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Wearing more than one dosemeter – how do we explain the differences?

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Abstract

Increasingly, radiation workers are wearing more than one dosemeter, either a passive and an active one supplied by their employer, or a combination of employer's and site operator's dosemeters. Electronic dosemeters now have a level of dosimetric performance which equals, and often exceeds, that of passive dosemeters. As such, wearers are increasingly inclined to compare the results of various dosemeters issued to them and to be concerned when there are, to their eyes at least, significant differences between the results. This is particularly true for users who work at high levels of precision in their jobs and who find it difficult to appreciate the relatively low accuracy of field radiation measurement.
This paper goes into the various reasons why differences are generally inevitable.
It covers from the simple – "Did you wear both dosemeters all the time" to the more subtle, such as the radiation fields to which the dosemeters have been exposed and the factors used to make corrections to the apparent recorded dose. The analysis uses data from a wide range of sources and gives various simple methods which can be used to investigate differences.

Introduction

Increasingly, radiation workers are asked to wear more than one dosemeter. Sometimes it is a combination of two dosemeters both supplied by the employer, one a passive dosemeter, generally from an approved dosimetry service (the "legal" dosemeter) and the other an electronic dosemeter, which is intended to act as an alarm, to supply information on task doses, or to act as an ALARA tool, i.e. to encourage the wearer to minimise dose by moving away from higher dose rate areas.

Dual wear has been current for many years, with film badges and quartz fibre electroscopes (QFEs) in the early days, moving to thermo-luminescent dosemeters (TLDs) and simple Geiger- Müller (GM) based dosemeters in the 1970s and then to more capable GM and silicon diode based dosemeters in the 1980s and 1990s. Until the introduction of these more capable dosemeters, there was a very low expectation of the performance of the QFE or other supplementary dosemeter (1) and staff generally did not expect a high level of agreement. However, with modern electronic dosemeters, staff expect their performance to be at least comparable with that of any passive dosemeter and hence expect a much higher level of agreement. This is particularly the case where wearers know that the electronic dosemeter, such as the Thermo EPD Mk2, is used in other organisations as part of the approved dosimetry service.

Moreover, life can be even more complicated, particularly for contractors who may wear a passive dosemeter from their employer, which is used for their legal dose record, a passive dosemeter from the site operator and an active dosemeter from the site operator. On occasions, the employer may require an electronic dosemeter as well, giving a total of 4 dosemeters, often of very different types. With modern dose control systems, the wearer can end up with up to 4 dosemeter reports per month, some of which measure both personal dose equivalent, penetrating (Hp(10)) and personal dose equivalent, superficial (Hp(0.07). It is extremely unlikely that these will produce the same numerical values. How then do we deal with all these numbers and why do they not agree? This is a frequent question from staff who are used to accurate measurement in their trade or profession and find it puzzling, and unsettling, to have often quite a wide range of values quoted for what they regard as the same exposure.

Currently, there is a project to produce international guidance on the matter (2) but this is strongly biased to addressing only relatively large exposures (> 1 mSv/month) and quite large differences (> 30 %) between the two values. In the authors' experience, wearers often have significant concerns at much lower levels both of dose and difference.

This paper discusses the reasons why there are differences both in terms of the dosemeters and in terms of the radiation fields encountered. It is concerned purely with photon (X and gamma) radiation and the measurement of personal dose equivalent, Hp(10).

Causes of difference

The list of causes of difference is extensive, and ranges from the very obvious to the quite subtle. The dosemeters themselves often provide information that can be used to identify causes of difference:

- Were both dosemeters worn over the same period?
- Were the dosemeters worn close together or were they separated on the body?
- Are the dosemeters clipped to the wearer or can they move away from the body and rotate?
- Were they worn the right way round?
- Does the worker generally stand close to a source or is he or she generally exposed to distant or diffuse sources?
- Is the wearer generally working in the one position or is he or she mobile?
- What is the nature of the workplace fields, in terms of energy, angular distribution and dose rate?
- Does the dosemeter only accumulate dose in use or does it require correction for dose accumulated in storage? Is the dose rate during storage properly understood? How is storage dose corrected for?
- What are the radiological characteristics of the dosemeters?
- What are the environmental characteristics of the dosemeters?
- Is there the possibility of contamination of a dosemeter and can that be checked?
- Is there any possibility of malice?
- Ways to identify causes of disagreement using the dosemeters themselves

Issue procedures

Passive dosemeters are generally issued for relatively long periods, typically one month in the UK for workers with a significant dose accumulation rate or 3 months for others. Active dosemeters are sometimes allocated to a user permanently but the more sophisticated ones are generally issued on a random basis on entering the work area and returned when leaving. The user's dose record is updated every time the dosemeter is returned, but typically twice a day. This means that a user rarely ends up wearing the same dosemeter over a period of any length. This has the advantage that the user's dose history is generally derived from the average of the dosemeter's performance rather than from an individual dosemeter which could be at an extreme for some aspect or other.

Were both dosemeters worn over the same period?

This is the most obvious cause of difference, but is generally very easy to identify. Some workers have a relatively constant exposure but others, particularly maintenance staff, have a much more variable day to day exposure and, hence, even a day's difference in wear or calculation can have a significant effect.

Were the dosemeters worn close together or were they separated on the body?

The closer dosemeters are worn, the more similar their radiation exposure. The angular distribution of radiation fields depends on the plant, but there can be a mix of isotropic, rotationally and unidirectional components (3). In large industrial plant such as at Sellafield, the exposure geometry can be very complicated, with a wearer exposed to radiation incident from above, below and over a range of horizontal angles. Differences between dosemeters can be increased if the exposure is to a relatively close source, simply as a consequence of the inverse square law, or where there is significant but irregular local shielding such as the use of lead blankets or the presence of waist high walls. This is further complicated by whether the wearer moves around during the exposure or is essentially stationary. In some circumstances, particularly where the exposure has a strong uni-directional component and the wearer is stationary, then the wearing position can have a major influence on the result from a dosemeter.

Were they worn the right way round?

This is a problem generally associated with electronic dosemeters. The older designs, which were intended for penetrating X and gamma radiation only, often had the clip to the outside, allowing them to be carried in a pocket. This was sensible, as it reduced the breakage rate. When newer designs were introduced, these often also measured relatively non-penetrating radiation such as beta and low energy X radiation, and these are used with the clip to the inside. Despite the fact that either the display is hidden (for dosemeters with the display on the front, or upside down, for dosemeters with the display on the front, dosemeters are occasionally used the wrong way round. As the dosemeter is not, in terms of its energy and polar response, front/back symmetrical, the wrong value will be recorded.

Are the dosemeters clipped to the wearer or can they move away from the body and rotate?

Some wearers clip their passive dosemeter to a pass chain or lanyard. This allows the dosemeter to move away from the body and to rotate. Generally any electronic dosemeter is worn on the body. There are four potential effects:

- A dosemeter which dangles away from the body will not be shielded to the same extent as one worn on the body for radiations from behind the wearer. This will lead to an incorrect high answer for rotational and isotropic fields.
- A dosemeter which dangles away from the body will not experience the same level of backscatter as one worn on the body. This is particularly important for dosemeters which respond efficiently to backscatter, such as most TLDs, but is less important for dosemeters with an inherent low response to backscatter, such as many electronic dosemeters at lower (30 to 150 keV) X and gamma energies. These dosemeters produce the correct result when worn on the body by over-responding to the incident beam, which compensates for their under-response to the backscatter.
- A dosemeter on a lanyard may be much nearer the radiation source than one worn on a shirt or a coverall pocket. This can produce a major increase in recorded dose
- A dosemeter which rotates will have a different response than one which is static in a radiation field.

Wearing a dosemeter on a lanyard is clearly a bad idea, and radiation protection staff will generally point out to the wearer that the dosemeters should be worn in the standard positions for the site or facility.

Does the worker generally stand close to a source or is he or she generally exposed to distant or diffuse sources?

The closer the wearer is to the major source of exposure, the more variable will be the radiation field over the body, simply from inverse square effects. Local shielding is also more likely to have a major effect. Hence the larger the difference that can be expected between dosemeters worn in even relatively adjacent positions. Collimated beams, as found in calibration laboratories by design and in facilities as a consequence of essential penetrations through shield walls, will also produce major differences.

Is the wearer generally working in the one position or is he or she mobile?

The more mobile the wearer, the more any differences of wearing position and radiation angular distribution will be blurred out. Stationary workers will generally produce bigger differences between dosemeters than the same dosemeter worn in the same plant by mobile workers.

What is the nature of the workplace fields, in terms of energy, angular distribution and dose rate?

Photon fields can range in energy from many MeV (clinical linacs, for example) down to low energy X-rays from beam tetrode transmitter valves and from plutonium surface contamination. Generally the energy of the original radiation is well understood. However, as soon as the radiation source is shielded from the wearer, then the radiation energy spectrum can change. For example, intact lead shielding around an X-ray facility will preferentially attenuate the lower energies, leading to a reduction in dose rate but an increase in the mean or effective energy. In the opposite sense, radiation which escapes from a well shielded cell by way of scatter will lose energy. The position of the radiation source is generally well known, but again as soon as shielding is introduced then the direction from which radiation strikes a worker becomes more complicated. In a relatively extreme case, the major exposure of a worker operating a fuel decanning machine was to relatively low energy (100 – 200 keV) radiation incident from behind. This was caused by multiply scattered radiation which had escaped relatively high up through the relatively thin cell roof and through penetrations from manipulators scattering again from the wall behind the worker (3).
The difference between an unscattered (free air) source and a practical exposure field (bulk waste) generated by the same nuclide is shown below (4). Note that these are raw spectra from an hpGe detector, but they clearly show the gross difference in the two spectra.

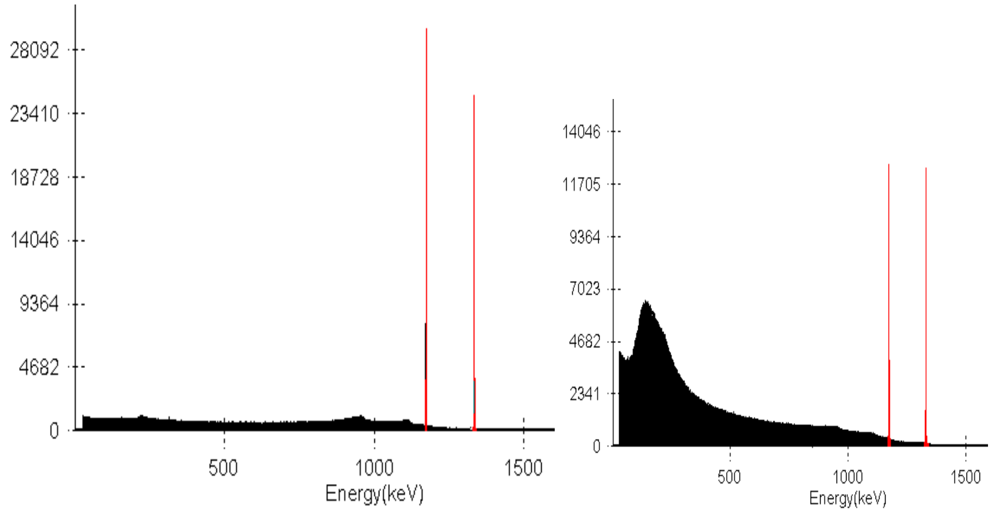

Figure 1 A comparison of spectra from Co-60 in a low scatter environment (left) and from bulk waste (right)

Dosemeters do not have perfect energy responses and the differences will interact with the radiation field to produce a different dose increment rate. With well chosen dosemeters, this difference will not be of radiological or regulatory significance, but it may produce differences in recorded doses which cause unease in the wearers. This will be discussed later.

A significant complication is the presence of pulsed fields. Passive dosemeters will generally respond correctly to workplace pulsed fields in the sense that the response will be very close to that to the same radiation in a non-pulsed form. However, for a pulse counting electronic dosemeter, the average count rate for narrow pulse (μs) radiation fields has to be less than 30 % of the pulse repetition frequency. For higher count rates, the instrument will increasingly under-respond until at saturation the pulse rate from the detector will equal that of the source. For a typical sensitive GM based instrument using a Centronic ZP1320 GM detector and a 400 Hz machine then the limiting count rate is about 130 per second, which is equivalent to a dose rate of 150 µSv/h. If the wearer steps into the main beam from such a machine, the dose increment rate would be 460 µSv/h, whereas the true dose rate could be Sv/h

Does the dosemeter only accumulate dose in use or does it require correction for dose accumulated in storage?

Passive dosemeters cannot be turned on and off. Dosemeters are generally only being worn for approximately 20 % of the time. However, during the remaining 80 % of the time they will still be responding to any radiations present. This is managed, or not managed, in a variety of ways. In the least disciplined, wearers are issued with dosemeters and left to deal with them as they see fit. They can be left on laboratory coats and hung on a wall adjacent to a source store. They may be taken home and left on a granite table or they may be taken home and left next to a radium luminised compass. All of these will result in significant excess dose. They may be stored sensibly but the dosimetry service provider may use a relatively high overall background correction (4). The best course is that they are stored sensibly in an area of known and controlled background. This then allows sensible corrections to be made for background.

Electronic dosemeters in large organisations, such as power stations, generally have the dose allocated to each wear period recorded, which means there is no real need for background correction. The only correction which may be applied is for the self-dose recorded by the dosemeter. GM based dosemeters generally record an excess of approximately 2 µSv per day, generated by K-40 decay within the detector itself. This will only be significant where recorded working doses are low. For smaller organisations, electronic dosemeters may be treated the same way as passive dosemeters, and the users left to do as they see fit. They may stay with the passive dosemeter, in which case differences may be small, or they may be separated, with the electronic dosemeter left at work on the desk and the passive dosemeter taken home.

What are the radiological characteristics of the dosemeters?

This is a major category, which can be subdivided with advantage into:

- Energy dependence
- Rejection of other radiations which do not contribute to Hp(10)
- Interpretation algorithm
- Polar response
- Minimum useful recorded dose
- Dose rate linearity
- Loss of signal or fading

Energy dependence

There are 3 aspects to this. One is the energy range over which the dosemeter has a useful response, another is the energy dependence within that range and the third is the normalisation energy.

Older energy compensated GM designs had a minimum useful energy of approximately 50 keV. Below that point, the response dropped rapidly. Hence these would under-respond in any radiation field with a significant component below that energy.

More recent designs such as the Tracerco T404 have extended the useful energy range down to approximately 30 keV. Hence they are deficient, in terms of Hp(10), only in the 10 to 30 keV region. Single silicon diode instruments also suffer from the same problem, with a response that falls rapidly generally below 50 keV. However, multi-diode instruments, such as the Thermo EPD, use a combination of at least 2 diodes, one of which dominates for the higher (>50 keV) energies while the other dominates the 10 to 50 keV region. The result of this is a dosemeter which is capable from close to 10 keV upwards. The

actual lower energy threshold is driven by the need for RF shielding, problems of dealing with electronic noise and the avoidance of false pulses caused by vibration (microphony).
Passive dosemeters generally are sensitive from 10 keV upwards.

Energy dependence within the range produces its own influence. IEC specifications for electronic dosemeters generally demand a response within 25 % of true for radiation incident in the reference direction from 50 keV to 1.25 MeV (5). GM detector based dosemeters are generally set to read correctly for 662 keV (Cs-137 gamma radiation), the high energy minimum, and have a response which increases by a few % for 1.25 MeV (Co-60 gamma radiation) and can reach a factor as high as 2 for 6 MeV radiation. In contrast, silicon diode dosemeters generally under-respond by a few % at 1.25 MeV (4).

TL and optically stimulated dosemeters can be split into two classes, those that use essentially tissue-equivalent materials and those which use a combination of a non-tissue equivalent material or materials and filters, in a manner similar to the now near obsolete (in the UK) film badge. The HPA badge is a near tissue equivalent design using lithium fluoride. Its energy response is shown in Figure 1, (6).

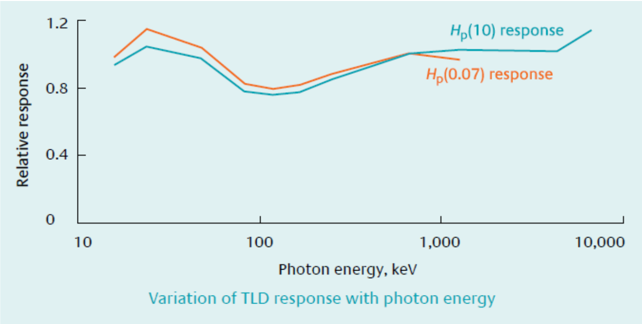

Figure 2 Energy response of the HPA TLD body dosemeter

Generally, dosemeters are adjusted to read corrctly for on body normal incidence Cs-137 gamma radiation, but it is perfectly possible, and it has been known, for dosimetry services either to use a different radiation energy as the reference radiation, typically Co-60 gamma radiation, or to use a different normalisation factor for Cs-137 to balance the highs and lows of the energy response on either side of unity, ignoring the fact that exposure to low energy radiation is generally much less significant that that to higher energies. Either of these approaches will influence the reported result (4).

Rejection of other radiations which do not contribute to Hp(10)

In some workplaces, staff are exposed to a mixture of radiations which includes energetic beta radiation. This is particularly common during decommissioning operations in the nuclear industry, where workers enter cells for short periods where there is significant contamination by Sr-90 + Y-90 (beta only) and Cs-137 (beta) + Ba-137m, (662 keV gamma).
Y-90 has a maximum energy of 2.27 MeV which penetrates 1 g cm^{-2} of tissue at the level of approximately 0.3 % in terms of dose (7). Most dosemeter designs produce approximately the correct result for Y-90 simply because they have close to 1 g cm^{-2} of tissue equivalent material over the main Hp(10) sensing element. This is inevitably a fairly clumsy part of the dosemeter holder, even where, as in the HPA badge, part of the cover is PTFE, which has a density of 2.16 (8), resulting in a much reduced bulge. Some designs attempt to get avoid this by using a process which does not use a suitable cover and attempts to identify the presence of beta radiation and make a correction for it. On at least one occasion, this lead to excessive Hp(10) dose being recorded, a factor of 2 higher than the correct value. The same dosemeter under-reported the value of Hp(0.07) by a similar value.

Interpretation algorithm

For non-tissue equivalent materials, there is a need for some form of algorithm to combine the results from the different dosimetric elements. This is generally done using a linear algorithm, i.e. the apparent doses from each element are combined in a linear form to produce the best estimate of the dose. Areas where problems can arise is where the algorithm uses a very high level of precision in the factors used to add and subtract the apparent doses. The inevitable statistical variability in the results at low doses can result in an unstable energy response.

Polar response

Inevitably, any dosemeter has a response which depends on the angle of incidence of the radiation, particularly at low energies. The radiation quantity itself, Hp(10), is not defined at 90^0 (9). Differences in polar response will be important where a significant dose component is incident at large angles to the normal. As part of the philosophy of the measurement of personal dose equivalent, the dosemeter is recommended to be worn on the most exposed part of the body, but it is rare for the primary dosemeter to be worn anywhere than on the front of the trunk. Hence it is possible in some circumstances that the wearer is subject to a strong lateral component (3) which inevitably will produce a variation between dosemeters both from the polar response point of view but also from the wearing position, as discussed earlier.

Minimum useful recorded dose

Any dosemeter has a minimal useful dose and any dosemeter produces a more statistically variable result at low doses. Electronic dosemeters are generally better in this respect that passive dosemeters. The Tracerco T404, for example, generates approximately 3000 pulses per µSv, which means that exposures as low as 0.1 µSv have a reasonable statistical robustness. Combined with the ability to record single issue dose means that doses as low as 1 µSv can be valid. TLDs, on the other hand, have higher minimal useful recorded doses with HPA quoting a value of 10 µSv and a reporting minimum of 20 µSv to take account of the problems of background correction. There is no argument that such doses are significant in the radiological sense but this aspect can contribute to a significant (to the user) difference between two dosemeters when the ratio of reported doses is calculated over a year.

Dose rate linearity

For normal operational conditions, the variation in response with dose rate has no influence, except when dealing with pulsed fields, as described before.

Loss of signal or fading

Longer wear periods will result in slight loss of signal from many TLD materials but this is generally insignificant after the first few hours.

Summary for this section

In many ways, for typical low dose wear, active electronic dosemeters have a clear advantage over typical passive dosemeters because of the sensitivity and the ease of background correction.

What are the environmental characteristics of the dosemeter?

Dosemeters are routinely exposed to changes in temperature and humidity, to chemicals, to bright light and to RF fields. All of these have the potential to corrupt the recorded dose. Film badges, in particular, were susceptible to chemicals. However, other passive dosemeters such as TLDs and optically stimulated dosemeters are relatively robust. Electronic dosemeters, on the other hand, can be relatively vulnerable, particularly silicon diode based dosemeters. This is because they operate on the very small signals generated directly in the detector by the radiation. For example, the W value for silicon is 3.62 eV (10) at 20^0 C. For an energy threshold of 15 keV, this demands the efficient detection of a pulse of only 4000 electrons and the effective limitation of noise pulses to significantly less than this value. This contrasts with the charge per pulse from a typical GM detector which is approximately 3 x 10^9 electrons, approximately 1 million times larger.

Temperature, if taken to extreme levels, will cause noise pulses, simply because the noise from a resistor depends on the square root of the absolute temperature and because the leakage current from a detector has a strong temperature component. Humidity can also cause problems at extreme levels, particularly from sweat, which is conductive (11).

However, the major problems are RF interference and microphony. Electronic dosemeters have to be well shielded but inevitably there are energetic radiofrequency fields will generate spurious pulses. This is particularly a problem with electrical welding where often a convenient position for the cable is over the left shoulder, which brings it very close to a dosemeter worn on the left side of the chest. Normally, the apparent dose rate is so high that the dose rate alarm sounds, which alerts the user. This is a characteristic of most electrical interference.

Silicon diode electronic dosemeters are also subject to microphony. Generally, this is treated by stopping the dose accumulation process during periods of high microphony and correcting for the missing time period using the rate from the previous period. This process is suppressed if the microphony continues over a long period, however, but will show up when the dosemeter is interrogated.

Contamination

In any area using unsealed radioactive material, there is always the possibility of contamination. Again, the film badge was particularly easy to deal with, as any surface contamination tended to produce a very obvious image. With TLD dosemeters, the influence is much more difficult to detect as the dosemeter card may be clean and the contamination on the housing, which the user generally retains. Electronic dosemeters will indicate contamination by a standing dose rate beyond a given time, which the user will often observe. It is important to realise that a few Bq of a gamma emitter can produce a measurable dose over 8 hours simply from close proximity to a detector. The effect on any Hp(0.07) measurement will be a factor of 100 greater for a nuclide such as Cs-137, given its relatively energetic beta emission (mainly 514 keV Emax).

Malice

With poor dosemeter storage, it can be possible to remove another user's dosemeter and place it in a high radiation field. This can be a mechanism for removing someone from the workplace during the investigation into the high recorded dose. Again the film badge was effective at identifying this (12), as the image produced would lack any effect of movement and would also produce energy information. The Landauer Luxel dosemeter (13) also has a perforated copper filter which again will produce an image which indicates that it was stationary during exposure.

Electronic dosemeters which are not returned at the end of shift etc are also susceptible to malice, but those which store a dose rate profile would clearly indicate an unusual exposure pattern.

Operational experience

Detailed intercomparison was made of the relative responses of a TLD system and the Thermo EPD Mk2 for boiler entry on an Advanced Gas-cooled Reactor (AGR). This revealed that both dosemeters produced dosimetrically acceptable results, despite the difference of 8 %, with the TLD producing the higher value. Further investigation using modelling of the radiation fields within the boiler indicated that both dosemeters over-estimated Effective Dose (E), which is generally to be expected as the radiation exposure geometry was close to isotropic, and that the EPD Mk2 was produced a better estimate of Hp(10). Despite the relatively small average difference of 8 %, there was significant user concern.

A similar exercise was undertaken at Devonport Dockyard following similar differences between the active and passive dosemeters in use at the time. It was traced essentially to a passive dosemeter which read slightly high for Co-60 (1.25 MeV) gamma radiation, combined with an electronic dosemeter which read slightly low compared to the Cs-137 (662 keV) used as the calibration nuclide for both dosemeters.

Investigation

Using the dosemeter

Dosemeters themselves can frequently provide information which helps explain the differences.
This comes in two forms:

- Energy information
- Time information

Many dosemeters provide limited energy information. These are dosemeters where the sensing element is not tissue equivalent, i.e. has an effective atomic number which is significantly different from that of tissue. These dosemeters produce an estimate of Hp(10) using a series of filters combined with an algorithm which takes each element, multiplies it by a defined factor and sums the results. Dual detector, multiple energy threshold silicon diode based dosemeters will also produce limited energy information in the same way. The ratio of the apparent doses under each element can give an indication of the radiation field to which the dosemeter was exposed. The film badge was particularly effective in this way. However, it is vital to appreciate that there may be a huge range of radiation spectra which can produce exactly the same ratios under filters and simply estimating the single gamma energy which would produce the ratio observed is naive. For example, a mixture of high energy gamma radiation and 60 keV Am-241 gamma radiation might well look like a 200 keV exposure.

Many electronic dosemeters also record a dose rate profile. This can be used to identify the time when the majority of the dose was accrued. Knowing that can often then define the place. This simplifies any on plant investigation.

Using other techniques

There are two approaches. Often the simplest one is to wear a relatively sensitive electronic dosemeter with a rate indication and then rotate to identify directions of high and low intensity. The same approach can be used with a survey instrument held close to the body. In both these approaches, the body acts as a shield. Radiation protection dose rate meters are generally designed to have a very good polar response, i.e. to have an indication which does not depend on the direction in which it is pointed. Moving the instrument around at a particular position will generally not help identify the direction of irradiation. However, it is possible to use a compact detector, such as that fitted to the Thermo 900D survey meter, and make a simple collimator from rolled sheet lead. This can then be used to identify any dominant radiation direction.

Alternatively, phantoms can be used, placed at the work position. These are suitable when most of the exposure takes place in a particular position. A large polyethylene container filled with water can have dosemeters placed in several positions and can then be left for a period. The disadvantage of this approach is that this is not possible when work is taking place and it is also difficult to be confident that the phantom will not be moved during the exposure period.

Recently, it has become much easier to characterise radiation fields than it was 20 years ago. This is due to the relatively easy availability of hand-held gamma spectrometers which indicate dose rate and record the incident spectrum. Interpretation still requires skill, as even a mono-energetic 662 keVgamma line will produce a mixture of a photopeak and a Compton continuum. However, it is relatively easy to identify, for example, the highest energy of significance and to decide if there is negligible or significant scatter present. Previously, all that could normally be done on plant was to use lead absorbers to produce an approximation to the radiation field.

Angular distribution can still pose problems. Single unit hand-held gamma spectrometers are too bulky to collimate easily. However, it is possible to use sodium iodide detector + photomultiplier combinations as the input element to a multi-channel analysis system. These, being cylindrical, are easier to collimate while still remaining portable. Their spectra can be stripped to produce a dosimetrically weighted spectrum which will make clear the important energy ranges present. The thickness of the crystal can be chosen so that it is sufficiently effective at the highest energy of interest and the diameter can be chosen so that the expected count rate can be controlled. This is particularly important at dose rates over a few 10s of µSv/h. For higher dose rates, materials such as CZT are useful. Alternatively, and very simply, a dosimetric detector such as an energy compensated GM tube can be collimated using a hole drilled in a lead brick. This can be connected to a simple ratemeter. This means that the detector is used end-on which is not the reference orientation. Care has to be taken to select a detector with a good energy response end on. The sensitivity of the detector can be chosen to match the expected dose rate. For example, the Centronic ZP1202 (14) has a reasonable response end on, a sensitivity of approximately 1.7 cps/µSv/h and a maximum useful dose rate on a typical ratemeter of approximately 30 mSv/h. Hence it can be used effectively from a few µSv/h to 30 mSv/h. This covers the typical exposure range for many workers.

References

1 Evaluation of Discrepancies between Thermoluminescent Dosimeter and Direct-Reading Dosimeter Results, K R Shaw, ORNL/TM-12365, US DoE, 1993
2 ISO, Radiological protection – Recommendations for dealing with discrepancies between personal dosimeter systems used in parallel, ISO/DIS 15690, 2012
3 The measurement of occupational exposure to external radiation: Principles and Practice, Britcher A R, Bartlett D T, Burgess P H; 1991, J. Radiol. Prot, **11**, 3, 185-190
4 Personal photon dosemeter trial – Devonport Royal Dockyard, Collison R, 2005, J. Radiol. Prot, **25**, 1-32
5 Radiation protection instrumentation - Measurement of personal dose equivalents Hp(10) and Hp(0,07) for X, gamma, neutron and beta radiations - Direct reading personal dose equivalent meters, IEC61526 ed 3, 2010
6 HPA Body Thermoluminesce Dosemeter Data Sheet, 2012
7 The Design of the New HPA Personal Thermoluminescence Dosemeter, Eakins J S, HPA-CRCE-0007, 2010, HPA, Didcot
8 http://www.boedeker.com/ptfe_p.htm
9 Conversion Coefficients for use in Radiological Protection against External Radiation, ICRP Publication 74, 1997
10 Review of the Physics of Semi-conductor Detectors, www.ortec-online.com
11 Tait S, National Physical Laboratory Ionising Radiations Metrology Forum 36 minutes, http://www.npl.co.uk/upload/pdf/Minutes_from_IRMF_Mtg_36_-_Nov_08.pdf
12 “Inside Sellafield”, 1996, Border Television
13 http://www.osldosimetry.com/introduction/technology.asp
14 Centronic GM Detector Data Handbook, Centronic Ltd, Croydon