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PLUTONIUM IN LICHEN COMMUNITIES OF THE THULE, GREENLAND REGION DURING THE SUMMER OF 1968*

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Abstract—Modest amounts of ^{239}Pu, ^{240}Pu attributable to the January 1968 aircraft accident near Thule, Greenland were found in lichens collected near that site during July–August 1968. It was mostly associated with particles of estimated 0.5–1.0 μ diameter that contained slightly greater than background levels of plutonium radioactivity.

On 21 January 1968 a United States Air Force B-52 bomber carrying nuclear weapons crashed on the sea ice of Bylot sound near Thule, Greenland. The incident in no way involved nuclear fission; however, conventional explosives contained in the weapons and aircraft fuel produced a substantial explosion and fire that scattered about 3150 g of plutonium over a 1.223 km^2 area of sea ice.[1] The clean-up operation (Project Crested Ice) was promptly and effectively conducted by Danish and U.S. personnel, and most of the contamination was removed. Environmental consequences of the small amount of radioactivity released to the environs was investigated by a Danish–American expedition during the summer of 1968.[2] Emphasis was placed upon marine aspects because (i) most of the contamination was associated with the sea ice of Bylot Sound, and (ii) marine ecosystems are of the greatest importance to the Eskimo populations of that region. Terrestrial food webs in the Thule region are restricted because of the limited land area available and rigorous environment.[3]

A cloud of smoke and debris, which contained an estimated 1–5 Ci of plutonium, drifted west-southwesterly from the crash site and deposited in uncertain amounts on the sea ice and landscape.[1] Terrestrial aspects of this investigation included collection and analyses of lichen samples for various radionuclides, including ^{238}Pu, ^{239}Pu and ^{240}Pu, because of the ability of the lichens to retain appreciable amounts of airborne materials.

Samples of foliose and fruticose lichens were collected from 27 sampling sites in the Thule region (Fig. 1) during the period 26 July–26 August 1968. Samples were air dried at Thule and returned to the home laboratory, where they were moisturized and meticulously hand-separated into the various lichen species, vascular plants, plant debris and soil that normally comprise a lichen community. This was necessary to make interspecific comparisons at various sampling locations and to remove extraneous material that would modify true weights and radionuclide determinations. These components were dried to constant weight at 70°C for 48 hr to determine percentage of the total community, were then separately ground in a Wiley mill, and aliquots processed according to standard procedures[4] to obtain standard dry and ash weights. Selected samples representative of the Thule lichen communities were processed for ^{238}Pu, ^{239}Pu and ^{240}Pu by standard radiochemical procedures;[5] the number of samples was necessarily restricted by the time and expense involved.

The term community included all lichen species (populations) within a sample, which was then designated by the dominant lichen species at that location. The dominant species contributed an average of 90% of the lichen biomass in the 80 samples obtained and the remainder consisted of varying amounts of several species.

Cetraria nivalis was the most common fruticose

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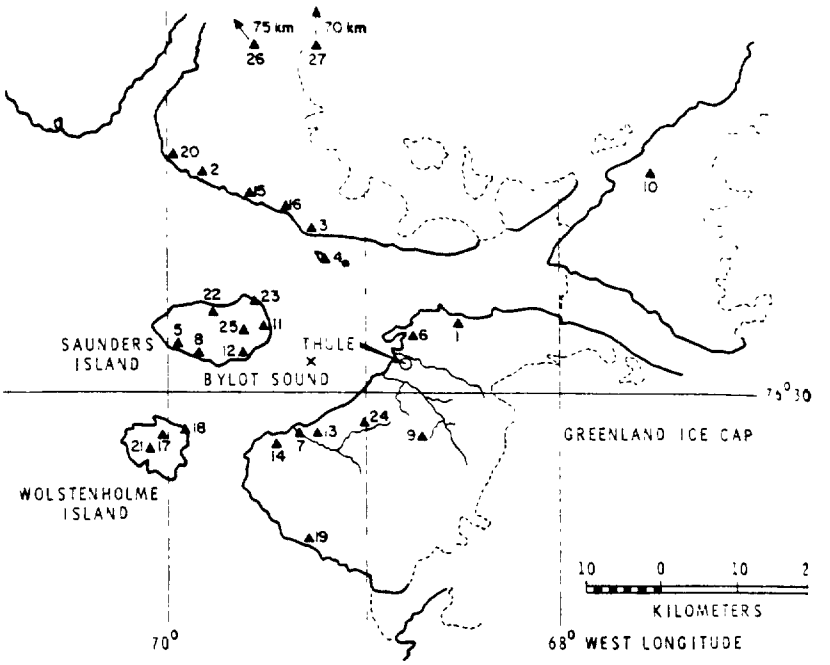

FIG. 1. Map of Thule, Greenland environs showing lichen sampling locations.

lichen community of the Thule region and served as a standard for comparison with other major lichen communities that were represented in the region, including *Stereocaulon paschale*, *Alectoria ochroleuca*, *Cetraria cuculata*, *Cetraria delisei*, *Cornicularia divergens*, *Cornicularia nigricans*, *Neuropogon sulphureus*, *Thamnolia vermicularis*, *Umbilicaria* spp. and *Peltigera* sp.

The fruticose lichen communities of the Thule region were discontinuously distributed over the landscape. Most lichens were found in rills, stone stripes and nets or other irregular surface features that provided moisture, sites for organic matter accumulation and shelter from the substantial winds. Moisture appeared to be one of the more apparent limiting factors for both plant growth and fallout deposition. Annual precipitation at Thule during the period 1960–1967 averaged 13 cm, compared to 32 cm at Fairbanks, Alaska.[6] When weighted for the differing precipitation regimes at Thule and Fairbanks, fallout deposition at the two sites was nearly equal during the maximum fallout period 1962–1965 and was more efficient (greater deposition per [illegible] precipitation) at Thule during low [illegible] periods.

Plutonium analyses of Thule lichens and [illegible] ciated plant debris showed a general backg[illegible] level of less than 1.0 pCi ^{239}Pu, ^{240}Pu g [illegible] dry weight, with a mean of about 0.4 [illegible] samples (Table 1). Similar amounts [illegible] found in 2 lichen samples collected [illegible] thern Alaska 1 month prior to the [illegible] survey. Four lichen samples contained [illegible] pCi/g, considered slightly above backg[illegible] and two lichens and one plant debris [illegible] were significantly above background (2.6, [illegible] and 2.8 pCi/g). The seven higher values [illegible] red in samples collected at locations 7, [illegible] and 19, which were adjacent to the impac[illegible] or on the downwind trajectory of the air[illegible] plutonium contamination.

The mean activity ratio ^{238}Pu/^{239}Pu,^{240}Pu in the ten lichen samples and three plant debris samples considered to contain no accident debris was 0.033 ± 0.006 (S.E.), slightly greater than the ratios of about 0.02[7,8] and 0.5[9]

Table 1. Plutonium concentrations and activity ratios in lichen components from Thule, Greenland and Alaskan locations

Component type		Location	$^{239,240}Pu$ pCi/g std dry Mean ± S.E.	Activity Ratio $^{238}Pu/^{239,240}Pu$ Mean ± S.E.
Greenland lichen communities				
C. nivalis	lichens	13	42.6 ± 2.7	0.019 ± 0.001
S. paschale	lichens	13	3.50 ± 0.21	0.028 ± 0.001
C. cuculata	lichens	19	1.24 + 0.09	0.022 ± 0.002
C. nivalis	lichens	12	1.22 ± 0.06	0.019 ± 0.002
A. ochroleuca	lichens	12	1.12 ± 0.06	0.029 ± 0.006
C. nivalis	lichens	7	1.00 ± 0.06	0.030 ± 0.002
A. ochroleuca	lichens	12	0.84 ± 0.04	0.027 ± 0.002
N. sulphureus	lichens	21	0.66 ± 0.06	0.028 ± 0.002
Umbilicaria sp.	lichens	21	0.63 ± 0.04	0.031 ± 0.003
C. nivalis	lichens	12	0.59 ± 0.04	0.024 ± 0.004
C. nivalis	lichens	5	0.36 ± 0.03	0.031 ± 0.004
C. nivalis	lichens	8	0.30 ± 0.03	0.041 ± 0.012
C. nivalis	lichens	3	0.29 ± 0.04	0.048 ± 0.017
C. delisei	lichens	13	0.26 ± 0.03	0.041 ± 0.011
C. nivalis	lichens	10	0.18 ± 0.01	0.047 ± 0.007
C. nivalis	lichens	21	0.18 ± 0.01	0.051 ± 0.010
C. cuculata	plant debris*	19	2.8 ± 0.21	0.026 ± 0.003
C. nivalis	plant debris*	3	0.67 ± 0.04	0.030 ± 0.003
C. nivalis	plant debris*	27	0.46 ± 0.02	0.047 + 0.003
C. delisei	plant debris*	13	0.33 ± 0.02	0.026 ± 0.006
N. sulphureus	plant debris*	21	0.08 ± 0.08	—
C. cuculata	soil and rocks*	19	0.11 ± 0.01	—
C. delisei	soil and rocks*	13	0.05 ± 0.02	—
Alaskan lichen communities				
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

* Separated from lichen samples.

reported to represent background in air and precipitation samples prior to the entry of SNAP-9A generator debris in April 1964. However, the longevity and radionuclide retention capacity of lichens provide an integrated history of fallout deposition that has contained variable amounts and ratios of plutonium following each series of nuclear weapons tests and the gradual deposition of SNAP-9A ^{238}Pu.

Most of the ^{239}Pu, ^{240}Pu radioactivity in the six lichen samples considered "above background" was associated with particles of indeterminate size but tending toward a diameter of 0.5–1.0 μ. This estimate was based upon variation of about 30% among several replications of the samples (whereas the analytical method usually yielded results with a variation of only 10%), repeated analyses, and radioautographic techniques. This is considerably larger than the SNAP-9A debris particles[10] and indicates that they originated from the Thule accident. This was corroborated by photomicrographs of contaminated snow and ice samples obtained in the downwind vector of the accident cloud[11] and was consistent

with projected particle sizes observed in laboratory studies of ignited and oxidized metallic plutonium.[12]

There is no immediate explanation for the greater ^{238}Pu concentrations in the Alaskan lichens compared with Thule background samples. It may be due to local fallout deposition phenomena associated with atmospheric nuclear weapons tests or SNAP-9A debris. TUOMINEN[13] suggested that variable cation composition of lichens from different regions might indicate a close relation between thalli and their substrate. We have not made such observations and can, therefore, only speculate upon the differences.

It is concluded that plutonium concentrations slightly greater than background and attributable to the Thule, Greenland Broken Arrow incident occurred in about one-third of the lichen samples collected at locations adjacent to and downwind from the impact site.

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