

destruction of some of the component cells. Furthermore, it appears that under certain conditions multiple impacts on the target area are required in order to produce lethal effects. However, extensions of this method of approach to the problem meet with increasing success in explaining the effects of radiation in many-celled tissues.

C. INJURIES IN HIGHER FORMS OF LIFE

When we come to more complicated organisms and, in particular, to the human body, the lethal effect of ionization on individual cells plays the dominant role in the injuries produced. An additional factor enters, however, in that the various groups of cells in the organism co-operate to repair the damage so that the destroyed cells may be replaced. Consequently the human body may be exposed repeatedly to intensities of radiation that destroy many individual cells without producing a permanent bodily injury, if sufficient time for recovery intervenes between exposures, no one of which is sufficient to overburden the restorative processes. It is on this fact that the commonly accepted ideas regarding tolerance limits of exposure to radiation are based. However, not all types of cells in the human body can co-operate to repair damage. For example, parts of the eye, brain, and most muscular tissues are unable to produce new tissue to replace that which has been destroyed. Great caution must be exercised to prevent exposure of these parts to excessive radiation.

D. GENETIC EFFECTS OF RADIATION

In recent years biological investigations have revealed that certain kinds of injury may occur to cells in the human body that are more complicated than the outright destruction of a cell or of a group of cells. This new information has come from the study of the genetic effects of radiation. These studies show that radiation produces a definite effect on the structure of the chromosomes, the threadlike structures in the cell nuclei that control the characteristics of the cell, and, if it is a cell that later divides, control also the characteristics of its descendants. This control is accomplished by an intricate system of elements, called genes, in the chromosomes, under the assumption that a normal cell has a definite set of chromosomes with an equal number of genes arranged in a particular way in the chromosomes for each type of cell. The effect of the radiation is to alter or destroy either the chromosome, or genes, or both.¹ The result is a mutation in which subsequent cells resulting from division of the affected cell are different from the parent cell. This effect has been proved many times experimentally, using organisms which reproduce rapidly, such as the fruit fly. For man this genetic effect of radiation has two important implications. In one case, cells altered in this way may produce abnormal organs in the body. In the other, if the change has been produced in a germ cell, subsequent offspring

¹ G. Failla, *J. Appl. Phys.*, 12, 279 (1941).

may develop abnormally. The importance of these possibilities becomes more prominent in the light of the knowledge that mutational changes are irreversible; there is no recovery. And if a certain dose of radiation will produce a certain percentage increase in mutations, it does not matter whether this dose is administered over a few days or a few years.² This is illustrated in Figure 1, which shows that there is no variation in the mutation rate for a given dose administered over a variety of periods.

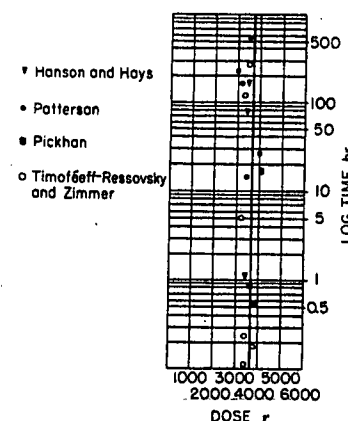


Figure 1. The heavy vertical line, drawn to represent an average of the observations, shows that the mutation rate for *Drosophila melanogaster* is independent of a time factor when a given dose of radiation is administered over various different periods of time.² From radiation experiments of the authors listed, the dose of radiation in *r* that will produce an increase of 10 per cent in the sex-associated mutation rate is calculated and plotted against the time selected for the irradiation. For convenience, a logarithmic time scale is used. These doses fluctuate within statistically expected limits about the value of 3600 *r*.

An additional fact, which now seems well established, is that the percentage change in mutations is directly proportional to the dose.² This is shown in Figure 2. Therefore, taking these two properties together, we see that from the standpoint of genetics the effects of radiation are permanently cumulative. A very weak exposure over several years, therefore, may be as injurious potentially as a large exposure administered at one time.

These facts have an important bearing on tolerance limits of exposures of individuals to radiation, particularly to penetrating radiation, such as x-rays and gamma rays, where germ cells may be affected. It is obvious that as far as man

² Timoféeff-Ressovsky, Zimmer, and Delbrück, *Nachr. Ges. Biol. Göttingen*, 1, No. 13 (1935).