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Atmospheric Radioactivity in Antarctica 1956-1963

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CONTENTS

Abstract	ii
Problem Status	ii
Authorization	ii
INTRODUCTION	1
COLLECTION AND MEASUREMENT OF SAMPLES	1
NATURAL RADIOACTIVITY	2
Radon	2
Thoron	2
Lead-210	5
FISSION-PRODUCT RADIOACTIVITY	5
Gross β Activity	5
γ -Spectrometric Analysis of South Pole Samples	7
Radiochemical Analysis of Air Filter Samples	8
FUTURE TRENDS IN ANTARCTIC RADIOACTIVITY	13
CONCLUSIONS	13
REFERENCES	15

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ABSTRACT

Continuous measurements of the radioactive aerosol content of the surface air in Antarctica have been made since 1956, first at Little America and later at the Amundsen-Scott South Pole Station. Both the radioactivity due to bomb-produced fission products and to the naturally occurring radionuclides of the radon and thoron series were measured in daily collections; composite samples covering three-month periods were subjected to radiochemical analysis for such long-lived radionuclides as Sr^{90} , Cs^{137} , Ce^{144} , Pm^{147} , and Pb^{210} .

The observed natural radioactivity was lower in Antarctica than at any other geographical location, as might be expected from the absence of any quantity of exposed land surface in the vicinity. The fission-product concentrations, however, were equal to or greater than those observed in the southernmost parts of South America. Well-defined seasonal variations in airborne radioactivity were noted, with maxima in the summer.

PROBLEM STATUS

This is a final report on one phase of the problem; work on other phases is continuing.

AUTHORIZATION

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ATMOSPHERIC RADIOACTIVITY IN ANTARCTICA
1956 - 1963

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INTRODUCTION

As part of its general study of atmospheric radioactivity, the U.S. Naval Research Laboratory, with the cooperation and support of the Polar Operations Branch, Office of Meteorological Research, U.S. Weather Bureau, established an air-monitoring station at Little America V in 1956 (1). In early 1959 it was transferred to the Amundsen-Scott South Pole Station and put in operation there. The equipment employed was capable of measuring with a reasonable degree of accuracy radon concentrations as low as 10^{-19} curies/cc of air, and thoron decay products and gross fission products in concentrations as low as 10^{-20} curies/cc of air. Similar equipment has been operated for various periods of time in a number of other areas of the world, so a reasonable comparison of radioactivity levels in Antarctica can be made with those existing elsewhere (1-6).

Some of the earlier measurements in this program in Antarctica have already been described (1); other measurements have been reported for Base Roi Baudouin in Queen Maud Land (7-9) and for Base Dumont d'Urville on the Adélie Coast (10-12). More recently some information has been obtained at McMurdo Station on Ross Island and at New Byrd Station in Marie Byrd Land in connection with the operation of a power-producing reactor in Antarctica (13-15).

This report summarizes the available information on the radioactive aerosols in surface air in Antarctica; it also includes a survey of the seasonal (quarter-year) changes there in the concentration of the long-lived airborne radionuclides Sr^{90} , Cs^{137} , Ce^{144} , Pm^{147} , and Pb^{210} obtained by radiochemical analysis of composited daily air-filter samples.

COLLECTION AND MEASUREMENT OF SAMPLES

The basic measurements of airborne radioactivity were, of necessity, made at the collecting site; air-monitoring equipment identical to that employed in other studies of atmospheric radioactivity carried out by NRL was employed (1-6,16). The concentrations of radon-222, of lead-212 (ThB), and of gross fission products were determined from these on-site measurements. Later (several years later, in some cases) radiochemical analyses were performed on composite samples covering three-month periods for the radioisotopes Sr^{90} (28-yr half-life), Cs^{137} (29 yr), Ce^{144} (285 day), Pm^{147} (2.65 yr), and Pb^{210} (22 yr).

The on-site procedure consisted of the daily exposure of a 2-1/2-in. circle of Type 5 cellulose-asbestos filter paper during a 24-hr period to an air flow of about 33 cu ft/min (ambient), immediately after which the radioactivity was measured during a 16-hr period. From an initial 10-min count and two subsequent 3-hr counts centered about the sixth hour and the 15th hour of the decay measurement, it was possible to determine the contribution of radioactivity from the radon daughters RaB plus RaC (half-lives 26.8 min and 19.7 min, respectively), the thoron daughters ThB plus ThC (10.6 hr and 60.5 min, respectively), and the gross long-lived β -emitting radioisotopes (primarily fission products with an infinite effective half-life). Corrections for air-flow rate, filter efficiency, and counter efficiency and geometry permitted calculation of the actual air concentrations of the radon, ThB, and gross fission products. Weekly summaries of results were received by teletype; the actual daily data sheets were subsequently examined in detail after their return, following the reopening of the station to routine traffic.

After receipt in Washington, the air-filter samples were assembled by months, ignited to an ash at 650°C, and compressed into disks suitable for counting with conventional end-window β counters. The count rate was measured and the gross β activity determined by comparison with a standard composed of a known amount of a RaD-RaE equilibrium mixture (effective β energy 1.17 Mev) contained in a similar quantity of ash.

A number of the ashed samples from the South Pole station were sent to Argonne National Laboratory for gamma spectrometric analysis. On their return to NRL, these and the remaining samples were combined by quarter years and subjected to radiochemical analysis by standardized procedures (17).

NATURAL RADIOACTIVITY

Radon

The measured radon concentrations at Little America V (April 1956 through October 1958) and at the Amundsen-Scott South Pole Station (February 1959 through December 1963) are summarized by months in Table 1. The overall monthly averages are shown graphically for the two sites in Fig. 1. There is definite evidence for a maximum in the radon concentration at Little America during the antarctic summer; there is a barely perceptible maximum during the same period at the South Pole site.

These radon concentrations are compared in Table 2 with those observed elsewhere over extended periods of measurement through use of identical equipment and techniques. The results, moreover, are in good agreement with similar measurements made by different techniques at other sites in Antarctica (7,10,13-15). Low radon values are to be expected for an area of the world which has a minimum of exposed, radon-emitting land surface and which is far removed in space and time from such sources.

The seasonal variation in radon concentration is attributable to a seasonal difference in the mixing rate or path between air masses in Antarctica and those in temperate latitudes where sources of radon exist. At some sites, locally exposed land surfaces may contribute to the radon concentration during the summer months (13). Such seasonal variations have been observed at most of the other sites for which long-term measurements have been reported (18).

Thoron

Thoron (Rn^{220}) is a short-lived (54 sec half-life) noble gas that diffuses from the soil into the atmosphere in the same manner as radon (Rn^{222}), but in smaller quantities due to its short lifetime. Though it rapidly disappears through decay and never establishes secular equilibrium with its descendants, its longest-lived descendant, ThB (10.6 hr half-life), can serve as a useful tracer for short-term atmospheric motions. In Antarctica, however, due to its distance from sources of thoron (or ThB), no significant amounts of ThB were detected. The air concentrations of the longest-lived radionuclide representative of this natural radioactive series were consistently less than 10^{-20} Ci/cc (<0.01 pCi/m³) except at McMurdo Station, where some land surface is exposed (13,14). Such low ThB levels are to be expected, since a hundred-fold decrease in concentration would occur in less than three days from radioactive decay alone; transit of air masses from major sources of thoron would require a much greater period.

On the few occasions when measurable thoron daughter activity has been found, it could be attributed to extraneous sources—as for example, when sampling was conducted indoors during equipment checks (1,7).

Table 1
Radon Concentrations in the Air in Antarctica

Month	Little America V				Amundsen-Scott South Pole Station					
	1956	1957	1958	Average	1959	1960	1961	1962	1963	Average
January		3.3 (29)	4.3 (31)	3.8 (60)	-	0.82 (28)	0.17 (28)	0.42 (23)	-	0.47 (79)
February		1.79 (18)	3.7 (28)	3.0 (46)	1.05 (9)	0.67 (26)	0.48 (26)	0.51 (27)	0.63 (10)	0.61 (98)
March		3.0 (17)	6.2 (31)	5.1 (48)	0.18 (28)	0.77 (26)	0.45 (31)	0.33 (30)	0.24 (25)	0.39 (140)
April	1.30 (22)	0.54 (15)	1.53 (30)	1.23 (67)	0.33 (28)	0.38 (28)	0.73 (29)	0.48 (25)	0.25 (29)	0.43 (139)
May	1.63 (25)	1.84 (30)	3.1 (31)	2.23 (86)	0.26 (7)	0.42 (30)	0.42 (30)	0.37 (30)	0.18 (29)	0.34 (126)
June	1.21 (27)	1.49 (27)	2.8 (30)	1.87 (84)	0.34 (12)	0.36 (28)	0.51 (30)	0.34 (30)	0.32 (30)	0.38 (130)
July	3.7 (21)	0.88 (31)	2.4 (24)	2.14 (76)	0.44 (25)	0.41 (28)	0.49 (31)	0.28 (30)	0.16 (28)	0.36 (142)
August	1.75 (27)	1.5 (3)	2.1 (31)	1.92 (61)	0.60 (30)	0.24 (27)	0.55 (28)	0.25 (30)	0.24 (29)	0.38 (144)
September	2.2 (10)	- (1)	1.64 (28)	2.12 (32)	0.33 (17)	0.40 (29)	0.51 (30)	0.28 (30)	0.26 (27)	0.36 (133)
October	2.6 (8)	1.93 (17)	2.3 (26)	2.22 (51)	0.41 (5)	0.34 (30)	0.58 (29)	0.33 (29)	0.18 (28)	0.36 (121)
November	1.30 (14)	0.84 (23)	-	1.01 (37)	- (0)	0.36 (29)	0.44 (29)	0.29 (11)	0.46 (28)	0.40 (97)
December	2.7 (25)	1.71 (20)	-	2.26 (45)	0.99 (25)	0.31 (24)	0.30 (29)	-	0.34 (19)	0.49 (97)
Weighted Averages	Daily 2.37 (693) Monthly 2.41 (12)				Daily 0.41 (1446) Monthly 0.41 (12)					

NOTE: Radon concentration is given in pCi/m³ of air (ambient); the number of measurements is indicated in parentheses. Dashes indicate that no data are available.

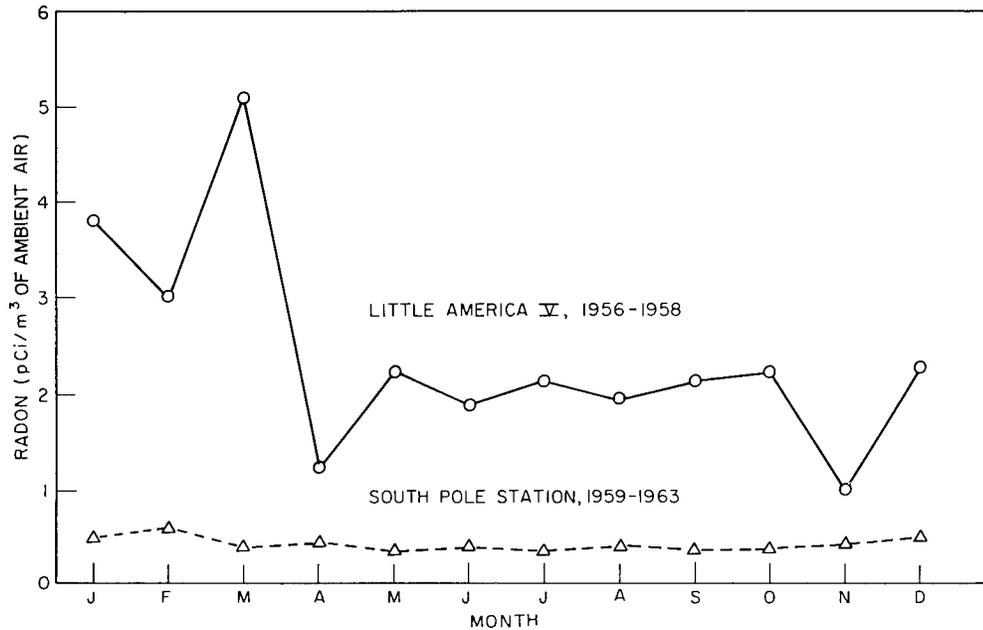


Fig. 1 - Atmospheric radon concentrations in Antarctica

Table 2
Comparison of the Observed Natural Radioactivity Concentrations in the Air in Antarctica
with Long-Term Measurements at Other Geographical Locations

Site	Location		Period of Observation	Radioactivity Concentration (pCi/m ³)		References
	Lat.	Long.		Radon	Thorium B	
Alaska						
Wales	65°37'N	168°03'W	1953-59	20	0.16	5
Kodiak	57°45'N	152°29'W	1950-60	9.9	0.04	5
U.S.A.						
Washington, D.C.	38°49'N	77°01'W	1950-61	122	1.34	6
Japan						
Yokosuka	35°20'N	139°35'E	1954-58	56	0.48	4
Peru						
Lima (Ancon)	11°47'S	77°09'W	1959-65	41	1.43	1*
Bolivia						
Chacaltaya†	17°10'S	68°15'W	1958-63	40	0.50	1*
Brazil						
Rio de Janeiro	23°00'S	43°25'W	1958-64	54	2.7	1*
Antarctica						
Terre Adelie	65°30'S	144°E	1960	0.8	-	10
Base Roi Baudouin	70°26'S	24°19'E	1958	<1.0	<0.05	7,8
McMurdo Station	77°51'S	168°E	1961-63	4.4	0.10	13,14
Little America V	78°10'S	162°13'W	1956-58	2.4	<0.01	1
New Byrd Station†	80°01'S	119°31'W	1962	0.2	<0.01	13,15
South Pole†	90°00'S		1959-63	0.41	<0.01	1*

NOTE: The dash indicates that no data were reported.

*Data more recent than has been previously reported are included.

†Elevations: Chacaltaya 5220 meters, New Byrd Station 1500 meters, South Pole 2800 meters.

Lead-210

Lead-210 (RaD) is a long-lived descendant (22 yr) of radon; its concentration in the air is the resultant of its generation through radon decay and its removal by atmospheric scavenging processes (fallout, rain-out, and impingement) and, to a lesser extent, radioactive decay. The lack of radon sources in the antarctic area and the lengthy time required for air to move from continental areas into this region would lead one to expect both low radon concentrations and low RaD concentrations in Antarctica.

Data on the Pb^{210} content of the air at Little America V and the South Pole obtained through radiochemical analyses of composited filter collections is contained in Table 3 and is shown graphically in Fig. 2. Though Pb^{210} , through its daughter RaE (5.0 day half-life; 1.17 Mev β), is a contributor to the gross β activity of the filters, as seen from the data in Table 3, it seldom contributes more than a few percent to the observed long-lived β activity at these antarctic sites. The low concentrations of Pb^{210} found in the ground-level air in Antarctica are in agreement with the observed decreasing concentration of Pb^{210} with increasing latitude along the west coast of South America (19). Any seasonal effects are not readily discernible.

FISSION-PRODUCT RADIOACTIVITY

Gross β Activity

On the basis of the small contribution of Pb^{210} relative to the total fission-product β activity, the on-site measurement of the long-lived β component in the air-filter collections can be considered as representative of the fission-product concentrations in the air at Little America and the South Pole. This information is given in Table 4 and is shown graphically in Fig. 3; also shown in Fig. 3 are measurements made at other sites in Antarctica by other organizations (9,11,13,14). Very pronounced seasonal variations were observed each year at the various sites, with maxima in the southern hemisphere summer. The maxima observed in the early months of 1960, 1961, and 1962 cannot be related to direct tropospheric contamination by nuclear devices and, hence, must be attributed to a seasonal variation in the rate of downward mixing from a stratospheric source. It is of interest that the seasonal dependence of gross fission-product concentrations in the air at ground level in Antarctica is much more pronounced than at most of the other southern hemisphere sites (20).

It is unfortunate that during two periods of especial interest (Nov. 3, 1958 to Feb. 17, 1959 and Nov. 12, 1962 to Feb. 17, 1963) the NRL equipment was in the process of being relocated and was not in operation. Both of these inoperative periods occurred, apparently, at a time when the highest fission-product levels were being encountered in Antarctica, namely, during the season of maximum stratospheric deposition following testing of high-yield nuclear weapons near the Equator. However, information available from McMurdo Station (14) and Base Roi Baudouin (9) bridges these gaps and documents the higher radioactivity levels encountered during these periods.

There is a slight indication that tropospheric contamination from U.S. Operation Dominic (Apr. 25 to Nov. 4, 1962) held near Christmas Island penetrated into several areas of Antarctica in June 1962 and again, on a larger scale, in the months of September, October, and November. The highest recorded activity was in February 1963 and must have been the result of the seasonal downward mixing of stratospheric debris from the Dominic test series. The close correspondence of the rates of decrease of long-lived β activity at the South Pole and McMurdo Stations (Fig. 3) during the period February through June 1963 also suggests a common stratospheric source for this radioactivity. There has been no indication of any radioactivity release from the nuclear power plant in operation at McMurdo Station.

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Table 3
Radiochemical Analyses of Air Filter Samples from Antarctica

Station	Date of Collection	Days Sampled	Volume* (m ³)	Radioactivity (pCi/1000 m ³)†						Activity Ratios				
				Gross β ‡	Ce ¹⁴⁴	Pm ¹⁴⁷	Sr ⁹⁰	Cs ¹³⁷	Pb ²¹⁰	Ce ¹⁴⁴ / Sr ⁹⁰	Pm ¹⁴⁷ / Sr ⁹⁰	Cs ¹³⁷ / Sr ⁹⁰	Sr ⁹⁰ / Gross β	Pb ²¹⁰ / Gross β
Little America V	1956													
	Apr-June	85	95,600	13.1	-	4.50	1.26	2.12	0.40	-	3.6	1.68	0.096	0.031
	July-Sept	81	90,700	16.3	-	3.56	1.11	1.55	0.54	-	3.2	1.40	0.068	0.033
	Oct-Dec	90	96,900	32.6	-	2.60	0.99	2.13	0.83	-	2.6	2.15	0.030	0.025
	1957													
	Jan-Feb	57	60,200	22.1	-	3.10	1.16	1.17	0.29	-	2.7	1.01	0.052	0.013
	Mar-June	101	106,000	14.0	-	2.70	1.30	1.88	0.21	-	2.1	1.45	0.093	0.015
	July	35	37,700	9.9	-	1.97	1.08	1.37	0.24	-	1.8	1.27	0.109	0.024
	Oct-Nov	47	49,600	21.1	-	1.67	0.63	1.55	0.21	-	2.7	2.46	0.030	0.010
	1958‡													
	Jan-Mar	90	89,000	25.2										
	Apr-June	91	112,000	11.7										
	July-Sept	83	98,500	12.8										
	Oct	26	30,400	19.8										
	Amundsen-Scott South Pole	1959												
Feb-Mar		38	46,100	82	22.5	8.01	2.94	3.30	0.47	7.7	2.7	1.12	0.036	0.006
Apr-June		52	62,800	47	13.0	4.68	1.75	2.19	0.46	7.4	2.7	1.25	0.037	0.010
July-Sept		73	87,500	21	4.91	2.63	1.11	1.40	0.38	4.4	2.4	1.26	0.053	0.018
Oct-Dec		35	41,500	32	4.95	3.22	1.29	0.90	0.64	3.8	2.5	0.70	0.040	0.020
1960														
Jan-Mar		91	109,200	21	5.81	3.06	1.40	1.40	0.60	4.2	2.2	1.00	0.067	0.029
Apr-June		89	104,500	10.4	2.84	1.73	0.81	0.93	0.35	3.5	2.1	1.15	0.078	0.034
July-Sept		92	110,300	8.6	2.25	1.51	0.77	0.80	0.52	2.9	2.0	1.04	0.090	0.060
Oct-Dec		86	101,000	14.9	6.89	1.96	1.28	1.12	0.23	5.4	1.5	0.88	0.086	0.015
1961														
Jan-Mar		86	98,700	24	7.34	4.73	2.27	2.00	0.46	3.2	2.1	0.88	0.095	0.019
Apr-June		90	105,000	12.7	3.20	3.06	1.50	1.91	0.44	2.1	2.0	1.27	0.118	0.035
July-Sept		90	105,000	8.9	2.13	1.49	1.11	1.76	0.41	1.9	1.3	1.59	0.125	0.046
Oct-Dec		90	107,000	11.9	2.25	1.95	1.34	1.75	0.40	1.7	1.5	1.31	0.113	0.034
1962														
Jan-Mar		80	94,000	16.8	3.69	3.75	2.27	2.36	0.22	1.6	1.7	1.04	0.135	0.013
Apr-June		85	101,000	16.0	2.33	2.58	1.69	1.62	0.15	1.4	1.5	0.96	0.106	0.009
July-Sept	87	102,000	22	3.50	1.71	0.97	0.88	0.12	3.6	1.9	0.91	0.044	0.005	
Oct-Nov	38	49,900	35	6.03	1.95	1.09	1.18	0.27	5.5	1.8	1.08	0.031	0.008	
1963														
Feb-Mar	37	42,100	88	30.3	8.69	3.65	3.98	0.28	8.3	2.4	1.09	0.041	0.003	
Apr-June	85	97,500	50	18.2	5.67	2.04	2.04	0.18	8.9	2.8	1.00	0.041	0.004	
July-Sept	82	94,400	29	10.6	4.01	1.51	1.67	0.14	7.0	2.7	1.11	0.052	0.005	
Oct-Dec	76	87,400	27	8.73	3.15	1.56	0.86	0.14	5.6	2.0	0.55	0.058	0.005	

* All volumes are given in standard cubic meters of air.

† Radioactivity has been corrected for decay to the midpoint of the collection period.

‡ Total long-lived β activity was determined by on-site measurement.

§ Little America operations were terminated Nov. 3, 1958; samples for this year were lost in transit from Antarctica (data were obtained from weekly dispatches).

NOTE: Dashes indicate that radioactivity was too low for accurate measurement at time of analysis.

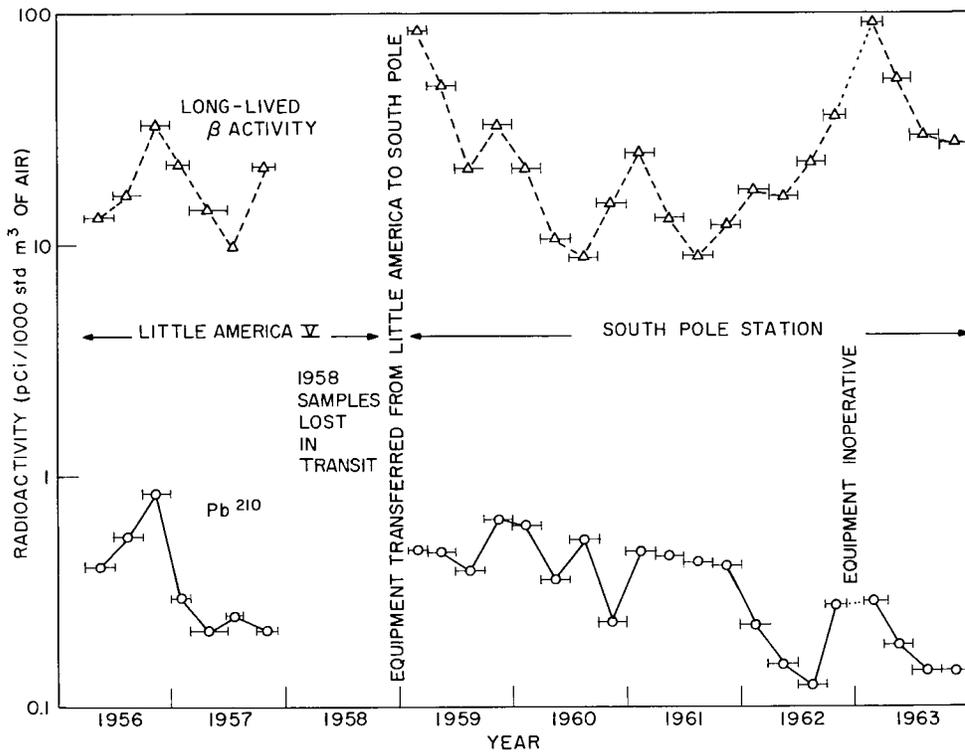


Fig. 2 - Quarterly averages of the Pb^{210} and gross β activity in the ground-level air in Antarctica

γ -Spectrometric Analysis of South Pole Samples

Prior to dissolution of the South Pole air-filter samples for radiochemical analysis, they were submitted to Dr. Philip F. Gustafson, Division of Biological and Medical Research, Argonne National Laboratory, for evaluation by γ -spectrometric techniques developed there in connection with environmental radioactivity studies (21). The monthly filter ash samples, prepared as described previously, were counted at NRL for gross β activity using RaD + E activity as a standard immediately before shipment to Argonne.

The results of the γ -spectrometric analysis* for Cs^{137} , and in some cases for Ce^{144} , Ru^{106} , Sb^{125} , and Mn^{54} are listed in Table 5 together with the collection data and the results of the gross β measurements made at NRL. Both the Cs^{137} measurements and the gross β measurements are in general agreement with the on-site fission-product measurements shown in Fig. 3. The lower gross β activity in these later measurements is due in large part to radioactive decay. The low concentrations of γ -emitting radionuclides during 1960 and 1961 made the process of spectrum analysis extremely difficult because of the large statistical variations in measured counting rates. However, the overall agreement between the γ -spectrometric and radiochemical techniques is remarkably good.

The calculated monthly Cs^{137} air concentrations at the South Pole site have been plotted in Fig. 4 as a function of time for the period January 1960 through October 1963. Also shown

* P.F. Gustafson, ANL, personal communications, 1963-1965.

Table 4
Fission Product β Activity in the Air in Antarctica

Month	Little America V			Amundsen-Scott South Pole Station				
	1956	1957	1958	1959	1960	1961	1962	1963
January		0.025 (29)	0.034 (31)	-	0.018 (28)	0.024 (28)	0.016 (23)	-
February		0.024 (18)	0.026 (28)	0.064 (9)	0.023 (26)	0.022 (26)	0.017 (27)	0.079 (10)
March		0.022 (17)	0.024 (31)	0.073 (28)	0.013 (26)	0.016 (31)	0.011 (30)	0.075 (25)
April	0.021 (22)	0.020 (15)	0.022 (30)	0.052 (28)	0.014 (28)	0.009 (29)	0.011 (25)	0.052 (29)
May	0.015 (25)	0.014 (30)	0.011 (31)	0.028 (7)	0.008 (30)	0.013 (30)	0.013 (30)	0.050 (29)
June	0.009 (27)	0.011 (27)	0.006 (30)	0.023 (12)	0.005 (28)	0.011 (30)	0.017 (30)	0.027 (30)
July	0.015 (21)	0.011 (31)	0.012 (24)	0.014 (25)	0.006 (28)	0.008 (31)	0.014 (30)	0.026 (28)
August	0.020 (27)	- (3)	0.011 (31)	0.022 (30)	0.007 (27)	0.008 (28)	0.008 (30)	0.026 (29)
September	0.020 (10)	- (1)	0.020 (28)	0.017 (17)	0.009 (29)	0.007 (30)	0.035 (30)	0.024 (27)
October	0.032 (8)	0.016 (17)	0.022 (26)	0.020 (5)	0.008 (30)	0.006 (29)	0.029 (29)	0.024 (28)
November	0.045 (14)	0.029 (23)	-	-	0.013 (29)	0.012 (29)	0.034 (11)	0.020 (28)
December	0.032 (25)	0.027 (20)	-	0.030 (25)	0.019 (24)	0.013 (29)	-	0.026 (19)

NOTE: Radioactivity is given in pCi/m³ of air (ambient); the number of measurements is indicated in parentheses. Dashes indicate that no data are available.

are the quarterly Cs¹³⁷ averages for the period February 1959 through December 1963 obtained by radiochemical analysis at NRL. The seasonal increase in stratospheric deposition is very apparent, with pronounced maxima in the antarctic summer. This is definite evidence that the southern hemisphere does undergo seasonal variations in stratospheric-tropospheric interchange, such as are observed in the northern hemisphere. Radioactivity levels at the South Pole substantially increased in September 1962 following resumption of nuclear testing by the United States in the Christmas Island area in late April 1962. At this same time a marked increase in the Ce¹⁴⁴/Cs¹³⁷ activity ratio occurred, confirming the influx of fresher nuclear debris into the antarctic area.

Radiochemical Analysis of Air Filter Samples

The radiochemical results contained in Table 3 document the quarterly changes taking place in the concentrations of some long-lived radioisotopes in the ground-level air at the

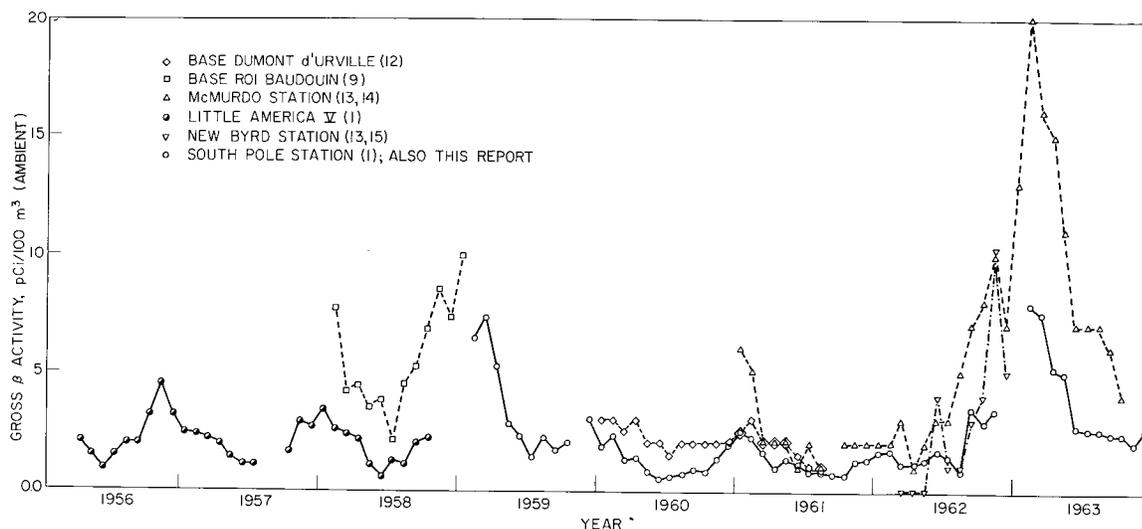


Fig. 3 - Concentrations of long-lived β activity in the ground-level air in Antarctica, 1956-1963

Little America V and South Pole sites in Antarctica. Due to transportation difficulties the Little America samples for 1958 were not received; otherwise, fairly complete coverage of radioactivity in the antarctic area for the eight-year period from 1956 through 1963 has been obtained. Analysis of the Little America samples was accomplished some six to eight years after collection, as a result of which the Ce^{144} results were of no significance due to the extent of radioactivity decay. Other analyses were affected to some degree by the low concentrations of radioactivity in Antarctica, but radioactive decay was not of primary importance; in all cases decay corrections were made to the time of sample collection.

The measured concentrations of Ce^{144} , Pm^{147} , Sr^{90} , and Cs^{137} at the Little America V and the South Pole sites for the periods 1956 through 1957 and 1959 through 1963, respectively, are shown graphically in Fig. 5. The most striking characteristic of these data is the well-defined summer maximum in the fission-product radioactivity that occurs here. While the seasonal effects are not as great as have been observed at most of the northern hemisphere sites, they are more readily recognizable than at sites along the west coast of South America (20). Part of the explanation for this may be the absence of any interaction with debris from the northern hemisphere troposphere which may penetrate to lower latitudes in the southern hemisphere and effectively mask the intrahemispheric seasonal changes.

The comparison in Fig. 6 of Sr^{90} air concentrations at the South Pole with those occurring at Punta Arenas, Chile (20,22) clearly shows the stronger seasonal effect at the South Pole and also indicates the higher fission-product levels occurring at this site. It is, therefore, not possible for the seasonal variations noted at the South Pole to have been caused solely by seasonal changes in the influx of surface air masses from lower latitudes. The actual air concentrations at the South Pole are comparable to those observed at Puerto Montt, Chile (41°27'S). The lower activity at Punta Arenas (53°08'S) thus resembles the northern-hemisphere minimum frequently observed at Moosonee, Canada (51°16'N) (20,22). This similarity suggests the operation of similar meteorological processes at this latitude in both hemispheres which could cause lower concentrations of stratospheric debris to be observed in these areas; it might be expected that such a zone would also serve as a partial barrier to transport of tropospheric debris from the mid-latitudes to the polar regions of both hemispheres, as has been observed.

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Table 5
Summary of Data on South Pole Samples Sent to Argonne National Laboratory
for γ -Spectrometric Analysis

Collection Period	Number of Days Sampled	Total Ambient Air Flow (m ³)	Gross β Activity*		γ -Activity† (pCi/1000 m ³ ambient)					
			dis/min	pCi/1000 m ³	Cs ¹³⁷	Ce ¹⁴⁴	Ru ¹⁰⁶	Sb ¹²⁵	Mn ⁵⁴	
1960										
Jan	28	38400	814	9.5	0.70	13.3	6.1			
Feb	26	36200	946	11.7	1.65	37.0	7.2			
Mar	26	36400	594	7.3	1.08	22.9	3.9			
Apr	28	39400	674	7.7	1.04	15.7	3.1			
May	30	41600	397	4.3	0.46	10.3	1.6			
June	28	36000	155	1.9	0.29	5.5	0.4			
July	28	38800	346	4.0	0.49	7.0	1.9			
Aug	27	37600	423	5.1	0.68	4.7	1.4			
Sept	29	40200	531	5.9	0.77	6.7	2.2			
Oct	31	41400	617	6.7	1.01	3.4	1.9			
Nov	29	40000	444	5.0	1.54					
Dec	27	35600	541	6.8	1.05					
1961										
Jan	28	36850	1003	12.2	2.70					
Feb	27	35860	830	10.4	1.54					
Mar	31	41480	804	8.7	1.50					
Apr	30	40320	542	6.0	1.32					
May	30	41010	646	7.1	1.51					
June	30	40710	708	7.8	0.92					
July	31	42380	509	5.4	0.63					
Aug	29	39590	451	5.1	0.41					
Sept	29.5	39650	620	7.0	0.94					
Oct	31	42500	642	6.8	2.25					
Nov	30	41310	664	7.2	1.42					
Dec	29	39530	830	9.4	1.70					
1962										
Jan	24	32520	849	11.7	1.87					
Feb	28	37800	824	9.8	2.90	3.53	3.65	2.05		
Mar	28	38400	652	7.7	2.45	2.79	2.98	1.39		
Apr	27	36800	492	6.0	1.70	1.77	3.99	1.09		
May	29	40100	589	6.6	1.82	2.09	2.78	1.89		
June	29	39760	563	6.4	1.55	2.56	3.20	1.52		
July	29	39410	340	3.9	1.11	1.14	2.34	0.65		
Aug	29	38920	237	2.7	0.61	0.55	0.94	0.67		
Sept	29	40100	749	8.4	1.57	4.08	2.82	0.80		
Oct	28	38610	629	7.3	1.00	3.18	1.82	1.02		
Nov	10	13800	308	10.0	1.46	5.60	2.63	0.64	0.45	
Dec†	0									
1963										
Jan‡	0									
Feb	12	15960	1443	40.7	3.67	26.4	8.73	2.32	2.46	
Mar	25	33250	2797	37.8	3.97	27.2	5.28	2.27	1.66	
Apr	28	37240	2317	28.0	2.53	22.5	3.74	1.73	1.96	
May	28	37240	2577	31.1	3.14	20.8	3.39	1.41	1.00	
June	29	38570	1420	16.6	1.69	9.38	3.47	0.75	0.70	
July	28	37240	1589	19.2	1.59	10.8	2.82	0.96	0.88	
Aug	28	37240	1546	18.7	1.81	10.4	2.54	0.80	0.75	
Sept	26	34580	1471	19.1	1.66	9.48	3.04	1.06	0.63	
Oct	23	30590	1434	21.1	1.60	8.33	3.61	1.38	0.89	
Nov										
Dec‡										

* Samples counted at NRL prior to sending to ANL, not corrected for decay; Jan.-Oct. 1960, counted Oct. 1961; Nov. 1960-Jan. 1962, counted July 1962; Feb.-Oct. 1962, counted Nov. 1963; Nov. 1962-Oct. 1963, counted Jan. 1964.

† γ -activity corrected for decay to midpoint of sampling period.

‡ Equipment inoperative Nov. 12, 1962 to Feb. 17, 1963.

§ Samples not received in time to send to ANL.

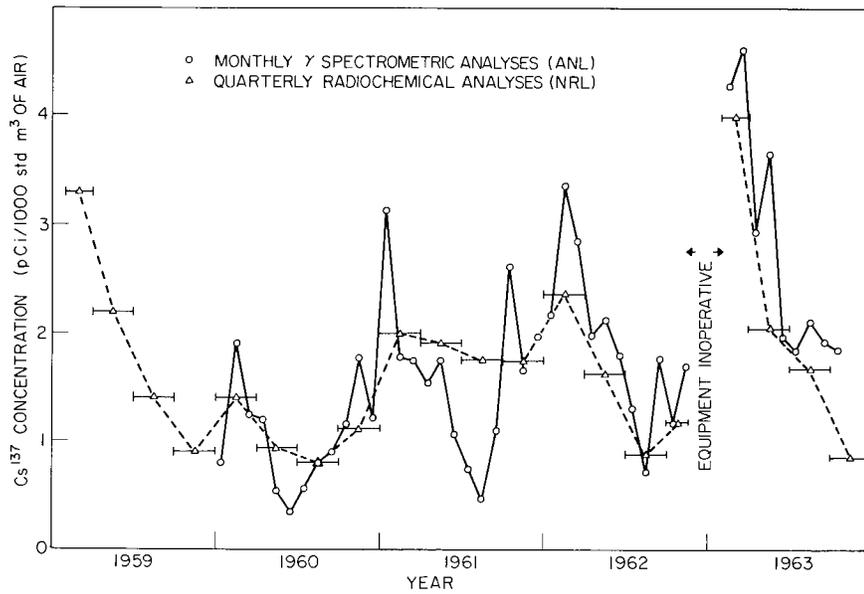


Fig. 4 - Cs¹³⁷ in air-filter samples from the Amundsen-Scott South Pole station

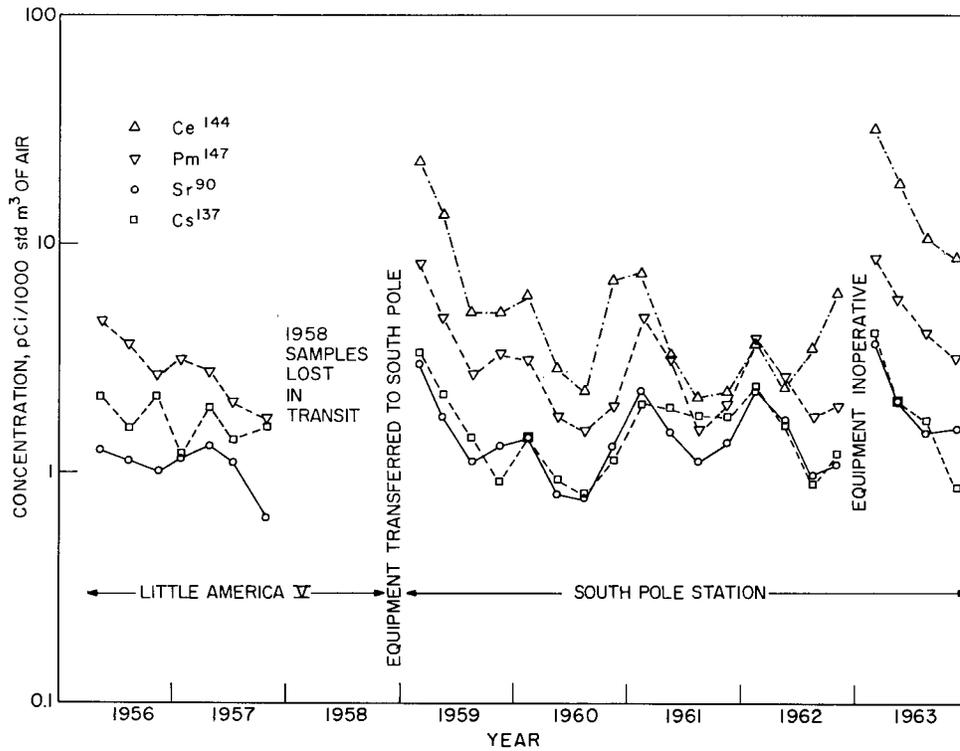


Fig. 5 - Concentrations of some long-lived airborne fission products at Little America V (1956-1957) and Amundsen-Scott South Pole station (1959-1963)

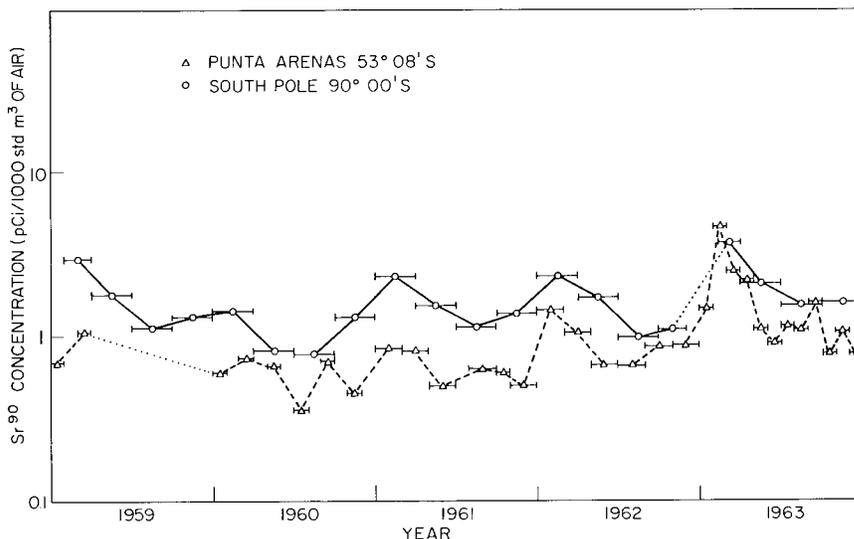


Fig. 6 - Comparison of Sr^{90} concentrations in the air at Punta Arenas, Chile and the South Pole, 1959-1963

The $\text{Ce}^{144}/\text{Sr}^{90}$ activity ratios obtained from atmospheric samples collected at the South Pole site during the period February 1959 through December 1963 are compared in Fig. 7 with similar data for Punta Arenas (20,22). Prior to the resumption of nuclear testing in the Christmas Island area this ratio was approximately the same at the two sites, indicating a common source for the radioactivity. A slow, continuous influx of fresher debris was observed at Punta Arenas beginning in early 1960, as evidenced by a slower rate of decrease in the $\text{Ce}^{144}/\text{Sr}^{90}$ ratio than that expected for debris from a single injection. A much larger contribution of this fresher material was evident at the South Pole during the 1960-61 summer season. As discussed elsewhere (23), these effects may be due to the appearance at ground level of debris injected at high altitudes over Johnston Island in the summer of 1958 by the Teak and Orange shots of the U.S. Hardtack series.

The $\text{Ce}^{144}/\text{Sr}^{90}$ activity ratio increased significantly in 1962 first at Punta Arenas (May-June) and later at the South Pole (July-September collections) as the result of the direct introduction into the troposphere of fresh radioactive debris from the U.S. Dominic tests held near Christmas Island (Apr. 25-Nov. 4). Similar but smaller changes in the $\text{Pm}^{147}/\text{Sr}^{90}$ activity were also observed at these times. A tropospheric path is indicated, since the fresh radioactivity appeared first and in larger quantity at Punta Arenas at a time when stratospheric deposition should have been near its minimum. A stratospheric path is indicated by early 1963, since tropospheric debris should have been rather well washed out of the atmosphere by this time and, especially, since the activity levels at the South Pole again exceeded those at Punta Arenas.

The sensitivity of the activity ratio to a young fission-product conglomerate is seen in a comparison of Figs. 6 and 7. The concentration of the long-lived Sr^{90} was scarcely affected by the influx of fresh debris into the Punta Arenas or South Pole areas at the time drastic changes were occurring in the $\text{Ce}^{144}/\text{Sr}^{90}$ ratios. This sensitivity is due to a $\text{Ce}^{144}/\text{Sr}^{90}$ ratio of about 48 at the time of formation, compared to a ratio of about 1.5 for the radioactivity background then existing in the atmosphere. The observed ten-fold increase in the ratio at Punta Arenas can thus be accounted for by a 20-percent contribution of fresh Sr^{90} to the total; the smaller increase observed in the third quarter of

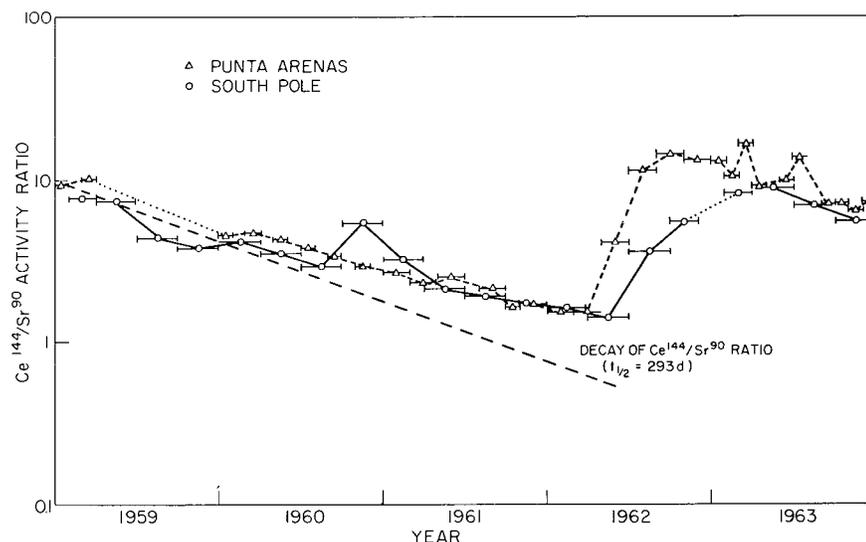


Fig. 7 - Comparison of the observed Ce¹⁴⁴/Sr⁹⁰ activity ratios at Punta Arenas, Chile and the South Pole

1962 at the South Pole can be attributed to the influx of fresh debris representing a 3-percent increase in the Sr⁹⁰ content of the air. Since the measured Sr⁹⁰ concentrations were less than 0.001 pCi/m³ of air, the actual contributions of Sr⁹⁰ from fresh debris were no more than 0.0002 and 0.00003 pCi/m³ at the two sites.

FUTURE TRENDS IN ANTARCTIC RADIOACTIVITY

The planned French series of high-yield nuclear devices should establish a major stratospheric source of radioactivity in the southern hemisphere at more southerly latitudes than previous tests have done. Since the effects of previous test series are wearing off in both hemispheres, this new source should permit an unambiguous determination of the magnitude of the seasonal variation in stratospheric-tropospheric interchange to be made in the southern hemisphere and a definite conclusion reached as to the similarity or lack of similarity of this phase of the meteorology of the two hemispheres. On the basis of observations made in the northern hemisphere, it can be predicted that the forthcoming French nuclear tests to be held near the Society Islands will have little immediate effect on radioactivity levels observed at latitudes more southerly than 50°S.

Though the U.S. Naval Research Laboratory terminated its connection with the 80th meridian air-monitoring program in December 1962 and with South Pole operations in December 1963, both of these operations are being continued by the Health and Safety Laboratory of the U.S. Atomic Energy Commission, the latter with the support of the Polar Operations Branch, U.S. Weather Bureau. Good coverage of radioactivity levels during and after the French test series can thus be expected.

CONCLUSIONS

The atmosphere above the antarctic continent exhibits extremely low concentrations of airborne radioactivity by virtue of its isolation from sources of both natural and man-made radioisotopes. The separation in time and space of air over Antarctica from that

in midlatitudes of the southern hemisphere, where the nearest large sources of radon and thoron (ThB) exist, permits their depletion by natural decay processes during transport into the polar region. The essentially complete ice and snow cover of the entire antarctic continent minimizes the effects of locally occurring sources of natural radioactivity.

This same isolation reduces the influence here of manmade radioactivity introduced into the atmosphere by nuclear tests. Tropospheric debris undergo extensive removal by deposition or "washout" processes before penetrating into this area; indeed, very little transport of material from the subtropical region of the southern hemisphere to as far south as 53° has been observed.

A well-defined seasonal variation in radioactivity from the stratosphere is observed in Antarctica. The appearance of the summer maximum is a little delayed compared to that observed in the higher latitudes of the northern hemisphere, and the amplitude of the variation is somewhat less. The ready identification of the seasonal effect in Antarctica may be due principally to the absence of secondary effects which tend to mask it in the more temperate regions (i.e., transport of debris from the generally larger northern hemisphere source). The actual magnitude of the artificial radioactivity in the antarctic air is considerably less than that in comparable areas of the northern hemisphere; this is primarily due to the smaller introductions of nuclear bomb debris into the stratosphere of the southern hemisphere.

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<p>Continuous measurements of the radioactive aerosol content of the surface air in Antarctica have been made since 1956, first at Little America and later at the Amundsen-Scott South Pole Station. Both the radioactivity due to bomb-produced fission products and to the naturally occurring radionuclides of the radon and thoron series were measured in daily collections; composite samples covering three-month periods were subjected to radiochemical analysis for such long-lived radionuclides as Sr⁹⁰, Cs¹³⁷, Ce¹⁴⁴, Pm¹⁴⁷, and Pb²¹⁰.</p> <p>The observed natural radioactivity was lower in Antarctica than at any other geographical location, as might be expected from the absence of any quantity of exposed land surface in the vicinity. The fission-product concentrations, however, were equal to or greater than those observed in the southernmost parts of South America. Well-defined seasonal variations in airborne radioactivity were noted, with maxima in the summer.</p>		

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