occur on atmospheric particulate matter. The identified products, however, account for only about a third of the disappearance of **1**. It is possible that, in addition to initiating oxidative paths, photochemical excitation can initiate polymerization pathways which lead to highly condensed systems (for example, soot), which are ultimately degraded by soil bacteria. We assume that, since other PAH can be oxidized by singlet oxygen (*16*), photooxidative decomposition may possibly be general for at least some other PAH constituents of particulate matter. Since oxidation products can form in atmospheric samples, studies that evaluate carcinogenicity solely on the basis of PAH content will probably consistently underestimate carcinogenicity.

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Atmospheric Burnup of the Cosmos-954 Reactor

Abstract. *On 24 January 1978 the Russian satellite Cosmos-954 reentered the atmosphere over northern Canada. By use of high-altitude balloons, the atmosphere was sampled during 1978 up to an altitude of 39 kilometers to detect particulate debris from the reactor on board the satellite. Enriched uranium-bearing aerosols at concentrations and particle sizes compatible with partial burnup of the Cosmos-954 reactor were detected only in the high polar stratosphere.*

The Russian satellite Cosmos-954 reentered the atmosphere at 55 to 67 km over northern Canada on 24 January 1978 (*1*). The reactor on board was assumed to be of the Romashka design—that is, a 40-kW (thermal) power plant containing as much as 50 kg of 90 percent enriched ^{235}U (*2, 3*). Special flights in the High Altitude Balloon Sampling Program of the U.S. Department of Energy were made in 1978 up to 39 km to intercept any Cosmos-954 debris that might have ablated. On these flights and on routine flights, samples were collected on IPC-1478 filter papers. The identification and collection parameters of the filter papers from the special and selected routine flights are shown in Table 1.

Fractions of these filter papers with the scrim backing removed were analyzed for uranium isotopes by the Knolls Atomic Power Laboratory (KAPL) at the General Electric Company, Schenectady, New York (*4-7*); the results are reported in Table 2. The reported errors are estimates of analytical precision equivalent to 1 standard deviation (S.D.) of the total number of counts for each mass assignment or the deviation about the mean of duplicate measurements of a single solution as indicated. In 13 of 16 sets of duplicate isotopic measurements of identical solutions in this study, the duplicate analyses agreed with each other within 1 S.D. of the counting errors. The error of an isotopic analysis, determined with uranium standards provided by the National Bureau of Standards, is less than 1 percent.

The analytical precision of the measurement of the total uranium in a filter fraction is about ±0.5 percent. In correcting the fractional data to the value for the whole filter, a constant weight of the appropriate filter size was assumed; this could vary by about ±5 percent. Therefore, a ±5 percent error is applied to all results in the last column of Table 2, except when the standard deviation of duplicate analyses is larger.

The six blank filters in Table 2 exhibit an enrichment in ^{235}U over natural uranium of 0.789 ± 0.070 percent (mean ± 1 S.D.). This enrichment probably occurred during the manufacture of the paper, possibly through use of a reagent such as HNO_3, which routinely shows higher ^{235}U atom percentages than natural uranium.

Considering the behavior of earlier radioactive tracers (*8, 9*), we believe that filters 3739, 3744, and 3763 sampled regions of the stratosphere where debris from a Cosmos-954 burnup should not have been present. As expected, these filters have ^{235}U atom percentages similar to the mean for the blank filters. Therefore, in examining the exposed filters in this study for the presence of Cosmos-954 debris, we had only to consider the departures in their isotopic composition from that of the blank filters. Filter 3751 also fits this description, although before launch we were not sure whether it would intercept debris from a possible Cosmos-954 burnup.

Filters 3747 and 3765 were recovered from the region with the highest probability of containing particulates from such an event, and both exhibited a marked increase in ^{235}U. We believe that interception of ablated particles from the reentry of Cosmos-954 is the only plausible cause of this increase.

To calculate the amount of Cosmos-954 uranium in these filters, we can write for each isotope an equation of the form

$$A_C x + A_B(N - x) = A_F N \qquad (1)$$

where A is the atom percentage of that isotope; subscripts B, C, and F refer to background, Cosmos-954, and filter, respectively; x is the total number of uranium atoms from Cosmos-954 in the filter; and N is the total number of uranium atoms from all sources in the filter. Until mass isotopic data for the Cosmos-954 uranium are available, we must assume its composition in order to apply Eq. 1. It was assumed that the Cosmos-954 reactor was of the Romashka design and was fueled with 90 percent enriched ^{235}U. We further assume that this uranium is similar in composition to the 90 percent enriched ^{235}U available from the National Bureau of Standards (*10*). This assumed composition of the Cosmos-954 uranium, rounded off to the nearest 0.5 percent, is shown at the bottom of Table 2. The ^{235}U and ^{238}U percentages should be within 5 percent of the true values for Cosmos-954, but the ^{234}U and ^{236}U values may be in error by as much as a factor of 2.

Substituting the data in Table 2 into

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Eq. 1 allows an evaluation of the amount of Cosmos-954 uranium in each filter. The masses of total uranium from Cosmos-954 per filter calculated from the ^{235}U analyses of the various fractions of filters 3747 and 3765 agree with each other in most cases to within 1 and in all cases to within 2 S.D. of the analytical precision. The mean values are 0.30 ± 0.05 and 0.16 ± 0.02 ng of Cosmos-954 uranium per filter for samples 3747 and 3765, respectively.

Identical patterns emerge for the estimates of Cosmos-954 uranium in the filters from the ^{234}U and ^{238}U data, and the mean values agree with the mean derived from the ^{235}U results. This agreement is to be expected for the ^{238}U data because ^{235}U and ^{238}U together constitute more than 99 percent of the total uranium in the samples. The quantities of Cosmos-954 uranium calculated from the ^{236}U data reflect similar precision, but the mean value is only half the ^{235}U result. Much of this difference may be due to improper assignment of the ^{236}U composition of Cosmos-954 debris. The ^{236}U data for filters 3739, 3751-A, and 3751-B in Table 2 are anomalous results for which we have no ready explanation. In all three cases, the ^{236}U percentage is elevated without a concomitant rise in the ^{234}U and ^{235}U percentages.

On the basis of the behavior of earlier radioactive tracers that were injected into the upper atmosphere, we expected that in mid-1978 any ablated debris from Cosmos-954 would be confined to altitudes above 30 km between 50° and 90°N. With complete burnup and homogeneous distribution within this region, the mean stratospheric concentration would be 9.3×10^{-12} g of total uranium per standard cubic meter of air. On the order of 75 percent of the fission products from the Cosmos-954 reactor are estimated to have been deposited in an impact area in northern Canada where fragments of the satellite have been found (*1*). Therefore, the expected stratospheric concentration should be reduced to 2.3×10^{-12} g/m^3. Dividing the mean mass of Cosmos-954 uranium on filters 3747 and 3765 by the appropriate volumes of sampled air in Table 1 gives similar concentrations of 4.7×10^{-12} and 2.3×10^{-12} g/m^3, respectively.

A very extensive study was made of filter 3747 to identify and characterize the uranium-bearing particles by fission track analysis (*11*). Suitable sections of the filter were ashed in a low-temperature asher. The resulting ash residue was dispersed in a collodion mixture and mounted on Lexan in a clean-room facility. The Lexan mounts were then irradiated with neutrons in the KAPL thermal test reactor, etched, and examined with an optical microscope. Under these conditions, a $^{235}UO_2$ particle 0.2 μm in diameter produces a cluster or star of 50 tracks.

In examining 200 cm^2 of filter 3747, we observed 339 single-track and six double-track stars but none larger. We can estimate the size of the uranium particles that caused these stars by applying the Poisson-distribution function to the single- and double-track data. For simplicity, we assume that all the uranium from Cosmos-954 on the filter is present as UO_2 particles of the same size. The emission of two fragments per fission compensates for the 2π geometry of the particle and Lexan, so that essentially one track is recorded for every fission event. The expected number of tracks per particle (λ) in the Lexan is

$$\lambda = N\sigma\varphi t = 5.2 \times 10^{-7} N \qquad (2)$$

where N is the number of atoms of ^{235}U in the particle; σ is the fission cross section of ^{235}U for thermal neutrons, 5.8×10^{-22} cm^2; φ is the thermal neutron flux, 3×10^{11} cm^{-2} sec^{-1} for the KAPL thermal test reactor; and t is the irradiation time, 3000 seconds.

Because λ is small, the Poisson probability function can be used to calculate the probability (P_r) of observing a particular number of tracks (r) per particle

$$P_r = \frac{\lambda^r e^{-\lambda}}{r!}, \quad r = 0, 1, 2, \ldots \qquad (3)$$

By substituting the observed frequencies of the single- and double-track stars into Eq. 3 and calculating their ratio for $r = 1$ and $r = 2$, respectively

$$\frac{P_2}{P_1} = \frac{6}{339} = \frac{\lambda^2 e^{-\lambda}}{2} \times \frac{1}{\lambda e^{-\lambda}} = \frac{\lambda}{2} = 2.6 \times 10^{-7} N \qquad (4)$$

Therefore, $N = 6.8 \times 10^4$ atoms of ^{235}U per particle.

The ^{235}U abundance of Cosmos-954 is 90 percent, so that the total number of

Table 1. Identification of filters.

Filter	Sampling data	Latitude (°N)	Altitude (km)	Area of filter (m^2)	Volume of air sampled (m^3)
3739	7 March 1978	9	27	0.0929	73.4
3744	4 May 1978	33	31	0.743	150
3747	4 June 1978	65	39	0.743	64.4
3751	3 June 1978	65	32	0.186	90.7
3763	20 July 1978	33	40	0.743	42.8
3765	11 September 1978	65	39	0.743	70.7

Table 2. Results of mass isotopic analysis ± standard deviations.

Filter	Atom percentage of isotope				Total uranium atoms per filter (10^{13})
	^{234}U (10^{-4})*	^{235}U (10^{-3})	^{236}U (10^{-4})	^{238}U	
			Cosmos-954 debris not expected		
3739†	89 ± 23	875 ± 26	226 ± 11	99.09 ± 0.03	1.90 ± 0.16
3744†	63 ± 3	685 ± 34	5.2 ± 2.6	99.31 ± 0.04	9.67 ± 1.77
3763	80 ± 2	828 ± 6	3.8 ± 0.4	99.16 ± 0.08	10.1 ± 0.5
			Cosmos-954 debris possible		
3747-A‡	160 ± 2	1564 ± 3	26.5 ± 0.6	98.42 ± 0.01	10.3 ± 0.5
3747-B	141 ± 2	1345 ± 5	19.5 ± 0.5	98.64 ± 0.02	10.7 ± 0.5
3747-C	130 ± 2	1342 ± 6	20.0 ± 0.9	98.64 ± 0.07	12.1 ± 0.6
3751-A	68 ± 1	773 ± 4	10.2 ± 0.3	99.22 ± 0.02	8.25 ± 0.41
3751-B†	71 ± 6	790 ± 39	18.7 ± 0.6	99.20 ± 0.04	11.7 ± 0.6
3765-A	116 ± 2	1162 ± 6	14.2 ± 0.5	98.83 ± 0.09	8.48 ± 0.42
3765-B	148 ± 2	1400 ± 8	19.0 ± 0.5	98.58 ± 0.03	6.89 ± 0.34
3765-C	137 ± 1	1321 ± 7	16.5 ± 0.5	98.66 ± 0.03	6.98 ± 0.35
Mean of six blank filters	70 ± 10	789 ± 70	1.9 ± 1.8	99.21 ± 0.07	1.95 ± 1.56
Natural uranium	55	720	0	99.28	
Cosmos-954 uranium	10,000	90,000	5,000	8.5	

*The value in parentheses at the top of each column is a multiplier for the values in that column; for example, for 3739 the ^{234}U result is (89 ± 23) × 10^{-4} atom percent. †These results are the means of duplicate analyses of a single solution and the standard deviation of the two measurements about the mean. ‡The suffixes represent individual fractions of a single filter.

uranium atoms per particle is 7.6×10^4. Since the density of UO_2 is 11 g/cm^3, the equivalent diameter of the particle, if it were pure UO_2, would be 18 nm. The statistical error of the number of ^{235}U atoms per particle is ± 100 $[(1/339) + (1/6)]^{1/2} = \pm 41$ percent, which corresponds to a change in the equivalent diameter of -3 to $+2$ nm.

No corrections have been made for the single tracks due to background uranium in the filter or for chance orientation of single tracks from adjacent particles to form an apparent double track. These corrections tend in the same direction so that P_2/P_1 would probably not change sufficiently to produce a significant change in the estimated particle size.

We consider 18 nm a reasonable estimate of the equivalent diameter of average mass of a probably lognormal distribution of Cosmos-954 reactor particles. This compares favorably to the equivalent diameter of average mass of 12 nm observed from the reentry burnup of the ^{238}Pu-fueled SNAP-9A generator in 1964 (*8*).

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Remote Detection of Biological Stresses in Plants with Infrared Thermometry

Abstract. *Green leaves of mature sugar beets infected with* Pythium aphanidermatum *and cotton infected with* Phymatotrichum omnivorum *had midday radiant leaf temperatures 3° to 5°C warmer than adjacent plants with no sign of disease. The temperature difference persisted under varying conditions of soil moisture and could be used to detect biological stress imposed by these soilborne root-rotting fungi.*

Remote sensing technology is rapidly emerging as a useful tool in the early detection of crop stresses for optimum agricultural resource management. Water stress, perhaps the most ubiquitous of all crop stresses, has also proved one of the most readily identifiable by remote techniques. Plants that have been subject to limited amounts of water exhibit higher leaf temperatures than those with an ample water supply (*1*). We have exploited this phenomenon by using infrared thermometry to detect water stress and to predict its ultimate effect on crop yield and water requirements (*2*).

Other types of crop stress that interfere with water uptake by plant roots or the translocation of water to the leaves for evaporation, or both, should also be amenable to previsual detection and characterization. Intrigued by this possibility, we initiated several experiments to assess the potential of infrared thermometry (*3*) to detect biological stresses imposed by two different soilborne fungal diseases. The first was a root-rot disease of mature sugar beets (*Beta vulgaris* L.), caused by *Pythium aphanidermatum* Edson (Fitz.) (*4*); the second was a root-rot disease of cotton (*Gossypium* sp.), caused by *Phymatotrichum omnivorum* (Shear) Dug. (*5*).

We used hand-held infrared thermometers (*6*) to measure radiant leaf temperatures of sunlit green leaves on plants in several commercial fields of sugar beets (south of Phoenix) and cotton (Marana, Arizona) where a relatively high incidence of the two fungal diseases had been confirmed. Next, we pulled each plant from the soil with as much of its root system as possible, and, based on the macroscopic appearance of the roots, two observers assigned to it a disease category as follows: (i) healthy plants with no evidence of disease; (ii) slightly diseased plants showing early signs of fungal infection (in sugar beets, lesions were evident on the root surface but less than 10 percent of the root volume was damaged; in cotton, the vascular structures of the root were discolored), and (iii) moderately diseased plants exhibiting more advanced symptoms of the disease (in sugar beets, we defined this class as those plants having 10 to 60 percent of the root volume destroyed; in cotton, we found that roots were decaying, the cortex was sloughing off, and the main root was covered with a network of fungal mycelia).

Our results (Table 1) revealed that the radiant leaf temperatures of moderately diseased sugar beets averaged 2.6° to 3.6°C warmer than those of healthy plants, yet we were unable to ascertain disease incidence visually without examining the roots. In subsequent visits to the same fields, we found that healthy sugar beets always remained cooler than moderately diseased plants despite progressively drier soil conditions which resulted in higher plant temperatures. In fact, by 6 July, all plants were wilting from obvious water stress, yet differences in the leaf temperature between diseased and healthy plants persisted. It was not possible to distinguish between healthy and slightly infected sugar beets either visually or with leaf temperature data. We interpreted these results to mean that a certain minimum volume or critical region of the root needed to be affected by the fungus before water uptake or translocation became impaired. Plants in which *P. aphanidermatum* had destroyed more than 60 percent of the root were conspicuous and easy to identify without root inspection. In these plants all the leaves were dead and either yellow or brown with radiant temperatures ranging between 50° and 60°C, usually slightly warmer than adjacent sunlit soils.

Our results with cotton infected with *P. omnivorum* were similar. Slightly diseased plants were not significantly warmer than healthy individuals, nor could we identify them visually without inspecting the roots. Sunlit green leaves on moderately diseased plants, however, averaged 3.3° to 5.3°C hotter than those on plants with no sign of fungal infection. The temperature difference was evident even on 18 August, 1 day after an irrigation, when aboveground visual clues to infection (that is, wilting) were not reliable. We did observe that, as soil moisture was depleted, the moderately diseased plants invariably wilted first. In fact, on 24 August, all these plants had wilted and, even though their foliage re-

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