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Applications of Nuclear Track Detectors in Radiation-Protection Monitoring

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The present paper deals with the solid state etch-track detectors and their applications to the detection/dosimetry of neutrons, radon, and radon-decay products.

Most of the scientists, actively engaged in the late 60's and in the 70's for monitoring the occupational neutron-exposure by etch-track detectors, became also involved in the development of personal monitors for the exposure to radon-decay products in mines.

The personal dosimetry of neutrons and that of radon decay products have had a parallel history and a lot of common traits, such as the same track detectors, the same etching and counting procedures, the same scientists and/or laboratories involved.

These parallel investigations have been conducive to the development of etch-track-based film-badges for the detection of the neutron fluency and the radon concentration respectively. Thanks to these parallel investigations, it was possible to demonstrate that radon may represent a strong disturbing factor for the response of neutron film-badges. In particular, it was finally possible to explain the erratic response obtained in the past with neutron film-badges, based on polycarbonate track detectors, characterized by a large radon sorption.

Finally, a strategy similar to that established for neutron dosimetry has been recently proposed to solve the long-standing problem of the dosimetry of radon-decay products.

Key words: track detectors, neutrons, cosmic rays, radon

1. Introduction

The response of conventional detectors like gas counters, scintillators, semiconductors, nuclear emulsions, thermoluminescent materials, etc., results from radiation-induced energy deposition in sensitive volumes of macroscopic amount of matter. These detectors are adequate for the dosimetry of sparsely ionizing radiations (X- and γ-rays), which loose energy by fairly random distribution of energy deposition. By contrast, heavily charged particles, and/or neutron-induced particles interact with matter by depositing high concentrations of ionization energy in microscopic and ultramicroscopic volumes surrounding the tracks, which properties determine the high biological effectiveness of these radiations.

In particular, to provide guidelines for the development of suitable detectors for neutron dosimetry, it is necessary to analyse the differences in the spatial distributions of energy deposition between neutron and γ-interactions with tissue[1]. Particular emphasis has been given to these differences in the field of microdosimetry, where an extensive analysis has been made on the local energy depositions both at the cellular and sub-cellular levels[2]

The comparison between neutron and γ-ray interactions with tissue is illustrated in the diagrams of the upper part of Figure 1[1, 2]. These diagrams show two monolayers

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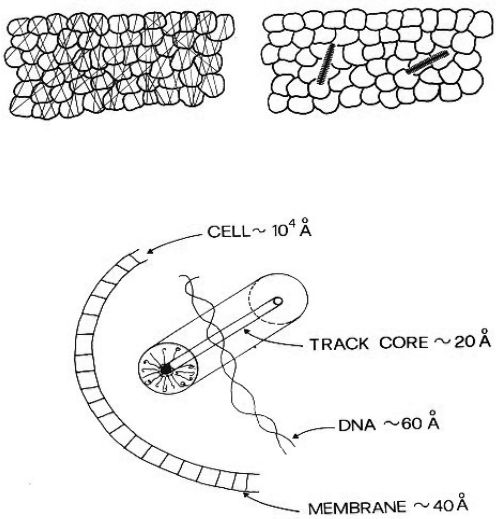

Fig. 1. Upper part: Monolayers of biological cells irradiated respectively to gamma rays (left side) and fast neutrons (right side). Lower side: Single proton track in tissue.

of biological cells (with diameter of about 5 μm) which received a dose of 1 mSv/y of gamma exposure (as typically received from natural terrestrial radiations) and 1 mSv/y of neutrons (as it occurs on high altitudes mountains such as Cervino-Italy[3]).

The differences appear very clear since, in the case of gamma rays, there is one radiation interaction for every cell in one year, while for neutron irradiation only one out of 2000 cells is crossed by a track which deposits a dose which is about 500 times higher than that due to gammas. The first detector capable of measuring energy depositions in a microscopic element of matter (typically biological tissue) is the Rossi counter[2, 4]. In fact, this counter has the characteristics that it can simulate a microsphere of biological tissue (namely a cell nucleus).

Advanced portable types of Rossi counters have been developed (known as the tissue equivalent proportional counter-TEPC), which are successfully used for radioprotection dosimetry in mixed field of radiations[5], such as gamma-neutron fields and/or cosmic rays.

In order to understand the mechanisms of track formation and etchability, it is necessary to refer to the spatial distribution of energy depositions at submicroscopic distances from charge-particle trajectories. The lower part of figure 1 shows a magnified view of a single neutron recoil track (typically 1 MeV proton track in tissue), together with important biological targets like DNA and the cell membrane. This track structure is formed by a track core (characterised by high energy deposition) and delta rays which deliver energy at a distance from the track core. For example, a dose of the order of 1 MGy is deposited at 10 Å radial distance from 1 MeV proton track in tissue[6]. At such submicroscopic distances from nuclear tracks, the difference between sparse radiation (X- and γ-rays) and high-LET particles are enormous. It is the high energy deposition

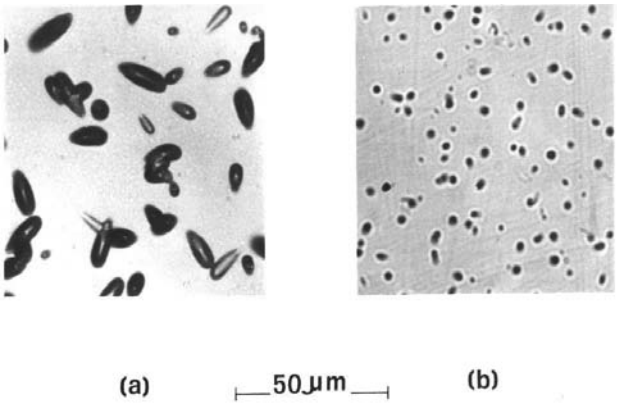

Fig. 2. Fission-fragment tracks (a) and neutron-induced-recoil tracks (b) in polycarbonate.

in the vicinity of the particle trajectory the most crucial quantity for the registration of damage tracks[7]. In fact, the most important characteristic of damage track detectors is that there is a minimum density of damage within an atomic-size volume surrounding the track-trajectory, that will permit the track to be enlarged by etching. The existence of this threshold is one of the most valuable characteristics of damage track detectors, which explains their ability to discriminate against large fluxes of lighter energetic particles, electrons, gamma rays, etc.

By contrast, the responses of detectors with macroscopic volumes are sensitive to the whole energy loss along the track. In situations where the saturation phenomena in the vicinity of the track are predominant, such as with organic scintillators, the response to the outer part of the track is relatively much larger than to the core. For these reasons, the scintillators can be considered to be just the converse of the damage track detectors[8].

2. Track etching and counting

A track becomes etchable when the rate of etching along the track, Vt, exceeds the rate at which the surface is etched, Vb[9]. If the track is not perpendicular to the surface, then the component of Vt perpendicular to the surface must exceed Vb for registration to occur. Figure 2 (a) shows tracks of neutron-induced fission fragments entering a polycarbonate detector from a fissile radiator, while Figure 2(b) presents tracks of recoil-particles, induced by neutrons in the detector itself. Since for fission fragments Vt is much larger than Vb the tracks are elongated and well defined. Short etch pits instead of fully developed tracks appear in Figure 2(b), since in this case Vt is not much larger than Vb. For most applications of damage track detectors in dosimetry, it is necessary to evaluate low track densities (1 to 1000 tracks per cm^2) for large number of detector foils). The shortcomings of counting individual track in large detector areas under the microscope have been overcome through the development of the spark counter and of different image analyzer systems for the automatic counting

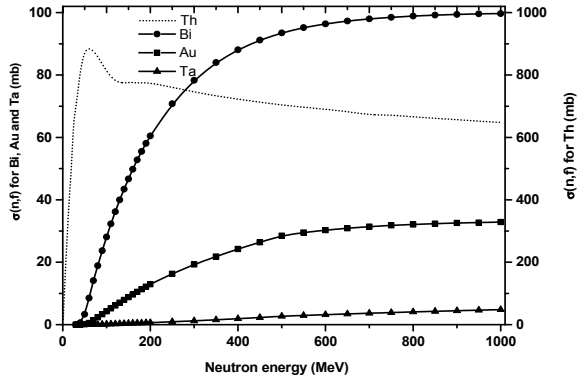

Fig. 3. The neutron fission cross-section, (σ(n,f)), of ^{232}Th, ^{209}Bi, 197Au and 181Ta versus the neutron energy. The right hand ordinate is scaled for the thorium cross-section.

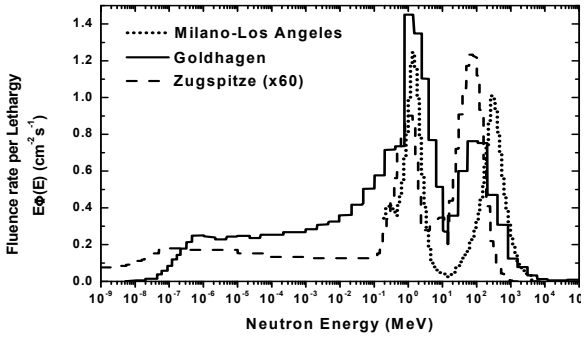

Fig. 4. Three different spectra of cosmic ray neutrons.

of both chemically and electrochemically etched tracks[9]. These developments have greatly facilitated the applications of track detectors in the measurement of cosmic ray neutrons, in personal neutron dosimetry and in large scale survey of radon in dwellings[9, 10].

3. Cosmic-ray-neutron measurements by etch-track detectors.

Passive detectors are very attractive for cosmic ray measurements both at aircraft and space altitudes, because of their small size, low weight, lack of need of electrical power and of the stringent requirements for the environmental parameters (temperature, vibration and interference with the on-board instrumentation). Different multidetector stacks have been developed for in-flight measurements, which make it possible to measure low- and high-energy neutrons[3, 10-11].

These stacks consist of several types of passive detectors for the registration of recoil- and fission-fragment-tracks induced by neutrons. Most of these detectors have been used on earth for the assessment of the occupational exposure[7], or in outer space for cosmic-ray physics and/or for the assessment of the dose received by astronauts[9-10, 12-13].

A great deal of efforts and new developments has been required to make these detectors useful for in-flight measurements[10, 14] with special regard to the use of large area stacks. Even though these multidetector systems present the complexity typical of cosmic ray stacks, the scanning of many different types of detectors is relatively simple and rapid, as required for dosimetric applications. In particular, a simple microfiche reader can be useful to scan large areas of different types of neutron detectors for the counting of both fission-induced aluminum spots in spark-counted replicas or electrochemically etched recoil tracks[10].

A major drawback of damage-track detectors is their large and unpredictable background. This problem has been finally solved by using the detection principle of counting coincidence-track events on matched-pair of detectors, not only for long-range particles but also for very short tracks such as those induced by neutron recoils[10] which, once etched electrochemically, can be easily seen on the screen of a microfiche reader.

Stack for neutron spectrometry

The basic requirements for a stack for neutron spectrometry (based on the unfolding procedures) is to have different detectors, which have a known response as a function of the neutron energy and chosen in such a way that all the parts of the expected energy range are included. In order to cover both the low-and the high-energy range of neutrons, two categories of detectors have been chosen which are based respectively on the registration of neutron-induced recoil-tracks in organic materials and neutron-induced fission fragments in heavy elements[10, 14].

Neutron-induced fission cross-sections for some heavy nuclei (^{235}U, ^{238}U, ^{232}Th, ^{209}Bi) are internationally recommended as secondary standards for neutron flux monitoring in the energy region above 20 MeV[10]. However, because of the possible concern about the radioactivity of uranium and thorium, they are not useful for onboard measurements. In practice, only bismuth, gold and tantalum films have been used for the detection of high energy neutrons through fission-induced reactions[10, 14].

These fission-track detectors are very important, since they make it possible to exploit the excellent characteristics of the fission reactions in bismuth, gold and tantalum for the measurements of high energy neutrons, such as:
-excitation functions well above 20 MeV which eliminate the influences of low energy neutrons,
-smooth variation of the cross-section with neutron energy,
-mono-isotopic and non-radioactive materials, which make them easy to transport and handle.

Figure 3 shows the fission-cross section of bismuth, gold, tantalum and thorium respectively[10].

The passive neutron spectrometer based on different types passive track detectors (hereafter referred to as ANPA-stack) is very compact and has a total weight of less than 1 kg[14]. The only other neutron spectrometer available consists of multisphere hydrogenous moderators, which are supplemented by different layers of lead shielding to extend the response to high energy neutrons[15, 16]. By contrast with the ANPA-stack, this multisphere spectrometer is so bulky

Table 1. Measured and calculated doses on roundtrips between Europe and Japan at different phases of the solar cycle.

Date	Roundtrip	N° of flights	Measured dose rate H*(10)/t (μSv h^{-1})	Measured H*(10) (μSv)	(CARI 6) E -(ISO) (μSv)	EPCARD 3.2v (μSv)	
						H*(10)	E
May-July 1997	Milan-Tokyo	8	4.7 ± 0.4	102 ± 8	115 ± 11	122 ± 11	145 ± 14
May-July 2001	Paris-Tokyo	10	4.6 ± 0.6	105 ± 11			
May 2002	Paris-Fairbanks-Tokyo	1	4.6 ± 0.8	130 ± 22	132	122	142
July 2002	Rome-Tokyo	1	4.5 ± 0.7	101 ± 16	93	93	109

and heavy that it can't be used in commercial flights. When compared with the multi-sphere spectrometer, the ANPA-stack, in addition to being very light and compact, does not require any technical assistance for on-board measurements. Because of its simplicity and compactness, the ANPA-stack has been exposed on passenger aircrafts simply by asking pilots to take the stack on-board.

Figure 4 shows the neutron spectrum obtained with a passive stack of track detectors flown in the cockpit of an MD-11 aircraft along the route Milan-Los Angeles for a total of 670 hours from November 1993 to May 1994[14].

Two other neutron spectra are reported in Figure 4, both taken by the multisphere spectrometer respectively on the top of the highest mountain (the Zugspite) in Germany[15] and onboard a dedicated NASA flight[16].

As it appears clear from Figure 4, all the three neutron spectra have a peak at high neutron-energies. This peak is not present in any of the spectra related to low-energy neutron sources, including reactors. Moreover, the spectra obtained by the multisphere spectrometer have different shapes and they are also different from that obtained by the ANPA-stack. In this last spectrum, the peak at high neutron energies is clearly located at about 300 MeV instead of 100 MeV as for the other two spectra. This 300 MeV peak-energy is consistent with the minimum of the neutron cross sections of O, C, and N[19]. As an aside, it is also important to mention that the proton fluence at aviation altitudes is peaked around a few hundreds of MeV[20].

Stack for cosmic-ray dosimetry

For on-board measurements, the most important quantity for the radiation protection point of view is the cumulative dose per flight[21]. Short-term variation may occur with the instantaneous values of the dose rate specially during the maximum solar activity, which, typically, has little or no effect on the cumulative dose[22].

The dosimetric ANPA stack[23, 24] is by far more simple than that for neutron spectrometry, since it contains only a stack of bismuth-fission detectors. With this bismuth stack, it is possible to measure the cosmic-ray-neutron dose with energy greater than 50 MeV for a single long-haul flight with a standard deviation better than 20%. In practice, this is the only detector, which has its principal response above 50 MeV. For the dosimetry of low-energy neutrons, this bismuth stack is supplemented by bubble detectors[23, 24]. Finally, the non-neutron (low-LET) component is measured by TLD detectors[23-25].

Within the extensive investigations carried to date, the ANPA-stack has been used on 107 long-haul flights. At geomagnetic latitudes greater than 50°C, the average route doses are not very dependent on the latitude[26]. For this reason, average dose rates measured on repeated flights along the route Milan-Tokyo give similar results (within 10%) to those measured during the same period along similar high-latitude flights, such as Milan-Los Angeles[27].

The cumulative dose and/or the average dose rate at high latitudes are of particular interest for the study of the solar cycle effects on the air crew exposure since, in addition to being little dependent on the latitude, they should be more dependent on the solar activity than the same quantities at low latitudes. The average rates of the route doses (for the return trips Milan-Tokyo, Rome-Tokyo, Paris-Tokyo) measured in terms of ambient dose equivalent-H*(10), by the ANPA-stack are reported in Table 1.

There are a number of computer programs to calculate dose rates and route doses, such as CARI 6 and EPCARD 3.2v respectively[28-31]. In Table 1, the effective dose-(E) and the ambient dose equivalent-H*(10), evaluated with the above two computer programs are also reported[32].

As it appears clear from Table 1, all the measured ambient-dose-equivalent rates are the same within better than 15%. This consistency applies also to the values of the total cumulative dose with the exception of that of the roundtrip Paris-Tokyo via Fairbanks, characterized by a relatively longer roundtrip flight-duration. Good agreement has been also found between measurement results and calculated doses respectively with CARI 6 and EPCARD programs.

From the extensive investigations carried out on the route Rome-Tokyo, all the data (in terms of the ambient dose equivalent) per flight at different phases of the solar cycle, for two different aircrafts (Boeing 747 and 767), and at different locations within the aircraft are the same within less than 20%[32, 33].

4. Neutron and radon monitoring: a parallel history

Since their discovery, damage track detectors have been extensively investigated for the solution of the complex

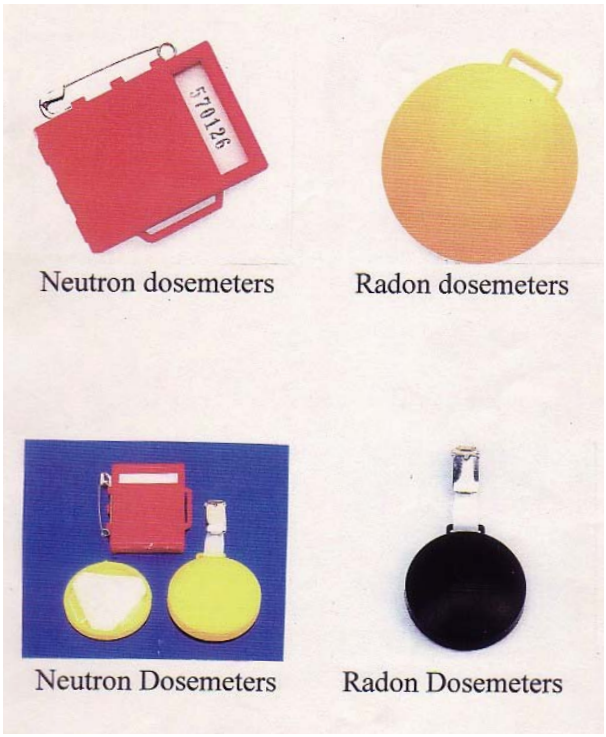

Fig. 5. Different shapes of personal neutron- and radon-dosemeters.

problem of personal neutron dosimetry[7, 9]. In the late 60's and 70's, several laboratories from throughout the world have developed new neutron dosemeters based on damage track detectors[9, 34-38].

Most of the scientists actively engaged in the late 60's and in the 70's in the solution of the complex problem of personal neutron dosimetry have extended their interests in the field of radon in order to develop individual monitors for the exposure to radon decay products in mines by using the same track detectors[9, 34-38].

The personal dosimetry of neutrons and that of radon decay products have had a parallel history and a lot of common traits, such as the same track detectors, the same etching and counting procedures, the same scientists and/or laboratories involved. Despite the fact that the dose to neutrons is due to external exposure while that to radon decay products to internal exposure, identical monitoring strategies have been often adopted, within which a given track density is converted into a neutron dose or otherwise into a dose of radon decay products by appropriate conversion coefficients. In the case of radon decay products, this approach has been facilitated by measuring the radon gas concentration (as surrogate), which can be converted into the radon decay product concentration if the equilibrium factor is either monitored or known to have a given value[39].

Passive radon monitors are formed by radon diffusion chambers, enclosing a track detector[40, 41].

These radon monitors have been increasingly successful both for radiation protection monitoring and elsewhere, because of their simplicity, robustness, and ease of automation of track counting[42-44]. For more than one decade, polycarbonate and cellulose nitrate detectors were the most common plastic detectors for both neutron and radon dosimetry. It was only in 1978 that the poly-allyl diglycol carbonate-PADC detector (known with its trade name CR-39: Columbia resin 1939) was first introduced as track detector[45]. Because of the relatively high sensitivity of CR-39 detector it possible to obtain compact passive detector devices. For example, by using CR-39 detectors, a new personal radon dosemeter has been developed at the National Radiological Protection Board-NRPB with such small size of the diffusion chamber that the entire device is compact as any other personal dosimeter for γ, g, and n radiation[46, 47], as shown in Figure 5. where it can be seen that even the shape and the volume of neutron and radon dosemeters may be identical.

5. Detection of neutrons and radon: The same-type of film badge

In spite of their possible identical geometry, a passive radon monitor is based on a radon diffusion chamber, enclosing a track detector, while a neutron film badge is formed by a solid radiator facing a track detector. However, the first passive radon monitor was termed radon film-badge by Geiger[48, 49], in analogy with the neutron badge. It consisted of a chamber, into which radon was allowed to diffuse, enclosing a nuclear track emulsion to detect the alpha particles, emitted from radon and its decay products. Because of the shortcomings of the nuclear emulsions, Becker[50, 51] deposited a patent on a similar radon badge, based on etch-track detectors. However, these monitors, instead of radon film badges, should be considered the first in-air radon-diffusion chambers, the principle of which has been exploited in all existing passive radon-monitors[41, 52].

Finally, truly radon film-badges have been recently proposed, which exploit the radon sorption in solids, which act as radiators in said badges[53-56].

At nanometer scale, these sorption processes can be explained in terms of the radon-atom nanoparticles being enclosed in bulk-distributed nanoholes (absorption) or surface-distributed nanoholes (adsorption). The radon sorption in a given material is expressed in terms of the radon partition coefficient, which is given by the ratio of the radon concentration in the given material to that of the surrounding air. Under equilibrium-absorption conditions, the partition coefficient of plastic materials is referred to as radon solubility, as in liquids[53]. Incidentally, all types of plastics in their rubbery states can be considered liquid-like materials.

Among the plastics used for track registration, polycarbonate present the largest values of the radon partition coefficient, while CR-39 the lowest[53]. Measurements of the radon partition-coefficient have been carried out for different types of polycarbonate films from Bayer AG (Makrofol DE, Makrofol G, Makrofol KG, Makrofol N), the values of which

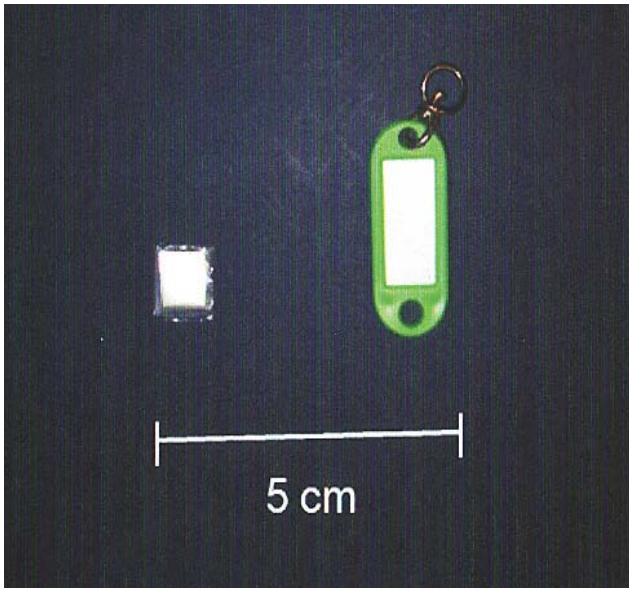

Fig. 6. A compact Rn-monitor (left-hand side) and the same monitor enclosed in a key ring (right-hand side).

have resulted in the range from about 30 to about 90[53-56].

According to the above results, the CR-39 is the most suitable as a detector of the radon film-badge, while the polycarbonate is the most valuable as radiator[56].

The track detector response can be considered proportional to the radon partition coefficient or to the radon solubility of the radiator[53-56].

Because of the availability of materials with a wide range of partition coefficients (with values from 1 to 2000), it is possible to obtain passive radon monitors with any desired response sensitivity, which is highly valuable, because of the large variability of the radon concentrations, which can be encountered in nature[53-56].

The newly developed badges make it finally possible to overcome all the shortcomings of existing passive radon monitors. In particular, with these monitors it is possible to measure short- and long-term exposures of radon outdoors, indoors, in soil, and in water. For in-water radon measurements, the radon film-badge is just enclosed in a heat-sealed polyethylene bag[53].

The left-hand side of Figure 6 shows a uniquely compact radon film badge enclosed in a small plastic bag, while the right-hand side shows a key-ring label containing the same radon film badge. This label-enclosed radon badge shows promise for application as back-up detector, highly valuable for all those measurements, which can't be carried out with existing diffusion-chamber-based monitors. Once proved successfully as back-up detector, this radon film-badge should not take a long time prior to become the principal and/or universal radon monitor.

6. Neutron response of radon film-badges and radon response of neutron film-badges

Very often in this paper, it was emphasized that there are several common traits between the personal dosimetry of neutrons and radon, obtained etch-track detectors.

The use of damage track detectors both for neutron- and radon-dosimetry obviously implies that passive radon dosimeters are also sensitive to neutrons.

Special care should be taken when passive radon dosimeters are used in places where neutron radiations are likely to be encountered, such as in the nuclear industry, in the surroundings of high energy X-ray facility where neutrons are produced by (γ, n) reactions, and around high-energy-particle accelerators.

Moreover, neutrons represent also an important component of the cosmic rays, the intensity of which increases with altitude and latitude. To study the cosmic-ray-neutron response of passive radon monitors[57], sets NRPB/SSI radon monitors have been exposed at an experimental facility at CERN, which simulates the cosmic-ray-neutron field[58].

The response, ε, per unit of neutron dose of these radon monitors is:

$$\varepsilon_{Rn} = (135 \pm 16)\ \text{Tracks}/(\text{cm}^2\ \text{mSv})$$

On the basis of this neutron response and considering a world-wide average of 80 μSv cosmic-ray neutrons at sea level[59], it is possible to evaluate that, on the average, only about (11 ±2) tracks/cm^2 per year can be induced in CR-39. According to the cosmic-ray-background data from UNSCEAR 2000[59], this CR-39 track-density per year increases to about (31 ±4) at Mexico-city altitude (2.240m.) and to about (82 ± 10) at La Paz altitude (3400m.). In a long-haul flight from Milan to Tokyo or from Milan to Los Angeles[10, 32], the track-density induced by cosmic-rays neutrons in CR-39 is about (3 ±1) tracks/cm^2.

In practice, by using the NRPB/SSI radon monitor for a long-term (six-months) exposure at high altitude (La Paz), the cosmic-ray-neutron-induced tracks is equivalent to a radon concentration of about (3 ± 1) Bq/m^3. In brief, it is safe to conclude that the cosmic-ray-neutrons have a negligible effect on the passive radon monitor response even at high altitudes.

By contrast with the cosmic-ray neutron-background, the radon concentrations are unpredictable and may vary from tens of Bq/m^3 up to several thousands of Bq/m^3. Special care is thus required to protect the neutron film-badges from radon exposures.

Recent investigations on the radon partition coefficient of the boron-loaded polystyrene films, used as radiators for neutron badges[60, 61], have proved that these neutron badges can be also considered as sensitive radon badges[56].

Moreover, radon absorption in the detector itself may represent a strong disturbing factor for the response of neutron detectors.

As mentioned earlier, CR-39 and Polycarbonate detectors are characterized by the lowest and the largest radon partition coefficients among plastics[53, 62, 63].

Because of the large radon absorption in polycarbonate, it is possible to explain the erratic response of polycarbonate-based neutron badges[64] in some long-term-integrated

neutron exposures.

Hofert[64] carried neutron measurements at CERN facilities by three different neutron film-badges, based respectively on CR-39, polycarbonate and nuclear emulsions.

The data with polycarbonate neutron film-badges were not consistent with those obtained with the other two passive neutron badges. However, since then it was suspected that the erratic results, obtained with polycarbonate, might have been due to radon exposures.

The strong effects of the radon exposure on the polycarbonate neutron dosimeter can be drastically reduced, by using an etchant made of a water-based KOH solution[65]. With this etchant, it is possible to register only tracks of neutron-induced recoils of carbon- and oxygen-nuclei. Alpha-tracks in polycarbonate can only be registered when alcohol is added to the KOH solution, as in the case of the polycarbonate neutron dosimeter used at CERN[64-66].

A typical neutron film-badge is based on a CR-39 detector facing a polyethylene radiator[67-68]. The response of this neutron badge is:

$$\varepsilon_n = (0.04 \pm 0.01)\ \text{Tracks}\ m^3/(cm^2\ kBq\ h)$$

According to the world-wide indoor radon-concentration of 39 Bq/m^3 [59], the tracks, produced in the above neutron film badge, can be estimated to be (14 ± 3) tracks/cm^2 per year. While this track density can be considered negligible, the real problem arises because the radon concentrations are unpredictable and very high concentrations may be easily encountered. In order to overcome the strong radon-disturbing factor on the neutron-badge response, it is necessary to enclose these neutron film badges in radon free containers[52-56, 64, 66].

7. Dosimetry of neutron and radon decay products: a similar strategy

A neutron-detection badge makes it possible to detect only the neutron fluency. Since the dose equivalent is strongly dependent on neutron energy, the evaluation of the dose on the basis of the neutron fluency requires a detailed information on workplace fields (field spectrometry) to evaluate the neutron quality factor and/or the appropriate dose conversion coefficient. In order to avoid the complex task of carrying out the neutron spectrometry, efforts have been made to obtain detector response (number of detected tracks per unit area) which closely matches the strong dependence of the dose conversion coefficient versus the neutron energy[67, 68]. This is done by choosing suitable reactions, radiator materials, detectors, processing and counting methods. Most of the development work in neutron dosimetry is based on this principle[9, 67, 68].

A strategy similar to that established for neutron dosimetry has been recently proposed by Mishra et al.[69] to solve the long-standing problem of the dosimetry of radon-decay-products. In this case, the dose equivalent of radon-decay products depends strongly on the sizes of airborne particles.

Airborne particles may have sizes from about 1 nm to tens of microns. These particles can be classified in two broad categories according to their deposition mechanisms, by using the size of 0.25 micron as a benchmark[69, 70]. This benchmark is justified by the fact, that particles with sizes less than about 0.25 microns are characterized mainly by diffusion-based deposition-mechanisms, and can be termed nanoparticles. The remaining particles (with sizes > about 0.25 microns) are characterized by gravitational-dominated deposition mechanisms and may be referred to as microparticles (i.e. particles with micrometer sizes). This type of characterization is of interest, since the deposition of airborne particles is an important parameter for the assessment of their effects on any target site (skin, lung, technological surface, museum artifact/painting, etc.). Mishra et al.[69], by using a screen capped bare radon film-badge, have proved that it is possible to simulate the lung deposition of airborne nanoparticles. This screen capped track detector makes it finally possible to obtain a passive monitor of radon decay products, the response of which closely mimics the strong dependence of the dose conversion factor versus the particle sizes.

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