EUROPEAN LABORATORY FOR PARTICLE PHYSICS

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INDIVIDUAL MONITORING IN HIGH-ENERGY RADIATION FIELDS

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Abstract

Suitable isotopic neutron sources do not exist for the calibration of personal dosimeters to be worn in the stray fields of high-energy accelerators or the cosmic ray field at aircraft altitudes. In addition existing personal neutron dosimeters cover only a limited energy range and their response varies widely to particles of different energies. Other available dosimetry systems suffer from similar inconveniencies. Thus at CERN, as at certain other accelerator laboratories, we have developed the philosophy of calibrating personal dosimeters in the field against standard instruments. These are calibrated in terms of Ambient Dose Equivalent which means that the personal dosimeters are essentially calibrated in terms of the same quantity. This has advantages when comparing the results of films actually carried by personnel with the results of measurements made by field instrumentation.

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1 Introduction

At high-energy proton accelerators such as at CERN the majority of the collective dose still comes from work on activated accelerator components although this contribution to the total dose has decreased from 95% thirty years ago to 85% twenty years ago and last ten years has been about 70% [1]. Personal dosimetry systems for assessing individual exposure in the radiation fields from induced radioactivity during the shut-down periods of an accelerator are classical. Two other types of situations exist in an accelerator environment where personal dosimeters are required. The first is the accidental or deliberate exposure to particles beams. However, since the lateral dimensions of most beams are measured in millimetres, a dosimeter worn by a person is most unlikely to be struck by a beam and thus to indicate that an exposure has occurred. The second situation is encountered in the stray fields that exist in the experimental halls of high-energy accelerators, outside the primary shields of the accelerator and of the targets used for producing the secondary beams necessary for physics research. In these fields which contain a large variety of particle types and energies, Ambient Dose Equivalent as defined in ICRU Reports 39 and 43 [2, 3] is the recommended quantity to categorize the risk of exposure. Thus all installed monitoring systems and all hand-held monitors are calibrated in terms of this quantity. However, the situation regarding personal dosimetry in these stray fields is far less clear. ICRU has proposed the quantity Personal Dose Equivalent for the calibration of individual dosimeters [4]. The unavailability of calibration sources at relativistic neutron energies means that this quantity is not suited for assessing the risk in mixed stray fields. Therefore personal dosimeters are better calibrated in-field against installed monitoring systems in terms of Ambient Dose Equivalent. The advantages of this philosophy will be demonstrated and its relevance to dosimetry in the fields encountered by air-crew flying at high altitudes will be illustrated.

2 The Radiation Field

Typical examples of the radiation fields outside the shielding of high-energy proton accelerators are being realized as part of a CEC Research Proposal on the "Measurement of dose equivalent in relativistic stray radiation fields" [5]. The fields are produced by allowing a beam of pions of approximately 100 GeV to impinge on a target of iron or copper, shielded by blocks of iron and concrete. Monte-Carlo simulations of the cascades generated by the high-energy particles made using the FLUKA program [6] allow one to predict the energy spectra to be expected outside these defined shielding configurations. Figure 1 illustrates the spectra of neutrons outside iron and concrete shields in the configuration of experiments performed in 1992. This Figure illustrates the relative abundance of neutrons in the 100 keV–1 MeV region for the iron shield configurations. Charged particle fluxes are significantly lower than those of neutrons; high-statistics Monte-Carlo simulations are in progress in order to obtain energy spectra of protons and charged pions.

Ambient dose equivalent as a function of particle type and energy has been derived [7]

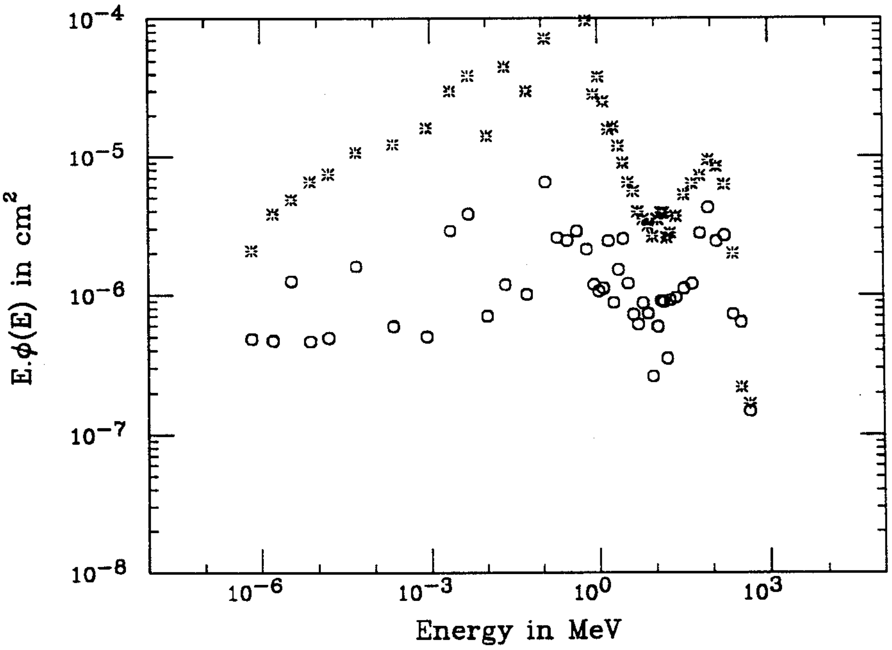

Figure 1: Neutron spectra outside the iron (∗) and concrete (∘) shielding of the CERN–CEC Relativistic Stray Radiation Field Facility. The spectra are the work of the I.N.F.N. Milan Section and are normalized to one pion in the incident beam.

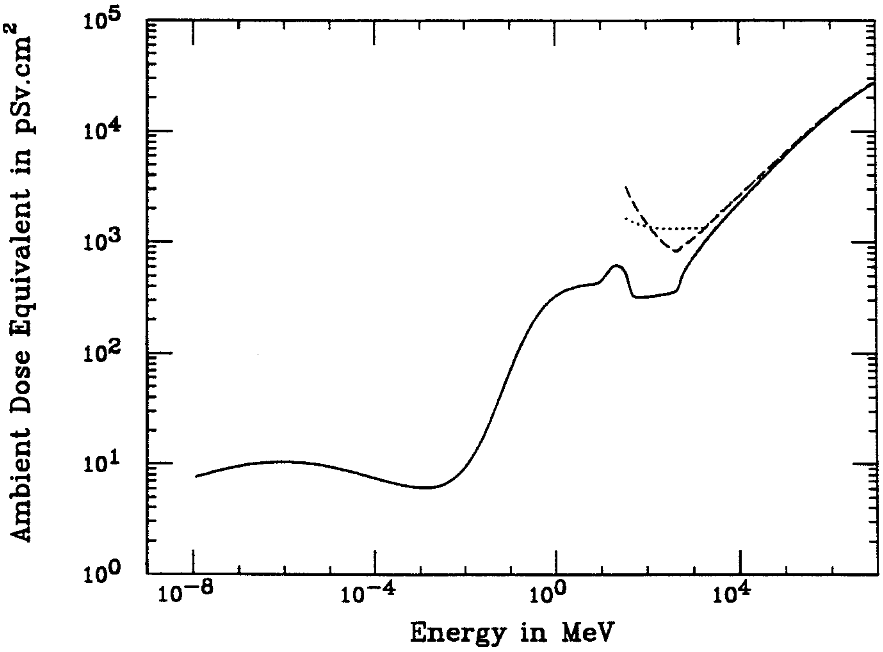

Figure 2: Ambient dose equivalent as a function of energy for neutrons (solid line), protons (dashed line) and charged pions (dotted line). The data are from [7].

using the data in ICRP Publication 51 [8] and the data of Wagner *et al.* [9], The conversion factors from fluence to ambient dose equivalent are plotted in Figure 2. These data use the QF-LET relation of ICRP Publication 26 [10], and in common with many other bodies such as the BCRU [11], CERN will not change its present conversion factors until there is a consensus between ICRP and ICRU on the way in which dose equivalent itself is defined.

Figure 3 shows the fraction of ambient dose equivalent below a certain energy as a function of that energy for the iron and concrete spectra of Figure 1 obtained by multiplying the spectra with the appropriate conversion factors. For the iron spectrum some 80% of the dose equivalent comes from neutrons with energies below 1 MeV. The concrete spectrum is significantly harder with about 40% of the dose equivalent coming from neutrons with energies above 10 MeV.

The spectrum of neutrons from isotopic neutron sources such as PuBe and AmBe are line spectra on the scale of Figures 1–3. Even the accelerator neutron sources provided by the PSI only provide neutron calibrations in a very limited energy region [12]. The available spectra are clearly insufficient to provide a suitable calibration of personal dosimetry systems for use in relativistic stray radiation fields.

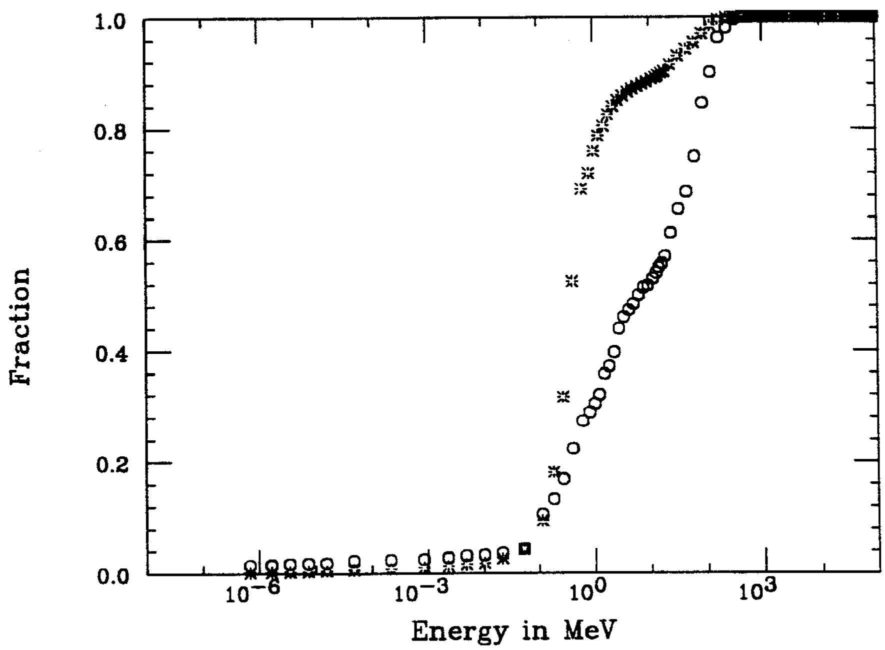

Figure 3: Ambient dose equivalent below a given energy as a function of that energy for the spectra of Figure 1. $*$ – iron, $\circ$ – concrete.

3 The NTA Film

Kodak NTA films have been used for personal neutron dosimetry around high-energy accelerators for over 30 years. Experience with these dosimeters has been summarized recently by Höfert [13]. It has long been recognized that their response in terms of dose equivalent is unsatisfactory. Because of the difficulty of recording short tracks, NTA film is not sensitive to neutrons below about 0.5 MeV. Even though high-energy proton recoil tracks become sparse at energies above 50 MeV and thus difficult to see, the NTA film retains some sensitivity to neutrons above this energy because of the lower energy of some of the recoiling protons or products of inelastic nuclear reactions. Hack reported on a study of the ratio of film to dose equivalent response as a function of the number of neutrons in accelerator stray fields with energies above and below 20 MeV. [14]. This study is illustrated in Figure 4 and shows that in the hard spectra the NTA emulsion when calibrated with Am-Be source neutrons will overestimate the actual ambient dose equivalent by up to an order of magnitude.

Earlier results and recent work by Höfert and Lehmann within the framework of the EURADOS irradiations have also shown the strong dependence of response of the NTA film on neutron energy but also confirmed the long term stability of this detector [15], see Figure 5. These studies confirm that the NTA film worn alone cannot be an acceptable dosimeter for use in relativistic radiation fields of unknown composition. Most individual neutron dosimeters presently available can at best be considered simply as neutron monitors.

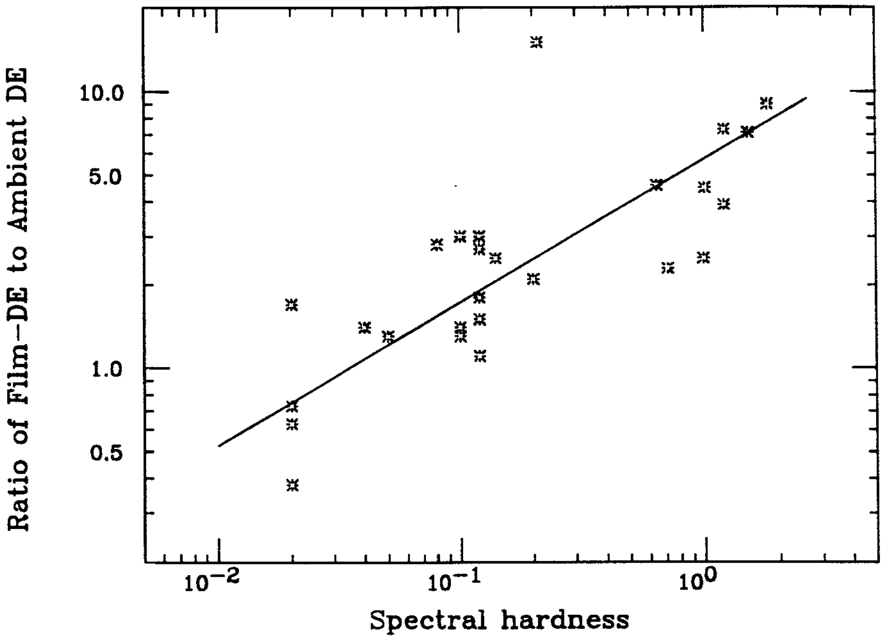

Figure 4: The ratio of the dose measured by personal neutron films to the neutron ambient dose equivalent as a function of spectral hardness (the ratio of the fluence of neutrons above 20 MeV to the fluence below 20 MeV). The data are from the NIMROD accelerator [14]. The solid line is a fit by eye to the data.

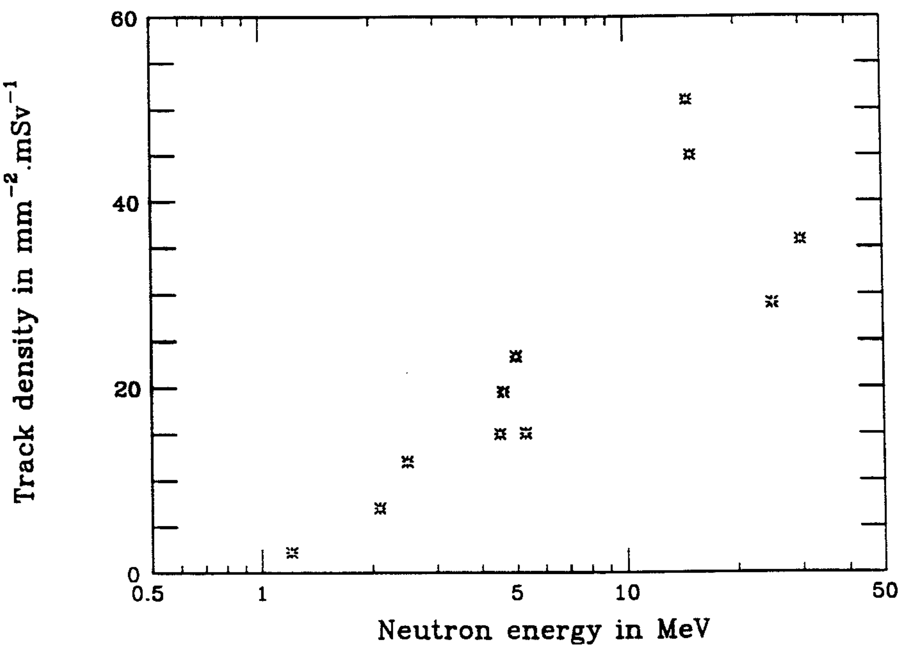

Figure 5: The ratio of the response of the neutron film, measured in tracks per mm^2, to the ambient dose equivalent as a function of neutron energy. The data are from [15].

One aim of the present CEC study at CERN is to find the least unacceptable dosimetry system for the use in relativistic stray fields.

4 Conclusions

The assessment of individual dosimetry at CERN has led us to the philosophy of trying to provide the best monitor of personal neutron irradiation rather than searching for the ideal personal neutron dosimeter. In the situation of stray radiation fields around high-energy accelerators the exact nature of the physical quantity estimated by the personal neutron dosimeter is irrelevant. For the calibration of individual monitors we have chosen to follow the philosophy used by Hack and others and make field irradiation on phantoms of personal neutron dosimeters placed around the body of the phantom, to take the average response of these dosimeters and to relate this to the ambient dose equivalent measured by multi-detector systems such as Cerberus [16] or microdosimetric counter systems [17]. Accumulated experience of these "calibrations" allows us to choose the optimum conversion factor and to know its practical limitations in the radiation fields encountered. A calibration of personal dosimeters in terms of ambient dose equivalent has the advantage of providing a coherent system of measurement where both dosimeters worn on the person and field instruments should in principle give the same reading, a situation which can never be attained when personal dosimeters are calibrated in terms of Personal Dose Equivalent and field instrumentation is calibrated in terms of Ambient Dose Equivalent. We suggest that this advantage should be borne in mind when calibrating personal dosimeters if they are to be worn by aircrew flying at high altitudes.

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