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Extremity Dosemeter Intercomparison

Summer 2016

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Abstract

Interlaboratory comparisons are recognised as important checks on the comparability of dosemeter measurements and on their quality control procedures. Participation allows a laboratory to demonstrate confidence in its ability to perform such measurements.

The Radiation Metrology Group within Public Health England's Centre for Radiation, Chemical and Environmental Hazards (PHE CRCE) performed an interlaboratory comparison of dosemeters designed to be worn on the extremities (fingers). This was done on behalf of the UK's Personal Radiation Monitoring Group (PRMG), a self-selected group with the Approved Dosimetry Services (ADS), as listed by the Health and Safety Executive (HSE).

Six laboratories participated and one laboratory sent two different types of dosemeters for irradiation, making seven sets in total for the intercomparison. The dosemeters were exposed to ^{137}Cs gamma radiation and ISO wide-series 80 kVcp X-radiation (W-80). The participants were invited to report the $H_p(0.07)$ doses received by their dosemeters. Once all reported doses were received, the reference doses were declared and the reported results evaluated.

One participant laboratory was able to achieve results that were within ±5% bias of the reference dose for the ^{137}Cs exposure. Four participants achieved results for bias that were between ±5% and ±10% for the ^{137}Cs exposure. Two participants achieved results for bias that were between ±10% and ±20% for the ^{137}Cs exposure. All sets showed a positive bias (overestimation of dose) for the W-80 exposures.

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Executive Summary

Six laboratories from the UK's Personal Radiation Monitoring Group (PRMG) participated in an extremity dosemeter interlaboratory comparison organised by the Radiation Metrology Group of Public Health England's Centre for Radiation, Chemical and Environmental Hazards (PHE CRCE). Seven sets of 17 dosemeters were submitted by six laboratories (one laboratory submitted 2 different types of dosemeter). Each laboratory's dosemeters were split into 3 groups of 5 dosemeters which were exposed in July 2016 to ^{137}Cs or X-ray ISO Wide 80 kVcp (W-80) radiation on ISO polymethyl-methacrylate (PMMA) rod phantoms; the remaining two dosemeters from each set were used to assess transit doses.

Draft individual laboratory results were reported to the participant laboratories in mid-August 2016 and summary results at a meeting shortly after the individual laboratory results were confirmed. Publication of this report has unfortunately been delayed due to other operational work. Similar intercomparison exercises were undertaken in 2017 and 2018, and individual and summary results were reported to the participant laboratories shortly after. Briefer reports on those later exercises are anticipated to be published shortly as the methodology was identical to this one.

Results for all the laboratories are reported here in anonymised format. The results are compared and evaluated. All participants reported ^{137}Cs results with reasonable accuracy; mean bias for all laboratory results combined was less than -4%. There was a positive bias (overestimation) of dose reported for the two W-80 exposures, with the mean bias for all the laboratory results combined being approximately 25%. The relative standard deviation was less than 5% for the ^{137}Cs exposure for each set of dosemeters, and less than 10% for the W-80 exposures. The over-estimation of dose for W-80 exposures may be an artefact of the non-tissue equivalence of response of the sensitive material in the dosemeters to photons in the 50 to 80 keV range: doped lithium fluoride is the most common material used in thermoluminescence extremity dosemeters, and is utilized by all of the laboratories that participated in this intercomparison.

The results presented in this work are valuable for identifying the accuracy and precision of the doses reported by the participating laboratories, and to assess problems not identifiable by blind-testing or other in-house quality procedures.

Contents

1 Introduction

The Personal Radiation Monitoring Group (PRMG) is a group of UK Approved Dosimetry Services (ADSs) that meets regularly to discuss issues of mutual interest and regularly arranges intercomparisons. The PRMG approached the Radiation Metrology (RM) group of Public Health England's Centre for Radiation, Chemical and Environmental Hazards (PHE CRCE) to organise a dosemeter intercomparison for extremity dosemeters. The PRMG agreed that RM would charge a direct fee to participants for the intercomparison and report. After initial discussions it was agreed that the exposures would take place in July 2016, to allow sufficient time for reporting of results before the next PRMG meeting, which occurred in September 2016.

The announcement included details of the irradiation qualities to be used, the dose range for the three doses to be given, the proposed schedule for the intercomparison, and the cost per set of dosemeters for participation. These are detailed below. Six ADSs participated in the intercomparison (Appendix A), with one ADS submitting two types of dosemeter, so for all practical purposes there were 7 participant laboratories.

2 Laboratory exposure and measurement facilities

The RM group has a range of ionising radiation exposure and measurement facilities at PHE CRCE Chilton. All reference radiation fields that are generated within the facilities are configured according to recognised international standards. The calibrations of all these fields are directly traceable to the UK's primary standards laboratory (the National Physical Laboratory, NPL) or to an equivalent international laboratory. In addition, RM has been operating a UKAS-accredited gamma facility for gamma dose and dose-rate measurements since 1999 (UKAS, 2013).

Air kerma rates are determined in the RM gamma facilities using a PTW TN32002 ionisation chamber connected to a PTW UNIDOS^{webline} electrometer. This is calibrated on a regular basis by the National Physical Laboratory in terms of air kerma for ^{60}Co, ^{137}Cs and ^{241}Am. This equipment is then used to determine the reference output values of air kerma rates in the group's two gamma exposure facilities.

The RM X-ray generator is used to provide high dose-rates for very low sensitivity detectors and for energy response measurements down to low photon energies. The facility produces filtered (transmission) X-ray qualities specified by ISO 4037-1 (ISO, 1996), i.e. the LOW, NARROW, WIDE and HIGH series fields, using a high frequency 300 kV constant potential (cp) X-ray generator. The fact that these radiations are highly filtered means that the applied potential must be accurately known and be very stable. A monitor chamber is permanently fixed in the beam (after any filtration) to monitor any fluctuations in the X-ray beam output so that this can be taken into account. As specified in ISO 4037-1, lead, tin, copper and aluminium of various thicknesses are used to filter the X-ray beam. Air kerma rates are determined in the RM X-ray facility using an Exradin A6 or A5 ionisation chamber connected to an NE Technology Ionex Dosemaster 2590A or PTW UNIDOS^{webline} electrometer. These are calibrated on a regular basis by the National Physical Laboratory in terms of air kerma, for a range of mean energies from 16 to 250 keV, and ^{137}Cs and ^{241}Am radionuclide sources. This

equipment is then used to determine the reference output values of air kerma rates in the X-ray laboratory.

Determination of ambient or personal dose equivalent rates within the RM facilities are obtained by applying the appropriate conversion coefficients for air kerma to $H^*(10)$, $H_p(10)$ or $H_p(0.07)$ contained within ISO 4037–3:1999 (ISO, 1999) or EN 62387:2016 where ISO have not published values for the relevant phantom used.

3 Dosemeter exposures

The X-radiation exposures were undertaken on 7 July and 13 July 2016 using the RM facilities at PHE CRCE Chilton. Because these were extremity dosemeters, the rod phantom was used. Dosemeters were carefully placed onto five parallel PMMA ISO rod phantoms (each defined as a right circular cylinder with dimensions 300 mm length x 19 mm diameter) that were fixed onto a PMMA table (Figure 1); the assembly process was performed in an area away from the laboratories so as to avoid any adventitious radiation exposure during preparation. The dosemeters were positioned such they were at least 5 cm from the ends of each rod. Dosemeters were placed adjacent to each other but with the relevant sensitive portion clearly visible to the beam. Seven dosemeters were placed on each rod and were taped in position. The dosemeters were affixed in a systematic manner so that each laboratory had a dosemeter on each rod. This ensured that each laboratory had a dosemeter in a variety of positions across the exposure beam. The position of each dosemeter was noted and is reported below (see Tables 2 to 5).

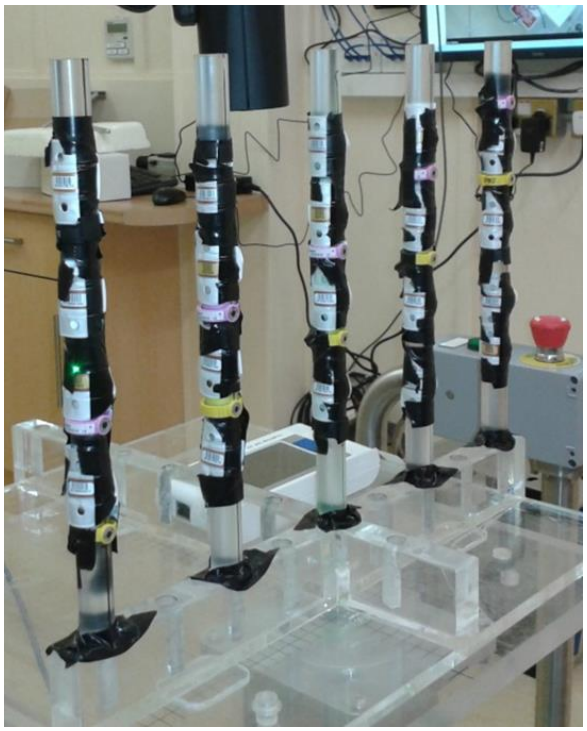

Figure 1: Dosemeters prior to the W-80 higher dose exposure, with the laser (green spot) indicating the vertical position of the reference point.

Details of each exposure are given in Table 1. When ready for the exposure, the table-mounted rod phantoms and dosemeters were placed normal to the beam with the dosemeters at the front of the rods. 3 mm thickness of PMMA build-up was placed in front of the dosemeters for the ^{137}Cs exposure (Figure 2), as detailed in the HSE measurement protocol for the performance testing of dosimetry services for extremity gamma radiation (HSE,1996). Because these were extremity dosemeters, the rod phantom was used with the ^{137}Cs conversion coefficient value for air kerma to $H_p(0.07)$ of 1.13 Sv/Gy given in BS EN 62387:2016 (BSI, 2016): no value for ^{137}Cs for the rod phantom is reported in ISO 4037-3:1999 (ISO, 1999). The value for finger doses previously published in ISO 12794:2000 (ISO, 2000) was 1.12 Sv/Gy, but that standard has now been withdrawn following publication of BS EN 62387:2016.

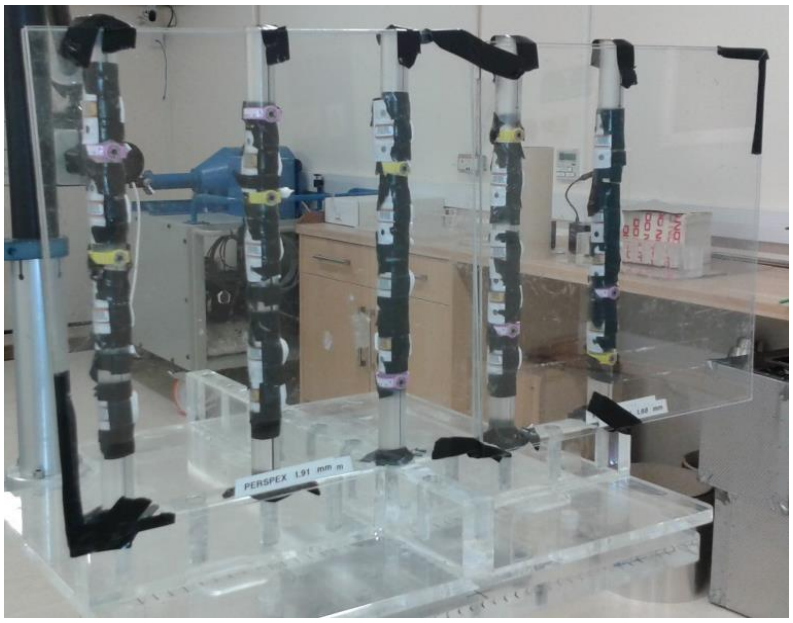

Figure 2: Dosemeters prior to the ^{137}Cs exposure, with PMMA build-up in front of the dosemeters mounted on rod phantoms.

Because each dosemeter was of slightly different shape and size, the reference point was taken as the centre of the front of the central rod phantom. A distance was set between the reference point and the source that was sufficient to ensure that all of the dosemeters in each exposure group were uniformly covered by the collimated beam. The reference doses applied in each exposure are given in Table 1, and the dosemeter labels and positions are given in Tables 2 to 5, where Rod 1 is the leftmost rod in Figures 1 and 2, Rod 2 is next to Rod 1, Rod 3 is in the middle and Rod 5 is placed on the furthest right. It was found that one dosemeter, H1017606 from Lab 11, was erroneously missed from the W-80 lower dose irradiation set. This was irradiated on the 13 July 2016 on its own as the 4th irradiation exposure. It was not possible to give it exactly the same dose as was applied to the rest of the dosemeters during the 'W-80 lower dose' exposure due to slight fluctuations in X-ray exposure at the PHE facility, however, the two lower dose W-80 irradiation sets (2nd and 4th exposures) agreed to within ±0.5%.

Table 1: Extremity Dosemeter Intercomparison Summer 2016 exposure details

Irradiation exposure set	Radiation field	Exposure date	Distance from source, mm	Air kerma rate, K_a, mGy h^{-1}	Exposure Duration, s	$h_{pK}(0.07)_{rod}$ $(Sv/Gy)^3$	Reference $H_p(0.07)$ dose, mSv
1st	W-80	7 July 2016	2000	44.70	275	1.13[1]	3.86
2nd	W-80	7 July 2016	2000	7.430	164	1.13[1]	0.382
3rd	^{137}Cs	7 July 2016	1500	11.58	513	1.13[2]	1.86
4th	W-80	13 July 2016	2000	7.556	162	1.13[1]	0.384

1. From ISO 4037-3:1999 (ISO,1999).
2. From BS EN 62387:2016. Note that the proposed value in the upcoming ISO/CD 4037-3:2014(E) draft is also 1.13 Sv/Gy.
3. Conversion coefficient $h_{pK}(0.07)_{rod}$ from air kerma, K_a, to the personal dose equivalent, $H_p(0.07)$, for the rod phantom

Table 2: Positions of dosemeters for 1st exposure ('W-80 higher dose'), starting from the top of each rod

Rod 1	
Lab and Set ID	Dosemeter ID
11	H1017615
2	374636
3	H1040120
1	03-H01523
16B	63555
16A	H1005421
15	62544

Rod 2	
Lab and Set ID	Dosemeter ID
2	374634
3	H1039439
1	04-H02250
16B	73151
16A	H1006740
15	1-62153
11	H1017618

Rod 3	
Lab and Set ID	Dosemeter ID
3	H1039309
1	07-H02132
16B	68002
16A	H1007050
15	61092
11	H1017619
2	374641

Rod 4	
Lab and Set ID	Dosemeter ID
1	11-H01674
16B	72258
16A	H1002909
15	61470
11	H1017602
2	374644
3	H1039499

Rod 5	
Lab and Set ID	Dosemeter ID
16B	64499
16A	H1003717
15	60913
11	H1017605
2	374631
3	H1039088
1	06-H05022

Table 3: Positions of dosemeters for 2nd exposure ('W-80 lower dose'), starting from the top of each rod

Rod 1		Rod 2		Rod 3		Rod 4		Rod 5	
Lab and Set ID	Dosemeter ID	Lab and Set ID	Dosemeter ID	Lab and Set ID	Dosemeter ID	Lab and Set ID	Dosemeter ID	Lab and Set ID	Dosemeter ID
16A	H1002735	15	60478	11	H1017600	2	374633	3	H1040124
15	61218	11	H1017603	2	374642	3	H1039588	1	15-H02043
11	H1017604	2	374640	3	H1039104	1	12-H01456	16B	74771
2	374639	3	H1039128	1	05-H01545	16B	74848	16A	H1005665
3	H1039994	1	09-H01632	16B	72465	16A	H1007472	15	62553
1	10-H01629	16B	72228	16A	H1004998	15	61748	11	H1017608
16B	77589	16A	H1002920	15	62154	2	374643	2	374638

Table 4: Positions of dosemeters for 3rd exposure (^{137}Cs), starting from the top of each rod

Rod 1		Rod 2		Rod 3		Rod 4		Rod 5	
Lab and Set ID	Dosemeter ID	Lab and Set ID	Dosemeter ID	Lab and Set ID	Dosemeter ID	Lab and Set ID	Dosemeter ID	Lab and Set ID	Dosemeter ID
1	16-H02086	16B	65287	16A	H1005769	15	62205	11	H1017612
16B	74583	16A	H1050808	15	61670	11	H1017613	2	374632
16A	H1035824	15	61455	11	H1017621	2	374637	3	H1039382
15	62181	11	H1017620	2	374628	3	H1040149	1	14-H01488
11	H1017610	2	374630	3	H1039124	1	17-H05043	16B	69459
2	374629	3	H1040155	1	01-H01648	16B	73189	16A	H1051286
3	H1039961	1	08-H01652	16B	66583	16A	H1016409	15	62045

Table 5: Position of dosemeter arrangement for 4th exposure ('W-80 lower dose'), for the outstanding dosemeter

Rod 1	
Lab and Set ID	Dosemeter ID
11	H1017606

The RM group's expanded uncertainty (with a coverage factor, k = 2) for air kerma rate measurements is ±5% for its UKAS accredited facility (UKAS, 2013a). These exposures were done in the non-accredited RM group facilities, which are treated in a similar manner to the accredited facility with regards to traceability to national primary standards. The estimated uncertainty for these measurements is considered by the authors to be similar to their accredited facility, and as a worst case no more than ±10% at the 95% confidence level.

4 Performance classification scheme

The HSE has a defined protocol for the assessment of dosimetry services for extremity dosemeters (HSE, 1996). Criteria for assessing results are defined in Table 3 of Appendix II of the HSE 'Statement of Approval of Dosimetry Services' (HSE, 2010) and reported below for ease of reference.

Criteria for a Band A rating:	
magnitude of bias in the overall results	< 20%
and relative standard deviation in the overall results	< 15%
and magnitude of bias for each of the groups of 5 dosemeters	< 20%
and relative standard deviation for each of the groups of 5 dosemeters	< 15%
Criteria for a Band B rating:	
magnitude of bias in the overall results	≥ 20% and < 25%
or relative standard deviation in the overall results	≥ 15% and < 20%
or magnitude of bias for each of the groups of 5 dosemeters	≥ 20%
or relative standard deviation for each of the groups 5 of dosemeters	≥15%
Criteria for a Band C rating:	
magnitude of bias in the overall results	≥ 25%
or relative standard deviation in the overall results	≥ 20%

The results of this intercomparison were assessed using these HSE criteria. Firstly, for each exposure group of n dosemeters, the bias (B) and relative standard deviation (RSD) are calculated. Bias is defined as

$$B = (\bar{D}_n - 1) \times 100, \% \qquad \text{Equation 1}$$

where in a batch of n dosemeters, D_i is the ratio of reported dose to reference dose for dosemeter i, and $\bar{D}_n$ is the mean ratio, defined as

$$\overline{D}_n = \frac{1}{n} \sum_{i=1}^{n} D_i$$ Equation 2

As the laboratories do not know which of their dosemeters have been used to assess transit dose and which were exposed to radiation, the laboratory staff were instructed not to subtract what they think might be transit doses from their reported results. This replicates the position the laboratories are in when sending and receiving dosemeters to and from their customers. The laboratories, however, did need to subtract any usual background corrections that they derive for their dosemeters.

The reported dose, D_i, for each dosemeter and the mean transit dose (defined as the arithmetic mean of the reported results for the two unexposed dosemeters for each set, except for Lab 2 where there was only 1 unexposed dosemeter) for each set are given in Appendix C, along with the mean ratio, *B* and *RSD*. Additionally, the 'mean net ratio' is given in Appendix C; this is derived by subtracting the mean transit dose for each set from the individual reported doses, normalizing these net doses to the applied reference doses, and then averaging them, analogously to the method used to calculate D_i. It is useful to report the mean net ratio in the event of high transit doses.

In the present sets of exposures, each batch contained *n* = 5 dosemeters, as discussed previously. However, for a complete set of 15 dosemeters from a laboratory, the overall bias and RSD were also calculated and reported. The definition of bias in the overall results is not defined in HSE (1996). In this report this has been calculated using an overall mean ratio for all 15 dosemeter results together, ie *n* = 15 for these overall results rather than *n* = 5 for the individual exposures (*n* = 16 for Lab 2). This may not be a mathematically correct interpretation of arithmetic mean, as three different sets of data are being considered together, however, it is useful in assessing a lab's overall performance, but should only be used as an indicator. The HSE criteria listed above require the *B* and *RSD* (ie the *n* = 5 data) for each separate exposure group to also be considered for a Band A rating.

The relative standard deviation (*RSD*) for each group of *n* dosemeters, as defined by HSE (1996) is

$$RSD = \frac{n}{\sum_i D_i} \left(\frac{\sum_i^n (D_i - \overline{D}_n)^2}{n-1} \right)^{\frac{1}{2}} \times 100\ \%$$ Equation 3

Again the RSD in the overall results (ie *n* = 15 data) is not defined in the HSE (1996) protocol. In this report, for a given laboratory this was calculated as the arithmetic mean of the 3 relative standard deviations from the 3 exposure groups. This might not be considered statistically valid as it combines the results from one ^{137}Cs exposure with those from two W-80 exposures. However, it is a useful method for reviewing a lab's overall performance by indicating if it has a problem with its spread of results.

It should be noted that, according to the above definition, it is possible to receive an overall relative standard deviation that is low, even though the underlying data might be poor; for example, by having a large positive RSD for one exposure group and a large negative RSD for another. If that is the case, the lab would not meet the HSE Criteria for Band A rating, which includes the bias and RSD for each group. Likewise, if some results were greatly overestimated and others greatly underestimated the overall bias may also appear small due to the averaging process.

It should be noted that the HSE Performance Test is not clearly specified in terms of whether it is intended to cover all energies and angles of incidence or just the calibration source. BS IEC 62387:2016 does specify performance criteria for different energies and angles: in this instance ^{137}Cs and W-80 for normal incidence would have allowed response limits of 0.71-1.67. That document specifies upper and lower confidence limits based on the Student's t-value, which for a sample of five dosemeters would amount to 1.24 times the sample standard deviation for the group.

5 Results and discussion

Detailed results for each laboratory are given in Appendix C, and only summary results are reported here.

The data in Table 5 summarize all measurements from a given laboratory taken together (ie n = 15 data for all the laboratories except Lab 2 where n = 16), rather than subdivided into the individual sets of results corresponding to the exposure groups. The transit exposures for each laboratory show results that are all less than 0.15 mSv, indicating no significant exposure outside of the irradiations at PHE. The summary results show that Lab 16A and Lab 3 achieved an overall bias of less than 2%. Lab 16B and Lab 11 achieved an overall bias of between 5% and 10%. Labs 2 and 1 had an overall bias of 19% and 25% respectively. Lab 15 had an overall bias greater than 40%.

Table 5: Summary results for all sets of dosemeters

Lab and set ID	15	16A	16B	1	3	2	11
Mean transit dose, mSv	0	0	0	0.08	0.12	0	0.0005
Overall *B*, %	42%	-0.7%	5.2%	24.8%	-1.8%	19%	9.8%
Overall *RSD*, %	4.1%	5.5%	6.3%	4.6%	5.6%	3.8%	4.3%
HSE Criteria Rating	Band C	Band A	Band A	Band B	Band A	Band B†	Band A

† Magnitude of bias for both W-80 sets were greater than 20%, see individual laboratory results, Table 14.

Reviewing the overall RSD reported in Table 5, all the labs and sets achieved a value of less than 10%. When these and the individual exposure group results (ie n = 5 data) are reviewed (Appendix C), the rating each lab would have received, had this been an HSE performance test, are also given in Table 5. Labs 16A, 16B, 3 and 11 achieved a Band A rating (i.e. a pass). Labs 1 and 2 achieved a Band B rating and Lab 15 a Band C rating (neither ratings are considered a pass by the HSE).

Table 6 provides a combined summary of results for all the dosemeters (i.e. $n = 5 \times 7$ laboratories) for each exposure. This is useful in providing an indication of whether there were any consistent or systematic biases. The small overall bias for the ^{137}Cs exposures provides reassurance that the PHE traceability to national standards is reliable. Renormalisation using each service's own result for ^{137}Cs then allows the ^{137}Cs -W-80 response ratio to be

considered without any issues of local source traceability influencing the results (Table 6). Mean ratio results for the individual exposure groups (i.e. *n* = 5 data) for the different participants are shown graphically in Figures 3 to 5.

Table 6: Combined results for all sets of dosemeters

	B	***RSD***	***B* normalised to service's own ^{137}Cs**
Mean Transit dose, 0.065 mSv			
^{137}Cs, 1.86 mSv	-4.4%	3.3%	1.00
W-80, 0.382 mSv	24%	6.4%	1.29
W-80, 3.86 mSv	23%	4.9%	1.28
Overall Bias, %	**14%**		
Overall Relative Standard Deviation, %		**4.9%**	
HSE Criteria Rating (if this was a Performance Test)	**Band B**		

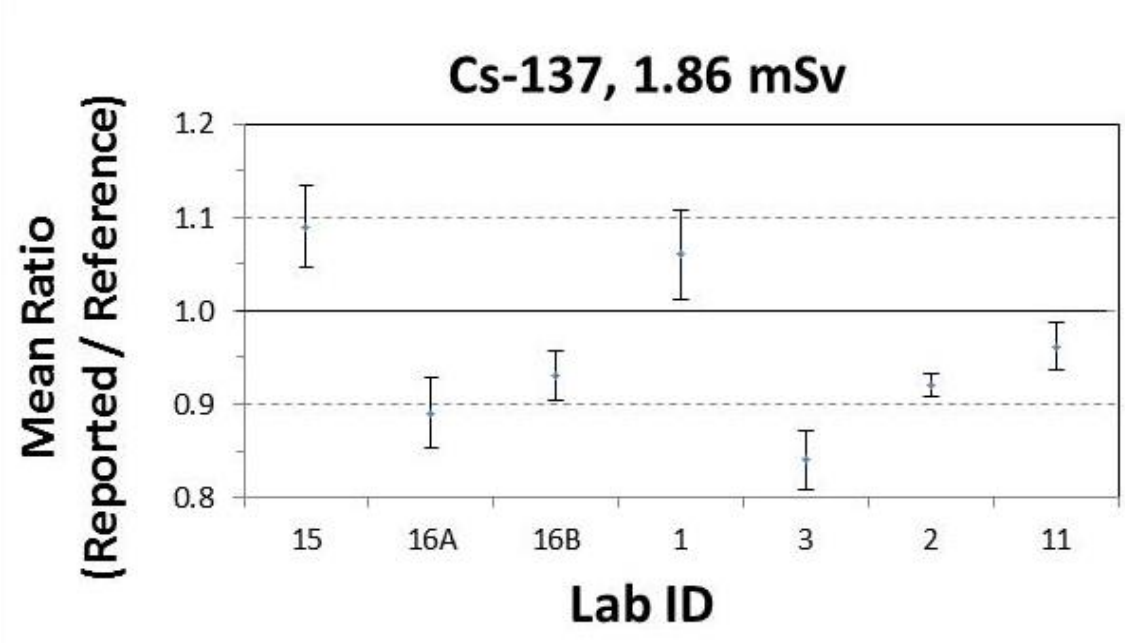

Figure 3: ^{137}Cs results for each set of dosemeters (error bars indicate ± RSD).

The data in Figure 3 demonstrate that Labs 16A, 16B, 3, 2 and 11 had under-estimates for their ^{137}Cs exposures (mean ratio as low as 0.84, see also Tables 9 to 15). Labs 1 and 15 over-estimated their ^{137}Cs exposures (mean ratio up to 1.10). Relative standard deviations were similar for all the labs, except for Lab 2 which had the smallest RSD (1.3%). The largest RSD was for Lab 1 (4.5%).

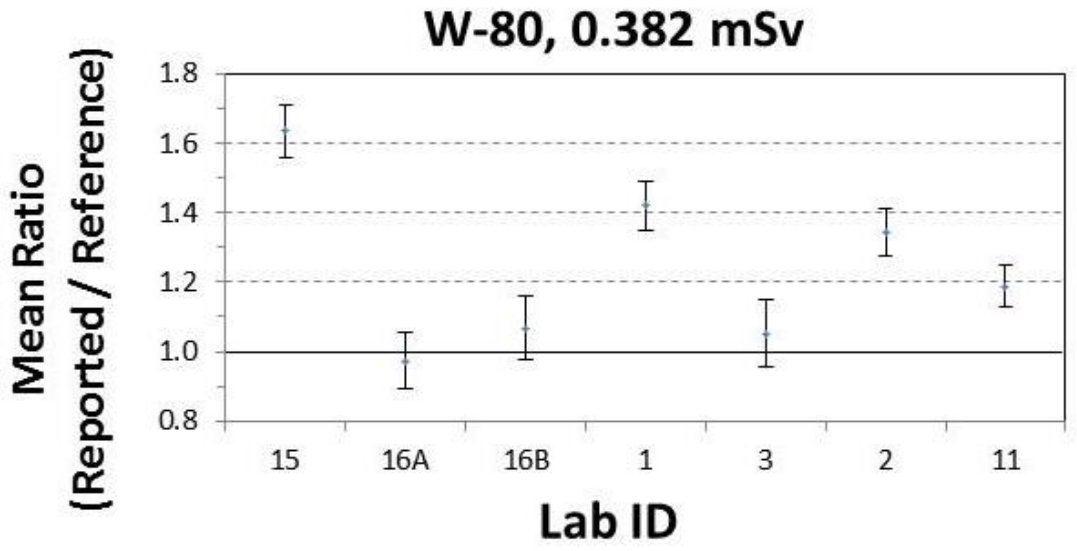

Figure 4: 'W-80 lower dose' results for each set of dosemeters (error bars indicate ± RSD).

The data in Figure 4 show the results for the 'W-80 lower dose' exposure, in which 0.382 mSv was applied. Labs 16A, 16B and 3 produced results that were within one standard deviation of a response of 1. The other labs show an over-estimate (with Lab 15 having the highest mean ratio of 1.63). Relative standard deviations are again similar in magnitude for all the laboratories, with Lab 3 having the highest value (9.4%).

For the 'W-80 higher dose' exposure of 3.86 mSv, all the laboratories over-estimate the dose (Figure 5). Labs 16A, 16B, 3 and 11 had mean ratios of less than 1.2. Labs 1 and 2 had mean ratios of between 1.2 and 1.4. Lab 15 had the highest mean ratio, greater than 1.5. Standard deviations were similar for all the labs, with Lab 16B having the highest value (7.7%).

All the laboratories use ^{137}Cs for calibrating their dosemeters (see Table 8), so the ^{137}Cs data (Figure 3) might be a reflection of the traceability to national standards of the various services. Only two of the services explicitly state that they use build-up, which should be used for $H_p(0.07)$ dosemeters for ^{137}Cs, which could be a potential source of bias.

The laboratories might apply a coefficient to their ^{137}Cs response to amend all their calculated doses in a systematic and consistent way. If we compare the data in Figures 3 to 5 with the data in Table 5, we see that those laboratories that had under-estimated the ^{137}Cs exposure had W-80 dose over-estimates of less than 20% (mean ratio less than 1.20), that is Labs 16A, 16B, 3 and 11. These laboratories may hence be applying a coefficient to lower all their calculated doses. These are the laboratories that achieved Band A Pass rating using the HSE Criteria described in Section 5. The exception to this is Lab 2, which despite having a mean ratio of 0.93 for the ^{137}Cs exposure, reported W-80 doses with mean ratios at and above 1.30, leading to a Band B rating.

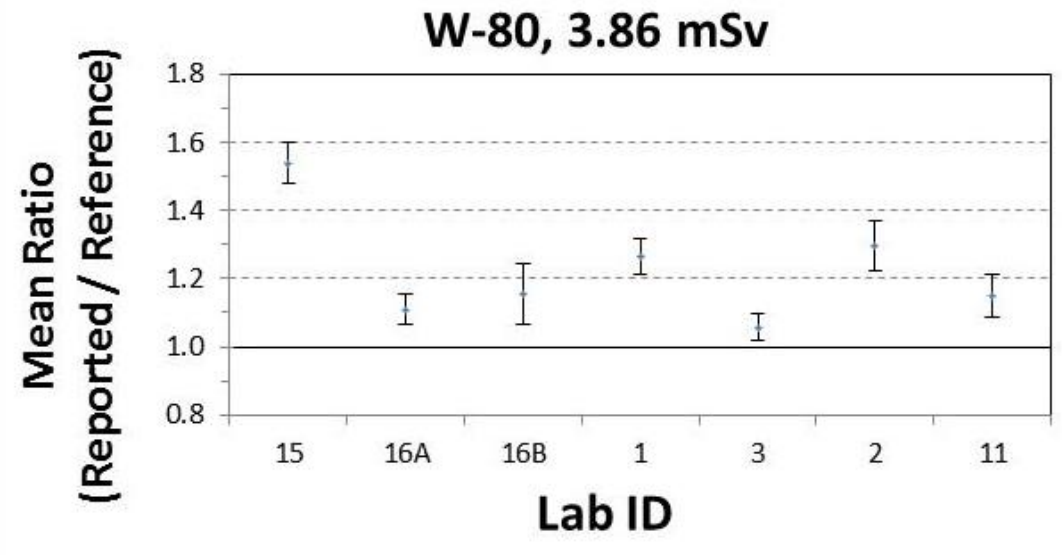

Figure 5: 'W-80 higher dose' results for each set of dosemeters (error bars indicate ± RSD).

Both Labs 1 and 15 reported a mean ratio for the ^{137}Cs exposure greater than 1.05. Lab 1 reported a mean net ratio for the W-80 exposures of above 1.25, however, the results normalized to their ^{137}Cs results were about 1.20. Had this laboratory applied a calibration coefficient that effectively lowered all its results, it could have slightly under-estimated the ^{137}Cs dose (but stayed within the acceptable dose tolerance) whilst reporting the W-80 doses closer to the reference doses, and possibly achieved a Band A rating. However, if the wearers of the laboratory's extremity dosemeter are known to be exposed predominantly to ^{137}Cs (or similar photon energies), the laboratory may prefer to maintain its current calibration to ensure that these doses are reported as accurately as possible, with an understanding that low energy photon exposures, such as to W-80, may be over-estimated.

Lab 15 reported the highest mean ratios for the W-80 exposures, with normalised results that were at and above 1.5. This led to Lab 15 having an overall bias of +42% which puts it into Band C. Similarly to Lab 1, Lab 15 may be able to improve its rating by applying a calibration coefficient to lower all its results, however, the renormalized results (notionally still greater than 1.2 after recalibration) may still prevent Lab 15 from achieving Band A Pass rating. Again there may be good operational reasons not to apply such a recalibration.

The highest bias group of dosemeters, the W-80 0.382 mSv set from Lab 15, do not fall within the 0.71-1.67 response range of BS EN 62387:2016 that would apply to all three exposures used in this intercomparison. In this case, the mean result of 1.63 is within the acceptable range, but the upper confidence level would be 1.72, so it would not be a pass based on the criteria in that standard.

6 Conclusions

In total, six laboratories participated and seven sets of dosemeters were submitted to the PRMG extremity dosemeter intercomparison exercise held in July 2016. A three-band (A-C) classification scheme was used to evaluate the performances of the detectors across two radiation qualities, one of which used exposures at two different dose levels. The overall mean bias was less than ±5% for all the laboratory results when assessing the ^{137}Cs dose. There was a consistent overestimation by the laboratories when assessing W-80 doses. The mean bias for the W-80 lower dose was +24%, and for the higher dose was +23%, for all the laboratory results.

The relative standard deviation was generally good for all the exposure groups, being less than 10% for all the labs.

Some laboratories quoted an uncertainty for their dosemeters of <10% in their questionnaires (Appendix B, Table 8). Such values are not consistent with the biases and relative standard deviations reported here (Table 5 and Section 10), and those laboratories are recommended to review their quoted uncertainties and report a more realistic value.

The results indicate generally good performance for ^{137}Cs exposures, which is not surprising because all six laboratories report this as their calibration field (Appendix B, Table 8). However, there is a tendency to overestimate doses for W-80 X-rays, which is probably a reflection of the non-tissue equivalence of lithium fluoride (LiF) causing over-response in the 50 - 80 keV energy range. The mean energy of the W-80 field is close to a peak of the $H_p(0.07)$ response for LiF, so it represents an approximate worst case for thermoluminescence (TL) dosemeters that use this material. All six laboratories use doped LiF in their dosemeters.

When judged against BS EN 62387:2016, which has energy and angle dependent response criteria, only one group of dosemeters would have not have had an acceptable response: Lab 15 for 0.382 mSv W-80. For the energy dependence of response this British Standard could be viewed as a more reasonable test for performance.

The intercomparison provided a useful external quality test for the participating laboratories. The intercomparison also provided further reassurance regarding the uncertainties associated with the doses that are received to the extremities by wearers of the participating laboratories dosemeters.

7 Acknowledgements

The authors would like to thank the participating members of the PRMG for their comments and suggestions throughout this intercomparison.

8 References

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Appendix A Appendix A Participant laboratories

The Approved Dosimetry Services (ADS) that took part in the intercomparison are listed in Table 7 with their address and the contact person for the intercomparison.

Table 7: Participants in the PHE RM Extremity Dosemeter Intercomparison Summer 2016

Contact Person	Organisation	Address
Kath Watson	AWE Aldermaston	Nuclear and Analytical Science Building A6.1 AWE Aldermaston Reading RG7 4PR
Paul Colley	Brighton and Sussex University Hospitals NHS Trust	Radiation Safety Service Royal Sussex County Hospital Eastern Road Brighton BN2 5BE
Darren Langridge	DSTL	Dosimetry Section DSTL Institute of Naval Medicine Crescent Road Alverstoke Gosport PO12 2DL
Sean Baker	PHE	PDS PHE Centre for Radiation, Chemical and Environmental Hazards Chilton Didcot OX11 0RQ
Elena Vorontsova	University College London Hospital NHS Foundation Trust	Radiation Protection Service Department of Medical Physics and Bioengineering Level -2, EGA Wing 235 Euston Road London NW1 2BU
Alessia Ceccatelli	University Hospitals Birmingham	RRPPS 63 Melchett Road Kings Norton Business Centre Birmingham B30 3HP

Appendix B Appendix B Questionnaire responses

The participating ADS were asked to fill-out a questionnaire to provide the details of their dosimetry system. Details are given in Tables 8a & 8b. No participants reported changes to their systems since they completed the questionnaire for the 2015 intercomparison (Ibrahimi, 2016).

Table 8a: Questionnaire responses from Participating labs

Questionnaire responses	AWE Aldermaston	Brighton and Sussex University Hospitals NHS Trust	DSTL
Calibration			
Usual calibration method:	^{137}Cs via UKAS approved irradiation facility	Dosemeters exposed free in air behind 3 mm perspex as per Performance Test by UKAS Laboratory. Calibration source ^{137}Cs with a 1.12 mSv/mGy conversion factor. This gives a direct reading on the TLD reader in terms of $H_p(0.07)$. Internal Sr-90 source "effective doserate" determined from QC dosemeters. Routine calibration by internal source and QC dosemeters.	Finger phantom
Typical calibration exposure (please specify units)	2 mSv	1.5 mSv	5 mSv
Calibration reference point	Front	Not stated	^{137}Cs photons
Quoted uncertainty in this range	Combined uncertainty of 4%	±3%	Calibration ~4% uncertainty, ~20% uncertainty at 95% CL at 5 mSv
Basis of uncertainty (eg 95% Confidence Level?)	95% confidence level	95% confidence level	95% CL
Dosemeter Application: Routine or experimental?	Routine	Routine	Routine
Dosemeter Characteristics:			
Material	TLD 700H	LiF: Mg,Cu,P	TLD
Dosemeter type (ring, stall, etc)	Stall	PVC Fingerstall	Ring
Manufacturer	Thermo Harshaw	Not stated	Harshaw
Detector thickness (mm)	<1mm	65 µm	0.38 mm (100 mg cm^{-2})
Dosemeter approx. size (mm^{-2})	25 mm x 8 mm	18mm^{-2}	7.1 mm^2
Reference(s):	Not stated	Not stated	Not stated

Table 8b: Questionnaire responses from Participating labs, continued

Questionnaire responses	PHE	University Hospitals Birmingham	University College London Hospital NHS Foundation Trust
Calibration			
Usual calibration method:	Free in air. ^{137}Cs secondary standards lab via tertiary source.	^{137}Cs in air with 3 mm build up	Harshaw 4500 TLD reader, last time calibrated January 2015. Calibration TLSs were irradiated by ^{137}Cs in Regional Medical Physics Department, Newcastle-upon-Tyne
Typical calibration exposure (please specify units)	1 - 3 mSv	2.5 mSv and 20 mSv	3 mSv
Calibration reference point	Rear face centred underneath sensitive element	Rear of dosemeter (ie point of contact with skin)	Not stated
Quoted uncertainty in this range	30%	Uncertainty in measurements: 7% (2.5 mSv) 6% (20 mSv)	Not stated
Basis of uncertainty (eg 95% Confidence Level?)	At 95% confidence limit. Note: This includes contribution from energy and angle dependence of response.	95% CL	Not stated
Dosemeter Application: Routine or experimental?	Routine	Routine	Routine
Dosemeter Characteristics:			
Material	TLD, ^{7}LiF(Mg,Cu,P)	TLD-100 (LiF)	LiF: Mg, Cu, P
Dosemeter type (ring, stall, etc)	Ring and Stall	Strap	Extrad 700H - stall
Manufacturer	Thermo (Harshaw)	Harshaw	Harshaw / Thermo Scientific
Detector thickness (mm)	Ring – 7mg cm^2 with 42mg cm^2 filter. Stall – 7mg cm^2 with 10mg cm^2 black PVC filter	0.9 mm	Not stated
Dosemeter approx. size (mm^{-2})	Ring 4.0mm diameter Stall 5.0mm diameter	0.81 mm^2	18 mm^2
Reference(s):	Not stated	Not stated	Not stated

Appendix C Appendix C Individual dosemeter results

The individual dosemeter readings are given separately for each laboratory in Tables 9 -15.

Table 9: Individual dosemeter results for Lab 15

Dosemeter Serial Number	ADS Reported Dose, $H_p(0.07)$, mSv	Radiation Quality + Reference Dose	Ratio (Reported / Reference)	Mean transit dose (mSv) or mean ratio	Mean net ratio	Bias, %	Relative Standard Deviation, %	Mean ratio normalised to ^{137}Cs mean ratio
60075	0.00	transit						
61943	0.00	transit		0.00				
60478	0.65	W-80 0.382 mSv	1.70					
61218	0.62	W-80 0.382 mSv	1.62					
61748	0.62	W-80 0.382 mSv	1.62	1.63	1.63	63%	4.6%	1.50
62154	0.65	W-80 0.382 mSv	1.70					
62553	0.58	W-80 0.382 mSv	1.52					
61455	1.97	^{137}Cs 1.86 mSv	1.06					
61670	2.13	^{137}Cs 1.86 mSv	1.15					
62045	1.98	^{137}Cs 1.86 mSv	1.06	1.09	1.09	9.0%	4.0%	1.00
62181	2.10	^{137}Cs 1.86 mSv	1.13					
62205	1.96	^{137}Cs 1.86 mSv	1.05					
60913	5.69	W-80 3.86 mSv	1.47					
61092	6.21	W-80 3.86 mSv	1.61					
61470	5.98	W-80 3.86 mSv	1.55	1.54	1.54	54%	3.8%	1.41
62153	6.09	W-80 3.86 mSv	1.58					
62544	5.73	W-80 3.86 mSv	1.48					
Overall Bias						**42%**		
Overall Relative Standard Deviation							**4.1%**	
HSE Criteria Rating (if this was a Performance Test)						**Band C**		

Table 10: Individual dosemeter results for Lab 16, Set ID 16A

Dosemeter Serial Number	ADS Reported Dose, $H_p(0.07)$ dose, mSv	Radiation Quality + Reference Dose	Ratio (Reported / Reference)	Mean transit dose (mSv) or mean ratio	Mean net ratio	Bias, %	Relative Standard Deviation, %	W-80 results normalised to ^{137}Cs
15028982	0.00	transit						
15028979	0.00	transit		0.00				
15028994	0.33	W-80 0.382 mSv	0.86					
15028993	0.36	W-80 0.382 mSv	0.94					
15028992	0.41	W-80 0.382 mSv	1.07	0.97	0.97	-2.6%	8.2%	1.09
15028988	0.37	W-80 0.382 mSv	0.97					
15028989	0.39	W-80 0.382 mSv	1.02					
15028986	1.74	^{137}Cs 1.86 mSv	0.94					
15028985	1.67	^{137}Cs 1.86 mSv	0.90					
15028987	1.57	^{137}Cs 1.86 mSv	0.84	0.89	0.90	-11%	4.2%	1.00
15028983	1.72	^{137}Cs 1.86 mSv	0.92					
15028984	1.62	^{137}Cs 1.86 mSv	0.87					
15028980	4.48	W-80 3.86 mSv	1.16					
15028995	4.14	W-80 3.86 mSv	1.07					
15028991	4.14	W-80 3.86 mSv	1.07	1.11	1.11	11%	4.2%	1.24
15028981	4.18	W-80 3.86 mSv	1.08					
15028990	4.48	W-80 3.86 mSv	1.16					
Overall Bias						**-0.7%**		
Overall Relative Standard Deviation							**5.5%**	
HSE Criteria Rating (if this was a Performance Test)						**Band A, Pass**		

Table 11: Individual dosemeter results for Lab 16, Set ID 16B

Dosemeter Serial Number	ADS Reported Dose, $H_p(0.07)$ dose, mSv	Radiation Quality + Reference Dose	Ratio (Reported / Reference)	Mean transit dose (mSv) or mean ratio	Mean net ratio	Bias, %	Relative Standard Deviation, %	W-80 results normalised to ^{137}Cs
17092888	0.00	transit						
17092890	0.00	transit		0.00				
17092876	0.42	W-80 0.382 mSv	1.10					
17092877	0.41	W-80 0.382 mSv	1.07					
17092878	0.42	W-80 0.382 mSv	1.10	1.07	1.07	6.8%	8.4%	1.15
17092880	0.44	W-80 0.382 mSv	1.15					
17092889	0.35	W-80 0.382 mSv	0.92					
17092879	1.80	^{137}Cs 1.86 mSv	0.97					
17092881	1.72	^{137}Cs 1.86 mSv	0.92					
17092883	1.68	^{137}Cs 1.86 mSv	0.90	0.93	0.93	-6.8%	2.9%	1.00
17092884	1.70	^{137}Cs 1.86 mSv	0.91					
17092891	1.77	^{137}Cs 1.86 mSv	0.95					
17092875	4.07	W-80 3.86 mSv	1.05					
17092882	4.31	W-80 3.86 mSv	1.12					
17092885	4.38	W-80 3.86 mSv	1.13	1.16	1.16	16%	7.7%	1.24
17092886	4.55	W-80 3.86 mSv	1.18					
17092887	4.99	W-80 3.86 mSv	1.29					
Overall Bias						**5.2%**		
Overall Relative Standard Deviation							**6.3%**	
HSE Criteria Rating (if this was a Performance Test)						**Band A, Pass**		

Table 12: Individual dosemeter results for Lab 1

Dosemeter Serial Number	ADS Reported Dose, $H_p(0.07)$ dose, mSv	Radiation Quality + Reference Dose	Ratio (Reported / Reference)	Mean transit dose (mSv) or mean ratio	Mean net ratio	Bias, %	Relative Standard Deviation, %	W-80 results normalised to ^{137}Cs
1531	0.09	transit						
1581	0.06	transit		0.08				
1456	0.57	W-80 0.382 mSv	1.49					
1545	0.57	W-80 0.382 mSv	1.49					
1629	0.51	W-80 0.382 mSv	1.34	1.42	1.22	42%	5.1%	1.20
1632	0.52	W-80 0.382 mSv	1.36					
2043	0.54	W-80 0.382 mSv	1.41					
1488	1.89	^{137}Cs 1.86 mSv	1.02					
1648	2.03	^{137}Cs 1.86 mSv	1.09					
1652	1.95	^{137}Cs 1.86 mSv	1.05	1.06	1.02	6.1%	4.5%	1.00
2086	1.90	^{137}Cs 1.86 mSv	1.02					
5043	2.10	^{137}Cs 1.86 mSv	1.13					
1523	4.62	W-80 3.86 mSv	1.20					
1674	5.09	W-80 3.86 mSv	1.32					
2132	5.07	W-80 3.86 mSv	1.31	1.26	1.25	26%	4.1%	1.22
2250	4.78	W-80 3.86 mSv	1.24					
5022	4.85	W-80 3.86 mSv	1.26					
Overall Bias						**24.8%**		
Overall Relative Standard Deviation							**4.6%**	
HSE Criteria Rating (if this was a Performance Test)						**Band B**		

Table 13: Individual dosemeter results for Lab 3

Dosemeter Serial Number	ADS Reported Dose, $H_p(0.07)$ dose, mSv	Radiation Quality + Reference Dose	Ratio (Reported / Reference)	Mean transit dose (mSv) or mean ratio	Mean net ratio	Bias, %	Relative Standard Deviation, %	W-80 results normalised to ^{137}Cs
1039142	0.11	transit						
1040158	0.13	transit		0.12				
1039104	0.40	W-80 0.382 mSv	1.05					
1039128	0.44	W-80 0.382 mSv	1.15					
1039588	0.37	W-80 0.382 mSv	0.97	1.05	0.74	5.2%	9.4%	0.96
1039994	0.36	W-80 0.382 mSv	0.94					
1040124	0.44	W-80 0.382 mSv	1.15					
1039124	1.59	137Cs 1.86 mSv	0.85					
1039382	1.50	137Cs 1.86 mSv	0.81					
1039961	1.50	137Cs 1.86 mSv	0.81	0.84	0.77	-16%	3.7%	1.00
1040149	1.63	137Cs 1.86 mSv	0.88					
1040155	1.55	137Cs 1.86 mSv	0.83					
1039088	4.30	W-80 3.86 mSv	1.11					
1039309	4.10	W-80 3.86 mSv	1.06					
1039439	4.09	W-80 3.86 mSv	1.06	1.06	1.03	5.8%	3.9%	1.33
1039499	4.07	W-80 3.86 mSv	1.05					
1040120	3.85	W-80 3.86 mSv	1.00					
Overall Bias						**-1.8%**		
Overall Relative Standard Deviation							**5.6%**	
HSE Criteria Rating (if this was a Performance Test)						**Band A, Pass**		

Notes

Result for 1039961 was resubmitted from 0.50 mSv to 1.50 mSv. The glow curve for this dosemeter and an almost identical TLD were also supplied by the laboratory as supporting evidence. Rating was amended from Band B to Band A on resubmission of this result.

Comment from laboratory contact person

There was a typographical transcription error for this dosemeter when first reported.

Table 14: Individual dosemeter results for Lab 2

Dosemeter Serial Number	ADS Reported Dose, $H_p(0.07)$ dose, mSv	Radiation Quality + Reference Dose	Ratio (Reported / Reference)	Mean transit dose (mSv) or mean ratio	Mean net ratio	Bias, %	Relative Standard Deviation, %	W-80 results normalised to ^{137}Cs
374635	<0.15	transit		0.00				
374633	0.50	W-80 0.382 mSv	1.39					
374638	0.53	W-80 0.382 mSv	1.31					
374639	0.50	W-80 0.382 mSv	1.36	1.33	1.33	33%	4.6%	1.44
374640	0.52	W-80 0.382 mSv	1.23					
374642	0.47	W-80 0.382 mSv	1.39					
374643	0.53	W-80 0.382 mSv	1.39					
374628	1.70	137Cs 1.86 mSv	0.91					
374629	1.72	137Cs 1.86 mSv	0.92					
374630	1.74	137Cs 1.86 mSv	0.94	0.92	0.92	-7.6%	1.3%	1.00
374632	1.69	137Cs 1.86 mSv	0.91					
374637	1.74	137Cs 1.86 mSv	0.94					
374631	4.78	W-80 3.86 mSv	1.24					
374634	5.28	W-80 3.86 mSv	1.37					
374636	4.65	W-80 3.86 mSv	1.20	1.30	1.30	30%	5.6%	1.40
374641	5.07	W-80 3.86 mSv	1.31					
374644	5.25	W-80 3.86 mSv	1.36					
Overall Bias						**19%**		
Overall Relative Standard Deviation							**3.8%**	
HSE Criteria Rating (if this was a Performance Test)						**Band B**		

Note

Only one transit dosemeter as 6 dosemeters were erroneously irradiated in the W-80 lower dose.

Table 15: Individual dosemeter results for Lab 11

Dosemeter Serial Number	ADS Reported Dose, $H_p(0.07)$ dose, mSv	Radiation Quality + Reference Dose	Ratio (Reported / Reference)	Mean transit dose (mSv) or mean ratio	Mean net ratio	Bias, %	Relative Standard Deviation, %	W-80 results normalised to ^{137}Cs
H1017609	0.001	transit						
H1017614	0.000	transit		0.0005				
H1017600	0.466	W-80 0.382 mSv	1.22					
H1017603	0.473	W-80 0.382 mSv	1.24					
H1017604	0.424	W-80 0.382 mSv	1.11	1.19	1.19	19%	4.9%	1.24
H1017606	0.439	W-80 0.384 mSv *	1.14					
H1017608	0.470	W-80 0.382 mSv	1.23					
H1017610	1.740	^{137}Cs 1.86 mSv	0.94					
H1017612	1.826	^{137}Cs 1.86 mSv	0.98					
H1017613	1.837	^{137}Cs 1.86 mSv	0.99	0.96	0.96	-4.3%	2.7%	1.00
H1017620	1.754	^{137}Cs 1.86 mSv	0.94					
H1017621	1.740	^{137}Cs 1.86 mSv	0.94					
H1017602	4.745	W-80 3.86 mSv	1.23					
H1017605	4.563	W-80 3.86 mSv	1.18					
H1017615	4.120	W-80 3.86 mSv	1.07	1.15	1.15	15%	5.3%	1.20
H1017618	4.326	W-80 3.86 mSv	1.12					
H1017619	4.431	W-80 3.86 mSv	1.15					
Bias						**9.8%**		
Overall Relative Standard Deviation							**4.3%**	
HSE Criteria Rating (if an HSE Performance Test)						**Band A, Pass**		

Notes: * Dosemeter H1017606 was irradiated after the other dosemeters and had a slightly higher Reference Dose. The laboratory was informed that their transit doses were the highest of the participants' sets. The laboratory reviewed their results and realised they had not subtracted their normal background. Rating went from Band C to Band A when results were resubmitted.

Comment from Laboratory Contact Person

I misunderstood the instruction not to subtract transit doses from the results to mean there should be no background subtraction at all. I have a manual reader and measure background every month.