

REPORT

Fourth IRMF Comparison of Calibrations of Portable Gamma-ray Dose-rate Monitors, 2001 - 2002

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**Fourth IRMF Comparison of Calibrations of Portable
Gamma-Ray Dose-Rate Monitors
2001 - 2002**

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Approved on behalf of Managing Director, NPL, by
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ABSTRACT

The Ionising Radiations Metrology Forum (IRMF) organised a fourth comparison of calibrations of gamma-ray dose-rate monitors in which fifteen establishments in the UK participated. The exercise involved the circulation of three gamma-ray monitors for calibration in the fields produced using ^{137}Cs , ^{241}Am and ^{60}Co .

The instruments used were an Electra with MC 20 probe, a Mini-Instruments Mini-rad 1000 and a Siemens electronic personal dosimeter Mk 2 (EPD). The responses relative to 'true' dose equivalent rate were calculated by the individual participants and submitted to the authors for analysis along with details of the facilities and fields employed. Details of the estimated uncertainties were also reported.

The results are compared and demonstrate generally satisfactory agreement between the participating establishments. However, the participants' treatment of uncertainties needs improvement and demonstrates a need for guidance in this area.

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1 INTRODUCTION

One of the main aims of the Ionising Radiations Metrology Forum (IRMF) is to encourage good practice in radiological measurements, including traceability to the national standards, through the organisation of regular comparisons. Following the completion of the first three IRMF comparisons of calibrations of portable gamma-ray dose-rate meters [1,2,3] (McClure and Hunt, 1994; Lewis and McClure, 1998; Lewis and McClure, 2000), the IRMF organised the present comparison that has been carried out during 2001 and 2002. As before, the main objective was to assess the ability of calibration laboratories to perform routine calibrations of area survey instruments in pursuance of Regulation 19 of the Ionising Radiations Regulations 1999 [4].

The present comparison involved the circulation of three radiation protection monitors for participants to calibrate in fields produced by up to a total of three gamma-ray emitting radionuclides and at a number of dose rates. The participants restricted their measurements to the gamma fields and dose-rates normally used for routine instrument calibrations, employing the same equipment to calibrate the three transfer instruments as was routinely used within their establishment. Details of all four IRMF comparisons are summarised in Appendix 1.

The calibration quantities for the present comparison were **ambient dose equivalent** and **personal dose equivalent**.

The comparison was planned by a working group made up of representatives from several of the participating laboratories -

Duncan McClure, Chairman	NRPB, Radiation Metrology, Chilton
Graham Bass, Secretary	NPL, Teddington
Jan McClure	NRPB, Radiation Metrology (UKAS)
Jeff Palethorpe	RRPPS, Edgbaston
Martin Palmer	NPL, Teddington
Max Pottinger	BNFL, Berkeley
Tony Richards	Consultant, Leeds
John Simpson	RWE NUKEM, Winfrith
Jon Wardle	DRMS (formerly DraStaC), AWE

The participants' measurements started in September 2001 and took ten months to complete. Instrumentation matters were referred to and dealt with by Duncan McClure at NRPB. All results were reported on standard forms for analysis and collation.

The results were analysed by Vic Lewis, NPL, who was not involved in the calibrations carried out at NPL. A wash-up meeting for participants to discuss the results and their analysis was held in November 2002.

2 PARTICIPANTS

The fifteen establishments participating in the comparison are listed in Appendix 2 in alphabetical order.

The policy on whether or not to reveal which calibration results belonged to individual participants had been discussed by IRMF members following the previous IRMF comparison. Prior to this exercise, all participants chose to disclose the identification of their results. It was also agreed that participants would not be allowed to withdraw results.

3 PROTOCOL

A comprehensive protocol (Annex 1) was produced by the Working Party. This provided guidance and included pro forma for reporting various information and the results of measurements to the organisers. Instructions were given for mounting and operating the instruments correctly. Deviation from the preferred orientation was discouraged unless it was physically impossible to achieve such an orientation in the facility used. The format for the main text along with the diagrams showing the orientations of the monitors and the pro-forma for reporting results was similar to that for previous comparisons [2].

The preferred (“target”) dose equivalent rates were given for each instrument in each gamma-ray field for a specified monitor range.

3.1 Participants’ facilities

Participants were asked to supply the following details of their facilities -

- 3.1.1 Sources and traceability;
 - sources geometries,
 - basis of the calibration,
 - traceability to national standards.
- 3.1.2 Collimation;
 - primary beam diameter at one metre from the source,
 - minimum beam diameter used in the measurements,
 - associated minimum source-to-instrument separation distance.
- 3.1.3 Exposure room;
 - approximate dimensions of the exposure room,
 - source height above floor and distance from walls,
 - source - instrument separation distance,
 - wall material.

The reported details are summarised in Tables 1, 2.

3.2 Background measurements

Participants were asked to measure the background response for each monitor in each field before any calibration measurements were carried out.

3.3 Calibration measurements

The results of the calibration measurements were recorded on the pro-formas provided. Instrument readings were recorded as observed. Participants were required to correct the indication for background (as applicable) and calculate the response factor for each of the measurements performed.

Participants were requested to report three uncertainties. The first was the uncertainty associated with the derivation of the true dose equivalent rates used for the calibration measurements. The second was that associated with the recorded instrument readings. The third was the overall uncertainty derived from the combination of the other two. All uncertainties were expressed at the 95% confidence level. In addition, a full uncertainty budget was requested for one of the measurement points performed per instrument.

3.4 Air kerma to dose equivalent conversion coefficients

As the calibration quantities were ambient dose equivalent and personal dose equivalent, participants were asked to state the values they used to derive these quantities from air kerma.

3.5 Uncertainties

For each response factor participants were asked to provide values for -

- uncertainty associated with the dose equivalent rate used for the calibration,
- uncertainty associated with the instrument readings (in beam and for background),
- overall (expanded) uncertainty of the calculated response factor,

all at 95 % confidence level

In addition, participants were asked to provide details of their uncertainty budget derivation for each field/instrument combination. For convenience, an Excel template was provided as a guide to the information required.

4 RADIATION FIELDS

Gamma-ray fields produced employing ^{137}Cs and ^{241}Am sources were used by all participants. Eight participants used ^{60}Co gamma fields in addition. All ^{137}Cs and ^{60}Co sources were capsular and collimated apart from those at one laboratory. Full details of the sources are given in Table 1. The collimated beams were very similar geometrically; the beam diameter at one metre distance was generally in the range 16 to 35 cm. Nine of the ^{241}Am sources were planar and six were capsular. All but two planar sources were collimated. The collimated beams varied considerably geometrically; the beam diameter at one metre distance ranging from 14 to 133 cm.

For the area survey monitor calibrations there were several target dose equivalent rates for each radionuclide, including 2.5, 7.5 and 30 $\mu\text{Sv h}^{-1}$. For ^{137}Cs and ^{60}Co a rate of 300 $\mu\text{Sv h}^{-1}$ was also specified along with two further rates to be chosen by each participant. The maximum dose equivalent rates used were around 800 $\mu\text{Sv h}^{-1}$. No participant made calibrations with a ^{60}Co rate of 2.5 $\mu\text{Sv h}^{-1}$. The rates to be used for the EPD calibrations were a matter of choice for each participant and tended to be higher than those above; up to 1 mSv h^{-1} for ^{241}Am , 8 mSv h^{-1} for ^{137}Cs and 20 mSv h^{-1} for ^{60}Co . See the figures of the results for more detail.

All participants reported that the ^{137}Cs , ^{241}Am and ^{60}Co air kerma rates (and hence the dose equivalent rates) were traceable to national standards.

5 INSTRUMENTATION

Three widely-used gamma-ray dose-rate monitors were used as transfer instruments. In order to have a more realistic exercise, the participants were asked to employ the same methods and equipment to calibrate the transfer instruments as were routinely used within their organisation.

5.1 Electra with MC 20 probe

The MC 20 was chosen partly because it had been used in previous IRMF comparisons. Also, the instrument required setting up by each participant prior to the measurements. This was performed by reference to the instrument manual provided with the instrument. Although most of the parameter values used to set up the Electra were provided, it was necessary for each participant to determine the dead time in the manner in which the laboratory usually used or by following a procedure detailed in the protocol. In the former case the participant was

required to provide details of the method used. The measured value of the dead time was entered into the Electra for the calibration measurements. On completion of the calibrations, the parameters in the Electra had to be reset to the values given in the manual. This was to ensure that the next participant would have to follow the set up procedure.

The probe was mounted horizontally, as shown in the Protocol, with its major axis normal to the radiation beam. Participants were asked to report deviations from the preferred orientation.

This instrument records in the integrating rate mode. The Electra has a digital display.

5.2 Mini-rad 1000

The Mini-rad 1000 monitor was included because it is a simple analogue, logarithmic-scaled instrument and as such is representative of a significant number of popular radiation monitoring instruments. It also exercised the participant's ability to average a fluctuating needle display. The instrument had previously been used in the second IRMF comparison six years earlier and its use in the present comparison would provide a measure of the progress made between the two exercises.

The instrument was mounted horizontally, as shown in the Protocol, i.e. with the front face facing the radiation source and the beam axis aligned with the instrument case. Participants were asked to report deviations from this preferred orientation.

This instrument records in the rate mode.

5.3 Electronic Personal Dosimeter, EPD Mk2

An EPD had been used in the second IRMF comparison for ^{137}Cs fields only. In the present exercise, participants were asked to select two different dose rates for each nuclide. It was recommended that the EPD be exposed for a period sufficient to accumulate a minimum indication of 200 μSv . Participants were advised to either zero the EPD immediately before each exposure or to record the time taken for the EPD to change between indicated readings.

The EPD was mounted as shown in the Protocol with its front towards the incident beam with its central axis of symmetry aligned normal to the incident beam axis.

The dosimeter could be irradiated either on or off a suitable phantom.

6 MEASUREMENTS

The operation of the transfer instruments was checked by NRPB (Metrology). The monitors were then sent to the first participant, NPL. From then on participants were responsible for making their measurements and sending it to the next participants within a two-week slot. Various delays, often with transport, meant that the original timetable had to be adjusted and extended several times. The final schedule is shown in Appendix 3.

Checks were repeated by NRPB upon completion of the comparison measurements. All three monitors appeared to perform well throughout the comparison and no problems were reported to NRPB. No adjustments were necessary for any monitor.

7 ANALYSIS

Participants were requested to send copies of the completed pro-forma report forms, including the additional information, to both co-ordinators within four weeks from completion of their measurements. Most participants reported within this time; some were a few days late due to the additional (non-routine) task of preparing and reporting uncertainty budgets. Two participants (BNFL and DRMS) were several weeks late. Although the Protocol threatened participants who reported late with expulsion from the comparison, it was decided to allow them to remain because of extenuating circumstances and because the exercise would be less authoritative without their results.

The results were analysed by NPL and tables of calibration factors along with graphical summaries were produced (see Figures 2 to 10).

7.1 Outlying response factor values

The obvious outlying calibration values were investigated by the NPL co-ordinator and discussed with the participant. By agreement, the following changes were made –

- Calibration factors (i.e. reciprocal responses) had been calculated as was normally done for routine calibrations (Velindre); changed to response factors by evaluator.
- A response factor for the EPD was low by almost 50% for no apparent reason (DRMS); as all other values were in reasonable agreement with the general consensus the participant was asked to repeat the measurement and obtained reasonable result.
- A set of values for Electra/MC20 in the ^{60}Co field were 30% below general consensus although the values for other monitors in ^{60}Co were satisfactory (RWE NUKEM); it was thought that the operator set up the instrument to give a calibration factor of unity, as was normally done for routine calibrations, instead of using the setting specified by the Protocol. These values could not be fitted into Figure 4.
- A minor transcription error (Guy's and St Thomas') was found; the response factor was recalculated from reported data and Figure 6 was adjusted accordingly.

No other results were omitted or changed except for adjustments due to the use of different air kerma to dose equivalent conversion coefficients (see next section).

A few sets of results were initially incomplete because they lacked some uncertainty values. No changes were made to the uncertainty values although some required clarification and some were questionable to say the least.

7.2 Air kerma to dose equivalent conversion coefficients

The participants had been asked to state the values they used for the air kerma to ambient dose equivalent conversion coefficients for the calibration of the area survey monitors. All quoted values of 1.20 Sv Gy^{-1} for ^{137}Cs and 1.74 Sv Gy^{-1} for ^{241}Am , as recommended by ICRU 57 [5]. Most participants used 1.16 Sv Gy^{-1} for ^{60}Co , also recommended by ICRU 57, and two used 1.15 Sv Gy^{-1} as recommended earlier by UKAS [6].

For the calibration of the EPD most participants used values of 1.21 Sv Gy^{-1} for ^{137}Cs , 1.89 Sv Gy^{-1} for ^{241}Am and 1.15 Sv Gy^{-1} for ^{60}Co for the air kerma to personal dose equivalent conversion coefficients as recommended by ICRU 57 [5]. Some participants used the above values for the air kerma to ambient dose equivalent conversion coefficients instead because this was their routine choice (see Table 3). This made little difference for ^{137}Cs and ^{60}Co , but introduced a large difference between the two groups using different values for ^{241}Am . To make

comparison of results clearer, particularly those for ^{241}Am , all response factors were normalised by the evaluator to the conversion coefficient for personal dose equivalent. See Section 8.6.

7.3 Consultation with participants

A draft copy of the present report incorporating the results in graphical form was distributed to participants in September 2002. The results were discussed and observations were made at the comparison wash-up meeting held in November 2002.

8 RESULTS

8.1 General

The values obtained by the participants are summarised in Figures 2 to 10. There are two types of figure. In the first (designated “a”), the sets of absolute values for the measured calibrations, expressed in response per unit dose equivalent or (dose equivalent rate), are plotted against dose equivalent rate. The values for the individual participants are denoted by different symbols for which the key is given in Figure 1. For the sake of clarity, the uncertainties are not shown.

In the second type of figure (designated “b”), the response factors and their uncertainties in the vicinity of a selected target dose equivalent rate are plotted against participating laboratory identified by a letter (see Appendix 3 for the key). **The uncertainties shown are those reported for the instrument reading only.** This is to illustrate more clearly the large variations in the values reported for that component of uncertainty.

8.2 Uncertainties in dose equivalent rates

The uncertainties reported for dose equivalent rates alone are given in Table 4. For each participant these were constant for rates of about $30 \mu\text{Sv h}^{-1}$ and above. Some participants reported larger uncertainties at lower rates.

The uncertainties that individual participants quoted for ^{137}Cs and ^{60}Co are equal and grouped around 2.5 to 4 %. This is reasonable because the uncertainty of the calibration of the secondary standards used for calibrating the fields was generally 1.7 % or slightly greater.

For about half of the participants the uncertainties reported for ^{241}Am are higher than those for ^{137}Cs and ^{60}Co ; for several they are, in fact, twice as large. The causes of these differences were not always apparent from the information supplied. In at least one case it was due to the calibration with the secondary standard being made at a low air kerma rate and in another case it was due to increased low energy scatter from the instrument mount and surroundings.

8.3 Uncertainties in instrument reading

The uncertainties reported for the instrument reading alone are given in Tables 5 and 6 for three target dose equivalent rates and ^{137}Cs and ^{241}Am . For nearly all participants there are variations with dose equivalent rate (increasing uncertainty with decreasing rate) and there are very large variations between the uncertainties quoted by different participants.

According to the information given, some participants reported the standard deviation multiplied by a factor 2.0, others reported the standard deviation of the mean multiplied by a factor 2.0, while others assumed a rectangular distribution and reported the semi-range. One participant reported the lowest and highest readings for each dose rate.

8.4 Electra with MC20 probe

8.4.1 Dead time determination

Nine of the fifteen participants reported values for the measured dead time. Of these, seven had used the technique described in the Protocol, one used another technique [8] and another participant used both techniques. The measured values, in ascending order of magnitude, are -

Dead time (μs)	18	43*	46	48	51	69	80	84*, 85	98	107
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* measured using second technique [8]

The explanation for the technique in the Protocol was rather brief and led to a number of queries from participants. It depends on the difference between two relatively close numbers, namely, the Electra reading at a high dose equivalent rate, with no dead time adjustment, and the reading derived from the dose equivalent rate and the response factor determined at a low rate. The uncertainties can be large relative to this difference and this may explain the spread observed above. The rate effect for a 50 μs dead time at the maximum rate of 800 $\mu\text{Sv h}^{-1}$ is about 7%. The manufacturer's published dead time value for this detector is approximately 100 μs .

8.4.2 ^{137}Cs calibrations (Figures 2a, 2b)

The measured response factor values as a whole are constant with ambient dose equivalent rate up to at least the maximum rate used of 0.8 mSv h^{-1} , as shown in Figure 2a,. The most obvious trend is the increasing spread of values with decreasing dose rate. This is in line with the increased uncertainties reported for the instrument reading at lower rates (and to a much lesser extent to the increased effect of background). Apart from the two outliers (a low value at about 5 $\mu\text{Sv h}^{-1}$ and a high value at 700 $\mu\text{Sv h}^{-1}$), the values in all dose equivalent rate regions lie within bands that are considered appropriate for those regions for reasonable values reported for the uncertainties in those regions. There is no evidence of a problem due to dead time problems.

A "cross section" is shown in Figure 2b for the response factors around 30 $\mu\text{Sv h}^{-1}$ with the associated uncertainties reported for the instrument reading (Table 5). The uncertainties vary markedly from around 1 % to 9 %. The approximate range of the response factor values, derived from the unweighted standard deviation of all values, is about ± 5 % for a confidence level of 95 %. The response factors are consistent within the **overall** uncertainties.

The uncertainties reported for the instrument readings for the lowest dose equivalent rate range from about 2 % to 30 % (Table 5). They are much reduced at 300 $\mu\text{Sv h}^{-1}$.

8.4.3 ^{241}Am calibrations (Figures 3a, 3b)

The range of dose equivalent rate and the number of data for the ^{241}Am calibrations (Figure 3a) are more limited than for the ^{137}Cs calibrations. The response factor for the former has been shown to be constant with rate by the latter, and there is no evidence to the contrary. There is an indication that the spread of the results increases with decreasing rate but it is not as clear as that for the ^{137}Cs results. The response factors are consistent within the overall uncertainties.

The spread in the uncertainties reported for the instrument reading at 30 $\mu\text{Sv h}^{-1}$ (Figure 3b) is similar to that for ^{137}Cs for the same rate. For some participants the uncertainty for ^{241}Am is higher and for others it is lower. The uncertainties are larger at lower rates (Table 6).

8.4.4 ^{60}Co calibrations (Figures 4a, 4b)

The results are limited in number and to the dose equivalent range from about 7 to 500 $\mu\text{Sv h}^{-1}$. They lie within a band of $\pm 5\%$ of the mean value; this is consistent with the reported overall uncertainties. There are no obvious trends.

8.5 Mini-rad 1000

8.5.1 ^{137}Cs calibrations (Figures 5a, 5b)

Compared with the Electra results, there is a greater spread of values ($\pm 15\%$) for the Mini-rad 1000 that is most evident for the higher dose equivalent rates (Figure 5a). There is a slight downward trend of the mean value with increasing dose equivalent rate above 100 $\mu\text{Sv h}^{-1}$. One participant has a similar outlying value at 5 $\mu\text{Sv h}^{-1}$ as that reported for the Electra calibrations. There are high outliers at low rates and low outliers at high rates.

The large spreads reflect the greater uncertainties reported for the monitor readings. This is illustrated in Figure 5b where uncertainties range from 3 % to 18 % for a rate of 30 $\mu\text{Sv h}^{-1}$, but is less clear at the lowest rates (Table 5) where some participants report higher uncertainties for one monitor and others report higher uncertainties for the other. At 30 $\mu\text{Sv h}^{-1}$ the response factors lie within a band of $\pm 13\%$ about the mean and all except one are consistent within the overall uncertainties.

The trend towards low response factors at higher dose rates observed by two participants was investigated at NRPB after the measurement phase of the comparison had ended. Figure 11 shows the NRPB (Metrology) values measured in January 2002 to be consistent with those of the investigation of November 2002. Both sets are constant with ambient dose equivalent rate. There is no change in response using a battery operating at the minimum possible voltage. However, the orientation of the monitor affects the response increasingly with increasing dose rate. Adopting the same orientation as RRPPS reproduces the same trend as that observed. Parallax has a much smaller effect.

8.5.2 ^{241}Am calibrations (Figures 6a, 6b)

As for the Electra, the ^{241}Am results (Figure 6a) span a smaller range of dose equivalent rate. No trends are evident. The sets of response factors appear to vary more smoothly with dose rate than those for ^{137}Cs , but there is no reason why this should be so. All response factors lie within a 26 % band and are generally consistent within the overall uncertainties; see for example the data at 30 $\mu\text{Sv h}^{-1}$ (Figure 5b).

8.5.3 ^{60}Co calibrations (Figures 7a, 7b)

The response factors for ^{60}Co (Figure 7a) show more variation and agree less well than the Electra data. However, because the uncertainties are larger, they are consistent.

8.6 Electronic Personal Dosemeter

Nine participants mounted the EPD on the face of a solid plastic or a water-filled phantom for the irradiation (Table 3). The other six irradiated the EPD free-in-air. Of these, two applied off-phantom correction factors to compensate for the enhancement that would be due to back-scatter by a phantom. The values are given in Table 3. Because the use of these factors introduced differences in the reported response factor values, the response factors were further renormalised by setting the correction factors to unity.

Note: Several participants do not offer calibrations of personal dosimeters routinely.

8.6.1 ^{137}Cs calibrations (Figures 8a, 8b)

The response factors for both on-phantom and off-phantom irradiations are shown in Figure 8a. A variety of dose equivalent rates have been used. There is no trend with rate.

In Figure 8b, the nine values for on-phantom calibrations are plotted in a group on the left hand side and the six values for free-in-air on the right hand side, along with the reported expanded uncertainties. The mean values for the two groups are 1.010 ± 0.013 (standard deviation of mean) and 0.935 ± 0.011 respectively. This 8% difference is consistent with that observed in the second IRMF comparison [2]. The values within the two groups are consistent within their uncertainties.

Apart from one participant, all values of the first group are within $\pm 5\%$ of the mean. The uncertainties of the phantom group appear to be lower than those of the free-in-air group, although the standard deviations of the means indicate similar variations.

8.6.2 ^{241}Am calibrations (Figures 9a, 9b)

The ^{241}Am response factors are shown in Figure 9a with the values normalised to an air kerma to personal dose equivalent conversion coefficient of 1.89 Sv Gy^{-1} . In Figure 9b the values are plotted in the two groups as for Figure 8b above. It is clear from visual inspection that the difference between the two groups is much less pronounced than for the ^{137}Cs calibrations. This time the mean values are 0.975 ± 0.013 and 0.955 ± 0.013 respectively.

The same comments may be made about the uncertainties and spreads for the ^{241}Am values as are made for the ^{137}Cs results above.

8.6.3 ^{60}Co calibrations (Figure 10a, 10b)

The ^{60}Co response factors are plotted in Figures 10a and 10b in the same manner as for the ^{137}Cs and ^{241}Am results above. Because the numbers are small, a comparison between the two groups is less meaningful. The mean values are 0.905 ± 0.021 and 0.853 ± 0.011 respectively, but the difference is due mainly to three outlying values.

9 DISCUSSION

9.1 Response factors

The results suggest that there is good consistency in the realisation of air kerma rate and consequently in dose equivalent rate. The very few outlying values are probably due to unique instrumental effects or are associated with recording the reading. The largest spreads were observed at low air kerma rates with the needle-reading monitor.

In previous comparison exercises, the ^{241}Am values have had a wider spread than for ^{137}Cs (and ^{60}Co), and this is the case for the Electra/MC20 values in the present exercise, as illustrated by the standard deviations in Table 7. This is reflected in the greater uncertainty in the ^{241}Am dose equivalent rate reported by some participants and may be partly due also to the greater variation of efficiency with energy in the ^{241}Am energy region and the consequent greater sensitivity to scattered radiation. The standard deviations reported for the Electra/MC20 are lower than those for the Mini-rad 1000 (around 6% for all three monitors) and EPD (around 5%). They are also lower than those reported for the Mini 6-90/MC20 monitor used in the previous comparison [3].

The ^{60}Co values have very similar features to those for ^{137}Cs for the two monitors where both nuclide fields were used. The spreads cannot be compared too closely because there are about half as many participants for the ^{60}Co measurements. There appear to be no problems with the realisation of accurate air kerma rates for ^{60}Co .

9.2 Uncertainties

Some of the values quoted for the uncertainties seemed to be much too large and some were too small. Examination of the information submitted revealed a variety of errors and bad practice. One particular cause of confusion lay in the conversion of the uncertainties of the data and components used to calculate response factors into the corresponding percentage uncertainties for the response factor itself. This process involved the derivation of sensitivity coefficients.

The uncertainties may be roughly divided into the three groups discussed below.

9.2.1 Uncertainties in dose equivalent rate

These include the calibration of the secondary standard, its reading at a reference position in the beam, the background reading and various corrections (pressure, temperature, instrument mount and room scatter, etc). Generally, the expanded uncertainties for kerma rate are reasonable and low in comparison with the uncertainties for the monitor readings (next section). However, there were some errors and bad practice including -

- Use of standard deviation instead of standard deviation of the mean for the reading in the beam and the background. This gave an over-estimate of the uncertainty.
- The percentage uncertainty of the background was used as that for the kerma rate.
- Use of absolute uncertainty of a component as the percentage uncertainty component for kerma rate. For example, an uncertainty of 2 mb pressure was assumed to give 2% uncertainty in kerma rate.

9.2.2 Uncertainties in monitor reading

The values reported for the uncertainties in the monitor readings also vary widely from one participant to another for the two survey monitors. This demonstrates that there are inconsistencies in the approaches used for estimating and treating such uncertainties. Some participants diligently calculated values for all situations, whereas others adopted a universal percentage value for each monitor.

Errors and bad practice included -

- Use of standard deviation instead of standard deviation of the mean. This gave an over-estimate of the uncertainty.
- Assumption of rectangular probability distribution for dominant uncertainty component; This resulted in an overall uncertainty that was greater than the linear sum of constituent components.
- Use of wrong divisor value and/or assumption of incorrect level of confidence.
- The value for the percentage uncertainty of the background was used as that for the response factor.
- The standard uncertainties due to the reading and background were not expressed in terms of fraction of background-corrected reading; this requires dividing by (reading – background). This applies also to dose equivalent rate but effect is much lower.

9.2.3 Uncertainties in corrections

The various corrections are generally not large and therefore the associated uncertainties should be reasonably small. Often when the reported values were greater than say 2% it was due to an error or bad practice. Examples include -

- The uncertainty in the dead time was taken as the uncertainty for the rate effect. As a result it did not vary with dose rate.
- Pressure and temperature (see above).
- The uncertainty in the scatter correction was assumed to be equal to the correction itself.

9.2.4 Other problems

There were instances of mistakes in the quadratic sum of standard uncertainties.

9.3 Reporting of results

In a change from the practice of the previous comparisons, participants calculated the response factors as well as submitting the calibration data. The change was made in order to make the exercise closer to routine calibrations and to encourage the examination of results thereby spotting obvious oddities that could be due to error or malfunction. The evaluator still checked the calculated values anyway. The number of bad results that were eliminated as a result of this change is not known, but very few values required investigation this time.

The setting of a deadline to report results within four weeks of the end of measurements assisted greatly in expediting the analysis and producing this report. (In the previous IRMF comparison some participants took three months to submit results.) Some participants found this requirement difficult to meet because they had unexpected problems in producing all the required information on their uncertainties. In such cases a few days grace was allowed; the participants concerned are not reported here. The situation regarding the reporting of uncertainties is expected to improve by the next comparison exercise.

9.4 Length of comparison

It was disappointing that the measurement phase of the comparison took as long as for the previous comparison that had four more participants. This was partly due to a two-month period when only one participant made measurements. It was also due to one or two participants over running their allotted scheduled period causing unnecessary problems and delays to subsequent participants who could not always fit the measurements into their timetable. It is felt that a period of two weeks per participant should not be unrealistic in future exercises. However, it would be advisable to have catching-up periods in the timetable.

10 CONCLUSIONS

The comparison again demonstrated that the overall accuracy is satisfactory and that the calibrating facilities could meet the requirements of NPL Good Practice Guide 14 [7].

The requirement to give detailed information on uncertainties was a useful extension to the previous exercise and provided valuable material for the forthcoming good practice guide on uncertainties in radiological measurements [9]. There was little improvement in the consistency of treatment of the uncertainties compared with the previous exercise, and values quoted by the participants varied greatly from one laboratory to another.

Although there were differences in the uncertainties quoted for the air kerma rates and some of the corrections, the main variation lay in the uncertainties for the instrument reading. This was due in part to differences in the techniques for recording the mean readings and partly to differences in the methods used for evaluating the associated uncertainties. Some of these methods were unsound. This indicates that more care needs to be taken with uncertainties and guidance is desirable to improve the treatment of uncertainties and the overall consistency.

Some of the participating laboratories do not calibrate electronic personal dosimeters routinely. Some variations in the reported response factors for the EPD were due to the -

- use or otherwise of phantoms for mounting personal dosimeters,
- use of different (or no) off-phantom corrections,
- use of different values for the conversion of air kerma to personal dose equivalent (significant only for ^{241}Am).

Normalising the response factor values to a dose equivalent quantity using a common value for the conversion coefficient produced good general consistency and indicated a small effect due to the use of a phantom, as would be expected.

This comparison is the fourth in a series of periodic exercises. It has been reassuring in demonstrating consistency and valuable in highlighting the problems that still exist.

11 ACKNOWLEDGEMENTS

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The co-operation of all participants is gratefully acknowledged.

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12 REFERENCES

- [1] McClure, D R and Hunt, J B. 1995
IRMF Intercomparison of Calibrations of Portable Gamma-ray Monitors Used for Area Monitoring. J Radiological Protection **15** 245 - 252
- [2] Lewis, V E and McClure, D R. 1998
Second IRMF Intercomparison of Calibrations of Portable Gamma-Ray Dose-Rate Monitors, 1995 – 1996, NPL Report CIRM 08.
- [3] Lewis, V E and McClure, D R. 2000
Third IRMF Intercomparison of Calibrations of Portable Gamma-Ray Dose-Rate Monitors, 1998 – 1999, NPL Report CIRM 34.
- [4] Ionising Radiation Regulations 1999 (London HMSO)
- [5] ICRU 57. 1998
Conversion Coefficients for use in Radiological Protection Against External Radiation. ICRU Report 57; International Commission on Radiation Units and Measurements, Bethesda, MD 20814, USA.
- [6] UKAS 1994
Calibration of radiological protection-level instruments: X-, γ - and β -rays. NAMAS Information Sheet NIS 0811, UKAS, Feltham
- [7] Scott, C J, Burgess, P H and Woods, M J. 1999
The Examination, Testing and Calibration of Portable Radiation Protection Instruments. Measurement Good Practice Guide 14. National Physical Laboratory, Teddington.
- [8] Knoll, G K,
Radiation Detection and Measurement, (3rd Edition) Chapter 3, John Wylie & Sons, New York, 2000, ISBN 0-471-073385
- [9] Lewis, V E, Woods, M J, Burgess, P H, Green, S, Simpson, J A, and Wardle, J. 2003
The Assessment of Uncertainty in Radiological Calibration and Testing. Measurement Good Practice Guide 49. National Physical Laboratory, Teddington.

APPENDIX 1 IRMF Comparisons of calibrations of gamma-ray dose-rate meters

	Report	Instruments	Nuclides	Specified dose rate ranges *
April 1992 to Dec 1992 12 participants	J Rad. Prot. 15 , 245 - 252 June 1993 [1]	NE PDM1B Mini 6-90 / MC 20	^{137}Cs , ^{241}Am , ^{60}Co	$2.5 \mu\text{Gy h}^{-1}$ to 200 mGy h^{-1}
June 1995 to May 1996 16 participants	CIRM 8 December 1997 [2]	NE PDM1B Minirad 1000 Mini 900 / 44A EPD	^{137}Cs , ^{241}Am , ^{60}Co ^{137}Cs , ^{241}Am , ^{60}Co ^{137}Cs only ^{137}Cs only	$2.5 \mu\text{Gy h}^{-1}$ to 200 mGy h^{-1}
July 1998 to July 1999 19 participants	CIRM 32 January 2000 [3]	Mini 6-80 / MC71 NE 2570 Farmer & 600 cc chamber Mini 900D Mini 6-90 / MC 20	^{137}Cs , ^{241}Am , ^{226}Ra ^{137}Cs only ^{137}Cs , ^{241}Am , ^{60}Co ^{137}Cs , ^{241}Am , ^{60}Co	0.5 to $50 \mu\text{Gy h}^{-1}$ $0.1, 0.5, 1, 10 \text{ mGy}$ 2.5 to $800 \mu\text{Gy h}^{-1}$ 2.5 to $800 \mu\text{Gy h}^{-1}$
Sept 2001 to July 2002 15 participants	This report December 2002	Electra / MC 20 Mini-rad 1000 EPD Mk 2	^{137}Cs , ^{241}Am , ^{60}Co	^{137}Cs , ^{60}Co : 2.5 to $300 \mu\text{Sv h}^{-1}$ ^{241}Am : 2.5 to $30 \mu\text{Sv h}^{-1}$

* In addition to specified ranges, participants also had choices of optional dose rates

APPENDIX 2 Participants**(In alphabetical order)**

BNFL Magnox Generation, Berkeley	N Butler
DRMS (formerly DraStaC), AWE, Aldermaston	J Wardle
DSTL Radiological Protection Service, Alverstoke	J T B Bennett
Guy's and St Thomas' Hospital Trust, London	D J Gallacher
Johnson Controls, Dounreay	D Mackenzie
National Physical Laboratory, Teddington	G A Bass
National Radiological Protection Board, Radiation Metrology, Chilton	D R McClure
National Radiological Protection Board Northern Centre, Leeds	J Shaw
National Radiological Protection Board Scotland, Glasgow	M Milton
National Radiological Protection Board Metrology (UKAS, Chilton	J McClure
Northern Ireland Radiation Protection Service, Belfast	K Cranley
Radiation Protection Service, Velindre Hospital, Cardiff	D W Thomas
Regional Radiation Physics & Protection Service, Edgbaston	D Delahunty
RWE NUKEM Ltd, Winfrith	J A Simpson
Thermo Electron Corp, Beenham	J Barnes

APPENDIX 3 Schedule of Measurements

2001		
August	Check	NRPB Radiation Metrology, Chilton
August		Protocol finalised
September	A	NPL, Teddington
October	B	RPS, Velindre Hospital, Cardiff
October	C	Northern Ireland RPS, Belfast
November	D	Guy's & St Thomas' Hospital
November	E	NRPB Northern Centre, Leeds
December	F	BNFL, Berkeley
2002		
January	G	NRPB Radiation Metrology, Chilton
February	H	NRPB Metrology (UKAS)
February	I	DSTL, Gosport
March	J	DRMS, AWE
April	K	Johnson Controls, Dounreay
April	L	NRPB Scotland, Glasgow
May	M	RRPPS, Edgbaston
June	N	RWE NUKEM Ltd, Winfrith
July	O	Thermo Electron Corp, Beenham
August	Check	NRPB Radiation Metrology, Chilton
November	Investigations	NRPB Radiation Metrology, Chilton

The periods indicated are approximate.

Table 1 Details of radiation fields

	Cs-137		Am-241		Co-60	
	Diameter at 1 m	Minimum diameter	Diameter at 1 m	Minimum diameter	Diameter at 1 m	Minimum diameter
NPL, Teddington	20	30 @ 150	40 *	40 @ 100	20	30 @ 150
RPS, Velindre, Cardiff	35	28 @ 80	32.5	15 @ 40		
Northern Ireland RPS	38	15 @ 38	38 #	15 @ 40		
Guy's & St Thomas', London	5, 8, 16, 48 ##	14 @ 29	5, 8, 16, 48 ##	19 @ 39		
NRPB Northern Centre	30	43 @ 123	30	11 @ 33		
BNFL plc, Berkeley	Uncollimated		Uncollimated		Uncollimated	
NRPB Radiation Metrology	36	36 @ 100	133 *	100 @ 75	36	44 @ 125
NRPB Metrology (UKAS)	36	44 @ 123	36	14 @ 39		
DSTL RPS, Alverstoke	20	16 @ 75	20 *	20 @ 100	20	16 @ 75
DRMS, Aldermaston	16	16 @ 136	25 *	25 @ 100	16	16 @ 100
Johnson Controls, Dounreay	21	22 @ 106	20 *	15 @ 70	21	20 @ 93
NRPB Scotland	17	10 @ 50	60 *	14 @ 21		
RRPPS, Edgbaston	18	18 @ 100	15	21 @ 120		
RWE NUKEM, Winfrith	35	40 @ 129	40 *	40 @ 210	35	40 @ 220
Thermo Electron, Beenham	21	18 @ 85	Uncollimated		21	14.5 @ 69

All dimensions and distances are in cm.

Uncollimated for EPD

Selectable collimator sizes used, consistent with application, to minimise scatter
 The ²⁴¹Am sources designated by an asterisk (*) are planar.

Table 2 Dimensions of facilities

	Room length	Distance: source to rear wall	Room width	Distance: source to side wall	Room height	Height of source from floor
NPL, Teddington	8	2.5	5	2	5	1
RPS, Velindre, Cardiff	7.7	1.0	2.5	1.3	3.0	1.1
Northern Ireland RPS: area survey EPD	6.5	0.4	3.5	1.4	3.3	1.5
	3.0	1.5	3.3	1.7	3.3	0.9
Guy's & St Thomas', London	5	0.4	2	0.4	2.0	1.1
NRPB Northern Centre	6.3	1.2	3.1	1.3	2.9	1.3
BNFL plc, Berkeley	8	2.5	8	1.5	3	1.4
NRPB Radiation Metrology	10	2.0	5.3	2.6	2.7	1.4
NRPB Metrology (UKAS)	5.6	1.4	3.5	1.8	2.6	1.3
DSTL RPS, Alverstoke	8.0	1.5	3.5	1.8	3.0	1.1
DRMS, Aldermaston	7	1.5	6	2.5	5	1.5
Johnson Controls, Dounreay	9.5	3.1	3.6	1.8	3.3	1.5
NRPB Scotland	6.5	0.8 / 1.1	3.2	1.6	3.1	1.0
RRPPS, Edgbaston ¹³⁷ Cs ²⁴¹ Am	4.3	0.7	2.6	0.6	3.6	0.2
	4.6	1.7	3.3	0.3	3.6	1.2
RWE NUKEM, Winfrith	7	2	7	2	4.5	1.5
Thermo Electron, Beenham	9.5	2.5	4.6	1.7	3.0	1.5

All dimensions and distances are in metres.

Table 3 Details of Electronic Personal Dosemeter calibrations

	Quantity used for reporting	Phantom	Dose Equiv conversion coefficient	Dose Equiv conversion coefficient	Dose Equiv conversion coefficient
NPL, Teddington	Air kerma	Off	not applicable	not applicable	not applicable
RPS, Velindre, Cardiff	H _p (10)	PMMA	1.12	1.05	
Northern Ireland RPS	H _p (10)	PMMA	1.20		
Guy's & St Thomas', London	H _p (10)	Water / PMMA	1.22	1.89	
NRPB Northern Centre #	H _p (10)	Off	1.21	1.87	
BNFL plc, Berkeley	H _p (10)	PMMA	1.21	1.89	1.15
NRPB Radiation Metrology	H _p (10)	Water / PMMA	1.21	1.89	1.15
NRPB Metrology (UKAS)	H _p (10)	Water / PMMA	1.21	1.89	
DSTL RPS, Alverstoke	H _p (10)	PMMA	1.20	1.89	1.16
DRMS, Aldermaston	H _p (10)	PMMA	1.21	1.89	1.15
Johnson Controls, Dounreay	H*(10)	Off	1.20	1.74	1.15
NRPB Scotland	H*(10)	Water / PMMA	1.20	1.74	
RRPPS, Edgbaston ##	H*(10)	Off	1.20	1.74	
RWE NUKEM, Winfrith	H _p (10)	Off	1.12	1.89	1.08
Thermo Electron, Beenham	H*(10)	Off	1.20	1.74	1.16
ICRU 57	H _p (10)		1.21	1.89	1.15
ICRU 57	H*(10)		1.20	1.74	1.16

Phantom correction factors of 1.14 and 1.09 used for ¹³⁷Cs and ²⁴¹Am respectively

Phantom correction factors of 1.07 and 1.55 used for ¹³⁷Cs and ²⁴¹Am respectively

The EPD results have been normalised to the ICRU 57 values for the air kerma to personal dose equivalent conversion coefficients and phantom correction factor of unity (where applicable).

Table 4 Reported uncertainties for dose equivalent rates

	Cs-137 (%)	Am-241 (%)	Co-60 (%)
NPL, Teddington	2.7	2.7	2.7
RPS Velindre, Cardiff	1.8	1.8	
Northern Ireland RPS	7.8	7.8	
Guy's & St Thomas' London	4.2	4.2	
NRPB Northern Centre	2.5	5.5	
BNFL plc, Berkeley	3	4	3
NRPB Radiation Metrology	2.2	2.2	2.2
NRPB Metrology (UKAS)	4	4	
DSTL RPS, Alverstoke	3.5	6.1	3.4
DRMS, Aldermaston	3	5	
Johnson Controls, Dounreay	3.9	10	4
NRPB Scotland	4	4	
RRPPS, Edgbaston	3.1	6.4	
RWE NUKEM, Winfrith	3	6	3
Thermo Electron, Beenham	3	6	3

The uncertainties are for a confidence level of about 95%

The values apply to dose rates of 30 $\mu\text{Sv h}^{-1}$ and above

Table 5 Reported uncertainties for monitor reading: ^{137}Cs fields

	Uncertainty (%)						
	Electra / MC20			Mini-rad			EPD
Dose equivalent rate ($\mu\text{Sv h}^{-1}$)	2.5	7.5	30	2.5	7.5	30	varied
NPL, Teddington	10	7	5	30	10	5	0.5
RPS Velindre, Cardiff	5	3.5	1.9	6	3.5	3.1	0.25
Northern Ireland RPS	8.9	8.9	8.9	4.6	4.6	4.6	0.6
Guy's & St Thomas' London	9.2	9.8	4.5	n/a	5.1	2.7	2.0
NRPB Northern Centre	3.2	2.8	1.1	29	26	16	1.0
BNFL plc, Berkeley	7	5	3	10	10	7	---
NRPB Radiation Metrology	26	3.4	2.9	8.7	21	6	1
NRPB Metrology (UKAS)	24	10	2	12	10	4	0.4
DSTL RPS, Alverstoke	18	9.2	7.1	13.3	13.7	10	1.4
DRMS, Aldermaston	10	5	< 5	20	20	10	1.0
Johnson Controls, Dounreay	15	7	4	18	18	18	1
NRPB Scotland	1.9	4.5	1.0	2.6	6.4	3.8	4.2
RRPPS, Edgbaston	30.5	18.4	5.3	15.6	10.1	3.1	4.3
RWE NUKEM, Winfrith	---	8.5	---	15	43	12	0.5
Thermo Electron, Beenham	15.5	4.0	1.7	15	15	15	0.5

The individual dose equivalent rates may be slightly different from the target values.

The uncertainties are for a confidence level of 95% or are the semi-range of a rectangular distribution.

Table 6 Reported uncertainties for monitor reading: ²⁴¹Am fields

	Uncertainty (%)						
	Electra / MC20			Mini-rad			EPD
Dose equivalent rate ($\mu\text{Sv h}^{-1}$)	2.5	7.5	30	2.5	7.5	30	varied
NPL, Teddington		10	10		15	10	0.5
RPS Velindre, Cardiff		1.7	2.2		2.9	3.5	0.25
Northern Ireland RPS	8.9	8.9	8.9	4.6	4.6	4.6	---
Guy's & St Thomas' London		5.9	3.5		0.5	2.3	2.4
NRPB Northern Centre	7.0	2.9	2.9	20	14	10	1.0
BNFL plc, Berkeley			2			11	---
NRPB Radiation Metrology	10	4	2.5	6	6	6	0.9
NRPB Metrology (UKAS)	14	7	3	14	8	3	---
DSTL RPS, Alverstoke		13.6	8.8		16.9	8.9	2.9
DRMS, Aldermaston						10	1.0
Johnson Controls, Dounreay			4		18	18	1
NRPB Scotland	5.9	1.5	1.0	5.4	7.6	1.7	0.7
RRPPS, Edgbaston		15.8	8.1		10.2	7.3	5.1
RWE NUKEM, Winfrith		8.5			20	11	0.5
Thermo Electron, Beenham			4.4			15	0.5

The individual dose equivalent rates may be slightly different from the target values.

The uncertainties are for a confidence level of 95% or are the semi-range of a rectangular distribution.

Three participants used dose rates much higher than $30 \mu\text{Sv h}^{-1}$; the associated uncertainties are not recorded here.

Table 7 Standard deviations of sets of calibration values at selected dose equivalent rates

	Electra / MC20	Mini-rad 1000	EPD *
Cs-137	(30 $\mu\text{Sv h}^{-1}$) 2.5 % (15)	(30 $\mu\text{Sv h}^{-1}$) 6.6 % (15)	(various) 3.5 % (15)
Am-241	(30 $\mu\text{Sv h}^{-1}$) 4.1 % (15)	(30 $\mu\text{Sv h}^{-1}$) 5.9 % (15)	(various) 5.0 % (14)
Co-60	(100 $\mu\text{Sv h}^{-1}$) 1.0 % (5)	(300 $\mu\text{Sv h}^{-1}$) 5.3 % (6)	(various) 5.0 % (7)

Dose equivalent rates and numbers of participants are given in parentheses.

* Applies to renormalised results; mean of standard deviations for on-phantom and free-in-air groups

A	—■—	NPL
B	—●—	Velindre
C	—▲—	NIRPS
D	—▼—	GSST
E	—◆—	NRPB(N)
F	—+—	BNFL(B)
G	—×—	NRPB(M)
H	—✱—	NRPB(S)
I	—+—	DSTL
J	—△—	DRMS
K	—■—	Johnson Controls
L	—●—	NRPB(Sc)
M	—▲—	RRPPS
N	—◆—	RWE NUKEM
O	—▽—	Thermo Electron

Figure 1 Key to following figures of response factors

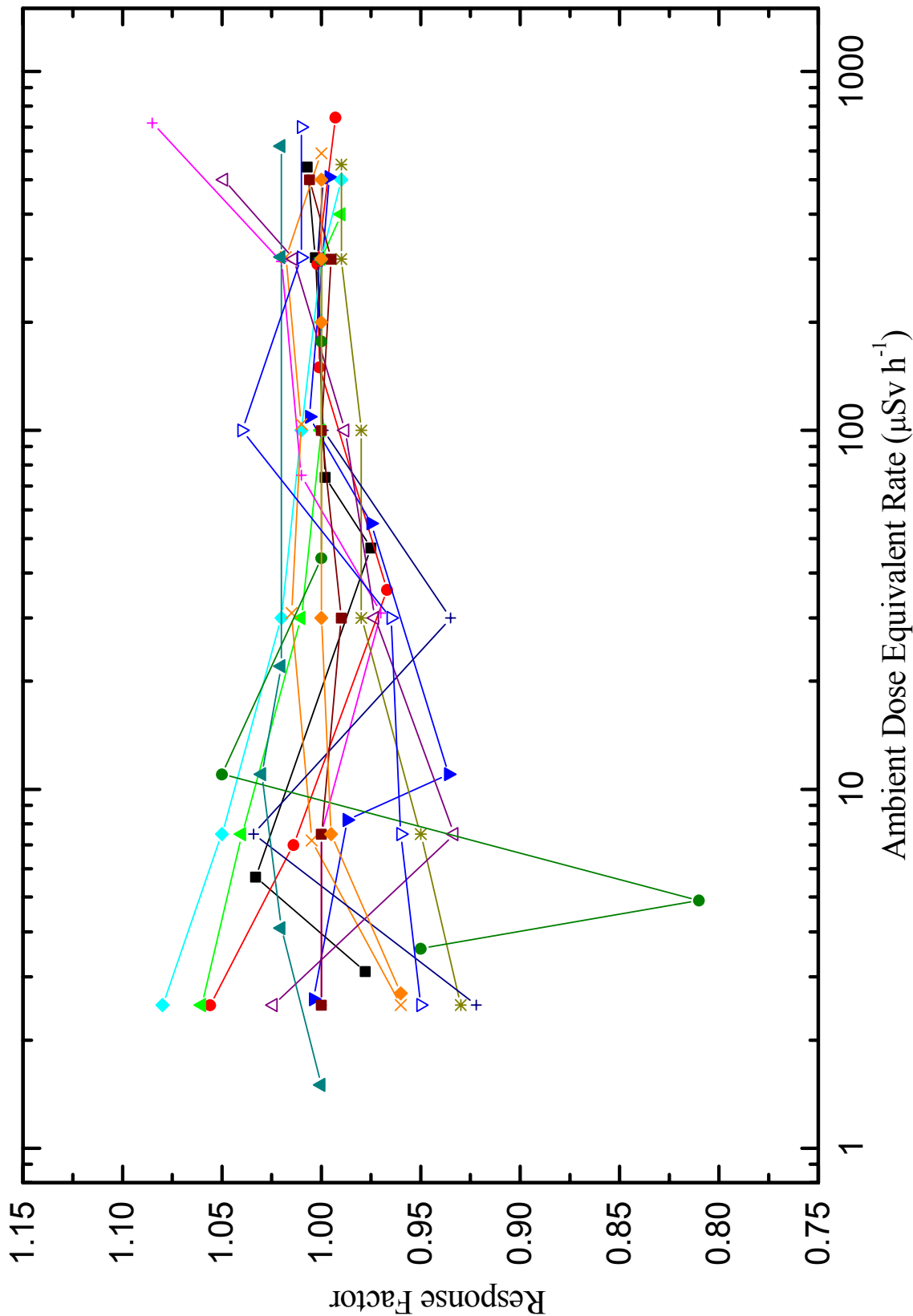


Figure 2a Response factors for Electra / MC20: ^{137}Cs field

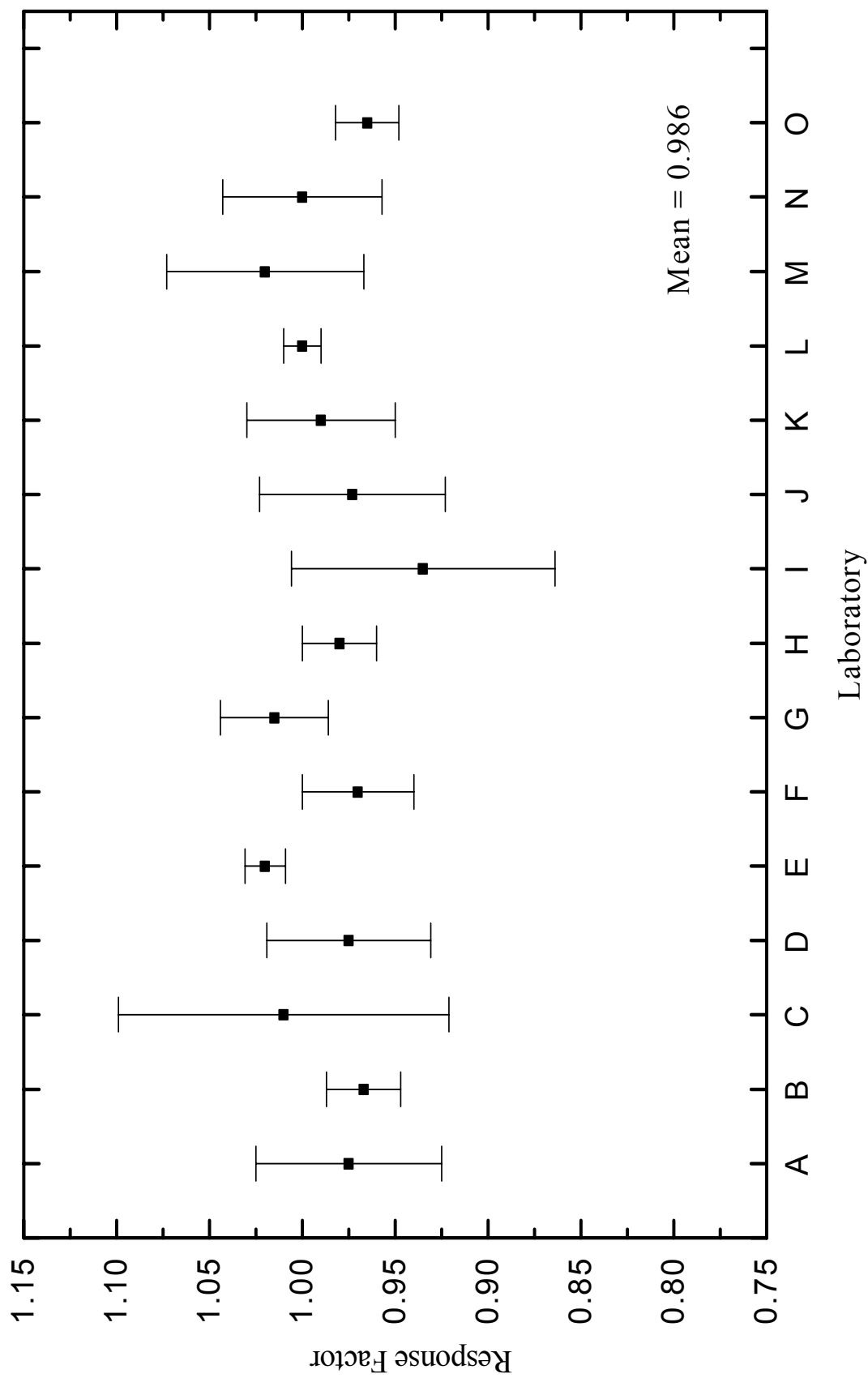


Figure 2b Response factors for Electra / MC20 around 30 $\mu\text{Sv h}^{-1}$, ^{137}Cs field

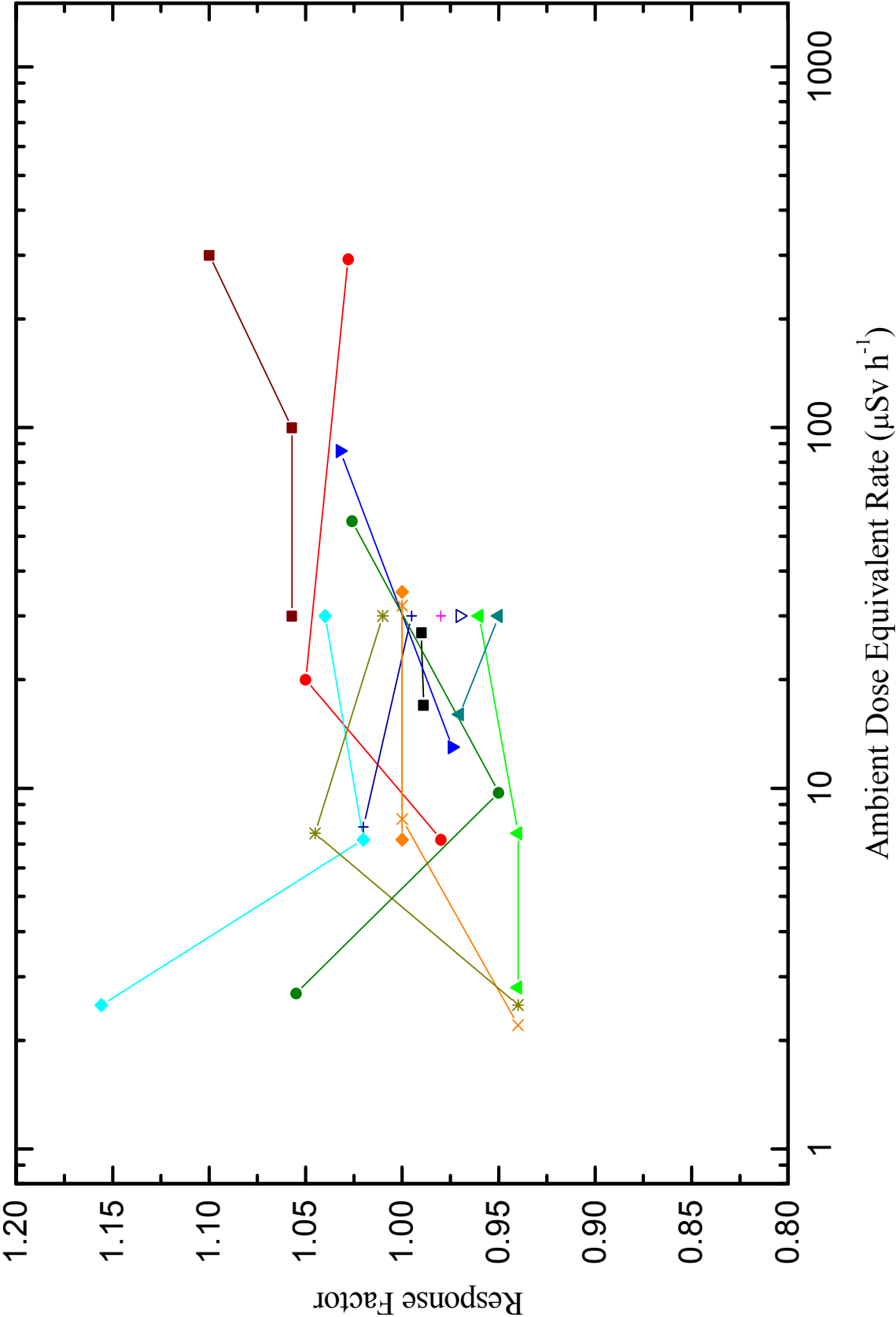


Figure 3a Response factors for Electra / MC20: ^{241}Am field

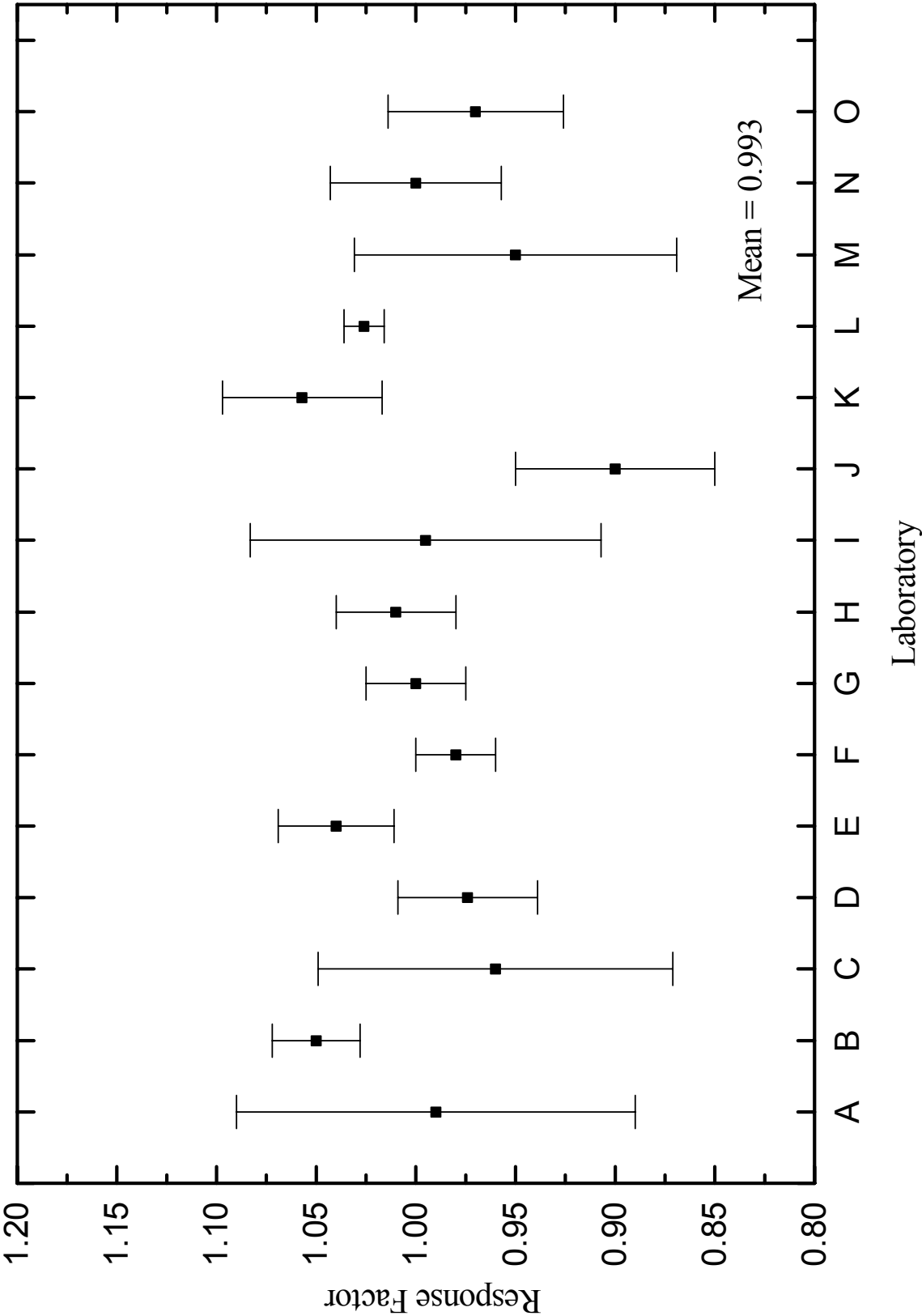


Figure 3b Response factors for Electra / MC20 around 30 $\mu\text{Sv h}^{-1}$, ^{241}Am field

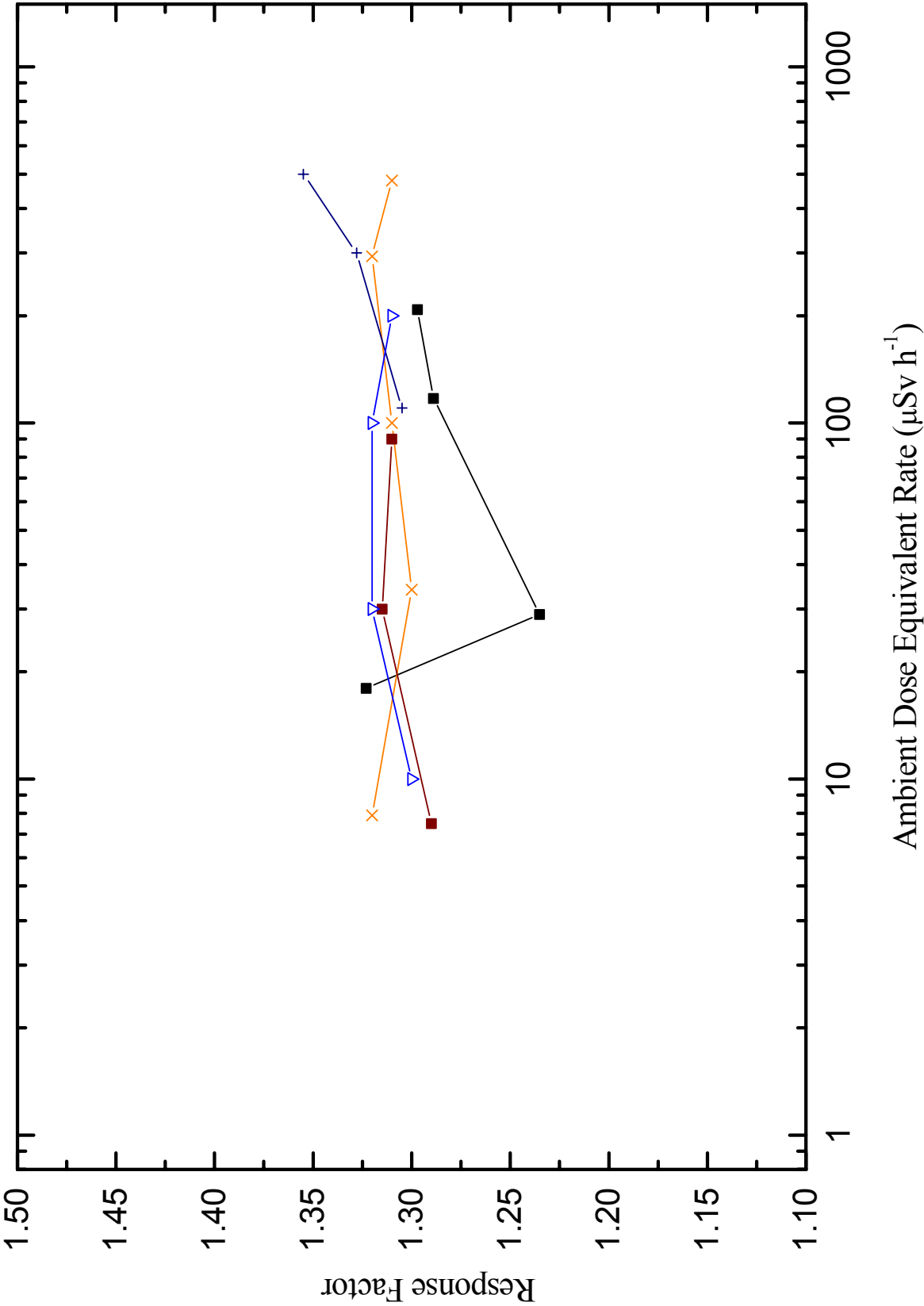


Figure 4a Response factors for Electra / MC20: ^{60}Co field

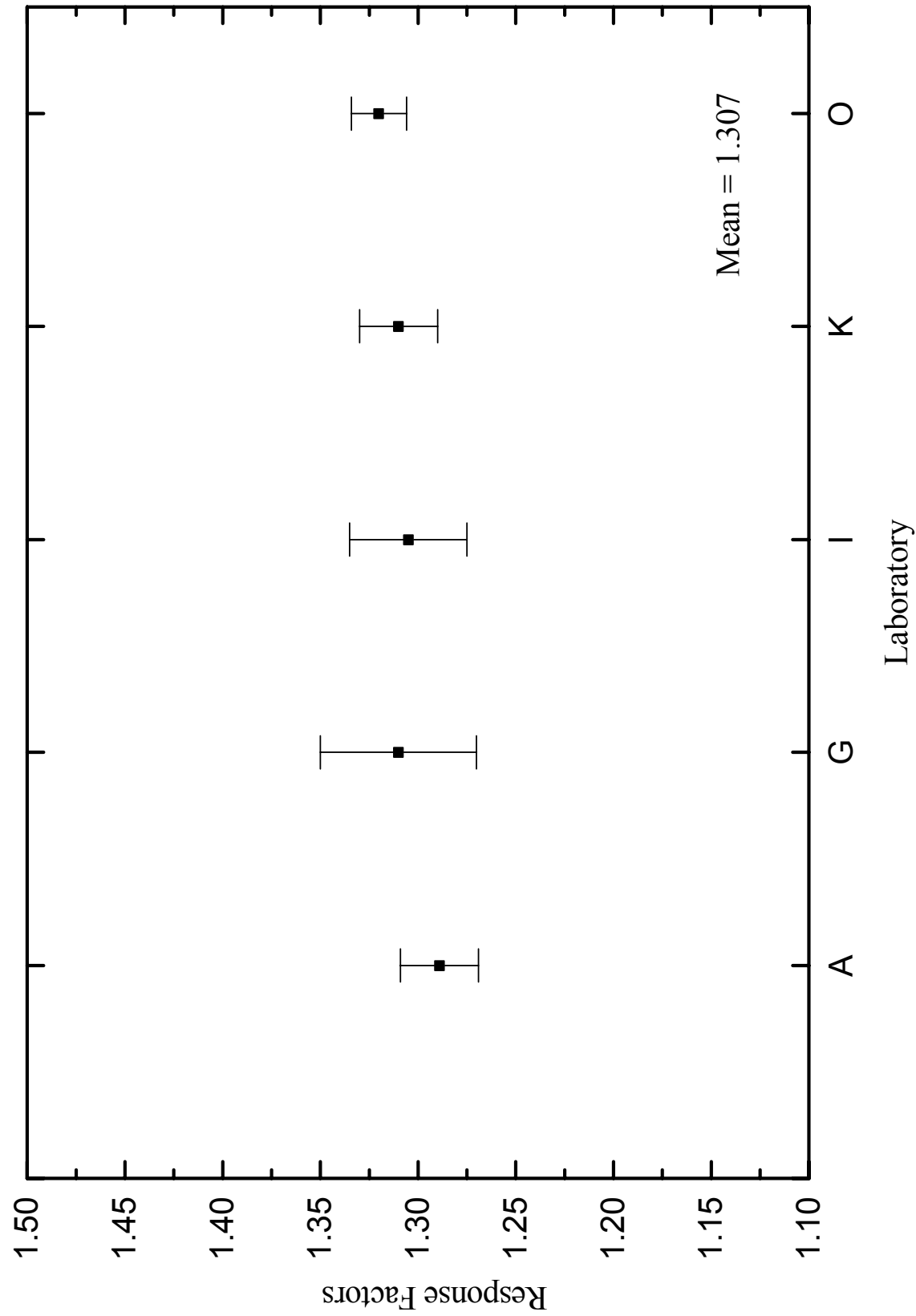


Figure 4b Response factors for Electra / MC20 around 100 $\mu\text{Sv h}^{-1}$; ^{60}Co field

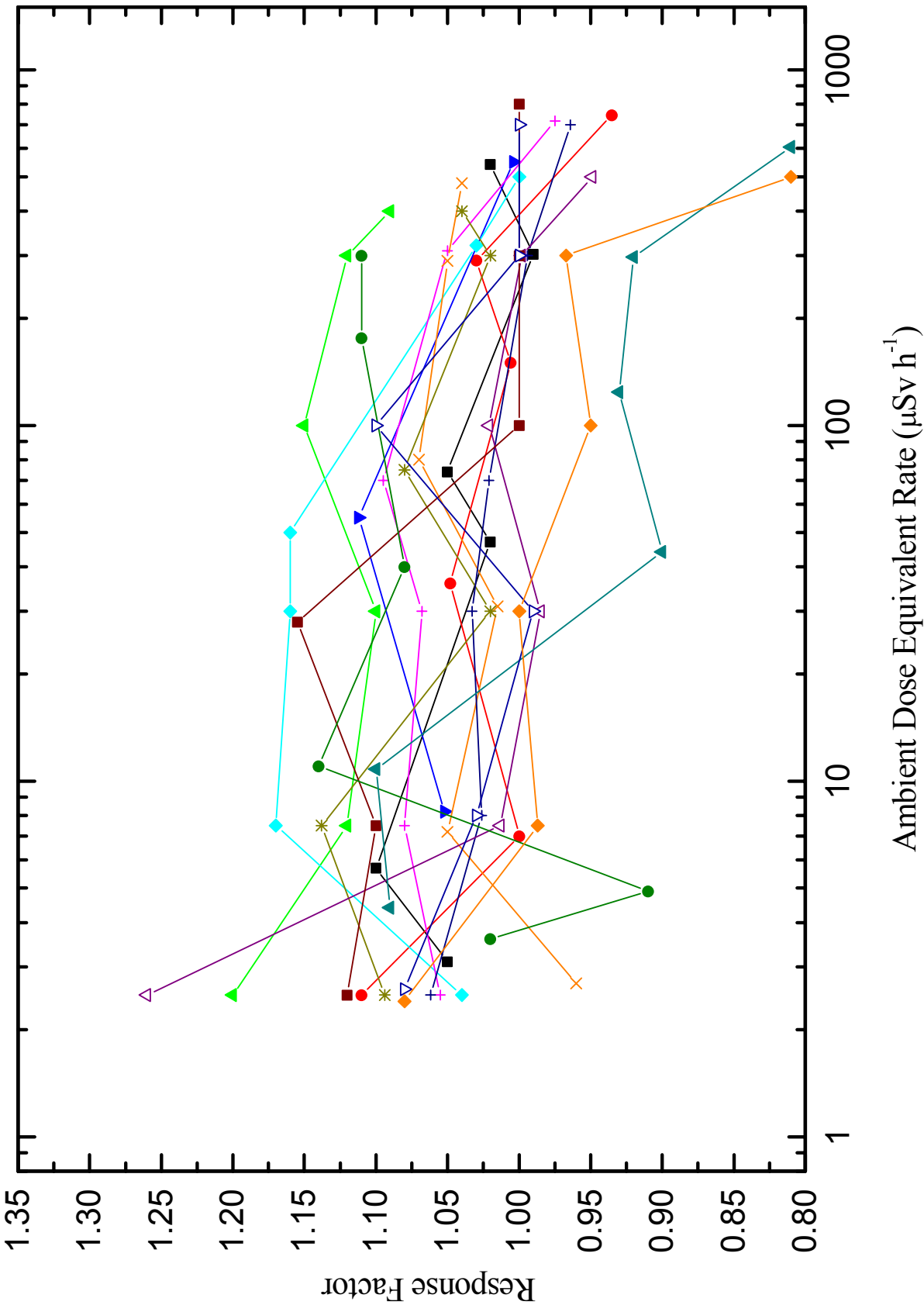


Figure 5a Response factors for Mini-rad 1000: ^{137}Cs field

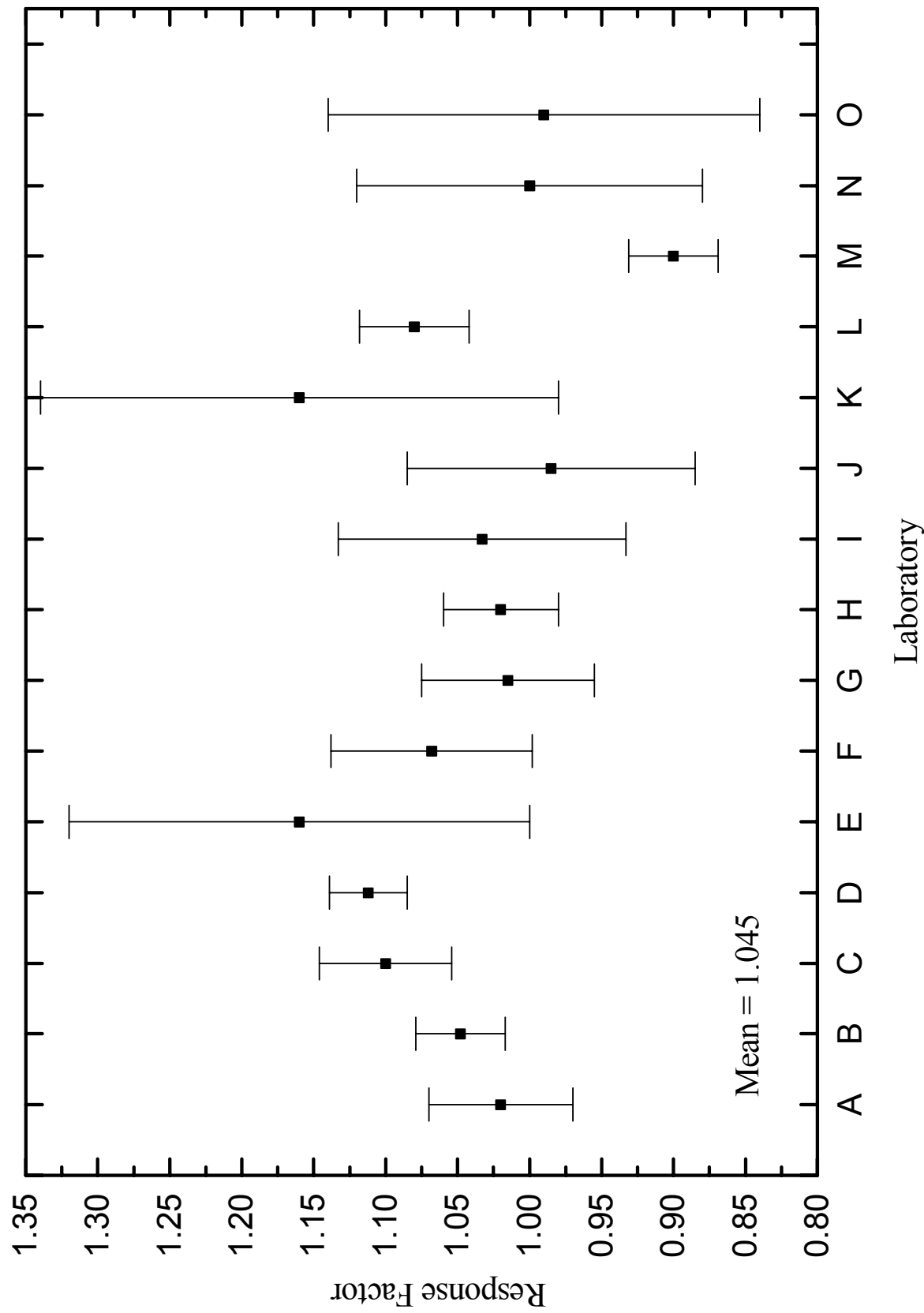


Figure 5b Response factors for Mini-rad 1000 around 30 $\mu\text{Sv h}^{-2}$, ^{137}Cs field

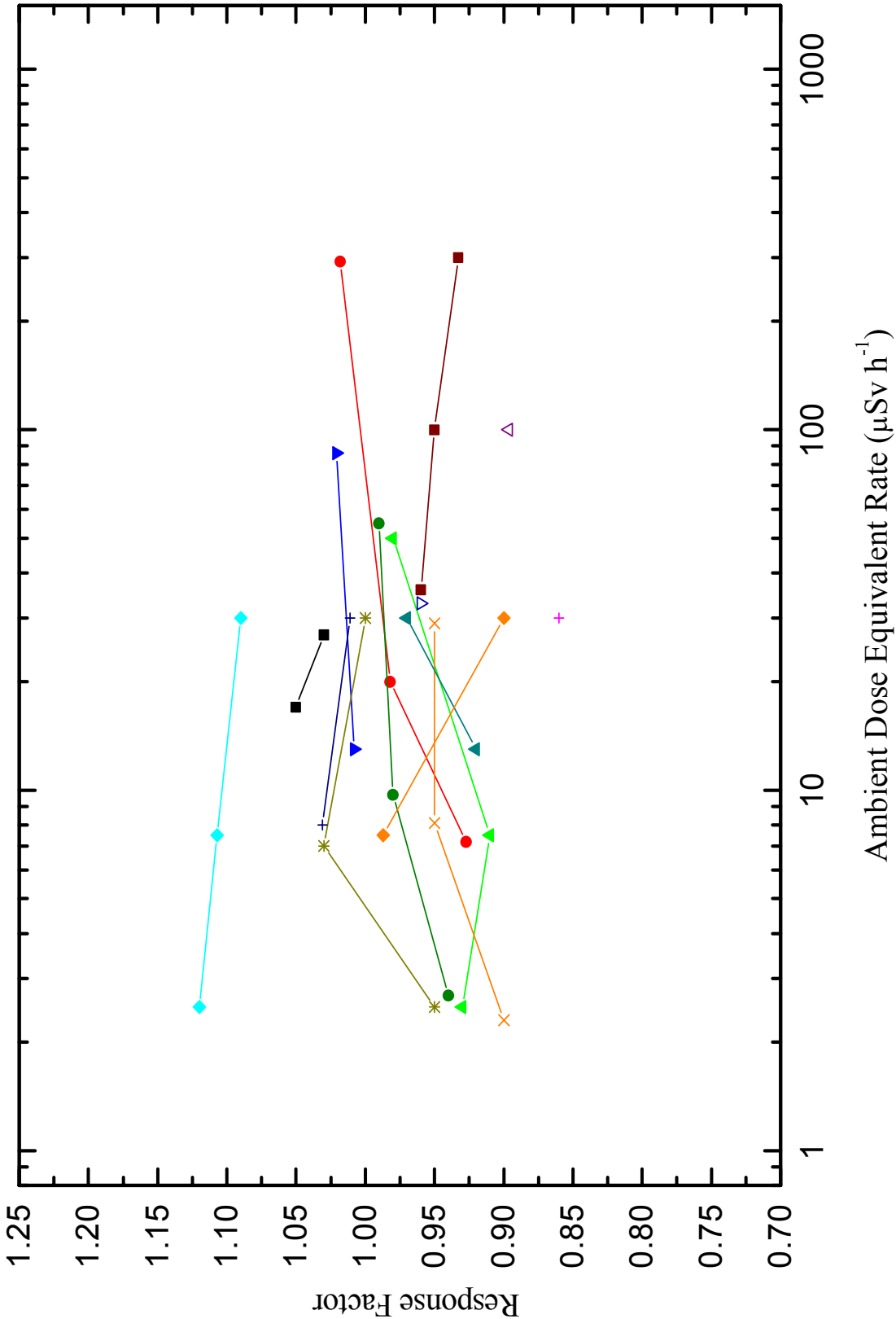


Figure 6a Response factors for Mini-rad 1000: ^{241}Am field

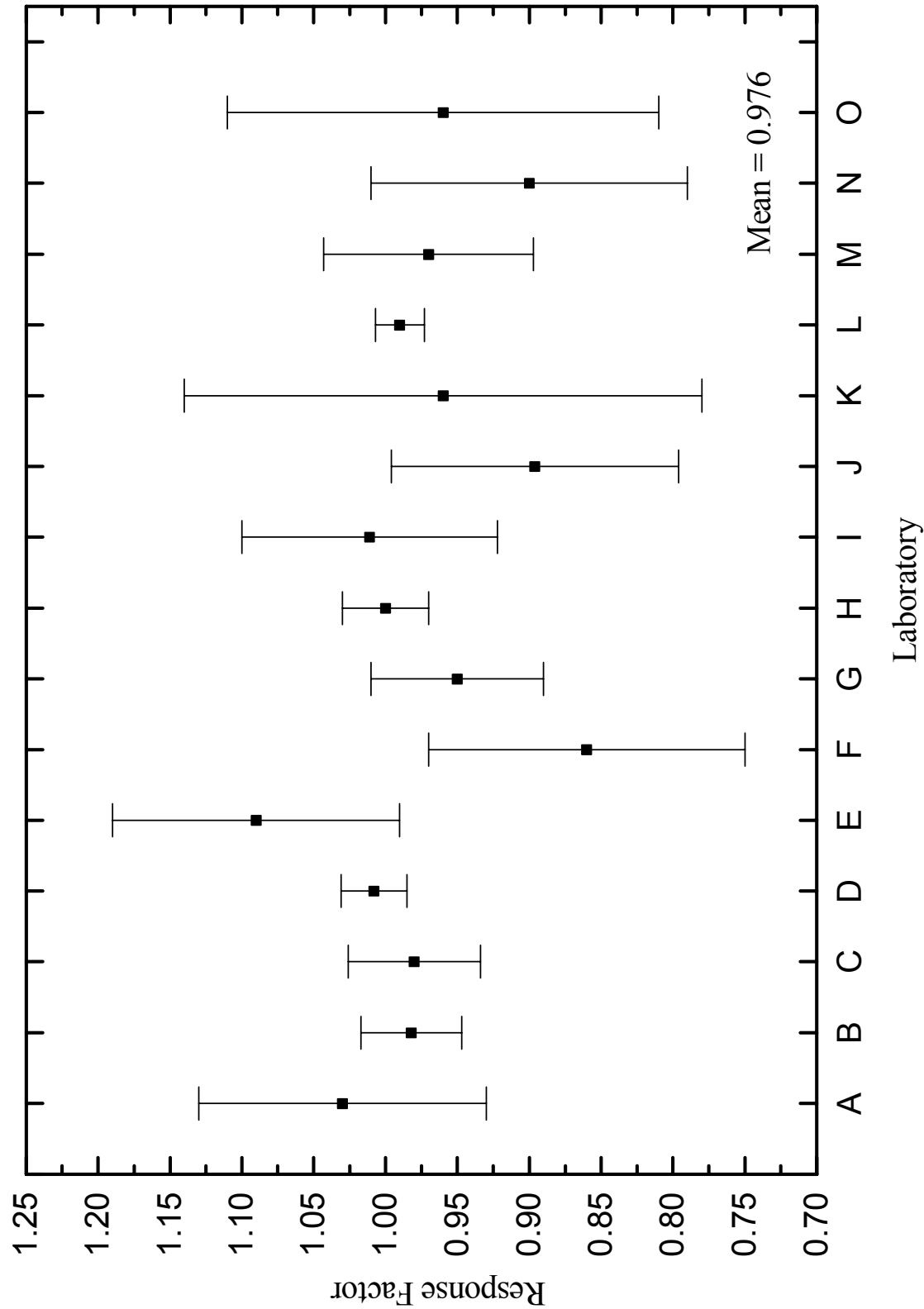


Figure 6b Response factors for Mini-rad 1000 around 30 $\mu\text{Sv h}^{-1}$; ^{241}Am field

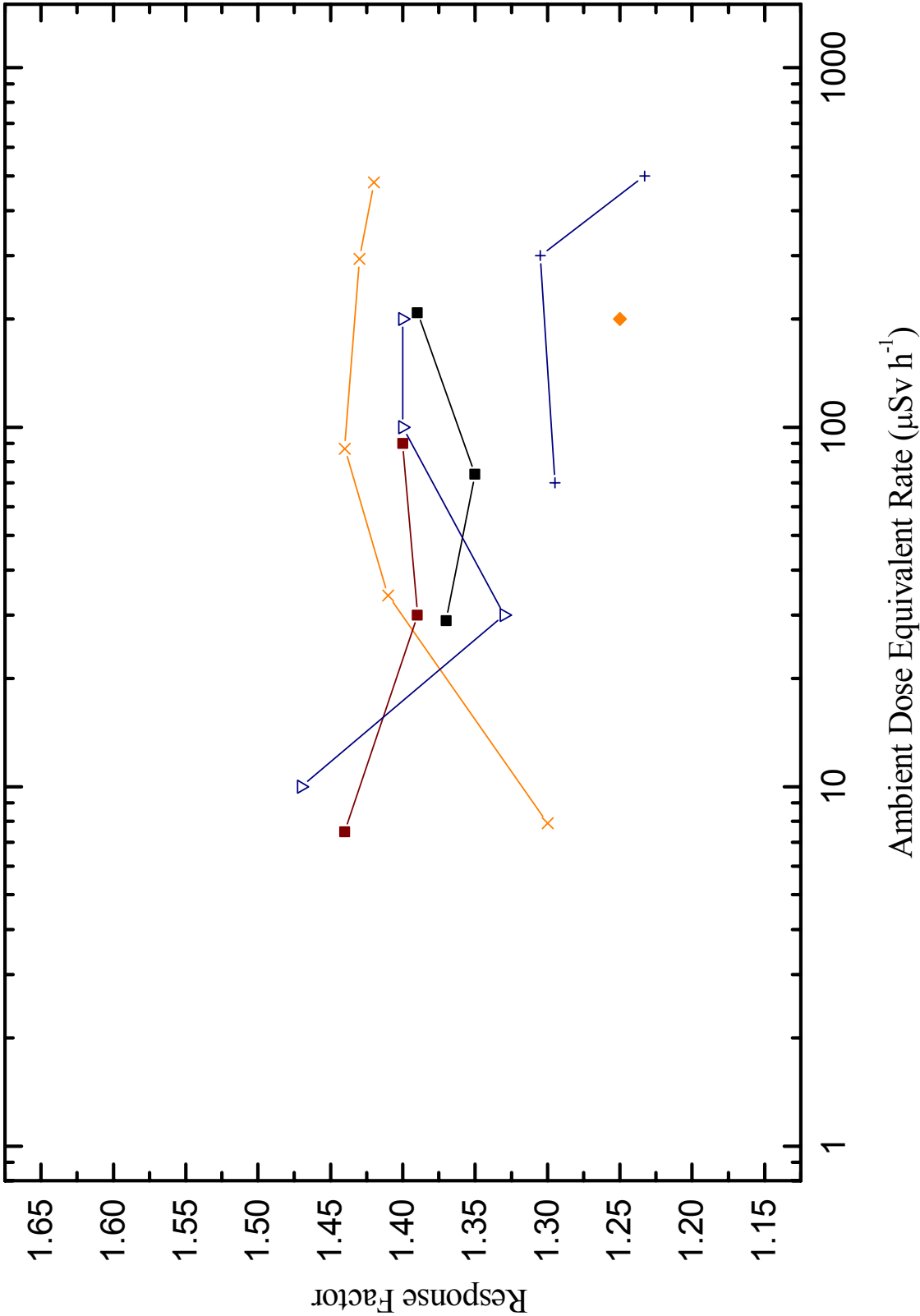


Figure 7a Response factors for Mini-rad 1000: ^{60}Co field

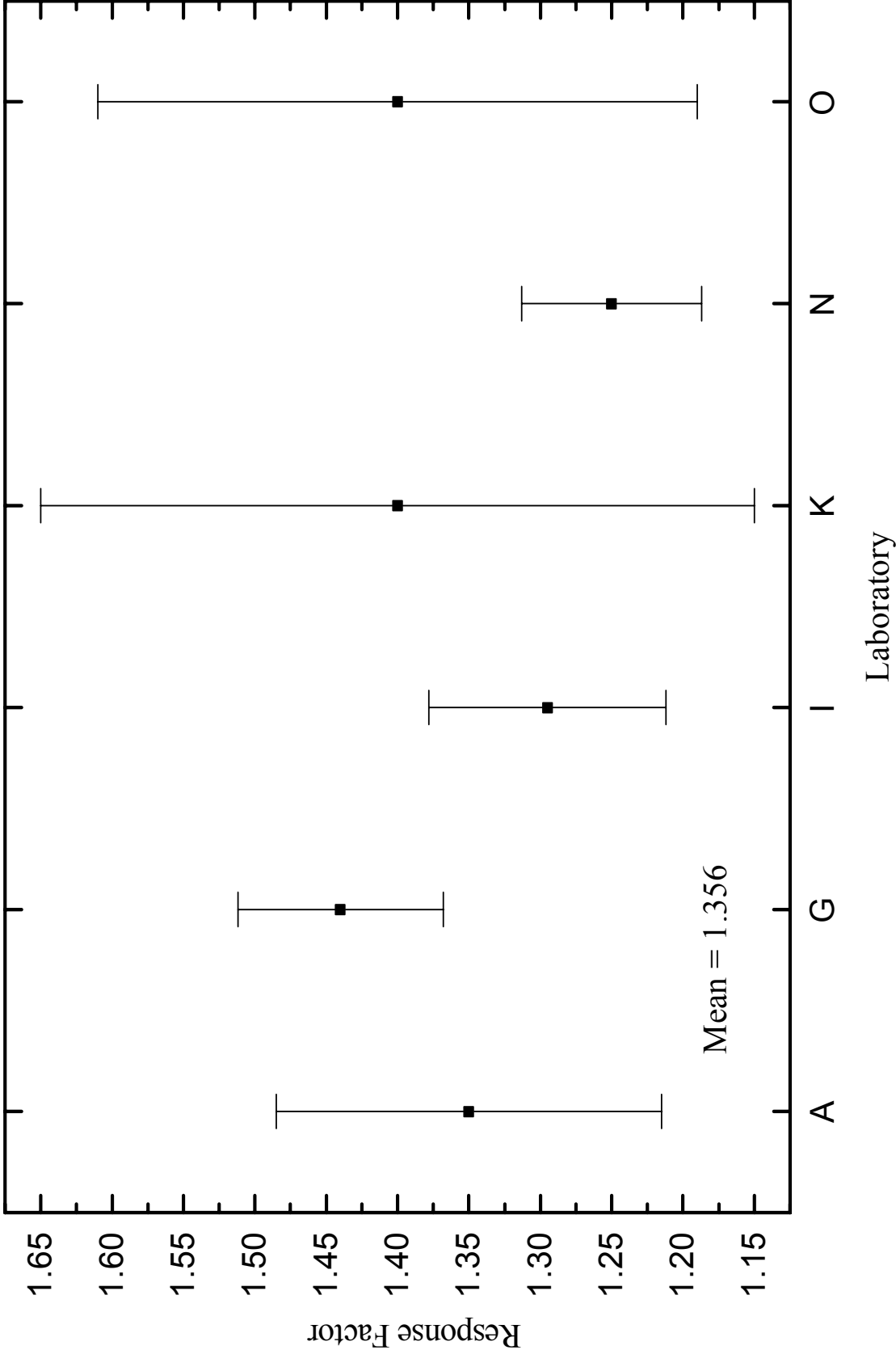


Figure 7b Response factors for Mini-rad 1000 around 100 $\mu\text{Sv h}^{-1}$ ^{60}Co field

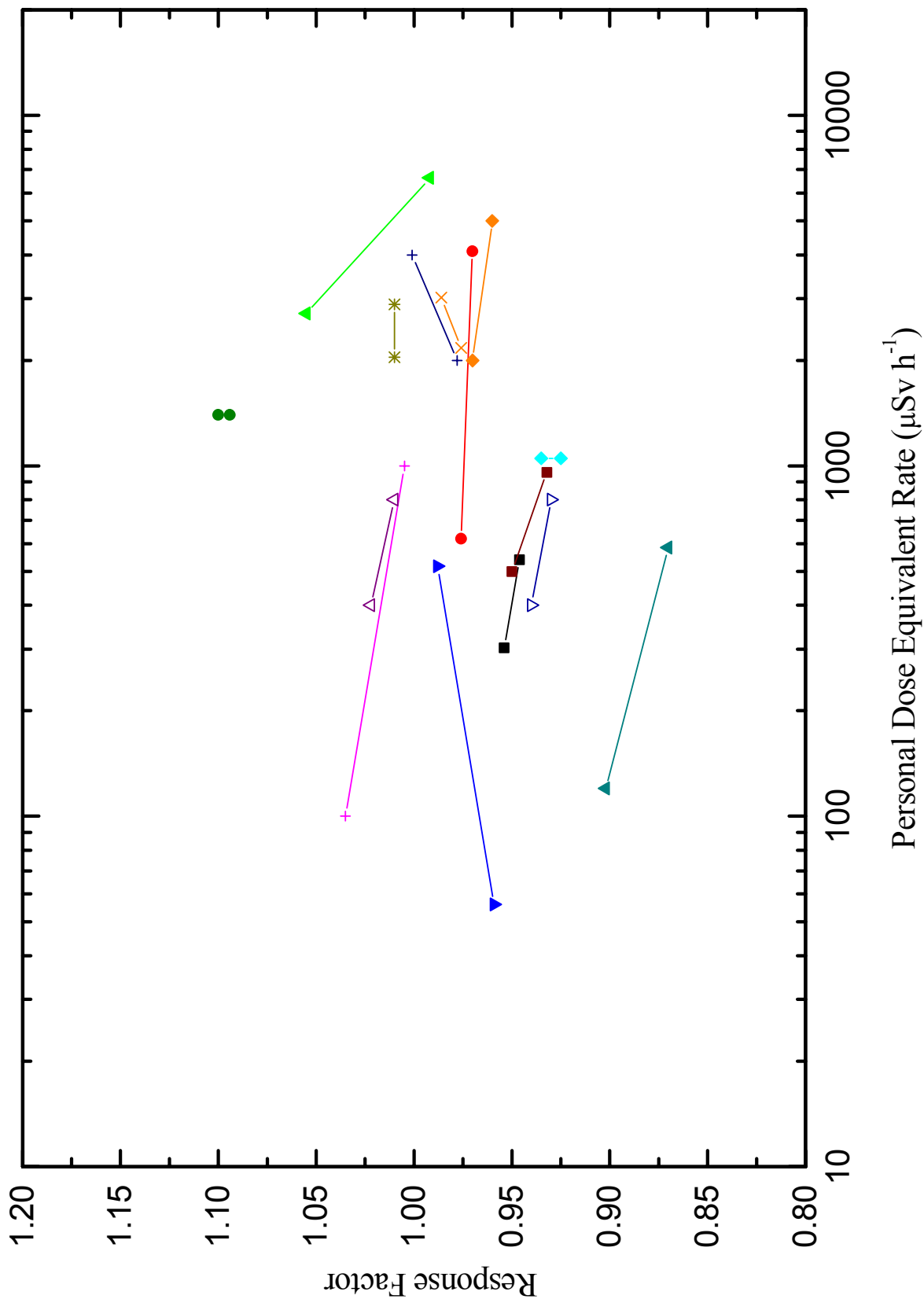


Figure 8a Response factors for Electronic Personal Dosimeter: ^{137}Cs field

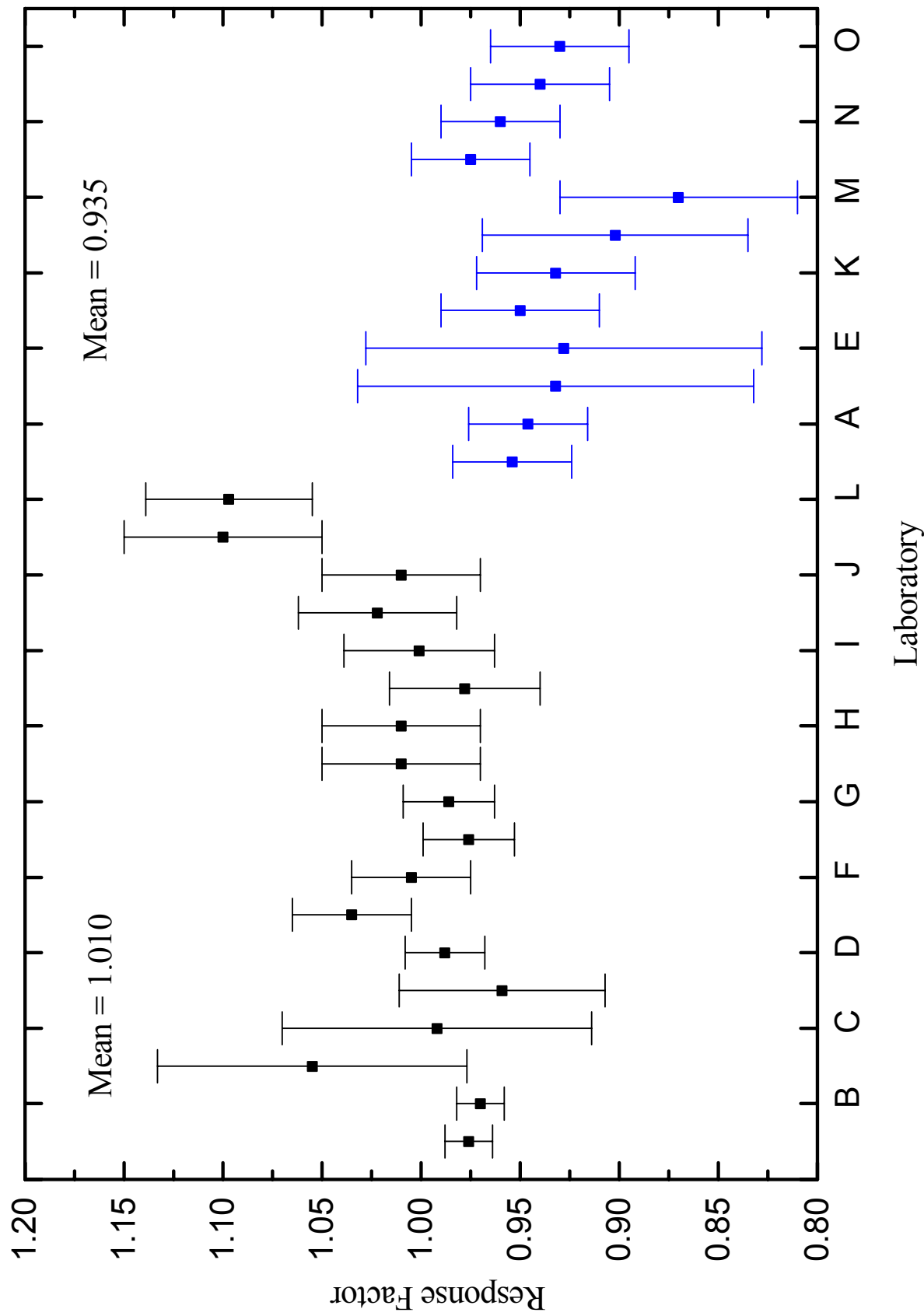


Figure 8b Response factors for Electronic Personal Dosimeter: ^{137}Cs field

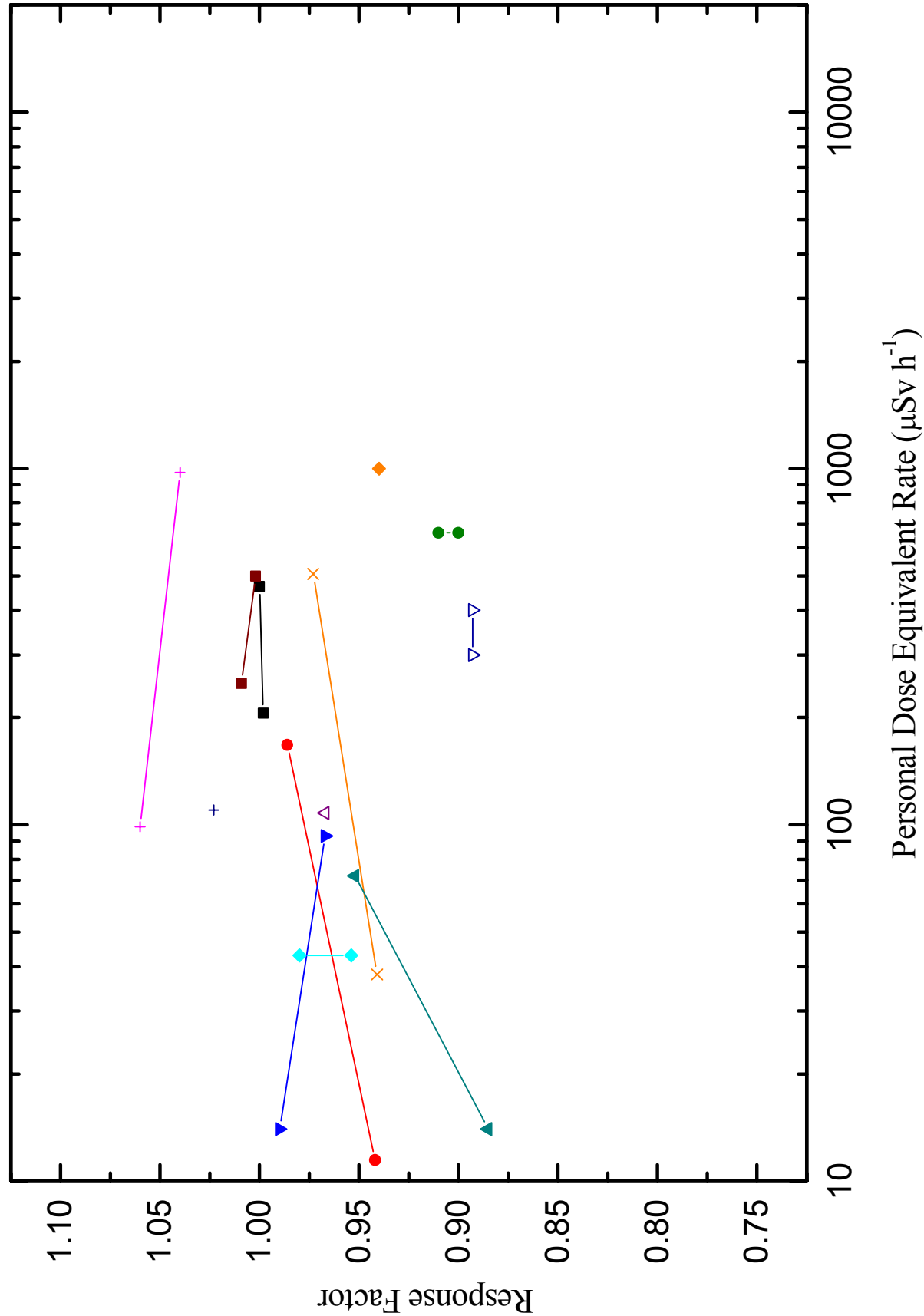


Figure 9a Response factors for Electronic Personal Dosimeter: ^{241}Am field

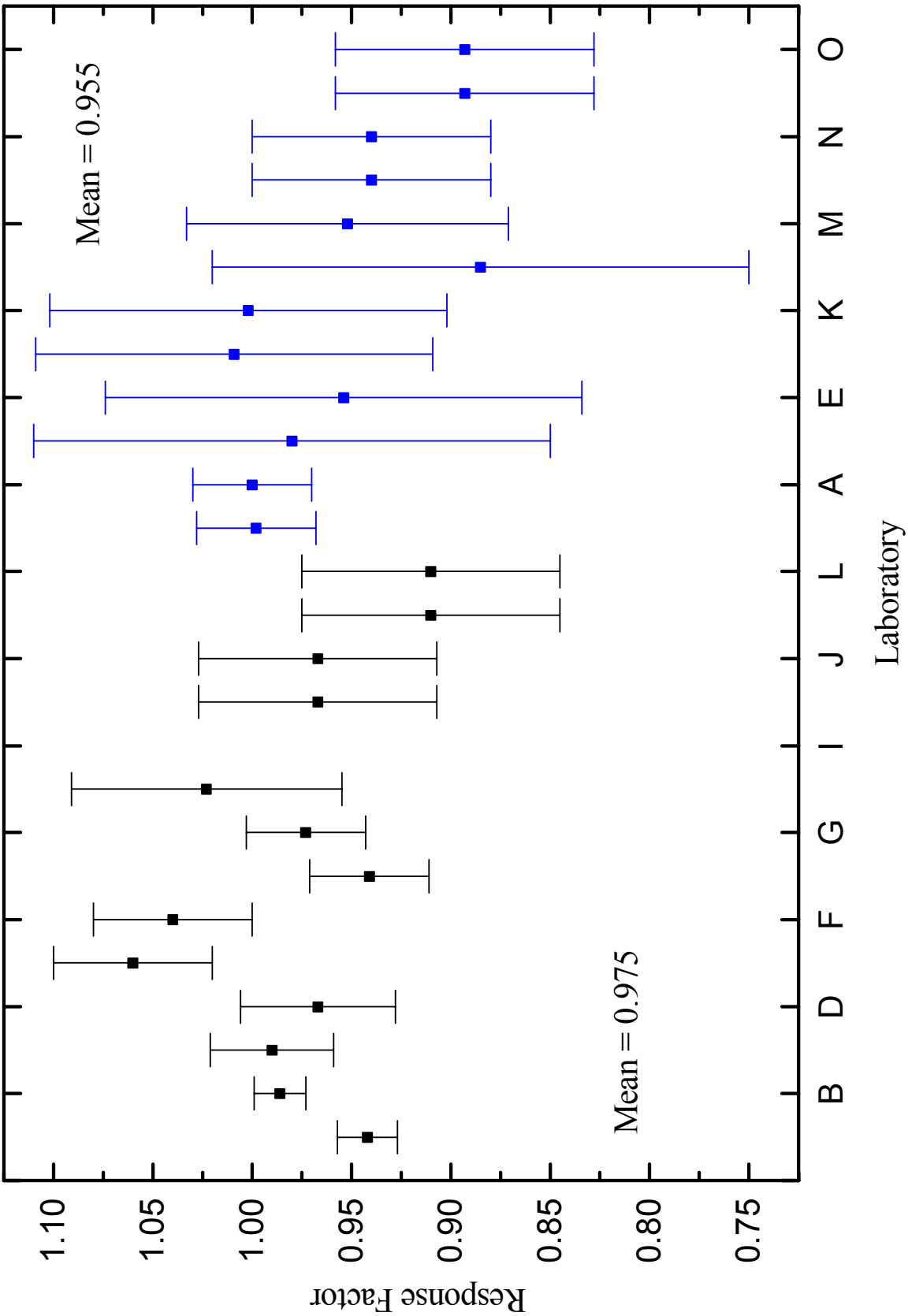


Figure 9b Response factors for Electronic Personal Dosimeter: ²⁴¹Am field

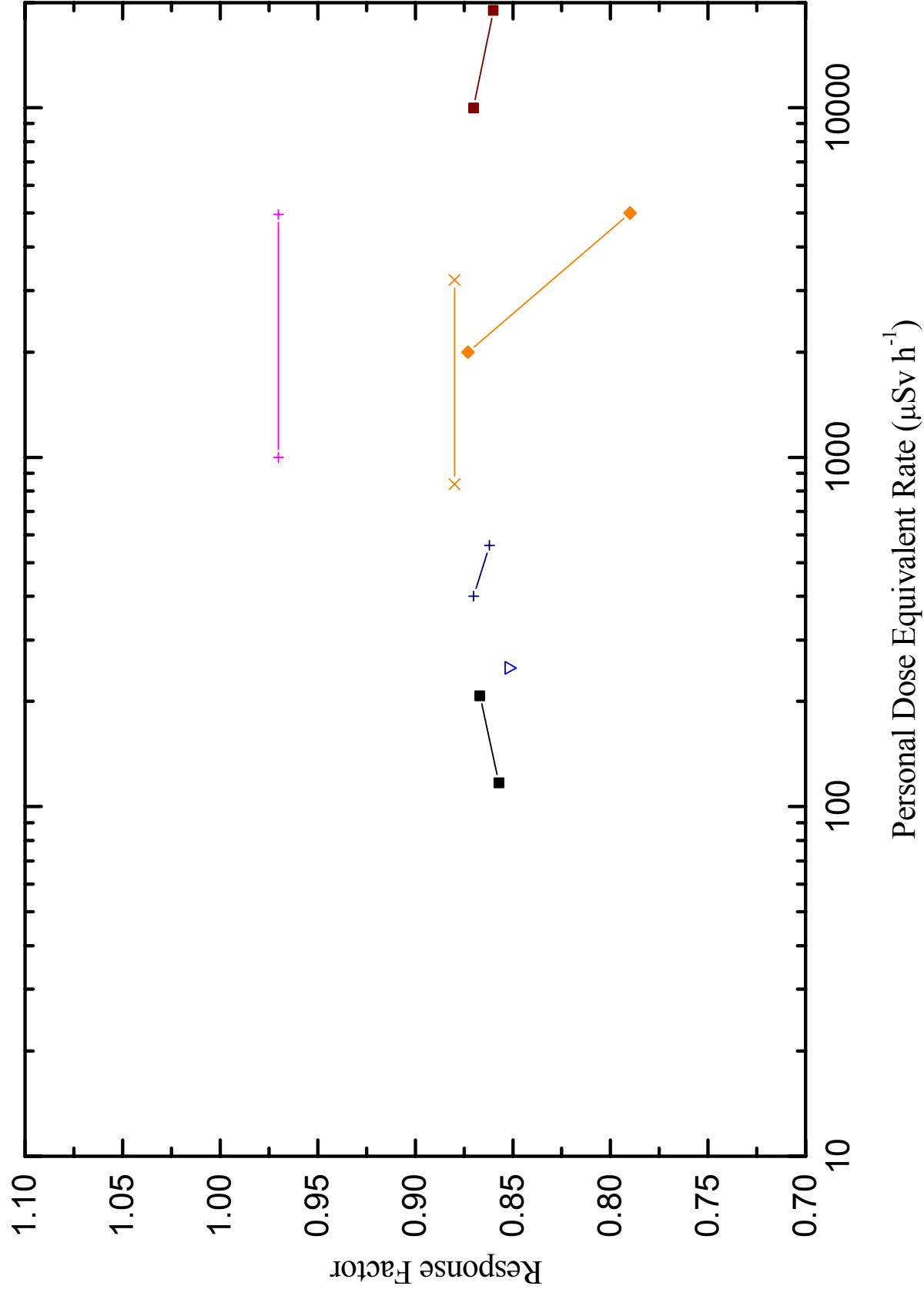


Figure 10a Response factors for Electronic Personal Dosimeter: ^{60}Co field

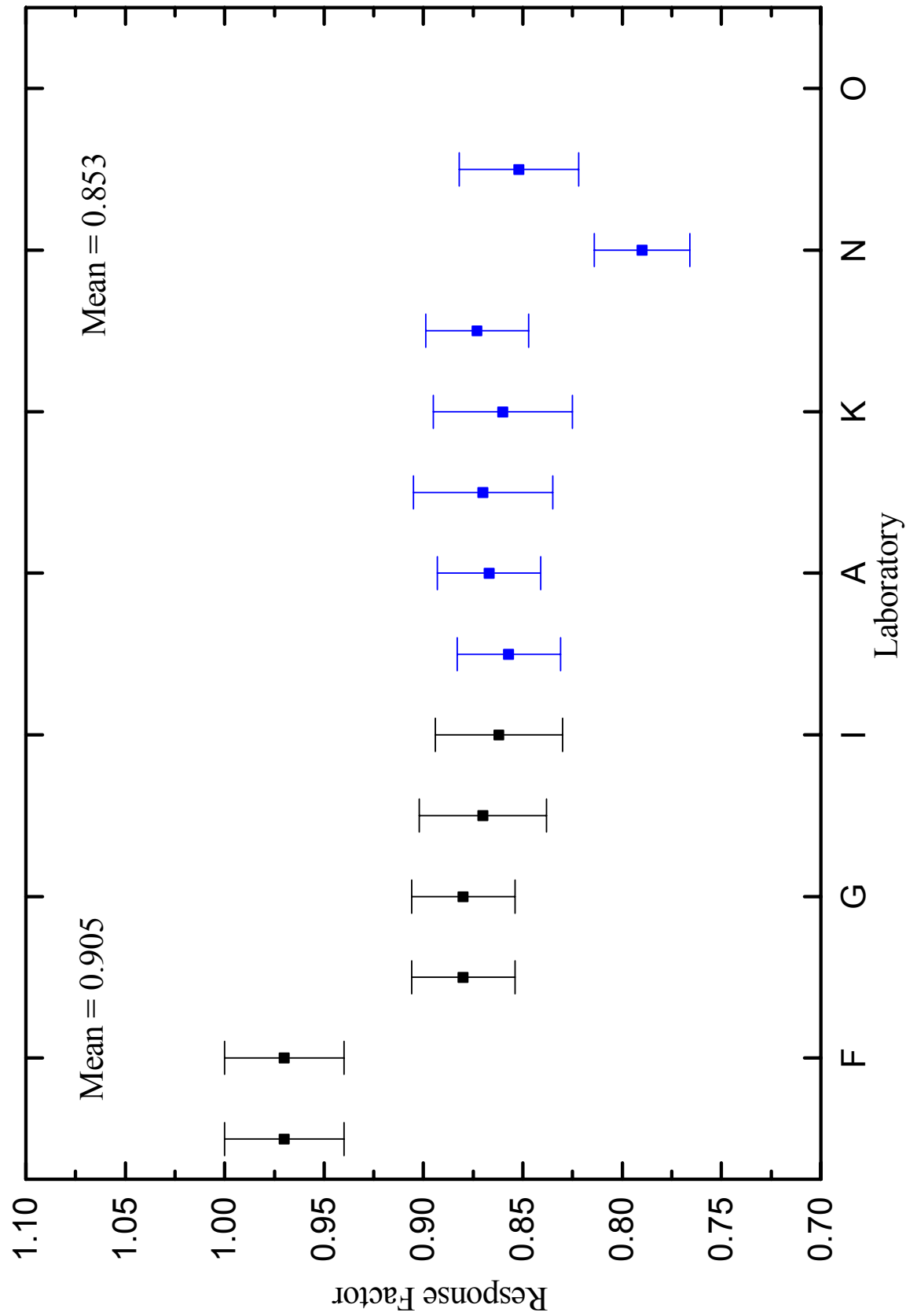


Figure 10b Response factors for Electronic Personal Dosimeter: ^{60}Co field

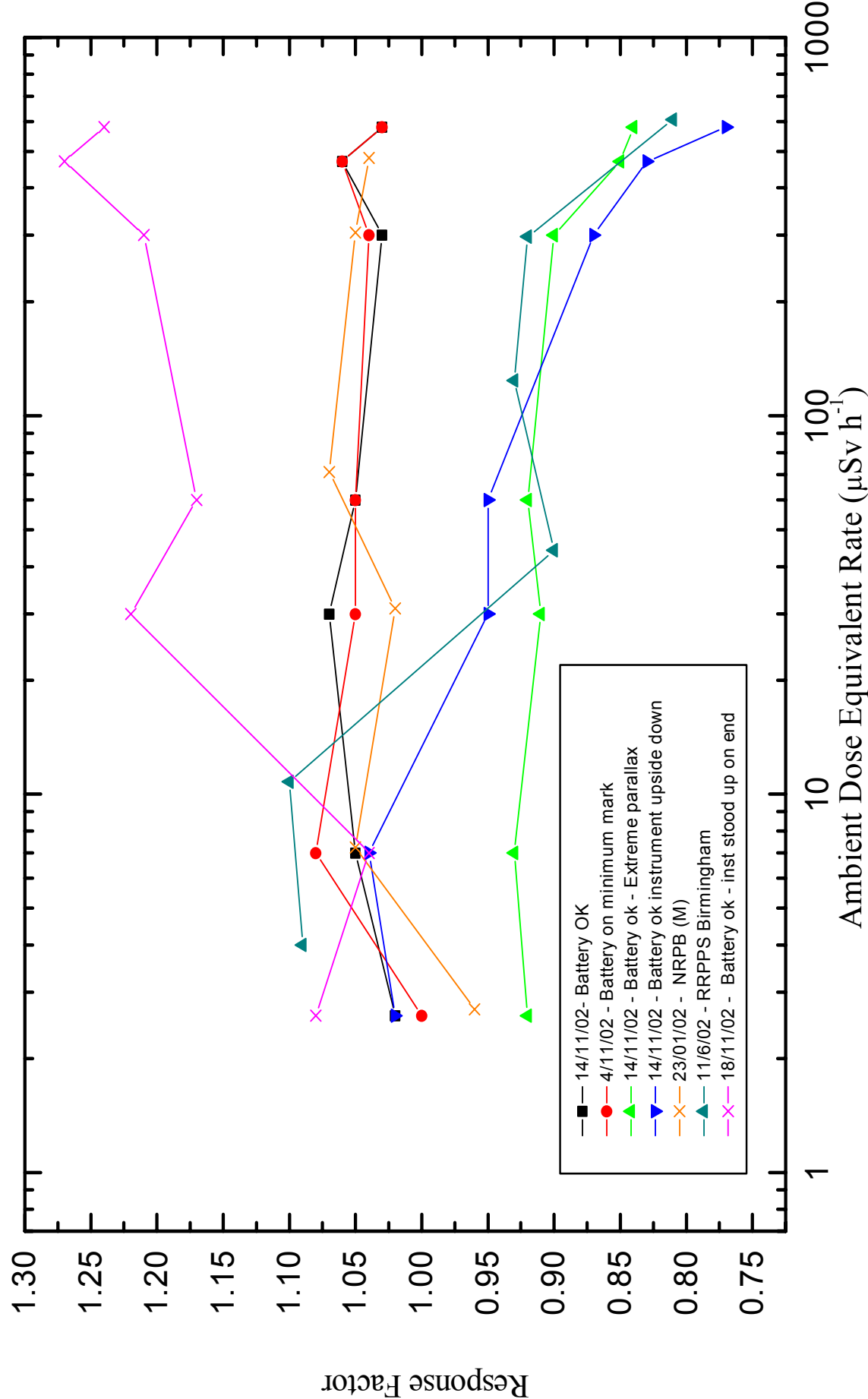


Figure 11 Investigation into low response at high doserates - Mini-rad 1000 ^{137}Cs

ANNEX Protocol

Fourth IRMF Comparison of Calibrations of Portable Gamma-Ray Dose-Rate Monitors Used for Area Monitoring and Personal Electronic Dosimeters

1 Introduction

Following the success of the three earlier comparisons of calibrations of hand-held gamma-ray dose-rate and electronic personal dosimeters it has been agreed that the IRMF will organise a fourth comparison to be carried out during late 2001 and early 2002. As before, the aim of the comparison is to increase confidence in the ability of the participants to perform such measurements.

The comparison involves the circulation of three radiation protection monitoring instruments whose electronics may have been deliberately off-set in order that their readings do not necessarily correspond to the true value of the incident radiation field. For a realistic and meaningful exercise it is essential that participants employ exactly the same techniques and methods to calibrate the instruments as routinely used within their organisation. The comparison is therefore not a research project.

The protocol embraces the use of the three gamma-ray sources ^{60}Co , ^{137}Cs and ^{241}Am . As the use of Am241 is normally restricted to confirming the energy response at one dose rate only, participants should make measurements as appropriate within the instrument range. The range of ambient dose equivalent rates covered is from about $2.5\mu\text{Sv h}^{-1}$ to 20mSv h^{-1} . However, it is emphasised that participants should restrict their measurements to the sources and dose-rates normally used in-house for routine instrument calibrations.

The quantities of interest for this comparison are ambient dose equivalent and personal dose equivalent. Participants are asked to provide the conversion coefficients used to derive these quantities from air kerma.

2. Organisation of the Comparison

It is intended to carry out the comparison during the period of September 2001 to June 2002. The transfer instruments and their packaging will be prepared by the NRPB at Chilton. The instruments will then go first to the NPL and this exercise will be used to check the suitability of the protocols before sending the instruments to the other participants.

Each participant has been allocated two weeks to complete the measurements and despatch the instruments to the next participant ready for use the following Monday morning. Participants are advised to use their preferred courier.

As a direct result of the experience gained in previous comparisons where the instrumentation proved most reliable, as no check sources will be circulated with the instruments. However, if participants are concerned for any reason regarding the condition of any of the instruments they should contact -

Duncan McClure (NRPB, Chilton)
Tel. No. 01235 822738
E-mail duncan.mcclure@NRPB.org.uk

The measurement protocol will be circulated to all participants electronically, but manuals for each of the instruments will be circulated within the transport case. Please ensure that these

remain within the case and are sent to the next participant with the instruments. Any participant not receiving the manuals should report this to the organisers immediately. Any participant who does not pass on the full complement of instrumentation and documentation in the transport case provided may be removed from the comparison.

3 Transfer Instruments

The following instruments are being used as transfer instruments for the comparison. The organisers wish to thank Saint-Gobin Crystals & Detectors UK Ltd, Siemens Environmental Systems Ltd and the National Physical Laboratory for providing the instruments.

3.1 Electra with MC 20 probe

This instrument and probe combination will require setting up by each participant before measurements can be made. This should be performed by reference to the measurement pro-forma and the instrument manual provided in the shipping case with the instrument. Whilst the majority of the parameters used to set up the Electra have been provided, it is necessary for each participant to calculate the dead time. This should be performed in the manner in which the laboratory usually perform the assessment for setting the dead time, in which case the participant should provide details of the method used, or by following the procedure detailed below. Once you have completed your measurements, the parameters in the Electra should be reset to the values given at the top of page 38 of the manual. This is to ensure that the next participant will have to follow the set up procedure. When making these changes start at parameter **F** and choose **S66**.

Electra & MC20 Set-up parameters

0 → Battery voltage	8 → Sv/h
1 → off	9 → 1.71
3 → 500V	A → on
4 → 5.0 μ A	b → on
5 → Initially off, then the value you derive	C → Auto
6 → 1.5V	E → int
	F → G

Method for calculation of dead time.

- Set the dead time value in the Electra to 0
- Set the instrument calibration factor to a value of $1.71 \text{ counts s}^{-1}/\mu\text{Sv h}^{-1}$
- Make a measurement at a high dose rate (a few hundred $\mu\text{Sv h}^{-1}$) and multiply the **true delivered dose rate** by the response factor given above. This is term B.
- The **instrument indication** obtained at the high dose rate is also multiplied by the response factor given above. This is term C.

The dead time can then be calculated using the formula below: -

$$\tau = \frac{B-C}{B \times C}$$

When a value for the dead time has been calculated it should be entered into the Electra and the measurements detailed on the pro-forma performed.

Calibrations

The probe should be mounted as shown in the attached diagram, i.e. horizontally with the reference spot facing the radiation source. The major axis of the probe should be normal to the radiation beam and the reference distance measured to the centre of the probe's cylindrical axis. Every endeavour should be made to mount the Electra out of the primary beam. This is the preferred orientation and you should only deviate from it if it is physically impossible to achieve such an orientation in your facility. Any deviations should be noted on the appropriate diagram and returned with the relevant measurement pro-forma.

All the measurements on this instrument are made in the rate mode.

The results of the calibration measurements must be recorded on the relevant attached pro-formas. Instrument readings should be recorded as observed. In this comparison, participants are required to correct the indication for background (as applicable) and calculate the response factor for each of the measurements performed.

An estimate of the uncertainty associated with the determination of the true delivered dose rate, the corresponding instrument reading and the calculated response factors should be recorded for each measurement on the relevant section of the pro-forma. These uncertainties should be expressed at the 95% confidence level. In addition a full uncertainty budget should be provided for one of the measurement points performed. See Section 6 below for further information on uncertainty budgets.

3.2 Gamma Monitor Mini-Rad 1000R

Participants should note that the instrument scale readings may have been offset and as such should not be surprised if the instrument indication does not correspond to the incident dose equivalent rate. A user manual is in the shipping case with the instrument.

The instrument should be mounted as shown in the attached diagram i.e. horizontally with the front face facing the radiation source. The beam axis should be aligned with the instrument case. The distance should be measured between the source and the marked reference point on the side of the instrument case. This is the preferred orientation and you should only deviate from it if it is physically impossible to achieve such an orientation in your facility. Any deviations should be noted on the appropriate diagram and returned with the relevant.

The results of the calibration measurements must be recorded on the relevant attached pro-formas. Instrument readings should be recorded as observed. In this comparison, participants are required to correct the indication for background (as applicable) and calculate the response factor for each of the measurements performed.

An estimate of the uncertainty associated with the determination of the true delivered dose rate, the corresponding instrument reading and the calculated response factors should be recorded for each measurement on the relevant section of the pro-forma. These uncertainties should be expressed at the 95% confidence level. In addition a full uncertainty budget should be provided for one of the measurement points performed.

3.3 Electronic Personal Dosemeter (EPD)

As stated above, the dosimeter response may have been offset, so participants should not be surprised if the dosimeter indicated incremental dose equivalent does not indicate the incident dose equivalent.

As supplied, the EPD default display is (H_p) in μSv . All displays options have been locked out with the exception of the H_p and H_s dose indications, these equate to measurements of $H_p(10)$ and $H'(0.07)$ respectively. In addition, the dose and dose rate alarms on the EPD have been set to their maximum values and should not operate during the comparison measurements.

The EPD dosimeter should be mounted as shown in the attached diagram i.e. dosimeter front towards the incident beam with its central axis of symmetry aligned at right-angles to the incident beam axis. The dosimeter may be irradiated either on or off a suitable 'phantom'. The distance should be measured from the gamma-ray source to the reference point, the 'beta-window' on the dosimeter. This is the preferred orientation and you should only deviate from it if it is physically impossible to achieve such an orientation in your facility. Any deviations should be noted on the appropriate diagram and returned with the relevant measurement pro-forma.

The participants should select two different dose rates for each nuclide. It is recommended that the EPD is exposed for a period sufficient to accumulate a minimum indication of 200 μSv . Participants are also advised to either zero the EPD immediately before each exposure, or to record the time taken for the EPD to change between indicated readings. e.g.

- EPD displays 11 μSv
- Display changes to 12 μSv – start timer.
- Display changes to 212 μSv – stop timer.
- Use measured time to calculate true dose to EPD
- Calculate response

The results of the calibration measurements must be recorded on the relevant attached pro-formas. Instrument readings should be recorded as observed. In this comparison, participants are required to correct the indication for background (as applicable) and calculate the response factor for each of the measurements performed.

An estimate of the uncertainty associated with the determination of the true delivered dose rate, the corresponding instrument reading and the calculated response factors should be recorded for each measurement on the relevant section of the pro-forma. These uncertainties should be expressed at the 95% confidence level. In addition a full uncertainty budget should be provided for one of the measurement points performed. See Section 6 below for further information on uncertainty budgets.

Your attention is also drawn to a number of additional questions included on the Pro-forma for this particular instrument, please complete as fully as possible and include additional pages if necessary.

4 Collation of Results

The co-ordinators of this exercise are

Vic Lewis at NPL, Teddington. Tel: 020 8943 6851
Duncan McClure at NRPB, Chilton. Tel: 01235-822738.

Participants are required to submit copies of their completed measurement pro-formas and report forms, including the additional information (see Section 5 below) to both co-ordinators within four weeks of the completion of their measurements.

Failure to meet this deadline will result in exclusion from the final report.

On the completion of the inter-comparison a summary report will be prepared and distributed to all participants prior to the holding of a 'summary meeting' to finalise the report and agree conclusions to be drawn from the inter-comparison. Following the satisfactory completion of this exercise a report will be prepared for publication by the NPL.

5 Information required from Participants

Please use attached pro-forma measurements report forms whenever possible, completing only the parts marked for participant's use.

There are three columns for uncertainties marked 'UN'.

- the first uncertainty is that associated with the derivation of the dose rates used for the measurements.
- the second uncertainty is that associated with the instrument readings
- the third uncertainty is that of the calculated response factors.

These should be quoted at the 95% confidence level.

See Section 6 for notes on uncertainties.

Participants are also requested to complete copies of the following pages 6, 7, 8, with the details requested and return them to the coordinators with the data pro-forma.

5.1 Participant's irradiation source and facilities

SOURCE AND TRACEABILITY

i) Are the sources capsules or planar?

^{241}Am

^{137}Cs

^{60}Co

ii) What is the basis of the calibration in terms of Ambient dose equivalent rate? Is this traceable to primary standards, and if so, how?

.....

COLLIMATION

What is the primary beam diameter (**in cm**) at a distance of **1 metre** from the source?

^{241}Am

^{137}Cs

^{60}Co

Please state for each source the minimum beam diameter used in the measurements and the associated minimum source to instrument separation distance.

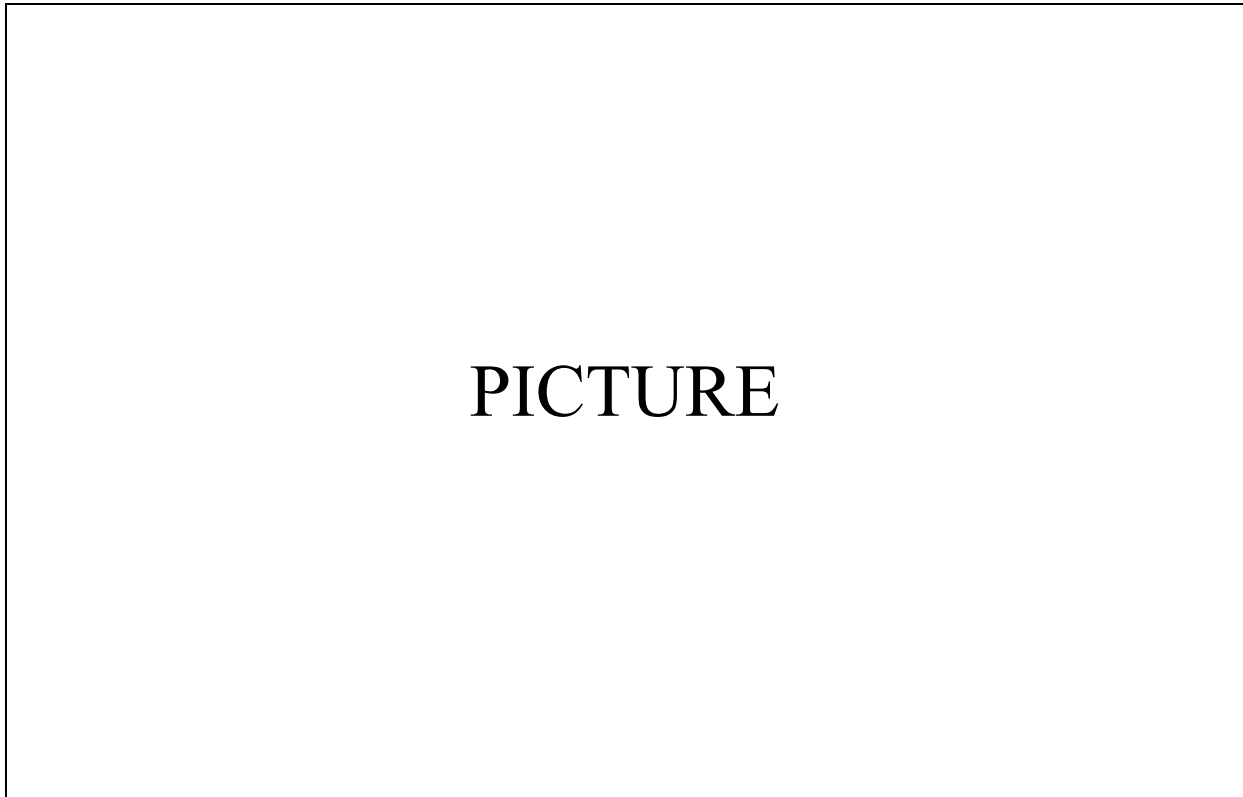
^{241}Am

^{137}Cs

^{60}Co

EXPOSURE ROOM

Please indicate the approximate dimensions of the exposure room as indicated on the diagram below.



Exposure room dimensions (in metres).

Length L:

Width W:

Height H:

What is the wall material?

Source/Instrument Geometry (**in metres**).

Height above floor H:

Distance from Walls Y:

Z:

Source/Instrument Separation Distance (**in metres**).

Minimum $X_{\min}$:

Maximum $X_{\max}$:

5.2 Dose equivalent conversion factors

AMBIENT DOSE EQUIVALENT

What is the value of the air-kerma to ambient dose equivalent conversion factors used for each source.?

^{241}Am
 ^{137}Cs
 ^{60}Co

PERSONAL DOSE EQUIVALENT

What is the value of the air-kerma to personal dose equivalent conversion coefficient used for each source? If the calibration of the EPD was not performed in terms of personal dose equivalent what quantity and conversion coefficients were used?

^{241}Am
 ^{137}Cs
 ^{60}Co

What is the source of the above conversion coefficients(s)?

.....

5.3 Comments

.....

6 Uncertainty budget

Please provide one sample uncertainty budget, using the template below (or equivalent) as a guide, for each calibration measurement pro-forma, demonstrating how the uncertainty values are derived for a calibration at a selected dose rate. Additional components may be included.

For convenience, an Excel spreadsheet is provided in a separate file.

Participant	Instrument	Nuclide	Distance

Symbol	Source of uncertainty	Value ($\pm$)	Probability distribution	Divisor	c_i	u_i ($\pm$ %)	v_i v_{eff}
S_{ak}	Secondary standard air kerma calibration	___%	normal	2	1.0		∞
S_d	Secondary standard setting up distance						
T	Temperature						
P	Pressure						
S_b	Secondary standard background reading						
S_r	Secondary standard repeatability						
t	Time of exposure						
I_d	Instrument setting up distance						
I_b	Instrument background reading						
I_r	Instrument reading						
u_c	Combined uncertainty	---	normal	---	---		∞
U	Expanded uncertainty	---	normal	($k=2$)	---		∞

Comments and additional information

Please see notes overleaf

Notes

- a. If the values of the uncertainty components are expressed in the same units as the quantity (eg. mm for distance, K for temperature, etc), the values of the associated c_i value (to convert u_i to percentage of response factor) must also be given.

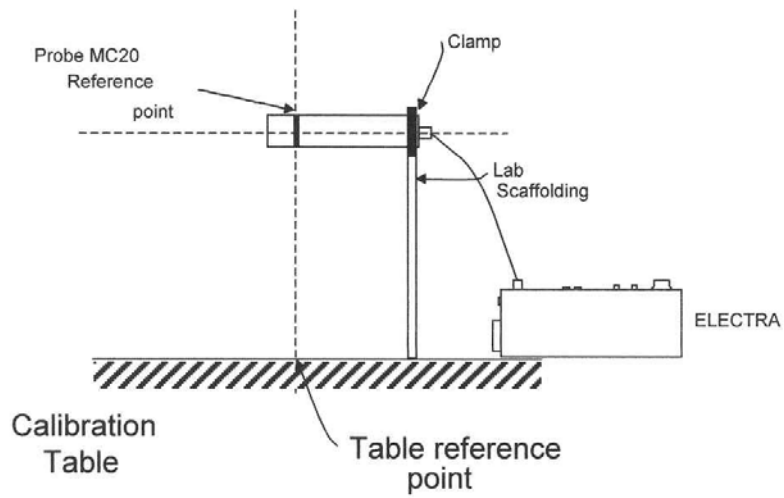
If the values of the uncertainty components are expressed in terms of the percentage of response factor, the associated c_i value will be unity.

- b. The uncertainty in dose equivalent rate is the combination of the first five components
- c. The uncertainty in the response factor is the combination of all components for the EPD but excludes that for the time of exposure for the other monitors used in the rate mode.
- d. The uncertainty associated with the air kerma to dose equivalent rate conversion coefficient is not included.
- e. The number (or effective number) of degrees of freedom (ν_i or ν_{eff}) is usually infinity.
- f. The values of the divisors are given in the table below

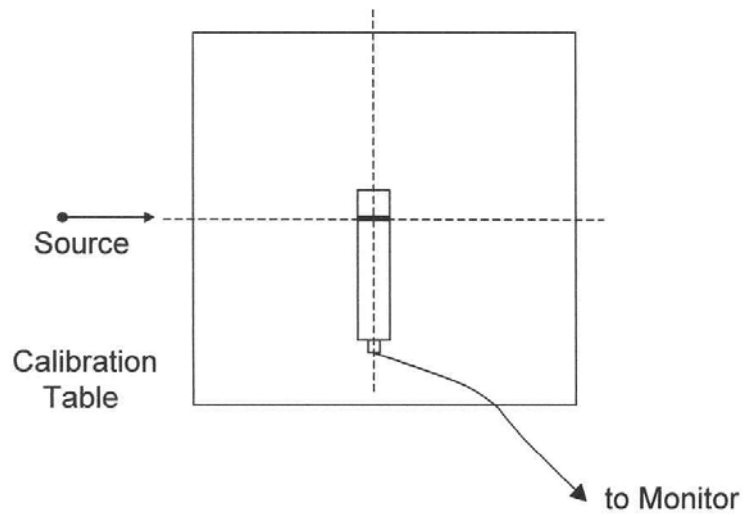
Probability distribution	Confidence level	Divisor
Normal	standard deviation	1.0
Normal	95%	2.0
Rectangular		$\sqrt{3}$

Dummy values for the uncertainties of various components are used in the accompanying Excel spreadsheets.

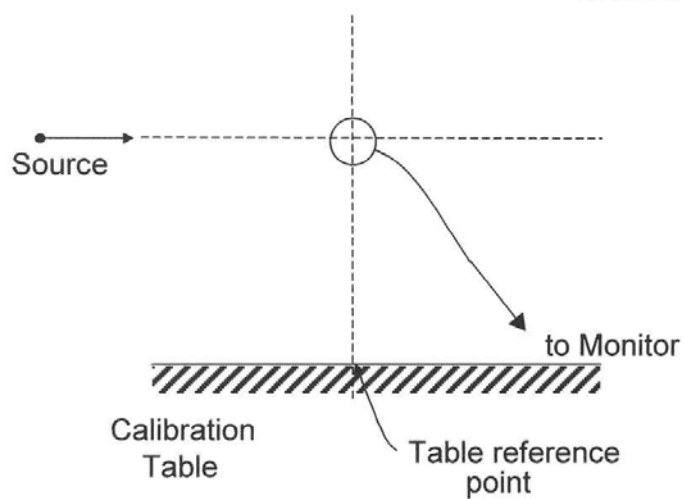
CALIBRATION ORIENTATION FOR ELECTRA WITH MC20



FRONT
ELEVATION

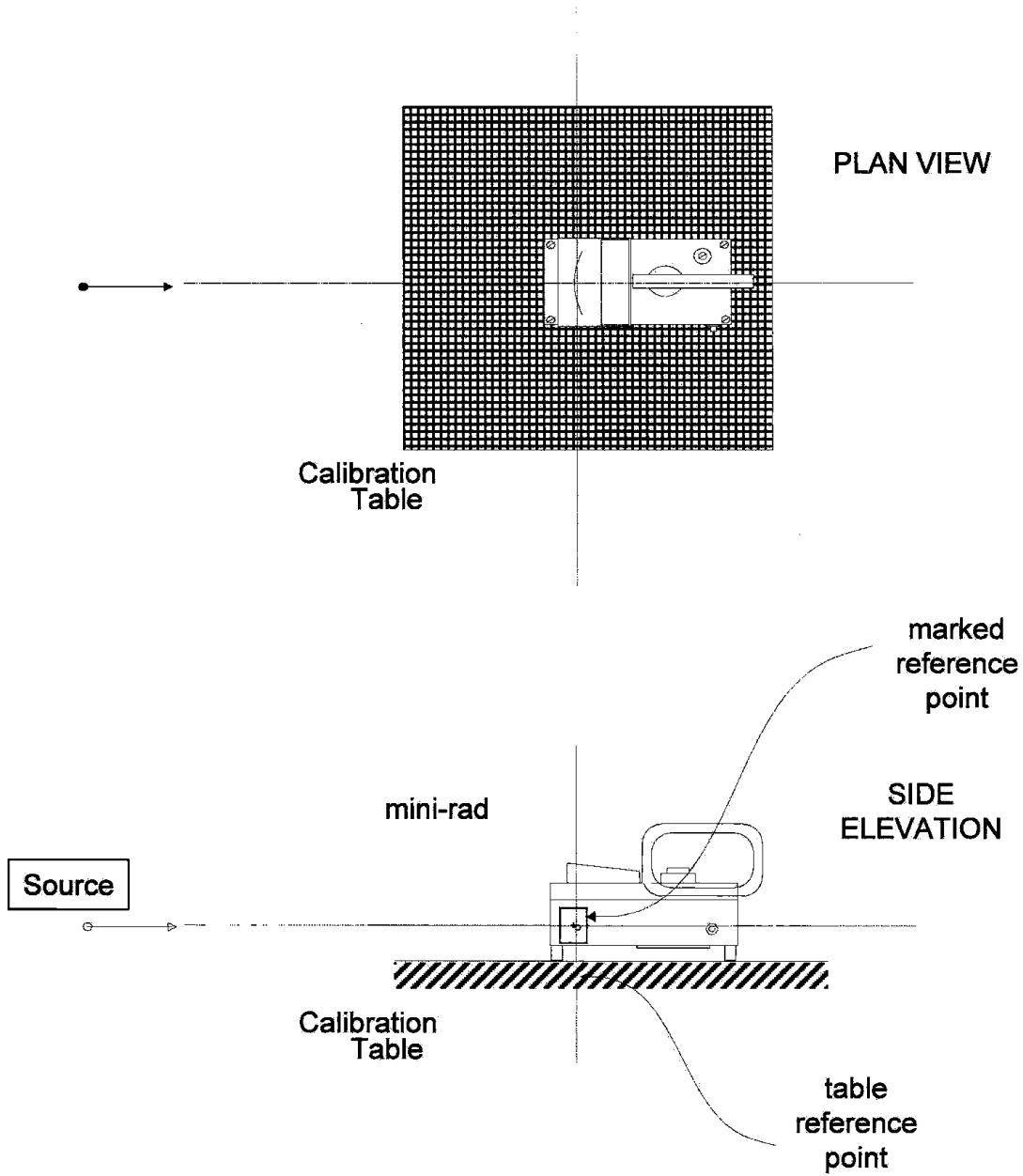


PLAN VIEW

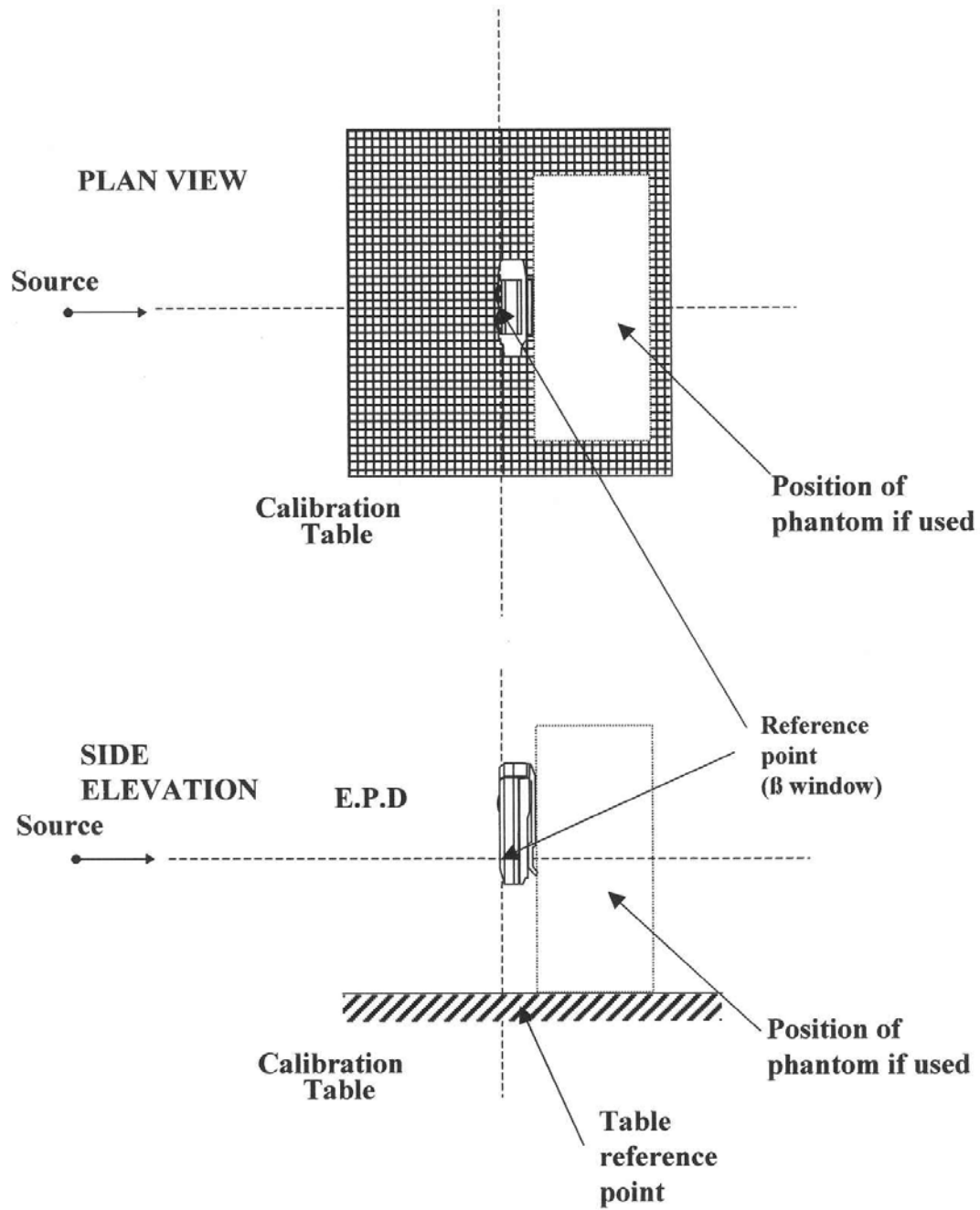


SIDE
ELEVATION

CALIBRATION ORIENTATION FOR
MINI-RAD (1000R)



CALIBRATION ORIENTATION FOR ELECTRONIC PERSONAL DOSEMETER (E.P.D.)



4th IRMF GAMMA-RAY CALIBRATION INTERCOMPARISON

Participant _____ Lab. Ref: _____
 Instrument type: Electra 1A / MC 20 Serial No. _____
 Comments: _____ Reference point: _____
 _____ Orientation: _____

PARTICIPANTS							OFFICIAL USE ONLY	
Nuclide	† Distance (mm)	Target Ambient Dose Equivalent Rate ($\mu\text{Sv h}^{-1}$)	True Ambient Dose Equivalent Rate ($\mu\text{Sv h}^{-1}$)	Un.	Instrument			
					Reading inc. BG $\mu\text{Sv h}^{-1}$	Un.	Response Factor	
BG								
^{137}Cs		2.5						
^{137}Cs		7.5						
^{137}Cs		30						
^{137}Cs		*						
^{137}Cs		300						
^{137}Cs		*						
BG								

† Distance from detector reference centre to centre of source

- Measurement points to be chosen by participant

Date: _____

Response factor = _____
 Instrument reading - BG $\mu\text{Sv h}^{-1}$
 True dose above BG $\mu\text{Sv h}^{-1}$

Signature: _____