Monitoring Personal Occupational Exposures
to Radon Progeny and Long-Lived Radioactive Dust

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Introduction

The personal alpha dosimeter (PAD) is a lightweight monitoring system designed to infer individual exposures to radon and thoron progeny and to long-lived radioactive dust (LLRD). Although used primarily in the uranium-mining industry, the PAD has also been used in non-uranium mines, radioactive waste cleanup and storage facilities, and a variety of other industries where workers may be exposed to uranium-bearing materials.

The PAD is licensed by the Canadian Nuclear Safety Commission (CNSC) under Regulatory Standard S-106 Revision 1 *Technical and Quality Assurance Requirements for Dosimetry Services*. This is the only licensed dosimeter in Canada capable of inferring the exposure of individual workers to radon and thoron progeny and LLRD.

Design

The dosimeter is comprised of a track-etch detector, commonly referred to as a dosimeter head, which is mounted inside a battery-powered air pumping system, referred to as the PAD body (Figure 1).

Résumé

Le dosimètre alpha personnel (DAP) constitue un moyen fiable pour déduire le niveau d'exposition individuel aux progénitures de radon et de thoron ainsi qu'à la poussière radioactive à période longue (PRPL). L'article examine en détail la conception et l'opération du DAP, puis discute des calculs utilisés pour déterminer l'exposition aux progénitures de radon et de thoron, ainsi qu'à la PRPL.

Figure 1: PAD body (yellow) and dosimeter head (green)

The PAD body is a lightweight air-pumping system that draws air through the dosimeter head at a nominal flow rate of 4 L/h. The pump is enclosed in a durable polycarbonate box, which is designed to be worn on an individual's belt.

The PAD is powered by a small rechargeable battery that is designed to operate for a minimum of 12 hours. The charger uses induction to recharge the PAD. An electric card on the charger generates a high-frequency alternating current, which feeds a coil that supplies the energy necessary to recharge the battery.

The dosimeter head (Figure 2) is an alpha-particle spectrometer capable of separately detecting the 5.99 MeV and 7.69 MeV alpha particles from radon progeny (Po-218 [RaA] and Po-214 [RaC′]) and the 8.78 MeV alpha particles from thoron progeny (Po-212 [ThC′]) without the use of electronics. This is achieved using a three-channel collimator, each channel having an energy-absorbing Mylar™ strip with a thickness specifically chosen for the alpha particle the channel is designed to identify. The thickness of each Mylar™ absorber is chosen so that the alpha particle of interest hits the cellulose nitrate film with the energy required to make an easily identifiable track.

Operation

The air flow through the PAD is determined using an indirect technique that utilizes the basic principles of air-flow circuit dynamics. By measuring parameters such as the PAD body-stall pressure (the pressure exerted by the PAD body at zero air flow) and the pressure drop across the dosimeter head (at a constant air-flow rate

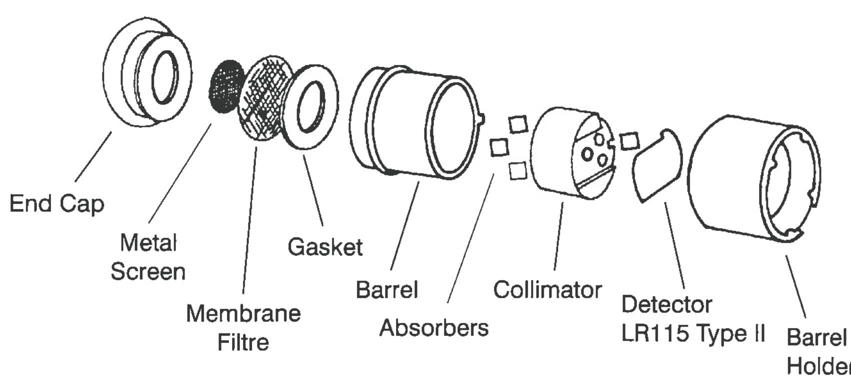

Figure 2: Exploded view of dosimeter head

of 4 L/h), the air flow through the PAD, Q, can be calculated using the equation

$$Q = 4 \times \frac{2 \times P_{Average}}{\Delta P_1 + \Delta P_2}$$

The parameter $P_{Average}$ denotes the average PAD stall-pressure measurement, which is measured weekly during the monitoring period. The terms ΔP_1 and ΔP_2 denote the initial and final pressure drops across the dosimeter head, which are measured before and after the monitoring period. Both the stall-pressure and the pressure-drop measurements are performed with a standard Magnehelic pressure gauge.

During operation, particulates in the air are drawn through the dosimeter head. The particulates, including any attached radon and thoron progeny and LLRD, will get caught in the filter inside the dosimeter head. Although worn outside the breathing zone of the individual being monitored, testing has shown that significant aerosol concentration gradients do not exist between the hip and the breathing zone. The sampled air can therefore be considered representative of the air breathed by the individual.

As the attached radon and thoron progeny decay, alpha particles are emitted. Some of these alpha particles will travel up the three-channelled collimator and pass through the absorbers attached to the collimator. The alpha particles will then strike the detector film located at the top of the collimator. The detector film (LR-115 Type II) is only sensitive to alpha particles that have energy in the range of 1.5–4.0 MeV.

To properly discriminate between alpha particles, each collimator is fitted with a Mylar™ absorber of a specific thickness. The thickness of each absorber is chosen so that the alpha particle of interest emerges from the Mylar™ absorber with an approximate energy of 1.5–4.0 MeV in order for it to leave identifiable tracks on the film. Alpha particles that are not of interest will either be stopped completely by the Mylar™ absorber or pass through the film with energy greater than that required to leave identifiable tracks. The result is three distinct film regions that only contain alpha damage tracks from RaA (Po-218), RaC′ (Po-214), and ThC′ (Po-212), respectively.

Figure 3: Damage tracks on film

The tracks on the film are then enlarged by etching the films for 90 minutes in a sodium-hydroxide solution at a temperature of 60°C. The etching process enlarges the damage tracks on the film so that they can be counted using a specialized image-analysis system (Figure 3). The number of damage tracks can then infer the individual's inhalation exposure to radon and thoron progeny using the following expressions:

$$WLM(Radon\ Progeny) = \frac{7.69 \times NRaC' + 5.99 \times (NRaA - 0.56 \times NThC')}{0.8 \times 0.001037 \times 1.3 \times 10^5 \times 170 \times Q}$$

$$WLM(Thoron\ Progeny) = \frac{8.78 \times NThC' + 0.56 \times 6.08 \times NThC'}{0.8 \times 0.001037 \times 1.3 \times 10^5 \times 170 \times Q}$$

where NRaA, NRaC′, and NThC′ refer to the number of tracks counted in the RaA, RaC′, and ThC′ regions, respectively. The constant 0.8 refers to the collection efficiency for radon and thoron attached aerosols, while the constant 0.001037 represents the efficiency factor of the dosimeter head. The constants 1.3×10^5 and 170 are the required factors to convert the result from MeV/L to Working Level Months (WLM).

Following a minimum waiting period to allow all radon and thoron progeny to decay, the gross alpha activity of the dosimeter-head filter is measured using a low background proportional counter. The activity of the filter can then be used to infer the individual's exposure to long-lived alpha emitting radionuclides, using the following expression:

$$LLRD\ Exposure\ [Bq] = \frac{LLRD\ Activity\ [Bq] \times 1200[L/h]}{0.8 \times Q[L/h]}$$

where 1200 [L/h] represents the average breathing rate of ICRP 23's reference man during light activity and 0.8 refers to the aerosol collection efficiency of the PAD for inhalable LLRD.

PAD Detection Limits

The limits of detection for the measurement of radon and thoron progeny with the PAD are governed by the ability to accurately determine the number of tracks on the exposed film.

Theoretically, the PAD can measure radon and thoron progeny to exposures as low as 0 Working Level Months (WLM), which would correspond to zero tracks on the film. However, at low exposure, the uncertainty in the results due to statistical errors is quite large. Therefore, the lower limit is governed by the number of background tracks and surface defects typically found on the detection film, which translates into a lower detection limit of approximately 0.002 WLM.

The upper limit of detection for the PAD is governed by track density on the film and the resolution of the track counting system being used. The upper limit of detection for the measurement of radon and thoron progeny is approximately 11 to 18 WLM.

The upper and lower detection limits for the measurement of LLRD are determined by the operating parameters of the low-background proportional counter.

PAD Testing

The PAD has undergone extensive testing in Canada, the United States, and Europe for the measurement of radon and thoron progeny and LLRD. This testing continues to provide results that are consistent with testing-facility reference systems and that are in compliance with the CNSC Regulatory Standard S-106 Revision 1 accuracy requirements.