LETTERS TO THE EDITORS

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NOTES ON POINTS IN SOME OF THIS WEEK'S LETTERS APPEAR ON P. 517.

CORRESPONDENTS ARE INVITED TO ATTACH SIMILAR SUMMARIES TO THEIR COMMUNICATIONS.

Quantitative Comparison of the Biological Effects of Neutrons and other Ionizing Radiations

A CONSIDERABLE number of tissues have been exposed to very high energy Be-D neutrons (~ 12 Mev.) with the help of cyclotrons, in the United States. The published values of the ratio γ/N of the gamma-ray to the neutron doses for a given biological effect range from 2 to 8. These ratios should be comparable among themselves, but since the neutron doses were measured in arbitrary units they cannot, without further experiment, be regarded as indicating the ratio of the absorbed neutron and gamma-ray energy. Two investigations have been reported in which an attempt has been made to measure this quantity. Zimmer¹, using Li-D neutrons, found the ratio of gamma-ray to neutron energy necessary to produce the same increase in mutation rate in *Drosophila* sperm to be $\gamma/N = 0.7$, whereas for the lethal effect on the bean root we² have found $\gamma/N = 11$. Comparable procedures were adopted for the estimation of the neutron energy absorbed in the tissue in the two cases, and these were roughly checked by the exchange of ionization chambers³.

Before attempting any biological interpretation of such a striking difference in the sensitivity of bean roots to gamma-rays and neutrons we have considered whether any known physical process could increase the energy absorption of a given beam of neutrons in tissue appreciably above the value which we have estimated. This value takes into account the recoil atoms of hydrogen, carbon, oxygen, and nitrogen, which contribute respectively 92 per cent, 1.7 per cent, 5.2 per cent, and 0.4 per cent of the total estimated energy absorption, and the disintegration of nitrogen, which adds a further 0.4 per cent. The interaction of fast neutrons with nearly forty elements has been measured by various authors⁴, including all elements, other than the inert gases, up to and including calcium. The energy absorbed per unit mass of the element by the process of nuclear recoil is maximum for hydrogen, and falls steadily to 1 per cent of this value for calcium, and 0.05 per cent for lead. In some cases, for example lithium, a single atomic disintegration together with the subsequent decay of the unstable nucleus, may liberate more than ten times as much energy as that of the average recoil hydrogen atom. Such atoms, however, are present in tissue in altogether too small amounts to make an appreciable contribution to the total energy absorption, and a careful study of the data makes it fairly certain that in the case of irradiation by D-D neutrons no atomic disintegration or induced radioactivity is likely to make a larger contribution than that estimated above for nitrogen.

Lest any of the minor atomic constituents of protoplasm had been overlooked, the matter was tested experimentally. Grass tips were incinerated with nitric acid so as to obtain a fifteen-fold concentration

of the non-volatile constituents. This ash was strongly irradiated for thirty minutes and tested (a) by insertion into a large ionization chamber connected to a Lindemann electrometer, (b) by a Geiger counter, for induced radioactivity. Measurements were commenced 30 sec. after the end of the irradiation. Method (b) showed some radioactivity. By introducing uranium into the position occupied by the ash it was possible to estimate the energy liberation in tissue corresponding to any given observed activity and decay constant. This made it clear that there was no element of period greater than ~ 3 sec. present in the irradiated ash which, either during irradiation or the subsequent five days*, could make any appreciable contribution to the energy absorption in this tissue. To test for short-period activity the ash was applied as a thin layer to the inside of a small electron metal ionization chamber, with 15 per cent by weight of dextrin as a binder. When irradiated, the difference between the observed ionization and that to be expected from the chamber plus dextrin represented only 7 per cent of the total energy absorption in tissue.

We are thus unable to find any reason for supposing that our estimates of neutron energy absorption in tissue are seriously in error. Probably the explanation of the greatly increased sensitivity of certain tissues to neutron, as compared with gamma-ray energy, must be sought in terms of specific relationships between the distribution of ionization and biological structure. It is very desirable, however, first to know whether neutron and gamma-ray energy are equally efficient in producing simple chemical changes, and this we are in process of investigating.

We gratefully acknowledge the financial assistance of the British Empire Cancer Campaign.

J. H. GRAY.

J. READ.

The Mount Vernon Hospital
and the Radium Institute,
Northwood, Middlesex.
July 29.

* The period during which the growth of the beans was observed.

¹ Zimmer, *Str. Th.*, 63, 517; 63, 523 (1933).

² Gray, Read and Mottram, *NATURE*, 144, 479 (1939).

³ Gray and Read, *NATURE*, 144, 439 (1939).

⁴ Ladenburg and Roberts, *Phys. Rev.*, 59, 1190 (1936). Kikuchi and Aoki, *Phys. Rev.*, 55, 103 (1939).

Scattering of D-D Neutrons

EXPERIMENTS hitherto performed on the scattering cross-sections of various substances for D-D neutrons have led to fundamentally different results. Most observers have found that the cross-section σ increases regularly with the atomic number, and some have deduced from their results the variation with Z of ξ , the 'sticking factor'. Kikuchi and Aoki and collaborators¹, however, have observed a periodic