Note on the Biological Effects of Densely Ionizing Radiation

Experiments with densely ionizing radiation offer an interesting possibility of testing some consequences of the so-called target-hypothesis of the biological action of radiation. As has been pointed out by Kingdon and Tanis[1] high concentration of ionization may be obtained by using either very great intensities of radiation or else radiations with very dense spatial distribution of ionization along the track of a primary or secondary particle. After describing their most interesting experiments with very high radiation intensities, the authors give some theoretical considerations on the possible influence of spatial density of ionization on the biological effect and are led to the conclusion that no appreciable influence is to be expected in such reactions which require only one ionization to occur within a certain target volume (e.g., the production of gene mutations[2]). This conclusion seems to us to be open to doubt because it would hold only if the radiation doses in question were such that the majority of all atoms present would be ionized with a probability equalling unity. Actually the dosages are of the order of 1000 r, producing 2×10^{15} ion pairs per cc of water and ionizing every 10^8th atom. In order to estimate the possible influence of spatial ionization density it seems, therefore, sufficient to make a determination of the probability for one ionization to occur within a certain volume (target volume) when the same total number of ion pairs is produced by different types of radiations. The size of the target volume for gene mutations varies according to the experimental technique used for their detection between 10^2 and 10^6 atoms,[3] but is always smaller than the average volume of 10^8 atoms within which an ionization occurs at a dose of 1000 r. It is therefore obvious that not every target volume is "supplied" with one ionization by a dose of 1000 r and that the probability of a given number of ionizations occurring within as many target volumes as possible is greatest when they are distributed homogeneously in space and not crowded along a track. To illustrate this it may be mentioned that the length of all tracks of secondary particles (Compton electrons and recoil protons, respectively) which are produced by the same dose of 1000 r within 1 cc of water is about 100 times longer for gamma-rays than for fast neutrons. A differential biological action of gamma-rays and neutrons is therefore to be expected irrespective of the number of ionizations per target volume required to bring about the biological change. It has, in fact, been observed not only in reactions requiring two or more ionizations per target volume (Zirkle and co-workers[4]) but also for one-hit reactions such as the production of gene mutations[5]) (Fig. 1).

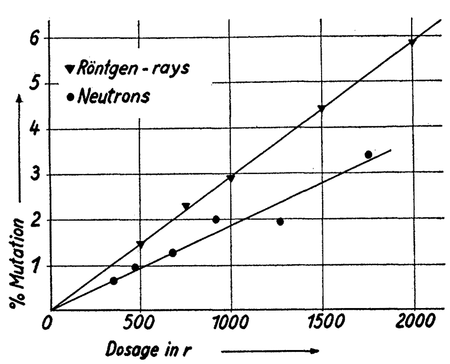

FIG. 1. Differential biological action of Röntgen rays and neutrons as a function of dosage.

K. G. ZIMMER
N. W. TIMOFÉEFF-RESSOVSKY

Genetics Department,
Kaiser Wilhelm Institute,
Berlin-Buch, Germany,
January 7, 1939.

[1] K. H. Kingdon and H. E. Tanis, Jr., Phys. Rev. **53**, 128 (1938); K. H. Kingdon, P. A. Zahl, C. P. Haskins and H. E. Tanis, Radiology **31**, 52 (1938).
[2] N. W. Timoféeff-Ressovsky, K. G. Zimmer and M. Delbrück, Göttingen Nachrichten N. F. **1**, 189 (1935).
[3] N. W. Timoféeff-Ressovsky and M. Delbrück, Zeits. indukt. Abstammungs- u. Vererbgsl. **71**, 322 (1936).
[4] R. E. Zirkle and P. C. Aebersold, Proc. Nat. Acad. Sci. **22**, 134 (1936); R. E. Zirkle, Occasional Publications A. A. A. S. No. 4, 220 (1937); R. E. Zirkle, P. C. Aebersold and E. R. Dempster, Am. J. Cancer **29**, 556 (1937); R. E. Zirkle and I. Lampe, Am. J. Röntgenol. **39**, 613 (1938).
[5] N. W. Timoféeff-Ressovsky and K. G. Zimmer, Naturwiss. **26**, 362 (1938); K. G. Zimmer, Strahlentherapie **63**, 517 (1938); K. G. Zimmer and N. W. Timoféeff-Ressovsky, Strahlentherapie **63**, 528 (1938).

Theory of Electrodisintegration of Beryllium

A disintegration or ionization of a nucleus by fast electrons can occur provided the energy of the electrons exceeds the binding energy of one of the constituents of the nucleus. The lowest threshold values occur for the beryllium nucleus and the deuteron. According to recent data[1] the threshold value for beryllium should be 1.65 Mev. The process for the electrodisintegration is the following one:

$$Be^9 + e_V = Be^8 + n^1 + e_{V'},$$

where V and V' indicate the voltage of the electrons before and after disintegration. The Be^8 nucleus disintegrates almost instantly into two slow alpha-particles.

For the calculation of the cross section it was assumed (based on the known theoretical work on the structure of light nuclei) that in the Be^9 nucleus a neutron is bound in a p state. The process taking place when an electron collides with a Be^9 nucleus can be described as follows. The electron collision causes the formation of an intermediate Be^9 nucleus with a neutron bound in an s state of the continuous spectrum leading to a disintegration and a spherically symmetrical distribution of the ejected neutrons.

The cross section was calculated both by using Møller's method and the semi-classical method. The order of the magnitude of the cross section for the electrodisintegration turns out to be:

$$\sigma_{el} \sim \alpha \cdot \sigma_{photo}; \qquad \alpha = 1/137.$$

For a voltage slightly above the threshold: σ is approximately 10^{-31} cm^2, in agreement with the experimental data reported below by Collins, Waldman and Polye.

EUGENE GUTH

Department of Physics,
University of Notre Dame,
Notre Dame, Indiana,
February 1, 1939.

[1] S. K. Allison, E. R. Graves, L. S. Skaggs and N. M. Smith, Phys. Rev. **55**, 107 (1939).