Chapter 4

Assessment of Human Exposure

The exposure of different Arctic populations to anthropogenic radionuclides was addressed during the first AMAP assessment (AMAP, 1998). However, several issues have since arisen which together justify further assessment: 1) data have become available for the Faroe Islands, 2) the Canadian population group selected to represent Arctic caribou herders has been criticized, 3) more detailed information has become available for some population groups in northwest Russia; and 4) owing to the increased releases of ^{99}Tc and ^{129}I from Sellafield and ^{129}I from Cap de la Hague, interest in the resulting doses has increased. No estimates of the uncertainties associated with the dose estimates are given, as the information needed for this was not available.

4.1. Atmospheric sources

The first AMAP assessment concluded that: *'The vulnerability of Arctic terrestrial ecosystems results in a five-fold higher exposure to radioactive contamination compared to that in temperate areas'*. Many post-Chernobyl studies have demonstrated that the highest exposures do not necessarily occur in the most contaminated areas, especially in the mid- to long-term after an accident. The reasons for this vary but can depend, for instance, on

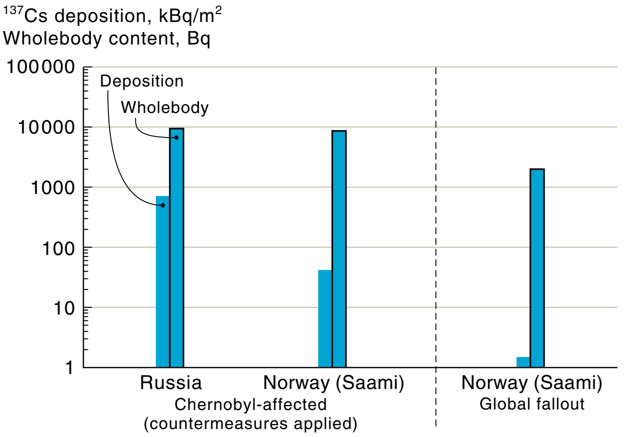

Figure 4·1. Wholebody content of ^{137}Cs for population groups in areas of different ^{137}Cs deposition in 1996 (Strand *et al.*, 2002).

variable plant uptake from different soil types or on the application of countermeasures. An example of the effects of countermeasures is shown in Figure 4·1. This shows the dose contribution from global fallout and Chernobyl fallout to two Saami populations in mid-Norway and to Russians living in the Novozybkov district. The Chernobyl fallout in both areas was high and required the application of extensive countermeasures. The effect was to dramatically reduce the ratio between the wholebody ^{137}Cs content of people and ^{137}Cs deposition in areas where countermeasures were applied, compared to areas in which they were not.

Estimates of doses to the public, based on measurements or model predictions, frequently generalize variations in environmental conditions, either owing to the limited availability of data or to an inadequately detailed knowledge of conditions in the environment that influence exposure. Such generalizations mask considerable variability in the distribution of dose, both in space and time, even if the rate of input of radionuclides to the environment is essentially uniform. While this is of little consequence to the calculation of collective dose, variations in individual doses resulting from variations in vulnerability can be masked and locations and populations receiving comparatively high doses may not be identified. Allowing for these variations in the calculation and prediction of individual dose enables improved insights into the doses that would occur in the event of accidental release. This is particularly valuable for the Arctic because of the comparatively heavy reliance on locally produced foods and semi-natural foods in some populations.

4.2. Faroe Islands

Sufficient data are now available for the Faroe Islands to enable a similar analysis to that carried for the other Arctic countries in the first AMAP assessment (AMAP, 1998).

4.2.1. Food consumption

There have been two extensive nutritional investigations in the Faroe Islands; the first in 1936 (Knudsen, 1940) and the second in 1981 to 1982 (Vestergaard and Zachariassen, 1987; see Table 4·1). Most of the mutton is lamb meat; about 18 kg/yr/cap according to unpublished information (Joensen pers. comm., 2002). Reliable food consumption rates are not available for the Faroe Islands as much of the food is acquired privately, particularly mutton and fish (mainly cod and haddock).

It is likely that the relative proportions of the different food groups have changed over time. Milk has been produced locally for the last 15 to 20 years but most other dairy products are imported, mainly from Denmark. It is also likely that the relative proportions of the different food groups vary across the country, but the available data are insufficient to confirm this.

Table 4·1. Annual mean consumption of foodstuffs (kg/yr/cap) in the Faroe Islands, 1981 to 1982 (Vestergaard and Zachariassen, 1987).

Dairy products	Faroese mutton	Marine fish	Potatoes	Grain products	Vegetables	Whale meat	Whale blubber
142	25	26	70	78	12	4.4	2.6

4.2.2. Dose estimation

Internal doses resulting from the dietary intake of ^{137}Cs in the Faroe Islands since 1950 were calculated on the basis of activity concentrations in foodstuffs and consumption rates (Table 4·1). Activity concentrations in milk were used to represent dairy products, those in lamb to represent mutton, and those in white bread to represent grain. Activity concentrations of ^{137}Cs in whale meat and vegetables were not available. The calculation method was similar to that used in the first AMAP assessment. Annual values based on actual ^{137}Cs measurements were collated to yield 5-year means since the beginning of the 1960s. Owing to gaps in the data set, values for 1950 to 1960 were obtained by linear interpolation. Estimates of doses since 2000 were made using an effective ecological half-life (T_{eff}; Box 3.1) for ^{137}Cs of 10 yr. The modelled integrated calculated dose for the average Faroese population through the nuclear age was 3.5 mSv, which is consistent with the estimated value of 3.3 mSv in the first AMAP assessment. The foodstuffs contributing the major part of the ^{137}Cs dose (approximately 60%) were milk and lamb.

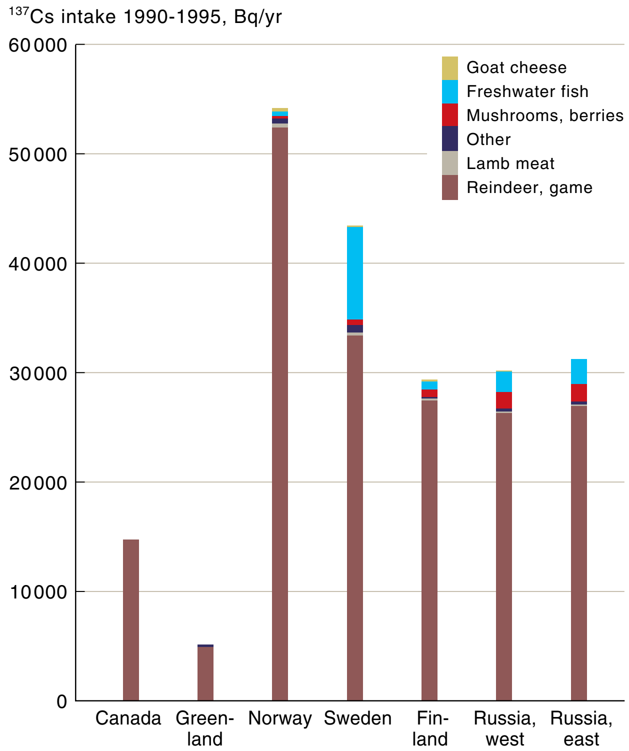

Figure 4·2. Intakes by the selected groups in the period 1990 to 1995 (AMAP Data Centre).

4.3. Canadian Arctic

Some reservations were expressed about the effective individual internal dose commitments due to ^{137}Cs intake calculated in the first AMAP assessment. These concerned the high rates of caribou meat consumption assumed for the Canadian selected (Gwich'in) population group, which appeared much higher than for selected high consumption groups in other Arctic countries. Since then, new dietary information for Canadian northern population groups has become available (Berti *et al.*, 1998; Kuhnlein *et al.*, 2000; Van Oostdam *et al.*, 1999). This indicates that the caribou consumption estimate applied to the Gwich'in selected group in the first AMAP assessment pertains to an extreme (high consumption) group in the population, and does not represent an 'average' consumption estimate for relatively large population groups, as was the case for the selected population groups for other Arctic countries. The Canadian selected group described in the first AMAP assessment was therefore not directly comparable with the selected groups for other Arctic countries. Consequently, the Canadian ^{137}Cs internal dose was re-evaluated in the present assessment using the new dietary data. The outcome is described in the rest of this section (Figure 4·2).

Berti *et al.* (1998) report on a dietary survey performed in five regions (16 communities) of Denendeh in 1994. During the study 1012 individuals completed a 24-hr dietary recall. Results were subdivided according to sex, age (20 to 40 yr, and 40+ yr), and (five) regions. The Gwich'in and Sahtú are groups with a high consumption of caribou meat (Table 4·2).

Table 4·2. Caribou consumption (g/d/cap) for the Gwich'in and Sahtú (three communities surveyed for each group) averaged over four seasons (Berti *et al.*, 1998).

	Female (mean ± SD)		Male (mean ± SD)	
Gwich'in	20-40 yr (n=19,32)*	40+ yr (n=8,35)	20-40 yr (n=17,29)	40+ yr (n=22,33)
Fresh meat	122±73	178±113	163±81	224±127
Dried meat**	15.8±9.7	7.8±4.6	34.8±23.9	12.9±7.3
Liver	0.8±0.8	7.4±7.2	4.4±4.9	7.2±7.0
Kidney	0.7±0.3	1.5±0.6	5.0±1.5	1.8±0.8
Sahtú	20-40 yr (n=24,22)	40+ yr (n=26,17)	20-40 yr (n=18,31)	40+ yr (n=29,13)
Fresh meat	126±67	227±129	135±85	250±132
Dried meat**	15.7±8.7	63±41.5	44.1±28.8	44.2±27.8
Liver	1.2±1.2	12.8±13.1	0.47±0.49	11.2±12.2
Kidney	0.8±0.3	5.9±2.3	2.8±1.0	4.9±2.4

*first number represents 24 hr diet recalls in the late winter and food frequency questionnaires for the winter, second number represents 24 hr diet recalls in the autumn and food frequency questionnaires for the summer;

**dry weight basis, all other values fresh weight.

Table 4·3. Average daily intakes (g ± SE) of caribou in Arctic Canada (after Kuhnlein *et al.*, 2000).

	15-19 yr	n	20-40 yr	n	41-60 yr	n	61+ yr	n
Inuvialuit – males								
Meat	88	24	132	100	114	32	72	14
Dried meat*	–	24	22	100	12	32	18	14
Ribs	–	24	7	100	27	32	16	14
Bone marrow	–	24	1	100	4	32	–	14
Liver	–	24	–	100	4	32	–	14
Heart	–	24	–	100	4	32	–	14
Kidney	–	24	–	100	4	32	–	14
Kivalliq – males								
Meat	428	7	259	87	365	33	440	15
Fat	–	7	12	87	–	33	56	15
Ribs	–	7	3	87	–	33	5	15
Dried meat*	–	7	4	87	–	33	7	15
Bone marrow	–	7	2	87	23	33	–	15
Tongue	–	7	–	87	–	33	14	15
Intestine	–	7	1	87	–	33	–	15
Stomach contents	–	7	2	87	–	33	–	15
Stomach	–	7	1	87	–	33	–	15
Baffin – males								
Meat	204	24	106	112	164	82	235	20
Fat	–	24	4	112	10	82	–	20
Dried meat*	2	24	3	112	6	82	–	20
Intestine	–	24	–	112	6	82	–	20
Stomach	–	24	–	112	10	82	–	20
Bone marrow	–	24	–	112	10	82	–	20
Liver	–	24	–	112	6	82	–	20
Kidney	–	24	2	112	0.1	82	–	20
Cartilage	–	24	2	112	–	82	–	20
Labrador – males								
Meat	142	18	148	80	135	68	74	21
Dried meat*	–	18	13	80	2	68	–	21
Heart	–	18	6	80	–	68	25	21
Ribs	–	18	6	80	–	68	–	21
Tongue	–	18	–	80	–	68	6	21
Bone marrow	–	18	–	80	0.5	68	–	21

n = number of 24 hr diet recalls and food frequency questionnaires in the autumn and late winter;
*dry weight basis, all other values fresh weight.

The Canadian Inuit also exhibit high intakes of caribou meat and other caribou products. Average daily consumption data for four Inuit regions are presented in Table 4·3. These data are based on 24 hr dietary recalls for individuals that had eaten caribou within the previous 24 hours (Kuhnlein *et al.*, 2000). The data reveal a high degree of variability in the frequency and amount of caribou consumed. Table 4·3 shows the average consumption for the groups as whole. Within each of these groups it is evident that the heaviest consumers had a fresh caribou meat intake of around 500 to 850 g/d on the days that they ate caribou during autumn and winter. Adding the consumption of other caribou products, especially dried meat, meant the total individual caribou product consumption rates could exceed 1 kg/d on certain days. Obviously, these high consumers represent a limited proportion of the population as a whole. Average consumption rates in the Canadian north are more typically around 100 to 400 g/d (Kuhnlein *et al.*, 2000; Table 4·3). These new data do not support the average consumption rate of 1000 g/d used in the first AMAP assessment, which would imply that individuals were consuming 1000 g of caribou meat per day seven days a week throughout the year. Although this new information indicates that the consumption rates for caribou meat in the selected Gwich'in population group, for which exposure calculations were performed in the first AMAP assessment, may have been substantially overestimated, it appears that there are individuals within the Canadian Arctic that periodically have consumption rates of a comparable magnitude.

The selected groups from the other Arctic countries represent 'average consumers' among larger groups involved in caribou/reindeer herding. The values for caribou/reindeer consumption were therefore lower than those used for Canada. The first AMAP assessment concluded that '*It cannot be ruled out that there are small numbers of individuals within other Arctic countries having similar dietary habits as the selected Canadian community. Accordingly, comparable or higher doses than those calculated for the Canadian selected group may exist within the Arctic*'.

Figure 4·2 shows a revised comparison of ^{137}Cs intake among selected groups using the new Canadian intake data (Berti *et al.*, 1998). The data for the selected Canadian group are now more comparable with those for the selected groups in other Arctic countries.

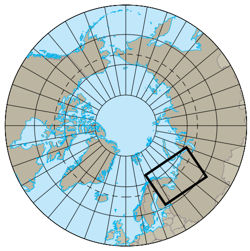

Figure 4·3. Settlements included in the 1998 to 2001 dietary study, and the larger cities.

4.4. Northwest Russia

Several datasets concerning radionuclide transfer to foodstuffs, dietary habit, and wholebody measurements associated with studies of ingested radiation dose in northwest Russia have become available since the first AMAP assessment. Data for the Kola Peninsula and the Nenets Autonomous Okrug (NAO) were collected under the European Union and the Russian–Norwegian bilateral project 'AVAIL', which involved five expeditions to northwest Arctic Russia between 1998 and 2001 (Borghuis *et al.*, 2002; see Annex Tables A4·1 and A4·2).

The purpose of the expeditions was to assess contemporary levels of environmental contamination by the long-lived radionuclides, ^{137}Cs and ^{90}Sr, and to determine site-specific characteristics for estimating current internal doses in the different population groups of northwest Russia.

Three population groups were considered: indigenous peoples, mainly reindeer herders and members of their families (Group I); rural populations and inhabitants of small villages and settlements having mixed diets (Group II); and the populations of big ports and cities whose inhabitants mainly consume imported foodstuffs (Group III).

The expeditions thus aimed to include a variety of different types of Arctic inhabitant. Surveys were undertaken in the areas shown in Figure 4·3, namely:

Lovozero village on the Kola Peninsula where Saami and Komi are occupied in reindeer herding. The Slavic population of the area is not directly connected with reindeer herding but does consume reindeer meat. Umba was also included although its inhabitants do not consume much reindeer meat;

Dolgoshelye village and Mezen town in the Mezen district of the Arkhangelsk Oblast. The Nenets nomad camp located by the mouth of the River Perechnaya was also included; and

Khongurey, Ust'-Kara, Nelmin Nos, and Krasnoye villages, and Nar'yan-Mar town in the NAO. Here, Nenets dominate the indigenous population and are largely occupied with reindeer herding. A nomad camp of reindeer herders, who have owned the land along the Kara Sea between Ust'-Kara and Amderma for many years, was also included.

A questionnaire was used to obtain information about the local population and the consumption and origin of the eight most important foodstuffs in the diet. Together with information on the levels of ^{137}Cs and ^{90}Sr in different foodstuffs, the dietary data were used to assess which foodstuffs contributed most to the radionuclide intake of each population group. The ^{137}Cs wholebody contents of individual local inhabitants were also measured.

4.4.1. Dietary preferences

4.4.1.1. Group I

The diet of reindeer herders in the Mezen district of the Arkhangelsk Oblast and the NAO was similar to that of the Saami and Komi reindeer herders on the Kola Peninsula, both in terms of the consumption of reindeer meat, and fish from local lakes and rivers, and the consumption of milk of local origin. Some differences occurred in the consumption of mushrooms and berries (Table 4·4).

The most significant differences occurred in the consumption of vegetables and fruit. This is primarily explained by 84% of the reindeer herders on the Kola Peninsula having kitchen gardens compared to only 16% in the NAO. However, the contribution of vegetables and fruit to internal dose is negligible. Since the

Table 4.4. Consumption of natural products by Group I inhabitants of northwest Russia (kg/d, mean ± SE) (Borghuis *et al.*, 2002).

	Mushrooms	Berries
Kola Peninsula	0.021 ± 0.005	0.045 ± 0.012
Mezen district	0.036 ± 0.009	0.042 ± 0.008
Nenets AO	0.014 ± 0.002	0.026 ± 0.003
Average	0.024 ± 0.011	0.038 ± 0.015

Table 4·5. Consumption of basic food products (kg/d; mean ± SE) by Group I inhabitants of the northern European part of Russia in 1998 to 2001 (Borghuis *et al.*, 2002).

	Milk	Reindeer meat	Other meat	Potato	Fish	Mushrooms	Berries
Local produce	0.086±0.013	0.310±0.011	0.007±0.001	0.110±0.015	0.130±0.009	0.024±0.011	0.038±0.015
Imported products	0.005±0.003	–	0.006±0.001	0.078±0.009	–	–	–
Total consumption	0.091±0.013	0.310±0.011	0.013±0.002	0.190±0.014	0.130±0.009	0.024±0.011	0.038±0.015

Table 4·6. Consumption of basic food products (kg/d; mean±SE) by Group II inhabitants of northwest Russia (Borghuis *et al.*, 2002).

	Milk	Reindeer meat	Other meat	Potato	Fish	Bread
Kola Peninsula						
Lovozero (1998) n=25						
Local produce	0.206±0.052	0.083±0.011	0.004±0.004	0.323±0.040	0.109±0.024	–
Imported products	0.079±0.029	–	0.072±0.013	0.049±0.021	–	–
Total consumption	0.285±0.066	0.083±0.011	0.076±0.013	0.376±0.033	0.109±0.024	0.302±0.031
Nenets AO						
Ust'-Kara (2000) n=41						
Local produce	–	0.084±0.016	0.056±0.009	–	0.155±0.014	–
Imported products	0.014±0.008	–	0.022±0.004	0.173±0.012	–	–
Total consumption	0.014±0.008	0.084±0.016	0.078±0.011	0.173±0.012	0.155±0.014	0.382±0.045
Nar'yan-Mar (2000) n=37						
Local produce	0.206±0.056	0.169±0.028	0.040±0.014	0.239±0.042	0.087±0.011	–
Imported products	0.021±0.015	–	0.036±0.010	0.061±0.021	–	–
Total consumption	0.227±0.056	0.169±0.028	0.076±0.019	0.300±0.039	0.087±0.011	0.292±0.019
Mezen district						
Dolgoshelye (1999) n=13						
Local produce	0.497±0.162	0.032±0.009	0.051±0.005	0.333±0.040	0.125±0.020	–
Imported products	–	–	0.004±0.007	–	–	–
Total consumption	0.497±0.162	0.032±0.009	0.055±0.003	0.333±0.040	0.125±0.020	0.324±0.025

n = number in survey.

Table 4·7. Consumption of basic food products (kg/d; mean±SE) by Group III inhabitants of northwest Russia (Borghuis *et al.*, 2002).

	Milk	Reindeer meat	Other meat	Potato	Fish	Bread
Kola Peninsula						
Umba (1998) n=58						
Local produce	0.128±0.041	0.002±0.002	0.021±0.005	0.334±0.026	0.113±0.011	–
Imported products	0.038±0.015	–	0.058±0.008	0.037±0.013	–	–
Total consumption	0.166±0.044	0.002±0.002	0.077±0.009	0.370±0.023	0.113±0.011	0.332±0.020
Mezen district						
Mezen (1999) n=22						
Local produce	0.414±0.110	0.012±0.005	0.024±0.007	0.420±0.055	0.073±0.014	–
Imported products	–	–	0.101±0.066	–	–	–
Total consumption	0.410±0.110	0.012±0.005	0.125±0.066	0.420±0.055	0.073±0.014	0.423±0.009

n = number in survey.

consumption of mushrooms and berries by this group makes a relatively small contribution to dose, the data for the reindeer herders for the entire northern European part of Russia can be combined (Table 4·5).

4.4.1.2. Group II

A comparison of reindeer consumption by reindeer herders (Table 4·5) and typical rural inhabitants of small towns and villages (Table 4·6) shows that, on average, rural inhabitants consume two to four times less reindeer meat than reindeer herders, with almost an order of magnitude lower consumption in Dolgoshelye in the Mezen district. This is explained by the gradual decline of reindeer herding in the Mezen district. In contrast, reindeer farms on the Kola Peninsula and in the NAO are comparatively stable, and Lovozero, Ust'-Kara and Nar'yan-Mar have shops selling reindeer meat.

Rural inhabitants, except inhabitants of Ust'-Kara, exceed the milk consumption rates of Group I by a factor of 2.5 to 5.5 and potatoes by a factor of 1.5 to 2. Ust'-Kara is on the shore of the Kara Sea, there is no agricultural production, and kitchen gardens are rare. Almost all foodstuffs, except reindeer meat and fish, are thus imported. Group II inhabitants have similar fish consumption rates to reindeer herders.

4.4.1.3. Group III

Inhabitants of large villages and towns in the European part of Arctic Russia do not consume significant amounts of reindeer meat (Table 4·7). However, milk consumption exceeds that of Group I by a factor of 1.8 to 4.5 and potato consumption by a factor of 2.

4.4.1.4. **All Groups**

Average consumption rates of mushrooms and berries by Group II and Group III inhabitants of northwest Russia, i.e. individuals unconnected with reindeer herding, are shown in Table 4·8. Fish consumption rates were similar in all the population groups surveyed. Rates of bread consumption were also similar, at 290 to 350 g/d.

Table 4·8. Consumption of mushrooms and berries (kg/d; mean ± SE) by Group II and Group III inhabitants of northwest Russia (Borghuis *et al.*, 2002).

	Mushrooms	Berries
Kola Peninsula	0.025 ± 0.010	0.045 ± 0.012
Dolgoshelye	0.036 ± 0.010	0.052 ± 0.010
Mezen district	0.042 ± 0.007	0.071 ± 0.011
Ust'-Kara	0.012 ± 0.002	0.028 ± 0.004
Nar'yan-Mar	0.024 ± 0.004	0.026 ± 0.005
Average	0.028 ± 0.006	0.044 ± 0.009

4.4.2. **Radionuclides in the diet**

The highest ^{137}Cs activity concentrations currently occur in reindeer meat, mushrooms, freshwater fish, and berries (Figure 4·4). The ^{137}Cs level in reindeer meat is around two orders of magnitude higher than in locally produced agricultural foodstuffs. As expected, there are significantly higher ^{137}Cs concentrations in lichen and fungi compared with grasses and agricultural products (potato, milk, and beef). Relatively high ^{137}Cs activity concentrations in Arctic freshwater fish are probably due to low mineralization (low dissolved potassium and other ions) of water and thus an elevated accumulation of ^{137}Cs. Activity concentrations of ^{137}Cs in marine fish are an order of magnitude lower than in freshwater species.

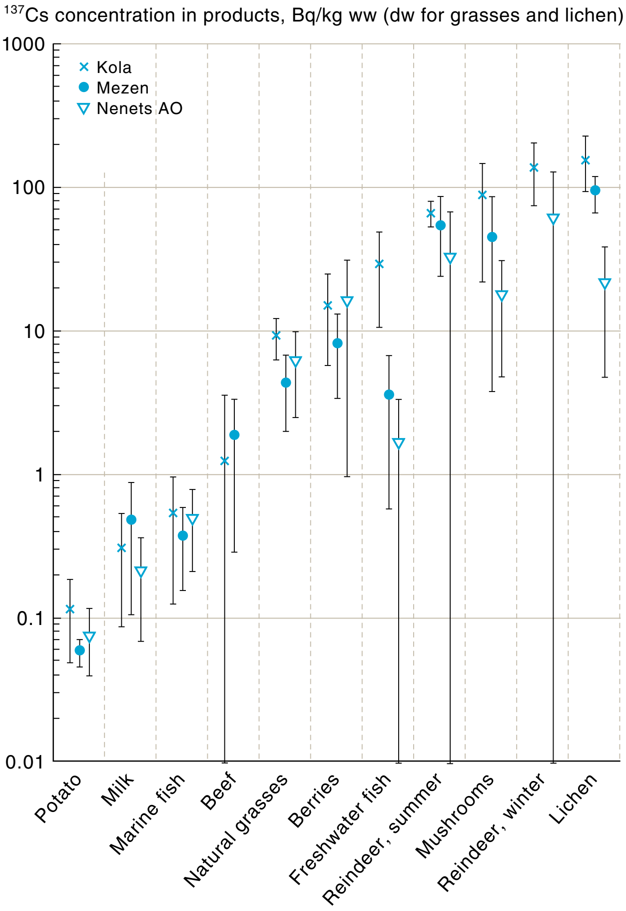

Figure 4·4. Activity concentrations of ^{137}Cs in products collected in northwest Arctic Russia 1998 to 2001 (Borghuis *et al.*, 2002).

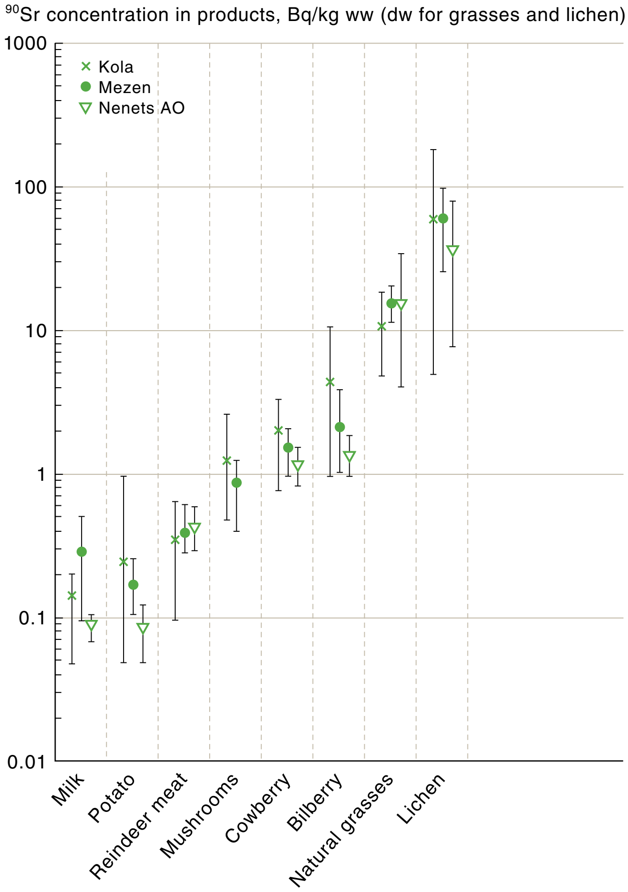

Figure 4·5. Activity concentrations of ^{90}Sr in products collected in northwest Arctic Russia 1998 to 2001 (Borghuis *et al.*, 2002).

Activity concentrations of ^{137}Cs (Figure 4·4) and ^{90}Sr (Figure 4·5) in locally produced milk and potatoes and the corresponding T_{ag} values are similar to those observed in mid-latitudes.

For almost all foodstuffs, ^{137}Cs and ^{90}Sr activity concentrations were higher on the Kola Peninsula than in the other regions, with the differences more pronounced for ^{137}Cs.

4.4.3. **Dose estimation**

Ingestion doses (E_{int}) were estimated from the dietary intake data for the different population groups and the radionuclide activity concentrations in the various foodstuffs according to the formula:

$$E_{int} = 30 \cdot \sum(dk_i \cdot I_i), \ \mu Sv/month \qquad \text{Eqn. 4.1}$$

where dk_i is the dose factor for ingestion of the i^{th} radionuclide in the body of an adult; dk_i is equal to 1.3×10^{-2} and 2.8×10^{-2} µSv/Bq for ^{137}Cs and ^{90}Sr, respectively (ICRP, 1993); I_i is the daily intake of the i^{th} radionuclide in the body with food in Bq/d; and 30 is the number of days in a month.

Table 4·9. Average daily intake of ^{137}Cs and ^{90}Sr in summer 1998 for Group I inhabitants of Lovozero village (Borghuis *et al.*, 2002).

	Activity concentration, Bq/kg		Consump-, tion, kg/d	Food pro- cessing factor	Intake, Bq/d	
	^{137}Cs	^{90}Sr			^{137}Cs	^{90}Sr
Milk	0.39	0.15	0.10	1.0	0.04	0.015
Reindeer meat	70	–	0.30	1.0	20.9	–
Mushrooms	58	0.13	0.021	0.5	0.61	0.0014
Berries	19	3.4	0.045	1.0	0.86	0.153
Potatoes	0.12	0.25	0.31	0.8	0.03	0.062
Fish	20	–	0.10	1.0	2.1	–
Total					24.5	0.23

Table 4·10. Average daily intake of ^{137}Cs and ^{90}Sr in summer 1998 for Group II inhabitants of Lovozero village (Borghuis *et al.*, 2002).

	Activity concentration, Bq/kg		Consump-, tion, kg/d	Food pro- cessing factor	Intake, Bq/d	
	^{137}Cs	^{90}Sr			^{137}Cs	^{90}Sr
Milk	0.39	0.15	0.28	1.0	0.11	0.042
Reindeer meat	70	–	0.083	1.0	5.8	–
Mushrooms	58	0.13	0.025	0.5	0.73	0.002
Berries	19	3.4	0.045	1.0	0.86	0.153
Potatoes	0.12	0.08	0.38	0.8	0.04	0.024
Freshwater fish	20	–	0.085	1.0	1.7	–
Total					9.2	0.22

Table 4·11. Average daily intake of ^{137}Cs and ^{90}Sr in summer 1998 by Group III inhabitants of Umba (Borghuis *et al.*, 2002).

	Activity concentration, Bq/kg		Consump-, tion, kg/d	Food pro- cessing factor	Intake, Bq/d	
	^{137}Cs	^{90}Sr			^{137}Cs	^{90}Sr
Milk	0.49	0.17	0.128	1.0	0.063	0.022
Mushrooms	59	–	0.021*	0.5	0.62	–
Berries	3.7	–	0.045*	1.0	0.17	–
Potatoes	0.12	0.18	0.33	0.8	0.032	0.048
Fish	2-20**	–	0.11	1.0	0.22-2.2	
Total					1.1-3.1	0.07

* consumption assumed to be the same as at Lovozero village;
** first number corresponds to the average ^{137}Cs activity concentration in marine fish and the second to freshwater fish.

The daily radionuclide intake is estimated by combining the intake of different foodstuffs:

$$I_i = \sum_p (C_{ip} \cdot V_{ip} \cdot K_{ip}),\ \text{Bq/d} \qquad \text{Eqn. 4.2}$$

where $(C_{ip}(t)$ is the concentration of the i^{th} radionuclide in the p^{th} foodstuff in Bq/kg; V_{ip} is the daily consumption rate of the p^{th} foodstuff in kg/d; and K_{ip} is the food processing factor accounting for the loss of the i^{th} radionuclide during cooking of the p^{th} foodstuff.

The internal dose to inhabitants from ^{137}Cs may also be assessed on the basis of measured activities in the human body. The mean monthly effective dose through internal exposure in adult inhabitants from ^{137}Cs (E_{137}), based on wholebody measurements, was calculated using the formula:

$$E_{137} = 30 \cdot kd_{137} \cdot Q/M,\ \mu\text{Sv/month} \qquad \text{Eqn. 4.3}$$

where Q is the ^{137}Cs activity in the body of a person under investigation in Bq; M is the mass of the body of the person in kg; kd_{137} is the dose rate coefficient converting the specific activity of ^{137}Cs in the body, Q/M, to the effective dose rate; $kd_{137} = 6.3 \times 10^{-3}$ (μSv/kg per Bq/d) (ICRP, 1993).

4.4.3.1. Group I

Table 4·9 shows the average daily ^{137}Cs and ^{90}Sr intakes from local foodstuffs in reindeer herders from Lovozero village. The consumption of reindeer meat in summer provides 83% of the ^{137}Cs internal dose. Fish and mushrooms and berries are also significant sources (at 8% and 9%, respectively). The average monthly internal dose from ^{137}Cs in summer 1998 was 10 μSv/month.

The diet of the reindeer herders was the same in spring as in summer. This is to be expected as the food supply of the indigenous population is generally stable throughout the year. Again, the major contributor to the internal dose was reindeer meat, at 88%, with the rest from local freshwater fish, and mushrooms and berries. As in summer, the contribution from milk was small. The average daily intake of ^{137}Cs by reindeer herders in late winter was 39 Bq and the monthly internal dose was 15 μSv. This is 1.5 times higher than in summer and consistent with a factor of 1.6 between the ^{137}Cs activity concentration in reindeer meat after the winter slaughter and in summer. To estimate the annual internal dose, appropriate weightings were assigned to the winter (seven months with snow) and summer periods.

If wholebody measurements are used for dose estimation (the average ^{137}Cs content in the body of reindeer herders in winter 1999 was 3250 ± 250 Bq), the calculated dose is 8.8 μSv/month. This is only 10% higher than the estimate for the summer period and 1.7 times lower than that estimated on the basis of ^{137}Cs intake using food product data. The contribution of ^{90}Sr to the total internal dose to reindeer herders is about 1-3%.

4.4.3.2. **Group II**

Estimated average daily intakes of ^{137}Cs and ^{90}Sr in key foodstuffs for inhabitants of Lovozero village not directly connected with reindeer herding are given in Table 4·10. Reindeer meat still contributes the most to internal dose (63%), although the average daily consumption (0.08 kg) is 3.5 times lower than for reindeer herders. The next most important contributions are from fish (18%), and mushrooms and berries (17%). The average monthly internal dose from ^{137}Cs to Lovozero rural inhabitants is 3.6 μSv. The contribution of ^{90}Sr to the total internal dose of village inhabitants is about 5%.

4.4.3.3. **Group III**

In Umba, inhabitants rarely consume reindeer meat and so their intake of radionuclides is considerably lower than at Lovozero. Instead, the greatest contribution to internal dose is from local mushrooms and berries. Based on Table 4·11, the internal dose from ^{137}Cs and ^{90}Sr ranges from 0.5 to 1.2 μSv/month.

4.4.3.4. **All Groups**

The contribution of ^{90}Sr to total internal dose is lowest for Group I (reindeer herders) at 2.4 to 3.4% and highest for Group III (urban inhabitants) at 16 to 20%. This reflects the considerable difference in reindeer meat consumption by the two groups. Reindeer meat is the main dose-contributing foodstuff for Group I (through ^{137}Cs intake rather than ^{90}Sr). In Group II (rural inhabitants), the contribution of ^{90}Sr to total dose varies from 3.8 to 5.0%. Only for inhabitants of Dolgoshelye does it reach 15% and this reflects the comparatively low reindeer meat consumption (only 0.032 kg/d).

Table 4·12. Current average internal doses (μSv/yr) in northwest Russia (Borghuis *et al.*, 2002).

	Group (n)	Monthly dose summer	Monthly dose winter	Annual dose
Kola Peninsula (Lovozero, Umba)				
	I (43)	10	19	183
	II (25)	4.5	6.9	71
	III (58)	1.2	1.2	14
Mezen district (Dolgoshelye, Mezen)				
	I (8)	5.3	8.6	87
	II (13)	1.5	1.8	20
	III (22)	1.2	1.4	16
Nenets AO (Ust'-Kara, Nar'yan Mar)				
	I (63)	4.9	8.2	82
	II (41)	1.6	2.5	26
	II (37)	2.9	4.7	47

Table 4·13. Current average internal doses due to the intake of ^{137}Cs and ^{90}Sr normalized to the specific activity per unit soil surface in northwest Russia (Borghuis *et al.*, 2002).

	Annual dose, μSv/yr per kBq/m² ^{137}Cs	Annual dose, μSv/yr per kBq/m² ^{90}Sr
Kola Peninsula		
Group I	100	2.8
Group II	37	2.6
Group III	6.6	2.2
Mezen district		
Group I	31	2.6
Group II	6.3	3.1
Group III	4.6	3.2
Nenets AO		
Group I	30	1.9
Group II	13.0 (9.2-17)	1.1 (0.7-1.5)

Similar dose assessments were performed for inhabitants of the Mezen district in the Arkhangelsk Oblast and the NAO. Estimated doses are summarized in Table 4·12. The calculations were based on the intake of ^{137}Cs and ^{90}Sr with food.

Current doses to inhabitants of the Russian Arctic are <200 μSv/yr, much lower than during the 1960s when global fallout was at its highest. Doses on the Kola Peninsula are higher than in the Mezen district and the NAO. The highest doses occur among reindeer herders. Doses to reindeer herders on the Kola Peninsula are twice those in other regions.

A direct comparison of different areas is achieved by normalizing the internal doses due to ^{137}Cs and ^{90}Sr intake to the ^{137}Cs and ^{90}Sr activity concentrations per unit soil surface (Table 4·13). This shows that doses to Groups I, II, and III per unit deposition are higher on the Kola Peninsula than in the other areas. This presumably reflects the higher transfer to foodstuffs in the Kola region. Table 4·14 shows the contributions of different foods to effective internal dose in northwest Russia.

Table 4·14. Percentage contribution of different foodstuffs to effective internal dose in northwest Russia (Borghuis *et al.*, 2002).

	Kola Peninsula Group I	Kola Peninsula Group II	Kola Peninsula Group III	Mezen district Group I	Mezen district Group II	Mezen district Group III	Nenets AO Group I	Nenets AO Group II
Dairy products	0.14	0.88	2.7	0.54	13	14	0.21	0.86
Beef	0.02	0.03	0.88	0.07	2.3	1.4	0.08	1.3
Reindeer meat	89	63	7.4	90	40	19	95	86
Mushrooms	2.5	7.9	39	4.8	21	31	0.84	2.4
Berries	2.5	6.6	32	2.8	15	26	2.8	7.4
Potato	0.15	1.1	5.7	0.22	2.8	4.5	0.14	0.52
Freshwater fish	5.1	20	11	1.3	5.5	4.1	0.67	1.7
Marine fish	0.09	0.04	1.8	0.14	0.57	0.42	0.19	0.47

Currently, the annual effective dose from external exposure to anthropogenic gamma radiation (^{137}Cs of global and Chernobyl fallout origin) varies from 1 to 10 µSv/yr. The highest values correspond to reindeer herders and the lowest to urban inhabitants.

Reindeer meat consumption is important to all groups, with the exception of the coastal community at Umba, and dominates intake for reindeer herders. For rural inhabitants, fish, mushrooms, berries, and dairy products are also important. For urban dwellers, dairy products, mushrooms, berries, and freshwater fish can be important contributors to internal dose.

This assessment of communities in northwest Russia has shown that some of the current variations in food product contribution and total dose are explained by the following factors:

- the rate of reindeer meat consumption;
- the higher transfer of radiocesium to foodstuffs on the Kola Peninsula than in areas further east;
- the location of the community – coastal communities receive the lowest doses;
- land use – communities on the Kola Peninsula cultivate their own crops and buy local produce in shops to a greater extent than communities further east; and
- the rate of mushroom and berry consumption.

4.4.4. Comparison of past and present estimates of internal dose

Table 4·15 compares the internal doses estimated for the 1990s in the first AMAP assessment (AMAP, 1998) with those of the present assessment (based on the data in Sections 4.4.1. to 4.4.3.). Because the recent data were obtained after those considered in the first AMAP assessment, the annual values of internal dose for 'average' and 'selected groups' (reindeer herders) for the period 1990 to 1994 (Tables 8·13 to 8·16 in AMAP, 1998) were corrected to allow for the expected decline in activity with time. For reindeer meat and freshwater fish the T_{eff} for ^{137}Cs was taken as 12 yr. For other foodstuffs, the corresponding physical half-lives of ^{137}Cs and ^{90}Sr were used as the effective ecological half-lives.

The two dose estimates for the average population agree well. However, the effective internal dose estimated for the reindeer herders in the first AMAP assessment is approximately twice that of the present estimate. This is mainly due to the lower average radionuclide activity concentrations in the data used in the present assessment, and is despite the slightly higher intakes of reindeer meat used in the present assessment.

Table 4·15. A comparison of annual internal effective doses (µSv) due to the intake of ^{137}Cs and ^{90}Sr for the average population and reindeer herders in western Arctic Russia in the late 1990s estimated during the first AMAP assessment (AMAP, 1998) and the present assessment.

	AMAP (1998)		Present assessment	
	Average population	Reindeer herders	Average population	Reindeer herders
^{137}Cs	14	280	12	80-180
^{90}Sr	1	5.6	1.5-2.2	1.3-2.0

4.5. European spent nuclear fuel reprocessing plants

The first AMAP assessment addressed discharges from the Sellafield and Cap de la Hague spent nuclear fuel reprocessing plants in Western Europe, the transport of released radionuclides into the Arctic, and the associated doses to Arctic inhabitants. This assessment focuses on ^{99}Tc and ^{129}I, two radionuclides released from these sources which were not discussed in detail in the previous assessment and about which concern has recently been raised.

4.5.1. Technetium-99

Technetium-99 has two isomers, ^{99}Tc and ^{99m}Tc. The latter has a short half-life ($T_{1/2}$ = 6 hr) and is used in medical applications. It is of little concern outside the area of medical health physics. The former, however, is a long-lived fission product ($T_{1/2}$ = 212 000 yr) that has generated increased interest since the first AMAP assessment. The main sources of ^{99}Tc are nuclear weapons tests and the nuclear fuel cycle. The most important sources for western Scandinavia and Arctic environments are the European nuclear fuel reprocessing plants at Sellafield and Cap de la Hague (Dahlgaard *et al.*, 1997). Releases of ^{99}Tc from Sellafield have increased substantially in recent years (Section 2.2.1). As a result, a steep increase has been observed in the levels of ^{99}Tc in some marine biota, particularly crustaceans and seaweeds (Section 3.3.1). Owing to its long half-life and conservative behavior in seawater, ^{99}Tc is now of concern to some European nations (especially Ireland and the Nordic countries) as evidenced by discussions at the Ministerial Meeting of the OSPAR Commission in 1998 (OSPAR, 1998).

The contribution of ^{99}Tc to average individual doses to members of the local critical group of seafood consumers for Sellafield discharges during the period 1994 to 1996 are estimated at 18 to 42 µSv/yr (Uranium Institute, 1998).

An assessment of ^{99}Tc in the marine environment, around Ireland which included an estimate of doses to members of the Irish population, was developed in preparation for the 1998 Ministerial Meeting of the OSPAR Commission (Pollard *et al.*, 1998). This concluded that the individual (committed effective) doses to average seafood consumers were 0.053 µSv in 1996 and 0.068 µSv in 1997, reflecting a moderate increase associated with the increased concentrations in seafoods resulting from the increased discharges of ^{99}Tc from Sellafield that began in 1993. For heavy seafood consumers (presumably corresponding to a critical group), the corresponding values were 0.21 µSv in 1996 and 0.27 µSv in 1997. However, it should be noted that there are no estimates of the uncertainties associated with these dose estimates. In a follow-up to this work, Smith *et al.* (2001) extended the calculations to 1998, a period when ^{99}Tc activity concentrations in the marine biota of Western Europe were still increasing. The values quoted for average and heavy consumers of seafood for the years 1996 and 1997 were identical to those quoted by Pollard *et al.* (1998). The doses for 1998 were estimated at 0.062 µSv for average consumers and 0.25 µSv for heavy consumers of seafood. As stated by Smith *et al.*

(2001), these doses are of negligible radiological significance when compared to the annual dose limit of 1000 μSv for members of the public from practices involving controllable sources of radiation (ICRP, 1991). The authors also noted that doses to the same seafood consumer groups associated with ^{210}Po, a natural radionuclide for which doses through marine pathways are usually dominant, were 32 μSv and 148 μSv, respectively, for average and heavy seafood consumers.

Since conservative radionuclides discharged from Sellafield can be transported with the prevailing marine currents into Arctic waters it is appropriate to consider the biogeochemical behavior of ^{99}Tc, and associated impact in terms of human doses, in northern marine environments. Although human doses in Arctic regions are likely to be significantly below those observed in areas close to discharge points, differences in biological uptake and human dietary patterns may offset lower ambient contamination levels caused by dilution. In other words, uncertainties associated with the fate of ^{99}Tc in Arctic marine environments require attention.

Within the context of estimating human exposure in northern marine environments based on analyses of ^{99}Tc activity concentrations in foodstuffs derived from the sea, the Norwegian Radiation Protection Authority (Brown *et al.*, 1998) observed that: *'Individual radiation doses from human consumption of seafood from Norwegian waters are probably low due to the present low levels of contamination and the low dose conversion factor of ^{99}Tc'*.

The Uranium Institute (1998) has estimated the dose in relation to the quantities of specific seafoods consumed in Norway on the basis of reported ^{99}Tc activity concentrations in seafood (Brown *et al.*, 1998). The Uranium Institute calculated that the consumption of Norway lobster (*Nephrops norvegicus*), containing ^{99}Tc in the range 11.2 to 42 Bq/kg, would give rise to an individual dose to the consumer of <0.03 μSv/kg ingested. The corresponding value for mussels and shrimps, with ^{99}Tc in the range 0.54 to 0.68 Bq/kg, is 0.5 nSv/kg. These are very low dose/mass consumption ratios. Even an extreme seafood consumer eating 1 kg/d of Norway lobster would receive an annual dose of <11 μSv.

Thus, it can be argued that discharges of ^{99}Tc from Sellafield, even at rates close to the authorized release rate of 200 TBq/yr, as in 1995, lead to levels in Arctic marine waters that are of no radiological significance for human populations. However, there is much uncertainty regarding the biogeochemical behavior of ^{99}Tc in the marine environment, which undermines the ability to make prospective human impact assessments with any great conviction. It is notable that uptake levels under field conditions for some crustaceans (Brown *et al.* 1999; Busby *et al.* 1997) were largely unstudied before the recent discharges from the Enhanced Actinide Removal Plant (EARP) caused environmental levels to increase dramatically (Section 2.2.1), although laboratory studies had indicated that uptake rates could be high in these groups and that large inter-species variability existed. Technetium uptake by many Arctic species remains largely unstudied and thus an additional area of uncertainty with respect to human dose assessment. Finally, although technetium forms the highly soluble pertechnetate ion in oxygenated seawater and can therefore be modelled using hydrodynamic models, little attention has been given to the field behavior of ^{99}Tc under anoxic conditions, as occur in some Norwegian fjords, for example. In reality, little is known about the environmental transfer and biological uptake of reduced forms of this radionuclide.

4.5.2. Iodine-129

Iodine-129 is a long-lived fission product ($T_{1/2}$ = 17 000 000 yr) released from the nuclear fuel cycle. The release of ^{129}I to the European marine environment has increased in recent years primarily due to increased release rates from the Cap de la Hague fuel reprocessing plant (Yiou *et al.*, 1995). Owing to its long physical and environmental half-life ^{129}I is globally dispersed. The total global release from the civilian nuclear fuel cycle (reactors and reprocessing operations) is 14.8 TBq. This corresponds to a collective dose commitment, truncated at 10000 years, of 295 manSv (UNSCEAR, 2000). The maximum individual dose from globally dispersed ^{129}I is 0.005 μSv/yr (UNSCEAR, 2000). Thus, current individual dose rates are of little significance and a virtually insignificant source of risk to human health.

4.6. Conclusions

This chapter presents some dose assessments based on newly available information. The main outcome is as follows.

Doses to the Faroe Islands' population were consistent with the outcome of the preliminary assessment during the first AMAP assessment.

The consumption of caribou by the indigenous peoples in Arctic Canada has been reassessed and the doses to critical groups are now shown to be lower.

There is good agreement between the present dose rates estimated for the average population in northwest Russia in this assessment and those of the first AMAP assessment. However, the effective internal dose estimated for reindeer herders in the first AMAP assessment has now been halved. This is mainly due to data reporting lower average radionuclide activity concentrations in reindeer meat, and is despite slightly higher intakes of reindeer meat.

Although doses to the Arctic population from the release of ^{99}Tc and ^{129}I are very low, because these radionuclides behave conservatively in seawater, have very long half-lives, and because ^{99}Tc accumulates strongly in certain species, more work should be done to assess their effects on marine biota.

The doses to populations from a number of nuclear power plants within or near the Arctic were assessed during the first AMAP assessment. As this situation is not known to have changed significantly since then, that assessment has not been updated.

Further work should be carried out to assess the uncertainties for calculated internal doses.

Annex. **Tables**

Table A4·1. Activity concentrations of ^{137}Cs (Bq/kg ww) in products from northwest Arctic Russia 1998-2001 (Borghuis *et al.*, 2002).

	Kola Peninsula		Mezen district		Nenets AO	
	n	mean ± SD	n	mean ± SD	n	mean ± SD
Reindeer meat						
summer	10	70 ± 14	3	58 ± 33	21	34 ± 38
winter	44	146 ± 68	–	–	30	64 ± 73
Fish marine	8	0.56 ± 0.43	4	0.39 ± 0.23	8	0.51 ± 0.29
Fish freshwater	19	31 ± 20	9	3.8 ± 3.2	20	1.8 ± 1.9
Mushrooms	57	93 ± 70	35	47 ± 43	26	19 ± 14
Berries	22	16 ± 10	7	8.7 ± 5.2	34	17 ± 16
Milk	34	0.32 ± 0.23	9	0.51 ± 0.40	9	0.22 ± 0.15
Beef	18	1.3 ± 2.3	5	1.9 ± 1.6	–	–
Potatoes	12	0.12 ± 0.07	3	0.060 ± 0.013	4	0.08 ± 0.04
Lichen*	20	164 ± 80	8	100 ± 28	23	23 ± 18
Natural grasses*	3	9.7 ± 3.2	4	4.6 ± 2.5	8	6.6 ± 4.0

*dry matter.

Table A4·2. Activity concentrations of ^{90}Sr (Bq/kg ww) in products from northwest Arctic Russia 1998-2001 (Borghuis *et al.*, 2002).

	Kola Peninsula		Mezen district		Nenets AO	
	n	mean ± SD (range)	n	mean ± SD (range)	n	mean ± SD (range)
Reindeer meat	10	0.36 ± 0.18 (0.10-0.65)	3	0.42 ± 0.1 (0.30-0.63)	4	0.44 ± 0.13 (0.31-0.61)
Mushrooms	19	1.30 ± 0.80 (0.50-2.70)	–	–	4	0.90 ± 0.38 (0.42-1.30)
Berries	8	2.80 ± 2.40 (0.80-11.0)	8	1.61 ± 0.44 (0.70-4.00)	7	1.00 ± 0.51 (0.40-1.90)
bilberry	3	4.61 ± 5.20 (1.0-11.0)	3	2.20 ± 1.62 (1.10-4.00)	2	1.40 ± 0.64 (1.00-1.90)
cowberry	5	2.12 ± 1.10 (0.80-3.40)	3	1.62 ± 0.61 (1.00-2.10)	2	1.20 ± 0.45 (0.86-1.50)
Milk	5	0.15 ± 0.09 (0.05-0.21)	4	0.30 ± 0.21 (0.10-0.54)	5	0.094 ± 0.018 (0.07-0.11)
Potatoes	12	0.25 ± 0.11 (0.05-1.00)	9	0.18 ± 0.08 (0.11-0.27)	5	0.090 ± 0.034 (0.05-0.13)
Lichen*	14	62 ± 56 (5.2-187)	9	61 ± 27 (27-99)	16	38 ± 22 (8-83)
Natural grasses*	3	11 ± 7 (5-19)	6	16 ± 3.7 (12-21)	6	16 ± 12 (4.2-35)

*dry matter.