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PRACTICAL LOW DOSE LIMITS FOR PASSIVE PERSONAL DOSEMETERS AND THE IMPLICATIONS FOR UNCERTAINTIES CLOSE TO THE LIMIT OF DETECTION

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Recent years have seen the increasing use of passive dosemeters that have high sensitivities and, in laboratory conditions, detection limits of <10 μSv. However, in real operational use the detection limits will be markedly higher, because a large fraction of the accrued dose will be due to natural background, and this must be subtracted in order to obtain the desired occupational dose. No matter how well known the natural background is, the measurement uncertainty on doses of a few tens of microsieverts will be large. Individual monitoring services need to recognise this and manage the expectations of their clients by providing sufficient information.

INTRODUCTION

Users of dosimetry services should understand the practical limits and uncertainties in the doses assessed for monitored personnel. Recent years have seen increased attention being paid to low, sub-millisievert doses, and there is a danger that, without proper consideration of the uncertainties, too much attention can be paid to these results.

The increased focus on low doses is in part due to the growing use of electronic dosemeters, but also to the widespread operational use of passive personal dosemeters with very high intrinsic sensitivities. Under laboratory conditions, typical decision thresholds for such dosemeters are now substantially <10 μSv. This means that, for these technologies, the sensitivity of the dosemeter and the 'laboratory' uncertainties of assessment are no longer the limiting factors on practical low-dose performance. Other factors, in particular natural background, dominate.

This paper will:

- outline the definitions relating to the evaluation of the limits of detection and uncertainties;
- outline contributions to uncertainty;
- describe uncertainties on the background, with examples drawn, where applicable, from the authors' services (including how these affect the decision threshold and detection limit); and
- discuss the uncertainties on the assessment of occupational dose at low doses.

Finally, some recommendations are made on the practical limitations at low doses, their consequences on dosimetry services and the information they provide their clients.

HIGH SENSITIVITY PASSIVE DOSEMETERS

The detector materials used in modern passive dosemeters are now of very high sensitivity. As examples, the UK Health Protection Agency (HPA) and LANDAUER EUROPE are two services, amongst others, which offer high-sensitivity dosimetry, using thermoluminescent (TL) and optically stimulated luminescent techniques[1, 2]. The HPA uses TL dosemeters with LiF:Mg,Cu,P, which have an intrinsic sensitivity at least 10 times higher than that of 'conventional' LiF:Mg,Ti. LANDAUER EUROPE uses optically stimulated luminescent (OSL) dosimetry technique using aluminium oxide doped with carbon (Al_2O_3:C). These detectors are packaged into badges designed to measure both the operational quantities $H_p(10)$ and $H_p(0.07)$. The respective dosemeters are pictured in Figures 1 and 2.

DEFINITIONS

Definitions of relevant terms are given in appropriate international standards, including ISO 11929-7-2005[3].

- Decision threshold is the threshold above which a physical effect is present (i.e. the ability to distinguish between background and a significant occupational dose).
- Detection limit (limit of detection) is the smallest level of the measured quantity (measurand) detectable with the measuring method (i.e. is the smallest dose that can be detected on a dosemeter using the readout method chosen).

Rules of thumb for calculating these quantities are given in ref. (4), viz:

Figure 1. The HPA personal dosemeter based on TL detectors.

Figure 2. The LANDAUER EUROPE personal dosemeter based on OSL detectors (left InLight® version and right Luxel® as used in the UK).

- decision threshold = 1.7u(0),
- detection limit = 3.3u(0),

where u(0) is the standard uncertainty in the background.

The detection limit is often used by dosimetry services as the reporting level (minimum dose quoted) on dose reports, although other practices (using the decision threshold, or following a national legal requirement) are also adopted.

CONTRIBUTIONS TO UNCERTAINTY

Various methods exist for determining the uncertainty of assessments made by routine dosimetry services, for example ref. (3). Recently, the European Commission has published recommendations, prepared by EURADOS, for individual monitoring services, including recommendations for the evaluation of uncertainties and limits of detection[(4)]. The uncertainties comprise numerous Type A and B effects, including energy and angular dependence, dose response, calibration and so on. In a laboratory environment these uncertainties can be in the region of 5–10% for one standard deviation.

External effects for dosemeters that issued for personal monitoring include variations in background, the way in which the badge is worn and so on.

UNCERTAINTIES IN THE BACKGROUND

Operational dosimetry services use a number of techniques for the management of background dose in the assessment of occupational exposure. These include making an assessment of the background at an individual site, or issuing special ‘control’ dosemeters that are manufactured/annealed at the same time as the occupational dosemeters, travel to and from the client with the dosemeters for personal monitoring and read out at the same time. (Dosemeter measurements are usually in terms of personal dose equivalent Hp(10), but since the external radiations that contribute to natural background have high energies, measurements of ambient dose equivalent H*(10) are also acceptable for these purposes.)

In any event, there is an intrinsic uncertainty in the assessment of the background dose. For example, experiments have been made at LANDAUER EUROPE’s Fontenay-aux-Roses offices (near Paris, France) in which InLight® dosemeters annealed at the same time were stored in the laboratory and read out at approximately monthly intervals to assess both the local background and the uncertainty on the background, Perks and Faugoin[(5)] (Figure 3).

From this experiment, the background was measured as 0.041 mSv per 30 day period with a 15% uncertainty (2 standard deviations).

In the UK, the HPA have determined the background as 1.27 μSv per day (0.038 mSv per 30 day period) at their office in Chilton; 2.85 μSv per day (0.086 mSv per 30 day period) at their office in Leeds; and 3.41 μSv per day (0.108 mSv per 30 day period) at their office in Glasgow (all subject to about 10% uncertainty at the 95% confidence level).

Further data on background levels throughout the world can be found in Passmore and Kirr[(6)], in this conference. As regards measurement uncertainty at low doses, the most important point is that the background doses are large—substantially larger than the reporting levels used. A secondary point is that the natural background is variable (see, for example, ref. (6)), so that it must be assessed properly if low reported doses are to have any meaning.

Effects of background uncertainties on the decision threshold and detection limit

Clearly the assessed background increases linearly with time and similarly the standard uncertainty of

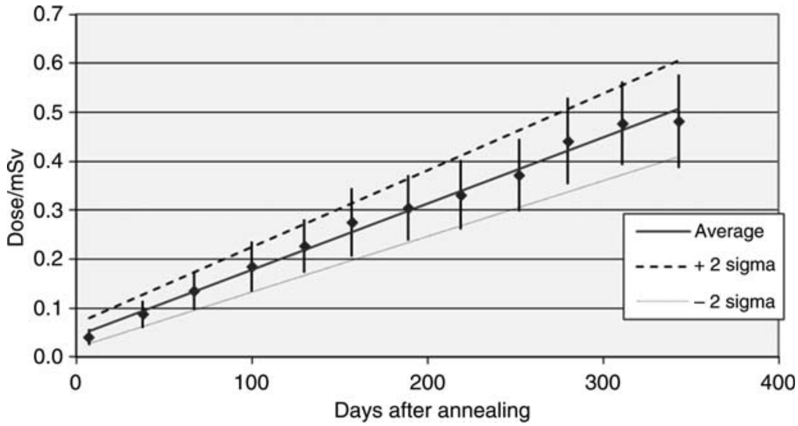

Figure 3. Background as measured using InLight dosemeters at Fontenay-aux-Roses.

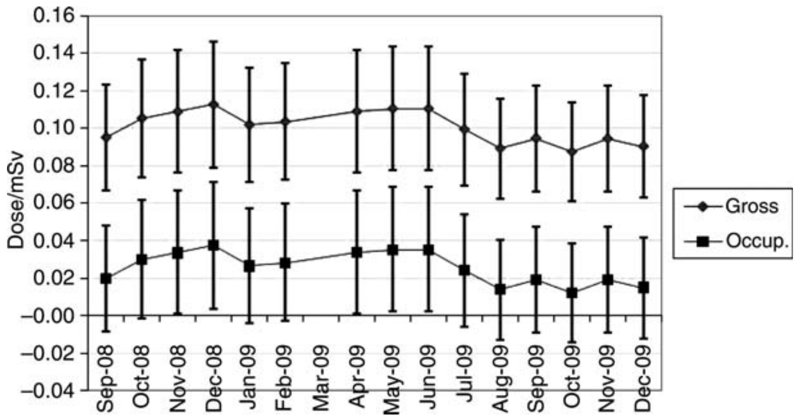

Figure 4. Measurements of approximately 0.025 mSv dose with HPA TL dosemeters.

the background also increases. Therefore, the decision threshold and the detection limit are also similarly dependent on the duration of the wear period. Taking values from Figure 3 for a 30 day period, the accumulated background is 0.041 with a standard uncertainty of 0.003 mSv (7.5%). Using the rules of thumb above, these figures give:

- decision threshold = 0.005 mSv,
- detection limit = 0.01 mSv.

Detailed uncertainty analyses should be undertaken for dosimetry services, taking into account the relevant national and international standards.

UNCERTAINTIES AT LOW DOSES

To determine the occupational dose, the assessed background dose H_{nat} is subtracted from the gross dose assessed from the dosemeter worn by the monitored person, H_{gross}, to give the net occupational dose, H_{occ}. Hence:

$$H_{\mathrm{occ}} = H_{\mathrm{gross}} - H_{\mathrm{nat}}.$$

At low doses, the occupational dose is only a small fraction of the background dose. For example Figure 4 shows how H_{occ} is derived from H_{gross} for sets of monthly dosemeters issued at the HPA. The natural background at the HPA is well known, and will itself contribute little to the overall uncertainty. For the purposes of this illustration the unrealistic assumption has been made that it is known perfectly, i.e. that it makes no contribution to uncertainty.

The gross measured monthly dose shows an average of about 0.100 mSv. The uncertainty from all sources other than natural background is estimated to be 30%, i.e. ± 0.030 mSv. If the typical natural background for a 1-month issue is now subtracted, with some time allowed for normal issue and return, the lower, resultant values for the occupational dose are arrived at. Here the average is just over 0.025 mSv. (Note that the error bars appear to allow for negative dose values, but the normal convention will be to report these as zero.)

The important point here is that the overall uncertainty remains at ± 0.030 mSv, which now represents well over 100% of the reported occupational dose. (Note that this is without considering any contribution from the uncertainty on the natural background.) This illustrates the fact that, at occupational doses around a few tens of microsieverts, the calculation involves subtracting two large numbers from each other. Whenever two large numbers with only moderate uncertainties are subtracted, the uncertainty on the resultant is always, *relatively*, much larger.

Note that the examples above have discussed monthly change intervals. Where quarterly change intervals are used, the natural background dose, and the corresponding limitations, will be much greater.

As dose increases

Of course, the uncertainties reduce dramatically as the proportion of the gross dose due to the occupational dose increases, Figure 5. This figure assumes a dosemeter exposed to a nominal background of 0.1 mSv, with an uncertainty of 5% and a measurement uncertainty of 10%.

Clearly at very low doses the uncertainties approach or exceed 100%. However, as the occupational dose increases, the uncertainty quickly asymptotes to the intrinsic measurement uncertainty of the dosemeter.

OTHER TYPES OF DOSEMETERS

The effects described apply to high-sensitivity dosemeters where the natural background subtraction is a significant factor in determining the occupational dose, and for which the intrinsic limits of detection (minimum reporting levels) are low. (For other dosemeter types such as photographic film and track etch, other factors are more important in determining the limit of detection.)

This is the case for passive dosemeters measuring whole-body dose. For passive dosemeters assessing an extremity dose for which the legal dose limits are substantially higher, or for neutron dosemeters, where the natural background dose rate is negligible, this effect on uncertainty is substantially less important.

For electronic dosemeters, the measurement regime is rather different from that of passive dosemeters, in that the dosemeters are worn only during occupational exposure and the dose is assessed immediately at the end of that wear period. Therefore, the background dose is only accumulated for that short period of time (rather than for the full month or quarter of the wear period for passive dosemeters). In general this small background dose is not subtracted from the gross dose assessed by the electronic dosemeter.

CONCLUDING REMARKS AND RECOMMENDATIONS

With the use of very sensitive materials, the occupational dose assessed for workers wearing passive dosemeters can potentially be measured to very low detection limits. It has been demonstrated that the key factor in determining the uncertainty in the doses assessed at very low doses (and, indeed, the decision threshold) is principally determined by the need to subtract a relatively large background dose from the measured dose. This uncertainty reduces asymptotically to the intrinsic uncertainty of the detection method as the occupational dose increases.

In the authors' positions as heads of contract approved dosimetry services in the UK, it seems to

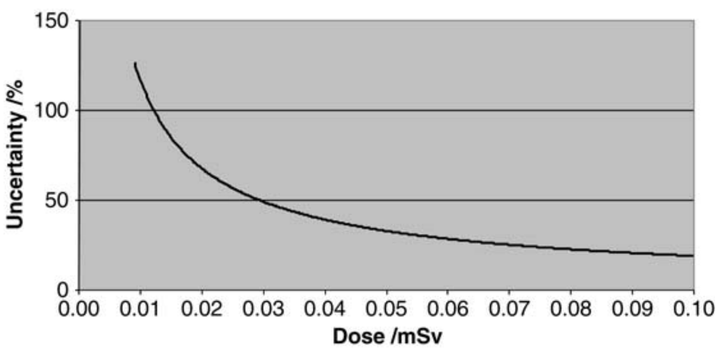

Figure 5. Uncertainty as a function of occupational dose.

them that their clients are not always aware of the uncertainties at low reported doses. It is recommended that all Individual monitoring services actively manage the expectations of their clients by providing adequate information: because of natural background, even the most sensitive passive dosemeters have limited accuracy at low doses.

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