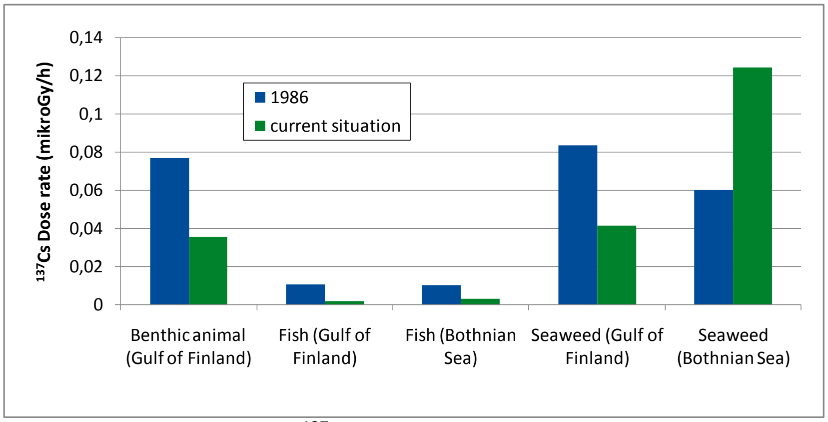

Fig 1. Total dose rate from^{137} Cs to various biota at present and in 1986.

The dose rates from the two other artificial radionuclides evaluated, ^{90}Sr and ^{239,240}Pu, were generally 10 and 100 times smaller than those of ^{137}Cs, respectively (Fig 2). For both ^{90}Sr and ^{239,240}Pu the internal dose rate dominated over the external. The total dose rate from all studied artificial radionuclides combined is currently 0.002-0.1 µGy/h and is dominated by ^{137}Cs.

In addition to the artificial radionuclides, the natural radionuclides, ^{210}Po,^{210}Pb and ^{40}K, were also considered. ^{210}Po, an alpha emitter, generally contributed the highest dose for the species studied (Fig 2). The dose from ^{210}Po originates almost completely from the internal exposure. The dose rate from ^{210}Pb was higher than that of ^{90}Sr for macroalgae, but lower for fish where the dose rates from ^{210}Pb and ^{239,240}Pu were in the same order. The dose rates from ^{40}K were similar to those from ^{137}Cs for macroalgae and benthic animals but about 10 times higher for fish when compared to ^{137}Cs.

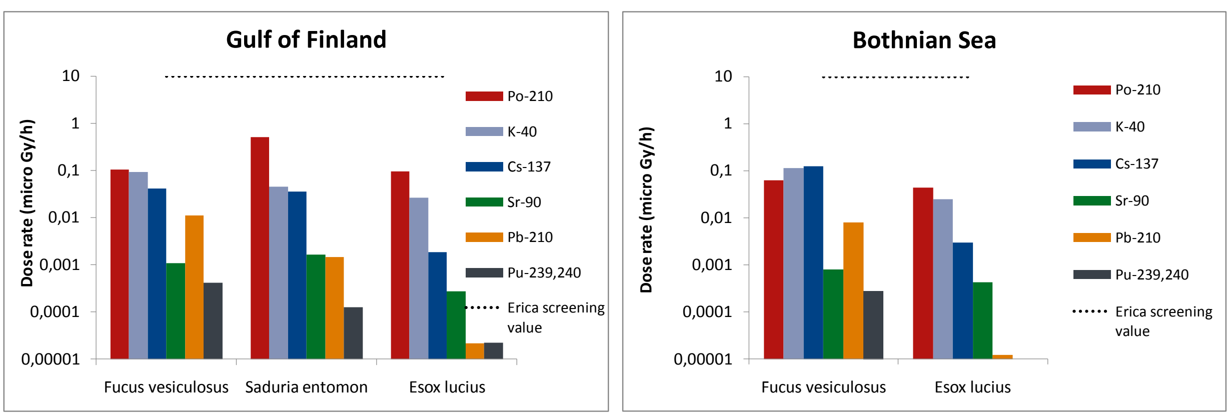

Fig. 2 Average dose rates (micro Gy/h) from various radionuclides to biota in the Baltic Sea at present.

CONCLUSIONS

The doses to the Baltic Sea biota were mainly dominated by the natural radionuclide ^{210}Po, while the contribution of ^{137}Cs to the dose was generally less than one tenth of the proportion of ^{210}Po. The dose rates from ^{40}K were in the same order than those from ^{137}Cs, except for fish where the dose rates from ^{40}K were 10 times higher than those from ^{137}Cs. The contribution from the other radionuclides evaluated (^{90}Sr, ^{239,240}Pu and ^{210}Pb) to the total dose were of minor importance.

The dose rates from the evaluated radionuclides were clearly below the screening level of 10 µGy/h. Therefore, the biological effects of ionising radiation on biota in the Gulf of Finland and in the Bothnian Sea can be concluded to be negligible in the current radiation situation. However, it should be kept in mind that the screening value of 10 µGy/h, derived in the ERICA project and adopted in this assessment, is a generic value for all organism groups despite their different radiosensitivities. Until scientific knowledge improves with respect to ecologically relevant low-dose effects and, for instance, variation in radiosensitivity between different groups of species, particularly for mammals and birds, the conclusion from this assessment is that the level of protection of biota from ionising radiation in the Baltic Sea has been sufficient.

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