shows that this demands $2^1/_2$ children per couple to maintain the population on a genetic argument based solely on spontaneous mutation and ignoring all other causes of genetic death.

The real question then becomes, what effect an increase in mutation by radiation will have on this situation. There are few data for computing the efficiency of radiation in producing mutation but present preliminary investigations show that the increased mutation rate in mice is from 15 to 26×10^{-8} per roentgen per gene or one mutation per roentgen in a given gene among four million gametes. Thus, it can be computed that a dose of 80 roentgens will be equal to the effect of the spontaneous mutation rate. The addition of this radiation per productive lifetime would cause 4 out of 10 individuals to suffer genetic death per generation and each couple escaping would have to produce $3^1/_3$ children for population equilibrium. Not to be overlooked is the fact that all survivors would carry twice as many mutant genes as a result of the radiation.

These arguments suffice to show that on the basis of population survival the increase in mutation rate becomes a matter for serious consideration. Müller, for example, suggests that an increase of 25 per cent in the mutation rate should be the limit, or 20 roentgens per lifetime per individual. This would require readjustments in our mode of living for ultimate survival that probably could be made. Actually, the use of x-rays for diagnostic purposes has brought the average dose to reproductive organs in this country very near this level already.

To return to the workers with radioactive materials, it is fortunate that they are a relatively small fraction of the population. This fact renders the 0.3 roentgen per week or 400 roentgens in 26 years as permissible from the genetic viewpoint. However, even this can be regarded with equanimity only if there is a corresponding lowering of the general exposure of the population to radiation. At any rate, increase in the use of x-rays may well have a more profound effect on limiting the population than the exposure of a few individuals to the larger lifetime doses encountered under present regulations for handling radioactive materials.

E. VISIBLE EVIDENCE OF INJURY FROM RADIATION

The generally known injurious effects of radiant energy are customarily classified under the type of radiation that produces them. This custom has arisen not so much because the effects are different, since basically they are not, but for the convenience of those dealing primarily with one particular type of radiation. Since this chapter is concerned primarily with hazards which arise in industrial processes where radiation is present, we shall discuss the subject under the headings of gamma rays, x-rays, infrared radiation, and corpuscular radiation. Radioactive poisoning, resulting from taking radioactive substances into the body, is no longer confined to radium poisoning. However, radium dials are still produced and a separate section is devoted to this problem. With the appearence of artificially produced radioisotopes in commerce and the possibilities of

industrial applications still largely unexplored, a considerable increase in the industrial use of these products can be expected. Already Co^{60} is replacing radium in radiography and many similar trends will be encountered. Fortunately, the basic principles of protection from injury as well as the nature of the possibilities of injuries are still the same.

The disruptive effects that radiation can produce in living cells result in a great variety of bodily injuries in persons exposed to the radiation. These effects depend on the type of radiation, particularly its penetrating power; on the method of exposure, whether local or over the whole body; and on the parts of the body affected. Injuries range all the way from a slight erythema, such as can result from a small dose of soft x-rays or ultraviolet, to radiation osteitis, which may be followed by crippling bone lesions and osteogenic sarcomas that soon prove fatal. Such injuries may result from large doses of gamma radiation and are also a possible result of severe radioactive poisoning. In many cases of overexposure, anemias occur that may be aplastic or regenerative, depending on the cell groups affected, which, in turn, frequently depend on the type of radiation and its mode of application to the body. Fatal leucopenias also have been observed.

Admittedly, these and other similar symptoms and disabilities are of importance chiefly to the physician who may be called upon to treat a person suspected of suffering from an overexposure. Also, the studies of persons affected by radiation have resulted in valuable additions to the general knowledge of bodily functions. They are cited here primarily to indicate the severity of injury that may result from injudicious exposures of the body to radiant energy. In most situations, ample information is now available so that protective measures can be set up to prevent all but the foolhardy, or grossly ignorant, from suffering any of the more serious consequences of overexposure. It will be our aim to point out these protective procedures in the course of the detailed discussions of the various industrial hazards that involve radiant energy.

II. Penetrating Ionizing Radiation

A. TYPES OF EXPOSURES AND INJURIES

The penetrating radiations typified by x-rays and gamma rays, through the ionizing effects of their secondary corpuscular radiation, produce similar effects on the human body. The distinction between these radiations is purely arbitrary since gamma rays may now be produced by the same mechanism as was formerly used to produce x-rays. These penetrating radiations, when compared with other forms of radiant energy, possess the distinguishing property of being able to produce effects throughout the whole body at one time. This ability accrues from the low coefficient of absorption which permits the radiation to pass entirely through any part of the body with only a moderate diminution of intensity. Naturally, it is still possible to expose only a part of the body, as by