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.

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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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1. Cosmic-ray ionization intensity as a unction 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.

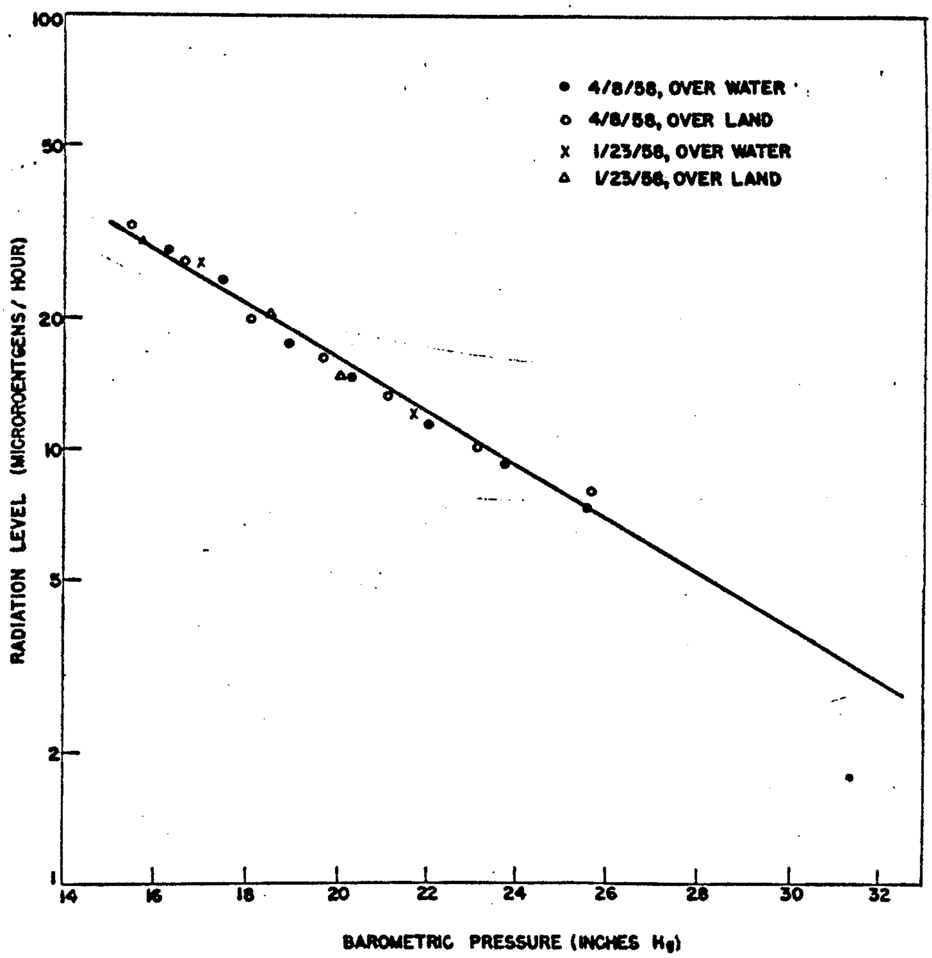

Fig. 1. Measurements of cosmic radiation ionization intensity made inside a C-47.

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 ± 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.	12.4–15.4 (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)	13.0
Wood frame, New Rochelle	10.1–11.0 (2)	13.8

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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