workers from neutron radiation, a subject which heretofore has been of interest only to a relatively small number of persons engaged in research in this field.

The neutron is a particle of approximately the mass of a hydrogen nucleus but without electric charge. Therefore it does not ionize atoms directly to any important extent. However, secondary products of its reaction with matter do produce ionization, and are therefore biologically dangerous. There are a variety of ways in which these secondary effects are produced, but for practical purposes we may divide neutron radiation into two general classes characterized by the speed with which the neutrons are moving. Those that move with a speed corresponding to that of the thermal agitation of molecules, at a given temperature, are classed as slow or thermal neutrons. Those that move at greater speeds are classed as fast neutrons, and may have energies up to several million electron volts, whereas the thermal neutrons have energies of approximately 0.03-electron volt.

The effects of these two classes of neutron radiation are quite different in relation to biological hazards. When tissue is irradiated by fast neutrons, the biological effects are predominantly due to the secondary radiation. These neutrons on collision with the hydrogen atoms in the tissue give them a considerable portion of their energy. These hydrogen atoms thus become protons and, having a positive charge, they are capable of producing strong ionization. Since from the nature of the process these protons are produced in all depths of tissue, they can produce injury in all parts of it.

2. Measurement

The measurement of the intensity of fast neutrons must be based on the information in the preceding paragraph. Since the neutrons do not ionize directly, the ionization chamber, or other detector, must have walls composed of material containing hydrogen atoms, or be surrounded with such material in such a way that the protons can enter the effective volume of the detector and produce ionization. For example, the Victoreen minometer equipped with a 100-r chamber will satisfy this requirement since the bakelite wall contains hydrogen. It would be preferable for biological purposes to replace the bakelite with a substance containing the same concentration of hydrogen as living tissue. However, this discrepancy can be taken account of in the specification of the tolerance exposure. It has become conventional to designate a reading on an instrument of this kind as 1 r when the meter gives the same indication in the beam of fast neutrons that it does for 1 r of gamma radiation. However, it can be estimated that the biological effect of the neutron beam will be nearly three times as great as that produced by 1 r of gamma radiation, from the consideration of the recoil protons alone. Experiment has shown that this factor may vary from 2 to 10. Therefore, it has been the practice to set the tolerance for fast neutrons at 0.01 r, when r is defined as on page 241, for an 8-hour day.

Contrasted with fast neutrons, which have a high degree of penetration in matter, slow neutrons are very quickly absorbed in matter. This absorption is in the nature of a nuclear combination of the neutron with the atoms, resulting in the

production of new types of atoms and the liberation of gamma and beta rays. This absorption occurs in the first few centimeters of animal tissue. Under these circumstances the surface layers of the body are converted into an artificial source of radiation in which gamma rays predominate. Therefore, the biological effects to be expected can be determined by means of any device for measurement of gamma rays located close to the body. The Victoreen "fountain-pen" type of chamber worn on the person should provide a reliable guide to this type of exposure.

In those situations, occurring frequently in practice, where both slow and fast neutrons may be present, as well as gamma radiation, it is important to control exposures in terms of all three. Since slow neutrons and gamma rays contribute to one general effect, which can be measured in terms of the gamma radiation in roentgens, this means that in addition the intensities of the fast neutrons must be measured. In general, conditions should be arranged so that the combined intensity is always well below the tolerance level, so that measurements made in a general survey are needed only to confirm that such a situation exists. Monitoring stations of continuous recording, or integrating instruments located at strategic points, will then indicate whether safe conditions are maintained. Since it is usually relatively easy to insure that the sum of effects from all three radiations, fast neutrons, slow neutrons, and gamma rays, is below the tolerance level for any one, a measuring device that responds to both gamma rays and fast neutrons may be used. Any ionization chamber with walls containing hydrogen satisfies this requirement, after suitable calibration.

3. Shielding

The shields for stopping the two types of neutrons, swift and slow, are as different as their properties would indicate. Since swift neutrons are reduced in energy and finally stopped only by direct collision, most effectively with hydrogen atoms, the shield must contain hydrogen atoms. Water or paraffin is effective and must be used in thicknesses up to several feet, depending on the initial energy of the neutrons. For neutrons of thermal energy, cadmium or boron is quite opaque, so that thicknesses of approximately 1 or 2 mm. of metallic cadmium are sufficient. Gamma rays are generated in the process of capture of these neutrons, however. Consequently, for strong neutron radiation an additional layer of lead or other material must be added to absorb the gamma rays on the side of the emergent radiation.

V. Poisoning from Radium or Thorium

A. RADIUM POISONING

1. Historical Summary

Radium poisoning as a definite source of injury was first brought to light in this country by a report, in 1924, by Blum, a New York dentist, who encountered a case of chronic osteomyelitis in the mandible of a girl engaged in applying radioactive paint. Without any knowledge of the kind of material with which this girl worked,