versity of Wisconsin. This study was aided by grants from the Research Committee of the Graduate School, University of Wisconsin, of funds supplied by the Wisconsin Alumni Research Foundation and by a grant from the National Science Foundation.

9 December 1957

Measurements of External Environmental Radiation in the United States

Recent interest in the dose to man from natural radioactivity has been stimulated by the assumption by many geneticists of a linear relationship between radiation dose and the incidence of genetic mutations. Although this has not been demonstrated at the low dose rates prevailing in nature, the likelihood of such a relationship has led to the suggestion that geographical variations in the frequency of spontaneous mutations may be correlated ultimately with differences in the radiation dose to populations (*1*). This question has recently been reviewed by Gopal-Ayengar (*2*).

The studies of the dose received by man from naturally occurring ionizing radiations can be divided into that received from external and internal sources. The dose to the germ plasm is primarily due to the external radiation, although one internal source, potassium-40, does deliver a dose to the reproductive organs amounting to about 15 mr/year (*3, 4*).

Studies of the radiation dose from external natural sources have been reviewed by Sievert (*3*), Libby (*4*), and Lowder (*5*), and extensive sets of measurements with particular emphasis on dwellings have been reported by Hultqvist (*6*) in Sweden. Although measurements have been made in this country by Hess (*7*) and Neher (*8*), no systematic study of the environmental radiation dose rate over an extensive area of the United States has been reported previously.

During the summer of 1957 our laboratory made measurements in the United States to establish the approximate range of population exposures to cosmic and terrestrial gamma radiation. 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 variations in the observed natural radiation levels produced by localized sources (for example, the proximity of granite buildings, brick paving, and fallout).

Measurements were made with a 20-lit., air-filled, polyethylene-walled ionization chamber at atmospheric pressure inside an automobile under essentially identical field conditions of loading and ionization chamber orientation. It had been established previously that the attenuation by the vehicle did not affect the measured values in an important way (about 5 percent). The ionization current was measured with a vibrating-reed electrometer, connected as a continuously reading voltmeter and driving a pen recorder. To shield it completely against beta radiation, the chamber was mounted in an aluminum container so that, including the polyethylene wall, the gas volume was enclosed by 1.08 g/cm^2 of material, corresponding to the Feather range of a 2.26-Mev beta particle.

As is well known, minute alpha contamination in an ion chamber at atmospheric pressure can produce an ion current which may be of the same order as the ion current being measured. For this reason it is important that the effect of the contamination be measured or that the alpha-produced current be suppressed. Several different methods have been used by previous investigators. In our measurements we have resorted to a technique which relies on the difference in electric fields necessary to effect total collection of ion pairs produced by particles of low and high specific ionization—that is, electrons from gamma or cosmic-ray interactions and alpha particles, respectively (*9*).

Readings were taken at 155 locations in 19 states, between New York and Utah. The natural environmental radiation levels encountered ranged from a low of 8.4 μr/hr along the Pennsylvania Turnpike to a high of 38.6 μr/hr at the summit of Pikes Peak (altitude 14,110 ft). A summary of the dose rates measured in the principal cities along the route is given in Table 1. Of the major cities listed, Denver had the highest natural background, an average of 18.5 ± 1.5 μr/hr; this level is almost twice that found in eastern and midwestern cities.

These measurements were made during part of the period of Operation Plumbbob, the 1957 series of United States continental weapon tests at the National Test Station in Nevada, and these tests influenced certain of the measured values. Elevated levels were encountered in eastern Arkansas (26.0 to 50.2 μr/hr) and in the Black Hills of South Dakota (22.0 to 33.8 μr/hr). That the initial elevated levels were attributable to fresh fallout was demonstrated by the reduction in the measured levels

Table 1. Environmental radiation levels measured in principal United States cities during August 1957. The number of observations for each range is shown in parentheses. Elevated radiation levels produced by localized sources are shown in the last column.

Location	Range of radiation levels (μr/hr)	Mean annual dose (mrad)*	Av. pressure (in.-Hg)	Atypical radiation levels (μr/hr)
Harrisburg, Pa.	9.6–11.9 (2)	88	29.8	
Pittsburgh, Pa.	9.8–13.9 (3)	96	29.2	
Cleveland, Ohio	10.5–11.8 (2)	91	29.4	
Toledo, Ohio	8.7–10.0 (2)	76	29.5	14.9 (over granite paving stone)
Chicago, Ill.	10.3–11.6 (4)	88	29.4	17.0 (adjacent to U.S. Post Office, of granite construction)
Madison, Wis.	10.1–10.4 (3)	84	29.1	
Minneapolis–St. Paul, Minn.	9.1–12.5 (4)	92	29.3	
Sioux Falls, S.D.	11.5–11.8 (2)	95	28.8	
Cheyenne, Wyo.	17.2–17.6 (2)	142	24.4	
Denver, Colo.	16.6–19.4 (10)	147	25.0	22.4 (between U.S. Mint and City and County buildings)
Colorado Springs, Colo.	19.3–22.3 (4)	168	24.2	
Grand Junction, Colo.	15.7–18.4 (3)	138	25.5	
Albuquerque, N.M.	13.8–14.5 (4)	116	25.2	
Amarillo, Tex.	12.9–13.6 (4)	108	26.4	
Oklahoma City, Okla.	9.9–10.5 (4)	84	28.7	
Tulsa, Okla.	10.8–11.6 (4)	92	29.3	
Little Rock, Ark.	12.8–13.3 (2)	106	29.7	
Memphis, Tenn.	9.4–11.0 (2)	83	29.8	13.3 (near brick apartment house)
Chattanooga, Tenn.	11.1–12.3 (2)	95	29.6	14.8 (near brick-faced motel units) 16.1 (on narrow business street; 8th between Broad and Market)

* Dose in soft tissue, assuming constant dose rate. 1 rad = 100 erg/g; 1 μr/hr = 8.152 mrad/yr.

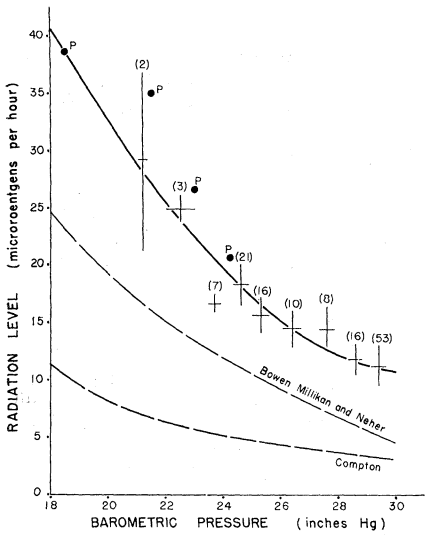

Fig. 1. Variation of environmental radiation dose rates with barometric pressure. The lower curves are for cosmic radiation intensities alone. The number of observations incorporated in plotting each point is shown in parentheses. Points marked *P* are observations on Pikes Peak.

by 50 to 75 percent upon resurvey about 3 weeks later. A resurvey of the Denver area almost 3 months later furnished results essentially identical with those of the earlier survey.

In general, one finds that the background radiation level increases as a function of decreasing barometric pressure. This is shown in Fig. 1, for which the data have been reduced in the following way. When the radiation levels were demonstrably elevated from local sources, the measurements were removed from consideration. The remaining 137 measurements were classified according to the barometric pressure at the time of measurement in intervals of 1 in. of mercury. The average values and standard deviations of the measured background and pressure for each pressure interval were then calculated; these results are exhibited in the figure. The number of observations for each pressure interval is indicated in parentheses. The four Pikes Peak observations are plotted separately as *P*, though they have also been included in the averages. The point with barometric pressure 21.2 in. of mercury has a large standard deviation in the measured radiation level, being derived from only two observations which differed substantially (Pikes Peak Highway, 35.0 μr/hr, and Leadville, Colorado, 23.5 μr/hr).

On the same figure are plotted the adapted ionization chamber measurements of the intensity of the cosmic radiation alone by Bowen, Millikan, and Neher (*10*) and Compton (*11*). The most important difference between these two sets of cosmic-ray data is the amount of filtration of the ion chambers used; in the first set, measurements were made in a thin-walled chamber (0.5 mm of steel), while Compton's measurements were made with the argon gas cavity shielded with 5 cm of lead and 2.5 cm of bronze in addition to the steel wall of the chamber.

It should be pointed out that even at sea level the numerical value of the total cosmic-ray intensity is not something on which there is universal agreement. Burch, in his critical review (*12*), concluded that the best value for the ionization intensity at sea level may be deduced from the experimental work of Clay. This value is 1.77 ion pairs/cm^3 sec (3.1 μr/hr) compared with Neher's value (*13*) of 2.74 ion pairs/cm^3 sec (4.8 μr/hr). Hess's value (*7*) of 1.96 ion pairs/cm^3 sec (3.4 μr/hr) falls between these two. It would appear that the discrepancies are too large to depend merely on differences in the thickness of the ionization chamber wall or on calibration technique.

If the results of our measurements are compared with the cosmic-ray data of Bowen, Millikan, and Neher, it is clear that a substantial part of the variability in mean outdoor radiation intensities over extensive areas in the United States is attributable to the variation in the intensity of cosmic radiation with altitude. Most of the measurements made at higher altitudes were obtained in Colorado, and the shift of the total radiation curve in Fig. 1 away from the cosmic-ray curve at higher altitudes may be due to a higher terrestrial radiation component in the mountainous areas of Colorado.

Expressed on an annual basis, our measurements indicate a range of approximately 70 to 175 mrad/yr for external environmental radiation dose rates in populated areas in the United States, with the lower dose rates prevailing in the more populated eastern and mid-western states. This compares with estimates made in the recent report of the National Academy of Sciences on the biological effects of atomic radiation (*14*), which gives an average annual background dose of about 135 mrad and a maximum dose of about 170 mrad in populated areas.

LEONARD R. SOLON, WAYNE M. LOWDER,
ALBERT V. ZILA, HARRIS D. LEVINE,
HANSON BLATZ, MERRIL EISENBUD
Health and Safety Laboratory,
U.S. Atomic Energy Commission,
New York

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20 February 1958

A Differentiation of Spontaneous Unit Firing in Subcortical Structures of the Cat's Brain

On many occasions, reports have attempted to establish a relation between the patterns of spontaneous discharges of neuronal units in the brain and the mass voltage fluctuations as recorded, for instance, in the electroencephalogram. Interesting observations have already been made which permit a differentiation in this respect among various types of neuronal behavior. For simplification, it may be possible to restrict the distinction to the existence of only two general categories. In subjects either without anesthesia or under light barbiturate anesthesia, one may observe (i) the production of bursts of high-frequency cellular spikes occurring in a more or less fixed phase relation to the local slow rhythmical activity or (ii) a relatively regular and continuous firing completely unaffected by the potential variations of the base line.

Typical samples of these two patterns are illustrated in Fig. 1*A*, which shows the simultaneous microelectrode recordings from two subcortical neurons of a cat under light Nembutal anesthesia. Such patterns are largely represented in various cortical and subcortical structures and, although a further differentiation could be achieved inside these groups by a finer analysis, the two extreme cases described here would conveniently define the more commonly encountered alternatives under the specified experimental conditions of recording.

On the assumption that these differences in spontaneous firing may assist in the recognition of functionally differing neurons or neuronal organization, or both, records of neuronal activity were systematically derived with microelectrodes from various diencephalic and mesencephalic regions of the cat's brain. The animals were prepared under ether anesthesia and paralyzed with Flaxedil. The slow wave activity captured by the microelectrodes was observed as it naturally