8 July 1955, Volume 122, Number 3158

SCIENCE

Dosages from Natural Radioactivity and Cosmic Rays

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The radiation dosages that people receive from the natural radioactivities and cosmic rays have been calculated and are given in Tables 1, 2, 3, and 4. Some direct observations are given in Table 5.

Table 1 gives the dosages in milliroentgens per year for exposures at various altitudes directly over ordinary granite, typical sedimentary rock, and open oceans. Surface dosages decrease with height above the ground because of air absorption; 50-percent reduction occurs for every 370 ft (*1*). For comparison purposes, it is interesting to note that in the United States, the average exposure *rate* from total fallout from atomic tests on 1 Jan. 1955, was about 1 mr/yr (*2*). The total dose during 1954 probably averaged about 15 mr (*2*), principally because of the Pacific tests in the spring.

The values listed in Table 1 were calculated on the following basis. The roentgen was taken to be 100 ergs of energy per gram of water. (Actually this definition is that of the rad, the internationally recognized unit of radiation dosage. For gamma rays it is nearly equal to the roentgen, which is 93 ergs/g.) The absorption coefficients of all radiations in tissue were taken as being equivalent to those of water. The dosages from the natural radioactivities in the earth were calculated on the approximation that the energy absorbed per gram by the human body on the surface of the earth is, to a sufficient approximation, equivalent to that absorbed per gram by the top layers of the rock of the earth's surface itself from the gamma radiation emitted by the rock (*3*). In other words, the total gamma-ray energy produced in a gram of granite from the thorium, uranium, and potassium contained was taken to be equal to the energy absorbed per gram of human tissue in the human body on the surface, except that a factor of 2 was used to correct for the geometric loss. It was interesting to observe that this simple method of calculation gave results in good agreement with those based both on separate consideration of each of the complicated radiations emitted by thorium and uranium in the rocks and on the use of the individual absorption coefficients for these radiations in tissue, together with correction for the "build-up" factors as the radiation is scattered and diffuses out of the rock (*4*).

The abundances of uranium, thorium, and potassium in granite were taken as 4×10^{-6} g/g (*1*), 13×10^{-6} g/g (*1*), and 0.03 g/g, respectively (*1*). In selecting these numbers, it was realized that these were only averages and that fluctuations around these values do occur, that uranium contents as high as 200 ppm have been found in granite, and that thorium has been found as abundant as 500 ppm in some granites.

For sedimentary rocks, the general average figure of one-fourth of the values quoted for granites has been used. It is realized, however, that this is very approximate, because the amounts of the various radioactive minerals in the sedimentaries fluctuate widely. The abundances of uranium and potassium in sea water were taken, respectively, as 1.3×10^{-9} g/g (*1*) and 3.5×10^{-4} g/g (*1*). The abundance of potassium in the human body was taken as 2×10^{-3} g/g (*5*), and the abundance of carbon in the human body was taken as 18 percent. For the calculation of the dosage from radium assimilated in drinking waters throughout the normal lifetime, the bone weight was taken as 10 percent for the adult man. But for relatively brief periods of assimilation when the radium would be expected to be concentrated in the small volumes of the bone most metabolically active, the figure of 1 percent was used. All these numbers on the human body were taken as being equivalent to those of the "standard man" (*6*).

The dosages resulting from cosmic radiation were calculated from the ionization chamber data of Millikan *et al.* (*7*). From these data the dosages were calculated at altitudes up to 20,000 ft and at the latitude of 55°N (geomagnetic) as well as at the geomagnetic equator. The results are given in Table 2. It should be mentioned that the biological effects per unit energy may be larger for cosmic radiation, because it consists of high-energy particles rather than gamma radiation.

The natural radioactivity in the human body contributes the dosages given in Table 3. Of the 19-mr/yr dosage from potassium, 17 mr/yr is from the beta rays of the potassium itself. These were taken to be of a mean energy 40 percent of the maximum energy of 1.36 Mev. The specific activity of natural potassium was taken as 1800 beta rays per gram, per minute and 180 gamma rays of 1.45-Mev energy per gram, per minute (*8*). The gamma rays that contribute the remaining two units of the dosage of potassium were calculated on the basis of the assumption that only half of the gamma-ray energy is actually absorbed in the body. This leads to the result that in a packed crowd the radioactivity from the potassium in one's neighbors' bodies contributes an additional dosage of 2 mr/yr.

The dosage from carbon was calculated on the basis of the assumptions that the body is 18-percent carbon; the specific radioactivity of carbon is 15 disintegrations/g, per minute (*9*); and that the mean energy of the beta radiation is 40 percent of the maximum energy of 167 kev (*8*).

In Table 4, various ordinary but somewhat unusual circumstances are used to illustrate the types of exposure that can occur in normal living. A wrist watch worn 24 hr/day that has a luminous dial assumed to have 1 μc of radium per watch—a figure perhaps slightly larger than the average—would give the central body, including the sex organs, a dosage of about 40 mr/yr. An airplane pilot flying 24 hr/day with an instrument panel consisting of 100 dials with 3 μc of radium each would receive, at an aver-

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Table 1. Total radiation dosages from normal background radiation (mr/yr)

Altitude of ground surface (ft)	Ordinary granite		Typical sedimentary rock		Open ocean	
	Equator	55°N	Equator	55°N	Equator	55°N
Sea level	143	147	76	80	53	57
5,000	150	170	83	103		
10,000	190	230	123	163		
15,000	270	350	203	283		
20,000	414	560	347	493		

age distance of 1 yd, a dosage of 1300 mr/yr.

In order to check whether the dosages calculated here and given in Tables 1 to 4 are essentially correct, some direct measurements reported by various observers are given in Table 5. They agree reasonably well with the external component of the total dosages given for sea level in Table 1—the residues after subtracting 20.5 mr/yr, the dosage from body radioactivities given in Table 3.

It is interesting that the variations in natural dosage are large and under certain conditions the natural dosage may be nearly 100 times higher than the minimum—the dosage of seafarers. The fallout dosage rate in the United States on 1 Jan. 1955—1 mr/yr—was only 2 percent of this lowest natural dosage rate. Of course, during a test period when bombs are fired, the fallout dosage rates may approach, or somewhat exceed, the natural dosage rate for a few days before decay and weathering processes reduce them in a few weeks to rates that are small percentages of the natural background.

Table 2. Cosmic ray dosages

Altitude (ft)	Dosages (mr/yr)
Sea level	33 to 37
5,000	40 to 60
10,000	80 to 120
15,000	160 to 240
20,000	300 to 450

Table 3. Radiation dosages from the natural radioactivity of the human body

Source of radioactivity	Dosage (mr/yr)
Potassium	19
Carbon	1.5
Radium (bones only), uniform distribution	6.7
Radium (bones only), nonuniform distribution	67*

* The radium content of the human body is based on data of A. F. Stehney of Argonne National Laboratory.

References and Notes

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Table 4. Radiation dosages in various ordinary circumstances

Radiation source	Location	Dosage (mr/yr)
Wrist watch (1 μc of Ra per watch)	Central body, including sex organs, at average distance of 1 ft	40
Luminous dials in airplane cabin (100 dials with 3 μc of Ra each)	Pilot is taken to be at an average distance of 1 yd from the dials	1300
X-rays (*10*)	Lumbar spine, anterior-posterior	1500 each
	Lumbar spine, lateral	5700 each
	Pregnancy, anterior-posterior	3600 each
	Pregnancy, lateral	9000 each
Uranium ore (0.1 percent —the minimum accepted by the AEC for purchase)	Flat surface ground	2800
	Mine with all walls of ore	5600 (neglecting radon)
Phosphate rock (commercial fertilizer 0.01 to 0.025 percent U)	Flat surface ground	280–700
People	Packed in crowd	2

Table 5. Experimental data for hard background radiation (mr/yr)*

Observer	Cosmic rays	Gamma rays		Cosmic and gamma rays (total)	Location
		From air	From ground		
Sievert and Hultquist	44			121–150	Streets of Stockholm
				104–182	Over igneous rocks, Sweden
				94	Clay soil (*11*)
				104	Wood houses (average center of room)
				145	Brick and concrete houses (types 1, 2) (*11*)
				296 (max., 520)	Brick and concrete houses (type 3) (*11*)
Cowan				98	Outdoors, Brookhaven, N.Y., measured (*12*)
Hess and Vancour	34	2	53	90	Outdoors, Fordham Univ. campus, N.Y., 1 m above ground (*13*)
Burch	31–34		62	94–96	Leeds, England (*14*)

* Kindly collected by L. D. Marinelli of Argonne National Laboratory.