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A SURVEY OF RADIOACTIVE FALLOUT DATA IN ALASKA

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Prepared for Robert S. Dyer
U.S. Environmental Protection Agency
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ANALYTICAL SCIENCES DIVISION

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TABLES

1. INTRODUCTION

Considerable attention has been directed by the scientific community to assessing the levels and fate of radionuclides in Arctic ecosystems. The following text and tables present available data and discussion of radionuclide fallout in Alaska. A literature search of 23 on-line databases (Table 1) using Alaska, Strontium (Sr), Cesium (Cs), Plutonium (Pu) and Radionuclide as constraint terms responded with 177 possible citations. After eliminating duplicate citations, 31 articles were available: 17 were relevant to the subject matter; the remainder addressed geologic issues. All of the cited literature addressed ^{137}Cs, ^{90}Sr and $^{239,240}Pu$ as a result of radionuclide fallout from nuclear testing or accidental release. Presented below in text and tabular format are summaries from these studies.

Table 1: List of databases searched.	
Biosis	Water Resources Abstracts
NTIS	Health Periodicals Index
Agricola	Health Planning
Oceanic Abstracts.	Toxline
Enviroline	Medline
Pollution Abstracts	Cancerlit
Aquatic Science and Fish Abstract	Occupational Safety and Health
Environmental Bibliography	Chemical Abstracts
Life Sciences Abstracts	Sci Search
DOE	AMA Journals
Nuclear Science Abstracts	New England Journal of Medicine
Agricola (older)	

2. CESIUM

^{137}Cs is an anthropogenic by-product of nuclear testing. It was introduced into the biosphere after ~1953 as a result of fallout deposition and from accidental releases from nuclear facilities. It is long-lived with a half life of 30.2 years. In many Arctic regions, this radionuclide is detected predominately within the top 10 cm of tundra, associated with mosses, lichens, and other vegetation. ^{137}Cs body burdens are of public health interest because of their distribution throughout the soft body tissue. Exposure arises mainly from ingestion of milk, meat, and vegetables.

2.1 Food chain measurements

In the Arctic, the lichen-to-caribou(reindeer)-to-man pathway is the most important food chain contributing to the ^{137}Cs body burdens. This chain results from the unusual capacity of lichens to absorb and retain fallout materials (especially ^{137}Cs), the utilization of lichens for food in winter by caribou and reindeer, and the dependence upon caribou and reindeer for food by several northern populations. Table 2 presents data for ^{137}Cs fallout measurements between 1962 and 1965.

Table 2: Cumulative ^{137}Cs fallout in Alaska (nCi/m^2) derived from soil and precipitation samples at Barrow, Fairbanks, and Palmer, and from lichens at Anaktuvuk Pass during 1962-1965 (Hanson, 1967).

	Soil and Precipitation			Lichens
Date	Palmer	Fairbanks	Barrow	Anaktuvuk Pass
July 1962	23	20	8	18
July 1963	32	29	13	28
July 1964	38	33	16	41
July 1965	45	38	16	48

Lichens accumulate more ^{137}Cs than their associated seed plants. ^{137}Cs values in old world Cladonia lichens ranged from 8.4 to 6.1 pCi/g dry weight, as compared to values ranging between 30-43 pCi/g for mixtures of Alaskan lichens (Cladonia and Cetraria) (Rickard et al., 1965). Table 3 presents data for ^{137}Cs bioconcentration in Alaskan vegetation.

Table 3: ^{137}Cs in the vegetation of the Ogotoruk Creek Valley, Alaska 1959, 1960 and 1961.

Aquatic Emergent Stands	Location	^{137}Cs pCi/g
Arctophila		
8-6-59	Pumaknak Pond	0.47±.30
8-6-59	Ikaknak Pond	0.21±0.21
9-1-60	Pond No. 4	0.82±0.42
8-7-61	Pond No. 4	0.47±0.70
Hippoutris		
8-6-59	Pumaknak Pond	0.43±0.22
8-6-59	Ikaknak Pond	1.6±0.027
9-1-60	Pond No. 4	0.95±0.090
8-7-61	Pond No. 4	0.91±0.65
Wet meadow Stands		
Seed plants and Mosses		
7-31-59	Lower Creek	11±6.4
7-30-61	Ikaknak Pond	13±0.74
Seed plants		
8-6-59	Ikaknak Pond	5.0±1.0
7-3-60	Lower Creek	5.3±0.12
7-3-60	Upper Creek	6.9±0.094
7-4-60	Lower Creek	8.2±0.32
7-14-60	Ikaknak Pond	8.3±0.28
8-18-60	Ikaknak Pond	4.3±0.31
8-1-61	Ikaknak Pond	8.7±0.75
8-3-61	Lower Creek	6.5±0.46
Seed Plants Annual Growth		

9-11-60	Ikaknak Pond	3.2±0.067
7-31-61	Ikaknak Pond	5.9±0.45
Tussock Stands		
Seed plant		
7-31-59	Lower Creek	7.5±0.20
8-29-60	Ikaknak Pond	7.0±0.69
8-1-61	Ikaknak Pond	7.0±90
Mosses and Lichens		
8-1-61	Ikaknak Pond	18±1.1
Seed Plants		
Lupinus arcticus		
8-30-60	Ikaknak Pond	2.7±0.28
Salix spp		
8-9-59	Lower Creek	5.6±0.036
	Mid Creek	3.2±0.51
Dryas octpetala		
9-1-60	Mid Creek	9.2±1.4
8-3-61	Lower Creek	4.5±0.53
Ledum decumbens		
8-9-59	Lower Creek	12
Mosses		
Sphagnum spp		
8-9-59	Lower Creek	12
8-31-60	Ikaknak Pond	18±4.1
9-1-60	Ikaknak Pond	19
Lichens		
Cetraria and cladonia spp		
8-9-59	Lower Creek	27±5.9
8-28-60	Upper Creek	26±3.7
6-27-61	Upper Creek	37±1.4
Corniculria spp and Others		
8-5-61	Upper Creek	20±1.1
9-23-61	Upper Creek	21±0.79

Grazing habits and location of Alaskan caribou and reindeer herds was studied to determine the seasonal and environmental effects of ^{137}Cs concentrations in caribou flesh. Table 4 presents data from a study comparing ^{137}Cs and natural radioactivity uptake by Alaskan caribou and reindeer. Table 5 presents data of ^{137}Cs concentrations in caribou and reindeer muscle samples.

Table 4: ^{137}Cs content of caribou-reindeer samples (Blankard and Kearney, 1967).

Location	Muscle pCi/g fresh wt.	Rumen Content pCi/g dry wt.
Anaktuvuk pass	11.2±3.8	23.5±1.3
Anaktuvuk pass	7.2±0.6	28.0±1.4
Anaktuvuk pass	18.5±0.8	31.0±1.9
Nunivak Island	8.9±0.7	
Nunivak Island	8.3±0.3	
Nunivak Island	28.6±1.5	30.0±1.8
Nunivak Island	38.6±1.5	70.0±4.2
Nunivak Island	6.7±0.9	13.1±0.4
Ugashik Lake	45.7±2.4	
King Salamon	22.8±1.4	49.5±3.0
Teller	27.1±1.4	40.5±2.4
Teller	19.1±0.9	19.0±1.2
Shiahmaref	16.1±1.4	
Black Mountains	17.7±1.2	24.5±1.5
Nome	23.8±1.4	29.5±1.9

Table 5: Average radionuclide concentration in caribou and reindeer muscle (Chandler and Snavely, 1966).

	Average ^{90}Sr (pCi/kg)	Average ^{137}Cs (pCi/kg)
Caribou		
Arctic Herd		
December 63	17	4860
May 64	40	13800
August 64	40	700
October 64	19	6880
December 64	19	3900
April 65	22	9600
September 65	11	7720
November 65	1	6220
March 66	26	18400
Nelchina herd		
November 63	33	21800
April 64	54	5560
August 64	31	14300
October 64	20	4220
December 64	30	14000
March 65	48	27600
July 65	7	4000
September 65	26	8160
December 65	33	17200
Peninsula herd		
December 63	84	44800
April 64	14	14800
July 64	5	1680

September 64	11	4630
December 64	31	18000
August 65	4	2000
September 65	15	18000
November 65	7	20100
March 66	18	43800
Reindeer		
Kotzebue herd		
December 63	31	7190
September 64	74	3340
December 64	268	23000
Selawik herd		
December 64	578	34000
Buckland and Candle herd		
September 64	68	19600
December 64	64	14000
Shismaref herd		
September 64	38	8490
December 64	68	12000
March 65	25	18000
September 65	14	6000
November 65	25	16800
February 66	55	18600
Teller herd		
December 64	66	35000
November 65	90	27000
June 66		19000
Golovin herd		
December 64	96	19000
Stebbins herd		30000
December 64	86	7050
Nunivak Island herd		
September 64	75	25000
December 64	128	31200
April 65	28	7700
August 65		
January 66	90	27200
April 66	21	33400
St Paul Island herd		
September 64	10	4860
November 64		13000
Nome herd		
June 66		22000
Deering herd		
December 64	127	28000

Concentrations in pCi/kg wet weight

There has been a gradual decrease in bioavailable radiocesium since the cessation of atmospheric weapons testing. For Alaska, radiocesium concentrations in lichens, caribou and reindeer have decreased from peak concentrations of 32.4-48.6 nCi/kg in the mid-1960s to less than 8.1 nCi/kg in

January 1986 (Baskaran et al. 1991). The accident at Chernobyl on April 26. 1986 released 5-10% of the total amount of radiocesium emitted from all atmospheric nuclear weapons tests. In Alaska, the radiocesium deposition rate was estimated at approximately 13.5 pCi/m^2 for the period April 1986 (pre-Chernobyl) to August 1986 (post Chernobyl). Table 6 shows ^{137}Cs measurements after 1987.

Table 6: ^{137}Cs concentrations in selected environmental samples after the Chernobyl accident.

	Total activity	Chernobyl-derived
Arctic soil sediment		
	4.1±4.2	-
	44.0±1.3	-
	2.8±3.5	-
	8.1±1.7	-
	2.1±2.2	-
	2.4±2.3	-
Arctic lichen, moss, ledum		
	16.6±4.2	-
	22.3±1.3	-
	92.2±3.5	-
	39.3±1.7	-
	242.0±2.2	-
	39.7±2.3	-
	58.5±4.2	-
Arctic fish, whale, caribou		
	BD	-
	0.52±0.09	-
blubber	BD	-
muscle	0.57±0.11	-
liver	BD	-
blubber	BD	-
muscle	BD	-
muktuk	BD	-
	60.0±4.2	-
	31.0±1.0	2.1
	1.1±0.2	-
Subarctic lichen, moss, ledum, mushrooms		
	97.0±1.0	27.0
	89.0±1.0	24.0
	86.0±3.0	32.0
	60.0±1.0	23.0
	3.5±1.1	-
	BD	-
	3.8±1.0	-
	32.0±1.0	8.0
	43.0±1.0	28.0
	51.3±2.2	-

Bq/kg = Becquerel per kilogram (1 Bq = 27pCi), BD = Below detection

2.2 Human body burden measurements

Early studies (e.g., Hansen, 1662) showed that higher than average ^{137}Cs burdens were associated with the consumption of caribou and reindeer meat and indicated that elevated ^{137}Cs body burdens were prevalent generally throughout Alaska. The average body burdens for the caribou eaters were significantly higher than for noncaribou eaters. Table 7 presents data for ^{137}Cs body burdens. Radiation dosage received by the average adult Anaktuvuk Pass Eskimo from ^{137}Cs body burdens during 1964 were estimated at 135 to 150 mrem. Table 8 presents data on radiation dosage from ^{137}Cs body burdens. The average ^{137}Cs body burdens measured in the people showed a substantial decline after 1966, especially from the summer of 1970 to 1971. Table 9 shows a comparison of average and maximum ^{137}Cs concentrations from 1966 to 1967. The measurements observed during the summers of 1971, 1972, and 1973 suggest that an equilibrium had been reached. Although caribou meat still comprised most of the fresh meat consumed, imported food contributed substantially to the diet as more money entered the village though improving economic prosperity. This is believed to be the major factor for the decline in radiocesium in the resident population. It is supported also by the increase of body-burdens from those of July 1973 to 1974, during a period when freight or funds were not available (Hedlund, 1976).

Table 7: ^{137}Cs body burdens.

Location	Body Burden (nCi)
Anaktuvuk Pass	1052
Anchorage	70
Bethel	93
Kanankank	178
Kotzebue	454
Mount Edgecumbe	43
Tanana	44

Table 8: Estimated annual radiation doses from ^{137}Cs body burdens of average adult Eskimo residents of Anaktuvuk Pass 1962-79 (Hanson, 1982).

Year	Dose (mrad)	Year	Dose (mrad)
1962	60	1971	60
1963	90	1972	50
1964	140	1973	40
1965	130	1974	60
1966	140	1975	25
1967	100	1976	20
1968	70	1977	10
1969	100	1978	12
1970	100	1979	8

Table 9: Comparison of 1967 to 1966 average and maximum ^{137}Cs concentration in Alaskan males (Rechen et al., 1968).

Location	Weight (Kg)	Number Counted/y	Cesium-137 concentrations		Ratio of 1967 to 1966	
			Avg. Ci/Kg	Max. Ci/Kg	Average	Maximum
Anaktuvuk Pass	46-65	3-1966	9.62	16.81		
		9-1967	8.86	18.49	0.92	1.10
	>65	5-1966	10.29	13.17		
		14-1967	8.38	17.16	.82	1.30
Barrow	46-65	6-1966	2.25	3.79		
		9-1967	.65	1.00	.29	.26
	>65	40-1966	2.21	5.99		
		2-1967	1.01	1.31	.46	.22
Egegik	46-65	12-1966	5.22	13.49		
		18-1967	4.21	14.05	.81	1.04
	>65	19-1966	2.71	8.02		
		14-1967	2.80	7.18	1.03	.90
Noorvik	46-65	1-1966	6.42	6.42		
		22-1967	8.50	18.08	1.32	2.82
Point Hope	46-65	1-1966	.58	.58		
		14-1967	1.48	2.88	2.55	4.97
Selawik	46-65	11-1966	17.56	24.37		
		19-1967	11.39	19.30	.65	.79
	>65	22-1966	17.48	31.91		
		15-1967	9.71	17.28	.56	.54
Shishmaref	>65	1-1966	6.28	6.28		
		25-1967	4.63	11.46	.74	1.82
Wainwright	>65	1-1966	2.25	2.25		
		45-1967	3.71	7.09	1.65	3.15
Total	46-65	34-1966	8.97	24.37		
		91-1967	6.32	19.30	0.71	0.79
	>65	88-1966	6.64	31.91		
		115-1967	5.15	17.28	0.78	0.54

The ^{137}Cs concentrations in Alaskan Arctic ecosystem components during the period 1962-1965 varied with seasonal and environmental conditions, emphasizing the important influence of ecological factors upon fallout accumulation in the lichen-caribou(reindeer)- man food chain. Concentrations in lichens at Anaktuvuk Pass, Alaska increased with time and varied among several species. Caribou flesh contained maximum ^{137}Cs levels during winter periods and lowest values during summer months, corresponding to lichen utilization. Body burdens in natives using the caribou as a food base reflected the ^{137}Cs cycle in caribou flesh, but lagged by a few months. Maximum values occurred during summer, and minimum values were found during mid-winter (Hanson, 1967). Table 10 demonstrates the seasonal effect on body burdens.

Table 10: ^{137}Cs body burdens in native residents of Anaktuvuk Pass Alaska, 1970-1974 (nCi).

	Adults				Minors				Children			
Year	n	Winter	n	Summer	n	Winter	n	Summer	n	Winter	n	Summer
1970	34	330 ± 24	28	740 ±55			3	380 ± 51	35	40 ± 2	44	150 ± 12
1971	34	230 ± 18	35	383 ± 24	1	170	5	168 ± 28	38	32 ± 13	34	67 ± 5
1972	36	192 ± 15	33	391 ± 24	1	70	8	154 ± 22	46	27 ± 2	32	70 ±4
1973	32	163 ± 13	30	312 ± 22	1	90	8	181 ± 22	32	22 ± 2	24	65 ± 7
1974	31	135 ±11	29	578 ± 57	7	86±17	6	308 ± 42	23	52 ± 8	25	148 ± 17

3. STRONTIUM

During the period of extensive nuclear weapons testing from 1952-63, public concern developed about the possible health effects of radioactive fallout. ^{90}Sr was considered to be a critical long lived fission product due to its daughter ^{90}Y, which emits an energetic Β-particle. Particular concern was expressed about the possible effects on Eskimos and other northern people who depended on caribou for most of their food.

3.1 Food Chain

^{90}Sr concentrations had been determined in a variety of foods used by the native population. However, the highest concentrations were found in samples associated with caribou. The stomach contents of caribou showed extremely high concentrations indicating that the ^{90}Sr fallout must have been concentrated on the surface and soaked up by the lichens mosses and other plant life which existed on top of the permafrost (Shulert, 1962).

Table 11 shows elevated ^{90}Sr concentrations in Alaskan soil samples. Caribou from the tundra carried 10 to 20 times the concentration level of ^{90}Sr of domestic cattle and also significantly higher concentrations than other native foodstuffs. Table 12 shows data for ^{90}Sr concentrations in caribou which lived on the mosses and in low vegetation overlying permafrost zones, foodstuffs grown on farms along the coastal belt, and native fish.

Table 11: Mean soil samples from 9 sites near Cape Thompson, Alaska for ^{90}Sr content for the years 1961-1964 (Holowaychuk et al., 1969).	
Site	Soil sample in mCi/Km^2
1	14.1
2	13.4
3	13.4
4	14.0
5	16.0
6	14.0
7	17.5
8	11.1
9	20.9

Table 12: Available data of ^{90}Sr concentration 1957-61 (Schulert, 1962).

Sample	Location	Date	Dpm/kg wet	Dpm/g ash	μμ/g Ca
Antlers	Arctic Tundra	1958		98	106
Antlers	Anaktuvuk River	Oct.59	9450	238	281
Antlers	Anaktuvuk River	Oct.59	6480	146	170
Antlers	Tolugak Creek	Oct.59	6400	143	170
Meat	Anaktuvuk Pass	Nov 59	16.0		160
Stomach Contents	Anaktuvuk River	Nov 59	7880	245	1264
Caribou-A	Shungnak	Mar 61			
Backbone				136	177
Leg bone				179	180
Meat				3.3	162
Stomach Contents				300	3444
Caribou-B	Shungnak	Feb 61			
Backbone				121	140
Leg bone				150	175
Meat				1.3	146
Stomach Contents				231	2968
FARM CROPS					
Sample	Location	Date	Dpm/kg wet	Dpm/g ash	μμ/g Ca
Wheat	Fairbanks	1957	22.0	1.42	22.6
	Fairbanks	1958	98.0	6.38	104
	Fairbanks	1959	106	6.20	125
	Fairbanks	1960	50.2	3.03	60.5
Cabbage	Fairbanks	1959	5.9	1.11	7.8
	Fairbanks	1960	4.1	0.52	4.4
Potatoes	Fairbanks	1959	1.6	0.17	7.8
	Fairbanks	1960	1.5	0.26	7.6
MILK					
	Anchorage	1960			8

NATIVE FOODS					
Marine fish					
Tom Cods	Pt Hope	Dec. 59	3.45	0.05	0.1
Needle fish	Hooper bay	Oct. 59	605	7.24	7.6
Beluga Meat	Kotezebue	Oct. 59	0.39	0.12	8.8
Beluga Meat	Kotezebue	Fall 59	26.3	0.81	142.3
Beluga Muktuk	Kotezebue	Oct. 59		0.67	11.5
Dried Flounder and Herring	Newfok	Oct. 59	110	1.46	2.7
Cod	Kotezebue	Oct. 59	362	6.63	7.9
Fresh water Fish					
Whitefish	Kobuk River	Oct. 59	156	2.25	15.7
Whitefish	Kobuk River	Spring 60	2390	42.4	62.4
Whitefish	Kobuk River	Spring 60	115	2.03	3.5
Whitefish	Kobuk River	Spring 60	1410	25.0	32.8
Marine Mammals					
Whale Meat	Pt Hope	Oct. 59	<0.04	<0.07	<2.4
Whale Rib	St. Lawrence	May 59	<64	<0.12	<0.1
Seal backbone	Pt Hope	Fall 59	8.40	0.07	0.1
Walrus Backbone	St. Lawrence	Spring 60	324	0.65	0.8
Walrus Meat	St. Lawrence	Spring 60	180	9.38	360
Walrus Meat	Gambell	Dec. 60		0.66	25.2
Land Animals					
Polar Bear Meat	Pt Hope	Fall 59	<0.06	<0.06	<2.8
Plants					
Plant Roots	Shungnak	Oct. 59	106	4.30	16.7

3.2 Human body burden measurements

Eskimos for were found to have four times the ^{90}Sr content of the average for the world population of the North Temperate Zone. Table 13 gives data for estimated annual intake of ^{90}Sr for these populations.

Table 13: Estimated annual ^{90}Sr intake via caribou meat for various age groups of Anatuvuk Pass residents during the period 1954-75 pCi/yr.

Years	Adult Men (>21 yr)	Adult Women (>21 yr)	Minors (14-20 yr)	Children (<14 yr)
1954-1960	1700	760	940	360
1961	1900	840	100	400
1962	3400	1500	1900	700
1963	6300	2800	3500	1300
1964	9800	4300	5400	2100
1965	6900	3300	3700	1300
1966	5900	2900	3100	1100
1967	3800	2100	2100	740
1968	3000	1800	1800	600
1969	1600	1000	100	380
1970	1300	870	870	350
1971	1900	1200	1200	590

1972	1700	1100	1100	610
1973	1500	930	930	560
1974	1400	760	760	510
1975	1100	550	550	390

Predictions of ^{90}Sr body burdens are based on models that estimated total body burdens from measured concentrations found in bone and urine samples. Table 14 lists results of bone analysis in children and adults and Table 15 gives data on ^{90}Sr concentrations in urine samples.

Table 14: ^{90}Sr content of bones from native Alaskan children and adults. Nov. 1959-Dec. 1960.

Age (years)	μμ ^{90}Sr/g Ca
0.33	2.4±0.3
7	3.4±0.3
16	2.4±0.1
20	1.0±0.2
20	0.8±0.2
20	0.6±0.1
24	0.4±0.1
24	0.7±0.2
25	0.2±0.1
26	0.4±0.2
26	<0.3
26	<0.1±0.0
26	1.0±0.2
29	0.4±0.1
30	0.5±0.1
30	<0.2
32	0.2±0.1
33	0.7±0.1
35	1.4±0.1
36	<0.2
38	0.3±0.1
38	0.3±0.1
39	0.8±0.1
40	<0.4
42	<0.4
44	0.4±0.1
46	<0.4
46	<0.2
48	0.5±0.1
53	0.4±0.1
56	0.7±0.2
56	0.3±0.2
58	0.2±0.1
60	0.8±0.2
60	0.4±0.1
60	0.4±0.1

61	0.4±0.1
62	0.5±0.1
38	0.58±0.06
38	0.38±0.04

Table 15: ^{90}Sr content in human urine specimens from Alaska February 1961.

Sample	Dpm/liter	$\mu\mu\ ^{90}Sr/g$
1	10.4	23.4
2	22.6	32.1
3	11.4	19.9
4	8.9	21.1
5	12.3	31.6
6	7.5	22.1
Avg	12.2	25.0

4. PLUTONIUM

Pu contamination in Alaska resulted from fallout from nuclear weapons tests from two major periods. The first and most sustained during 1953-1959 and the second during 1961-1964, reflecting the atmospheric nuclear weapons test regimes of Great Britain, the former Soviet Union and the United States. Pulses of lesser stratospheric fallout deposition occurred during 1967-1970 following weapons tests by France and the Peoples Republic of China. Pu isotopes in the Alaskan ecosystem have been of most interest following the atmospheric reentry and burnup of radioactive power generators aboard satellites (i.e., SNAP 9A in 1964, Cosmos 954 in 1978 and Cosmos 1402 in 1983) and the crash of a nuclear-armed B-52 at Thule Greenland (Molnia 1993). Table 16 shows concentrations of Pu in air at Pt. Barrow Alaska following the times following heavy nuclear testing.

Table 16: ^{238}Pu and ^{239}Pu concentrations in air at Pt. Barrow, Alaska (Simpson, 1974).

	^{238}Pu	^{239}Pu	^{238}Pu / ^{239}Pu
1965	0.0256	1.3142	0.01948
1966	0.0576	0.6003	0.09595
1967	0.0856	0.1622	0.5277
1968	0.1289	0.4300	0.2998
1969	0.0987	0.3941	0.25.4
1970	0.4976	0.3024	0.1646

Table 17 shows Pu in surface samples collected from various points in Alaska. The greatest amounts were in Fairbanks samples, although these values were not significantly different, nor were the Anaktuvuk Pass and Bettles values. Pu in surface soils decreased at a 0.4-0.5 yr. half time and was measured with considerable difficulty, due to the particulate nature of plutonium and large samples required to provide statistically valid measurements (Hanson, 1980).

Table 17: Plutonium concentrations in soil samples collected at Anaktuvuk Pass, Bettles and Fairbanks, Alaska during summer periods of 1975 and 1976 (Hanson, 1980).

Location	Number of Samples	Date	^{238}Pu		^{239,240}Pu	
			pCi/g	nCi/m^2	pCi/g	nCi/m^2
Anaktuvuk Pass	3	7/75	-0.0018		0.0078	0.152
			±0.0018		±0.0054	±0.101
Anaktuvuk Pass	6	7/76	0.0004	0.0185	0.0012	0.042
			±0.0001	±0.0050	±0.0012	±0.030
Beetles	2	7/76	0.0004	0.0287	0.0016	0.115
			±0.000	±0.0130	±0.0006	±0.081
Fairbanks	2	7/76	0.0022	0.0858	0.0057	0.222
Anaktuvuk Pass	4	9/76	0.0003	0.0040	0.0010	0.032
			±0.0001	±0.0023	±0.0010	±0.017

Pu isotopes in lichens from northern Alaska during 1967-1979 occurred in pronounced peaks during 1968, 1972, 1974, and 1976 that correlate well with periods of high-yield (>200kt) nuclear tests by the People's Republic of China and France, and demonstrate a 1-2 yr. stratospheric residence time of the test debris. Table 18 presents data on Pu concentrations in lichen communities during this time period. Table 19 also supports this conclusion by showing a general increase of both ^{238}Pu and ^{239,240}Pu from 1968 to 1972, a decline during 1972 and 1973 and a sudden increase in 1974. Pu concentrations in Alaska soils were often near minimum detection limits (MDL) for ^{238}Pu and slightly above the MDL for ^{239}Pu. A best estimate is 0.0035 to 0.0038 pCi/g for ^{239}Pu during 1975 to 1979. A continuous series of Pu measurements of Alaska lichens during 1967 to 1979 showed a consistent agreement in pattern of accumulation for both ^{238}Pu and ^{239}Pu. The ^{238}Pu/^{239}Pu ratio was consistently near 0.1 rather than the 0.022 reported in fallout. Also, ^{238}Pu in the top 6 cm of lichens was 4 to 5 times greater than in the lower 6 cm, while the ^{239}Pu concentrations were 2.1 to 2.4 times greater in the top 6 cm. Ratios in the top 6 cm were 0.06 to 0.08 and in the lower 6 cm were 0.03 to 0.04, suggesting that ^{238}Pu was retained in the top section of lichens. A mean of ^{238}Pu/^{239}Pu of 0.064 ± 0.006 (N = 57), consistently higher the presumed ratio in fallout (0.022), was maintained. Table 20 presents 1969 Pu concentrations and activity ratios in lichen that are slightly above background levels.

Table 18: ^{238}Pu and $^{239,240}Pu$ concentrations in Northern Alaskan lichen communities during 1971-1976 (Hanson, 1980).				
Year	Number of samples	^{238}Pu	$^{239,240}Pu$	$^{238}Pu/^{239,240}Pu$
1971	6	0.012 ± 0.002	0.201 ± 0.100	0.065 ± 0.010
1972	4	0.026 ± 0.003	0.280 ± 0.026	0.091 ± 0.003
1973	8	0.013 ± 0.003	0.146 ± 0.026	0.089 ± 0.010
1974	4	0.017 ± 0.004	0.280 ± 0.006	0.064 ± 0.005
1975	3	0.003 ± 0.001	0.058 ± 0.002	0.050 ± 0.004
1976	6	0.014 ± 0.003	0.176 ± 0.010	0.078 ± 0.012

Table 19: Estimated inventories of ^{238}Pu, $^{239,240}Pu$, in areal samples of Alaskan lichen communities during summers of 1968-1976 (Hanson, 1980).				
Year	Taxon	Number of samples	^{238}Pu n/Ci/m^2	$^{239,240}Pu$ n/Ci/m^2
1968	Cladonia-Cetraria	1	0.019	0.28
1969	Cladonia-Cetraria	5	0.018	0.36
1970	Cladonia-Cetraria	3	0.027	0.41
1971	Cladonia alpestris	1	0.030	0.47
	Cetraria delisei	1	0.013	0.18
	Alectoria ochroleuca	1	0.002	0.04
1972	Cladonia-Cetraria	2	0.024	0.28
	Cladonia alpestris	1	0.029	0.30
	Cetraria delisei	2	0.028	0.30
1973	Cladonia-Cetraria	3	0.024	0.33
	Cladonia alpestris	1	0.038	0.30
	Cetraria delisei	2	0.007	0.10
	Stereocaulon paschale	2	0.069	0.32
1974	Cladonia-Cetraria	2	0.040	0.67
	Alectoria ochroleuca	2	0.023	0.40
1975	Cladonia-Cetraria	2	0.008	0.14
	Alectoria ochroleuca	2	0.009	0.16
1976	Cladonia-Cetraria	2	0.030	0.43
	Alectoria ochroleuca	2	0.034	0.34

Table 20: Plutonium concentrations and activity ratios in Alaska lichen communities.			
Lichen Type	Location	$^{239,240}Pu$ pCi/g Mean ± S.E.	Activity Ratio $^{238}Pu/^{239,240}Pu$ Mean ± S.E.
C. alpestris	Anaktuvuk Pass	0.53 ± 0.04	0.054 ± 0.008
C. alpestris and C. cuculata	Anaktuvuk Pass	0.24 ± 0.06	0.069 ± 0.018
C. cuculata	Anaktuvuk Pass	0.15 ± 0.01	0.083 ± 0.029

Measurements of the transfer of ^{238}Pu and ^{239}Pu to caribou and carnivores in the food web was complicated by very low concentrations, and constraints of analytical procedures. Concentrations of Pu in caribou bone samples during the

1971-1975 period of maximum were barely detectable (Table 21). Concentration ratios of the Pu isotopes were generally similar; the lichen/soil ration was 140-180; the caribou/lichen flesh ratio was 0.004-0.005; and the wolf caribou ration was 0-0.9. The concentration ratio relative to lichens were usually in the range of 0.02 for ^{238}Pu and 0.001 for ^{239,240}Pu. This suggests that ^{238}Pu was more readily transferred through the food chain. This can be explained by its greater ability to be retained in the upper strata of lichens.

Table 21: Concentrations of ^{238}Pu ^{239,240}Pu muscle and bone samples composited from several animals collected at Anaktuvuk Pass, Alaska, during April and May 1976 (Hanson, 1980).

Species sample type	Number of animals	Sample ash weight, g	^{238}Pu fCi/g ash	^{239,240}Pu fCi/g ash
Caribou				
Muscle	9	60.5	-0.19 ± 0.17	0.90 ± 0.20
Bone	3	83.4	0.03 ± 0.07	0.23 ± 0.11
Bone	6	100.2	0.33 ± 0.11	0.53 ± 0.14
Wolf				
Muscle	6	43.0	-0.40 ± 0.20	0.80 ± 0.40
Bone	3	71.7	-0.09 ± 0.11	0.30 ± 0.13
Bone	2	92.2	0.07 ± 0.15	0.05 ± 0.10
Fox				
Muscle	9	38.0	-0.30 ± 0.30	0.40 ± 0.40
Bone	4	85.6	-0.07 ± 0.12	0.09 ± 0.13

5. CONCLUSION

Most data for radionuclide fallout in Alaska were collected during late 1950's to mid 1970, a period of time immediately following intensive nuclear weapons testing by the former Soviet Union, China, and the United States. Since Alaskan native populations were still heavily reliant on local food sources at the time, researchers found that most human exposure was a direct result of the lichen-caribou-human-food chain. Therefore, data collected focused on concentrations in this food chain. After the cessation of nuclear testing and the introduction of state side food supplies, human uptake decreased and data collection stopped. With the exception of the effects from the accidental release at Chernobyl, all later studies reviewed (e.g., Hanson, 1982) still relied on data from the 1960's for further analysis or predictions.

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