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Dose Estimates from Ingestion of Marine and Terrestrial Animals Harvested in the Beaufort Sea and Northwestern Alaska

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Abstract

Between 1993 and 1995, marine and terrestrial animal samples were collected from the Beaufort Sea and northwest Alaska. These samples were analyzed at Los Alamos National Laboratory for the presence of the anthropogenic radionuclides, ^{90}Sr, ^{137}Cs, ^{238}Pu, $^{239+240}$Pu, and ^{241}Am. The measurement data were combined with food consumption rates based on survey results for populations residing in three northwest Alaskan communities and published age-dependent ingestion dose coefficients to estimate potential radiological impacts from the consumption of traditional animal foods harvested in this region.

The results of this study indicate that committed equivalent doses to adults from ^{90}Sr and ^{137}Cs, due to consumption of traditional food sources, are consistent with currently accepted estimates of average doses to adults in North America due to atmospheric nuclear weapons testing fallout.

Introduction

Since the era of atmospheric nuclear weapons testing, there has been a keen interest in the arctic environmental pathways for human exposure to anthropogenic radionuclides; e.g., see Reference [1]. This interest heightened again in 1993 when the Russian Federation disclosed historical information about the dumping of nuclear wastes into the Arctic Ocean. These waste materials included submarine reactors, fuel assemblies, and other radioactive wastes that were dumped into the Kara and Barents Seas between 1959 and 1992 [2]. Additionally, three major Russian nuclear weapons production facilities, Chelyabinsk, Tomsk, and Krasnoyarsk, located at the headwaters of the Ob and Yenisey Rivers, which flow from the Urals into the Kara Sea, discharged over 10^{18} Bq of radioactive materials into these two rivers since the early 1950s [2, 3]. The announcement about direct dumping of waste into the Arctic Ocean and the potential for future contamination from materials in the Ob and Yenisey Rivers, raised questions regarding exposure of Alaskan native communities through their traditional food supplies, and potential effects on Alaskan fisheries resources [4, 5, 6, 7].

Between 1993 and 1995, a series of marine sediment and animal samples were collected from the Beaufort Sea, and terrestrial animal samples were collected in the vicinity of Barrow, Alaska. Marine samples were collected by National Oceanic and Atmospheric Administration personnel on board the U.S. Coast Guard icebreaker "Polar Star." Radiochemical analyses of the collected samples were performed at Los Alamos National Laboratory (LANL) for the presence of ^{90}Sr, ^{137}Cs, ^{238}Pu, $^{239+240}$Pu, and ^{241}Am [8].

The results of the radioactivity concentration measurements were combined with food consumption data for traditional animal food sources harvested from the Beaufort Sea and terrestrial animal food sources harvested near Barrow, Alaska. These results were then combined with age-dependent ingestion dose coefficients and ingestion rates to estimate the committed doses to age 70 y for youth age groups and 50 y committed doses for adults. The resulting committed dose estimates for adults are compared to currently accepted values of internal dose from background radiation (excluding doses from exposure to radon sources) and radioactive fallout from atmospheric nuclear weapons testing for adults in the United States.

Methods

Consumption Rates of Traditional Food Sources

The results of the radioactivity concentration measurements, listed in Table 1, were combined with food consumption rates, collected and compiled by the Alaska Department of Fish and Game (ADFG) between 1980 and 1997, to estimate ingestion intake rates of the detected radioactive species in three Alaskan communities, Barrow, Kaktovik, and Nuiqsut [9]. The ADFG compilations focus on consumption of marine and terrestrial food sources harvested for subsistence in Alaskan communities, i.e., the foodstuffs are used as a primary food source. Average consumption rates for estimation of intake of the measured radionuclide concentrations in this paper were based on a series of surveys conducted by the ADFG in Alaska in the 1985-1992 time frame [9, 10, 11, 12, 13, 14]. The annual consumption rates used in this study are listed in Table 2. Age-dependent ingestion rates were estimated using the scaling factors listed in Table 3.

Age-Dependent Dose Coefficients

Age-specific annual radioactivity intakes from traditional food sources were estimated by combining the ADFG data, the measured radionuclide concen-

Table 1: Measured radionuclide concentrations (Bq/kg, wet weight of the edible fraction) in food sources collected from northwest Alaska and the Beaufort Sea. Less than values (<) indicate the measured result was less than the indicated decision level. The uncertainty values indicate one standard deviation.

Resource	^{90}Sr	^{137}Cs
Fish		
broad whitefish	0.11 ± 0.06	0.06 ± 0.01
arctic char	0.12 ± 0.08	< 0.04
arctic cod	< 0.05	1.35 ± 0.05
arctic cisco	0.47 ± 0.24	0.62 ± 0.12
least cisco	not measured	0.26 ± 0.09
Dolley Varden	0.13 ± 0.03	0.17 ± 0.07
chum salmon	< 0.04	0.11 ± 0.03
Marine Mammals		
bowhead whale	0.015 ± 0.003	0.11 ± 0.03
bearded seal	< 0.02	< 0.2
polar bear	0.03 ± 0.03	0.17 ± 0.14
Migratory Fowl		
king eider	< 0.001	< 0.13
Land Mammals		
caribou	not measured	9.2 ± 1.1

Table 2: Average per capita, annual consumption rates of traditional marine and terrestrial foodstuffs listed in Table 1 for Barrow, Kaktovik, and Nuiqsut, Alaska. Results reported without an associated uncertainty are based on only one or two survey results.

Resource	Barrow (kg/capita/year)	Kaktovik (kg/capita/year)	Nuiqsut (kg/capita/year)
Fish			
broad whitefish	5.96 ± 5.24	0	41.2
arctic char	0.03 ± 0.03	22.0 ± 12.7	0
arctic cod	0.51 ± 0.17	0.15	0.01
arctic cisco	0.21 ± 0.16	3.31 ± 3.03	36.5
least cisco	0.66 ± 0.34	0.82	4.1
Dolley Varden	0	0	0
chum salmon	0.17 ± 0.17	0	1.05
Marine Mammals			
bowhead whale	32.4 ± 22.4	138	52.5
bearded seal	3.98 ± 1.96	8.65 ± 1.61	2.16
polar bear	1.39 ± 1.35	2.47 ± 0.85	0
Migratory Fowl			
king eider	0.02 ± 0.02	0.79 ± 0.39	0.99
Land Mammals			
caribou	23.4 ± 9.2	47.0 ± 13.4	72.2

Table 3: Age-dependent fraction of daily intake relative to adult intake of food.

Median Age (years)	Fraction of Intake
0.25	0.08
1	0.25
5	0.42
10	0.42
15	0.72
> 18 (adult)	1.00

trations in Table 1, and the age-dependent fractions of daily intake. Dose coefficients published by the International Commission of Radiological Protection (ICRP) were used to convert these annual ingestion intakes into committed doses for youths (less than 18 years of age) to age 70 y and to 50 y committed doses for adults as recommended by the ICRP [15, 16, 17, 18, 19].

Results

Measured Activity Concentrations

Table 1 contains measured ^{90}Sr and ^{137}Cs activity concentrations, expressed in wet weight of the edible fraction, in marine and terrestrial biota collected from the Beaufort Sea and northwest Alaska [8]. Alpha-spectroscopic analysis found no measurable activity of ^{238}Pu, $^{239+240}$Pu, and ^{241}Am in the biological samples listed in Table 1. Table 4 contains the average α-spectroscopy analytical sensitivities for ^{238}Pu, $^{239+240}$Pu, and ^{241}Am for these biological materials analyzed at LANL [8].

Table 4: Estimated α-spectroscopy analytical uncertainties (σ_0) for actinide concentration (Bq/kg, wet weight) measurements in biological materials.

^{238}Pu	$^{239+240}$Pu	^{241}Am
1.3×10^{-4}	2.0×10^{-4}	6.3×10^{-4}

Intakes of Traditional Food Sources

Table 2 contains a summary of the average intake values for the food sources listed in Table 1, derived from the ADFG survey results. The uncertainties listed in Table 2 are calculated as the standard deviation of the average annual per capita results; these uncertainties are not based on individual variations in intake. Results reported without an associated uncertainty are based on only one or two annual survey results. The per capita masses refer to the wet weight edible fraction "brought into the household kitchen for use" [9]. The ADFG survey indicates, on average, that over 85% of the subsistence harvest brought into a household is ultimately consumed [14]. This correction is not applied in the current analysis.

Figure 1 contains a bar chart summary of the total subsistence quantities determined for each community. Note that the measurement data used for dose estimation here do not include several species included in the ADFG report (e.g., moose, brown bear, dall sheep, squirrel, lake trout, grayling, goose, ptarmigan, belukha whale, spotted seal, ringed seal, and walrus).

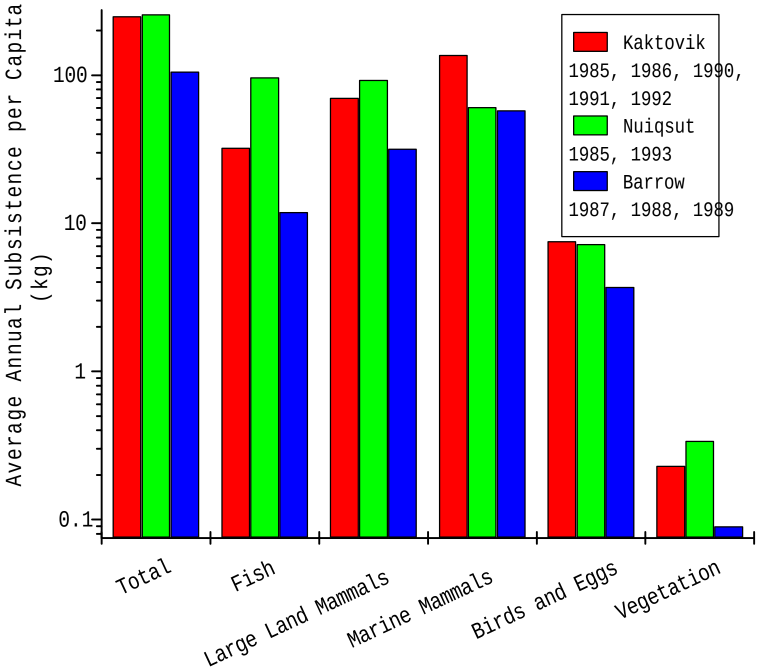

Figure 1: Summary of ADFG survey results for annual subsistence, in three Alaskan communities. The years of surveys for each community are also noted.

Figure 2 contains a summary of demographic data for the communities of Kaktovik and Nuiqsut taken from Scott et al. [14]. The ADFG study did not contain this detailed demographic information for Barrow, Alaska (population approximately 4000) [10, 11, 12, 13, 14].

Committed Dose Estimation

Table 5 contains the estimated age-dependent committed equivalent dose values for ^{90}Sr and ^{137}Cs after a single year of consumption of the food sources listed in Table 2. Table 6 contains a compilation of the fraction of dose from each general food source, for each community.

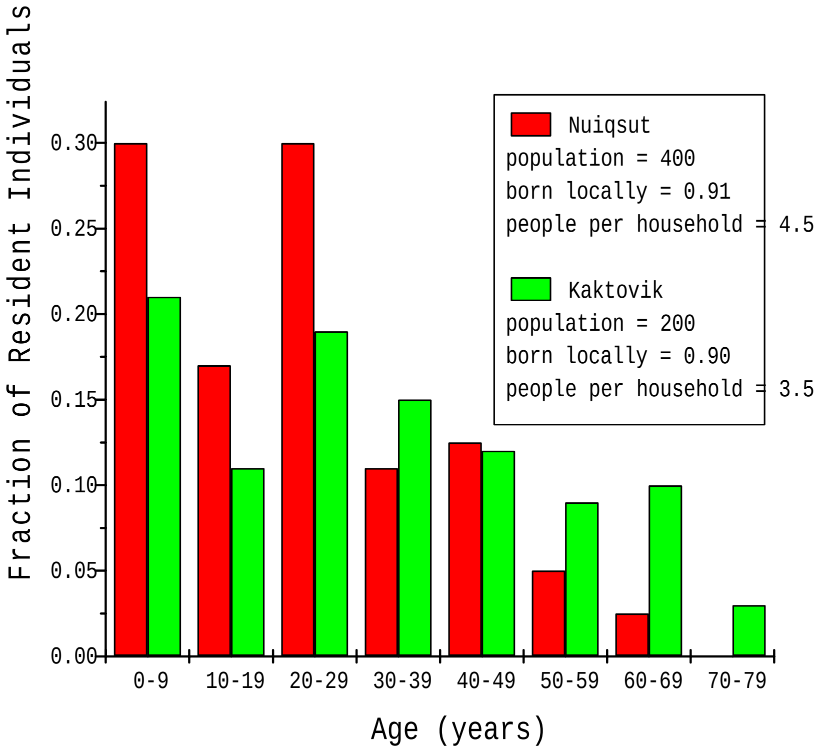

Figure 2: Summary of demographic data for two Alaskan communities evaluated in this study.

Discussion

Food Sources

The results presented here are based on a small data subset of species used as subsistence in the region. The analyses further assume that the subsistence harvest is all consumed by humans in the location harvested (e.g., harvested animals are not given away to other communities) and that individuals in these locations have annual dietary habits (e.g., total intake and age-dependent intake) that are similar to other populations in North America. The assumption regarding transfer of food to other communities holds for estimating annual averages: transfers do take place in years where a community that experiences an abundant harvest will share the harvest with communities experiencing a lean harvest. The ADFG report notes that at least 85% of food taken in as subsistence harvest is consumed in the communities of Kaktovik and Nuiqsut [14]. Individual variations in food intake were not included in final dose estimate uncertainties. The ADFG study was based on subsistence for all household members, including infants and children [9, 14]. It is assumed here that children and infants ingest a fraction of the estimated per capita intake of the traditional food sources. This assumption is valid, given the harvested products are a primary food source for each household [9]. Infants are also exposed to the radionuclides in the harvested products via breast feeding

A notable difference between the three communities is that Barrow serves as a local government and oil exploration industry center, the community is dominated by households with salaried incomes and a larger fraction of nontraditional food sources. Households in the communities of Kaktovik and Nuiqsut have a significantly greater reliance on natural food sources collected locally, approximately 250 kg per year out of an expected total consumption of 420 kg per year [14, 20]. Intake of local terrestrial and marine plant species, not taken into account in this analysis, should have little effect on final dose estimates because of the remarkably small fraction of local vegetation harvested for consumption (see Figure 1).

Doses due to ^{137}Cs

The metabolic behavior of ^{137}Cs is similar to that of potassium. Cesium tends to be distributed throughout the soft tissues of the body, mainly inside cells. The principal source of ^{137}Cs in the arctic environment is from atmospheric testing of nuclear weapons during the 1950s, fallout from the 1986 accident at the Chernobyl Nuclear Power Plant, and releases from the nuclear reprocessing plant in Sellafield, U.K. [2]. In arctic and subarctic environments, the lichen-to-caribou-to-man food chain constitutes a well documented pathway for concentration of a radioactive species in a human food source [21]. Note the caribou ^{137}Cs tissue concentrations are much larger relative to the other animal tissues listed in Table 1. Another instance of this food chain transfer effect has been found in cesium concentrations in freshwater fish. In some cases, freshwater fish at the higher trophic levels have been found to have tissue concentrations that are up to several thousand times higher than concentrations in their surroundings [21].

Cesium has a biological half time, in humans, on the order of 100 days [22]. This biological retention time results in 99% of the committed dose being delivered in the year following intake. The National Council on Radiation Protection and Measurements (NCRP) has published a value of 150 μSv from chronic intakes of environmental ^{137}Cs over a 30 year period (from 1970

Table 5: Age-dependent committed equivalent dose estimates from ^{90}Sr and ^{137}Cs after a single year of consumption of marine and terrestrial food sources listed in Tables 1 and 2, for three Alaskan communities.

Median Age (years)	Bone Surface Equivalent Dose (μSv)	Effective Dose (μSv)	Effective Dose (μSv)
Barrow			
	^{90}Sr		^{137}Cs
0.25	0.11 ± 0.03	0.010 ± 0.003	0.27 ± 0.04
1	0.10 ± 0.03	0.010 ± 0.003	0.46 ± 0.07
5	0.15 ± 0.04	0.011 ± 0.003	0.63 ± 0.10
10	0.26 ± 0.07	0.014 ± 0.004	0.69 ± 0.10
15	0.74 ± 0.19	0.033 ± 0.009	1.7 ± 0.2
$>$ 18 (adult)	0.23 ± 0.06	0.016 ± 0.004	2.2 ± 0.3
Kaktovik			
0.25	2.43 ± 0.48	0.24 ± 0.05	0.73 ± 0.21
1	2.43 ± 0.48	0.24 ± 0.05	1.25 ± 0.37
5	3.58 ± 0.71	0.26 ± 0.05	1.72 ± 0.51
10	6.20 ± 1.20	0.34 ± 0.07	1.87 ± 0.55
15	17.0 ± 3.0	0.76 ± 0.15	4.59 ± 1.35
$>$ 18 (adult)	5.5 ± 1.1	0.37 ± 0.07	5.91 ± 1.74
Nuiqsut			
0.25	4.74 ± 1.66	0.47 ± 0.17	1.11 ± 0.13
1	4.71 ± 1.65	0.46 ± 0.16	1.92 ± 0.22
5	6.93 ± 2.43	0.51 ± 0.18	2.63 ± 0.31
10	11.9 ± 4.17	0.65 ± 0.23	2.87 ± 0.34
15	33.4 ± 11.7	1.47 ± 0.51	7.02 ± 0.82
$>$ 18 (adult)	10.6 ± 3.70	0.72 ± 0.25	9.06 ± 1.06

Table 6: Fractions of contribution, from general food source categories, to the dose estimate results listed in Table 5.

Food Source	Barrow	Kaktovik	Nuiqsut
^{90}Sr			
Fish	0.57	0.66	0.96
Marine Mammals	0.43	0.34	0.04
Caribou	0	0	0
^{137}Cs			
Fish	0.004	0.008	0.038
Marine Mammals	0.021	0.032	0.009
Caribou	0.957	0.960	0.953

to 2000) for an adult in the United States [23]. Table 7 contains a summary of average dose equivalent commitment to the year 2000 for individuals in the United States from atmospheric nuclear weapons testing through 1970.

Table 7: Average dose equivalent commitment to the year 2000 for adults in the U.S. population from nuclear weapons testing through 1970 (from the National Council on Radiation Protection and Measurements [23]).

Source	Tissue	Dose Equivalent Commitment (μSv)
External		
	effective (whole body)	750
Internal		
^{90}Sr	bone marrow bone, endosteal surfaces	450 650
^{137}Cs	effective (whole body)	150
$^{239+240}$Pu	bone	20
^{3}H	effective (whole body)	20
^{14}C	effective (whole body)	80

Assuming an exponential decrease with a half time of 30 y, and no other competing pathways to remove cesium from the food chain, the committed dose for a single year of uniform daily intake in 1993 would be on the order of $4\,\mu$Sv. The committed effective dose from ingestion of ^{137}Cs measured in the marine and terrestrial food sources listed in Table 1 ranges from 2.2 ± 0.3 to $9.1 \pm 1.1\,\mu$Sv, for an adult. The developing embryo-fetus would be expected to have a ^{137}Cs tissue concentration equal to the maternal tissue concentration in periods of uniform intake of caribou [24].

Aarkrog, et al. [25] have estimated a committed dose to an adult of $0.03\,\mu$Sv from annual fish consumption worldwide, in Scandinavia the mean individual dose is ten times higher for a consumption rate of 100 kg of fish per year. This result may be compared to a range of $0.09\ \mu$Sv, in Barrow, to $0.5\ \mu$Sv, in Nuiqsut, per 100 kg of fish consumed per year. The ^{137}Cs activity concentrations in fish collected in the Beaufort Sea, used in this study, were on the order of 0.1 to 1 Bq kg^{-1}. This result is approximately 50% of the values measured in fish taken from the Barents Sea, 0.2 to 3 Bq kg^{-1}, and significantly lower than samples collected from the Kara Sea 11 to 26 Bq kg^{-1} [6].

Doses due to ^{90}Sr

In this study, the ^{90}Sr activity concentrations in fish in the Beaufort Sea were on the order of 0.1 to 0.5 Bq kg^{-1}. This result is a factor of three to four times lower than values measured in fish taken from the Kara Sea, 0.3 ± 1.9 Bq kg^{-1} [6]. Kryshev and Sazykina estimated an annual dose rate of $4\,\mu$Sv per year, from consumption of 220 kg of fish from the Kara Sea in the time period 1986-1990 [6]. This dose roughly converts to a committed dose of $0.5\,\mu$Sv per kg of fish consumed from the Kara Sea. This result may be compared to $0.13\,\mu$Sv (committed bone surfaces equivalent dose) and $0.009\,\mu$Sv (committed effective dose) per kg of fish consumed from the Beaufort Sea. The expected lifetime dose to the developing embryo-fetus, from chronic maternal consumption of Arctic fish during gestation, would be about an order of magnitude lower than the mother [24].

The NCRP has estimated a committed bone surface dose of $650\,\mu$Sv from chronic intakes of environmental ^{90}Sr (see Table 7) over a 30 year period, from 1970 to 2000, for adults in the United States of America [23]. Assuming an exponential decrease of ^{90}Sr in foods, with a half time of 30 y, and no other competing pathways to remove strontium from the food chain, the committed bone surface dose for a single year of uniform daily intake in 1993 would be on the order of $14\,\mu$Sv. The committed bone surface equivalent dose to adults for a single year intake of ^{90}Sr, estimated in this study, is in the range $0.23 \pm 0.06\,\mu$Sv to $10.6 \pm 3.7\,\mu$Sv. The committed bone surfaces equivalent dose, for a teenaged individual, ranges from $0.74 \pm 0.19\,\mu$Sv in Barrow to $33.4 \pm 11.7\,\mu$Sv in Nuiqsut.

Conclusions

The results presented here indicate that internal radiation doses from intakes of traditional marine and terrestrial animal food sources in northern Alaska are consistent with published estimates of doses to adults in the U.S. population due to natural background and fallout from atmospheric nuclear weapons testing. It is emphasized that the doses reported here are based on a subset of subsistence intakes; doses from total annual ingestion could be 10% to 30% higher. Communities that rely on these traditional food sources, such as Nuiqsut and Kaktovik, incur larger doses. The internal dose is smaller in a community such as Barrow, where traditional food sources make up a smaller fraction of the total diet. This finding is particularly important for populations that use animals harvested in the Arctic as a primary food source.

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