6. Assessment of Risks to Alaskan Populations from Exposures to Radionuclides in Subsistence Diets

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This section assesses the potential health risks to man of the various sources of nuclear wastes from the FSU addressed in Section 2. The focus of the assessment is on Alaska coastal communities within the area outlined in Figure 6-1. This area contains a linear coastline distance of over 3,200 km, 29 coastal communities, and a population of more than 18,000 people, of which 76% are native (Alaska Department of Community and Regional Affairs, 1996). Table 6-1 provides population information from the United States 1990 Census on these communities. Residents of the coastal communities obtain large portions of their subsistence foods from the marine environment. Because the consumption of such foods is the principal exposure pathway of concern, the RAIG begins the assessment with a review of data on the intakes of subsistence foods for Alaskan coastal communities. To provide a context for evaluating the results of the dose assessment, the RAIG also provides estimates of the naturally occurring and anthropogenic (man-made) radiation doses associated with the consumption of these marine foods. The team then predicts the doses for various source-term releases of nuclear materials from the Kara Sea, storage ponds at the Mayak and Tomsk nuclear facilities, and dumpsites in the Northwest Pacific. It concludes with analyses of the magnitude of potential risks, key uncertainties, and the benefits of subsistence diets versus potential risks.

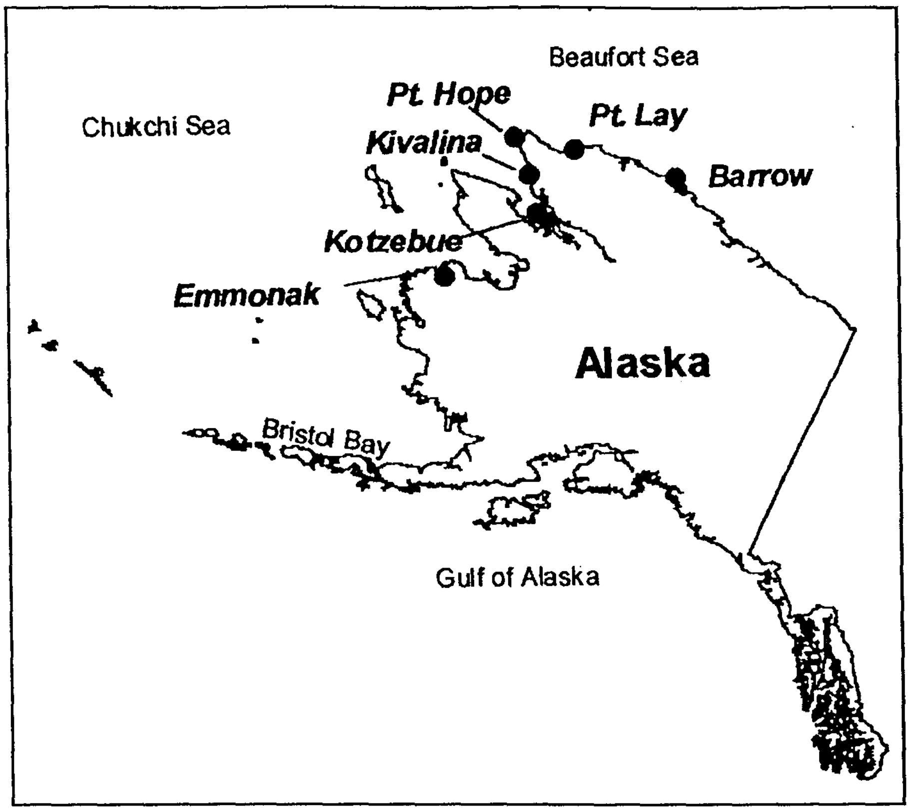

Figure 6-1. Coastal communities of Alaska addressed in the risk assessment of nuclear wastes derived from the former Soviet Union.

6.1 Subsistence Life-style

Alaska Native values are centered on their close relationship with the land and sea and its resources. The subsistence-based life-style of Alaska Natives integrates cultural values with hunting, gathering, and processing of local resources. The acquisition of subsistence foods provides a core emotional and spiritual tie within the community that links them with the past and present. For example, whaling activities embody the values of sharing, social relations both within and between communities, leadership, kinship, Arctic survival, and hunting prowess. This holds true for all the other subsistence activities, such as fishing and berry gathering.

Table 6–1. Census data for coastal communities in Alaska in 1990 (Alaska Dept. of Community and Regional Affairs).

Location	Indian	Eskimo	Aleut	Alaska Native Population	Total Population	% Alaska Native
Barrow	66	2144	7	2217	3,469	64%
Buckland	2	300	0	302	318	95%
Deering	1	145	2	148	157	94%
Diomede	1	163	3	167	178	94%
Elim	0	237	5	242	264	92%
Emmonak	8	583	0	591	642	92%
Gambell	1	504	0	505	525	96%
Golovina	1	117	0	118	127	93%
Kaktovik	1	186	2	189	224	84%
Kivalina	0	309	0	309	317	98%
Kotlik	1	441	5	447	461	97%
Kotzebue	44	2,017	6	2067	2,751	75%
Koyuk	2	216	1	219	231	95%
Nome	68	1745	11	1824	3,500	52%
Nuiqsut	1	327	0	328	354	93%
Pt. Hope	1	585	1	587	639	92%
Pt. Lay	2	111	0	113	139	81%
Saint Michael	1	268	0	269	295	91%
Savoonga	0	493	1	494	519	95%
Selawik	8	560	1	569	596	96%
Shaktoolik	0	164	4	168	178	94%
Shishmaref	1	429	1	431	456	95%
Solomon	0	6	0	6	6	100%
Stebbins	2	376	1	379	400	95%
Teller	1	130	0	131	232	87%
Unalakleet	4	574	4	582	714	82%
Wainwright	2	462	0	464	492	94%
Wales	0	143	0	143	161	89%
White Mountain	2	154	2	158	180	88%
Totals	221	13,889	57	14,167	18,525	

In the North Slope Borough, 54% of all households surveyed indicated that half or more than half of the meat, fish, and birds consumed came from subsistence activities (Harcharek, 1995). The same survey indicated that 72% of Inupiat households obtained half or more of their foods from subsistence harvest, compared with 16% of the non-Inupiat households. Limited data from the North Slope Borough indicate that the number of Inupiat households reporting that they contain over half of their food from subsistence activities has increased since surveys from 1977 and 1988. Figure 6-2 provides the number of meals per week that contained food from subsistence activities

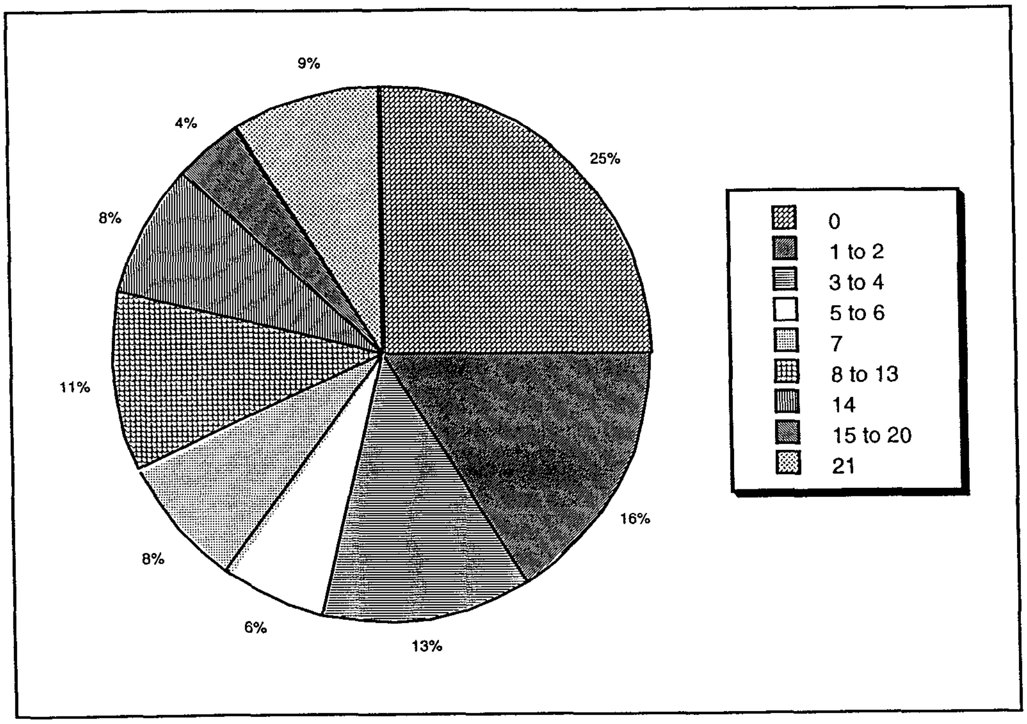

Figure 6-2. Number of subsistence-derived meals consumed each week by residents of the North Slope Borough in Alaska.

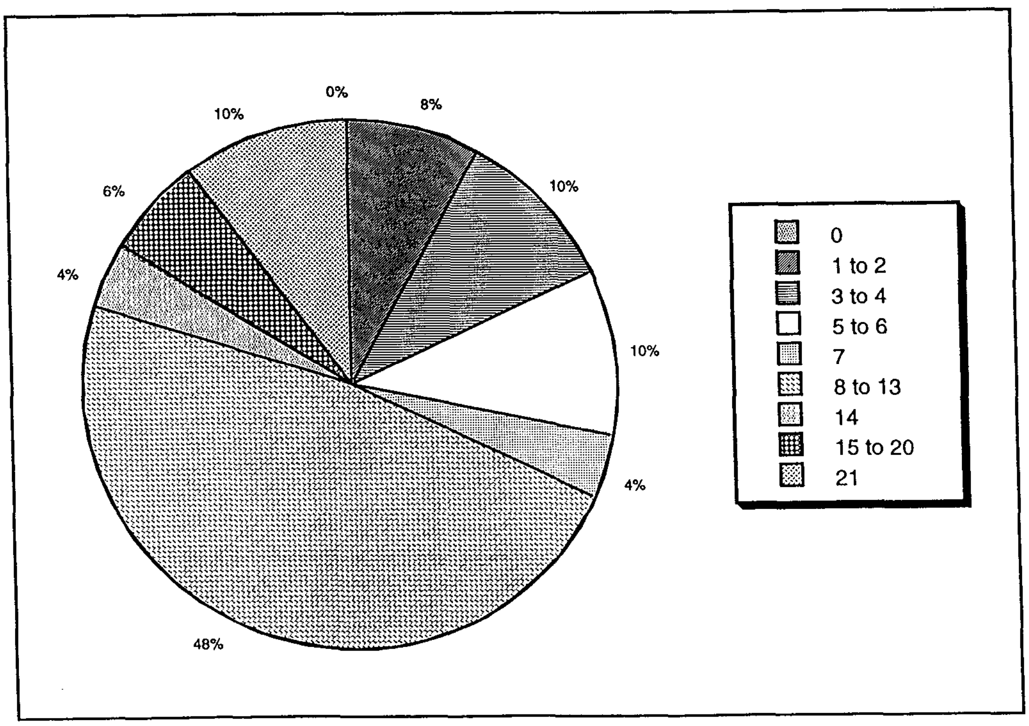

Figure 6-3. Number of subsistence-derived meals consumed each week by Point Lay residents.

within the North Slope Borough. In some communities the consumption rates increase because of economic and other factors, as shown in Figure 6-3 for Point Lay (Harcharek, 1995).

6.2 Dietary and Harvest Patterns

A review of the literature indicates that dietary pattern data for many of these coastal communities were never established, or were collected some time ago. Existing dietary information varies in survey methodology, age groups considered, food descriptions, and composition. Even if consumption rates are known for one locality, the migratory patterns of animals, seasonal climatic conditions, and differences in cultural and economic conditions between communities make it difficult to extrapolate diets between different places and time periods (e.g., historic v. modern). The lack of comprehensive dietary information, including food processing, is a data gap that must eventually be addressed to more accurately estimate radiation exposure and resulting risks to Alaska Natives.

As an alternative technique for developing reference diets of subsistence foods for Alaska Natives in coastal towns and villages, the RAIG has analyzed data on the annual harvesting of marine organisms compiled by the Alaska Department of Fish and Game (ADF&G), Division of Subsistence, to estimate the per-capita intakes of various subsistence foods (Scott et al., 1995). Harvest information for the coastal communities covers all wild resources harvested for personal and family use, including human and animal consumption, such as by sled-dog teams.

Data on commercial harvests of fish and marine invertebrates are not included. Appendix D summarizes representative per-capita intake rates of food items derived from the community-based subsistence-harvest surveys. In all cases marine mammals and fish make up the major portion of the marine organisms harvested for these coastal communities. Total marine-resource consumption levels calculated from the harvest data range from 72 to 328 kg/yr. These fall within marine-resource consumption ranges reported for indigenous populations in Canada (Health Canada, 1995; Kinloch et al., 1992) and for Alaskan coastal villages in the 1960s (Wilimovsky and Wolfe, 1966). Harvest patterns differ among communities because of migratory pathways and seasonal patterns. For example, the harvesting and consumption of fish changes dramatically as one moves from the salmon-rich Yukon Delta area, represented by Emmonak, to the Point Lay community, which relies heavily on a major harvest of beluga whales in the early summer. Although these reference dietary patterns establish a realistic range to assess the radiation dose from the consumption of marine-subsistence foods, they provide no information on the dietary intakes of critical groups who may consume most, if not all, of their foods from local subsistence resources. In addition, the reference diets do not necessarily include unique dietary items, for example, ascidians (also termed sea squirts or tunicates) consumed by residents of St. Lawrence Island in the Bering Sea (Nobmann, 1996).

People are concerned with their own diet patterns and may feel that the representative dietary information does not address their particular situation. The development of data on dose per pound of marine-subsistence food items is used to address this concern. A simplified worksheet for estimating personal doses is provided in Appendix E. An individual concerned about his or her own individual diet could consult with his local health organizations and determine his exposure level.

6.3 Reference Diets for Specific Communities

The ANWAP RAIG model for radionuclide transport identifies three general regions along the Alaska coastline: areas adjacent to the Bering, Chukchi, and Beaufort seas. For the assessment the RAIG team selected villages and towns within each region and established their representative exposures. While these exposures are based on reference diets that may not be completely adequate for any one real person, they provide insight into the overall magnitude and importance of the potential radiation doses received by Alaskan coastal community residents who rely heavily on marine foods. The selected locations are listed below in roughly south-to-north order.

6.3.1 Emmonak

With a 1990 population of 642, Emmonak is an Eskimo village involved in commercial fishing, processing, and subsistence activities. It is located at the mouth of the Yukon River on the north bank of Kwiguk Pass in the Yukon-Kuskokwim Delta, 175 miles northwest of Bethel. For the purposes of the RAIG assessment, this settlement is considered to be associated with the waters of the Bering Sea. Residents of Chuloonawick, a nearby summer fish camp, also live in the village. Emmonak has a seasonal economy, with most activity occurring during the summer. It is becoming a center for commercial fishing, purchasing, and processing on the lower Yukon River. Subsistence activities, trapping, and public assistance supplement income. A representative diet for this area is presented here (see Appendix D for details of this diet):

- Fish 400 lb/yr
- Marine Mammals 95 lb/yr
- Birds/Eggs 0 lb/yr
- Marine Invertebrates 0 lb/yr

6.3.2 Diomede

Diomede is located on the west coast of Little Diomede Island in the Bering Strait, 135 miles northwest of Nome. It is only 2.5 miles from Big Diomede Island, Russia, and the international boundary lies between the two islands. Diomede is a traditional Ingalikmiut Eskimo village with a subsistence life-style dependent upon sea mammals, cod, crab, and birds. Its 1990 population was 178. Mainland natives come to Diomede to hunt polar bears. Seal and walrus hides are used to make individual clothing items, parkas, hats, mukluks, and furs and skins for trade. The Diomede villagers depend almost entirely upon a subsistence economy for their livelihood. For the purposes of the RAIG assessment, this settlement is considered to be associated with the waters of the Bering Sea. A representative diet for this area is presented here, based on research conducted in the 1960s (see Appendix D for details of this diet):

- Fish 30 lb/yr
- Marine Mammals 715 lb/yr
- Birds/Eggs 137 lb/yr
- Marine Invertebrates 20 lb/yr

6.3.3 *Kotzebue*

Kotzebue is located on the Baldwin Peninsula in Kotzebue Sound, near the discharges of the Kobuk and Noatak rivers, 26 miles above the Arctic Circle and 549 air miles northeast of Anchorage. The population in 1990 was 2,751, primarily Inupiat Eskimos, and subsistence activities are an integral part of the life-style. As a regional economic center, Kotzebue offers a mixture of government, transportation, and other private-sector businesses. It has a healthy cash economy, a growing private sector, and a variety of public agencies. The majority of income is related directly or indirectly to government spending, the Maniilaq Association, and the Red Dog Mine. Commercial fishing of chum salmon and trout, and processing at Kotzebue Sound Area Fisheries provide some seasonal employment. Most residents rely on subsistence activities to supplement income. For the purposes of the RAIG assessment, this settlement is considered to be associated with the waters of the Chukchi Sea. A representative diet for this area is presented here, based on research conducted in the 1960s (see Appendix D for details of this diet):

- Fish 16 lb/yr
- Marine Mammals 216 lb/yr
- Birds/Eggs 77 lb/yr
- Marine Invertebrates 0 lb/yr

6.3.4 *Kivalina*

Kivalina is situated at the tip of an 8-mile barrier reef located between the Chukchi Sea and Kivalina Lagoon. Its 1990 population was 317. Kivalina is a traditional Eskimo village where subsistence activities, including whaling, provide most food sources. For the purposes of the RAIG assessment, this settlement is considered to be associated with the waters of the Chukchi Sea. A representative diet for this area is presented here (see Appendix D for details of this diet):

- Fish 234 lb/yr
- Marine Mammals 487 lb/yr
- Birds/Eggs 3 lb/yr
- Marine Invertebrates 0.1 lb/yr

6.3.5 *Point Hope*

The community of Point Hope, in the North Slope Borough, is located near the tip of Point Hope Peninsula, a large gravel spit that forms the westernmost extension of the northwest Alaska coast, 330 miles southwest of Barrow. A traditional Inupiat Eskimo village dependent upon subsistence activities, Point Hope's 1990 population was 639. For the purposes of the RAIG assessment, this settlement is considered to be associated with the waters of the Chukchi Sea. A representative diet for this area is presented here, based on research conducted in the 1960s (see Appendix D for details of this diet):

- Fish 187 lb/yr
- Marine Mammals 394 lb/yr
- Birds/Eggs 124 lb/yr
- Marine Invertebrates 0 lb/yr

6.3.6 Point Lay

The community of Point Lay is an unincorporated village in the North Slope Borough. Located near the mouth of the Kokolik River, about 300 miles southwest of Barrow, Point Lay is a traditional Inupiat Eskimo village, with a dependence upon subsistence activities and a 1990 population of 139. For the purposes of the RAIG assessment, this settlement is considered to be associated with the waters of the Chukchi Sea. A representative diet for this area is presented here (see Appendix D for details of this diet):

• Fish	25 lb/yr
• Marine Mammals	637 lb/yr
• Birds/Eggs	18 lb/yr
• Marine Invertebrates	0 lb/yr

6.3.7 Barrow

Barrow is situated on the Chukchi Sea coast, 10 miles south of Point Barrow from which it takes its name. It is the economic center of the North Slope Borough, the city's primary employer, and numerous businesses provide support services to oil-field operations. The majority of Barrow's 3,500 residents are Inupiat Eskimos who have traditionally depended on subsistence marine mammal hunting, supplemented by inland hunting and fishing. Marine mammal hunts and other subsistence practices are an active part of their culture. Although technically still within the Chukchi Sea, this point is the dividing line between the RAIG model's Chukchi and Beaufort calculational zones. For this assessment, the ocean water offshore of Barrow is assumed to be best represented by the Beaufort box. Two representative diets for this area are presented here, one for current conditions and one as described in the 1960s; (see Appendix D for details of these diets):

	Current Diet	1960s Diet
• Fish	27 lb/yr	110 lb/yr
• Marine Mammals	128 lb/yr	183 lb/yr
• Birds/Eggs	3 lb/yr	48 lb/yr
• Marine Invertebrates	0 lb/yr	0 lb/yr

6.3.8 Eastern North Slope Villages

Relatively few people live along the coast to the east of Barrow. This area is considered to be represented by the concentrations of radionuclides in the Beaufort Sea. Exposure and dietary patterns for residents of this area are taken to be similar to those defined for Canadian residents of the far north (Health Canada, 1995). A representative diet for this area is presented here (see Appendix D for details of this diet):

• Fish	187 lb/yr
• Marine Mammals	858 lb/yr
• Birds/Eggs	0 lb/yr
• Marine Invertebrates	0 lb/yr

6.4 Current and Historical Doses from Natural and Background Sources

Radiation is a natural part of the earth's environment. It comes from the sky above us, the earth beneath us, and even from our own bodies. The air we breathe and the food we eat contain some natural radioactivity. In fact, the average person in the United States receives a radiation dose of about 3,000 microsievert (µSv) per year from natural sources compared to a dose of about 500 µSv per year from "man-made" sources, including medical X-rays.

6.4.1 Radioactive Materials in Rocks and Soil

Natural radioactive material in rocks and soil account for about 280 µSv, or 8% of the radiation dose the average person receives in a year. The earth's crust contains small amounts of uranium and thorium as well as a radioactive isotope of potassium. The radiation dose to people comes directly from the rocks and soil and from building materials that come from the earth such as bricks and concrete. Small amounts of radon, a radioactive gas that comes from the radioactive decay of uranium, seep into the atmosphere from the soil. On average, radon in homes and other buildings in the continental United States accounts for 2,000 µSv per year, or about 55% of the total radiation dose an individual receives in a year from all sources, including medical X-rays. Radon, however, is not expected to be an important source of background dose for people living in coastal Arctic communities, because it can not easily diffuse out of frozen soils.

6.4.2 Radioactive Materials in the Body

About 11% (400 µSv) of the radiation dose the average person receives comes from naturally occurring radioactive materials in the body. Radioactive isotopes of potassium and polonium, as well as other radioactive materials that occur naturally in air, water, and soil, are incorporated into the food we eat and then into our body tissues. This is the type of exposure this assessment addresses. Doses to northern peoples from natural polonium sources such as caribou (Thomas, Sheard, and Swanson, 1994) and seafoods (see subsection 6.4.4 below), are somewhat higher than the national average.

6.4.3 Cosmic Rays

Cosmic radiation comes from outer space. The radiation dose from cosmic radiation increases with altitude, roughly doubling every 6,000 feet. A resident of Florida (at sea level), therefore, receives 260 µSv per year from cosmic radiation while a resident of Denver, Colorado, which is a mile high, receives a dose of 500 µSv per year. Residents of Leadville, Colorado (about 2 miles above sea level) receive about 1,250 µSv per year from cosmic radiation. A passenger in a jetliner traveling at 37,000 feet receives about 60 times as much dose from cosmic radiation as a person at sea level.

The cosmic radiation background also varies slightly with latitude. Lower-energy charged prides are defected back into space as a result of the influence of the earth's magnetic field. The geomagnetic cusp at northern latitudes allows a greater flux of low-energy protons to reach the top of the earth's atmosphere, slightly increasing the ionization and generation of secondary particles. At sea level, this results in an increase in the cosmic radiation background at high latitudes of about 10% over its value at the equator (UNSCEAR 1993). Thus, a northern Alaska resident might receive about 285 μSv/yr from this source, compared to the 260 μSv/yr to a Florida resident.

The average dose from natural background radiation varies across the country from 2,500 μSv/yr on the coasts to 5,000 to 6,000 μSv/yr in the Rocky Mountain West. Background doses to residents of coastal Alaska are expected to be near the lower end of this range, about 2,500 μSv/yr, primarily because of the lower dose from radon.

6.4.4 Internal Doses from Natural Radioactivity in Seafoods

Seafoods provide one source of radioactive materials taken into the body. Fish, mammals, birds and eggs, and shellfish eaten by Alaska residents all contain radionuclides from both natural and existing man-made sources. Foods derived from the ocean all have relatively high concentrations of ^{210}Po, the radionuclide that provides most of the dose to people from natural sources. Depending on how much of these types of foods one eats, the fraction of the total dose received from internal sources may be larger or smaller. Table 6-2 presents estimates of the annual background dose for each reference diet described above. These dose rates have remained essentially constant for many thousands of years, and will remain so into the distant future, because the source is the continuing decay of materials that make up the earth itself.

It should be noted that the individual dose rate conversion factor (the quantity that converts intake to radiation dose) for ^{210}Po is itself somewhat uncertain. The uptake of polonium from the gastrointestinal tract has been shown to vary from a few percent to as high as 80%. This, combined with lack of knowledge about the actual behavior of polonium in the human body, results in an uncertainty of at least a factor of 3 around the recommended value. The International Commission on Radiological Protection has recently raised the recommended value by about a factor of 2 to partially account for these difficulties (ICRP, 1994). Recent studies involving residents of northern Canada indicate that the dose-conversion factor could be even higher (Thomas, 1994; Health Canada, 1995).

Table 6-2. Background doses resulting from the ingestion of ^{210}Po in seafoods.

			Food Source		
Location/Diet	Fish	Mammals	Birds/Eggs Dose, μSv/yr	Invertebrates	Totals
Barrow	13	54	22	0	90
Barrow 1960s Diet	55	77	356	0	488
Canadian Diet	92	361	0	0	453
Emmonak	198	40	0	0	238
Diomede 1960s Diet	15	301	1,014	145	1,474
Kivalina	116	205	22	1	344
Pt. Lay	12	268	131	0	411
Kotzebue 1960s	8	91	568	0	667
Pt. Hope 1960s	93	166	919	0	1,177

6.4.5 Internal Doses from Historical Man-Made Sources

Just as seafoods contain naturally occurring radionuclides, they also now contain radionuclides from past human activities, primarily fallout from the testing of atomic bombs in the 1950s and 1960s, and from the fallout after the accident at the Chernobyl nuclear-power plant. The primary radionuclide contributing these doses is ^{137}Cs. As with the natural radionuclides, the amount of foods eaten controls how large the dose is from this source. Doses from consuming ^{137}Cs in subsistence foods have been larger in the past, peaking in the 1960s during the period of atmospheric testing of nuclear weapons (see Table 6-3). Current dose rates associated with man-made radionuclides in the Arctic presented in Table 6-4 are much lower than previous dose rates and are about one-tenth of the historical peak values from the 1960s. The doses from fallout radionuclides are decreasing slowly and will continue to do so unless new sources are introduced.

Table 6-3. Doses associated with the consumption of seafoods during the 1960s that contain ^{241}Am, ^{137}Cs, ^{239}Pu, and ^{90}Sr present in Arctic waters as a result of nuclear fallout from weapons testing.

	Food Source				
Location/Diet	Fish	Mammals	Birds/Eggs Dose, µSv/yr	Invertebrates	Totals
Barrow	0.3	1.1	0.1	0.0	1.5
Barrow 1960s Diet	1.1	1.6	0.9	0.0	3.6
Canadian Diet	1.8	7.7	0.0	0.0	9.5
Emmonak	3.8	0.8	0.0	0.0	4.7
Diomede 1960s Diet	0.3	6.4	2.5	0.7	9.9
Kivalina	2.2	4.4	0.1	0.0	6.7
Pt. Lay	0.2	5.7	0.3	0.0	6.3
Kotzebue 1960s	0.2	1.9	1.4	0.0	3.5
Pt. Hope 1960s	1.8	3.5	2.3	0.0	7.6

6.5 Projected Doses from Russian Nuclear Sources

The principal nuclear source terms addressed in this assessment are reactor-related wastes disposed of in the Kara Sea and radioactive liquid wastes stored at inland locations adjacent to the Ob and Yenisey rivers. To assess the potential magnitude of the risks such sources pose, the RAIG developed two basic types of scenarios, one describing accidental or acute discharges of nuclides and the other time-varying or chronic discharges (Section 2). To facilitate comparisons of the various source-term scenarios, the RAIG assesses the peak doses for each scenario.

Table 6-4. Doses associated with the consumption of seafoods during the 1990s that contain ^{241}Am, ^{137}Cs, ^{239}Pu, and ^{90}Sr present in Arctic waters as a result of nuclear fallout from weapons testing.

Location/Diet	Fish	Mammals	Food Source Birds/Eggs Dose, µSv/yr	Invertebrates	Totals
Barrow	0.04	0.16	0.01	0.00	0.21
Barrow 1960s Diet	0.15	0.23	0.11	0.00	0.49
Canadian Diet	0.25	1.09	0.00	0.00	1.34
Emmonak	0.53	0.12	0.00	0.00	0.66
Diomede 1960s Diet	0.04	0.91	0.32	0.08	1.35
Kivalina	0.31	0.62	0.01	0.00	0.94
Pt. Lay	0.03	0.81	0.04	0.00	0.89
Kotzebue 1960s	0.02	0.28	0.18	0.00	0.48
Pt. Hope 1960s	0.25	0.50	0.29	0.00	1.04

6.5.1 Doses Derived from Nuclear Materials Disposed of in the Kara Sea

Reactor components and other radioactive materials, as described in Section 2, were dumped into the Kara Sea, primarily in the vicinity of the island of Novaya Zemlya. The RAIG model helped simulate the transport of these materials to the coasts of Alaska (Section 3), and the BCFs described in Section 4 helped estimate the concentrations of radionuclides in foods that Alaskans might eat. The models predict that, for an instantaneous release of the entire inventory of all radionuclides from the dumped wastes into the ocean water, the highest concentrations will occur in about 10 years. The potential doses to people living in the selected communities are provided in Table 6-5 for the acute, or instantaneous, release and for the time-varying release of nuclides from the Kara Sea sources. The radionuclide providing the largest portion of the dose is ^{137}Cs, for all pathways except shellfish (marine invertebrates). For the filter-feeding shellfish, the long-lived actinides ^{239}Pu and ^{241}Am represent a major contribution. However, because shellfish are not major portions of the diet in any of the Alaskan locations, the actinides constitute no significant contributor to the overall doses. The models indicate that the dose rates along the Alaska coast will decrease with time after the initial peak (Section 3). This reduction is caused by radioactive decay of the primary radionuclides, ^{137}Cs and ^{90}Sr, by loss of these and other radionuclides into sediments in the deep waters, and by dilution of the radionuclides into waters of the North Atlantic Ocean. The time-varying release of nuclides, controlled by the corrosion-based discharge of nuclides to the Kara Sea, results in predicted doses for the Beaufort and Chukchi Sea coastal locations that are approximately 100 times lower than the instantaneous case. The predicted doses for the more realistic time-varying release of the Kara Sea sources are well below the doses associated with ^{210}Po (Table 6-2) and with fallout nuclides present in Alaskan waters during the 1960s and 1990s (i.e., Tables 6-3 and 6-4).

As an example of the dose calculations, consider the dose to an individual in Barrow from consuming fish contaminated with ^{137}Cs from the expected time-varying release in the Kara Sea. From Figure 3-9, the peak concentration in the Beaufort Sea adjacent to Barrow will be 7.1×10^{-4} Bq/m^3 in the year 2080. From Table 4-7, the BCF for cesium in fish is 0.1 m^3/kg. From Table 2-11, the dose-conversion factor for cesium is 1.4×10^{-8} Sv/Bq. As discussed in this section, an esti-

Table 6-5. Summary of the doses predicted for different Alaskan coastal communities, diets, and release scenarios for FSU nuclear wastes.

Food/Scenario	Barrow	Barrow 60s[a]	Canadian (Beak)	Emmonak	Diomede 60s[a]	Kivalina	Pt. Lay	Kotzebue 60s[a]	Pt. Hope 60s[a]
	Annual Dose, µSv/yr								
Kara Sea instantaneous									
Fish	6.4×10^{-4}	2.6×10^{-3}	4.4×10^{-3}	6.0×10^{-5}	4.3×10^{-6}	2.5×10^{-3}	2.6×10^{-4}	1.7×10^{-4}	2.0×10^{-3}
Mammals	2.7×10^{-3}	3.8×10^{-3}	1.8×10^{-2}	1.3×10^{-5}	9.6×10^{-5}	4.6×10^{-5}	6.0×10^{-3}	2.0×10^{-3}	3.7×10^{-2}
Birds/eggs	1.6×10^{-4}	2.6×10^{-3}	0.0	0.0	4.7×10^{-5}	7.3×10^{-5}	4.3×10^{-4}	1.9×10^{-3}	3.0×10^{-3}
Mollusks	0.0	0.0	0.0	0.0	4.1×10^{-5}	1.5×10^{-5}	0.0	0.0	0.0
Totals	3.5×10^{-3}	3.0×10^{-3}	2.2×10^{-2}	7.2×10^{-5}	1.9×10^{-4}	7.2×10^{-3}	6.7×10^{-3}	4.1×10^{-3}	8.7×10^{-3}
Kara Sea time-varying									
Fish	1.3×10^{-5}	5.3×10^{-5}	9.0×10^{-5}	1.8×10^{-6}	1.4×10^{-7}	5.1×10^{-5}	4.0×10^{-6}	3.5×10^{-6}	4.1×10^{-5}
Mammals	5.8×10^{-5}	8.3×10^{-4}	3.9×10^{-4}	4.1×10^{-7}	3.1×10^{-6}	1.0×10^{-4}	1.3×10^{-4}	4.5×10^{-5}	8.1×10^{-5}
Birds/eggs	3.2×10^{-6}	5.1×10^{-5}	0.0×10^{0}	0.0×10^{0}	1.4×10^{-6}	4.2×10^{-5}	2.5×10^{-4}	1.1×10^{-3}	1.8×10^{-3}
Mollusks	0.0×10^{0}	0.0×10^{0}	0.0×10^{0}	0.0×10^{0}	1.2×10^{-7}	2.9×10^{-7}	0.0×10^{0}	0.0×10^{0}	0.0×10^{0}
Totals	7.5×10^{-5}	2.3×10^{-4}	4.8×10^{-4}	2.2×10^{-6}	4.7×10^{-6}	1.9×10^{-4}	3.9×10^{-4}	1.1×10^{-3}	1.9×10^{-3}
Accidental Riverine Sources									
Fish	7.6×10^{-5}	3.1×10^{-4}	5.1×10^{-4}	7.2×10^{-6}	5.4×10^{-7}	3.0×10^{-4}	3.2×10^{-5}	2.1×10^{-5}	2.4×10^{-4}
Mammals	1.4×10^{-4}	2.1×10^{-4}	9.7×10^{-4}	6.4×10^{-7}	4.9×10^{-6}	2.5×10^{-4}	3.3×10^{-4}	1.1×10^{-4}	2.0×10^{-4}
Birds/eggs	1.4×10^{-4}	2.2×10^{-3}	0.0×10^{0}	0.0×10^{0}	4.2×10^{-5}	6.4×10^{-5}	3.7×10^{-4}	1.6×10^{-3}	2.6×10^{-3}
Mollusks	0.0×10^{0}	0.0×10^{0}	0.0×10^{0}	0.0×10^{0}	9.0×10^{-8}	3.3×10^{-8}	0.0×10^{0}	0.0×10^{0}	0.0×10^{0}
Totals	3.6×10^{-4}	2.7×10^{-3}	1.5×10^{-3}	7.8×10^{-6}	4.8×10^{-5}	6.1×10^{-4}	7.2×10^{-4}	1.8×10^{-3}	3.1×10^{-3}
Chronic Riverine Sources									
Fish	2.9×10^{-5}	1.2×10^{-4}	2.0×10^{-4}	4.0×10^{-6}	3.0×10^{-7}	1.1×10^{-4}	1.2×10^{-5}	7.8×10^{-6}	8.9×10^{-5}
Mammals	3.7×10^{-5}	5.3×10^{-5}	2.5×10^{-4}	2.6×10^{-7}	2.0×10^{-6}	6.4×10^{-5}	8.3×10^{-5}	2.8×10^{-5}	5.2×10^{-5}
Birds/eggs	6.3×10^{-5}	1.0×10^{-3}	0.0×10^{0}	0.0×10^{0}	2.8×10^{-5}	2.9×10^{-5}	1.7×10^{-4}	7.3×10^{-4}	1.2×10^{-3}
Mollusks	0.0×10^{0}	0.0×10^{0}	0.0×10^{0}	0.0×10^{0}	4.9×10^{-8}	1.2×10^{-8}	0.0×10^{0}	0.0×10^{0}	0.0×10^{0}
Totals	1.3×10^{-4}	1.2×10^{-3}	4.4×10^{-4}	4.3×10^{-6}	3.0×10^{-5}	2.0×10^{-4}	2.6×10^{-4}	7.7×10^{-4}	1.3×10^{-3}

[a] Doses calculated using dietary information for the 1960s.

mated fish-consumption rate for an individual with a subsistence life-style in Barrow is about 27 lb/yr. An adjustment also must be made for radioactive decay of the radionuclides in the food between the time they are caught and the time they are eaten. For all radionuclides considered this is negligible because of their long half-lives (except for ^{210}Po, for which it is a factor of 0.46). The individual's annual dose is just the product of these factors, with the units made to conform: $(7.1 \times 10^{-4}$ Bq/m^3) (0.1 m^3/kg) (27 lb/yr) (0.454 kg/lb) (1.4×10^{-8} Sv/Bq) (10^6 μSv/Sv) (1.0) = 1.2×10^{-5} mSv.

Table 6.5 indicates that the total dose for these assumptions is 1.3×10^{-5} μSv/yr, which shows that ^{137}Cs contributes over 95% of the dose.

6.5.2 Doses from Releases to the Ob and Yenisey Rivers

Existing radionuclide releases to the major western Siberian river systems consist mainly of run-off from global fallout deposited on the watersheds of the Ob and Yenisey rivers. As described in Section 2, large releases of fission products from the former-Soviet nuclear-processing facilities, have not resulted in dramatic increases in concentration at the mouths of the rivers. If the current rates of discharge into the Kara Sea continue at rates declining only through radioactive decay, the doses in the future will be somewhat lower than they are today. The RAIG analyzed two riverine release scenarios, a worst-case one involving the yearlong release of the entire inventories of ^{90}Sr and ^{137}Cs from reservoirs at Mayak on the Ob River, and the other the slow leakage of liquid wastes from reservoirs as well as watershed runoff along both river systems, focusing on ^{90}Sr. The predicted doses for these releases are shown in Table 6-5. Note that they represent only a small percentage of the dose one receives from global fallout, as presented above in Table 6-4. This is reasonable, because the global fallout in the Arctic comprises that which fell directly into the ocean, that which washed off from North American and other Asian rivers, as well as that fraction from the Ob and Yenisey rivers.

The source of these doses, too, will decrease exponentially with time because of the radiological decay of the radionuclides. The primary radionuclide released in the riverine scenarios is ^{90}Sr– in large part because ^{137}Cs is depleted in waste waters because of particle scavenging and therefore less is available for transport. The predicted doses for the accidental and chronic release scenarios are comparable because the total inventories released to the Kara Sea (~1 PBq) over time are similar. However, the peak doses occur about 30 years later in the Beaufort and Chukchi seas as a result of the slower discharge to the Kara Sea estuary.

6.6 Uncertainty and Sensitivity Analysis

To help understand the key parameters and assumptions involved in making our dose estimates, the RAIG performed a series of simple uncertainty analyses using computer spreadsheets and accessories to determine the overall ranges of the estimated doses (Decisioneering, 1993). To date, the analyses have not included the source-term or transport portions of the RAIG model, but only the environmental accumulation and dosimetry portions. Overall, the dose results appear to have a lognormal distribution, with a geometric standard deviation of about 2. This indicates that the overall doses can be estimated with fair precision (to within a factor of about 4 high or low, with 90% confidence). In environmental modeling, this represents an acceptable level of reliability in the answer.

For the evaluation of background doses, the doses and their uncertainties are controlled by the range of measured values of ^{210}Po in fish and mammals. The RAIG has an insufficient number of measurements of marine mammals or seabirds to allow for high precision on these estimates. Additional work in this area would be beneficial.

Uncertainties in doses from riverine sources are dominated by the range of bioaccumulation factors for ^{137}Cs in fish and mammals. Because there is a large body of these measurements, the RAIG assumes that this reflects natural variability of ^{137}Cs uptake in these resources. The uncertainties in dose from both historical background and future waste-related releases are also dominated by the variability in the bioaccumulation for ^{137}Cs. Overall, doses from the pathways of fish, marine mammal, and birds/eggs ingestion are dominated by environmental levels of ^{137}Cs. Doses from shellfish, on the other hand, are controlled by the variability in the bioaccumulation factors for ^{239}Pu and ^{241}Am. However, in the situation as the RAIG understands it in Alaska, this pathway is only a marginal contributor to doses, and therefore the uncertainty in the actinide uptake by shellfish is of minor importance.

6.7 Assessment of Risks

The following discussion of radiation risk is adapted from the Health Physics Internet site at the University of Michigan (Busby, 1996).

Radiation causes ionizations in the molecules of living cells. These ionizations result in the removal of electrons from the atoms, forming ions or charged atoms. The ions formed then can go on to react with other atoms in the cell, causing damage. An example of this would be if a gamma ray passes through a cell, the water molecules near the DNA might be ionized and the ions might react with the DNA, causing it to break.

At low dose rates, such as what humans receive every day from background radiation or our estimates of dose rate resulting from Arctic contamination, the cells usually repair the damage rapidly. Occasionally, the cells may be unable to repair the damage and may either be changed permanently or die. Most cells that die are of little consequence, the body can just replace them. Cells changed permanently may go on to produce abnormal cells when they divide. In the right circumstance, these cells may become cancerous. This is the origin of our increased risk in cancer, as a result of radiation exposure.

At even higher doses, the cells cannot be replaced fast enough and tissues fail to function. An example of this would be "radiation sickness." This is a condition that results after high doses to the whole body (>1,000,000 μSv), where the intestinal lining is damaged to the point that it can no longer take in water and nutrients and protect the body against infection. This leads to nausea, diarrhea, and general weakness. With higher whole-body doses (>3,000,000 μSv), the body's immune system is damaged and cannot fight off infection and disease. At whole-body doses near 4,000,000 μSv, if no medical attention is given, about 50% of the people are expected to die within 60 days of the exposure, mostly from infections. No doses are projected to reach these levels for anyone living around the Arctic Ocean from the radionuclide releases that have occurred or are projected to occur.

Risk estimates for radiation were first evaluated by scientific committees in the 1950s. The estimates are under continual review and updating, and numerous groups have reached essentially the same conclusions. Studies by the U.S. Environmental Protection Agency (Puskin and Nelson 1994), the National Council on Radiation Protection and Measurements (NCRP 1993), the British National Radiological Protection Board (NRPB 1993), and the International Commission on Radiological Protection (ICRP 1990) have focused on estimating the risks associated with radiation exposure.

It is difficult to estimate radiation risks because most of the radiation exposures that humans receive are very close to background levels. In most cases, radiation effects are not distinguishable from diseases occurring for other reasons. With the beginning of radiation use in the early part of the century, however, the early radiation researchers and users were not as careful as we are today. The information from medical uses and from the survivors of the atomic bombs in Japan has given us most of what the RAIG knows about radiation and its effects on humans. Risk estimates have their limitations:

1. The doses from which risk estimates are derived were much higher than the doses projected here;

2. The dose rates were much higher than normally received;

3. The actual doses received by the bomb survivors and some of the medical-treatment cases have had to be estimated and are not known precisely; and

4. Many other factors, as ethnic origin, natural levels of cancers, diet, smoking, and stress affect the estimates.

According to the scientific groups mentioned above, the risk of cancer death is about 10% per million µSv for doses received rapidly (acute) and might be about half that (5% per million µSv) for doses received over a long period (chronic). These risk estimates are an average for all ages, males and females, and all forms of cancer. A great deal of uncertainty is associated with the estimate. The estimates made by the various groups discussed above are not exactly the same as these, because of differing methods of calculating risk and assumptions used in the calculations, but all are close.

The real question is: how much will the radiation exposures estimated in this report increase the chances of cancer death over a lifetime or the chances of subsequent generations of children or grandchildren?

To answer this, the RAIG must make a few general statements of understanding. First, in the United States the current death rate from cancer is about 20%: in any group of 10,000 U.S. citizens, about 2,000 of them will die of cancer. Second, because the induction of cancer is a random process, the RAIG can estimate that about 20% will die from cancer but cannot determine which individuals will actually die. Finally, a conservative estimate of risk from low radiation doses is thought to be one in which the risk is linear with dose, that is, that the risk increases with a subsequent increase in dose. Most scientists believe that this is a conservative model of the risk.

If one were to take a large population, such as 100,000 people, and expose each of them to radiation amounting to 1,000 µSv (to his or her whole body), one would expect about 10 additional deaths (i.e., 10% per million microsievert multiplied by 100,000 people times 1,000 µSv). So, instead of the 20,000 people expected to die from cancer naturally, one would now have 20,010. This small increase in the expected number of deaths would not be seen in this group, because of natural fluctuations in the rate of cancer. What needs to be remembered is that it is not known that 10 people will die, but that there is a risk of 10 additional deaths in a group of 100,000 people if they all received a radiation dose of 1,000 μSv instantaneously. If they received the 1,000 μSv over a long period, such as a year, the risk would be less than half of this (<5 expected fatal cancers).

The doses predicted for the Alaskan coastal communities in this assessment from Russian releases are very small. The highest doses for Alaskans from Russian waste-disposal activities are about 0.02 μSv per year. If a person were to expose his or her entire life (about 70 years) to these dose rates, his/her total dose would be about 2 μSv. Even if the entire Alaskan coastal population of about 18,000 people received these doses, the expected number of fatal cancers above those expected naturally in this group would be less than 1. In essence, there is no anticipated risk to the population of Alaska from the historic Russian waste disposal activities via marine pathways where ingestion of contaminated seafoods is the principal pathway of exposure.

6.8 Risk v. Benefits

In evaluating contaminants in subsistence foods it is important to address risks and benefits. If recommendations are made to limit a food because of contamination, then one must consider what may be consumed in its place (Nobmann, 1996). Any changes in dietary patterns wrought by concerns with contaminants can have broad impacts (Usher et al., 1995). This is especially true in Alaska Native communities where social structures and customs have evolved based on successfully obtaining sea mammals. The positive aspects of sharing the work, dividing the harvest, and celebrating the success of providing marine mammals in the community extend beyond the food's value as a source of nutrients (Nobmann,1996).

Work continues on an international scale to minimize the amount of man-made radionuclides entering the environment, and the levels continue to drop in the overall Arctic environment. Assessment of the dose received from the consumption of man-made radionuclides in marine-subsistence foods results in finding that it is well below that observed to cause acute effects. Risk to the public health from the man-made radionuclides in the marine-subsistence foods is very small. Benefits from the consumption of these foods outweigh any risk posed by these man-made radionuclides. For example, the consumption of some traditional foods is associated with cardiovascular-disease prevention (Nobmann, 1996). The RAIG therefore recommends that Alaskan residents make no changes to their life-styles in response to the disclosures of past Russian waste dumping in the Arctic.

6.9 Summary

- Our analyses of doses associated with naturally occurring ^{210}Po and background levels of ^{137}Cs and ^{90}Sr in Arctic water indicate that the largest doses to individuals living in Alaskan coastal communities who consume subsistence seafoods is from ^{210}Po, followed by ^{137}Cs and ^{90}Sr, derived from global nuclear fallout.

- The nuclear sources the assessment dealt with included reactor-related components in the Kara Sea and radioactive wastewaters stored at nuclear facilities on the Ob and Yenisey rivers, which drain into the Kara Sea. Two types of release scenarios were used to represent the discharge of radionuclides to Arctic waters and rivers: one involves acute releases and the other, slow, chronic discharges.

- Although very low, the highest predicted doses to Alaskan coastal residents were for the instantaneous release of ^{241}Am, ^{137}Cs, ^{239}Pu, and ^{90}Sr contained in the Kara Sea wastes. These doses, however, were well below background levels for ^{210}Po and nuclear fallout. The corrosion-driven chronic release of nuclides from the nuclear reactors, which is a far more realistic release scenario, results in doses that are about 100 times lower than the acute case.

- The acute and chronic discharges of ^{90}Sr and ^{137}Cs from wastewater storage ponds and reservoirs into the Ob and Yenisey rivers produce doses as low as chronic discharge of radioactive wastes in the Kara Sea.

- The potential health risks associated with the ingestion of Alaskan seafoods containing radionuclides derived from hypothetical releases from Russian nuclear wastes are extremely low, which essentially means that those wastes pose no threat to human health. Alaska Native communities need not alter any of their dietary habits associated with subsistence foods obtained from Alaskan waters on the basis of concern over radioactivity stemming from waste-management practices in the FSU, based on the RAIG analysis.