Food Control 133 (2022) 108658

Contents lists available at ScienceDirect

Food Control

journal homepage: www.elsevier.com/locate/foodcont

Concentration of radionuclides in Swedish market basket and its radiological implications

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ARTICLE INFO

Keywords:
Natural radioactivity
Caesium
Polonium
Radium
Uranium
Seafood

ABSTRACT

The entrance of radionuclides to the human food chain together with the ingestion favour tissues deposition of radionuclides throughout the human body, which may have long-term implications for radiation doses. That affects world population, since it represents approximately 12% of the annual effective dose received for the public. This contribution will be quite variable depending on the food habits, food origin and the background levels of the place of residence. It is therefore necessary to monitor the food to be able to control and quantify the risk of exposure of the public. A wide range of food products (vegetables, fruits, meat, fish etc.) have been collected and analysed by different radiometric techniques in order to measure the activity concentration of naturally occurring and anthropogenic radionuclides (^{40}K, ^{137}Cs, ^{210}Po, ^{226}Ra, ^{228}Ra, ^{234}U and ^{238}U). The results of the investigation highlighted that the average committed effective dose from one year's food consumption in Sweden ranged from 82 to 142 μSv for children and it was around 134 μSv for adults. Additionally, considering the consumption percentile 95 (P95), the total ingestion exposure could raise up to 560 μSv/y for children and 340 μSv/y for adults. In all population groups analysed, the internal exposure was mainly controlled by the intake of ^{210}Po ($\sim$ 94–98%), in particular via seafood consumption for example, as a result of the high levels of ^{210}Po in shellfish such as shrimp (30 $\pm$ 2 Bq/kg) or blue mussel (55 $\pm$ 7 Bq/kg).

1. Introduction

The concentration of radionuclides in food is due to the presence of radionuclides in the environment finding its way into edibles through uptake and atmospheric deposition, and also through bioaccumulation in the food chain (IAEA, 2016). Plants and animals take up radionuclides with the nutrients that they need to survive. The uptake of radionuclides in human food chain will depend on the radionuclide content in the environment (soil, bedrock, groundwater, seawater, etc.) and the chemical properties such as pH and availability of competing elements with similar chemical properties. Consequently, some radionuclides tend to concentrate in certain parts of the organism and hence, consumption of these parts can lead to an increase of several magnitudes in radionuclide concentration in the host body. This may have long-term implications for radiation doses (IAEA, 2016). For some radionuclides, such as ^{40}K, are stabilized through excretion. Also, studies on the ingestion of uranium have shown that most of the uranium is excreted within a few days while only 0.2 %- 5% enters the bloodstream (Brugge & Buchner, 2011).

The radionuclides present in food and water contributes to approximately 12% of the annual radiation dose, which is estimated to be 2.4 mSv (UNSCEAR, 2000). Although this largely depends on the type of diet and on the origin of the food. In that sense, the radiological risk concerning the intake of the progenies of the uranium and thorium series (^{210}Po $>$ ^{228}Ra $>$ ^{210}Pb $>$ ^{226}Ra $>$ ^{234}U $>$ ^{238}U $>$ ^{224}Ra $>$ ^{235}U) as well as anthropogenic radionuclides (^{137}Cs and ^{90}Sr) by food consumption, requires special attention.

After the Chernobyl nuclear accident, many studies were conducted to investigate the radiological impact to the human food chain in regions of the world contaminated by anthropogenic radionuclides (IAEA, 1989; Pearson et al., 2016; Raaf et al., 2006). Most recently, the Fukushima nuclear power plant accident has resulted in increased research on the radiological risk regarding consumption of food from areas affected by the fallout (Hachinohe et al., 2020; Steinhauser & Saey, 2016). Over the

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https://doi.org/10.1016/j.foodcont.2021.108658
Received 10 September 2021; Received in revised form 20 October 2021; Accepted 30 October 2021
Available online 3 November 2021

last half-century, IAEA and UNSCEAR have tried to raise concern for the intake of naturally occurring radionuclides by food consumption (UNSCEAR, 2000). At present, IAEA/FAO/WHO are working on a project regarding radionuclides in food and drinking water, collecting recent data on radionuclides in food (1998–2017) from publications and Member States (Colgan, 2021) while the Joint Research Centre (European Commission) is working on the European atlas of natural radiation including radionuclides in food (Cinelli et al., 2019). However, despite its relevance to radiation exposure, natural radioactivity in food rarely receive much attention and the data available are limited. European monitoring programs are mainly focusing on anthropogenic radionuclides that will be released in case of a hypothetical nuclear accident, and the legislation regarding natural radioactivity is scarce. Although some studies were carried out in different countries, especially in areas with high natural activity concentration levels like Iran or India (Ghiassi-Nejad et al., 2003; Shanthi et al., 2010), little is known regarding the levels of naturally occurring radionuclides in foodstuff around the world. Some investigations reported at the *International topical conference on Po and radioactive Pb isotopes*, held in Seville (Spain) in 2009, showed the importance of the surveillance of ^{210}Po uptake by foodstuffs (Holm & Garcia-Tenorio, 2011). Also in Sweden, only few studies have so far focused on the impact of naturally occurring radionuclides related to the food consumption (Gjelsvik et al., 2012; Komperød et al., 2020; Rosén et al., 2012).

The assessment of effective dose by ingestion of radionuclides from food is influenced by a large number of sources of uncertainty (Ould-Dada, 2006). For that reason, it is necessary to build mathematical models based on data from radioactivity measurements of products collected in market places or local distribution centres that provide foodstuff to large population groups, in order to provide good estimations. The Article 36 of the EURATOM Treaty, "*Concerning the monitoring of the levels of radioactivity in the environment for the purpose of assessing the exposure of the population*"; considers that the monitoring of foodstuff, instead of mixed diet, is the best choice to carry out a representative study to assess the radiological risk by food consumption (2000/473/Euratom, 2000). For that reason, monitoring of food is necessary to be able to control and quantify the risk of exposure of the public.

The aim of this study is to examine the activity concentration of natural and anthropogenic radionuclides in food consumed in Sweden, in order to evaluate the fraction of the annual committed effective dose received by the Swedish population through food consumption. To achieve these goals a suitable radiochemistry methodology together with specific sampling campaigns were performed. The research was focused on naturally occurring and anthropogenic radionuclides: ^{40}K, ^{210}Po, ^{228,226}Ra, ^{234,238}U and ^{137}Cs. In addition, a large review of the food consumption in different age groups in Sweden was performed to ensure a realistic dose assessment. Therefore, the current investigation provides consumers and stakeholder with valuable data and information regarding the radioactivity levels in food and their radiological implications.

2. Material and methods

2.1. Food sampling

Altogether, 129 food samples, representing 55 different foodstuff, were purchased from August 2017 to April 2019 in different supermarkets, shops, fish markets, groceries, and local farms, and gathered wild food was collected when appropriate. The representative foodstuff samples were chosen considering the Swedish food habits (Livsmedelsverket, 2012, 2018; Martin et al., 2016) together with the most relevant statistics regarding food consumption in Sweden (Jordbruksverket, 2015).

2.2. Measurement of radioactivity levels

As regular pre-treatment, if needed samples that could contained dust or soil were washed, and non-consumed parts of all the food samples analysed were removed before being weighed and oven dried. The samples were dried at 80 °C to avoid any loss of polonium (IAEA, 2017). Then, dried samples were blended, sieved (0.5 mm) and homogenized. Specific pre-treatments were then applied for certain radiometric analyses of, e.g. ^{210}Po and ^{234,238}U (see section 2.2.2). When possible, dried samples were burned to ashes at 600 °C in order to remove organic matter and improve the detection limits for the determination of radionuclides of interest.

2.2.1. Gamma-ray spectrometry

Homogenized samples were packaged in cylindrical containers of 35 mL (Nolato Hertila, Sweden). After preparation, the containers were vacuum-sealed using a vacuum sealer (OBH Nordica, Sweden) and plastic vacuum bags from OBH Nordica (art. 7954) to minimize radon losses in order to determine ^{226}Ra by secular equilibrium, after at least 30 days. The radionuclide measurements were performed using a high-purity germanium detector Ortec GEM 50P4 (AMETEK ORTEC, USA), with a relative efficiency of 52% and an energy resolution of 1.65 keV at 1.33 MeV. Table 1 shows the radiological properties of the radionuclides analysed by gamma-ray spectrometry. Self-absorption correction was not applied because of the thin geometry used (not higher than 15 mm) and the gamma energies (over 200 keV in all cases) of the radionuclides under study. Procedure was validated and satisfactory results were achieved in annual proficiency tests (Mantero et al., 2019; Piñero-García et al., 2021). Samples were measured from 2 to 4 days and spectra were analysed by GammaVision for Windows version 8 (AMETEK ORTEC, USA). Minimum Detectable Activity (MDA) was calculated according to ISO11929, and the results are shown in Table 1 based on the average measurement times.

2.2.2. Alpha emitting radionuclides

Sample masses used varied depending on the examine radionuclide. For the determination of ^{210}Po 2–4 g of dried samples were used and for uranium radioisotopes, 1–2 g of ashed samples. These samples were digested by Ethos Easy microwave digestion system (Milestone S.r.l., Italy). Before digestion, the samples were spiked with ^{209}Po (Eckert & Ziegler® Isotope Products, USA) or ^{232}U (National Physical Laboratory, UK) to assess the recovery yield as well as to determine the activity concentration of the radionuclides of interest. Analytical grade reagents were used to carry out the radiochemical procedures: nitric acid (HNO_3, 65%, Fisher Scientific™; UK), hydrochloric acid (HCl, 37% Fisher Scientific™; UK) and hydrogen peroxide (H_2O_2, 35%, Chem Lab nv, Belgium).

Table 2 shows the microwave acid digestion procedure of dried food and food ash samples. After digestion, the aliquots were diluted in 1.5 L distilled water. Then, the isolation of ^{210}Po and uranium radioisotopes and the determination by alpha-particle spectrometry were done in the corresponding aliquot following the radiometric procedure previously

Table 1
Radiological properties of the radionuclides analysed by gamma-ray spectrometry.

	Half-life (year)	Photo-peaks (keV)		I_γ (%)[a]	MDA (Bq/kg)
^{40}K	$1.3 \cdot 10^9$	1460.8		11.0	2.58
^{137}Cs	30.2	661.7		85.2	0.04
^{226}Ra	$1.6 \cdot 10^3$	**Secular Equilibrium**			
		^{214}Pb	351.9	37.6	0.26
		^{214}Bi	609.3	46.1	
^{228}Ra	5.8	**Secular Equilibrium**			
		^{212}Pb	238,6	43.3	0.32
		^{228}Ac	911,2	25.8	

[a] I_γ gamma relative intensity http://nucleardata.nuclear.lu.se/toi/.

Table 2
Microwave acid digestion procedure.

	Sample weight	Reagents[a] and tracer	Temperature	Ramp time	Step time	Power
Dried food	2–4 g	5 mL HNO_3 (65%) 5 mL distillate water 2 mL H_2O_2 (35%) ^{209}Po (ca. 50 mBq)	200 °C	15 min	15 min	1800 W
Food ashes	1–2 g	15 mL HNO_3 (65%) 1 mL HCl (37%) 1 mL H_2O_2 (35%) ^{232}U (ca. 50 mBq)	210 °C	20 min	15 min	1800 W

[a] per vessel

described (Piñero-García et al., 2021). Further details on the alpha-particle spectrometry system and the quality assurance could be found in (Piñero-García et al., 2021).

2.3. Committed effective dose

Assessment of the committed effective dose from food consumption during one year was calculated using the dose coefficients for intake of radionuclides by members of the public from International Commission on Radiological Protection publication 119 (ICRP, 2012), presented in Table 3, and the following equation:

$$E\,(\mu Sv/y) = \sum a_i \cdot c \cdot e_i$$

where a_i is the activity concentration for radionuclide i [Bq/kg], c is the annual food consumption [kg/y], and e_i is the committed effective dose coefficient for radionuclide i [Sv/Bq].

Annual food consumption data for different population groups, adults and children having 4, 8, 11, 14 and 17 years old, were extracted from the Swedish national food surveys and statistics dataset from Swedish Board of Agriculture if necessary (Jordbruksverket, 2015; Livsmedelsverket, 2012, 2018; Martin et al., 2016). Table 4 summarizes the average annual consumption (kg/y) of food in mean together with the percentile 95 (P95) used to carry out the dose assessment study.

3. Results and discussion

3.1. Activity concentration of radionuclides in Swedish market basket

Table 5 shows the activity concentrations of ^{210}Po, ^{234}U, ^{238}U, ^{40}K and ^{137}Cs with results higher than minimum detectable activity (MDA) together with the average intake for adults in Sweden of the foodstuff studied. The activity concentration of radionuclides showed in Table 5 refer to fresh weight of the edible parts analysed. ^{226}Ra and ^{228}Ra results are not shown in Table 5 since the values were mainly lower than MDA, 256 mBq/kg and 321 mBq/kg, respectively. ^{226}Ra was only detected in five out of the 129 samples analysed: 2 berry samples (blue berry: 520 ± 98 mBq/kg and lingonberry: 477 ± 94 mBq/kg); 1 beetroot sample (503 ± 109 mBq/kg); 1 carrot sample (351 ± 103 mBq/kg) and 1 apple sample (540 ± 90 mBq/kg). With the exception of the apple sample that it was a mix of international apples from Italy and France bought in supermarket, the remaining samples with high levels of ^{226}Ra were grown in Sweden. In particular, the blue berry sample (Kolsva, Köping), the beetroot sample (Köping, Köping) and lingonberry sample (Hanåsen, Gävle) were collected in granitic areas of Sweden rich in uranium (SGU, 2021).

Table 3
Committed effective dose coefficient (Sv/Bq) for internal exposure via ingestion (food or water) for different age groups and radionuclides.

Radionuclide	4 y	8 y	11 y	14 y	>17 y
^{137}**Cs**	$9.6 \cdot 10^{-9}$	$1.0 \cdot 10^{-8}$	$1.0 \cdot 10^{-8}$	$1.3 \cdot 10^{-8}$	$1.3 \cdot 10^{-8}$
^{210}**Po**	$4.4 \cdot 10^{-6}$	$2.6 \cdot 10^{-6}$	$2.6 \cdot 10^{-6}$	$1.6 \cdot 10^{-6}$	$1.2 \cdot 10^{-6}$
^{234}**U**	$8.8 \cdot 10^{-8}$	$7.4 \cdot 10^{-8}$	$7.4 \cdot 10^{-8}$	$7.4 \cdot 10^{-8}$	$4.9 \cdot 10^{-8}$
^{238}**U**	$8.0 \cdot 10^{-8}$	$6.8 \cdot 10^{-8}$	$6.8 \cdot 10^{-8}$	$6.7 \cdot 10^{-8}$	$4.5 \cdot 10^{-8}$

^{210}Po was detected in all the samples analysed, ranging from 3 ± 1 mBq/kg (cabbage) to 54773 ± 6690 mBq/kg (blue mussel) with an average value of 1800 mBq/kg. The yield recovery of ^{210}Po procedure ranged from 16% to 76% with an average value of 52%. High activity concentration of ^{210}Po was detected in small sea predators such as shrimps, mackerel and herring, while the highest activity concentration of ^{210}Po was detected in blue mussel. High bioaccumulation of ^{210}Po in seafood, in particular shellfish has previously been presented (Carvalho, 2011). The high accumulation of ^{210}Po in blue mussel is the result of several environmental processes (IAEA, 2017; Jia et al., 2020): i) ^{210}Po only exists at ultratrace levels without stable isotopes; therefore, no isotopic dilution of ^{210}Po takes place. ii) High absorption rate of polonium on suspended particles occurs in seawater favouring the bioaccumulation of ^{210}Po in internal tissues of blue mussel via the ingested food. iii) Low polonium excretion by blue mussels. Moreover, high activity concentration of ^{210}Po was also detected in plaice, which is a blue mussel predator. However, lower levels of ^{210}Po were detected in some top predators such as cod, wild salmon and farm salmon (Heldal et al., 2019) as well as freshwater species such as pike and perch. Probably, the main reason is the lower levels of ^{210}Po in the diet of these carnivores species compare to for example primary herbivores (planktivorous) (Carvalho, 2011). On the other hand, wild and lamb meat showed higher activity concentration of ^{210}Po than farm meat (beef, pig or chicken) since farm animal are mainly fed on fodder with lower levels of naturally occurring radionuclides. Similar results were obtained if we compare the results of wild and farm salmon. The total annual intake of ^{210}Po in Sweden was approximately 105 ± 7 Bq/y, which is almost double the world average annual intake 58 Bq/y (UNSCEAR, 2000), mainly due to the high consumption of seafood with high polonium levels in shellfish.

The uranium chemical recovery fluctuated between 14% and 95% with an average value of 68% and the MDA was 0.9 mBq/kg. The activity concentration of ^{238}U and ^{234}U varied from 1 ± 1 mBq/kg to 440 ± 37 mBq/kg (blue mussel), with a mean value of 21 ± 3 mBq/kg, and from 1 ± 1 mBq/kg to 536 ± 44 mBq/kg (blue mussel) with an average value of 27 ± 4 mBq/kg; respectively. The highest activity concentration was detected in blue mussel, which seems reasonable due to high distribution of uranium in sea water (~ 3 ppb) (Liu et al., 2017). In fact, high levels of uranium radionuclides in blue mussel have been reported by other authors, highlighting that the intake of uranium is via diet and it is influenced by the total load of suspended material in seawater (Jia et al., 2020). In addition, high activity concentration of uranium isotopes were detected in wild meat, especially in samples collected from granite areas of Sweden rich in uranium. The ^{234}U/^{238}U ratio ranged from 0.3 ± 0.3 (portabella mushrooms) to 2.3 ± 1.3 (cheese) with an average value of 1.1 ± 0.4, similar to the results reported in Poland (Pietrzak-Flis et al., 1997, 2001). Considering the experimental uncertainties, the ^{234}U/^{238}U ratio was higher than average value in approximately 30% of the foodstuff studied, highlighting uranium disequilibrium. In particular, large enrichment in ^{234}U was detected in wild meat, gathered food such as fruit berries, as well as some dairy products like cheese, which has been also reported in cheese samples

Table 4
Average annual food consumption (kg/y) in mean for different age groups in Sweden together with the percentile 95 (P95).

	4 y		8 y		11 y		14 y		17 y		Adult	
	(kg/y)		(kg/y)		(kg/y)		(kg/y)		(kg/y)		(kg/y)	
	mean	P95	mean	P95	mean	P95	mean	P95	mean	P95	mean	P95
Vegetables	14	41	19	53	38	103	45	103	49	119	61	107
Root vegetables	3	13	5	19	7	28	6	28	6	25	12	30
Fungi	0.2	1	0.4	2	1	4	1	4	1	7	2	3
Fruits	43	94	37	94	23	90	27	90	27	96	56	120
Berries	4	14	4	14	4	20	3	20	4	21	5	10
Potatoes	29	65	38	86	30	96	32	96	34	102	45	99
Bread	16	32	26	51	38	87	43	87	46	111	52	66
Rice	9	31	12	41	13	57	18	57	15	64	10	35
Pasta	15	40	22	57	21	70	24	70	24	75	10	37
Meat	21	49	32	66	18	53	19	53	24	68	33	54
Processed meat	8	24	11	32	16	53	15	53	15	54	16	28
Blood products	1	8	1	7	0.4	7	0.2	7	0.4	5	3	5
Poultry	4	18	6	24	11	43	12	43	14	51	17	5
Fish	6	21	7	24	7	34	9	34	6	41	14	43
Shellfish	0.4	2	0.4	2	1	3	1	3	1	5	2	6
Egg	2	9	2	9	2	11	2	11	5	19	12	19
Milk	98	356	130	469	110	329	119	329	86	350	57	278
Sour milk and yoghurt	33	149	30	178	24	103	21	103	20	96	16	218
Cheese	3	10	4	15	10	33	13	33	17	41	12	28

from Western Europe (Froidevaux et al., 2004). The total annual intake of ^{238}U was 9 Bq/y each, which was similar to European average annual intake of 8.0 Bq/y (UNSCEAR, 2000).

^{40}K was detected in all the foodstuffs analysed (Table 5). The activity concentration of ^{40}K ranged from 17 ± 6 Bq/kg (plum) to 222 ± 6 Bq/kg (beetroot) with a mean value of 100 ± 3 Bq/kg. The growing conditions of fungi and some vegetables like roots or spinach favour the uptake and bioaccumulation of potassium. On the other hand, there are many seafood species rich in potassium, since the uptake is higher than the excretion favouring the bioaccumulation of this alkali metal in the organism (Mallick et al., 2014). However, other seafood species, in particular, blue mussel (22 ± 1 mBq/kg) and shrimp (40 ± 1 mBq/kg) showed low levels of ^{40}K. In addition, the potassium levels in plaice (89 ± 1 mBq/kg), whose diet is based on blue mussel, were lower than the average value in seafood. It is known that shrimp has low levels in potassium. Moreover, the low salinity levels (15–18 psμ) of the Kattegat Sea where these samples came from, influenced the low levels of ^{40}K detected in blue mussel and shrimps.

The activity concentration of ^{137}Cs was higher than MDA (Table 1) in 31% of the foodstuff samples analysed, with a mean value of 8205 ± 137 mBq/kg. The minimum ^{137}Cs detected was 42 ± 3 mBq/kg in a champignon sample from Lithuania, whereas the maximum levels were found in Swedish wild boar products: meat (64659 ± 1088 mBq/kg) and sausage (74929 ± 262 mBq/kg). Wild boar meat has previously shown high ^{137}Cs concentration and bio-accumulation (Dvorak et al., 2010).

Food habits play a key role in the uptake of ^{137}Cs in wild animals, with higher levels in omnivores (such as the wild boar) than in herbivores (Hachinohe et al., 2020). In addition, some studies highlighted that underground mushrooms like deer truffles (*Elaphomyces* ssp) are the main source of ^{137}Cs for wild boar (Beňová et al., 2016; Fritzson, 2013; Hallqvist, 2013) contributing up to 75% of the radiocesium intake by wild boar, while the reminder contribution is controlled by soil (~ 13%) and other food items (<12%) (Steiner & Fielitz, 2009). For instance, in Sweden the highest activity concentration of ^{137}Cs in wild boar diet was detected in deer truffles with an average value of $31 \cdot 10^3$ Bq/kg dry weight (Fritzson, 2013). On the other hand, the high levels of ^{137}Cs detected in gathered wild food (berries and mushrooms) demonstrate that vegetation from the forest ecosystem could efficiently capture and recover the radioactive fallout (Coppin et al., 2016), probably as a result of high retention of the soluble fraction of radiocesium in the humus layer (Kostiainen, 2007). Finally, the high level of ^{137}Cs detected in pike-perch from Swedish lakes also reflects the environmental consequences of the Chernobyl accident in Sweden (Häkanson et al., 1992; Sundbom et al., 2003).

3.2. Committed effective dose

Fig. 1 shows the contribution of each radionuclide studied and each food group, respectively, to the committed effective dose from one year's consumption, E, at different ages together with the increase of E when high consumption rates are considered, percentile 95 (P95). The contribution of ^{40}K was not considered for the dose assessment since potassium is naturally regulated in the body by metabolic processes, which maintain constant the potassium levels and therefore the activity concentration of ^{40}K (IAEA, 2016). It is assessed that the contribution of ^{40}K to E is approximately 170 μSv for adults and 185 μSv for children (UNSCEAR, 2000).

The committed effective dose from one year's consumption, E, for internal exposure via food consumption was 142 ± 22 μSv for children aged 4 y; 98 ± 16 μSv for children aged 8 y; 106 ± 17 μSv for children aged 11 y; 82 ± 13 μSv for children aged 14 y; 87 ± 15 μSv for children aged 17 y and 134 ± 23 μSv for adults. The results show that the internal exposure by food was dominated by the intake of ^{210}Po (~ 94–98%). The highest contribution to the dose came from seafood consumption in all population groups: 70 ± 5 μSv for children aged 4 y; 43 ± 3 μSv for children aged 8 y; 57 ± 5 μSv for children aged 11 y; 47 ± 4 μSv for children aged 14 y; 59 ± 6 μSv for children aged 17 y and 100 ± 9 μSv for adults. Previous studies demonstrated that seafood rich diet resulted in a 4.5 higher committed effective dose from ^{210}Po than for example lacto-ovo vegetarian diet (Bengtson, 2018).

In addition, for population groups with high food consumption rates (P95), the total ingestion exposure could raise up to 560 μSv/y for children and 340 μSv/y for adults, coming the highest contribution from seafood 354 μSv for children and 261 μSv for adults. The results are in agreement with the world average values. It is estimated that the worldwide exposure to natural radiation from uranium and thorium progeny is considered ~ 120–240 μSv/y whereas average exposure to anthropogenic radiation is ~ 16 μSv/y; being approximately the average contribution to E, 140 μSv/y for ^{210}Po and 4 μSv/y for ^{137}Cs (Colgan, 2021; UNSCEAR, 2000). Moreover, depending on radionuclide composition of food and drinking water, the total ingestion exposure could range between 200 and 800 μSv/y (UNSCEAR, 2000).

Table 5
Activity concentration (mBq/kg) of radionuclides detected in Swedish market basket by food group together with the average annual intake for adults in Sweden of foodstuffs analysed and the water content (%). All activity concentrations refer to fresh weight and they are shown with an uncertainty of one standard deviation (coverage factor k = 1). Results of ^{226}Ra and ^{228}Ra are not shown since the values were mainly lower than MDA, 256 mBq/Kg and 321 mBq/kg, respectively. Additionally, the number of samples per foodstuff is shown in brackets.

	Water content (%)	Intake (kg/y)	^{210}Po	^{238}U	^{234}U	^{40}K	^{137}Cs
			(mBq/kg)	(mBq/kg)	(mBq/kg)	(Bq/kg)	(mBq/kg)
			VEGETABLES				
Beetroot (n = 2)	84.9	1.7	15 ± 1	9 ± 5	14 ± 5	222 ± 6	<0.04
Broccoli (n = 2)	88.2	4.8	55 ± 2	1.1 ± 0.6	2 ± 1	133 ± 3	<0.04
Cabbage (n = 2)	91.7	4.8	3 ± 1	2 ± 1	2 ± 1	72 ± 1	<0.04
Carrots (n = 4)	88.9	10.7	23 ± 2	6 ± 2	8 ± 2	67 ± 2	779 ± 91
Cauliflower (n = 3)	91.8	1.4	6 ± 1	5 ± 1	6 ± 1	116 ± 3	<0.04
Cucumber (n = 2)	97.7	6.2	8 ± 1	4 ± 1	5 ± 1	71 ± 2	<0.04
Leek (n = 1)	88.8	1.0	11 ± 1	<0.9	<0.9	84 ± 2	<0.04
Lettuce (n = 2)	95.1	6.1	15 ± 1	7 ± 2	5 ± 2	95 ± 2	<0.04
Onions (n = 1)	86.4	8.1	12 ± 1	14 ± 7	13 ± 7	85 ± 2	<0.04
Pepper (n = 1)	85.8	9.0	6 ± 1	<0.9	<0.9	67 ± 2	<0.04
Potatoes (n = 6)	77.8	45.2	50 ± 3	60 ± 4	60 ± 4	127 ± 3	1071 ± 139
Spinach (n = 2)	91.4	6.3	152 ± 6	16 ± 4	15 ± 4	187 ± 5	<0.04
Tomato (n = 1)	89.4	10.4	22 ± 1	6 ± 1	6 ± 1	59 ± 2	<0.04
Zucchini (n = 2)	93.6	3.0	8 ± 1	7 ± 1	4 ± 1	96 ± 2	<0.04
			FUNGI				
Champignon (n = 4)	95.2	0.6	75 ± 5	7 ± 4	8 ± 5	109 ± 1	111 ± 6
Chanterelle (n = 1)	90.9	0.6	1721 ± 199	<0.9	<0.9	160 ± 4	28068 ± 529
Portabella (n = 1)	39.0	0.6	98 ± 3	7 ± 3	2 ± 2	117 ± 1	<0.04
Shiitake (n = 1)	72.7	0.3	175 ± 12	7 ± 1	6 ± 1	71 ± 1	546 ± 14
			FRUITS				
Apple (n = 3)	85.6	11.2	32 ± 1	31 ± 2	28 ± 2	40 ± 2	<0.04
Banana (n = 2)	70.1	20.7	11 ± 1	<0.9	<0.9	126 ± 2	<0.04
Fruit berries (n = 3)	85.9	2.0	161 ± 7	3 ± 1	6 ± 1	32 ± 1	10038 ± 329
Orange (n = 2)	85.8	18.2	289 ± 16	5 ± 1	5 ± 1	32 ± 5	<0.04
Pear (n = 1)	84.6	2.5	14 ± 1	2 ± 1	1.4 ± 0.7	39 ± 1	<0.04
Plum (n = 1)	88.7	3.1	46 ± 2	4 ± 1	4 ± 1	17 ± 6	<0.04
Strawberries (n = 1)	89.4	2.8	51 ± 2	24 ± 2	24 ± 2	71 ± 2	<0.04
			CEREAL PRODUCTS				
Bread (n = 4)	35.6	51.6	28 ± 2	35 ± 4	23 ± 4	72 ± 4	<0.04
Flour (n = 2)	10.4	7.8	75 ± 4	4 ± 1	5 ± 1	67 ± 6	<0.04
Pasta (n = 4)	8.1	9.5	114 ± 4	10 ± 3	11 ± 3	81 ± 2	<0.04
Rice (n = 4)	10.2	9.5	28 ± 1	2 ± 1	2 ± 1	26 ± 1	<0.04
			DAIRY PRODUCTS				
Cheese (n = 4)	39.0	12.2	49 ± 2	10 ± 5	23 ± 6	28 ± 1	<0.04
Milk (n = 4)	87.3	57.0	27 ± 2	25 ± 2	26 ± 2	106 ± 3	47 ± 34
Sour milk (n = 2)	85.8	5.3	12 ± 1	4 ± 1	7 ± 1	50 ± 1	45 ± 6
Yoghurt (n = 3)	86.5	10.6	27 ± 1	4 ± 1	3 ± 1	58 ± 1	58 ± 22
			MEAT AND EGG PRODUCTS				
Beef (n = 2)	64.8	12.5	77 ± 3	4 ± 2	4 ± 2	87 ± 1	219 ± 14
Chicken (n = 3)	72.7	14.9	15 ± 1	14 ± 4	16 ± 4	102 ± 2	308 ± 24
Egg (n = 6)	72.5	11.5	138 ± 9	12 ± 4	12 ± 4	41 ± 2	<0.04
Lamb (n = 2)	67.2	1.0	267 ± 12	10 ± 1	14 ± 1	81 ± 2	295 ± 123
Liver pâté (n = 1)	55.4	3.0	46 ± 2	<0.9	<0.9	58 ± 4	<0.04
Pork (n = 1)	60.6	15.8	92 ± 6	35 ± 4	35 ± 4	103 ± 3	<0.04
Rabbit (n = 1)	73.0	1.0	20 ± 1	<0.9	<0.9		<0.04
Sausage (n = 1)	13.5	15.6	79 ± 3	11 ± 4	18 ± 5	65 ± 8	<0.04
Turkey (n = 1)	63.5	2.0	61 ± 5	4 ± 1	4 ± 1	84 ± 3	<0.04
Wild meat (n = 5)	69.3	3.0	170 ± 8	70 ± 10	107 ± 12	75 ± 2	35733 ± 426
			SEAFOOD				
Cod (n = 4)	79.3	3.1	687 ± 37	9 ± 1	11 ± 1	147 ± 1	365 ± 4
Hake (n = 2)	75.2	0.3	1151 ± 92	1.1 ± 0.6	<0.9	126 ± 3	290 ± 28
Herrings (n = 4)	76.9	1.5	1322 ± 76	4 ± 3	<0.9	116 ± 1	<0.04
Mackerel (n = 2)	67.9	2.0	1933 ± 165	15 ± 2	12 ± 2	108 ± 1	<0.04
Pikeperch (n = 2)	76.9	1.5	366 ± 34	<0.9	<0.9	112 ± 2	4993 ± 94
Plaice (n = 5)	73.8	1.5	1089 ± 39	11 ± 2	7 ± 2	89 ± 1	<0.04
Saithe (n = 2)	76.8	2.0	476 ± 48	62 ± 10	68 ± 10	125 ± 1	<0.04
Salmon (farm)[a]		1.8	13 ± 1	N/A	N/A	115 ± 8	130 ± 50
Salmon (wild) (n = 2)	83.0	0.5	170 ± 14	N/A	N/A	N/A	N/A
Blue mussel (n = 2)	74.4	0.2	54773 ± 6690	440 ± 37	536 ± 44	22 ± 1	<0.04
Crab[b]		0.2	5270 ± 791	N/A	N/A	N/A	N/A
Shrimp (n = 3)	70.5	2.0	29750 ± 1903	N/A	N/A	40 ± 1	N/A

N/A: *Not Analysed.* [a]*(Heldal et al., 2019).* [b]*(Komperød et al., 2020).*

4. Conclusions

The concentration of the radionuclides studied in the Swedish market basket vary widely between the food categories studied and trended as follow: ^{40}**K:** Fungi > Vegetables > Seafood > Meat and egg > Fruit > Cereal > Dairy products. ^{210}**Po:** Seafood > Meat and egg > Fungi > Fruit > Cereal > Dairy products > Vegetables. **Uranium radionuclides:** Seafood > Meat and egg > Dairy products > Cereal > Vegetables and fruit > Fungi. ^{137}**Cs:** Meat and egg > Fungi > Seafood > Vegetable > Dairy products.

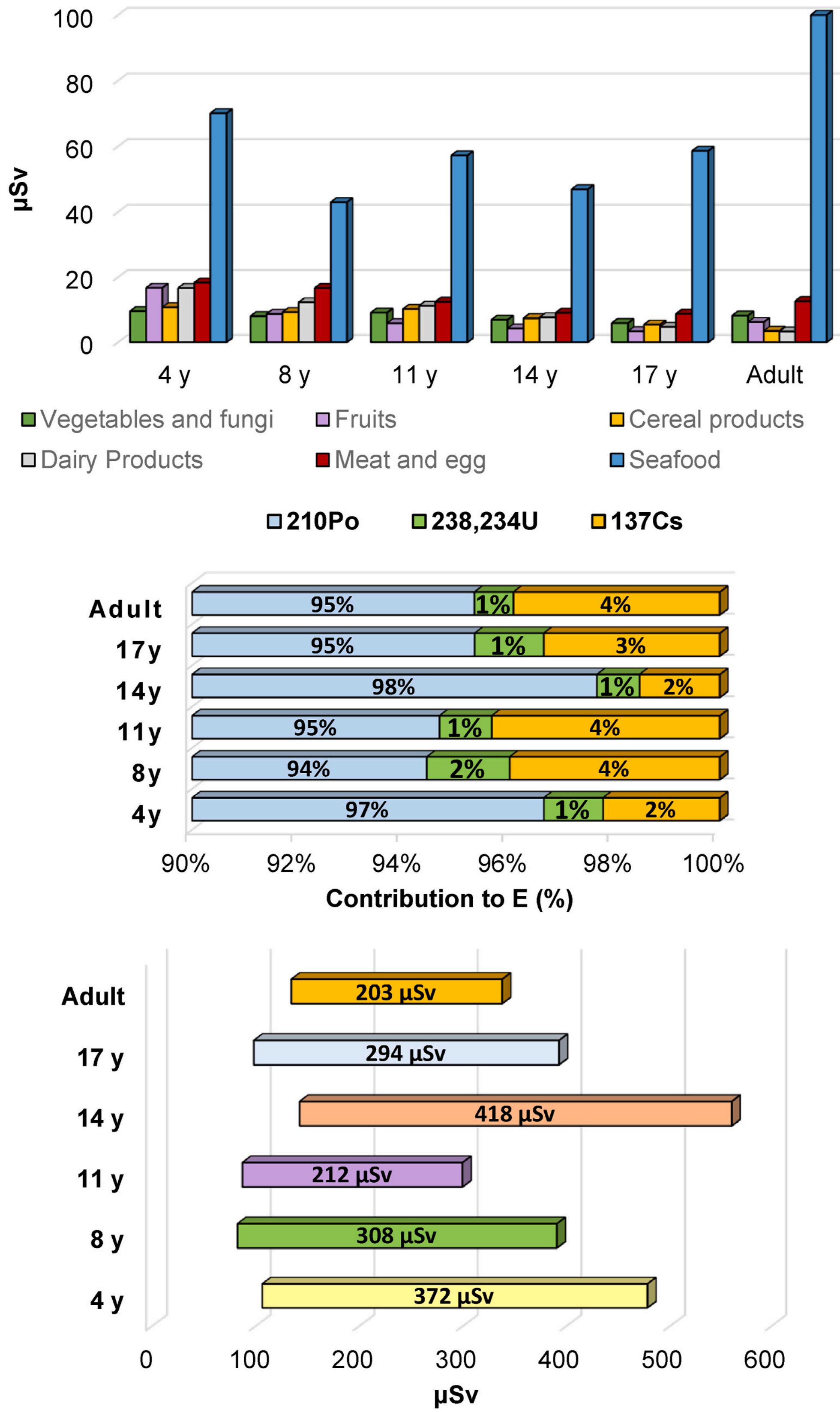

Fig. 1. Committed effective dose assessment from one year's consumption, E, at different ages. ***Up:*** contribution of each food group analysed to E. **Middle:** contribution of each radionuclide studied to E. **Bottom:** increase of E if high consumption rates are considered, percentile 95 (P95).

Altogether, the results of the study demonstrated that seafood as well as gathered wild food, game and high consumption of some food products like milk, potatoes and carrots, are the main contributors to the intake of radionuclides in Sweden. In addition, wild food, such as wild boar meat or berries from Swedish ecosystems were still affected by Chernobyl nuclear power plant accident more than 30 years after the fallout, with high exposure to ^{137}Cs for population groups with high consumption of wild food.

According to the dose assessment, the committed effective dose received by Swedish population could range from 82 to 560 μSv/y for children and between 134 and 340 μSv/y for adults being the ingestion dose mainly controlled by the intake of ^{210}Po via seafood consumption.

CRediT authorship contribution statement

F. Piñero-García: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Funding acquisition. **R. Thomas:** Investigation, Writing – review & editing. **J. Mantero:** Investigation, Writing – review & editing. **E. Forssell-Aronsson:** Resources, Writing – review & editing, Funding acquisition, Supervision. **M. Isaksson:** Resources, Writing – review & editing, Funding acquisition, Supervision.

Acknowledgements

The authors are grateful for the support and helpful discussions from our now deceased colleague professor Elis Holm, who collaborated in this study. Furthermore, we wish to thank Ida Bengston's work during her master thesis, carried out in the framework of this investigation.This investigation was supported by the Swedish Radiation Safety Authority, SSM (grant number SSM2017-570) and NKS Nordic nuclear safety research (grant number NKS-416 and NKS-435).

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