and balanced all the time by an arrangement of antagonist muscles, one of which lengthens under tension whenever the other shortens.

Soon after the work of 1951 was finished, an attempt was made by three of my colleagues (*9*) to see how the physiological expense of "negative" work in man compares with that of ordinary positive work. At that time research workers were not so certain as they are now that stretching a muscle during contraction can cause a reversal of chemical processes, and they were more cautious in interpreting what they found than they would need to be today. Their results, indeed, were quite unexpectedly large and were certainly due in part to the fact that the force exerted by a muscle while it is being stretched is much greater than the force exerted while it is shortening at the same speed, so a smaller number of muscle units could be employed for a given force. But that is probably not the whole story, and the partial reversal of chemical reactions probably plays a substantial part. That possibility should be examined critically in further experiments on man.

The original experiments were entertaining ones to make, or to watch. Two bicycles were arranged in opposition; one subject pedaled forward, the other resisted by back-pedaling. The speed had to be the same for both, and (apart from minor loss through friction) the forces exerted were the same. All the work done by one subject was absorbed by the other; there was no other significant resistance. The main result was evident at once, without analysis: the subject pedaling forward became fatigued, while the other remained fresh. The rate of working was varied, and the physiological effort was measured by determining the rate of oxygen consumption. It was found that the slopes of the lines relating oxygen usage to rate of working differed greatly between positive and negative work. The experiment was shown in 1952 at a *conversazione* of the Royal Society in London and was enthusiastically received, particularly because a young lady doing the negative work was able quickly, without much effort, to reduce a young man doing the positive work to exhaustion. It is evident now that further investigation is necessary. But however much, or little, the results of stretching isolated muscles may explain the findings in studies of negative work in man, it is interesting to see how the experiments on man arose directly from those on toads. The moral is, if you have a bright idea, try it and see: the result may be much more amusing than you expected.

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Investigations of Natural Environmental Radiation

A profile of external dose rates, cosmic and terrestrial, has been obtained with ionization chambers.

Leonard R. Solon, Wayne M. Lowder, Arthur Shambon, Hanson Blatz

We have reported previously the results of external environmental measurements made during the summer of 1957 by members of the United States Atomic Energy Commission's Health and Safety Laboratory (*1*). The purpose of these measurements was to establish the approximate range of population exposures to penetrating cosmic and terrestrial gamma radiation; exposure to terrestrial beta radiation was excluded.

In the present article are summarized further measurements made in the eastern United States and in New England, and a series of measurements made in Western Europe. In addition, cosmic radiation ionization intensities as a function of altitude have been obtained by several series of measurements made in an airplane. By subtracting the cosmic radiation component from the observed total radiation, estimates of the terrestrial radiation dose rates alone have been derived.

Since ground measurements were made in an automobile, an average attenuation factor for terrestrial radiation by the automobile has been determined experimentally, and all observations, including those presented in the earlier reports, have been corrected correspondingly.

Also reported are measurements made in single-family and multiple-family dwellings in the metropolitan New York area, including three boroughs of New York City, nearby Long Island, and Westchester County.

The ionization chamber used in the measurements has been described in detail elsewhere (*2*). This chamber has a gas volume of 20 liters and is filled with air at atmospheric pressure. Ionization current is measured with a vibrating-reed electrometer, connected

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Table 1. Cosmic-ray ionization intensity as a function of altitude.

Altitude (ft)	Radiation intensity (μr/hr)
Sea Level	3.8
500	4.1
1,000	4.5
2,000	5.2
3,000	6.0
4,000	6.9
5,000	7.9
6,000	9.0
8,000	11.7
10,000	14.8
12,000	18.5
14,000	22.8
16,000	27.7

as a continuously reading voltmeter, driving a pen recorder. It is estimated that the over-all accuracy of a single observation is correct to about 1 microroentgen per hour.

To shield completely against beta radiation, the chamber is mounted in an aluminum container such that, including the polyethylene wall, the gas volume is enclosed by 1.08 g of material per square centimeter; this corresponds to the Feather range of a 2.26-Mev beta particle.

Cosmic Radiation

For measurement of the cosmic radiation dose rate, the instrument was flown between altitudes of 4000 and 17,000 feet in a C-47 airplane furnished by the U.S. Air Force. Measurements were made over land and water. As one might expect, no difference was detected between measurements made over land and over water, the attenuation of terrestrial radiation at an altitude of 4000 feet being greater than a factor of 10^3 (*3*).

The results of the airplane measurements are shown in Fig. 1. A simple exponential, with the radiation level as ordinate and barometric pressure as the abscissa, has been fitted to the data.

The method of least squares furnishes the equation,

$$\log C_P = 2.4595 - 0.0627\ (\pm\ 0.0018)\ P \qquad (1)$$

where C_P is the measured radiation level inside the plane in microroentgens per hour and P is the barometric pressure in inches of mercury. The error indicated is the standard deviation of the regression coefficient.

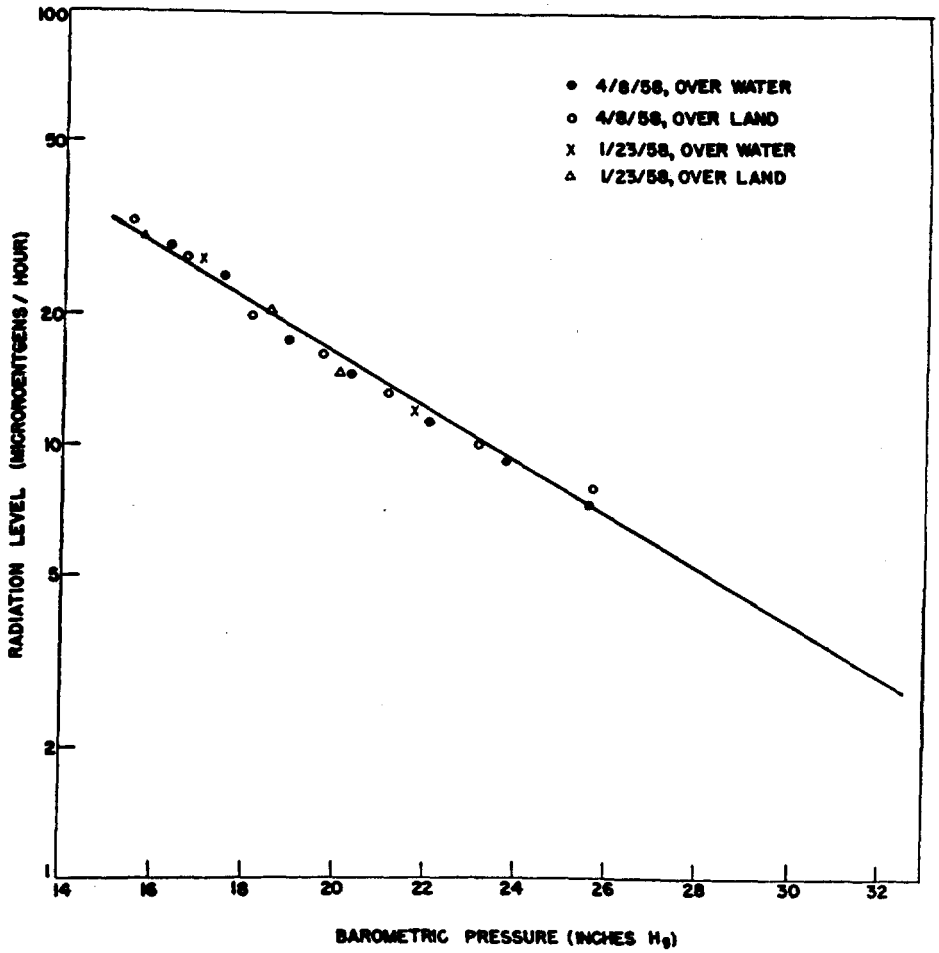

Fig. 1. Measurements of cosmic radiation ionization intensity made inside a C-47.

From the standard atmospheric pressure-altitude relationship (*4*) and the above equation, the approximate cosmic-ray dose rates at different altitudes in the latitude of New York were determined; they are listed in Table 1.

The sea-level value was estimated by extrapolation of the airplane data to the corresponding pressure (P = 29.92 in.-Hg). The resulting value of 3.8 μr/hr for the cosmic-ray ionization intensity at sea level is comparable to values obtained by other investigators. Neher (*5*) and Hess (*6*) obtained values of 4.7 and 3.4 μr/hr, respectively. Burch (*7*) carefully reviewed the earlier experimental work in arriving at his estimate of 3.1 μr/hr for the ionization intensity at sea level, and concluded that the discrepancies cannot be regarded as altogether resolved. Further measurements of this important dosimetric parameter would be useful.

Outdoor Environmental Radiation Measurements in the United States

An experimental determination, based on observations in about 20 different locations of varying backgrounds in New York City, indicates that the terrestrial radiation as measured by the ionization chamber mounted inside the automobile is 0.77 $\pm$ 0.02 (standard deviation) of the outdoor intensity.

The first series of measurements made in an automobile—made during August 1957 (*1*)—are summarized here, corrected for attenuation of the terrestrial radiation component by the automobile. Measurements made in the New England states in May 1958 and in the southeastern states in August 1958 have been corrected similarly.

A portable scintillation detector with a sodium iodide phosphor was used for scanning purposes at locations inaccessible to the automobile. This detector was also turned on and observed continuously in the automobile between points of measurement. The detector, though not capable of reading absolute dose rate, can measure a change in radiation level of about 0.4 μr/hr.

In all the measurements throughout the United States, an effort was made to obtain results which would be representative of the unperturbed natural background, affected as little as possible by the occasional substantial variation in the observed natural radiation levels produced by localized sources (for example, by granite buildings, brick paving, and fallout).

In Table 2 are summarized the measurements for major cities in the United States, including the range of total radiation levels encountered and an estimate of the mean annual dose (*8*).

Most of the readings taken in the eastern United States are between 10 and 15 μr/hr. Low radiation levels were found in New Haven, Connecticut; in the state of Vermont; and in the region north of Charleston, South Carolina. Relatively elevated levels were observed with the scintillation detector along U.S. highway 401 northeast of Raleigh, North Carolina, to the Virginia line. The highest reading found with the ionization chamber in the 1958 measurements, 19.7 μr/hr, was made on a dirt road off the aforementioned highway, 2 miles south of Louisburg, North Carolina.

Measurements in 1957 were made during part of the period of Operation Plumbbob, that year's series of United States continental weapon tests at the National Test Station in Nevada, and, as reported earlier, these tests influenced certain of the measured values in an important way, particularly in eastern Arkansas and in the Black Hills of South Dakota.

The measurements made during August 1958 were undertaken during part of the period of Operation Hardtack, the series of United States weapon tests at the Pacific proving ground. By comparing scintillation detector readings taken over patches of bare ground and grassy spots, it was inferred that nuclear debris had some influence on almost all of these observations. Where test fallout is present, the larger surface presented by patches of grass or weeds results in elevated readings as compared to readings for bare ground.

In April 1959, 84 of the measurements were repeated as close to the original positions as possible in order to estimate the effects of fallout on the initial readings as well as to check the reproducibility of the data. Reductions in the readings were observed at almost all these locations and in some instances were considerable. In six locations the reductions were greater than 10 μr/hr, ranging up to 54 μr/hr in one Arkansas town. If these locations are excluded, the average reduction was about 2 μr/hr. These changes probably are due in large part to the radioactive decay and dispersion of fallout debris which affected the original measurements.

Table 2. Environmental radiation levels measured in principal United States cities. The number of observations for each range is shown in parentheses. Elevated radiation levels produced by localized sources are shown in the last column.

City	Range of radiation levels (μr/hr)	Mean annual dose (mrad)	Cosmic radiation (μr/hr)	Atypical radiation levels (μr/hr)
New York, N.Y.	8.2–15.6 (19)	91	3.8	
Harrisburg, Pa.	11.3–14.3 (2)	104	4.0	
Pittsburgh, Pa.	11.5–16.8 (3)	114	4.3	
Cleveland, Ohio	12.4–14.1 (2)	108	4.2	
Toledo, Ohio	10.1–11.8 (2)	89	4.1	18.1 (over granite paving stone)
Chicago, Ill.	12.2–13.9 (4)	105	4.1	20.9 (adjacent to granite U.S. post office building)
Madison, Wis.	11.8–12.2 (3)	98	4.3	
Minneapolis–St. Paul, Minn.	10.6–15.0 (4)	109	4.2	
Sioux Falls, S.D.	13.6–14.0 (2)	112	4.5	
Cheyenne, Wyo.	19.8–20.4 (2)	164	8.5	
Denver, Colo.	19.2–22.9 (9)	172	7.9	26.8 (between U.S. mint and city and county buildings)
Colorado Springs, Colo.	22.5–26.4 (4)	197	8.7	
Grand Junction, Colo.	18.2–20.8 (3)	159	7.2	
Albuquerque, N.M.	15.7–16.5 (4)	132	7.5	
Amarillo, Tex.	14.9–15.8 (4)	126	6.4	
Oklahoma City, Okla.	11.5–12.3 (4)	99	4.6	
Tulsa, Okla.	12.8–13.9 (4)	109	4.2	
Little Rock, Ark.	15.5–16.1 (2)	129	3.9	
Memphis, Tenn.	11.0–13.2 (2)	99	3.9	16.2 (near brick apartment house)
Chattanooga, Tenn.	13.2–14.8 (2)	114	4.0	18.0 (near brick-faced motel units) 19.7 (on narrow business street)
Bridgeport, Conn.	10.8–13.8 (2)	100	3.8	
New Haven, Conn.	8.7– 9.1 (2)	73	3.8	
Hartford, Conn.	11.9 (2)	97	3.8	
Springfield, Mass.	12.9–13.9 (2)	109	3.8	
Worcester, Mass.	14.0–16.4 (2)	124	4.0	
Providence, R.I.	11.1–13.8 (2)	101	3.8	
Boston, Mass.	11.0–14.3 (4)	103	3.8	
Portland, Me.	12.5–13.5 (3)	106	3.8	
Philadelphia, Pa.	11.7–12.5 (3)	99	3.8	
Baltimore, Md.	9.0–12.1 (3)	86	3.9	
Washington, D.C.	11.1–13.3 (3)	99	3.9	
Lynchburg, Va.	12.4–13.4 (2)	113	4.2	
Winston-Salem, N.C.	12.9–14.7 (2)	112	4.3	
Charlotte, N.C.	10.6 (2)	86	4.1	
Columbia, S.C.	15.0–15.2 (2)	123	3.9	
Charleston, S.C.	13.5–14.5 (3)	114	3.7	
Raleigh, N.C.	12.1–13.5 (2)	108	4.0	
Richmond, Va.	9.8–11.1 (3)	85	3.9	

Table 3. Radiation levels in dwellings in the metropolitan New York area. The number of observations for each range is shown in parentheses.

Construction and location	Radiation levels (μr/hr)	
	Indoors	Outdoors
Apartments		
Second floor, brick private dwelling, Bronx	10.2–12.3 (6)	12.4
Third floor, brick apartment house, Manhattan	9.9–12.0 (6)	10.9
Fourth floor, brick apartment house, Bronx	10.4–10.8 (2)	
First floor, brick apartment house, Manhattan	9.6–11.0 (2)	10.7
Third floor, brick apartment house, Manhattan	11.9–13.5 (2)	
Fourth floor, brick apartment house, Manhattan	9.0– 9.3 (2)	9.5
One-family dwellings, Long Island		
Ranch type, cedar shingle, concrete basement; Roslyn	7.4– 9.2 (13)	8.4 (concrete patio)
Split level, cedar siding, concrete basement; East Norwich	8.0– 9.1 (12)	11.8 (4 ft from brick wall)
Two-story contemporary, brick veneer, glass, cypress siding; Sea Cliff	8.5– 9.4 (4)	10.9
Two-story, stone; Freeport	9.6–11.2 (5)	11.0 (50 ft in front of house) 13.8 (9 ft in front of house)
One-family dwellings, Staten Island		
Native serpentine stone, Radcliff Road	7.3– 8.7 (4)	10.6
Stone, Bard and Forest Aves.	6.5– 7.5 (4)	11.4
Westchester granite veneer, Beacon Ave.	6.7– 9.8 (4)	9.8
One-family dwellings, Westchester County		
Three-story dolomite and sandstone, New Rochelle	12.0–13.8 (5)	13.6
Wood frame, Pelham	7.3–12.9 (5)	12.1
Wood frame, Pelham	8.7–11.3 (3)	

Environmental Radiation Measurements in Houses

Seventeen single-family and multiple-family dwellings in the metropolitan New York area, including three boroughs of New York City, nearby Long Island, and Westchester County, also have been investigated. The apparatus used was essentially the same as that used for the outdoor measurements, except that the ionization current was measured with a Cambridge Lindemann-Ryerson quadrant electrometer rather than with a vibrating-reed electrometer.

A summary of these measurements is shown in Table 3. The general conclusion that may be reached is that the radiation level inside houses in this area, essentially irrespective of construction materials, is generally somewhat lower than, but not very different from, the outdoor level in the same location.

Measurements in Western Europe

A 20-liter ionization apparatus which had been exhibited at the second International Conference on the Peaceful Uses of Atomic Energy was taken to Radiofysika Institut in Stockholm, Sweden, by one of us (H. B.) for comparison with the environmental radiation equipment of Rolf Sievert's laboratory (*9*). En route between Geneva and Stockholm, a number of measurements were made. Some of these observations were made over granite paving blocks or near granite buildings, which presumably produced somewhat higher readings than would have been obtained over unpaved or more open areas.

A tabulation of these measurements is given in Table 4. In general, the radiation levels observed are similar to measurements made at corresponding altitudes in the United States. The four measurements made in Sweden are consistent with the published work of Sievert (*10*).

Table 4. Radiation measurements in Western Europe, September 1958.

Location	Radiation (μr/hr)			Notes
	Cosmic	Terrestrial	Total	
Geneva, Switzerland	4.6	6.9	11.5	Airport
Geneva, Switzerland	4.6	9.0	13.6	Near Cathedral of St. Pierre
Geneva, Switzerland	4.6	8.1	12.7	Residential area
Montreux, Switzerland	4.6	9.0	13.6	Center of town
Offenburg, Germany	4.1	11.6	15.7	Center of town; block pavement
Heidelberg, Germany	4.0	11.8	15.8	Business district
Cologne, Germany	4.0	8.3	12.3	Near cathedral
Wesel, Germany	3.9	10.4	14.3	Center of town
Delft, Netherlands	3.9	10.0	13.9	Center of town; brick pavement
Leeuwarden, Netherlands	3.8	9.2	13.0	Center of town; brick roadway
Hamburg, Germany	3.8	9.9	13.7	Business district
Schleswig, Germany	3.7	12.4	16.1	Center of town; Belgian block pavement
Nyborg, Denmark	3.7	9.9	13.6	Off highway
Granna, Sweden	4.4	12.1	16.5	Off highway
Nykoping, Sweden	3.9	19.1	23.0	Center of town
Stockholm, Sweden	3.9	13.4	17.3	Business district
Stockholm, Sweden	3.9	19.5	23.4	Residential area; stone paving blocks

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SPECTROMETRIC DETERMINATION OF DOSE RATES FROM NATURAL AND FALL-OUT GAMMA-RADIATION IN THE UNITED STATES, 1962–63

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THE Health and Safety Laboratory of the U.S. Atomic Energy Commission has been examining for nearly a decade the dosimetric properties of environmental radiation, particularly the natural components. Instrumentation and analytical techniques have been developed which are directed toward securing precise interpretations of *in situ* radiation measurements in terms of air dose rate[1–3], from which quantities of biological interest may be derived. Because of the importance of total body and genetic exposure in considerations of the long-term interaction between ionizing radiation and man, our interest has been focused on the more penetrating radiations. These include the γ-radiation from potassium-40 and the daughters of radium-226 and thorium-232 in the Earth and the ionizing component of the cosmic radiation, consisting primarily of the high-energy muons and electrons. We have also had to take account of the presence of fall-out in the environment, and have developed techniques for determining the individual dose-rate contributions to the total environmental γ-field of the various significant natural and fall-out γ-emitters. These techniques are described in this article and a summary of the field data obtained during 1962 and 1963 is given.

During the late 1950's, the importance of the γ-radiation from locally deposited fission products from weapons tests was first noted. Gamma dose rates considerably in excess of the ambient natural levels were recorded by a number of investigators either by direct monitoring[4–6] or by inference from soil and/or air sample analyses[7–10]. Similar increases were noted during the testing period that began in September 1961 (refs. 11–14). Under such conditions, ionization chambers have proved valuable as monitors of changes in total environmental radiation-levels at individual locations, particularly when the mean natural radiation-levels are known from readings taken during periods of little or no fall-out[4–6,14]. Other techniques are needed if such readings are not available or if it is desired to survey new locations.

The most direct means for separating the fall-out γ-radiation from the natural is by means of energy discrimination. Many of the more prominent γ-energies characteristic of the natural emitters lie between 1·1 and 2·6 MeV, while almost all important energies from fission products are below 1·1 MeV. The properties of the significant γ-emitting fission products are given in Table 1. The 1·6 MeV γ-ray from lanthanum-140 is important in the upper energy range; but this is prominent only within a few months of production because of its short half-life. As a result, relatively simple spectrometric techniques have proved valuable in providing detailed information on the individual contributions to the total dose rate of the significant natural and fall-out γ-emitters.

In June 1962, several field measurements were made with a 5-in. diameter × 3-in-high sodium iodide (Tl) detector placed on a small wooden tripod at a height of 3 ft. above the ground. A 50-ft. cable connected this essentially unshielded detector to a Nuclear Data 256-channel pulse-height analyser mounted in the rear compartment of a Corvan truck and operated directly from the 12-V motor-car battery through a 300-W a.c.–d.c. inverter. 20-min readings provided adequate statistics, and two typical results are given in Fig. 1. The prominent total absorption peaks at 0·5, 0·75, 1·46 and 2·62 MeV are characteristic of the spectra obtained during 1962 and 1963. Ths most important peaks from the uranium series, at 0·61, 1·12 and 1·76 MeV, are generally not conspicuous and, in the case of the 0·61- and 1·76-MeV peaks, are usually hidden by more prominent neighbours.

Having determined that the field spectra obtained in the manner described showed considerable detail, it remained to find a means of inferring dose rates from the spectra. For the natural emitters, this has been accomplished using two related techniques. In the first method[15], the areas under the total absorption peaks were simply approximated by subtracting from the field data a straight-line fit between the continua on either side of each peak on semi-log paper as representative of the Compton continuum under that peak. These results were assumed to be proportional to the true peak areas and therefore to the incoming primary flux at the detector in the field situation. This assumption was tested satisfactorily in the laboratory for several γ-energies and the constants of proportionality between the measured areas and the incident primary fluxes determined. Assuming uniform source distributions in the ground half-space and known decay schemes for potassium-40 and the uranium and thorium series, the flux and angular distribution of the primary photons of the energies of interest and the total dose rate per unit source at 3 ft. above the ground were calculated[1,15]. Since the response of the detector in terms of peak counts per unit flux as a function of angle was

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Table 1. IMPORTANT FALL-OUT γ-EMITTERS

Isotope	Half-life	γ-Energy (MeV)	γ/d*
^{95}Zr	65·0 d.	0·724	0·5
		0·757	0·5
^{95}Nb	35·4 d.	0·768	1·00
^{103}Ru	39·7 d.	0·498	0·9
		0·610	0·06
^{106}Rh	30 s.†	0·513	0·205
		0·624	0·105
^{124}Sb‡	60·1 d.	0·603	0·98
		0·645	0·072
		0·722	0·105
		1·69	0·48
		2·09	0·063
^{137}Cs	30 yr.	0·662	0·94
^{140}Ba	12·8 d.	0·030	0·16
		0·537	0·25
^{140}La	40·2 h	0·325	0·2
		0·488	0·4
		0·815	0·2
		0·923	0·10
		1·60	1·00
^{141}Ce	32·5 d.	0·145	0·70
^{144}Ce	284·5 d.	0·134	0·105

*γ-lines with γ/d < 0·05 are omitted; data from *NAS–NRC Nuclear Data Tables* (to date).

† Effective half-life is that for ^{106}Ru, or approximately 1 year.

‡ Not a fission product.

obtained from laboratory measurements with standard radioactive sources, a simple calculation yielded the calibration constants of the measured peak areas in terms of dose rate. These results are given in Table 2.

A second method for determining natural radiation dose rates utilizes a well-known energy band technique (for example, refs. 16–18), where the total counts in the spectrum between energy values that bracket significant peaks are related to the dose-rate contribution from the radiation that contributes to these peaks. Three bands were therefore chosen to include the three total absorption peaks already calibrated, that is, from 1·32 to 1·60 MeV to include the 1·46-MeV ^{40}K peak, from 1·62 to 1·90 MeV to include the 1·76-MeV ^{214}Bi peak, and from 2·48 to 2·75 MeV to include the 2·62-MeV ^{208}Tl peak. The band and peak methods have given essentially identical values for the inferred natural radiation dose rates. The band method has the advantage of providing greater precision for individual measurements and being more easily amenable to routine data analysis, although it is sensitive to the instrument gain drift and to our determinations of the zero energy channel and energy per channel for the field spectrum.

The energy-band approach has also been extended to provide a measure of the total γ-dose rate. The total energy in the spectrum between 0·15 and 3·4 MeV has been found to correlate very well with total γ-dose rate as measured by a high-pressure ionization chamber[3]. Further, the calibration factor determined in the laboratory using a standard radium-226 source is consistent with that inferred from the ionization chamber readings[15].

The fall-out γ-dose rate can be estimated by taking the

Table 2. Dose-rate Calibration of Spectrometer

Peak energy (MeV)	Isotope	Source	Peak counts/μr./h
0·5	^{140}Ba–^{140}La	Exponential	6,000
	^{103}Ru–^{103}Rh	,,	35,000
	^{106}Ru–^{106}Rh	,,	18,000
0·75	^{95}Zr–^{95}Nb	,,	21,000
1·46	^{40}K	Uniform	5,550
1·76	^{214}Bi (U series)	,,	700
2·62	^{208}Tl (Th series)	,,	700

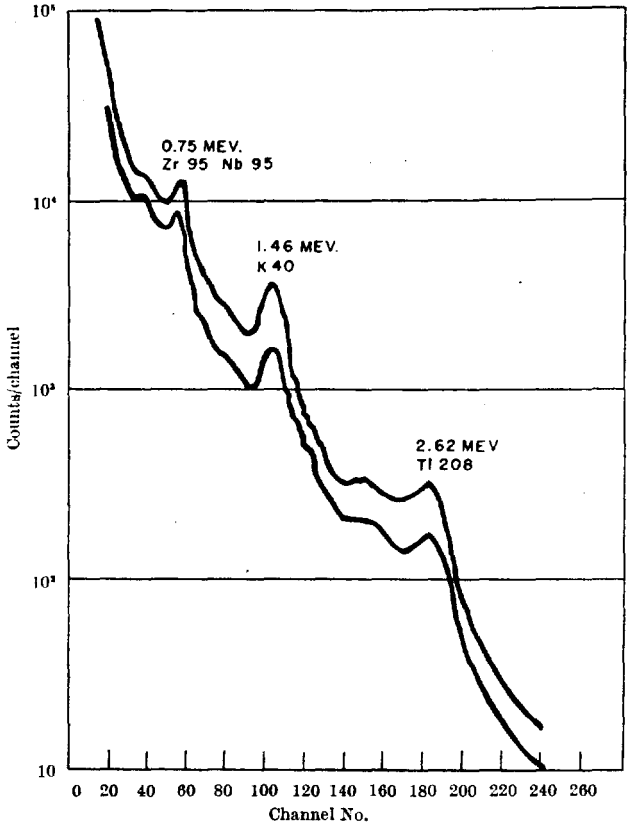
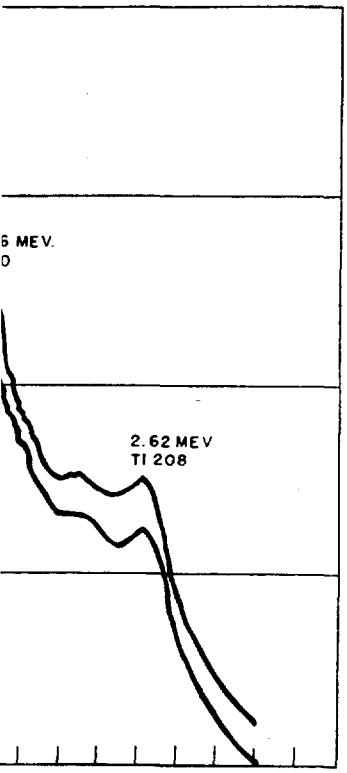


Fig. 1. Two typical field spectra obtained during late 1962. Top curve: Colorado Springs, Colo., October 11, 1962; bottom curve: Argonne, Ill., October 15, 1962. The cosmic ray, natural and fall-out levels are all somewhat higher at the Colorado Springs location

difference between the total γ-dose rate, as measured by the spectrometer and ionization chamber, and the natural γ-dose rate, as determined by the peak or energy-band analysis. A second method involves the determination of the areas of the 0·5- and 0·75-MeV total absorption peaks

E CALIBRATION OF SPECTROMETER

ce	Source	Peak counts/μr./h
	Exponential	6,000
1	,,	35,000
1	,,	18,000
	,,	21,000
	Uniform	5,550
ies)	,,	700
ries)	,,	700



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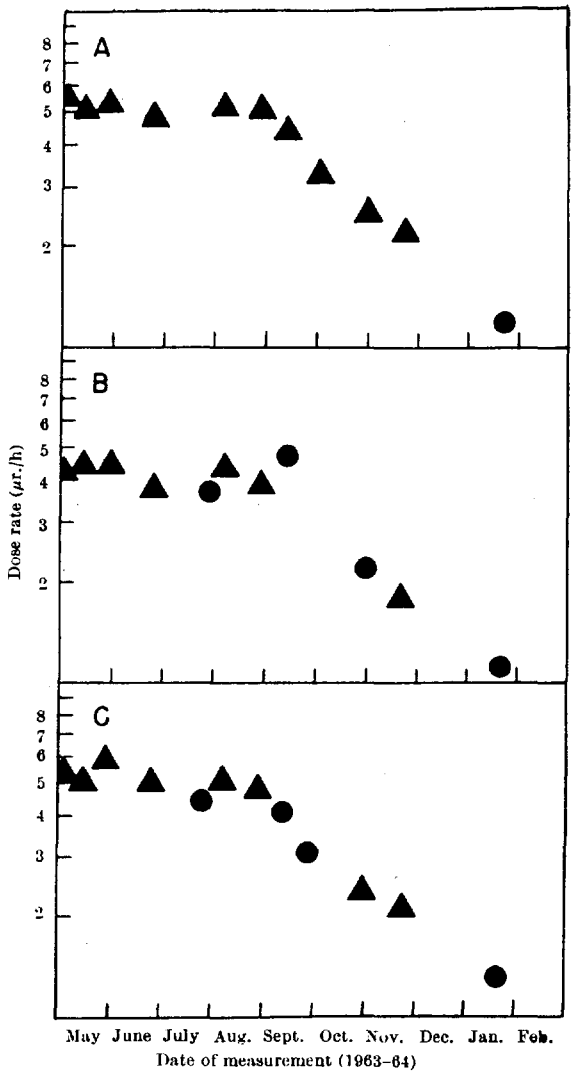

Fig. 2. Fall-out γ-dose rates at three locations in Westchester Co., N.Y. (*A*, Mamaroneck; *B*, West Harrison; *C*, Pelham.) The triangles refer to spectrometer readings and the circles to readings with the ionization chamber only

in a manner analogous to that for the higher energy peaks characteristic of the natural emitters. These areas can also be related to the incoming primary flux in the field situation and thus to the total dose rate from the contributing isotopes.

However, two problems arise with the peak method as applied to fall-out that are not encountered in the case of the natural emitters. First, the source distribution in the ground is less well defined than for the natural emitters, where the assumption of uniform concentration in the ground half-space is a reasonable one on the scale of our measurements. Fission products are, of course, not necessarily distributed uniformly in the upper layers of the ground, nor is the assumption of a uniform plane source distribution adequate for any but the most recently deposited fall-out. Measured soil-depth distributions of the significant γ-emitters[19-22] indicate that an exponential source distribution as a function of depth with a 'relaxation length' of 3 cm may be a reasonable model. Of course, significant deviations from this average situation would not be unexpected at some locations, particularly where there has been substantial recent deposition.

Secondly, several radionuclides contribute to the 0·5-MeV peak (Table 1). Since the total γ-dose rate per unit 0·5-MeV flux depends on the decay scheme of the nuclide or series of nuclides under consideration, the dose-rate calibration of the 0·5-MeV peak area depends on the relative population of these nuclides, which in turn is a function of the mean age of the fall-out. Since rhodium-106 dominates the 0·5-MeV activity for fall-out more than several months old and has an intermediate value for its peak calibration factor, the use of the rhodium-106 peak calibration and the exponential source distribution provides a reasonable estimate for the dose contribution of the 0·5-MeV emitters in most circumstances.

The peak calibration factors for the main fall-out γ-emitters are given in Table 2, along with those for the natural emitters. Part of the dose rate contribution of cæsium-137 (0·66 MeV) would be included with that of zirconium-95 (0·75 MeV), since the two peaks overlap in our spectra, the 0·66-MeV peak generally being completely hidden by the larger 0·75 MeV peak. Other fall-out γ-emitters generally give only a very small proportion of the dose rate.

The overall consistency of the two methods for determining the fall-out dose rates, obtained over a wide range of natural γ-fields, and the apparently high degree of precision of individual total γ-dose-rate measurements suggest that a standard deviation of about ± 0·5 μr./h would be appropriate for individual fall-out dose-rate estimates. The individual natural dose-rate components have standard deviations conservatively estimated at ± 10 per cent; the total dose-rate values have somewhat smaller deviations.

Since July 1962, a number of survey trips have been undertaken to various parts of the United States. These surveys have generally been motivated by an interest in natural radiation-levels in certain areas (for example,

s arise with the peak method as are not encountered in the case First, the source distribution in ned than for the natural emitters, f uniform concentration in the asonable one on the scale of our products are, of course, not neces- mly in the upper layers of the ption of a uniform plane source or any but the most recently sured soil-depth distributions of [19-22] indicate that an exponential function of depth with a 'relaxa- ay be a reasonable model. Of ions from this average situation l at some locations, particularly bstantial recent deposition.

dionuclides contribute to the Since the total γ-dose rate per ds on the decay scheme of the les under consideration, the dose- 5-MeV peak area depends on the ese nuclides, which in turn is a of the fall-out. Since rhodium- V activity for fall-out more than as an intermediate value for its the use of the rhodium-106 exponential source distribution timate for the dose contribution n most circumstances.

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of the two methods for determ- tes, obtained over a wide range the apparently high degree of total γ-dose-rate measurements deviation of about ± 0·5 μr./h or individual fall-out dose-rate al natural dose-rate components as conservatively estimated at dose-rate values have somewhat

mber of survey trips have been rts of the United States. These een motivated by an interest in in certain areas (for example,

northern New England[23], New York State (to be published), and Denver[15]). But spectrometric measurements were also carried out *en route* so that we now have spot readings of natural and fall-out radiation-levels at more than 200 different locations, fairly well scattered throughout the United States. Since such readings might be expected to vary quite considerably with time and quite possibly with small shifts in location, little significance can be attached to these data except in so far as they show a common pattern. The exceptions to this statement are those regions where a large number of measurements have been carried out at nearly the same time (New England, New York and Denver) and those locations where the variations with time have been followed (New York). In such cases, we have a reasonably adequate measure of typical natural and fall-out γ-levels at particular times. Unfortunately, to carry out such measurements on a national scale would be a tremendous undertaking. At present, we must rely on the relatively few data that are available and reasonable inferences therefrom to construct a coherent picture of the influence of deposited fission products on environmental γ-radiation-levels in the United States.

In order to make data obtained in different locales comparable, every effort was made to conduct our measurements at similar kinds of locations, namely, over flat, open ground, generally grass-covered, at a distance of at least 50 ft. from other surfaces. In every case, a survey of the immediate area was conducted with portable scintillation detectors to ascertain that the measured total dose rate was representative for the area. The requirement for flatness is an important one, for ground depressions have often shown elevated γ-ray-levels. Several spectrometer readings have been taken over depressions of large area where such elevated readings were observed. As expected, the resulting spectra exhibited large fall-out peaks (0·5 and 0·75 MeV). The observed dose rate increases above the values for adjacent flat areas generally were consistent with those predicted from the differences in peak areas.

It should be noted that open-field fall-out determinations may be representative of areas of bare or grass-covered ground, but not necessarily of all areas which are of significance with respect to the radiation exposure of the human population in their daily rounds. Thus, any consideration of the influence of fall-out on general population exposure-levels must take into account a number of factors not discussed here, such as the distribution of fall-out on roadways, sidewalks and buildings, the degree to which the activity is distributed to other locations, and the shielding effect of man-made structures. For example, Franke *et al.*[24] have reported finding very little artificial radioactivity in homes, and then only

Table 3. SUMMARY OF 1962–63 SURVEY RESULTS

Survey area	Date	No. Loc.	Dose-rate range (μr./h) (natural γ)	(fall-out γ)
New York State				
(1) South and west	8/63	35	5–7	3–4
(2) North	8/63	19	4–8	3–5
(3) New York City	5–9/62	3	5–10	3–5
	5–9/63	3	7	4–5
Vermont	7/62	26	4–8	2–3
	8/63	6	4–8	4–5
New Hampshire	7/62	39	6–15	2–3
	5/63	5	6–8	3–5
	9/63	10	6–15	3–5
South-eastern U.S.*	4/63	8	3–7	4–7
(1) South Carolina	4/63	6	3–10	4–7
(2) North Carolina	4/63	2	15–19	2–4
Western U.S.				
(1) Black Hills, S.D.	10/62	6	6–8	2–5
	10/63	4	6–8	3–4
(2) Seattle, Wash.	10/62	3	4	2
(3) Olympic Peninsula, Wash.	10/62	9	3–5	1–4
(4) San Francisco, Cal.	10/62	6	4–8	1–2
	10/63	6	5–8	1
(5) Nevada–Utah	10/62	6	5–9	1–4
	10/63	3	5–9	2–8
(6) Denver–Colorado Springs, Col.	10/62	9	9–14	2–3
	10/63	10	8–15	1–2
Central U.S.†	10/62	15	7–9	3–6
	10/63	11	7–9	2–4

* Includes locations in Texas (2), Louisiana (1), Arkansas (1), Alabama (2), Tennessee (1), and Georgia (1).

† Includes locations in Wisconsin (1), Minnesota (1), Eastern South Dakota (4), Illinois (4), Kansas (3) and Missouri (2).

near entrances from outside. Spiers[5] has observed dose rate increases inside various structures during periods of high fall-out deposition, although these were generally of lesser amplitude than the corresponding outdoor changes. It is evident that the effect of deposition of fission products in the environment on indoor γ-radiation levels must be strongly dependent on the type of building material, thickness of the walls, the number and size of apertures in the walls (that is, doors and windows), the location of rooms, the presence of other buildings nearby, as well as the degree to which the fall-out is tracked indoors. Spiers[5] has suggested applying a shielding factor of about two to outdoor measurements as a means of estimating an upper limit to the dose-rate contribution of fall-out to general population exposure, this figure being derived from ground-floor observations in houses. The removal of artificial radioactivity from hard surfaces by weathering processes plays a part in reducing the outdoor exposure-level of the population, particularly in urban areas where a large number of people see very little open ground. It is probable that open field measurements provide a substantial overestimate of the total exposure of the population to fall-out γ-radiation.

Table 3 presents a summary of the results obtained during the 1962 and 1963 survey trips with respect to both natural and fall-out γ-levels. The dose-rate ranges quoted generally include about 80–90 per cent of the individual measurements at various locations in the particular areas. The detailed data for individual loca-

OF 1962–63 SURVEY RESULTS

Date	No. Loc.	Dose-rate range (μr./h) (natural γ)	(fall-out γ)
8/63	35	5–7	3–4
8/63	19	4–8	3–5
5–9/62	3	5–10	3–5
5–9/63	3	7	4–5
7/62	26	4–8	2–3
8/63	6	4–8	4–5
7/62	39	6–15	2–3
5/63	5	6–8	3–5
9/63	10	6–15	3–5
4/63	8	3–7	4–7
4/63	6	3–10	4–7
4/63	2	15–19	2–4
10/62	6	6–8	2–5
10/63	4	6–8	3–4
10/62	3	4	2
10/62	9	3–5	1–4
10/62	6	4–8	1–2
10/63	6	5–8	1
10/62	6	5–9	1–4
10/63	3	5–9	2–3
10/62	9	9–14	2–3
10/63	10	8–15	1–2
10/62	15	7–9	3–6
10/63	11	7–9	2–4

), Louisiana (1), Arkansas (1), Alabama (2),

in (1), Minnesota (1), Eastern South Dakota
issouri (2).

side. Spiers[5] has observed dose
rious structures during periods
n, although these were generally
an the corresponding outdoor
that the effect of deposition of
vironment on indoor γ-radiation
ependent on the type of building
e walls, the number and size of
hat is, doors and windows), the
esence of other buildings nearby,
o which the fall-out is tracked
gested applying a shielding factor
r measurements as a means of
it to the dose-rate contribution
lation exposure, this figure being
or observations in houses. The
oactivity from hard surfaces by
vs a part in reducing the outdoor
pulation, particularly in urban
per of people see very little open
that open field measurements
erestimate of the total exposure
-out γ-radiation.

mmary of the results obtained
63 survey trips with respect to
γ-levels. The dose-rate ranges
about 80–90 per cent of the
s at various locations in the
etailed data for individual loca-

Table 4. MEASUREMENTS ON THE OLYMPIC PENINSULA, WASHINGTON, OCTOBER 1–2, 1962

Town	Mean annual rainfall (in.)*	^{90}Sr (mc./mile^2)†	γ-Dose rates (μr./h) K	U	Th	Zr–Nb	Natural	Total Fall-out‡ (1)	(2)
Sequim	14	42·0	1·2	0·9	1·2	0·6	3·3	0·8	0·6
Sequim	14	—	1·5	0·9	1·4	0·8	3·8	1·1	1·2
Port Angeles	24	65·3	1·6	0·9	1·0	1·0	3·5	1·4	1·4
Port Angeles	24	—	1·2	1·1	0·9	1·0	3·2	1·3	1·2
Joyce	54	84·1	1·7	1·2	0·8	1·8	3·7	2·4	1·8
Clallam Bay	81	133	1·0	1·3	0·4	2·2	2·7	2·8	2·6
Forks	118	153	1·7	2·2	1·3	2·6	5·2	3·4	2·7
Forks	118	—	1·5	1·7	1·2	2·5	4·4	3·7	2·8
Forks	118	—	1·1	1·1	0·9	2·3	3·1	3·4	2·8

* 1960–1962 value (ref. 25). † October 1–2, 1962, soil determinations (ref. 25). ‡ (1) From photopeak calibrations: (2) from total energy measurements with natural component subtracted.

tions will be published in future reports from the Health and Safety Laboratory.

Most of the inferred natural γ-dose rates are in the range 5–9 μr./h, and the average for all locations surveyed is 7·0 μr./h. The dose-rate contributions from potassium-40 and the thorium series are generally comparable, usually amounting to approximately 80 per cent of the total natural level. The uranium series contribution seldom accounts for more than 25 per cent of the total natural γ-dose rate. High natural levels have been encountered in northern New Hampshire, Denver and Colorado Springs, Colorado, and in an area of North Carolina north-east of Raleigh. These high levels are attributable to high thorium and potassium content of the soils, particularly the former.

At almost every location, the observed fall-out γ-dose rate is a significant fraction of the total. Between July 1962 and September 1963, dose rates of 3–4 μr./h seemed to be typical of the eastern United States. Somewhat lower levels were encountered in some areas in the western States, which may be related to relatively less rainfall. For example, the measurements in the San Francisco Bay area were carried out after periods of very little rainfall. The highest fall-out readings were observed during the spring and summer of 1963, when levels of 4–6 μr./h were found at a number of locations scattered throughout the eastern states.

Beginning in May 1963, an effort was made to monitor the changes in fall-out γ-levels in the New York City area by repeated measurements at several locations. Three flat grassy areas in Westchester County, New York, were chosen, separated by about 5 miles from one another. The spectrometer readings indicated that the natural γ-dose rates at the three locations were all approximately 7 μr./h. The measured total γ-dose rates were generally slightly more than 12 μr./h until September. Our best estimates for the fall-out γ-levels at these sites are shown in Fig. 2. These data provide strong evidence that open field fall-out γ-levels in the New York area remained roughly constant at a high level ($\sim$ 5 μr./h) from at least May until September 1963 and then decreased, roughly exponentially with an apparent 'half-life' slightly longer than that of ^{95}Zr–^{95}Nb. This is consistent with the evidence provided by the field spectra that ^{95}Zr–^{95}Nb has been contributing 60–80 per cent of the fall-out dose rates during the periods of measurement.

During the 1962 survey trip to the Pacific coast, a specific effort was undertaken to obtain measurements on the northern part of the Olympic peninsula (Clallam Co.), Washington. Over a distance of approximately 50 miles, the mean annual rainfall varies by a factor of nearly ten from east (Sequim) to west (Forks); under such conditions one might expect a substantial variation in the fall-out

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tural γ-dose rates are in the erage for all locations surveyed contributions from potassium- es are generally comparable, roximately 80 per cent of the uranium series contribution than 25 per cent of the total gh natural levels have been New Hampshire, Denver and o. and in an area of North leigh. These high levels are n and potassium content of the r.

n, the observed fall-out γ-dose n of the total. Between July dose rates of 3–4 μr./h seemed rn United States. Somewhat ed in some areas in the western ted to relatively less rainfall. nents in the San Francisco Bay periods of very little rainfall. ngs were observed during the , when levels of 4–6 μr./h were ions scattered throughout the

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trip to the Pacific coast, a n to obtain measurements on mpic peninsula (Clallam Co.), ce of approximately 50 miles, ries by a factor of nearly ten Forks); under such conditions tial variation in the fall-out

levels, since fall-out deposition is strongly influenced by the quantity of rainfall. Alexander *et al.*[25] have found a clear correlation between strontium-90 deposition and mean rainfall-levels at five sampling locations in Clallam Co. Measurements of external γ-levels at these and several other sites in early October 1962 are summarized in Table 4. The increase of the fall-out γ-dose rates with mean annual rainfall is noteworthy, and the degree of correlation seems quite as good as that for the accumulated strontium-90 soil content. But care must be exercised here in coming to appropriate conclusions, since the quantity of relatively short-lived γ-emitters present depends on recent rainfall to a much greater extent than is the case with strontium-90.

The Forks locations are of particular interest since these measurements were made during or between periods of heavy rainfall. The spectra show a distorted potassium-40 peak at 1·46 MeV, which is clearly the result of a considerable lanthanum-140 contribution at 1·6 MeV. This implies substantial recent fall-out deposition; this fact is also indicated by the lack of agreement between the two methods of estimating fall-out dose rates. As mentioned previously, recent deposition generally implies a more nearly plane source than used in our model and thus more peak counts per unit dose rate for the various radioisotopes. Therefore, using our depth source model and the peak method, we would tend to overestimate the dose rate. If the band method were used to estimate the natural dose rate, the difference method would provide an underestimate of the fall-out dose rate at Forks, since the lanthanum-140 peak would fall in the *K* and *U* bands and produce an overestimate of the inferred natural dose rate. Under such conditions, the actual dose rate at Forks probably lies between those listed in the last two columns of Table 4.

In addition to the conspicuous 0·5 and 0·75-MeV peaks seen at all locations and the 1·6-MeV peak found in the Washington spectra, we have observed a small fall-out peak near 1·7 MeV in many of our late 1962 spectra which we have tentatively attributed to antimony-124. This has also been found in a few 1963 spectra. In no case were there sufficient counts to indicate a significant dose-rate contribution. The origin of this debris is probably the late 1961 Soviet test series, as balloon sampling at high altitudes (60,000–100,000 ft.) in Texas and Australia indicated the presence of antimony-124 throughout 1962 (ref. 26).

In general, the agreement between our two methods of determining the fall-out γ-dose rate indicates that the assumptions involved in carrying out the peak method of analysis are reasonable. Thus, practically all the fall-out γ-radiation during late 1962 and 1963 derived from ^{95}Zr–^{95}Nb, ^{106}Ru–^{106}Rh, ^{103}Ru–^{103}Rh, and ^{137}Cs, with the

^{95}Zr–^{95}Nb contributing 60–80 per cent of the fall-out dose-rate. This is consistent with Gustafson's results[27] during a comparable period in 1959, when more than 90 per cent of the inferred fall-out γ-dose rate at a location at Argonne National Laboratory was found to be derived from these isotopes. Peirson and Salmon[9] obtained similar results at several locations in Great Britain at about the same time.

The Health and Safety Laboratory has therefore developed techniques for the accurate determination of environmental γ-dose rates and the partial dose-rate contributions of the significant natural and fall-out emitters utilizing high-pressure ionization chamber and γ-spectrometric measurements directly in the field. These techniques depend on reasonable assumptions as to the distributions in the environment of the various radioisotopes and on relatively unsophisticated procedures for interpreting the spectral data.

Measurements at more than 200 sites in the United States indicate that the open-field γ-dose rates from natural sources do not vary over a wide range from place to place in this country, generally falling between 5 and 9 μr./h. In those areas where high natural levels (up to 20 μr./h) have been observed, high thorium and potassium content of the soil is generally responsible. The relatively small magnitude and narrow range of the observed dose-rate contributions from the uranium series are interesting results deserving of further study, and are probably related to the leaching of uranium-238 and radium-226 from weathered material and the migration of free radon-222 from the upper layers of the soil[15].

During the second half of 1962 and 1963 it was observed that γ-emitting fall-out in the environment had elevated the γ-background by a measurable amount at every location and that increases of 50 per cent or more in the total γ-level appeared to be quite common over open ground. The highest fall-out levels were observed during the spring and summer of 1963; the autumn 1963 readings were lower, and generally comparable with those a year earlier in the western States and in northern New England. A decline in fall-out levels set in at the New York City area sites in September of 1963 after at least four months of quite large elevations above the normal background-levels. These results are consistent with those of Burch *et al.*[14] in England between August 1962 and April 1963, who recorded with an ionization chamber somewhat elevated readings at one location during August–November 1962 and then a jump to roughly 50 per cent above normal γ-background in November, which was maintained except for the effect of snow cover until at least April 1963. There is also rough agreement with Gustafson's data[28], which seem to indicate a rather steady increase in fission product dose rate at a site at Argonne National Laboratory from 2 μr./h to 7 μr./h between September 1962 and July 1963 and then a

decline to 3 μr./h by October 1963. With the signing of the Test Ban Treaty, it is expected that the decline in fall-out γ-dose rates observed in late 1963 will continue, but at a much slower rate as the long-lived ^{106}Ru–^{106}Rh and ^{137}Cs replace ^{95}Zr–^{95}Nb as the dominant contributors.

Any assessment of the significance of the fall-out data presented here in terms of population exposure-levels should take into account the relevance of open-field dose-rate determinations to such considerations and the degree to which the years 1962 and 1963 can be treated as typical for conditions of substantial weapons testing. If we reduce our open-field fall-out measurements by a factor of two to account for the effect of structural shielding as suggested by Spiers[5], and by another factor of two to correct for weathering processes not taken into account in our measurements, it would appear that an increase of the order of 10 per cent in total external environmental radiation exposure has been experienced by the population of the United States during this two-year period. If this is reasonable, it seems probable that, during and shortly after periods of significant nuclear weapons testing, the exposure of the general population to environmental γ-radiation from deposited fall-out is not negligible in comparison with that due to the natural radiation environment.

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