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PERSONNEL NEUTRON DOSIMETRY STUDIES AT THE LAWRENCE BERKELEY LABORATORY

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1. Introduction.

It is generally recognized that personal neutron dosimetry is a difficult task, but it is perhaps around high-energy accelerators that the problem is most severe. Firstly, a high-energy accelerator is a potent source of radiation--for example, Distenfeld[1] has reported that the Alternating Gradient Synchrotron (AGS) contributes 80% - 90% of both the gamma and neutron exposures to Brookhaven personnel. Secondly, the variety of radiation fields is great. At proton accelerators neutrons usually dominate the radiation field outside thick shields, but large differences in neutron spectrum are observed[2] which can make the interpretation of measurements made with a single dosimeter difficult. Furthermore, under poorly shielded conditions (for example adjacent to primary particle beams) the gamma : neutron ratio may change by more than two orders of magnitude.[3] At many high energy electron accelerators, too, neutrons are being identified as an important component of the radiation environment.[4]

2. Personal Dosimetry at Accelerators.

This author's experience at many high-energy laboratories with several different types of accelerators have led him to the following conclusions concerning individual dosimetry for accelerator personnel.

*Work done under the auspices of the U. S. Atomic Energy Commission.

a. The "Universal" Dosimeter - which is dose-equivalent responding under all the varied radiation conditions existing around a high energy accelerator does not exist at the present time. It probably is a physical impossibility given the present administrative definitions of dose-equivalent.

b. Neutron Dosimetry - Necessary. In most working environments around proton accelerators (and at many electron accelerators too) neutrons are dominant. It is therefore nearly always necessary to monitory the individual neutron exposure. (For example, it makes little sense to attempt to estimate 90% of the dose equivalent contribution due to neutrons from a measure of 10% of the dose equivalent with a gamma dosimeter.)

c. More than One Dosimeter Necessary. At least two personal dosimeters are necessary--one for photon exposures, at least one for neutrons. If personnel are exposed to a wide range of neutron energies two or more neutron dosimeters may be necessary.

d. The Appropriate Dosimeter? Intermediate energy neutrons rarely present a major problem at accelerators, although they may do so under certain shielding configurations, e.g., steel shielding,[5] at the entrance to labyrinths penetrating shielding.[6] For these unusual circumstances albedo-type dosimeters would be most helpful. At most proton accelerators the neutrons making the dominant contribution to the dose equivalent lie in the energy range 0.1 MeV-20 MeV.[2] This energy range is fairly well handled by nuclear track film--although this dosimeter is anathema to some it is still widely used by those who have a need to monitor neutrons. Fission foil track detector combinations have also been used to some degree in this energy region.[1]

Under certain conditions (e.g., shields with a high water content) the contribution to the dose equivalent due to neutrons greater than 20 MeV in energy may be more than 50%[3]--even for accelerators in the GeV energy region. Additionally, at accelerator energies in the hundreds of GeV range the energy sensitivity of neutron personal dosimeters must extend well beyond 20 MeV. It is with this extension of neutron personal dosimetry to higher energies that we have been concerned with at Berkeley during the past year.

3. Personal Dosimetry Studies at Berkeley.

Neutron track film has proved to be invaluable in assessing personal neutron exposures. We do not find ourselves in agreement with those who find it of no value in routine use. The most serious technical deficiency claimed for neutron track film--track fading--is not serious at the relatively low humidities which obtain at Berkeley. Many studies now show that at moderate temperature and RH errors in DE estimation due to track fading are less than 20%.[7] Furthermore, if track fading is significant it may be adequately controlled by film packaging.[7] As an example of routine use packaged nuclear track film has been successfully used at the Rutherford Laboratory, in conjunction with a crude ^{6}LiF albedo type dosimeter to obtain good estimates of neutron dose equivalent in a variety of radiation environments.[8]

a. Thick Emulsions.

At neutron energies above 20 MeV thick nuclear emulsions may be utilized as personal dosimeters. At Berkeley 600μ thick Ilford L4 emulsions and NTA films were exposed to neutrons of nominal energy 4.5, 14, 25, and 225 MeV. In addition, emulsion sensitivity was compared with fission foil detectors. These exposures have been described in detail elsewhere.[9] In summary, it was found that the normalized sensitivity of L4 emulsion was greater than that of NTA film at all energies because of the greater emulsion thickness and the greater sensitivity of L4 emulsion to higher energy proton recoil tracks. The sensitivity of the technique is adequate: for example, at 225 MeV a neutron fluence of 2×10^5 n cm^{-2} (about 10 mrem) may be measured in a scanning time of less than 30 mins. An interesting observation was that NTA film showed a significant response to the 225 MeV neutron beam which cannot be explained in terms of low energy contamination. The response of NTA film to high energy neutron spectra is worth serious study because there may be some significant response from protons in equilibrium with the neutron component of the nuclear cascade.

b. Electronic Personnel Dosimeter. Preliminary studies lead us to believe that it is now technically feasible to produce a small personal neutron monitor (about the size of a Hewlett Packard pocket computer). A typical instrument might utilize a 0.5-in. × 4.6 in. long BF_3 counter* moderated by 0.36 in. polyethylene surrounded by cadmium. Such a counter worn on the body would generate 350 counts/mrem for ^{252}Cf neutrons--easily detectable above background.[10] The basic electronic technology is now available and after some basic design work it would appear feasible to produce these dosimeters for less than $1000. (Consultation with manufacturers would almost certainly lower this figure.)

*20 cm Hg filling, 96% ^{10}B.

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