wiser, therefore, not to equate relative heterothallism to preferential cross-karyogamy for the time being.

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26 August 1954.

Radioactivity of the Human Being

We have obtained some data in this laboratory which supplement, and to some extent clarify, the article by A. T. Krebs [*Science* 119, 429 (1954)]. The gamma-ray emission from living subjects has been studied using a differential high-pressure ionization chamber apparatus (*1*). Three groups of subjects have been examined: (i) 11 male and 3 female medical students, resident locally, aged 19 to 20 yr; (ii) 11 males of widely scattered residence (mostly in England), aged 26 to 41 yr (average, 34 yr); and (iii) 4 males, resident locally, aged 60 to 79 yr (average, 70 yr). No individual in these groups had any known occupational or therapeutic exposure to radioactive materials. If in each case we assume that the gamma-ray emission may be attributed entirely to potassium-40, then we may express our results in terms of the percentage by weight of potassium in the body. The following average percentages were obtained: group (i), $(0.21_5 \pm 0.01)$; group (ii), $(0.21_2 \pm 0.01)$; and group (iii) $(0.21_5 \pm 0.02)$. Shohl (*2*) quotes 0.21_5 percent from chemical measurements. Edelman *et al.* (*3*), from measurements of "exchangeable" potassium (said to be approximately 5 percent less than total), found an average of 0.18_3 percent for 33 males and an average of 0.16 percent for 14 females. All these results are inconsistent with the figure of 280 g of potassium per body (corresponding to 0.4 percent) quoted by Krebs from Grosse and Libby (*4*).

For the purpose of comparison with Krebs' Table 2, we may express our findings in terms of the equivalent mass of radium, which, distributed throughout the body, would produce the response observed with our apparatus. Thus, for a 70-kg man, the observed gamma activity is equivalent to that which would be emitted by approximately 140×10^{-10} g of radium in equilibrium with its decay products. Hursh and Gates (*5*) determined the actual radium content of cremation ashes and deduced an average figure of 1.2×10^{-10} g for the radium content of the body. This burden, if typical of persons living outside areas of high natural radioactivity, would contribute only about 1 percent of the gamma-ray emission observed by us.

It appears, therefore, that most of the gamma-ray emission from the "unexposed" subjects tested by us may be attributed to the potassium content of the body. Within the rather wide limits of experimental error and biological variability, we find no significant change in total gamma-ray emission over the age range of 19 to 70 yr.

Krebs concludes that "the amounts of radioactive substances deposited in the body, however, exercise an irradiation burden on the body close to the accepted tolerance figures." It would be interesting to be given the magnitude of the tolerance figures that Krebs has in mind and to know whether any distinction is made between the dose to the general soft tissues of the body, including the gonads, and the dose to limited parts of the body, such as osteocytes. The latter will depend markedly upon the presence of bone-seeking radioactive elements. In Table 1 we give estimations of the dose rates to these two types of body tissue from "natural" sources and compare them with the permissible levels for large populations, given by the International Commission on Radiological Protection (*6*), and with other relevant dose data. The table lists the dose rates from cosmic rays, local gamma rays (Leeds situation), body potassium and body radiocarbon, calculated by us in an earlier publication (*7*) and now expressed in millirads per week. Dose rates to osteocytes from radium burdens uniformly distributed throughout the skeleton are also included, based on calculations by Spiers (*8*) and converted to milli-

Table 1. Dose rates to body tissues.

Radiation-source	Tissues affected	Dose per week (mrad)	Dose per week (mrem)
General irradiation			
Cosmic radiation	Soft tissues, including gonads	0.32	0.32
Local gamma radiation (Leeds)		1.12	1.12
Postasium-40		0.35	0.35
Carbon-14		.02	.02
		1.8	1.8
Radium in body			
1.2×10^{-10} g (Hursh and Gates)	Osteocytes	0.1	1.0
140×10^{-10} g (Krebs)	Osteocytes	11	110
100×10^{-10} g (I.C.R.P. maximum permissible level for large populations)	Osteocytes	8	80

rads per week and to millirems per week, using the newly proposed value of 10 for the R.B.E. for alpha radiation (*6*).

A "natural background" dose to soft tissues and gonads of 2 mrad/wk may be compared with the figure of 30 mrad/wk for large populations proposed by the International Commission. It amounts to about 3 rad per generation time of 30 yr. This is one-thirtieth of the dose found by Russell (*9*) to produce a mutation rate in mice equal to that occurring spontaneously and considered by Muller (*10*) to be the best available data to apply to man.

The dose from the body radium burden is unlikely to have any genetic consequences, but it can be compared with the dose level implied by the recommendations of the International Commission. The maximum permissible body burden of 0.01 μc suggested for large populations is estimated by us to produce an average dose rate to osteocytes of 80 mrem/wk. The dose rate of 1 mrem/wk associated with the radium burdens reported by Hursh and Gates is small compared with this value. Only if the entire radioactive burdens reported by Krebs were attributable to radium as such, and were typical of large populations, would the dose rates to osteocytes be of the order suggested as the maximum permissible level by the International Commission. The dose rate of 0.1 rem/wk calculated for the average radium burden reported by Krebs may be contrasted with values estimated as ranging from 45 to 350 rem/wk for osteocytes in the bones of some persons known to have developed bone tumors following retention of radium amounts of the order 8 to 50 μg (*8*).

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26 July 1954.

The communication from Burch and Spiers is a welcome contribution to the present state of the problem. It clarifies my article to some extent, but also calls to mind the complexity of the problem. This becomes apparent in briefly viewing some of the latest reports on the incorporation of naturally occurring radioactive substances.

While Sievert (*1*), measuring the gamma activity of the intact human being with a device similar to that used by Burch and Spiers, reported values in gamma-radium equivalent, giving the radium content at 50 yr of age as about 60×10^{-10} g of radium or, assuming an excretion of 25 percent radon, as 80×10^{-10} g of radium, Burch and Spiers attribute the measured gamma activity primarily to the K^{40} content of the body. Recent measurements by Reines *et al.* (*2*) with a special scintillation counter arrangement for total body measurements on the intact human being support this interpretation, provided that the potassium content of the human body is close to 0.2 percent of the body weight. Unfortunately, knowledge of the exact potassium content of the body is not much clearer than that of the radioactivity of the human being (*3*). The values that have been reported so far for the potassium content of the body range from 0.1 (*4*) to 0.35 percent, as quoted by Grosse and Libby (*5*).

In addition to K^{40}, other gamma-emitting substances contribute to the total body activity as shown by measurements of people from different regions and of people professionally engaged in work with radioactive material. These people show, while in actual contact with the material, a high activity of their clothes and an appreciable external contamination of the body. There is, however, one case reported by the Los Alamos group (*2*) with 0.01 μc radium content which may be interpreted as natural occurrence despite the fact that the subject has worked for many years—apparently very carefully—with radium, thorium, and mesothorium.

Another critical figure in the discussion of the radium content of the human being is the excretion rate of radon from the body. Detailed studies by Martin and Ferguson (*6*) show a great influence of physiological factors, especially of posture, on the radon output, the values for supine, seated, and erect posture being 1, 0.79, and 0.50, respectively.

Controversial also is the question of the influence of age on the body content. Sievert reports a probable increase with age, whereas Burch and Spiers do not find significant changes with age.

The statement that the amounts of radioactive substances deposited in the body exercise an irradiation burden on the body close to the accepted tolerance figures has to be viewed in connection with the assumptions of the kind of radioactive materials under discussion and with their specific, physical, and biological properties.

In the case in which the whole irradiation burden is attributable to radium as such, Burch and Spiers have already given the values. Under this condition a body content of 140×10^{-10} g of radium would deliver a dose rate to the osteocytes of the order suggested as the maximum permissible amount, namely 80 mrem/wk for 100×10^{-10} g of radium. If the activity were caused merely by potassium, the gamma radiation of about 150 g of potassium would be equivalent to that emitted by about 140×10^{-10} g of radium, a figure again close to the accepted standards.

Provided that one has uniform distribution of the incorporated substance and does not consider bone-seeking or nonbone-seeking properties of the proper radioactive element, similar calculations can be made for beta-emitting and alpha-emitting isotopes. Using the number of calories released per hour by 1 g of radium and its decay products (*7*), one can show that for alpha-emitting Po^{210}, for example, 1×10^{-8} curie of radium is equivalent to 0.6×10^{-8} curie of Po^{210}. Since 0.02 μc of Po^{210} is accepted as the maximum permissible amount per 70 kg of body weight (*8*), this again demonstrates how close, under the mentioned generalizing assumptions, the radioactivity of the human beings may come to the permissible amounts.

It must be emphasized in this connection that our present knowledge and experience are not great enough to justify making final statements. This becomes evident from recent studies in such a relatively simple field as the incorporation of radon by mouth as well as by inhalation. The role of the daughter-products connected with the decay of radon and/or thoron has surely been discussed frequently and thoroughly in the past (radontherapy, uranium mines, radium factories). However, it was not until 1951 that Bale and his coworkers (*9*) showed and discussed the role of the daughter-products, present in the air in a more or less general equilibrium with the radon, in considering the total dose delivered to the lungs and the body after incorporation of radon. Calculations as well as experimental studies by Shapiro (*10*) with rats, dogs, and models for the human being showed that these daughter-products constitute an effective dose many times higher than expected. Rats, breathing an atmosphere containing 10^{-9} curie/liter of radon, showed an average effective dosage received by the lungs from inhaled radon daughter-products amounting to about 330 mrem/hr, whereas the dosage from the inhaled radon and from the daughter-products of the radon molecules decaying in the lungs amounted to only 9 mrem/hr. Similar conditions hold, as reported by Aurand and Schraub (*11*), for orally incorporated radon in aqueous solutions, since, depending on the conditions, the solutions, as well as the naturally occurring waters, contain the daughter-products of radon in equilibrium in greater or smaller amounts.

The impact of these findings, not only on radon tolerance problems, but also on the question of the radioactivity of the human being, is obvious. In order to promote knowledge in the field the following studies may be recommended:

1) Measurement of the radioactivity of as many people as possible from different regions of the globe with the modern total-body activity measuring devices.

2) Measurement of the kinds of radioactive substances in the body, especially with regard to alpha-emitting, beta-emitting, and/or gamma-emitting elements.

3) Detailed invesigations of the radioactive materials incorporated daily by human beings from air, water, and food.

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27 September 1954.

Detection of M-Regions in Geomagnetic Data

The detection of 27-day recurrent geomagnetic disturbances, generally attributed to charged corpuscles ejected from the solar surface, has occupied the attention of many authors. Most have ascribed the source of these corpuscles to hypothetical stable regions of the solar surface that have a synodic rotation period of about 27 days (*1–4*). Bartels (*5*) earlier gave the name "M-regions" to such unidentified regions because of their geomagnetic effect.

We have recently undertaken studies (*6*) of the correlation between trends of geomagnetic disturbance ratings K_p and the locations of regions of bright coronal line emission around centers of heightened solar activity. Our work will be reported separately. We found, for a marked period of recurrent geomagnetic activity from July 1952 through June 1953, confirmation of the results of Allen (*1*), Bruzek (*3*), and others which suggest that the M-regions are to be identified with extensive undisturbed areas of the solar disk where the coronal emission intensities are low, and that the effect of the coronal maxima and other phenomena of moderate or weak active centers is to diminish geomagnetic disturbance activity 3 days after central solar meridian passage of these regions.

We interpret this diminution an denhancement of geomagnetic disturbance as modification of the density of flow of the responsible corpuscular streams by the physical conditions around the active center. The active centers, we suggest, divert the corpuscular flow

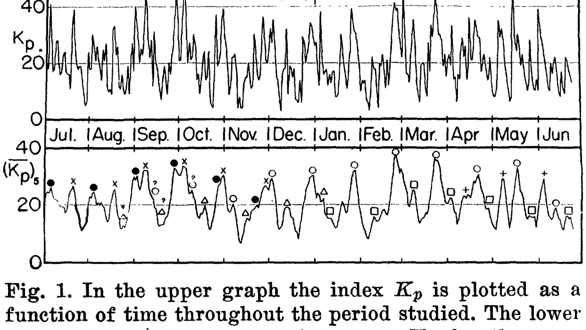

Fig. 1. In the upper graph the index K_p is plotted as a function of time throughout the period studied. The lower graph shows the 5-day running mean K_p for the same period. The different symbols represent the different M-regions. Question marks refer to dubious members of recurrent series.