Radiation Measurements xxx (2017) 1–5

Contents lists available at ScienceDirect

Radiation Measurements

journal homepage: www.elsevier.com/locate/radmeas

$H_p(3)$ response of the PHE PADC neutron personal dosemeter

Rick Tanner*, Luke Hager, Jonathan Eakins, Phil Gilvin

Public Health England, Chilton, Didcot, Oxon OX11 0RQ, UK

HIGHLIGHTS

- $H_p(3)$ conversion coefficients calculated for neutrons.
- $H_p(3)$ response of PHE neutron dosemeter determined.
- PHE neutron dosemeter shown to be appropriate for eye lens dosimetry in some circumstances without modification.

ARTICLE INFO

Article history:
Received 30 September 2016
Received in revised form
28 March 2017
Accepted 10 April 2017
Available online xxx

Keywords:
Neutron
PADC
$H_p(3)$
Eye lens

ABSTRACT

Doses to the lens of the eye have long been recognized as one of the hazards of ionizing radiation, with a 150 mSv limit having been set for radiation protection purposes (ICRP, 1991), but more recent analysis of the epidemiology of cataract induction (Ainsbury et al., 2009) has led to the recommendation that the dose limit for exposures of the lens of the eye should be reduced to 20 mSv (ICRP, 2012). This has led to increased interest in doses to the lens of the eye and the control of those doses. Most focus of this interest has related to exposures from weakly penetrating radiation. However, $H_p(3)$ assessments will need to be entered in dose records, including an assessment of the neutron dose in mixed fields. The response of the PHE PADC neutron dosemeter is presented in terms of $H_p(10)$ and $H_p(3)$. These data show that the dosemeter response is closer to ideal in terms of $H_p(3)$ than it is in terms of $H_p(10)$ and that the dosemeter can be used for the assessment of $H_p(3)$. PHE will be ready for changes in UK legislation that are anticipated in 2018.

1. Introduction

Cataract induction in the lens of the eye has long been recognized as one of the hazards of ionizing radiation, with a 150 mSv annual limit having been set for radiation protection purposes (ICRP, 1991). More recent recognition that there may be no threshold in dose for cataract induction, or that the threshold may be lower than had previously been assumed (Ainsbury et al., 2009), has led to the recommendation that the annual dose limit for exposures of the lens of the eye should be reduced to 20 mSv (ICRP, 2012; EURATOM, 2013). This has caused increased interest in doses to the lens of the eye and in the control of those doses. Most focus of this interest has related to exposures from beta particles and low energy photons, both of which are weakly penetrating. However, the requirement that $H_p(3)$ assessments will need to be entered in dose records means that this will need to include an assessment of the neutron dose in mixed fields.

It is well recognized that eye lens doses will be of great importance for occupational monitoring because of the potential photon and electron exposures, especially in medical environments (Vanhavere et al., 2012). However, the published conversion coefficients (ICRP 2010) for external exposures from photons (Fig. 1) and electrons (Fig. 2) show that the dose to the eye lens is likely to be higher than effective dose in almost all workplaces, unless a person is exposed predominantly from the back: with equal dose limits it can be argued that control of eye lens dose may be most important for most workplaces. For photons, the eye lens dose is higher than effective dose for AP ($\leq$1.5 MeV), LLAT ($\leq$5 MeV), RLAT ($\leq$5 MeV), ROT ($\leq$2 MeV) and ISO ($\leq$2 MeV), but lower than effective dose for PA for all energies below 30 MeV. For electrons, the eye lens dose is higher than effective dose for AP (from 0.8 MeV to 30 MeV) and ISO (from 0.8 MeV to 60 MeV). It is lower than effective dose for PA for all energies below 200 MeV. There are no published data for the eye lens absorbed dose for LLAT, RLAT or ROT.

The energy ranges for which $H_{Eye\ lens} > E$ for photons and electrons cover the ranges of most concern for radiation protection

* Corresponding author.
E-mail address: rick.tanner@phe.gov.uk (R. Tanner).

http://dx.doi.org/10.1016/j.radmeas.2017.04.003
1350-4487/© 2017 Published by Elsevier Ltd.

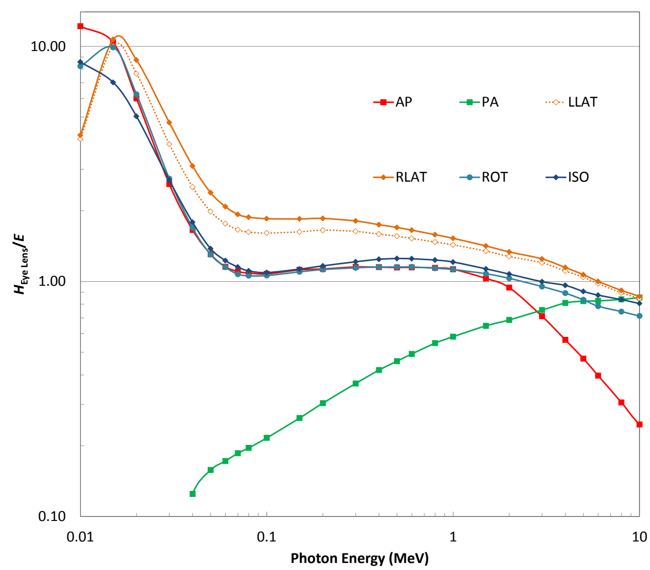

Fig. 1. Ratio of the eye lens dose to effective dose for AP, PA, LLAT, RLAT, ROT and ISO versus photon energy.

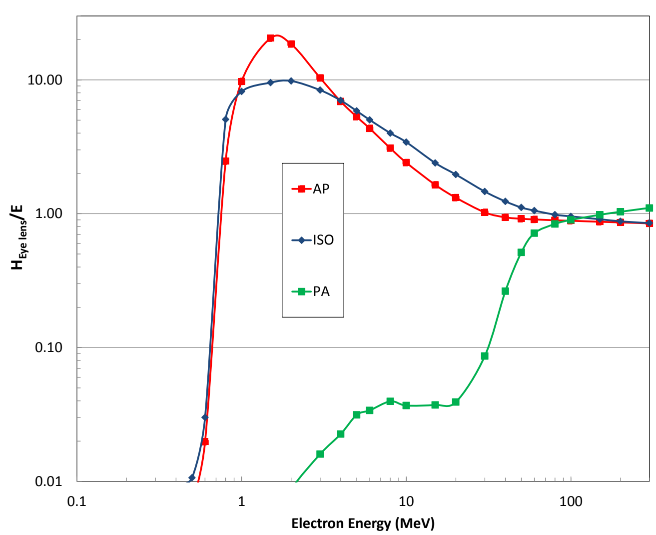

Fig. 2. Ratio of eye lens dose to effective dose for electrons.

in the workplace. Consequently, the need for eye lens dosimetry will extend to almost all workplaces, and the total $H_p(3)$ may become the most relevant quantity for control of exposures in workplaces where neutrons are also a significant contributor to the total radiation dose. In those workplaces the personal dosimetry will need to include an assessment of neutron $H_p(3)$. This can be addressed by designing a specific neutron $H_p(3)$ dosemeter or by using dose estimates from a neutron $H_p(10)$ dosemeter with its calibration adjusted to give dose estimates in terms of $H_p(3)$. This latter approach is simpler and cheaper, but would produce a poor response for a dosemeter for which the sensitive element is located at a tissue equivalent depth of 10 mm.

Public Health England (PHE) routinely supplies neutron personal dosemeters to measure $H_p(10)$ that incorporate polyallyl diglycol carbonate (PADC) sensitive elements, which are electrochemically etched during processing (Gilvin et al., 1987). However, to avoid excessive protrusion from the body the PHE neutron personal dosemeter has a total thickness of about 6 mm and the etched face of the PADC element is located at a depth of approximately 3 mm. Prior work has shown that increasing the dosemeter thickness to ensure that the etched face of the PADC is close to 10 mm tissue equivalent depth (Tanner et al., 2008) produces a "flatter" energy dependence of response, but it does not produce dosimetric improvements in workplace fields. Consequently, the PHE neutron personal dosemeter retains a design that it intrinsically suited to the assessment of $H_p(3)$. The current paper aims to characterize the PHE dosemeter in terms of its $H_p(3)$ response, and discuss its potential for use in eye lens dosimetry.

2. Results

PHE has run a neutron personal dosimetry service since 1986 (Gilvin et al., 1987). The service has had many improvements to it over the past three decades (Tanner et al., 2007), all of which have sought to enhance its response. The dosemeter is well characterized from thermal neutrons to 17 MeV for normal incidence and angles of incidence up to 75° on an ISO slab phantom, and also up to higher energies for cosmic and accelerator dosimetry.

To reinterpret the response of the neutron personal dosemeter in terms of $H_p(3)$ requires fluence to dose equivalent conversion coefficients for neutrons, values for which have not been calculated by the ICRP or ICRU. Values have been published (Ferrari et al., 2014) for angles from 0° to 75° that were obtained using the code MCNPX 2.5.0 (Pelowitz 2005). This restricted range of angles was used because it was assumed that only irradiation from the front would be of concern for eye lens dosimetry, but as has been shown (Figs. 1 and 2), a greater range of orientations does need to be considered.

Characterization of the dosemeter for neutron response in highly scattered fields requires a greater range of angles, for which $H_p(3)$ conversion coefficients were not published. PHE uses a procedure for calibrating its dosemeter in terms of $H_p(10)$ that utilizes conversion coefficients for normal incidence and rotational isotropy (Hager et al., 2016), so to facilitate a comparable analysis, conversion coefficients for $H_p(3)$ have been calculated (Table 1) using the code MCNP6 (Pelowitz 2013) for both normal incidence (0°) and for rotational isotropy. The conversion coefficients were calculated using the mean $Q(L)$ values (Siebert and Schuhmacher 1995) with the kerma coefficients (Chadwick et al., 1999) to multiply the fluence at 3 mm depth in a 20 cm high, 20 cm diameter cylinder of ICRU 4–element tissue to give the dose equivalent. Secondary charged particles were not transported.

The tallying volume was defined using three cylinders: two with axes coincident with the phantom axis, with radii of 19.69 and 19.71, thereby defining a 0.2 mm thick layer at a depth of 3 mm in the phantom, and another normal to the axis of the phantom defined at its midpoint. This third cylinder had a radius of 0.5642 cm and cut a 1 cm^2 element from the 3 mm deep shell. The resultant tally had a volume of about 20 mm^3. Since the scoring volume for use in the determining the ICRU operational quantities is not defined, this solution seemed to match the definition whilst yielding a large enough volume to achieve conversion relatively easily. The tally is at an average depth of 3 mm, but for plane parallel irradiation its edges require the radiation to travel through slightly more than 3 mm of ICRU tissue.

The standard uncertainty data (σ) in the table reflect just the statistical variations from the Monte Carlo process. The values for normal incidence were found to agree with the prior data within statistical uncertainties, but there are no comparable prior data for rotational isotropy so no comparison is made. These new data are compared (Fig. 3) alongside D_{lens} (ICRP 2010): the ROT conversion

Please cite this article in press as: Tanner, R., et al., $H_p(3)$ response of the PHE PADC neutron personal dosemeter, Radiation Measurements (2017), http://dx.doi.org/10.1016/j.radmeas.2017.04.003