Measurements of the Air Concentration of Gross Fission Product Radioactivity during the IGY July 1957—December 1958

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Abstract

Measurements of the gross fission product radioactivity in the air at 21 sites along the 80th meridian and 4 sites in the North Pacific area are reported for the period July 1957—December 1958. The activity levels at the various sites are related both to the stratospheric deposition of nuclear debris and to the direct introduction of radioactive material into the troposphere upwind of the collecting sites.

Radioactive debris injected into the troposphere at any particular site spreads rather rapidly throughout the same hemisphere but rarely crosses the equator in any quantity. An exception to this occurred during the Hardtack series in the Pacific when massive quantities of activity were transported to the Southern Hemisphere by winds in the upper troposphere.

It is again shown that periods of heavy rainfall, such as occur during the rainy season in Panama, cause a general decrease in the concentration of fission products in the air.

1. Introduction

In 1956 the U.S. Naval Research Laboratory, with the assistance of the U.S. Atomic Energy Commission, the U.S. Weather Bureau, and interested groups in Canada and South America, initiated a program of measurement of the fission product radioactivity in the air at a carefully selected group of sites along the 80th meridian. During 1957 this program was expanded to include collections at several other locations which were of interest to the U.S. Air Force Cambridge Research Center. This work has been carried out as part of the International Geophysical Year Program on Atmospheric Nuclear Radiation and was financed, in part, by the Division of Biology and Medicine, U.S. Atomic Energy Commission.

As the result of a study of several collecting devices (LOCKHART, JR., BAUS and BLIFFORD, JR., 1959), air filtration was found to be the method which gave the most readily interpretable information and which, in addition, furnished samples suitable for radiochemical analysis. It was further decided that data on the air concentration of fission products would be required ultimately for any understanding of the information obtained from methods which measure deposited radioactivity. The entire effort was therefore directed toward obtaining reliable measurements of the concentration of fission products in the ground-level air at the 25 collecting sites associated with this program (Table 1).

2. Experimental procedure

Each collecting station employed an identical positive-displacement blower having a free-air capacity of about 40 cubic feet per minute. The stations making daily air-filter

Table 1. Collecting Sites Associated with the NRL/IGY Program of Atmospheric Nuclear Radiation

Station	Latitude	Longitude	Elevation (m)	Operator
Daily Filter Collections				
Thule, Greenland	76° 35′ N	68° 35′ W	259	IGY Thule Coordinator, U.S. Air Force
Coral Harbour, N.W.T., Canada	64° 12′ N	83° 22′ W	59	Meteorological Branch, Department of Transport (Canada)
Moosonee, Ontario, Canada	51° 16′ N	80° 39′ W	10	Meteorological Branch, Department of Transport (Canada)
Bedford, Mass., USA	42° 27′ N	71° 22′ W	80	USAF Cambridge Research Center
Silver Hill, Maryland, USA (Washington, D.C.)	38° 50′ N	76° 57′ W	88	U.S. Weather Bureau
Columbia, S.C., USA	33° 57′ N	81° 07′ W	69	U.S. Weather Bureau
Miami, Florida	25° 49′ N	80° 17′ W	4	U.S. Weather Bureau
San Juan, Puerto Rico	18° 26′ N	66° 00′ W	10	U.S. Weather Bureau
Miraflores, Panama Canal Zone	9° 00′ N	79° 35′ W	10	Canal Zone Corrosion Laboratory U.S. Naval Research Laboratory
Bogotá, Colombia	4° 37′ N	74° 04′ W	2640	Instituto Geofisico de los Andes Colombianos
Quito, Ecuador	0° 08′ S	78° 26′ W	2818	Astronomic Observatory
Guayaquil, Ecuador	2° 10′ S	79° 52′ W	7	Meteorological Office
Iquitos, Peru	3° 45′ S	73° 11′ W	117	Corporación Peruana de Aeropuertos y Aviación Comercial (CORPAC)
Lima, Peru	12° 06′ S	77° 01′ W	134	Corporación Peruana de Aeropuertos y Aviación Comercial (CORPAC)
Huancayo, Peru	12° 07′ S	75° 20′ W	3353	Instituto Geofisico de Huancayo
Chacaltaya, Bolivia	17° 10′ S	68° 15′ W	5220	Universidad Mayor de San Andres, Laboratorio de Fisica Cosmica de Chacaltaya
Antofagasta, Chile	23° 37′ S	70° 16′ W	519	NASA Satellite Tracking Station
Porto Alegre, Brazil	30° 02′ S	51° 13′ W	24	Servico de Meteorologia
Santiago, Chile	33° 27′ S	70° 42′ W	520	Oficina Meteorologica de Chile
Puerto Montt, Chile	41° 27′ S	72° 57′ W	5	U.S. Weather Bureau
Punta Arenas, Chile	53° 08′ S	70° 53′ W	3	Oficina Meteorologica de Chile
Weekly Filter Collections				
Drifting Station Alpha*	83°-86° N	110°-180° W	3	U.S. Weather Bureau/IGY
Mauna Loa, Hawaii, T.H.	19° 28′ N	155° 36′ W	3394	U.S. Weather Bureau/IGY
Pearl Harbor, Oahu, T.H.	21° 22′ N	157° 58′ W	5	U.S. Naval Air Station, Ford Island
Subic Bay, Philippines	14° 49′ N	120° 17′ E	18	U.S. Naval Station, Subic Bay

*Station evacuated November 1, 1958.

collections used a circular piece of filter paper 8 inches in diameter which decreased the flow rate to about 30 cfm. Those stations making week-long collections employed a larger filter (17 × 13 inches) with a somewhat higher flow rate. The filter was an asbestos-based paper (U.S. Army Chemical Corps type 6) having essentially 100 % retention for particles as small as 0.3μ at the flow rate employed. The pumps were intercalibrated under standard conditions before being sent into the field and adjustments were made to take into account the effect of local conditions at each site on the flow rate. The equipment was housed in a louvered shelter to protect it from rain.

The exposed samples were returned to Washington, D.C., via air where they were ashed at 650° C and compressed to thin disks about 3 cm in diameter by an hydraulic press. Two weeks after collection, these were counted in an automatic sample changer which held each sample in turn under a shielded, end-window GM tube and recorded the time required to obtain a preset total of 2,000 counts.

Each day the count of a standard sample and the background were measured. The counter was calibrated against standards of filter paper ash of the same size and shape and containing known amounts of RaD (RaE) activity. The radioactivity has been reported in disintegrations per minute per cubic meter of air under the pressure existing at the collecting site.

3. Radioactivity profiles along the 80th Meridian

Profiles of the gross fission product concentration in the ground-level air along the 80th

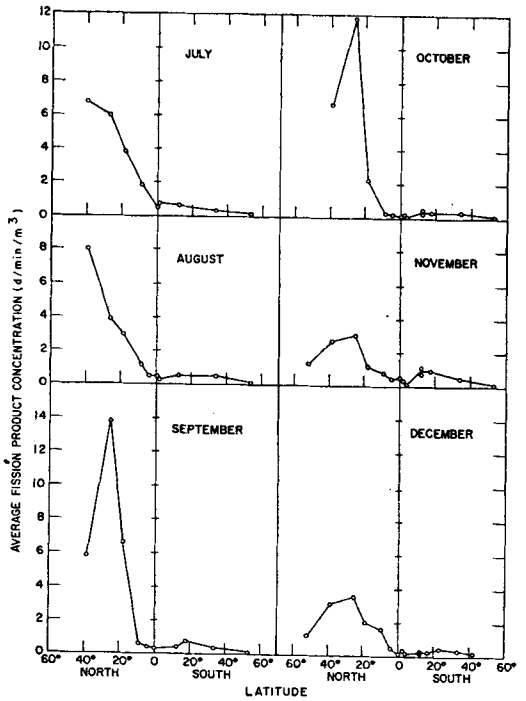

Fig. 1. Radioactivity Profiles, July—December 1957.

Meridian are shown in Figs. 1—3. The effect of nuclear tests can be readily noted by the increases in radioactivity of the air in the Northern Hemisphere during the Plumbbob tests in Nevada (May—October 1957), the Soviet tests of February and March 1958, when the effect lasted well into June, and the Soviet tests of 30 September—3 November 1958, when the effect was strong throughout the remainder of 1958 (and well into 1959). Neither of the U.S. test series of 1958 had any great effect in this hemisphere, though

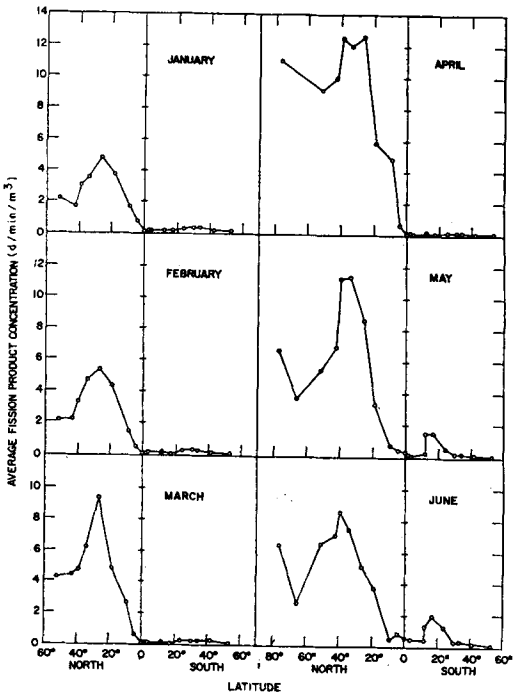

Fig. 2. Radioactivity Profiles, January—June 1958.

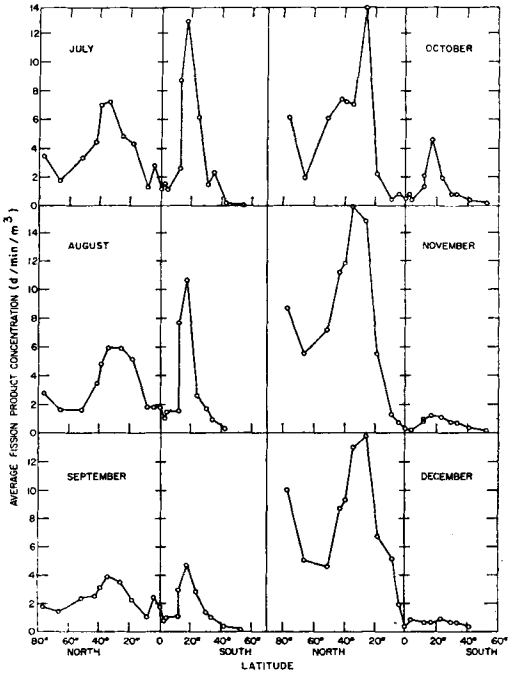

Fig. 3. Radioactivity Profiles, July—December 1958.

the presence of the debris from the Pacific tests of April—July was detected through the W^{185} isotope produced in this series of tests as a tracer (LOCKHART, JR., BAUS, PATTERSON, JR. and SAUNDERS, JR., 1959). The Nevada tests of September and October 1958 were generally of small yield or were carried out underground.

In the Southern Hemisphere, where the background of radioactive debris was considerably lower, fresh injections of fission products were more readily noted. This is reminiscent of the conditions in the Northern Hemisphere some five years earlier. The residual activity present in South America during July and August 1957 was due principally to the British tests held at Christmas Island in June. A small effect may be noted during September from a test held at the Maralinga Proving Ground in South Australia, and a stronger but short-lived effect from the Christmas Island test of November 8, 1957. During January—April 1958, a period when no testing occurred south of the Equator, very low activities were encountered there in spite of the high activities prevalent in the Northern Hemisphere. The sharp gradient occurring near the Equator during April and again during December 1958 (and several times in early 1959) indicated that, in general, little transfer of particulate matter in the tropospheric air took place across this "barrier".

That sometimes the equatorial barrier breaks down became evident during the U.S. Hardtack tests in the Eniwetok-Bikini area during April—August 1958. The activity appearing primarily at Huancayo and Chacaltaya during May may have been due in part to the British test held at Christmas Island on April 28, 1958. The large amounts of W^{185} tracer activity, however, identified the source of a large portion of this activity to have been the U.S. Pacific tests (LOCKHART, JR., BAUS, PATTERSON, JR., and SAUNDERS, JR. 1959). The enormous increases in activity during July and August, when the activity at some sites in South America for the first time exceeded that at all North American sites along the 80th Meridian, indicated a massive transfer of activity had taken place across the Equator. Radiochemical data has indicated that at least two bulk exchanges of air between the hemispheres occurred during May—July (LOCKHART,

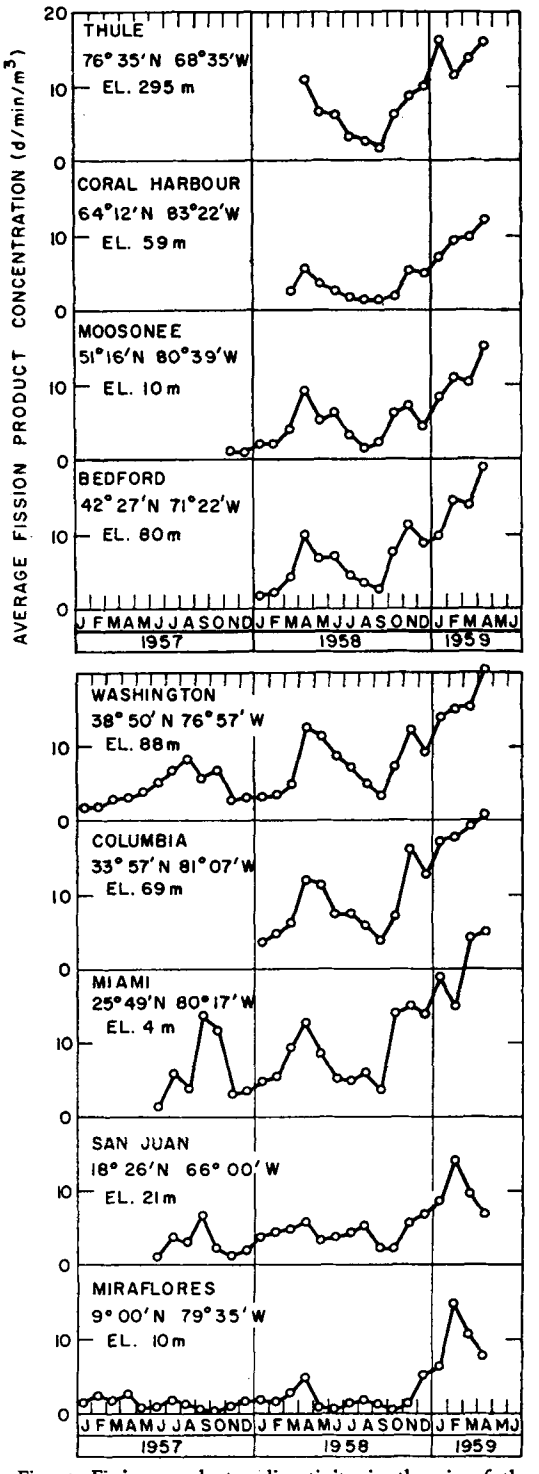

Fig. 4. Fission product radioactivity in the air of the Northern Hemisphere.

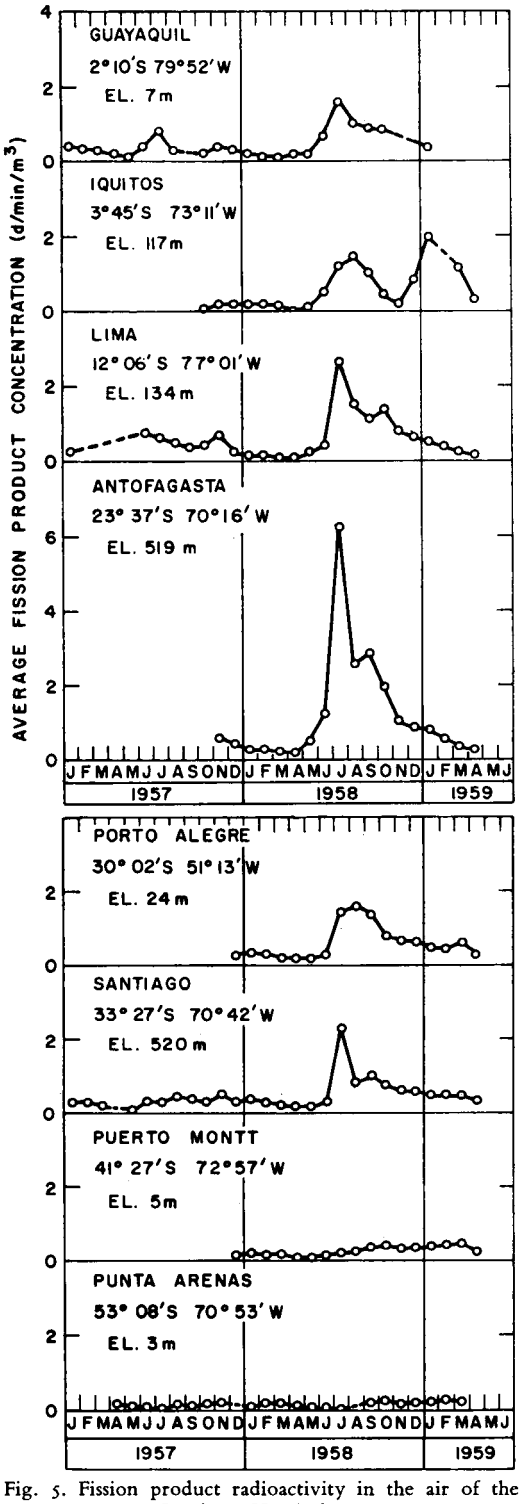

Fig. 5. Fission product radioactivity in the air of the Southern Hemisphere.

JR., BAUS, PATTERSON, JR. and SAUNDERS, JR. 1959).

It is important at this point to consider the mechanism by which this activity crossed the Equator. In the Northern Hemisphere high fission product concentrations were found in the Philippines during May and July (Fig. 7) and in Japan during early July (LOCKHART, JR. 1959), which were obviously due to the transport of activity from the test site to collecting station by winds of the lower troposphere. (Prevailing winds at lower altitudes in the test area are easterlies.) The debris appearing in South America, initially at the high altitude stations, must have been carried primarily by winds in the upper troposphere, which could account for their rapid transport and rapid detection at ground level. A large fraction of the activity, however, must have gone into the stratosphere as this normally occurs with explosions of high yield. (In fact, W^{185} from the Hardtack series of tests has been found at all collecting sites more than a year after the tests, demonstrating that debris from this series did contribute to the stratospheric inventory of radioactivity.)

4. Variations of activity concentrations with time

The data presented in the radioactivity profiles has been replotted in Figs. 4—6 to show the changes in activity levels with time, and to show the relative arrival times of debris at the different sites. The principal point of interest in the curves made at sites along the 80th Meridian in the Northern Hemisphere (Fig. 4) is the apparent lack of response to the U.S. Pacific Tests of 1958 and the long-continuing, high levels of activity caused by the Soviet tests of October and November 1958. Radiochemical data, however, does indicate the presence of some Hardtack debris at these sites. The highest monthly averages of activity ever encountered at any of these sites were recorded in early 1959, months after any nuclear explosion had taken place. Because of the age of the fission product mixtures, they must have been relatively rich in such longer-lived isotopes as Sr^{90}, Cs^{137} and Ce^{144}.

In Fig. 5, similar curves for the Southern Hemisphere show the great effect of the U.S. Pacific tests of 1958 on the radioactivity of

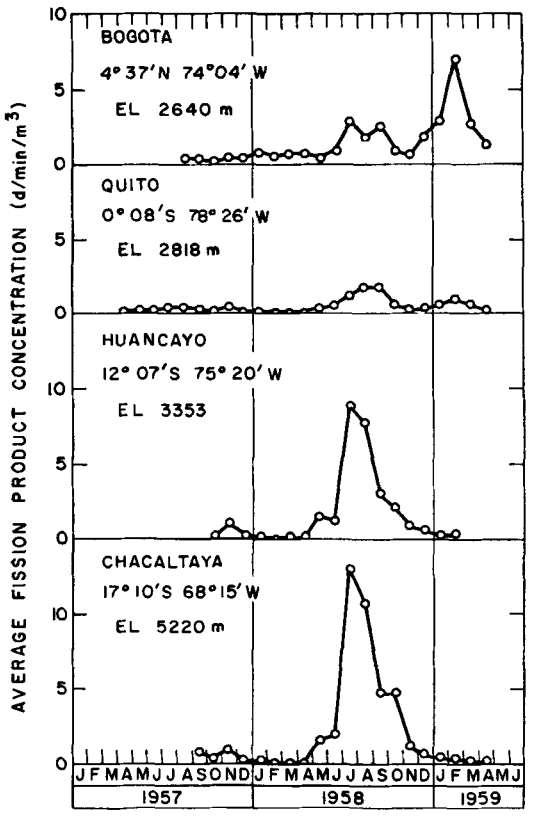

Fig. 6. Fission product radioactivity in the air at high altitude sites in South America.

the air at latitudes as far as 33° S (Santiago). The low response at Puerto Montt and Punta Arenas is noteworthy. The high altitude stations in South America are shown separately in Fig. 6 on a scale intermediate to those of Figs. 4 and 5. The maximum response to the U.S. Pacific tests occurred at the high altitude sites some 750 to 1,000 miles south of the Equator rather than at those sites due east of the test area. During the last months of 1958 and in early 1959, Bogotá (4° 37′ N) showed the typical behavior of stations north of the Equator, while Quito (0°) and the more southerly stations showed a return to the low background of fission products in the air which has been typical to the Southern Hemisphere.

In Fig. 7, the monthly average concentrations of fission products in the air are shown for the stations in the North Pacific area where week-long collections were made. The activity pattern at Drifting Station Alpha in the Arctic was not unlike that at Thule and Coral Harbour; the lack of sharpness of the maxima at Drifting Station Alpha and at Coral Harbour was due to the longer elapsed time between collection and counting at these sites occasioned by transportation difficulties, with the result that fresh fission product collections underwent considerable radioactive decay before being assayed.

Results from the triad of stations at Pearl Harbor, Mauna Loa, and Subic Bay are most interesting in that the activity patterns are so different. Pearl Harbor responded more strongly to the Soviet tests of early 1958 than did Mauna Loa, which is less than 200 miles away but situated at an altitude of 3,394 meters. (Actually, the gross activity per unit mass of air was higher at Mauna Loa, but radiochemical analyses indicated the debris there consisted of an older fission product conglomerate than that at Pearl Harbor.) This would indicate that the

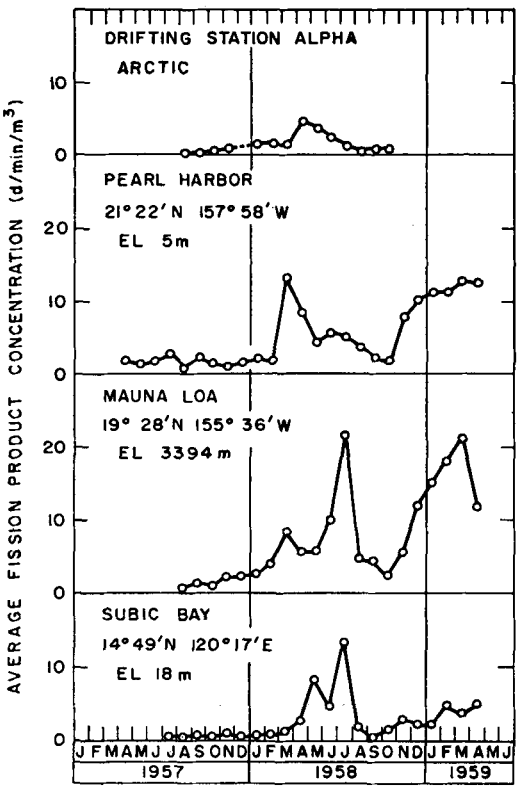

Fig. 7. Fission product radioactivity in the air at sites in the North Pacific area.

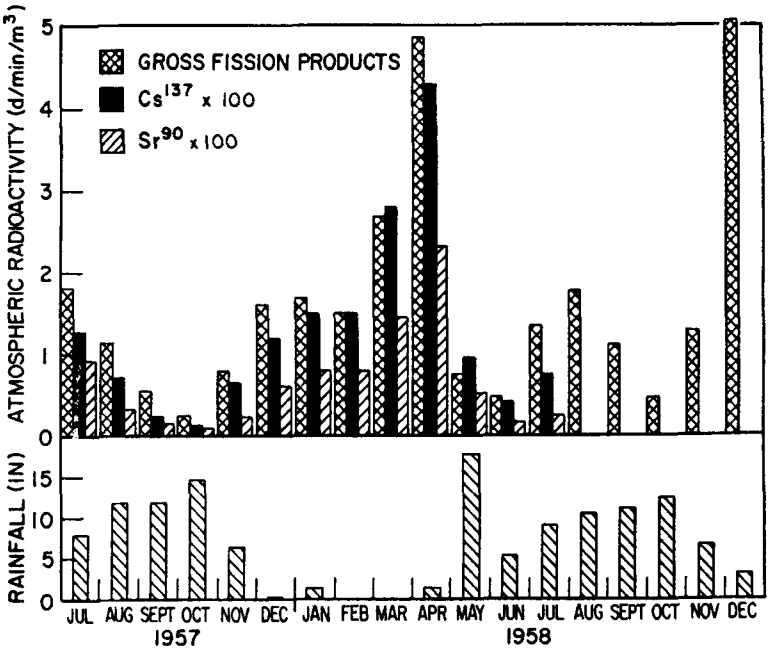

Fig. 8. Relationship between rainfall and the radioactivity of the air at Miraflores, Panama Canal Zone.

contamination was brought into this area by winds of the lower troposphere. Subic Bay received little activity from the USSR tests of either the spring or fall of 1958, but did intercept large quantities of debris from the U.S. Pacific series of 1958 (Hardtack) in both May and July. The transport of the activity was again by the prevailing easterlies of the lower atmosphere. Mauna Loa experienced its highest activity in July, also from Hardtack debris. Tungsten-185 data showed no Hardtack debris were collected at either Pearl Harbor or Mauna Loa during May. During the months of June and July, the contamination due to Hardtack debris was over ten times greater at Mauna Loa than at Pearl Harbor. This is consistent with the observations made at the South American sites where debris from these tests in the Eniwetok-Bikini area appeared in highest concentration at the high altitude sites.

5. Effect of rainfall on the radioactivity of the air

The relationship between rainfall and fallout is of great interest since rain is considered to be the principal mechanism by which radioactivity is removed from the air. Some work on this problem was done at NRL a number of years ago (BLIFFORD, JR., LOCKHART, JR. and ROSENSTOCK, 1952; KING, LOCKHART, JR., BAUS, PATTERSON, JR., FRIEDMAN and BLIFFORD, JR., 1956). More recently, a correlation of the gross radioactivity in the air with the rainfall at Miraflores, Panama, has been reported (LOCKHART, JR., BAUS and BLIFFORD, JR., 1959). As would be expected, the lowest air concentrations of fission products were obtained during the rainy season. New data on the relation between rainfall and fission products in the air at Panama are shown in Fig. 8. Here the monthly average Sr^{90}, Cs^{137}, and gross fission product activities are plotted against the total rainfall during the month. The increase in the air activity during the period December 1957—April 1958 correlates well with the dry season. The large increase in April must have been due at least in part, however, to the Soviet tests of February 23 to March 22. This is confirmed by the decrease in the amounts of Sr^{90} and Cs^{137} relative to the gross fission products during April as compared to the earlier months. Nevertheless, there is evidence of a spring maximum in

stratospheric deposition since the ratio of Sr^{90} activity to the gross fission product activity was too high to be representative of fresh debris. It seems that both increased stratospheric fallout and fresh debris were involved. In May the advent of the rainy season resulted in a great decrease in the total activity in the air and an apparent increase in the age of the radioactive material. The migration of tropospheric debris to this area was so inhibited by

Table 2. Monthly Maxima of Fission Product Concentrations at Sites along the 80th Meridian during July 1957—December 1958

Activity in micromicrocuries per cubic meter of air[1]

Location	1957					
	July	Aug.	Sept.	Oct.	Nov.	Dec.
Thule	—	—	—	—	—	—
Coral Harbour	—	—	—	—	—	—
Moosonee	—	—	—	—	2.5 (4)	1.27 (26)
Bedford	—	—	—	—	—	—
Washington	16.6 (22)	23.7 (12)	8.9 (24)	7.0 (10)	3.3 (1)	3.0 (28)
Columbia	—	—	—	—	—	—
Miami	7.9 (22)	6.2 (27)	32.3 (25)	22.9 (6)	5.9 (4)	2.7 (25)
San Juan	4.1 (26)	6.0 (3, 25)	19.2 (30)	2.6 (15)	1.32 (11)	2.9 (11)
Miraflores	3.2 (10)	1.41 (15)	1.62 (7)	0.75 (2)	1.47 (1)	1.16 (4, 5)
Bogotá	—	0.72 (1)	0.28 (8, 12)	0.19 (4)	0.72 (29)	0.59 (13)
Quito	0.75 (7)	0.52 (4)	0.27 (12)	0.09 (5)	1.10 (19)	0.14 (1, 19)
Guayaquil	0.71 (10)	0.32 (2)	—	0.21 (16)	0.52 (25)	0.37 (4)
Iquitos	—	—	—	0.09 (6, 8)	0.29 (21)	0.32 (8)
Lima	0.71 (25)	0.53 (15)	0.39 (30)	0.82 (31)	0.89 (4)	0.17 (13)
Huancayo	—	—	—	0.31 (29)	1.78 (19)	0.22 (4)
Chacaltaya	—	—	0.56 (23)	0.38 (28)	1.32 (21, 22)	0.51 (1)
Antofagasta	—	—	—	—	—	0.62 (4)
Porto Alegre	—	—	—	—	—	—
Santiago	0.44 (17)	0.46 (31)	0.46 (26)	0.38 (21)	0.80 (23)	0.22 (20)
Puerto Montt	—	—	—	—	—	0.17 (28)
Punta Arenas	0.09 (22,28)	0.34 (17)	0.14 (26)	0.21 (21)	0.16 (1)	—

Location	1958					
	Jan.	Feb.	Mar.	Apr.	May	June
Thule	—	—	—	14.1 (2)	6.4 (5)	7.8 (8)
Coral Harbour	—	—	—	—	3.9 (14)	3.3 (25)
Moosonee	1.92 (10)	1.81 (20)	4.0 (28)	7.6 (4)	5.5 (5)	6.6 (4)
Bedford	2.2 (14)	2.5 (7)	9.8 (29-31)	9.9 (4)	11.8 (1)	5.7 (7, 30)
Washington	3.1 (17)	3.4 (22)	10.0 (31)	11.8 (6)	13.6 (1)	8.4 (15)
Columbia	3.9 (21)	3.5 (6)	9.1 (11)	13.1 (7)	10.7 (9)	7.7 (1)
Miami	5.1 (13)	4.4 (20)	17.0 (24)	13.1 (20)	12.4 (16)	5.1 (7)
San Juan	4.6 (14)	4.4 (6)	5.0 (3)	7.8 (27)	5.2 (1)	3.3 (13)
Miraflores	2.4 (19)	1.22 (7)	1.82 (12)	6.9 (19)	1.24 (1)	0.54 (15)
Bogotá	0.92 (14)	0.64 (26)	0.73 (23)	0.96 (7)	0.76 (26)	1.15 (2)
Quito	0.23 (21)	0.15 (5)	0.09 (25)	0.17 (24)	0.71 (27)	1.36 (3)
Guayaquil	0.13 (6)	0.16 (5, 16)	0.20 (19)	0.22(24, 26)	0.32 (23)	—
Iquitos	0.28 (17)	0.28 (9)	0.25 (22)	0.14 (3)	0.12 (7)	0.50 (3)
Lima	0.11 (5, 15)	0.14 (11)	0.09 (6, 31)	0.12 (12)	0.50 (17)	0.79 (11)
Huancayo	0.14 (17)	0.09 (1)	0.10 (25)	0.07 (29)	2.7 (26)	2.5 (30)
Chacaltaya	0.14 (30)	0.14 (1)	0.07 (16)	0.09 (25)	3.4 (28)	5.7 (29)
Antofagasta	0.27 (31)	0.42 (5)	0.22 (3)	0.18(21, 22)	0.99 (31)	1.22 (5)
Porto Alegre	0.39 (29)	0.26 (10)	0.25 (9)	0.17 (1, 14)	0.14 (4)	0.52 (9)
Santiago	0.26 (10)	0.24 (8)	0.20 (16)	0.17 (8, 9)	0.12 (20, 30	0.53 (30)
Puerto Montt	0.18 (25)	0.14 (6)	0.24 (3)	0.09 (18)	0.11 (13)	0.44 (21)
Punta Arenas	0.12 (6)	0.14 (21)	0.16 (7)	0.12 (30)	0.07 (14)	0.07 (30)

Location	1958					
	July	Aug.	Sept.	Oct.	Nov.	Dec.
Thule	4.0 (8)	3.7 (15)	1.88 (27)	13.0 (26)	7.2 (8, 27)	9.2 (27)
Coral Harbour	2.8 (3)	1.59 (30)	1.42 (4)	2.4 (20, 30)	6.0 (4)	4.4 (26)
Moosonee	4.0 (15)	1.57 (6)	3.3 (25)	8.9 (24)	8.8 (3)	4.9 (31)
Bedford	5.3 (3)	3.2 (8)	2.2 (16)	18.1 (18)	10.9 (4)	7.7 (13)
Washington	8.0 (3)	5.1 (7)	4.9 (11)	11.1 (22)	10.9 (15)	7.0 (2)
Columbia	8.4 (18)	4.3 (11)	3.0 (11)	10.6 (13)	12.8 (15)	12.8 (1)
Miami	3.5 (31)	4.8 (1)	5.3 (5)	18.9 (31)	29.9 (3)	19.3 (1)
San Juan	3.6 (30)	4.0 (2)	2.4 (3)	2.8 (31)	7.0 (6)	5.7 (14)
Miraflores	1.58 (21)	1.32 (9, 22)	1.30 (8)	0.54 (27)	1.89 (13)	4.5 (16, 19)
Bogotá	4.5 (21)	2.3 (1)	2.4 (10)	1.09 (5)	1.29 (1)	2.0 (12)
Quito	1.86 (21)	2.3 (15, 24)	1.96 (24)	1.13 (14)	0.31 (20)	0.45 (14)
Guayaquil	2.0 (14)	0.95 (14)	0.87 (2)	—	—	—
Iquitos	1.15 (15)	1.43 (7)	1.21 (14)	0.39 (5)	0.17 (5, 30)	1.03 (30)
Lima	3.3 (13)	1.54 (11)	1.39 (6)	1.52(24,26)	0.86 (16)	0.87 (13)
Huancayo	7.3 (19)	7.7 (6)	3.2 (25)	3.3 (9)	1.56 (3)	0.55 (8, 10)
Chacaltaya	15.6 (6)	10.4 (7)	4.3 (2)	7.8 (9)	1.79 (1)	0.58 (8)
Antofagasta	6.6 (18)	3.2 (17)	5.2 (4)	3.9 (4)	0.88 (7)	0.69 (3)
Porto Alegre	1.78 (27)	3.5 (16, 17)	2.1 (21)	0.65 (28)	1.03 (15)	0.43 (2, 22)
Santiago	2.9 (11, 12)	1.65 (14)	1.35 (28)	0.84 (8)	0.96 (1)	0.54 (6)
Puerto Montt	0.54 (9)	0.35 (1)	0.50 (10, 11)	0.67 (22)	0.51 (23)	0.36 (29)
Punta Arenas	0.07 (12)	—	0.21 (7, 8)	0.98 (1)	0.16 (4)	—

Note: Figures in parentheses refer to the day (or days) on which the maximum occurred (date of end of collection).

[1] $1\mu\mu$ curie/m^3 = 10^{-18} curie/cc.

rain that the radioactivity collected was more nearly representative of stratospheric material. During June, but especially during July, some fresh material from the Hardtack tests did penetrate to this Panama site in spite of the rainy weather. This is shown by the low Sr^{90} and Cs^{137} values relative to the gross activity and also was demonstrated by the presence of W^{185} activity in the air filter collections. (No radiochemical analyses of Panama collections were made after July 1958.)

6. Maxima of fission product concentrations

In Table 2 the maxima readings of the concentration of fission products in the air for each month of the IGY are compared in terms of micromicrocuries per cubic meter of air. The two highest concentrations were recorded at Miami, Florida: 32.3$\mu\mu$ c/m^3 on September 25, 1957 and 29.9$\mu\mu$c/m^3 on November 3, 1958. These maxima occurred during periods when tests were being carried out both by the United States (Nevada) and the Soviet Union. The maximum concentration in South America was recorded at Chacaltaya, Bolivia, for the 24-hour collection ending July 6, during the U.S. Hardtack tests in the Pacific. This value of 15.6$\mu\mu$ c/m^3 is some seven times that recorded in June 1957 at Lima, Peru, following U.K. tests at Christmas Island (LOCKHART, JR., BAUS and BLIFFORD, JR., 1959).

7. Conclusions

The fission product radioactivity of the air increased markedly in the Northern Hemisphere during 1958 as the result of the intensive test programs carried out there during this period. This activity has continued to increase during early 1959 because of the delayed deposition of debris injected into the stratosphere by the recent high-yield nuclear explosions. (In spite of this great increase in the quantity of nuclear debris in the air, this material still contributes only a small fraction of the total radioactivity in the ground-level air.)

Radioactive debris injected into the troposphere at any particular site spread rapidly throughout the entire hemisphere but rarely cross the Equator in quantity. An exception to this

rule occurred during the U.S. Hardtack series in the Pacific (1958) when massive quantities of activity were transported to the Southern Hemisphere by winds in the upper troposphere. Radiotungsten (W^{185}) produced during the Pacific Hardtack tests has enabled debris from this one series to be traced as they spread throughout the ground-level air of both the Northern and Southern Hemispheres.

Periods of heavy rainfall, such as occur during the rainy season at Panama, cause a general decrease in the concentration of fission products in the air.

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REFERENCES

BLIFFORD, JR., I. H., LOCKHART, JR., L. B. and ROSENSTOCK, H. B., 1952: "On the Natural Radioactivity in the Air", *J. Geophys. Res.* **57**, p. 499.

KING, P., LOCKHART, JR., L. B., BAUS, R. A., PATTERSON, JR., R. L., FRIEDMAN, H. and BLIFFORD, JR., I. H., 1956: "RaD, RaE and Po in the Atmosphere", *Nucleonics* **14**, p. 78.

LOCKHART, JR., L. B., BAUS, R. A. and BLIFFORD, JR., I. H., 1959: "Fission Product Radioactivity in the Air Along the 80th Meridian — January—June 1957", *Tellus* **11**, p. 83.

LOCKHART, JR., L. B., BAUS, R. A., PATTERSON, JR., R. L. and SAUNDERS, JR., A. W., 1959: "Contamination of the Air by Radioactivity from the 1958 Nuclear Tests in the Pacific", *Science* **130**, p. 161.

LOCKHART, JR., L. B., BAUS, R. A., PATTERSON, JR., R. L. and SAUNDERS, JR., A. W., 1959: "*Radiochemical Analyses of Air-Filter Samples Collected During 1958*", NRL Report 5390.

LOCKHART, JR., L. B., 1959: "Atmospheric Radioactivity Levels at Yokosuka, Japan, 1954—1958", *J. Geophys. Res.* **64**, p. 1445.