In fact, where slow and fast neutrons are encountered, in practice, potential gamma ray exposure will also be present, therefore, it is important to control exposures in terms of all three radiations. Thus, if the ordinary gamma ray type of pocket ionization chamber is designed to measure fast neutrons it will be sufficient whenever the total reading gives a value well below tolerance level. In some installations, where alterations of equipment or procedures are infrequent, this condition can be ascertained by survey measurements, which can be made more accurately than by pocket meters. In some cases monitoring instruments located at strategic points and operated continuously during working hours may be desirable. Such monitoring arrangements may be a necessity where a variety of different operations are performed or where accidental increases in the level of the radiation may be anticipated.

3. Shielding

Shields for the two types of neutrons, swift and slow, are as different as their properties would indicate. Since fast neutrons are reduced in energy and finally stopped only by more or less direct collisions with atomic nuclei, most effectively with hydrogen nuclei, a shield for fast neutrons should contain plenty of hydrogen. Water and paraffin are good examples. When these neutrons have been reduced to thermal velocities their properties are the same as those of any other thermal neutrons.

Boron and cadmium are quite opaque to thermal neutrons so that thicknesses of these metals of the order of 0.040 inch will screen them off completely. In the case of cadmium, gamma rays are generated by the capture of neutrons, and whenever high intensities are involved, a layer of lead or other dense material must be placed between the cadmium layer and personnel to be protected. The adequacy of this layer should be checked by measurement of the radiation.

V. Poisoning from Radioisotopes

The discussion of radioactive poisoning will be based on the facts developed in connection with the poisoning of radium dial painters in this country following World War I. The principles involved apply to any other radioisotopes that are concentrated in the bone structure, such as radioactive strontium or calcium. However, the presence of these artificially radioactive substances is not as easy to detect and measure because with radium the radon gas can be used as a radioactive tracer. Therefore, greater precautions are required to ensure that the environmental conditions of the employees preclude the possibility of ingestion or inhalation of potentially dangerous amounts.

A. RADIUM POISONING

1. Historical Summary

Radium poisoning as a definite source of injury was first brought to light in this country through 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 to instrument and clock dials. Without any knowledge of the kind of material with which this girl worked, he concluded that the nature of the affliction was so unusual that it must result from some type of occupational poisoning, and published a statement to this effect.[10]

In the following year, Hoffman,[11] who was asked to investigate the plant in New Jersey where the girls were employed to apply radioactive paint, found from an examination of death certificates of deceased former employees that these certificates were strikingly similar, although made out by different family physicians, who were entirely ignorant of the true cause of death. There was frequent mention of jaw necrosis, anemia, and buccal lesions, although the immediate cause of death was usually given as some well-known disease that exhibits some of these symptoms. It was highly improbable, in Hoffman's opinion, that this could be accidental. After he had assembled data on five deaths and twelve living cases, where infected jaws and anemia were predominant features, he concluded that they represented a new type of occupational poisoning, since all cases had worked at the same plant. From his investigations of the working conditions and the nature of the material applied by these employees, he also formed the opinion that the mesothorium in the paint had something to do with the symptoms observed. This opinion was further confirmed in his mind by the observation that after dipping their brushes in the radioactive paint the girls habitually pointed them between their lips. This practice would give an excellent opportunity for ingestion of the paint.

These preliminary reports led to a series of investigations, sometimes with contradictory conclusions. In many cases the radioactive constituent of the paint was ignored and some other source of the disease was sought. However, in the same year Martland[12] examined two girls who were suffering from extensive jaw necrosis and anemia. Both girls died and, as a result of autopsies that he performed and of investigations on living patients suffering from the same symptoms and engaged in the same work, he was able to formulate an extensive report which clearly, for the first time, traced the disease to its true origin.[13] From an examination of the expired air, he was able to detect the presence of radon by the large number of alpha particles revealed by a zinc sulfide screen in a darkened room when the subject breathed against it. From the skeletons, after death, he proved the presence of radioactive material in the bones by electroscopic and autoradiographic tests. By chemical extraction methods he recovered 150 micrograms of radium from one skeleton. At the same time, from examinations of patients suffering with the disease, he was able to describe more accurately the type of anemia, as well as the nature and progress of the bone lesions. In this

[10] T. Blum, *J. Am. Dental Assoc.* (1924).
[11] F. E. Hoffman, *J. Am. Med. Assoc.*, **85**, 961 (1925).
[12] H. S. Martland, P. Conlon, and J. P. Knef, *J. Am. Med. Assoc.*, **85**, 1769 (1925).
[13] H. S. Martland, *J. Am. Med. Assoc.*, **92**, 466, 552 (1929).