Cosmos 954: Search for Airborne Radioactivity on Lichens in the Crash Area, Northwest Territories, Canada

Abstract. *The fission product radioactivity detected on lichens in the vicinity of the impact area of the Soviet satellite Cosmos 954 does not exceed the background levels found in the general area as a result of past nuclear explosions.*

The crash of the Cosmos 954 satellite on 24 January 1978 was followed by an immediate air search for satellite debris conducted with a large NaI gamma-ray spectrometer. The isotope ^{140}La, a fission product with a half-life of 40.2 hours, was detected on the frozen surface of the east arm of Great Slave Lake (*1*) and attributed to the destruction of the small nuclear reactor said to be on Cosmos 954. On 27 March, a further search program was launched with a NaI gamma-ray spectrometer which was flown at an altitude of 30 m over numerous transects located on Great Slave Lake (*2*). This survey revealed that the central and southeast regions of the lake were significantly, yet irregularly, contaminated with ^{103}Ru (39.6 days), ^{95}Zr (65.5 days), and ^{95}Nb (35.1 days), all of which are fission products. These isotopes are also present in the fallout due to nuclear explosions, but their distribution at ground level is more or less uniform and "hot spots" as observed in some parts of the lake would not be expected. This survey established beyond doubt that the Cosmos 954 reactor had begun to disintegrate before reaching the ground and that part of the reactor material impacted on Great Slave Lake.

The question arises as to whether a significant amount of vaporized fission product material was released at high altitude and subsequently distributed over a wide area by the prevailing winds. Our group has a continuing program of research on arctic plants, which includes examination of the distribution of ^{137}Cs in substrates and various plant species (*3*). We availed ourselves of an opportunity to collect plants in the general vicinity of the Cosmos 954 crash site to see whether a significant, possibly worrisome, increase in ground-level contamination accompanied the crash. Several hundred radioactive macroscopic pieces were recovered by teams of searchers organized by the Atomic Energy Control Board. We, on the other hand, were interested in the airborne vaporized fission products which would contaminate vegetation just as nuclear fallout does.

The search area for Cosmos 954 debris was a corridor (approximately 900 km by 45 km) extending from Hay River on the southwest shore of Great Slave Lake, eastward from Fort Reliance along the Thelon River to Beverly Lake (*1*) (Fig. 1). The vegetation surrounding the southern shore of Great Slave Lake is part of the boreal forest region of Canada and represents a transition zone between the coniferous forest and forest-tundra ecotone (*4*). *Sphagnum* bogs and Precambrian granitic outcroppings are intermixed with stands of coniferous species here. *Picea mariana* and *Pinus banksiana* are dominant at all forested sites, whereas *Picea glauca* favors better drained soils. The ground cover is dominated by dense mats of foliose lichens (standing crop, about 1.2 km/m^2) which include *Cladina rangiferina, Cladonia bellidiflora, Alectoria ochroleuca*, and *Stereocaulon* sp. *Larix laricina* occurs along the margins of bogs and is often accompanied by *Populus tremuloides* and *Betula papyrifera*. The southern margins of Great Slave Lake between Hay River and Fort Resolution are dominated by open *Pinus banksiana* on dry upland sites with bogs and marshes in valleys and lowlands. Lichens collected in this region included *Cladina rangiferina* and *Stereocaulon* sp.

Unlike the previous large-scale airborne survey (*1, 2*), we chose to sample on the land south and east of Great Slave Lake. It was assumed that the northwest wind at the time of the satellite descent (*5*) changed the path of the light particles and even more so that of vaporized elements and that these were deposited south of the trajectory calculated for the bulk of the satellite. This assumption was confirmed by subsequent findings of radioactive pepper-size particles in the area of Hay River, Fort Resolution, and even as far south as Fort Smith. Because this area is populated, we chose it as a prime target of our research.

Two transects, each about 100 km in length, were established for systematic sampling at ground level between Fort Smith and Lake Rutledge (Fig. 1, site E) and ground lichens were collected about every 10 km. In addition, numerous samples were collected by workers of the Northwest Lands and Forest Service from areas inaccessible to us (Fig. 1, sites B and D). A total of 112 samples, most of them extracted from areas of at least 100 m^2, were collected within the search area outlined by previous parties (Fig. 1). This number of samples was believed to be adequate to reveal whether at all or to which order of magnitude the region was contaminated by the vaporized fallout. As controls we used samples that we collected from additional sites remote from the area of impact (Fig. 1, sites A, C, F, G, and H). About 1.5 kg (dry weight) of lichens were sampled from the area surrounding each landing site. This material was dried in

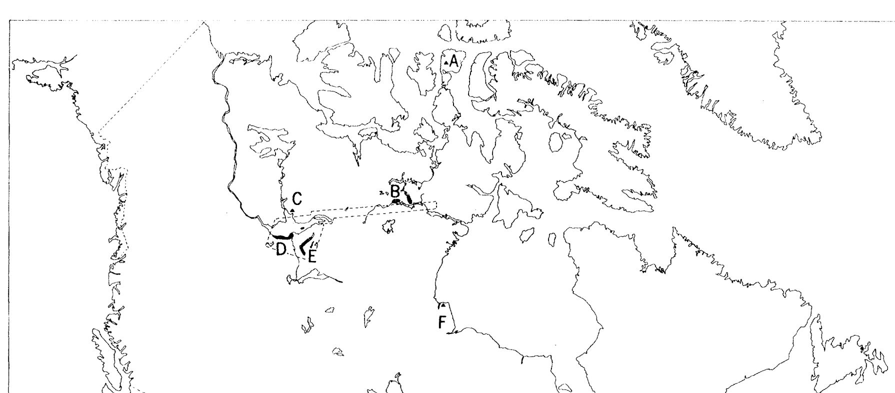

Fig. 1. Simplified map of Canada showing the areas (black) searched for airborne radioactivities after the crash of Cosmos 954 in January 1978. Samples of lichens were collected in the vicinity of the crash site (B, C, D, and E) and at remote sites (A, F, G, and H). Triangles identify the sites listed in the legend; black areas denote transects and areas sampled. For area D, the small black region on an island in Great Slave Lake is part of the sampling area. The dashed region designates a search area from Bristow (*1*).

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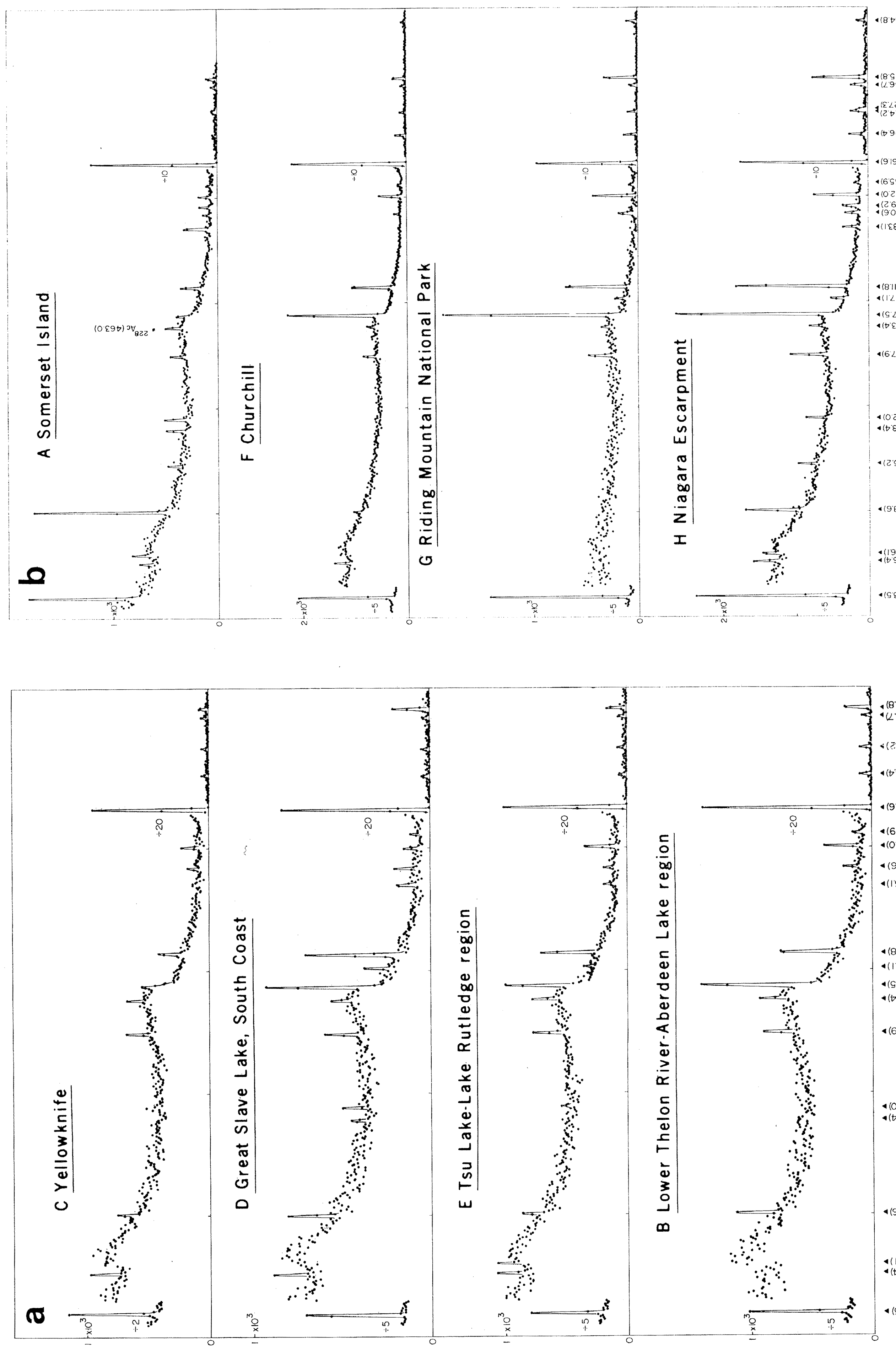
a
C Yellowknife
D Great Slave Lake, South Coast
E Tsu Lake-Lake Rutledge region
B Lower Thelon River-Aberdeen Lake region
b
A Somerset Island
F Churchill
G Riding Mountain National Park
H Niagara Escarpment
Counts

Fig. 2 (facing page). Gamma-ray spectra of samples collected in the vicinity of the crash site (a) and spectra of samples collected at remote sites (b). All gamma-ray energies are in kiloelectron volts.

the laboratory, powdered to increase the mass per unit volume, weighed, and placed in a plastic container designed to fit around the counter and so preserve a standard geometry; then its radioactivity was counted. The variation in the intensity of recent fallout along the northern transect (Fig. 1, site E) was within $\pm$ 60 percent of the average value along the transect. In order to further reduce the variability, nine individual samples were grouped together to represent a locality or region. The larger sample masses led to statistically more significant spectra and allowed more reliable identification of some radioactive elements present.

Our gamma-counting system consisted of a Ge(Li) counter (9.5 percent efficiency) of 2.1-keV resolution at 1332 keV coupled to a PDP 11/10 computer which was programmed to function as a multichannel analyzer. The counter was surrounded by a lead shield 5 cm thick. The counting period for each combined sample ($\sim$ 250 g) was 22 hours, and the background contribution was subtracted. The spectra for the eight sampling sites shown in Fig. 1 were normalized to the same mass. No correction was made for self-absorption in the sources because of the low density of the material used.

The spectra for the four sampling sites in the vicinity of the crash zone are shown in Fig. 2a; those considered as controls, from samples collected at considerable distances, are shown in Fig. 2b. The presence of ^{137}Cs (30.1 years) from past nuclear explosions (*3, 6*) is most apparent in all cases. Short-lived isotopes ^{144}Ce (284.4 days), ^{125}Sb (2.73 years), ^{7}Be (53.3 days), ^{103}Ru (39.6 days), ^{106}Ru (369 days), ^{95}Zr (65.5 days), and ^{95}Nb (35.1 days) were found in lichens from the vicinity of the crash site to which we had access. Except for ^{144}Ce, they represent only a small fraction of the ^{137}Cs background. The same isotopes, plus a few naturally occurring ones such as ^{228}Th (1.91 years) and ^{226}Ra (1600 years), were identified in the control samples, some with increased abundance over those collected near the crash zone. There is an increase in activity due to short-lived isotopes between Yellowknife (Fig. 2a, site C) and Great Slave Lake, South Coast (Fig. 2a, site D), which one might be tempted to ascribe to contamination after the crash of Cosmos 954. However, line intensities are even higher at Churchill, Manitoba, 1000 km from the crash site and even more intense in the southern collecting regions, such as Riding Mountain National Park and the Niagara Escarpment (Fig. 2b, sites F, G, and H). Hence we cannot attribute the variation in line intensity between Yellowknife and Great Slave Lake, South Coast, to Cosmos 954.

There are several possible sources of ^{7}Be at ground level. For example, this isotope is produced through spallation reactions between the secondary neutrons produced by the primary cosmic radiation and the nitrogen and oxygen of the atmosphere. The ^{7}Be produced in this way reaches the earth's surface continuously, but its intensity is subject to seasonal variations which vary with latitude, rainfall, and other factors (*7*). An additional source of ^{7}Be is the thermonuclear explosion. Often, LiD is a constituent of thermonuclear devices. The release of Li to the atmosphere after an explosion of this type has been well documented (*8*). The explosion can produce some ^{7}Be through the reactions ^{6}Li(d,n)^{7}Be and ^{7}Li(p,n)^{7}Be, which would then be distributed into the atmosphere with the fission products of the nuclear explosion. (However, ^{7}Be is not formed in low-yield nuclear explosions.) Traces of Li and ^{7}Be were found at the Cosmos 954 crash site in some of the engineering components of the satellite (*9*). Lithium compounds could have been used to shield various parts of the satellite against neutrons leaking from the reactor core. The ^{7}Be could be formed through bombardment of the ^{7}Li in the shielding with cosmic-ray protons while the satellite was in orbit. There is one more possible source of ^{7}Be, however. It is standard practice to surround the core of small reactors that use enriched U as fuel with a reflector of Be or a Be compound. Presumably some ^{7}Be could be made in the satellite by bombardment of a Be reflector with cosmic-ray neutrons through the reaction ^{9}Be(n,3n)^{7}Be. The creation of radioactive nuclides in satellite components through bombardment with cosmic rays while in orbit is well established (*10*). The ^{7}Be present in our spectra are clearly due to natural processes and thermonuclear explosions rather than to the components of Cosmos 954.

It is evident from Fig. 2 that the detected fission products are distributed over the entire Northern Hemisphere. There is, however, a significant reduction in the degree of contamination at the high latitudes (*3*). The vaporized core of the reactor on Cosmos 954 did not contribute to the fission product contamination at points distant from the impact site. At the crash zone itself and in the vicinity, it is possible that a small fraction of the contamination could arise from the vaporization of the reactor core. Even here, however, most of the short-lived radioactivity on our samples was probably contributed by the Chinese nuclear explosions of September 1977 and March 1978. The fact that the second of these explosions occurred soon after the crash of Cosmos 954 made it very difficult to discern the contributions to the contamination at ground level due to the destruction of the reactor. A comparison of the spectra of Fig. 2 indicates that the airborne contamination from the Cosmos 954 crash did not significantly increase the level of fission product contamination at ground level at the sites sampled. Since we could concentrate only on some areas within the potentially affected regions of the satellite impact, we limit our conclusions to the areas sampled. However, we believe it highly unlikely that substantial increases in fission product contamination due to the Cosmos 954 will be found in other areas.

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References and Notes

1. Q. Bristow, *Geol. Surv. Can. Pap. 78-1B* (1978), p. 151.
2. R. L. Grasty, *Trans. Am. Nucl. Soc.* **29**, 116 (1978).
3. J. Svoboda and H. W. Taylor, *Arct. Alp. Res.* **11**, (1979).
4. J. S. Rowe, Publication 1300 (Department of Environment, Canadian Forestry Service, Ottawa, 1972).
5. Personnel of the Atmospheric Environment Service, Canada, personal communication.
6. W. C. Hanson, *in Radioecology and Energy Resources*, C. E. Cushing, Jr., Ed. (Special Publication 1, Ecological Society of America, Olympia, Wash., 1976), p. 29.
7. C. W. Thomas *et al.*, in *Radionuclides in the Environment*, R. S. Gould, Ed. (American Chemical Society, Washington, D.C., 1970), p. 158.
8. H. M. Sullivan and D. M. Hunten, *Can. J. Phys.* **42**, 937 (1964).
9. R. L. Grasty, personal communication.
10. J. DeFelice, E. L. Fireman, D. Tilles, *J. Geophys. Res.* **68**, 5289 (1963).
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