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Post-Chernobyl ^{134}Cs and ^{137}Cs Levels at Some Localities in Northern Canada

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ABSTRACT. Samples of lichen, moss and caribou meat from the high and central arctic regions of Canada were measured for ^{137}Cs due to the Chernobyl accident of April 1986. They were compared to lichen samples from the boreal area of Wood Buffalo National Park, Alberta, and to moss samples from the temperate Niagara Escarpment of southern Ontario. Lichens from Ellesmere Island and mosses from the Niagara Escarpment had no detectable Chernobyl ^{137}Cs. Lichens from the central Arctic showed a ^{137}Cs increase of about 14% above the persistent burden from the past atmospheric nuclear weapons testing. Mosses and lichens from Wood Buffalo National Park showed an average ^{137}Cs increase of 19% due to Chernobyl fallout. In absolute terms, the contribution of Chernobyl fallout over Canadian northern regions was non-significant compared to the depositions experienced by countries such as the U.S.S.R., Sweden, Norway and some Central European countries.

Key words: Chernobyl, $^{134,137}Cesium$, fallout radionuclides in northern Canada, lichen samples, caribou samples

RÉSUMÉ. On a analysé des échantillons de lichens, de mousses et de viande de caribou venant des régions de l'Extrême-Arctique et du centre de l'Arctique canadiens pour mesurer le ^{137}Cs dû à l'accident de Chernobyl en avril 1986. On les a comparés à des échantillons de lichens des régions boréales du parc national Wood Buffalo en Alberta, et à des échantillons de mousses de la zone tempérée de l'escarpement du Niagara dans le sud de l'Ontario. Les lichens de l'île Ellesmere et les mousses de l'escarpement du Niagara ne contenaient pas de quantités décelables de ^{137}Cs de Chernobyl. Les lichens du centre de l'Arctique montraient une augmentation de la concentration de ^{137}Cs de 14%, par rapport à la charge persistante due aux essais antérieurs d'armes nucléaires dans l'atmosphère. Les mousses et les lichens du parc national Wood Buffalo montraient une augmentation moyenne de la concentration de ^{137}Cs de 19%, due aux retombées de Chernobyl. En valeurs absolues, la contribution des retombées de Chernobyl sur les régions du Nord canadien est insignifiante par rapport à celle des quantités déposées sur des pays comme l'U.R.S.S., la Suède, la Norvège et certains pays d'Europe centrale.

Mots clés: Chernobyl, $^{134,137}Césium$, retombées de radionucléides dans le Nord canadien, échantillons de lichens, échantillons de caribou

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INTRODUCTION AND PROCEDURES

The Canadian Arctic has been contaminated with ^{137}Cs, ^{90}Sr and other fission radionuclides since the days of atmospheric nuclear weapons testing, which ended in 1963. A grand total of 30 MCi (1 Ci [Curie] = 3.7×10^{10} disintegrations/s) of ^{137}Cs has been produced by aboveground nuclear testing (Levi, 1986); a fraction of this has reached the Arctic (Taylor *et al.*, 1985). During the period 1979-82, the present authors (H.W. Taylor and J. Svoboda) undertook a latitudinal survey of the ^{137}Cs deposited over the Canadian North (Hutchison-Benson *et al.*, 1985) as a result of all the atmospheric nuclear explosions to that date. In 1986, additional fallout reached Canada from the 26 April 1986 accident at a nuclear power station at Chernobyl, near Kiev, U.S.S.R., which expelled into the atmosphere between 0.5 and 1.0 MCi of ^{137}Cs (half-life 30.17 yr) as well as a number of other radioisotopes (Levi, 1986). Most of these additional isotopes were short lived and would be undetectable after a few weeks or months at most. Fortunately, from the point of view of identification of the new fallout, long-lived ^{137}Cs was also accompanied by ^{134}Cs, which has a half-life of 2.062 yr. From the ^{134}Cs and ^{137}Cs that was produced by the atmospheric nuclear testing more than 25 years ago, only ^{137}Cs persists on the ground, the ^{134}Cs having now decayed to levels below the detection limit. Thus the presence of ^{134}Cs in a sample collected after April 1986 is an indicator of the presence of fresh ^{137}Cs from Chernobyl, and it can be used to determine the percentage of Chernobyl ^{137}Cs in recent fallout, since no other atmospheric testing or nuclear accidents have been reported in this critical period of our sample collecting.

The selection of samples for the present study was not intended to be exhaustive but sufficient to give a reasonable indication of the increase caused by Chernobyl fallout, expressed as a percentage of the ^{137}Cs burden borne by the Canadian landscape as a result of earlier nuclear weapons tests.

During our 1986 summer expedition to Sverdrup Pass, central Ellesmere Island, N.W.T. (79°N, 80°W), between 10 and 15 July, we collected samples of five different lichens. In addition, we received lichen samples collected by R.F. Warren at Igloolik, N.W.T. (69°N, 82°W) during the summer months of 1986. From this locality we also received two samples of caribou meat. One of the meat samples was pre-Chernobyl, dated April 1986; the other was from an animal killed in January 1987, nine months after the Chernobyl accident. We also obtained a third caribou meat sample from Baker Lake area (64°N, 95°W) and a fourth from Somerset Island, N.W.T. (73°N, 93°W), both animals taken in March 1987. Finally in July 1986 we collected a wide range of plant samples from Wood Buffalo National Park, Alberta (60°N, 112°W) and in March 1987 moss samples from rocks at the Niagara Escarpment, Ontario (43°N, 80°W).

Plant samples were mechanically cleaned of external impurities, such as soil, but not washed; meat samples were freed of membrane and cut into small pieces; the bone (femur) samples were stripped free of meat and crushed into small pieces. All samples were dried in an electric oven at 65°C to constant weight. Clean, dried samples were used to fill a 0.5*l* Marinelli beaker. For counting, the beaker was placed on the cryostat enclosing a 10% efficient Ge(Li) detector. The energy resolution was about 2.5 keV at 1332 keV. Amplified pulses from the detector were analyzed with a 2048 channel Multichannel Analyser. The counter sensor was enclosed inside a 10 cm thick lead shield.

Each sample was counted for 24 hours. The ^{137}Cs counting rate was measured as counts·min^{-1}·g^{-1} of sample. A counting

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rate of 10^{-2}·min^{-1} corresponded to an activity of about 34 mBq (1 Bq = 1 disintegration per second). Since the samples were counted weeks after collection, the observed activities of shorter-lived ^{134}Cs were corrected for the decay during the period between the Chernobyl accident and the counting date. This permitted us to estimate the burden of Chernobyl fallout close to the time of deposition and to differentiate between the pre-Chernobyl and post-Chernobyl burden in the samples.

To differentiate between the old and new fallout, using the presence of ^{134}Cs as an indicator of Chernobyl fallout, we needed a sample free from previous fallout contamination, containing only fallout from the Chernobyl accident, so that the Chernobyl ^{134}Cs/^{137}Cs ratio could be determined. For this purpose we used dried figs from Greece harvested after Chernobyl in 1986 and purchased in Canada in December 1986. Panel (a) of Figure 1 shows a portion of the spectrum for the dried figs, which includes the strongest line of the ^{134}Cs gamma ray spectrum at 604.70 keV, two background (B) lines at 583.14 (^{208}Tl) and 609.31 (^{214}Bi) keV and the well-known ^{137}Cs line at 661.65 keV. The ratio of the area of the 604 keV ^{134}Cs peak and ^{137}Cs peak was determined by numerical integration to be 0.62 ± 0.03 at the time of the accident, 26 April 1986. This gives a ^{134}Cs/^{137}Cs ratio at the time of the Chernobyl accident of 0.54, since about 85% of ^{137}Cs decays are accompanied by a 661.65 keV gamma ray and close to 99% of the ^{134}Cs decays are accompanied by the 604.70 keV gamma ray. This value of the ratio is consistent with a value reported from Sweden of 0.57 (Persson *et al.*, 1987) and confirms our assumption that our Greek figs did not contain pre-Chernobyl ^{137}Cs. There is every reason to expect similar values of this ratio at different sites where Chernobyl fallout has been detected.

We did not attempt to measure the ^{90}Sr component of the Chernobyl fallout. ^{90}Sr is not expected to accompany the ^{137}Cs isotope in the same abundance observed in the fallout from past atmospheric nuclear tests. Medvedev (1986) has pointed out that ^{90}Sr was not found by Swedish experts in air samples, because of selective volatility of cesium and strontium in the Chernobyl low-altitude plume. However, newer information (Levi, 1986) suggests that a small fraction of ^{90}Sr has accompanied the ^{137}Cs.

EXPERIMENTAL RESULTS

Panel (b) of Figure 1 shows the post-Chernobyl gamma-ray spectrum obtained for a lichen species taken from a dry site at Sverdrup Pass, Ellesmere Island, N.W.T. A total of 7 lichen samples from Sverdrup Pass were measured; none of the spectra showed the 604 keV ^{134}Cs gamma ray line (Table 1). Our conclusion is that virtually no Chernobyl ^{137}Cs was deposited on the ground at this site on Ellesmere Island up to the end of July 1986. Panel (c) of Figure 1 shows the typical spectrum for a lichen sample collected at Igloolik, N.W.T. All of the lichen samples (*Cetraria telesii* and *C. islandica*) from Igloolik showed the presence of ^{134}Cs in addition to ^{137}Cs. Based on our predetermined ^{134}Cs/^{137}Cs ratio, the average increase in the on-ground ^{137}Cs content at this location due to Chernobyl fallout was 14% over the pre-Chernobyl background.

Panels (d) and (e) show the spectra of a lichen sample from Wood Buffalo National Park, Alberta, and of a *Brachythecium* sp. moss sample taken from an exposed site on the Niagara Escarpment, Ontario, respectively. The first site is in the boreal forest zone and the other in the temperate, deciduous forest zone. For three moss samples collected in Wood Buffalo Nation-

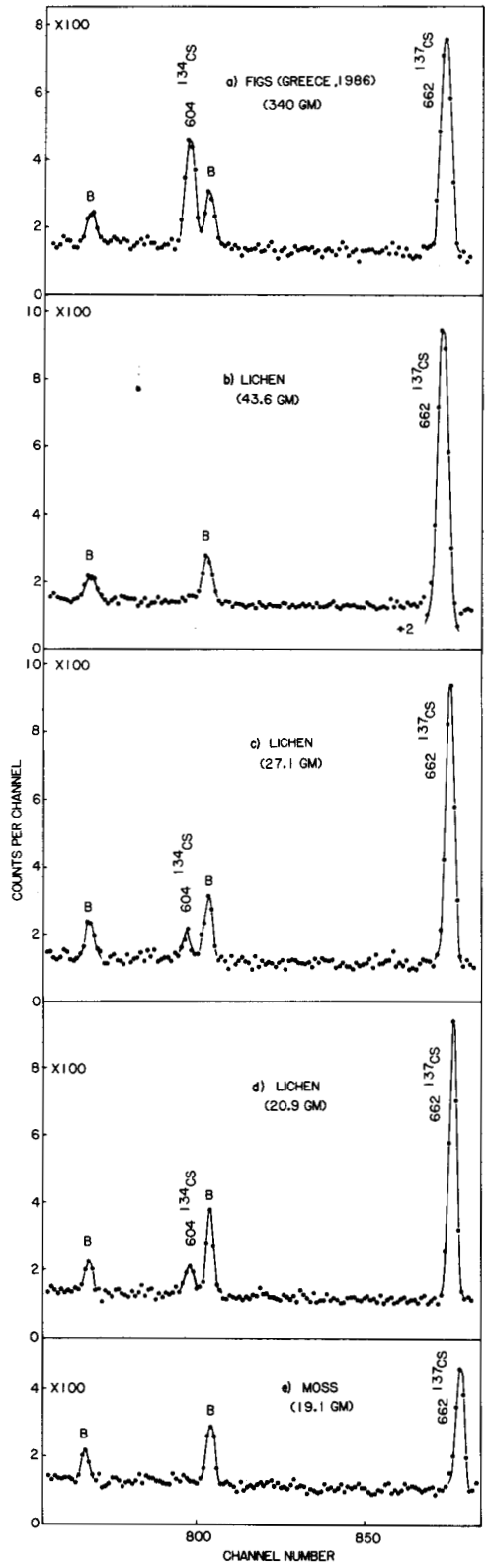

FIG. 1. Portion of gamma ray spectra showing the strongest gamma ray line of the ^{134}Cs spectrum and the ^{137}Cs gamma ray line. All energies in keV. Average counting time over all samples is 24.5 hours. Lines from the background due to the radium and thorium radioactive series are labelled B. a) Fig sample from Greece harvested in 1986. b) Lichen (*Cetraria telesii*) sample from Ellesmere Island (79°N), N.W.T., Canada. c) Lichen (*Cetraria telesii*) sample from Igloolik (66°N), N.W.T., Canada. d) Lichens (composite sample) from Wood Buffalo National Park, Alberta. e) Moss (*Brachythecium* sp.) sample from Niagara Escarpment, Ontario.

TABLE 1. Inventory of plant and caribou samples analyzed for ^{134}Cs and ^{137}Cs according to regions

Locality Sample	Mass (g dry wt)	Activity cts·min^{-1}·g^{-1} ^{134}Cs	 ^{137}Cs	%^{137}Cs due to Chernobyl	$^{134}Cs + ^{137}Cs$ activity Bq·g^{-1} dry wt		Comments
Sverdrup Pass, Ellesmere Island (79°N, 80°W)							Samples collected July 1986
Alectoria ochroleuca 1	24.1	nil	147×10^{-3}	nil	0.51		
2	14.1	nil	105×10^{-3}	nil	0.36		
3	12.8	nil	179×10^{-3}	nil	0.62		
Cetraria nivalis	43.6	nil	92×10^{-3}	nil	0.32		
Thamnolia vermicularis	21.9	nil	146×10^{-3}	nil	0.51		
Stereocaulon paschale	47.6	nil	164×10^{-3}	nil	0.57		
Umbilicaria proboscidea	17.7	nil	283×10^{-3}	nil	0.98		
Igloolik, Melville Peninsula (69°N, 82°W)							Samples collected July 1986
Cetraria tilesii 1	31.6	6.2×10^{-3}	91×10^{-3}	14	0.34		
2	27.1	4.6×10^{-3}	67×10^{-3}	14	0.25		
Cetraria islandica	18.3	40.0×10^{-3}	290×10^{-3}	16	1.14		
Wood Buffalo National Park (60°N, 112°W)							Samples collected July 1986
lichen mixture	20.8	8.7×10^{-3}	72×10^{-3}	28	0.28		
moss 1	18.5	9.4×10^{-3}	170×10^{-3}	12	0.62		
moss 2	14.4	9.5×10^{-3}	159×10^{-3}	13	0.58		
moss 3	2.0	7.5×10^{-3}	75×10^{-3}	24	0.29		
Black spruce needles	66.1	3.0×10^{-3}	9×10^{-3}	172	0.04		
					Dry wt	Fresh wt	
Igloolik, Melville Peninsula (69°N, 82°W)							
Caribou meat	81.8	nil	187×10^{-3}	nil	0.65	0.15	Killed April 1986
Caribou meat	43.4	9.0×10^{-3}	165×10^{-3}	13	0.60	0.13	Killed January 1987
Baker Lake, Keewatin District (64°N, 95°W)							
Caribou meat	107.6	19.5×10^{-3}	187×10^{-3}	28	0.71	0.16	Killed March 1987
Somerset Island (73°N, 93°W)							
Caribou meat	64.4	nil	28×10^{-3}	nil	0.09	0.02	Killed March 1987
Caribou bone	110.7	nil	2×10^{-3}	nil	0.005	0.004	

al Park, we measured an average ^{137}Cs increase of 16% due to the Chernobyl accident; the lichen sample measured from this site, whose spectrum is shown in panel (d), had a 28% increase. A black spruce needle sample from Wood Buffalo National Park showed a 172% increase in new ^{137}Cs. This percentage is unusually high because black spruce needles have an extremely low level of ^{137}Cs from the nuclear testing of the past.

Evidently, Chernobyl ^{137}Cs was deposited in detectable amounts over Baffin Island, Fox Basin, Upper Keewatin, N.W.T., and Ungava, Quebec (Crête *et al.*, 1987; Joshi and Roy, 1988). The Wood Buffalo National Park region was contaminated by fallout that drifted over the west coast of Canada, as the wind-pattern maps presented by Gilbert (1986) indicate. Very low levels of ^{134}Cs were measured in Ontario by Joshi (1987, 1988) in water samples, by Cohen (1986) and by the authors of this paper during May 1986 using air-sampling techniques. Consequently, the presence of some ^{134}Cs on the plants was to be expected; however the composite moss sample obtained at the Niagara Escarpment in March 1987 showed no detectable ^{134}Cs. Evidently the deposition was extremely low and the rains of the intervening months had removed all traces of Chernobyl fallout on plants at the Niagara Escarpment.

Fallout ^{137}Cs from the past nuclear tests as well as from the Chernobyl accident has been ingested by the caribou and reindeer herds feeding on contaminated lichens. In Figure 2, portions of the gamma ray spectra of two caribou meat specimens from Igloolik, N.W.T., are shown. The upper panel shows the ^{137}Cs line from a meat sample taken in April 1986; the lower panel displays the corresponding spectrum for an animal harvested in January 1987. The ^{137}Cs activity of the pre-Chernobyl sample was approximately 650 Bq·kg^{-1} dry weight (i.e., 150 Bq·kg^{-1} of fresh meat); it was 600 Bq·kg^{-1} dry weight (130 Bq·kg^{-1} fresh meat) for the 1987 sample. In the latter case, the presence of ^{134}Cs was used to estimate the ^{137}Cs activity from the Chernobyl contribution: 12.7% of the total ^{137}Cs activity.

The result for a caribou sample taken in March 1987 at Baker Lake, N.W.T., was 710 Bq·kg^{-1} dry weight (160 Bq·kg^{-1} of fresh meat); the Chernobyl contribution to the sample was 27% of the total ^{137}Cs activity. The observed ^{137}Cs body burdens were significantly lower than those commonly observed for Canadian caribou in the past (Crête *et al.*, 1987).

DISCUSSION

The original global distribution of fallout due to atmospheric nuclear tests showed a distinct geographical gradient, with the ^{137}Cs activity decreasing with increasing latitude (Feely *et al.*, 1978). According to published reports (Gilbert, 1986; Peterson *et al.*, 1986; Persson *et al.*, 1987), the low-altitude cloud of the Chernobyl fallout was first carried over Scandinavia to Greenland (Gilbert, 1986) and reached Canada in the areas of Baffin Island, Fox Basin and the Melville Peninsula. Western Canada, including northern Alberta, was contaminated by fallout from wind currents reaching North America from the northwest. Central Canada (provinces of Manitoba and Saskatchewan) were spared to a considerable extent from significant Chernobyl fallout. Changes in air movements subsequent to the Chernobyl accident carried fresh ^{137}Cs in other directions also. It was detected in Austria (Ambach *et al.*, 1987), the Netherlands (Ernst and van Rooij, 1987), the United Kingdom (Camplin, *et*

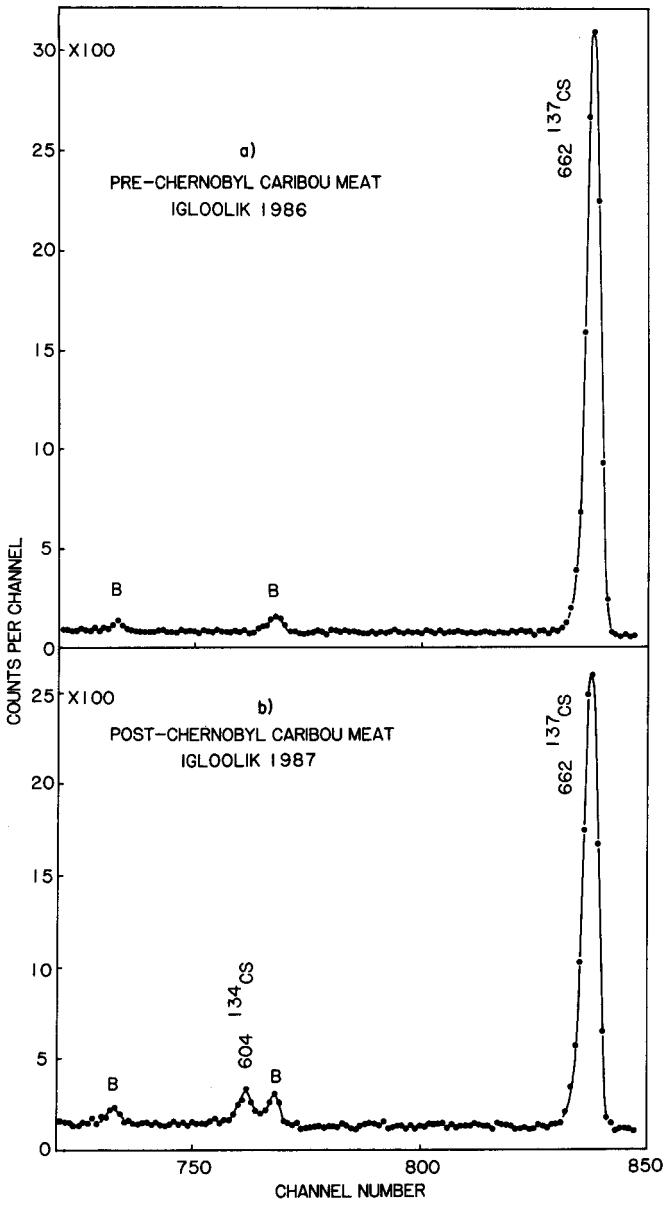

FIG. 2. Portions of gamma ray spectra of caribou meat from Igloolik. Dry weights of the sample were normalized to 43.4 g in each case. Counting time 23.5 hours. Energies are in keV. a) Sample taken in April 1986, *before* Chernobyl accident. b) Sample taken in January 1987, *after* Chernobyl accident.

al., 1986), Kuwait (Shibab-Eldin *et al.*, 1986) and in other countries.

In the Canadian Arctic, the radioactive fallout deposition from the Chernobyl accident appears to have a regional distribution in which very little ^{137}Cs has been deposited at 79°N in the Eastern Arctic. Between 60°N and 69°N (eastern Canada), the percentage increase over the present levels of weapons-testing fallout was of the order of 14-16% for lichens, which tend to retain ^{137}Cs. Generally speaking, the fresh load in northern Canada was 15%, consistent with a Government of N.W.T. report (GNWT, 1988). This, in our opinion, does not represent a significant additional hazard to the local wildlife or the people consuming game from the area, since total ^{137}Cs load of fresh caribou meat is below 300 Bq·kg^{-1}, which is considered safe by international standards (Crête *et al.*, 1987). However, Sweden will now permit consumption of reindeer meat with max. 1500 Bq·kg^{-1} (Cooper, 1987), while Canada, for reasons incomprehensible to us, proposes guidelines that would allow consumption of ^{137}Cs contaminated meat and other foodstuffs with loads up to 3500 Bq·kg^{-1}, as reported by Cooper (1987).

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