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REPORT

Third IRMF Intercomparison of Calibrations of Portable Gamma-Ray Dose-rate Monitors, 1998 - 1999

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Third IRMF Intercomparison of Calibrations of Portable Gamma-Ray Dose-Rate Monitors 1998 - 1999

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ABSTRACT

The Ionising Radiations Metrology Forum (IRMF) organised a third intercomparison of calibrations of gamma-ray dose-rate monitors in which nineteen establishments in the UK participated. The exercise involved the circulation of four gamma-ray monitors for calibration in the fields produced using ^{137}Cs, ^{60}Co, ^{241}Am and ^{226}Ra. The instruments used were an NE Technology Farmer Dosemeter NE 2570 with an NE 2575 600 cc ionisation chamber, a Mini-Instruments Mini 6-80 with MC71 probe, a Mini-Instruments Mini 6-90 with MC20 probe and a Mini-Instruments Mini-900D.

All results were submitted to the authors for analysis. Responses relative to 'true' air-kerma rate, as stated by the individual participants, were calculated. The results are compared and demonstrate generally satisfactory agreement between establishments.

CONTENTS

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 intercomparisons. Following the completion of the first and second IRMF intercomparisons of calibrations of portable gamma-ray dose-rate monitors [1,2] (McClure and Hunt, 1994; Lewis and McClure, 1998), the IRMF organised a third intercomparison that was carried out during 1998 and 1999. As before, the main objective was to assess the ability of calibration laboratories to perform routine calibrations of survey instruments in pursuance of Regulation 24 of the Ionising Radiations Regulations 1985 [3].

The present intercomparison involved the circulation of four radiation protection monitors for participants to calibrate in fields produced by up to a total of four 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 methods to calibrate the four transfer instruments as were routinely used within their establishment. All four monitors involved were area survey monitors. Details of all three IRMF intercomparisons are summarised in Appendix 1.

The calibration quantity for the present intercomparison was **air kerma**. All results were reported to the authors on a standard form for analysis and collation.

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

D R McClure	(NRPB Radiation Metrology, Chilton)
M P Pottinger	(BNFL, Berkeley)
A R Richards	(RPS, Leeds)
J Simpson	(AEA Technology, Winfrith)
J Wardle	(DRaStaC, AWE)
T T Williams	(NPL, Teddington)

The analysis was undertaken by the Secretary of the IRMF (V E Lewis, NPL), who was not involved in any of the calibrations carried out at NPL. Instrumentation matters were referred to and dealt with by D R McClure at NRPB.

Although there were more participants than in the second IRMF intercomparison, the measurement programme took a similar length of time to complete. The exercise started in late July 1998 and took about twelve months for all measurements, including checks, to be completed. The analysis, consultation and discussion of results took a further four months.

2 PARTICIPANTS

The nineteen establishments participating in the intercomparison 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 second intercomparison. Prior to this exercise, it was decided that participants would be allowed the individual choice of whether or not to disclose ownership of their results. All participants chose to disclose ownership. It was also agreed that participants would not be allowed to withdraw results.

3 PROTOCOL

A comprehensive protocol 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 (examples are shown in Figures 1, 2) and the pro-forma for reporting results was similar to that for the second intercomparison [2].

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

Participants' facilities

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

Sources and traceability;
- sources geometries,
- basis of the calibration,
- traceability to national standards.

3. 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. 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 Check source and background measurements

Participants supplied details of check source measurements for each instrument carried out before and after the measurements in the fields. Participants were asked to measure the background response for each monitor in each field before any calibration measurements were carried out. Results of check source and background measurements are summarised in Table 3.

3.3 Calibration measurements

The measured readings, uncorrected for background, temperature and pressure, were to be reported together with the uncertainties. Two uncertainties were reported; the first was the uncertainty associated with the derivation of the true air kerma rates used for the calibration measurements, and the second was that associated with the recorded instrument readings.

3.4 Ambient conditions

The ambient conditions, i.e., temperature and pressure during measurements, were requested in order to enable the organisers to apply a correction factor to the results for the Farmer plus ionisation chamber monitor system.

3.5 Ambient dose equivalent conversion factors

Participants were asked to state the values used for the air kerma to ambient dose equivalent conversion factors for each source, if the calibration factor was to be expressed in terms of ambient dose equivalent. All quoted a conversion coefficient of 1.74 Sv Gy^{-1} for ^{241}Am and 1.20 Sv Gy^{-1} for ^{137}Cs, as recommended by ICRU 47 [4], BCRU [5] and UKAS [6]. For ^{60}Co most participants used a value of 1.15 Sv Gy^{-1}, as recommended by UKAS [6], and three participants used 1.16 Sv Gy^{-1} as recommended by BCRU [5] and ICRU 47.

4 RADIATION FIELDS

Gamma-ray fields produced using ^{137}Cs and ^{241}Am sources were used by all participants. Eight participants used ^{60}Co gamma fields in addition and three used ^{226}Ra fields. In all, a range of gamma-ray air kerma rates from about 0.5 µGy h^{-1} to 10 mGy h^{-1} was covered. There were several selected rates for each radionuclide/monitor combination; the minimum and maximum specified rates varied from one to another (see Section 5 below). The use of ^{241}Am was normally restricted to lower dose rates.

All ^{137}Cs and ^{60}Co sources were capsular and collimated apart from one ^{60}Co source. The collimated beams were very similar geometrically; the beam diameter at one metre distance was generally in the range 16 cm to 35 cm. Full details of all sources are given in Table 1. Ten of the ^{241}Am sources were planar and nine were capsular. All but three planar sources were collimated. The collimated beams varied considerably geometrically; the beam diameter at one metre distance ranged from 14 cm to 133 cm.

All participants reported traceability of their ^{137}Cs, ^{241}Am and ^{60}Co air kerma rates to national standards. The ^{226}Ra fields were standardised using calibration factors interpolated from those for other fields, such as ^{137}Cs, ^{241}Am and ^{60}Co, that had traceability to national standards.

5 INSTRUMENTATION

Four different, routinely-used gamma-ray dose and dose-rate monitors, described below, were used as transfer instruments. In general, the electronics were not deliberately off-set to give readings that might not correspond to the true value of the incident radiation field. However, at least two monitors exhibited dose rate effects at some of the rates used, and these prevented the prediction of results at higher dose rates from those at lower rates. In order to have a more realistic exercise, the participants were asked to employ the same methods to calibrate the transfer instruments as were routinely used within their organisation.

5.1 NE 2570 Farmer with NE 2575 ionisation chamber

The NE Farmer with 600 cc ionisation chamber system was chosen because it was felt valuable to include a secondary standard device which would provide a good test of the accuracy of the reported air kerma rates. This system has a completely different mode of operation from the other monitors used in the intercomparison. It was not expected to exhibit kerma rate effects at the rates used in the exercise and has a flat energy characteristic. The monitor is manufactured by NE Technology Ltd†, and the unit used was kindly loaned by AEA Technology, Winfrith.

Calibrations were carried out using ^{137}Cs fields only (mainly to keep the measurements for all four monitors to a reasonable number) with air kerma rates ranging from 0.1 to 10 mGy h^{-1}.

† NE Technology Ltd, Bath Road, Beenham, Reading, Berkshire

5.2 Mini 900D

The Mini 900D (manufactured and loaned by Mini-Instruments Ltd[††]) was included because it could measure down to lower energies than the more conventional type of energy-compensated Geiger-Müller counter and would therefore be sensitive to scattered photons in the fields used by participants. The monitor is designed to realise the quantity *ambient dose equivalent* and is becoming increasingly popular. Unlike the other monitors, this is an analogue response device and it provides a test of the participants' ability to read the needle of a meter.

It can be used over a wide range of air kerma rates, and for lower rates than those at which the Farmer can be used. The selected target air kerma rates were 2.5 μGy h^{-1}, 7.5 μGy h^{-1} and 30 μGy h^{-1} for ^{241}Am; and ranged from 2.5 μGy h^{-1} to 800 μGy h^{-1} for both ^{137}Cs and ^{60}Co.

5.3 Mini 6-90 with MC20 probe

The Mini 6-90/MC20 monitor had performed well in the first IRMF intercomparison and could give a degree of cross-matching between the two exercises. The monitor is manufactured also by Mini-Instruments Ltd, and is based on an energy-compensated Geiger-Müller counter. It was used at the same air kerma rates as the Mini 900D and operated in the integrated count mode (without correction for the dead time). The monitor was loaned by NRPB Metrology.

5.4 Mini 6-80 with MC71 probe

It had been decided to include the Mini 6-80/MC71 environmental-level monitor primarily on account of NPL's new capability for calibrations in this area. The target air kerma rates ranged from 0.5 μGy h^{-1} to 50 μGy h^{-1} for ^{137}Cs. In addition, participants could use an ^{241}Am and/or a ^{226}Ra field at any air kerma rate that they preferred. Radium was included because many users considered it a good simulation of environmental spectra. Measurements were made in the count-integrate mode(without correction for the dead time). This monitor was also loaned by Mini-Instruments Ltd.

6. MEASUREMENTS

The transfer instruments, together with their check source jigs, were collected by NRPB and their operation checked. The instrumentation was then packaged and sent to the first participant. From then on participants were responsible for making their measurements and sending it to the next participants within a two-week slot. After every group of four participants the instrumentation was returned to NRPB for checking. 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.

Participants were asked to immediately confirm the correct operation of each instrument by making measurements using the check source and positioning jig provided. This was repeated upon completion of the intercomparison measurements. The measured values were compared with the expected readings as provided in the Protocol by the organisers and suspected malfunctions were reported back to NRPB.

Generally, all the monitors appeared to perform well throughout the intercomparison. NRPB reported no failures although minor mechanical adjustments to the Farmer system were required. No adjustments were necessary for the other monitors.

[††] Mini-Instruments Ltd, 15 Burnham Business Park, Springfield Road, Burnham-on-Crouch, Essex

7 ANALYSIS

Participants were asked 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. Few participants reported within this deadline and two took over three months to report. The results were analysed at NPL and tables of calibration factors were produced.

The obvious outlying calibration values were investigated by the NPL co-ordinator. One was confirmed as being due to a transcription error and adjusted accordingly. Two sets had to be changed for values at low air kerma rates because the participants concerned had reported total air kerma (ie. direct component from source plus background) instead of the direct source component only. No other values were changed. A few sets of results were incomplete (eg. some uncertainty values were not given) and sometimes the information on the facilities was incomplete.

A summary of the results in graphical form was distributed to all participants in August 1999. One participant repeated the measurements with one of the monitors in order to investigate a discrepancy. The results were discussed and observations were made at the intercomparison wash-up meeting held in November 1999.

8 RESULTS

8.1 Check source and background measurements

The check source and background measurement results, given in Table 3, show no significant trends. The standard deviations (given in parentheses) of the check source values are generally reasonable; overall there are two or three values outside two standard deviations.

8.2 Calibrations

The values obtained by the participants are summarised in Figures 4 to 22. For clarity, there are two types of figure. For the first type (designated *A*), the sets of absolute values for the measured calibrations, expressed in response per unit air kerma or (air kerma rate), are plotted against air kerma rate. Uncertainties are not shown. The values for the individual participants are denoted by different symbols for which the key is given in Figure 3. Where the participant used an air kerma rate other than a target value, the calibration value is plotted at the closest target rate for simplification.

In the second type of figure (designated type *B*), the results at a selected air kerma rate are normalised with respect to the (unweighted) mean for that rate and plotted against participating laboratory identified by a letter (see Figure 3 for key). The associated uncertainties are shown. These figures have identical formats, enabling easy comparison between results for the different monitor and field values. The air kerma rates selected were those for which there were the most values; these tended to be in the middle of the ranges used and therefore probably best reflected the most typical sets. These also tended to be the rates for which the spreads of calibration values were minimum. Because the participants did not all make measurements at every air kerma rate, using mean values was not practical.

Generally, the uncertainties for the air kerma rate components only are shown for all type B figures. The numerical values for these uncertainties, given in Tables 4 and 5 for the ^{137}Cs and ^{241}Am fields respectively, are those reported for the Farmer and Mini 6-90/MC20 calibrations respectively. In some cases the combined uncertainties (air kerma rate component combined with that due to the reading) are also shown for reasons explained below. These are shown as the outer bars, whereas those for the air kerma rate components appear as the inner bars.

NE 2570 Farmer with NE 2575 ionisation chamber

^{137}Cs calibrations (Figures 4, 5)

The measured calibration factor values, shown in Figure 4, display no trends with air kerma rate. The characteristics measured by most participants are flat with air kerma rate except for three sets which show large deviations, including one value which is about 10% higher than the mean. No explanation has been found for these. The other results fall within a band $\pm$ 6.5% around the mean. The lower NPL values are for kerma rates not used routinely for calibrations. The definitive NPL value, which is used for all customer calibrations is for 22 mGy h^{-1}; this is almost exactly in the middle of the spread of values.

The mean values for each participants set, normalised to the overall mean, are shown in Figure 5. (The outlier mentioned above is excluded and the mean value for NPL is taken as the value at 22 mGy h^{-1}). The standard deviation of the set of means is 2.5% (see Table 6). The uncertainties reported by participants for air kerma rate only (inner bars) and air kerma rate combined with reading (outer bars) are shown. The former range from less than 2% up to 10% (the high value is in fact that for an overall uncertainty). The uncertainty values reported for the readings of instrument response range from negligible to 5% plus two further values of 10% (see Table 4).

The mean values are consistent within the air kerma rate uncertainties alone except for those of four participants (A, H, I, N). The values for participants A (NRPB Northern) and H (RPII, Dublin) are consistent with the general consensus within the combined uncertainties. Those for participants I (Velindre Hospital) and N (RRPPS) are not.

Velindre Hospital carried out additional, subsequent measurements which had demonstrated that their values were too high on account of a small positioning error. It is possible that the relatively high RRPPS values may be due to their having a vertical source and that lead attenuators were used to vary the air kerma rate. (Gamma spectrometry has, however, demonstrated that the 662 keV beam is purer than for other laboratories.) The RRPPS values for the other monitors show values which tend to be higher than the general consensus.

8.4 Mini 6-90 with MC20 probe

^{137}Cs calibrations (Figures 6, 7)

The measured calibration factor values exhibit a clear trend with air kerma rate above 80 μGy h^{-1} which is clearly due to the dead time of the GM counter. Apart from the two outlying values at 80 μGy h^{-1}, which are unexplained and are thought to be unrelated, there are no obvious problems.
(Note: NRPB Scotland have since repeated their set of measurements and no discrepancies were observed. It is possible that the original problem was a transcription error.)

The trends and relative positions of participants were similar to those for the Farmer system. The normalised values at 30 μGy h^{-1} fall within a band of $\pm$ 5% and are nearly all consistent within the uncertainties for air kerma rate. The corresponding standard deviation of 3.3% is similar to that observed for the Farmer system.

The uncertainties reported for the response readings (Table 4) range from 0.4% to 10%, compared with the statistical uncertainty derived from the number of recorded events of 1.5%. For this monitor, these uncertainties have not been combined with those for air kerma rate.

^{241}Am calibrations (Figures 8,9)

The results for ^{241}Am calibrations have a larger spread than for those for ^{137}Cs. The measurements are for lower air kerma rates where no significant rate effects were expected - as shown by 8.4.1. The values lie within a band of about ± 10% apart from the high values of BNFL, Sellafield. This problem had already been suspected and was being investigated.

In contrast to the ^{137}Cs data, the normalised values at 30 μGy h^{-1} show clear inconsistencies, including the value noted above, within the reported uncertainties for air kerma rate. These are either the same as those reported for ^{137}Cs are slightly greater (compare Tables 4 and 5). The uncertainties for the response readings are also very similar, having the same unrealistically wide range of values. The standard deviation of 3.3% is twice that for ^{137}Cs calibrations at this air kerma rate.

^{60}Co calibrations (Figures 10, 11)

The measured calibration factor values exhibit a clear trend with air kerma rate above 80 μGy h^{-1} of a similar magnitude to that found in 8.4.1 above. The normalised values at 300 μGy h^{-1} are within about ± 3% of the mean, and are consistent within the reported uncertainties. The standard deviation of 1.8% is lower than that for ^{137}Cs, but no firm conclusions should be drawn from this since the number of participants is substantially fewer.

8.5 Mini 900D

^{137}Cs calibrations (Figures 12, 13)

The measured calibration factor values do not exhibit any clear trends with air kerma rate. The spreads were smallest at the medium air kerma rates. There were relatively large spreads at low air kerma rates (due to statistics) and at the higher air kerma rates. The latter was thought to be due to difficulties in reading the logarithmic scale. Most participants used closed circuit TV to observe the meter reading and any misalignment could cause errors due to parallax effects.

It is not clear why values of NI RPS at the higher rates appear to be high, although it was reported that the readings had been observed to increase with time, and also the check source reading was slightly high. No other participants reported the former effect. There were no problems with the NI RPS response values for other monitors at or near these air kerma rates with the other monitors. The RPII value at an air kerma rate of 660 μGy h^{-1} is also high and the response for AEA Technology, Harwell, was reported as off-scale at 800 μGy h^{-1}.

The normalised values for an air kerma rate of 30 μGy h^{-1} lie within a 15% band. The standard deviation (4.6%) is greater than that of the Farmer system; this is reflected by the reported uncertainties for the meter readings being greater, ranging from 2% to about 20%. Within the combined uncertainties nearly all values are consistent. The inconsistencies are probably due to underestimation of the uncertainty in reading the meter rather than an air kerma rate inconsistency.

8.5.2 ^{241}Am calibrations (Figures 14, 15)

The calibration factors were measured over the lower air kerma rates of those used for ^{137}Cs. The spreads of the ^{241}Am values are larger at 7.5 and 30 μGy h^{-1}; this is correlated with the wider spread observed for the Mini 6-90/MC20 monitor values. (The situation is reversed at 2.5 μGy h^{-1}, but there are fewer ^{241}Am values.)

There is also an unexplained outlier, albeit at a relatively high rate at which only two laboratories had made measurements. (This was an NPL value, but it was not at the air kerma rate used for calibrations. NPL did not normally calibrate dosemeters such as the Mini 900D and therefore should not be regarded as having a special status for any dosemeter in this exercise, with perhaps the exception of the Farmer.) There is no problem at this air kerma rate with the Mini 6-90/MC20. The BNFL, Sellafield, values are again high (as in 8.4.2 above).

The normalised values for an air kerma rate of 30 μGy h^{-1} are in a 20% band, with a standard deviation of 6.0%. There are several inconsistencies within the combined uncertainties.

^{60}Co calibrations (Figures 16, 17)

The calibration factor value characteristics measured by participants appear to be flat below 300 μGy h^{-1}. The normalised values show considerable variation of up to $\pm$ 15% of the mean, which is inconsistent in respect of the reported air kerma uncertainties.

8.6 Mini 6-80 with MC71 probe

^{137}Cs calibrations (Figures 18, 19)

The measured calibration values exhibit a clear trend with air kerma rate above 80 μGy h^{-1} due to the dead time of the GM tube. The results are similar to those for the Mini 6-90/MC20 for ^{137}Cs except that they are for lower air kerma rates. Originally both AEA Tech (Winfrith) and AEA Tech (Harwell) had low values at low kerma rates. After some discussion, it was clear that this was at least partly due to their practice of quoting the overall air kerma rate (direct field plus background) as the "true" air kerma rate instead of quoting just the direct field. The results shown are re-evaluated values.

The spread in the normalised values at 5 μGy h^{-1} was low, with a standard deviation similar to that for the Farmer system. This is a reflection of the high sensitivity of the monitor and the consequent good counting statistics.

^{1}Am calibrations (Figures 20, 21)

The measured calibration values are limited to one per participant at the air kerma rate of the participant's choice. This resulted in a range of air kerma rates of almost 100:1. To give a more accurate idea of their consistency the values were corrected for kerma rate effects using the value for the dead time derived for the ^{137}Cs measurements and normalised to the mean of these corrected values. All values lie within a band of about 18% and most are consistent within the reported uncertainties for air kerma rate.

^{226}Ra calibrations (Figure 22)

The three values measured for ^{226}Ra are shown as solid symbols. For ease of comparison they were corrected for kerma rate effects using the variation observed for the ^{137}Cs measurements and are plotted around an air kerma rate of 1 μGy h^{-1} (open symbols). The corrected values are just about consistent within the reported air kerma uncertainties and would be consistent when allowance is made for the components due to the response measurement and to the rate corrections. DRaStaC have since re-validated their standard, and this would give a closer result, but it was agreed that the reported value will remain.

9 DISCUSSION

9.1 Uncertainties

The values reported for the uncertainties for the air kerma rates vary widely both for the ^{137}Cs fields (from the Farmer system results) and for ^{241}Am fields (Mini 6-90/MC20). Generally, within any laboratory, these values vary very little (if at all) with air kerma rate and monitor; the values in Tables 4 and 5 are very typical. Some of these are so small that they are in fact comparable to those for primary standards.

The values reported for the uncertainties in the monitor readings also vary widely from one participant to another, for all four monitors. This demonstrates that there are inconsistencies in the approaches used for estimating and treating such uncertainties. Some participants carefully calculated values for all situations, whereas others adopted a universal percentage value for each monitor or even for all monitors. Some uncertainty values for Mini 6-90/MC20 and Mini 6-80/MC71 are even lower than the theoretical statistical uncertainty derived from the number of events observed.

9.2 ^{137}Cs calibrations

The results suggest that there is good consistency in the realisation of ^{137}Cs air kerma 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 analogue, needle-reading monitor with a logarithmic scale.

9.3 ^{241}Am calibrations

The Farmer system is used as a secondary standard instrument and as such would be expected to give better results than the other monitors. With hindsight, it seems unfortunate that it had not been used for ^{241}Am calibrations. The Mini 6-80/MC71 results are the most consistent of those of the monitors used.

The ^{241}Am values have a wider spread than for ^{137}Cs (and ^{60}Co) for the three monitors where both nuclide fields were used. This was also true for the previous intercomparison exercises. It is thought to be due to the greater variation of efficiency with energy in the ^{241}Am energy region and the consequent greater sensitivity to scattered radiation. There is no firm evidence of differences between the values from collimated and uncollimated sources.

9.4 ^{60}Co calibrations

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.

9.5 ^{226}Ra calibrations

Although there are no primary standards available for ^{226}Ra, the agreement between the three participants is good.

9.6 Length of intercomparison

The measurements by the nineteen participants plus the six checks by NRPB took almost a year to complete. A longer period would not be desirable. Scheduling periods of less than two weeks per participant or check would not be realistic - arrangements for the transportation of the instrumentation took longer than expected. In any future intercomparison the number of participants should be kept to twenty or less unless the amount of measurements is reduced.

Participants had been taking up to three months to submit their results for what should have been fairly routine calibrations. This is considered to be excessive - one month (from the end of the measurements) should be adequate. The times taken could be reported as well.

9.7 Reporting of results

Participants submitted their results in the form of air kerma rate with the corresponding reading of the instrument under calibration, leaving the organisers to calculate the calibration values. This had been requested by the Working Party who had planned the exercise, and it followed the practice of the previous intercomparisons. If the participants had been obliged to calculate the calibration values themselves (as they would for routine calibrations), they probably would have spotted the obvious discepancies and investigated the cause immediately. (In fact, many participants did calculate the calibration values there and then.) The dosimetry was generally accurate; the outliers had probably crept in due to failures in quality control. It is felt desirable for participants in the next intercomparison to be asked to calculate their calibration values. The organisers would still be expected to check the calculated values.

The intercomparison was supposed to be of routine calibrations, and participants were expected to report their results within four weeks. Most took longer than this; two took more than three months to report. In future, the reporting times of those laboratories taking longer than a specified time without good reason could also be reported.

10 CONCLUSIONS

The intercomparison was useful, demonstrating that the overall accuracy is satisfactory and that the calibrating facilities could meet the requirements of NPL Good Practice Guide 14 [7]. It is desirable to hold such exercises periodically. The next intercomparison could usefully build on the experience of the present one.

In the meantime, some of the problems unearthed could be investigated.-

- The consistency of the ^{241}Am measurements is not as good as would be expected from the reported uncertainties in the air kerma rates;

- The treatment and estimation of uncertainties varied greatly from one laboratory to another and resulted in a very wide range of quoted uncertainties values. More care and effort needs to be taken in this area and central guidance is required to improve the treatment of uncertainties and the overall consistency.

The exercise has also demonstrated that traceability using appropriate GM-counter based monitors could be achieved with a similar accuracy to that of ionisation chambers.

The policy of disclosure of identity of the results did not appear to deter participation. It is possible that it improved accuracies.

11 ACKNOWLEDGEMENTS

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	Report	Participants	Instruments	Nuclides	Dose rate ranges
First intercomparison April 1992 to Dec 1992	June 1993	12	NE PDM1B	^{137}Cs, ^{241}Am, ^{60}Co	2.5 μGy h^{-1} to 200 mGy h^{-1}
			Mini 6-90 / MC 20	^{137}Cs, ^{241}Am, ^{60}Co	
Second intercomparison June 1995 to May 1996	December 1997	16	NE PDM1B	^{137}Cs, ^{241}Am, ^{60}Co	2.5 μGy h^{-1} to 200 mGy h^{-1}
			Minirad 1000	^{137}Cs, ^{241}Am, ^{60}Co	
			Mini 900 / 44A	^{137}Cs only	
			EPD	^{137}Cs only	
Third intercomparison July 1998 to July 1999	January 2000	19	Mini 6-80 / MC71	^{137}Cs, ^{241}Am, ^{226}Ra	0.5 to 50 μGy h^{-1}
			NE 2570 Farmer & 600 cc chamber	^{137}Cs only	0.1, 0.5, 1, 10 mGy
			Mini 900D	^{137}Cs, ^{241}Am, ^{60}Co	2.5 to 800 μGy h^{-1}
			Mini 6-90 / MC 20	^{137}Cs, ^{241}Am, ^{60}Co	2.5 to 800 μGy h^{-1}

APPENDIX 1 IRMF INTERCOMPARISONS OF CALIBRATIONS OF GAMMA-RAY DOSE-RATE METERS

APPENDIX 2 PARTICIPANTS

(In alphabetical order)

AEA Technology (Harwell Laboratory), Harwell	R Bosley
AEA Technology (Winfrith Laboratory), Winfrith	J Simpson
British Nuclear Fuels plc, Sellafield	R McConnell
BNFL Magnox Generation, Berkeley	J Ford
Defence Radiological Standards Centre, AWE, Aldermaston	J Wardle
DERA Radiological Protection Service, Gosport	J T B Bennett
Guy's and St Thomas' Hospital Trust, London	D R 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	R Wheelton
National Radiological Protection Board Southern Centre, Chilton	M Potter
NE Technology Ltd, Beenham	J Barnes
Northern Ireland Radiation Protection Service, Belfast	K Cranley
Radiation Protection Institute of Ireland, Dublin	S Somerville
Radiation Protection Service, University of Leeds, Leeds	A G Richards
Radiation Protection Service, Velindre Hospital, Cardiff	D W Thomas
Regional Radiation Physics & Protection Service, Edgbaston	D Peach

APPENDIX 3 SCHEDULE OF MEASUREMENTS

July 1998	Check	NRPB Radiation Metrology, Chilton
August	A	NRPB Northern Centre, Leeds
August	B	Guy's & St Thomas' Hospital
September	C	AEA Technology, Winfrith
September	D	NRPB Southern Centre, Chilton
September	Check	NRPB, Radiation Metrology, Chilton
October	E	NRPB Radiation Metrology, Chilton
October	F	RPS Leeds
November	G	Northern Ireland RPS, Belfast
November	H	RP Institute of Ireland, Dublin
December	Check	NRPB Radiation Metrology, Chilton
December	I	RPS, Velindre Hospital, Cardiff
January, 1999	J	NPL, Teddington
January	K	Johnson Controls, Dounreay
February	L	DERA, Gosport
February	Check	NRPB Radiation Metrology, Chilton
March	M	BNFL, Sellafield
March	N	RRPPS, Edgbaston
April	O	AEA Harwell
April	Check	NRPB Radiation Metrology, Chilton
May	P	DRaStaC, AWE
May	Q	NE Technology
June	R	BNFL, Berkeley
June	S	NRPB Scotland, Glasgow
July	Check	NRPB Radiation Metrology, Chilton

The periods indicated are approximate.

Table 1 Details of radiation fields

	Cs-137		Am-241		Co-60		Ra-226	
	Diameter at 1 m	Minimum diameter	Diameter at 1 m	Minimum diameter	Diameter at 1 m	Minimum diameter	Diameter at 1 m	Minimum diameter
NRPB Northern Centre	30	12 @ 41	30	9 @ 29				
Guy's & St Thomas', London	4.8 to 48	14 @ 29	4.8 to 48	16 @ 100				
AEA Technology, Winfrith	35	35 @ 129	40 *	40 @ 209	35	35 @ 217		
NRPB Southern Centre	30	19 @ 42	30	11 @ 29				
NRPB Radiation Metrology	36	63 @ 175	133 *	100 @ 75	36	54 @ 150	36	90 @ 250
RPS, University of Leeds	16	@ 147	39 *	@ 148	14	@ 132		
Northern Ireland RPS	38	15 @ 40	38	16 @ 42				
RPI of Ireland, Dublin	24	48 @ 200	40	45 @ 150				
RPS, Velindre, Cardiff	35	28 @ 80	32.5	15 @ 40				
NPL, Teddington	20	40 @ 200	40 *	40 @ 100	20	40 @ 200		
Johnson Controls, Dounreay	21	21 @ 100	20 *	35 @ 167	21	13 @ 62		
DERA RPS, Alverstoke	22.5	17 @ 84	20 *	16 @ 75	22.5	16 @ 75		
BNFL plc, Sellafield	21	26 @ 122	17.5 *	37 @ 212	21	14 @ 67		
RRPPS, Edgbaston	18	18 @ 100	15	20 @ 130				
AEA Technology, Harwell	21	23 @ 108	Uncoll'd *	n/a				
DRaStaC, Aldermaston	16	30 @ 136	25 *	25 @ 100			16	40 @ 420
NE Technology Ltd	21	18 @ 85	Uncoll'd *	n/a	21	14.5 @ 69		
BNFL plc, Berkeley	Uncoll'd	n/a	Uncoll'd *	n/a			Uncoll'd *	n/a
NRPB Scotland	17	17 @ 100	60 *	60 @ 100				

The ^{241}Am sources designated by an asterisk (*) are planar. **All dimensions and distances are in cm.**

Table 2 Dimensions of facilities

	Room length	Distance of source from wall	Room width	Distance of source from wall	Room height	Height of source from floor
NRPB Northern Centre	6.3	1.3	3.3	1.3	3.5	1.3
Guy's & St Thomas', London	5	0.4	2	0.4	2.0	1.1
AEA Technology, Winfrith	7	2	7	2	4.5	1.5
NRPB Southern Centre	5.6	1.4	3.5	1.8	2.6	1.3
NRPB Radiation Metrology	10	2.0	5.3	2.6	2.7	1.4
RPS, University of Leeds	5	0.8	1.5	0.8	3	1.2
Northern Ireland RPS	6.5	0.4	3.5	1.4	3.3	1.5
RPI of Ireland, Dublin	5.4	0.5	3.6	1.8	2.4	1.1
RPS, Velindre, Cardiff	7.7	1.0	2.5	1.3	3.0	1.1
NPL, Teddington	8	0.5	3	1.5	3	1.1
Johnson Controls, Dounreay	9.5	3.1	3.6	1.8	3.3	1.5
DERA RPS, Alverstoke	8.0	1.5	3.5	1.8	3.0	1.1
BNFL plc, Sellafield	7.0	1.5	3.6	1.4	3.1	1.5
RRPPS, Edgbaston (^{241}Am source)	4.7	0.3	3.3	1.6	3.1	1.2
AEA Technology, Harwell	9	1.2	6	2.1	8	1.1
DRaStaC, Aldermaston	7	1.5	6	2.5	5	1.5
NE Technology Ltd	9.5	2.5	4.6	1.7	3.0	1.5
BNFL plc, Berkeley	8	1.5	8	2.5	3	1.4
NRPB Scotland	6.5	0.7	3.2	1.6	3.1	1.0

All dimensions are expressed in metres.

Table 3 Check source and background measurements

	Farmer & 600 cc chamber #		MINI 900 D	
	Source (nC)	Background (nC)	Source (µSv/h)	Background (µSv/h)
NRPB Northern Centre	9.85	0.006	80	0.2
Guy's and St Thomas'	9.75	0.006	80	0.1
AEA Tech, Winfrith	9.77	0.003	80	0.1
NRPB Southern Centre	10.03	0.003	80	0.1
NRPB Radiation Metrology	9.97	0.003	80	0.15
RPS, University of Leeds	9.89	0.000	80	0.1
Northern Ireland RPS	9.84	0.000	85	0.3
RPI of Ireland, Dublin	9.91	0.000	85	0.1
Velindre Hospital, Cardiff	9.82	0.006	81.5	0.11
NPL, Teddington	9.88	0.005	80 - 85	0.1
Johnson Controls, Dounreay	9.86	0.000	80	0.1
DERA, Alverstoke	9.96	0.006	81.5 - 83.5	0.14
BNFL plc, Sellafield	9.88	0.006	82	0.3
RRPPS, Edgbaston	9.82	0.000	80	0.2
AEA Tech, Harwell	9.59	0.003	85	0.1
DRaStaC, Aldermaston	9.77	0.000	80	0
NE Technology Ltd	9.81	0.000	82 - 83	0.2
BNFL plc, Berkeley	9.71	0.000	80	0.2
NRPB Scotland	9.63	-	-	-
MEAN (1σ)	9.83 (0.11)			

\# Readings normalised to 600 s

The source measurement responses are the means of values taken before and after the calibrations.

Table 3 Check source and background measurements continued

	MINI 6-80/MC 71			MINI 6-90/MC 20	
	Source	Background	Source corrected	Source	Background
NRPB Northern Centre	47.8	2.3	45.5	138.2	0.3
Guys' and St Thomas'	47.1	1.2	45.8	139.9	0.2
AEA Tech, Winfrith	47.0	1.7	45.3	138.4	0.3
NRPB Southern Centre	46.8	1.5	45.3	138.7	0.3
NRPB Radiation Metrology	47.4	1.5	45.9	138.3	0.3
RPS, University of Leeds	47.7	2.1	45.6	138.2	0.4
Northern Ireland RPS	47.8	2.3	45.5	139.0	0.3
RPI of Ireland, Dublin	46.8	1.6	45.2	137.7	0.3
Velindre Hospital, Cardiff	47.5	2.0	45.5	136.5	0.3
NPL, Teddington	47.8	1.4	46.4	136.4	0.3
Johnson Controls, Dounreay	48.0	2.5	45.5	136.9	0.4
DERA, Alverstoke	47.2	2.1	45.0	133.7	0.3
BNFL plc, Sellafield	48.3	4.7	43.7	134.7	0.5
RRPPS, Edgbaston	48.5	2.5	46.0	134.7	0.5
AEA Tech, Harwell	47.3	1.9	45.4	136.0	0.3
DRaStaC, Aldermaston	48.4	2.3	46.1	135.0	0.3
NE Technology Ltd	47.4	1.7	45.7	133.9	0.3
BNFL plc, Berkeley	46.3	1.5	44.8	134.9	0.3
NRPB Scotland	47.9	3.0	44.9	134.4	0.4
MEAN (1σ)			45.4 (6)	136.6 (1.9)	

Responses are count rates (s^{-1})

The source measurement responses are the means of values taken before and after the calibrations.

Table 4 Reported uncertainties for measurements in ^{137}Cs fields

	Air kerma rate (%)	Uncertainty reported for monitor reading (%)			
Monitor	Farmer	Farmer	Mini 6-90/ MC20	Mini 900D	Mini 6-80/ MC71
Air kerma rate ($\mu Gy\ h^{-1}$)		Mean	30	30	5
Statistical uncertainty		n/a	1.5	n/a	1.3
NRPB Northern Centre	1.7	10	10	10	10
Guy's & St Thomas' London	10	5	2	17	2
AEA Technology, Winfrith	3	1	1.5	15	1.5
NRPB Southern Centre	3.5	- -	- -	20	- -
NRPB Radiation Metrology	3	2	2	10	2
RPS, University of Leeds	5	1.5	1.5	17	1.2
Northern Ireland RPS	3.3	3.5	3.6	11	3.8
RPII, Dublin	3	0.2	0.6	5.3	0.2
RPS Velindre, Cardiff	1.8	0.1	0.8	3	0.8
NPL, Teddington	1.7	2	4	15	3
Johnson Controls, Dounreay	4	3	3	10	3
DERA RPS, Alverstoke	4	- -	- -	10	- -
BNFL plc, Sellafield	5	5	5	20	5
RRPPS, Edgbaston	4	1	2	4	2
AEA Technology, Harwell	3	1.5	1	2	1
DRaStaC, Aldermaston	3	4	4	10	3
NE Technology Ltd	5	0.2	2	10	2
BNFL plc, Berkeley	3	3	1.5	15	1.4
NRPB Scotland	5	10	10	10	10

The air kerma rates selected are those given in Figures 5, 7, 13 and 19.

Typical values are given for the uncertainties for the air kerma rates. In practice, these may vary from one air kerma rate to another in the facility concerned.

The statistical uncertainties are derived from the square root of the number of recorded events multiplied by a k-factor of 2.0

Table 5 Reported uncertainties for measurements in ^{241}Am fields

	Air kerma rate (%)	Uncertainty reported for monitor reading (%)		
Monitor	Mini 6-90/ MC20	Mini 6-90/ MC20	Mini 900D	Mini 6-80/ MC71
Air kerma rate (μGy h^{-1})		30	30	various
Statistical uncertainty		1.5	n/a	0.5 - 2.0
NRPB Northern Centre	1.7	10	10	10
Guy's & St Thomas' London	10	2	12	2
AEA Technology, Winfrith	5	1.5	15	1.0
NRPB Southern Centre	3.5	- -	10	- -
NRPB Radiation Metrology	3	2	10	2
RPS, University of Leeds	5	1.4	18	1.6
Northern Ireland RPS	3.3	3.3	15	3.5
RPII, Dublin	3	0.7	4	0.3
RPS Velindre, Cardiff	1.8	1.2	4.5	0.8
NPL, Teddington	1.7	3	10	2
Johnson Controls, Dounreay	4	3	10	3
DERA RPS, Alverstoke	4	- -	10	- -
BNFL plc, Sellafield	5	5	20	5
RRPPS, Edgbaston	4	2	7	2
AEA Technology, Harwell	3	1	2	1
DRaStaC, Aldermaston	3	4	10	3
NE Technology Ltd	6	2	10	2
BNFL plc, Berkeley	3	1.5	15	0.8
NRPB Scotland	5	10	10	10

The air kerma rates selected are those given in Figures 9, 15 and 21

Typical values are given for the uncertainties for the air kerma rates. In practice, these may vary from one air kerma rate to another in the facility concerned.

The statistical uncertainties are derived from the square root of the number of recorded events multiplied by a k-factor of 2.0

Table 6 **Standard deviations of sets of calibration values at selected air kerma rates**

	FARMER & 600 cc chamber	Mini 900D	Mini 6-90 & MC 20	Mini 6-80 & MC 71
Cs-137	mean **2.5 %** (19)	(30 μGy h^{-1}) **4.6 %** (19)	(30 μGy h^{-1}) **3.3 %** (19)	(5 μGy h^{-1}) **2.5 %** (19)
Am-241		(30 μGy h^{-1}) **6.0 %** (19)	(30 μGy h^{-1}) **6.7 %** (19)	(corrected) **3.8 %** (19)
Co-60		(300 μGy h^{-1}) **10.3 %** (8)	(300 μGy h^{-1}) **1.8 %** (8)	
Ra-226				(corrected) **7.3 %** (3)

Air kerma rates and numbers of participants are given in parentheses

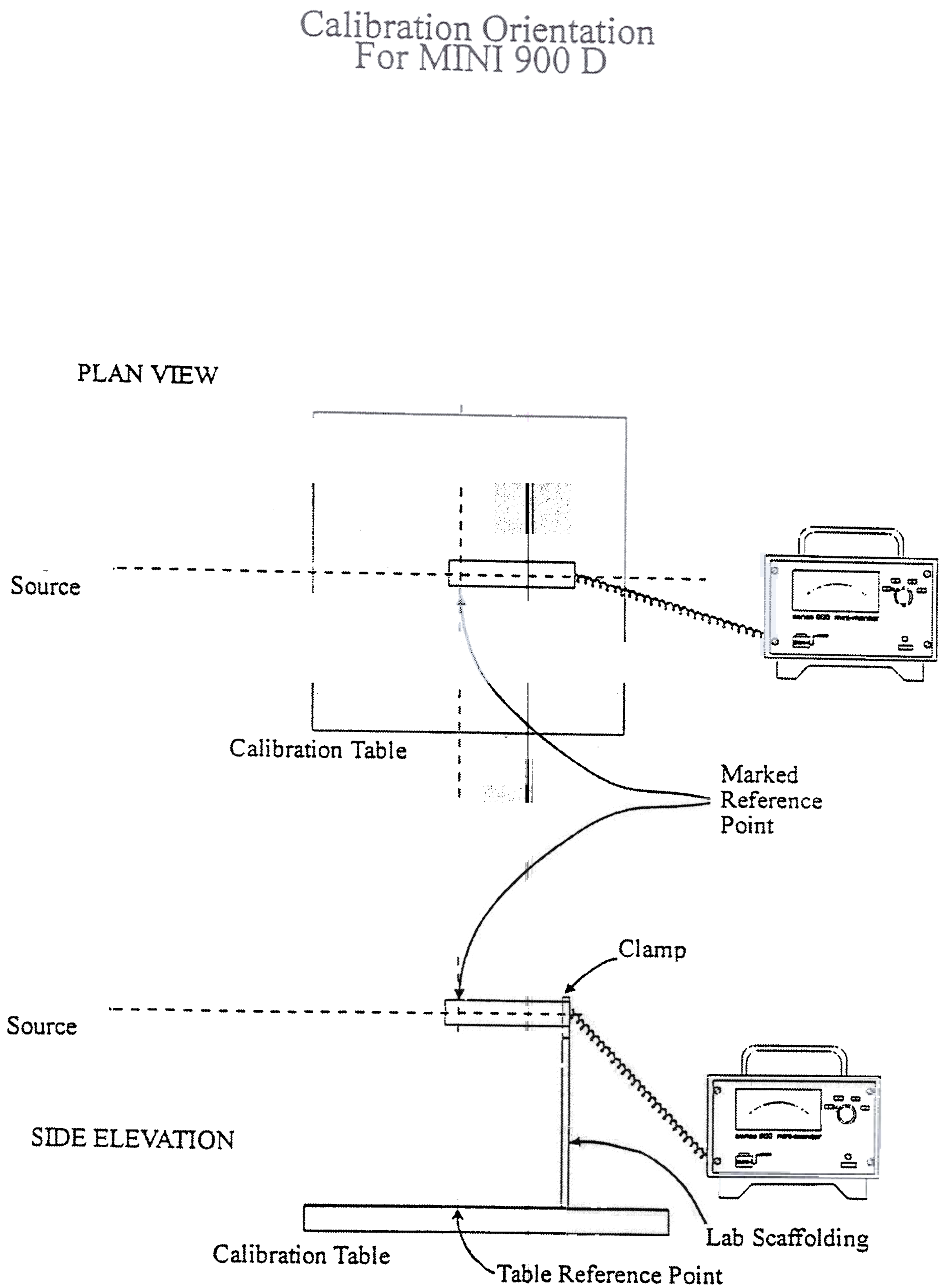
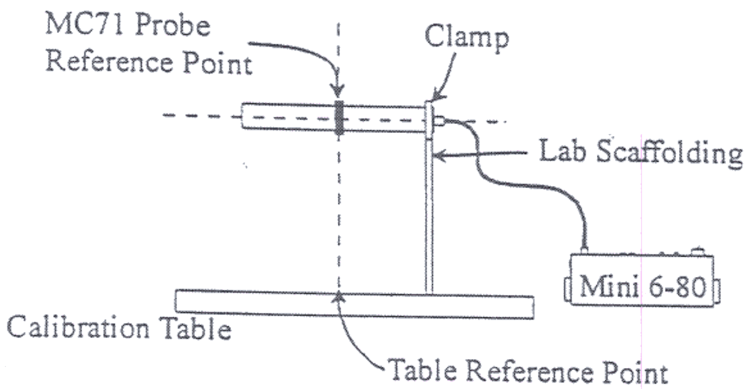
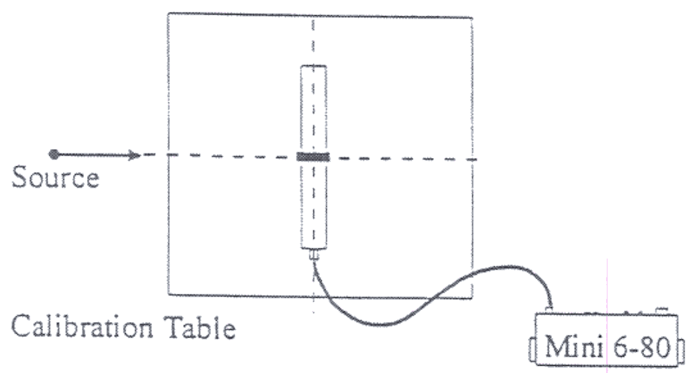


Figure 1 Calibration orientation for Mini 900D

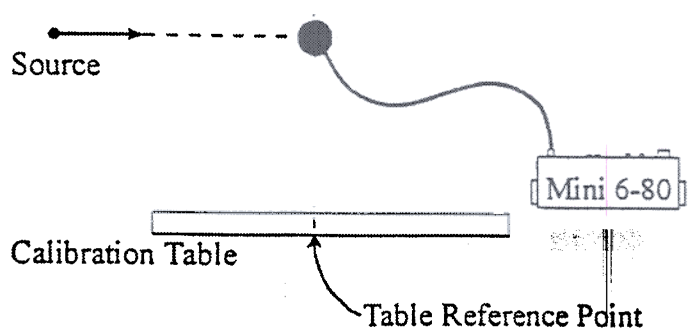
Calibration Orientation For MINI 6-80 With MC71 Probe



FRONT ELEVATION



PLAN VIEW



SIDE ELEVATION

Figure 2 Calibration orientation for Mini 6-80 with MC71 probe

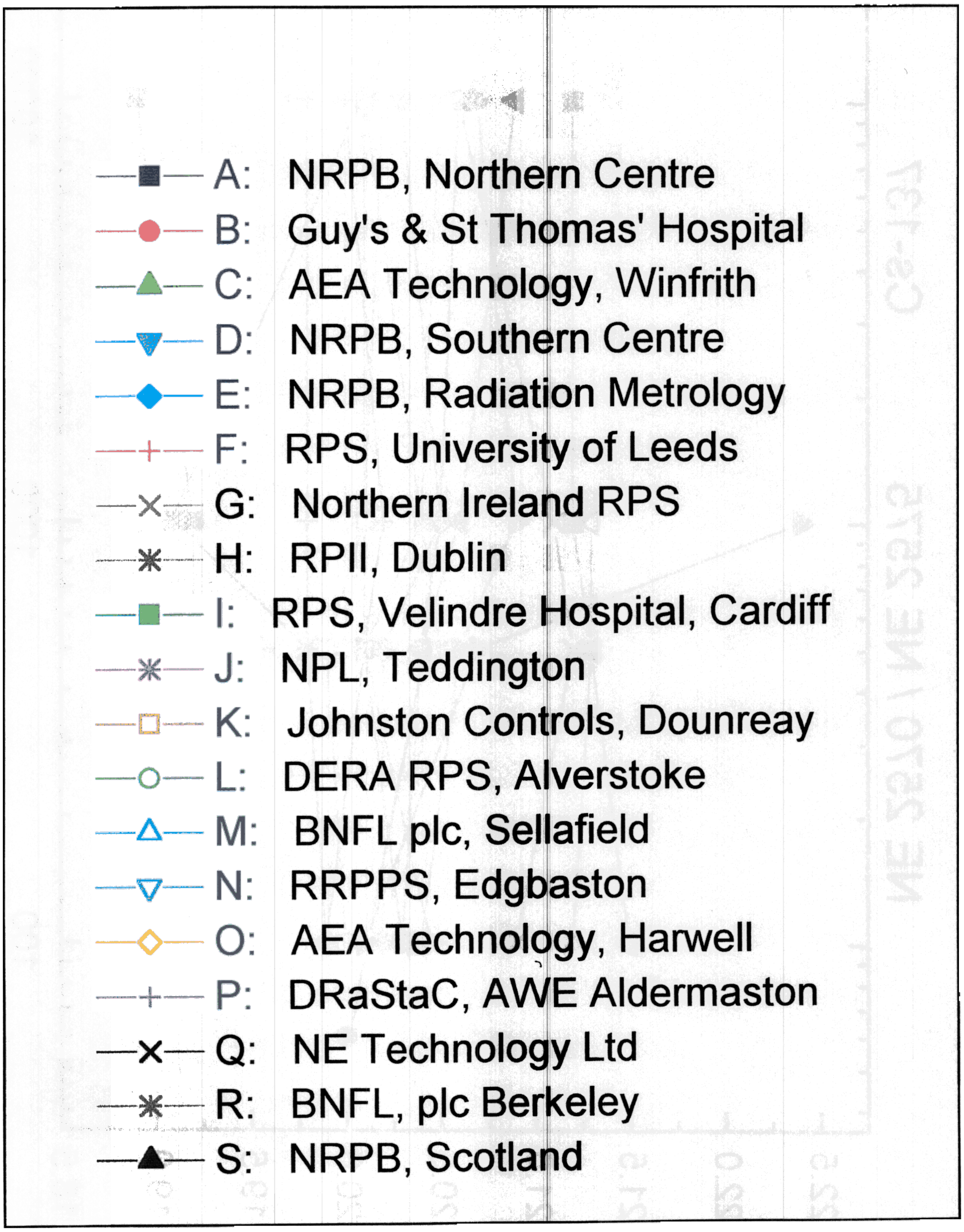


Figure 3 Key to following figures of measured calibration values

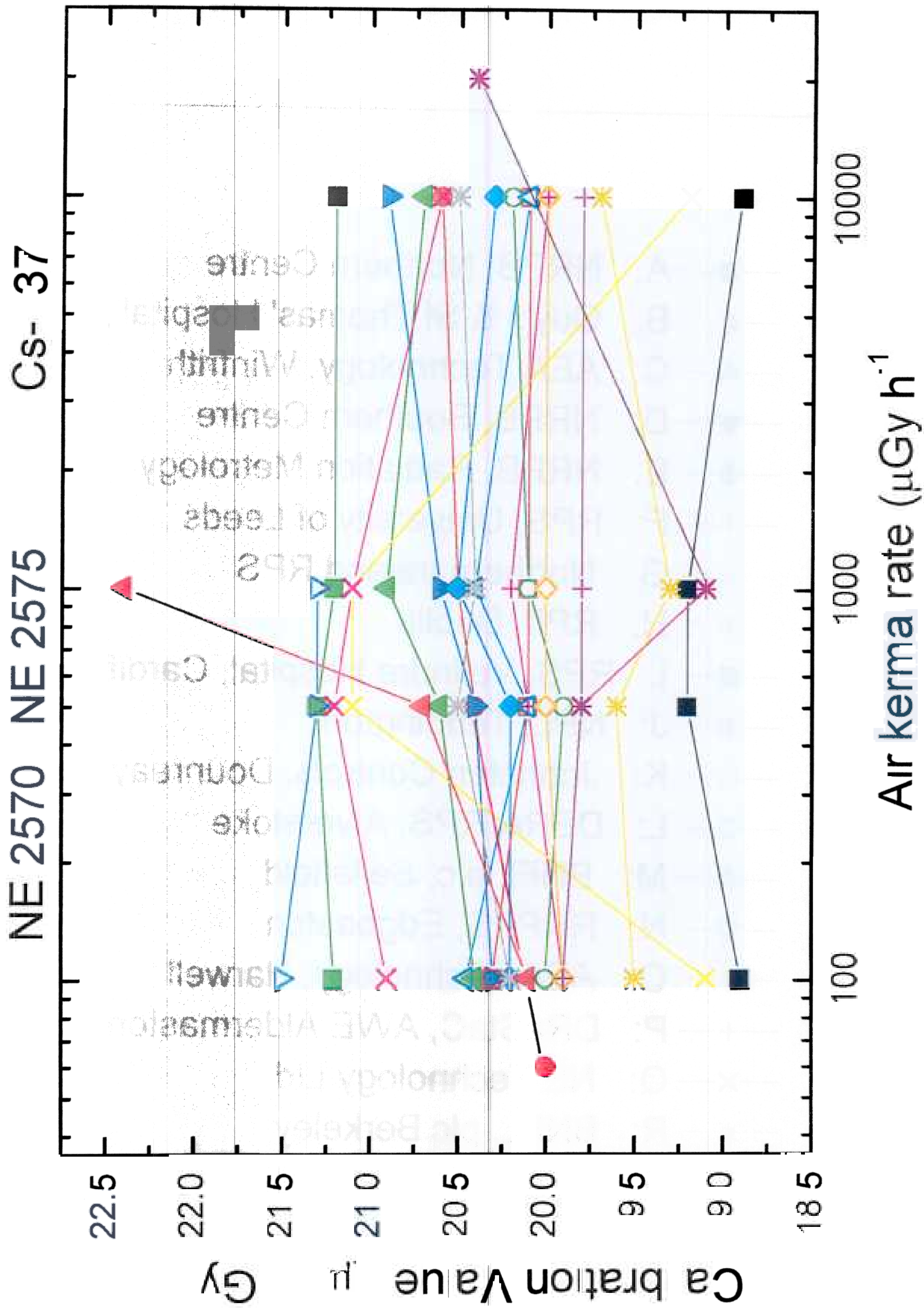


Figure Cs calibrations of NE 2570 Farmer NE 2575 Chamber

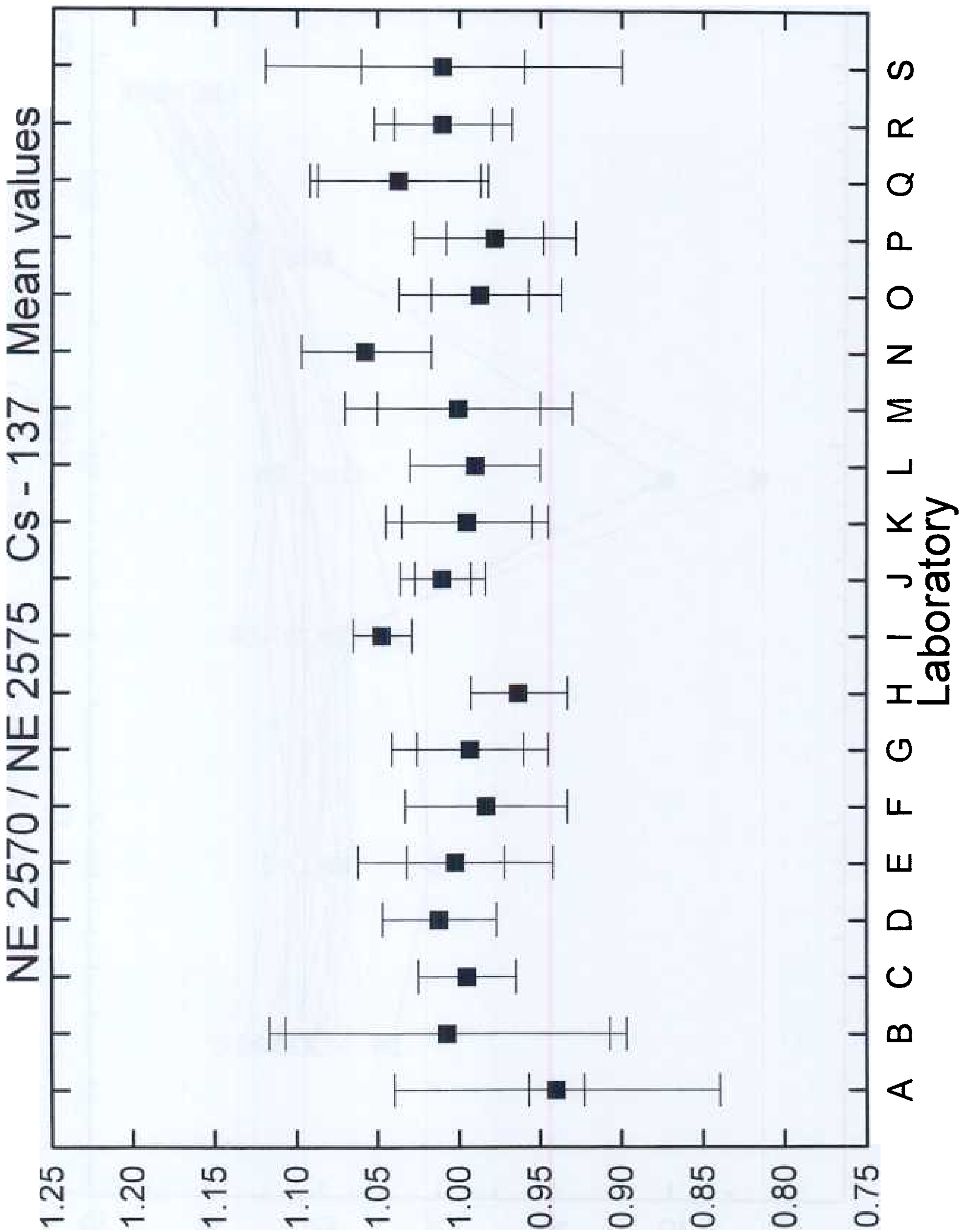


Figure 5 **^{137}Cs calibrations of NE 2570 Farmer / NE 2575 Chamber averaged over different air kerma rates and normalised to mean calibration value**

The inner uncertainty bars show the air kerma rate uncertainties and the outer bars show the combined air kerma rate plus monitor reading uncertainties.

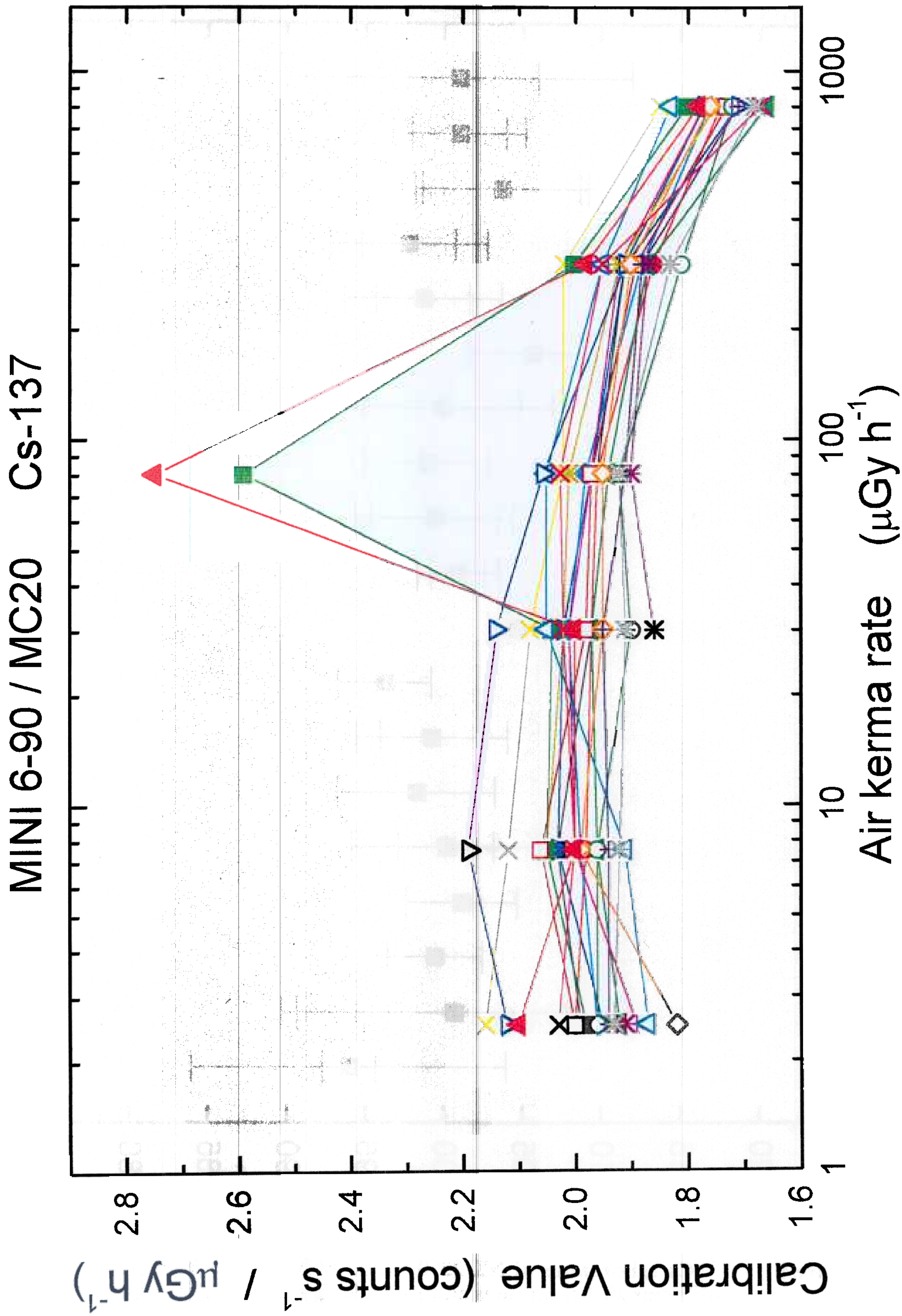


Figure 6 ^{137}Cs calibrations of Mini 6-90/MC20

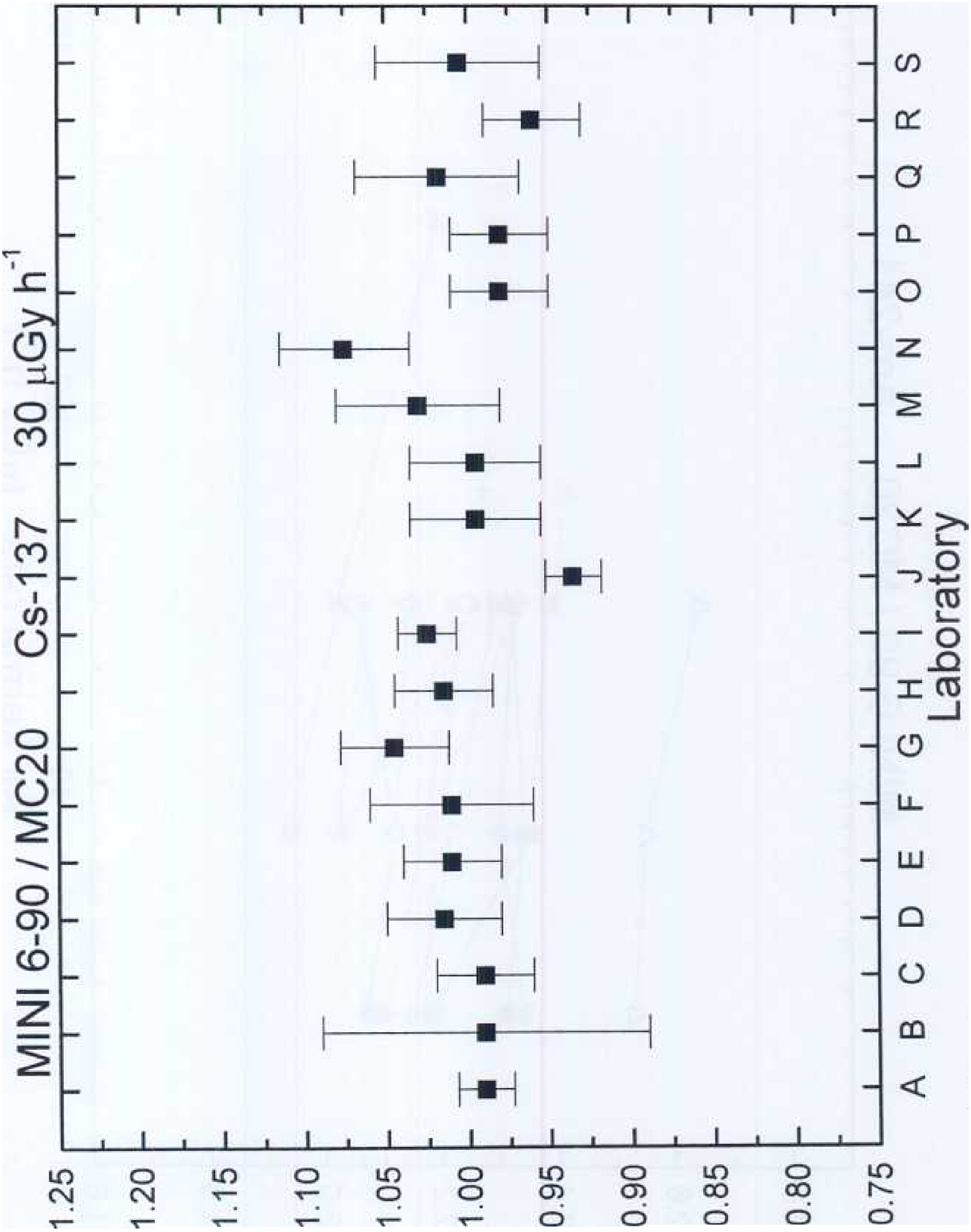


Figure 7 ^{137}Cs calibrations of Mini 6-90/MC20 at 30 μGy h^{-1}; normalised values

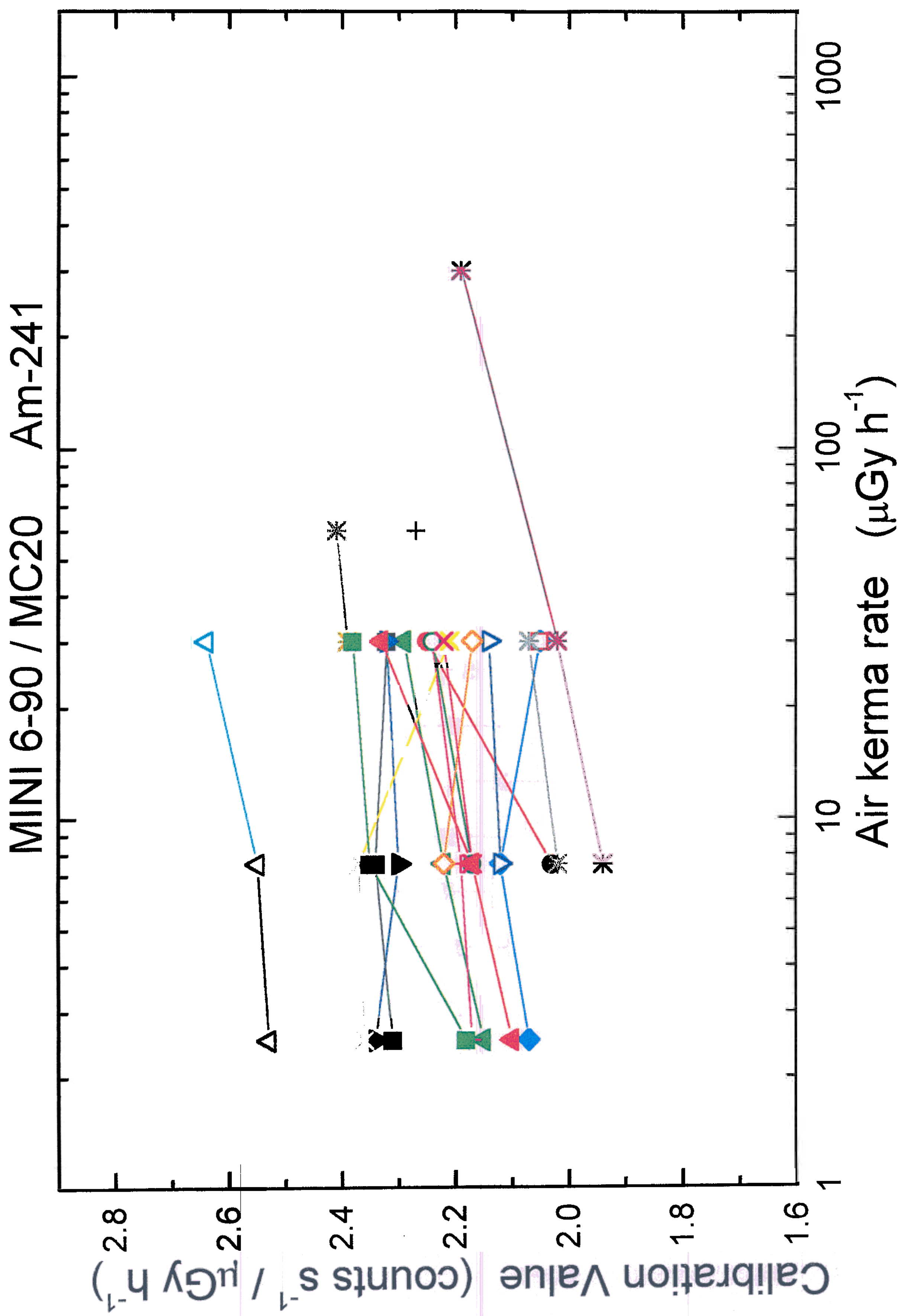


Figure 8 ^{241}**Am calibrations of Mini 6-90/MC20**

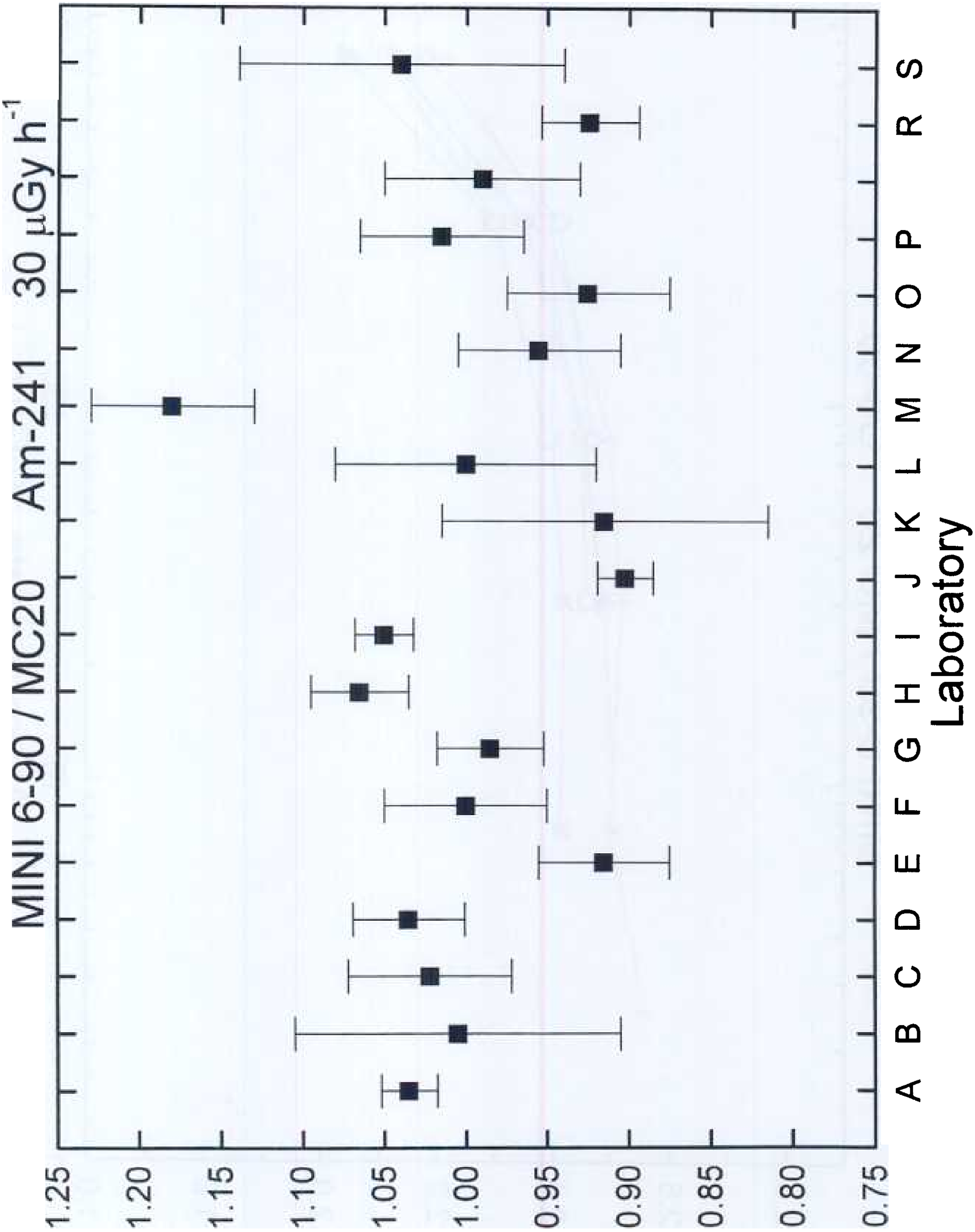


Figure 9 ^{241}Am calibrations of Mini 6-90/MC20 at 30 μGy h^{-1}; normalised values

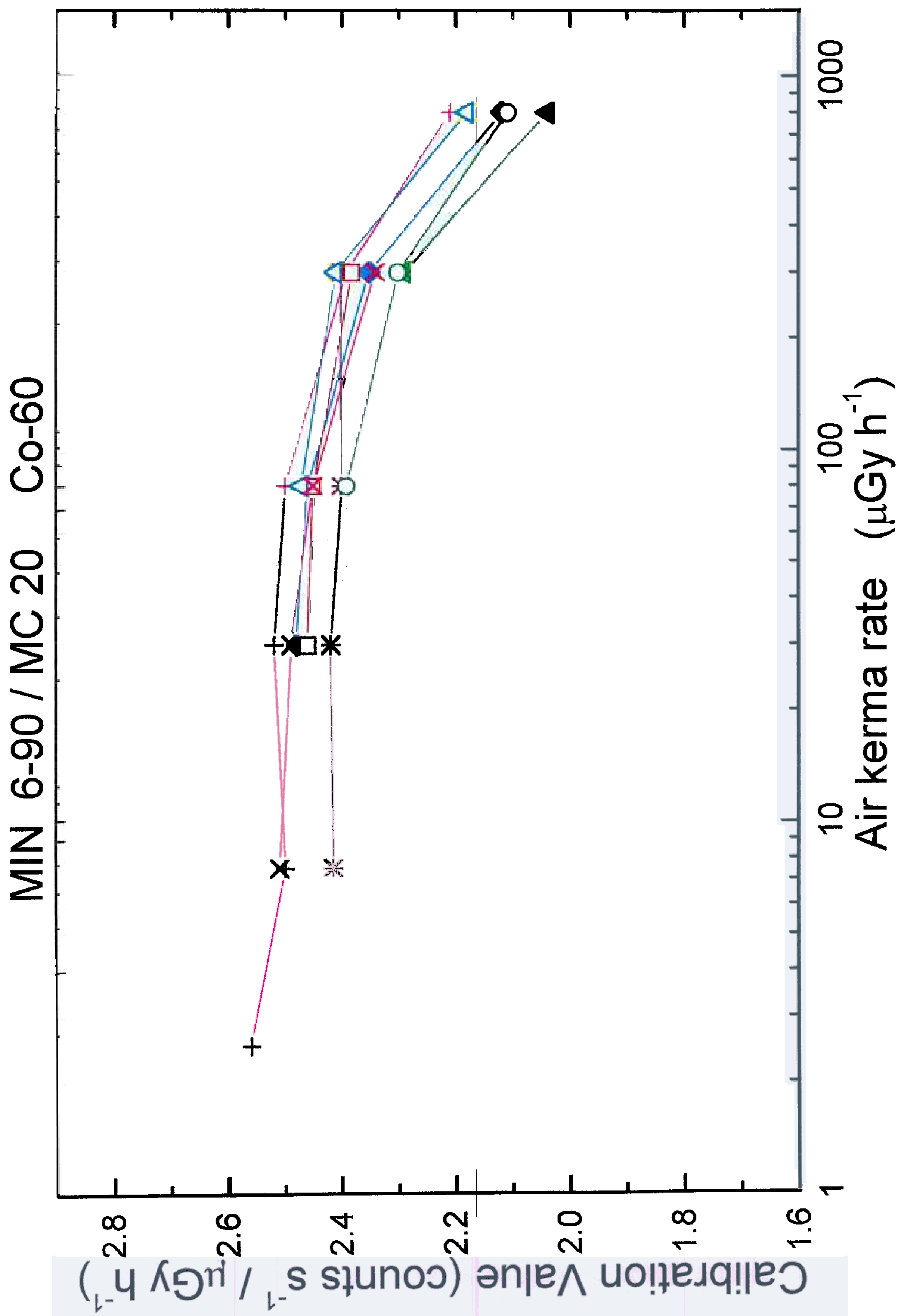


Figure 10 ^{60}**Co calibrations of Mini 6-90/MC20**

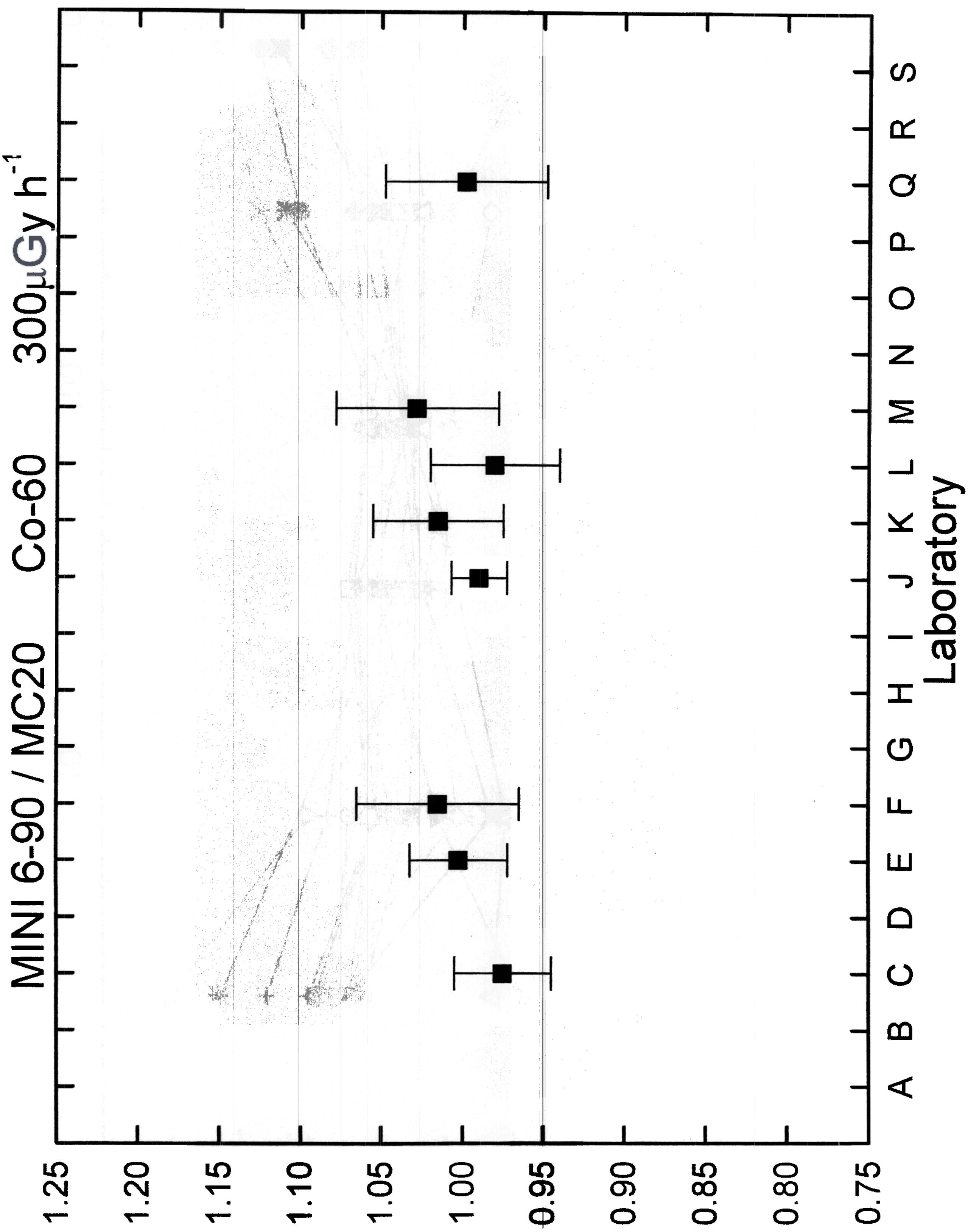


Figure 11 ^{60}**Co calibrations of Mini 6-90/MC20 at 300 μGy h^{-1}; normalised values**

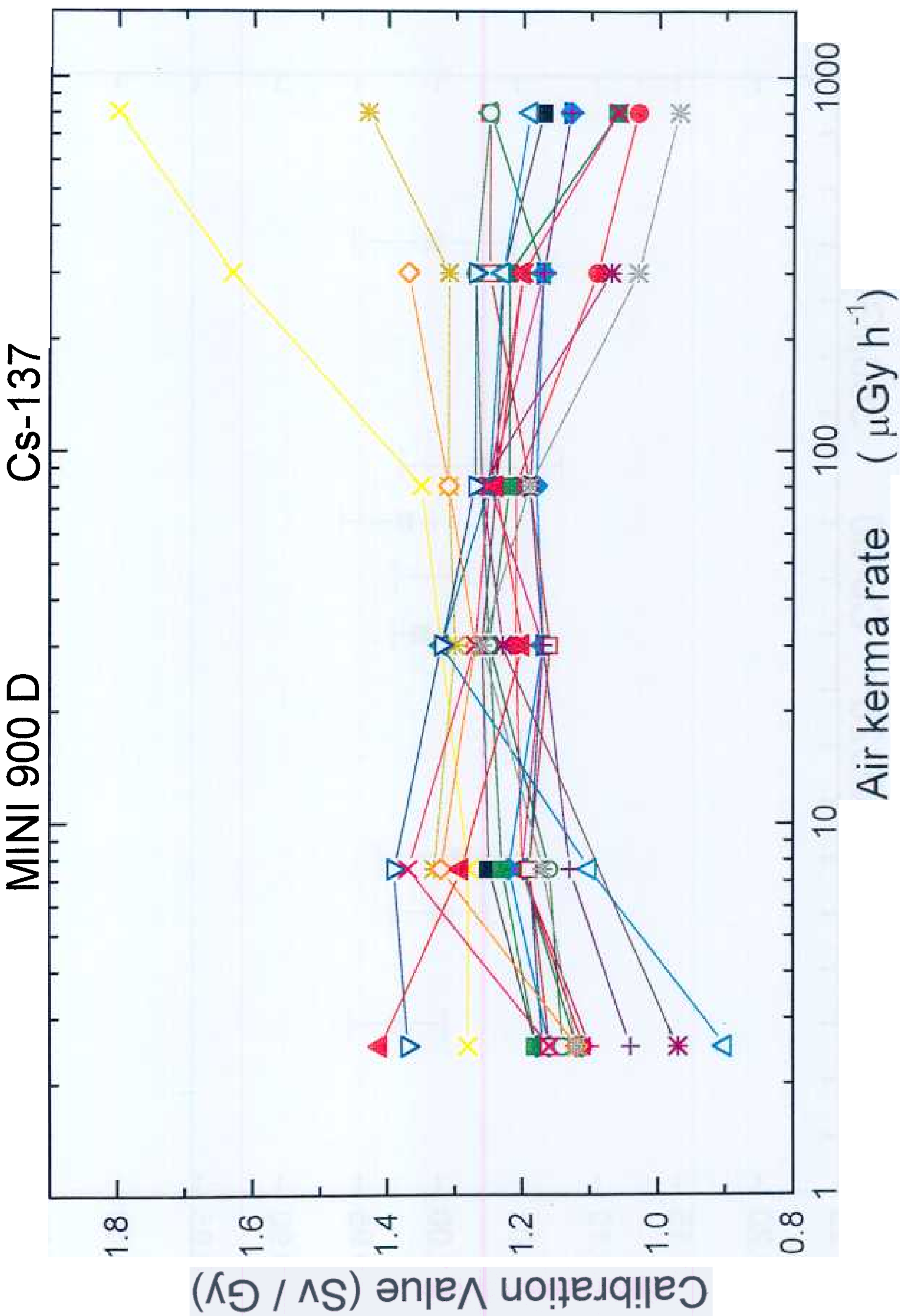


Figure 12 ^{137}**Cs calibrations of Mini 900D**

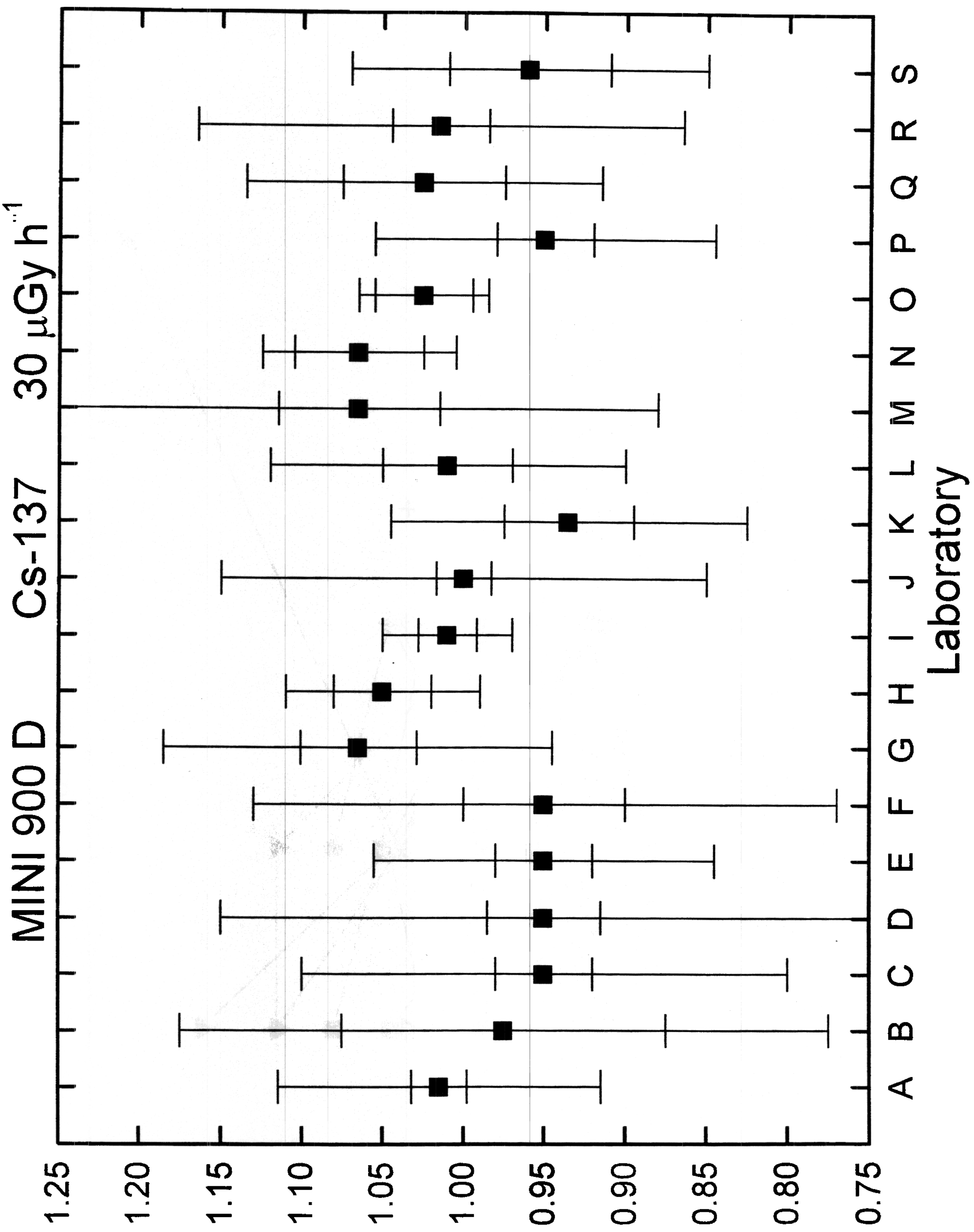


Figure 13 **^{137}Cs calibrations of Mini 900D at 30 μGy h^{-1} ; normalised values**

The inner uncertainty bars show the air kerma rate uncertainties and the outer bars show the combined air kerma rate plus monitor reading uncertainties.

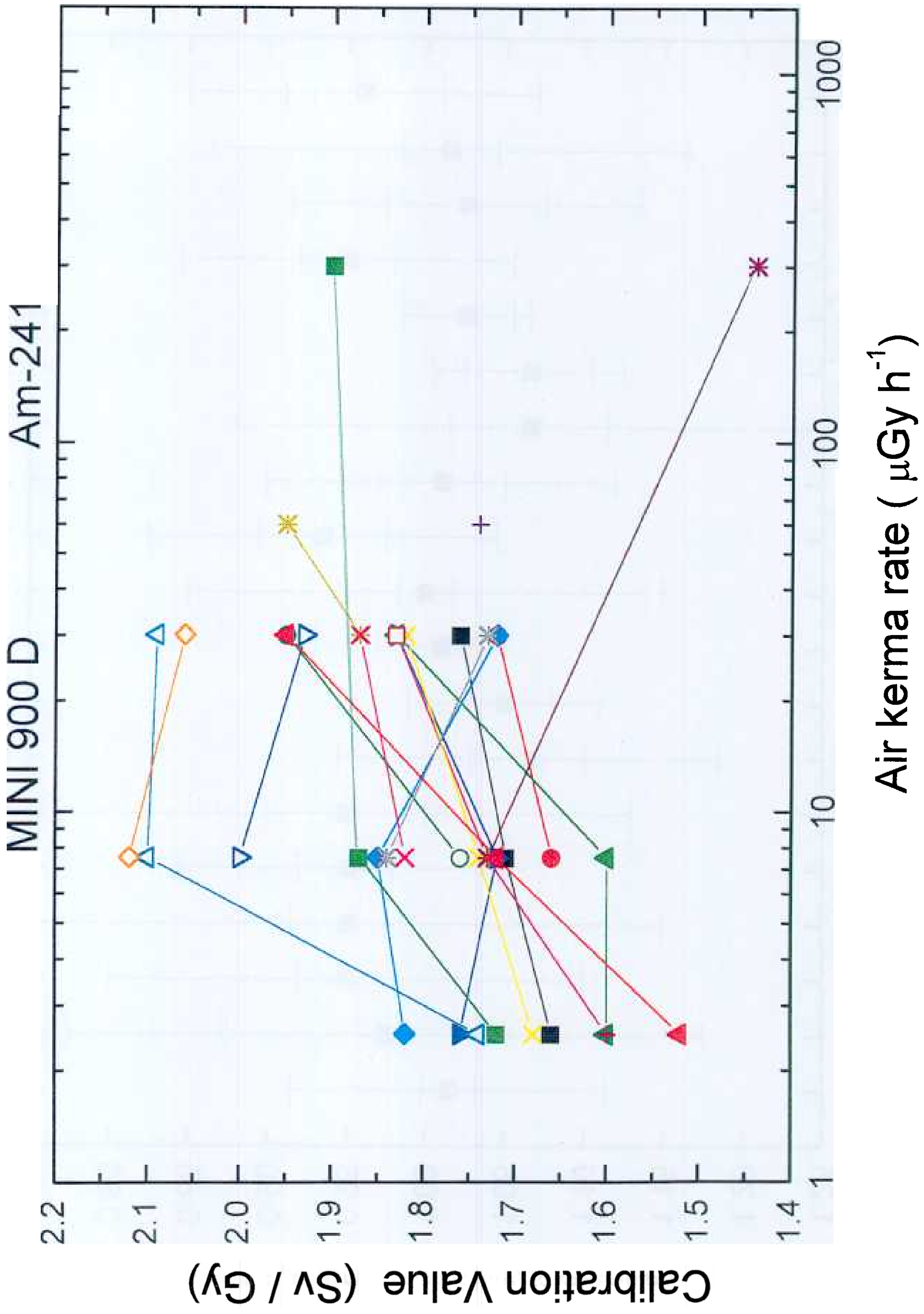


Figure 14 ^{241}**Am calibrations of Mini 900D**

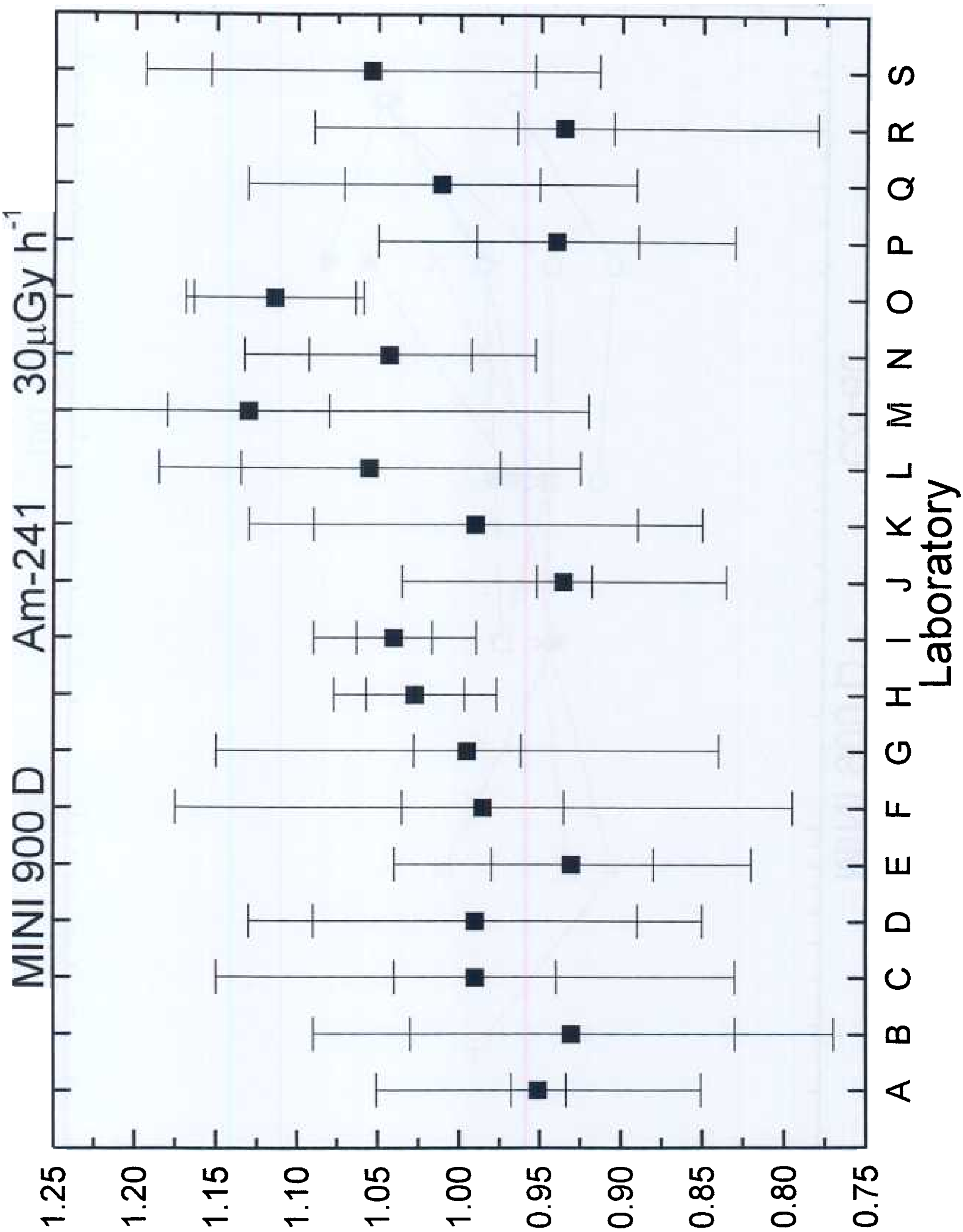


Figure 15 ^{241}**Am calibrations of Mini 900D at 30 μGy h^{-1} ; normalised values**

The inner uncertainty bars show the air kerma rate uncertainties and the outer bars show the combined air kerma rate plus monitor reading uncertainties.

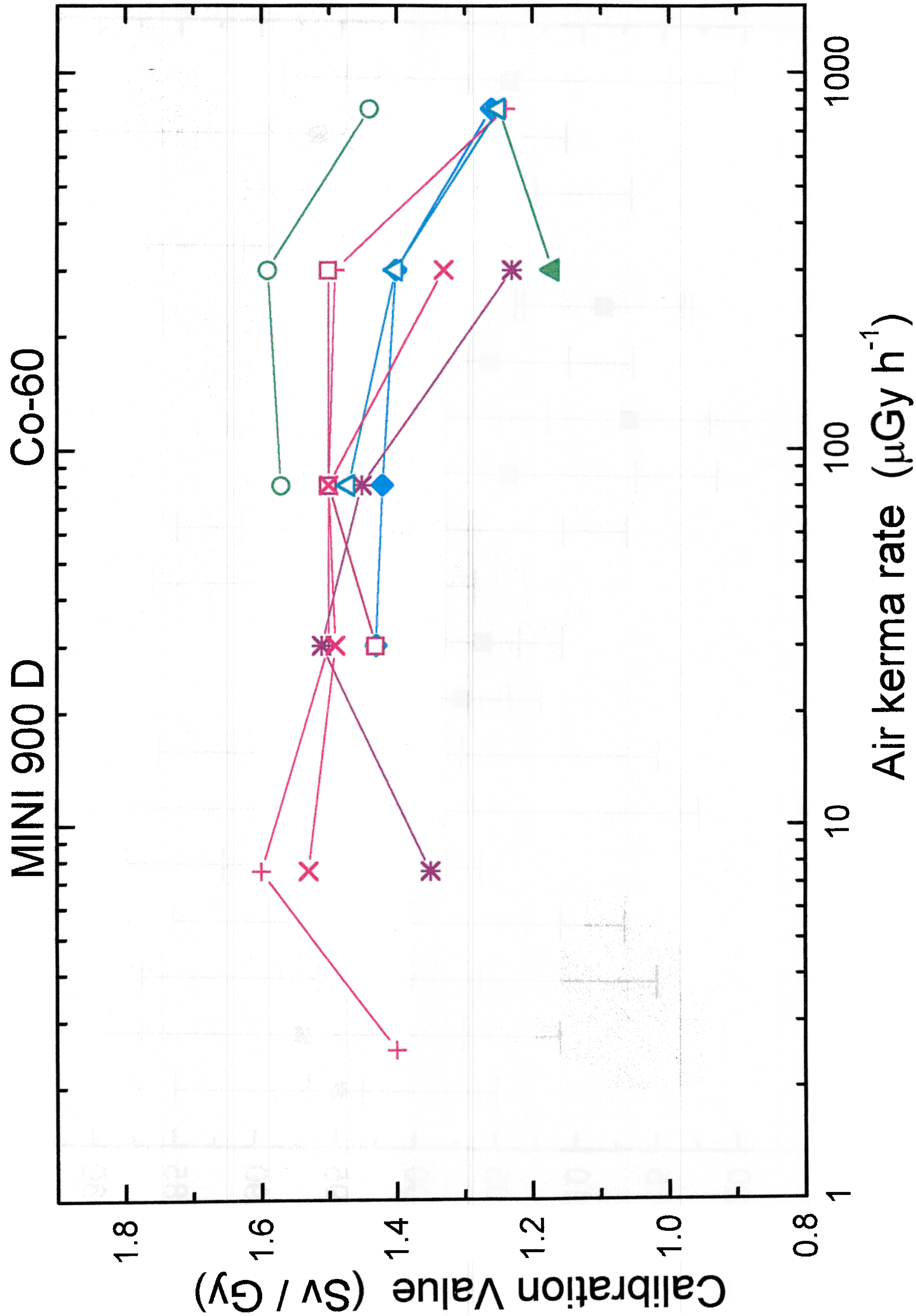


Figure 16 ^{60}Co calibrations of Mini 900D

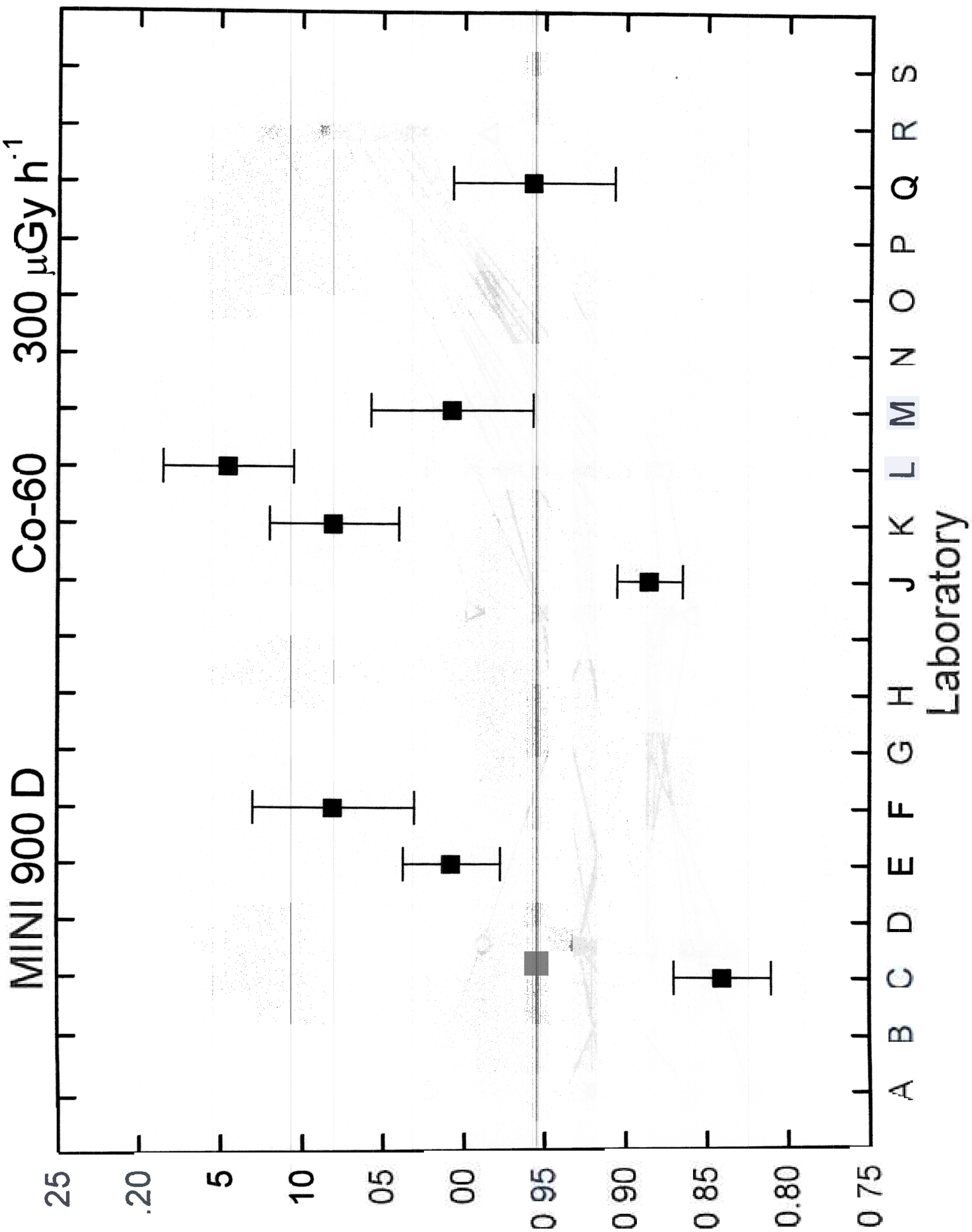


Figure ^{60}Co alibrations of Mini 900D 300 µGy h normalised al

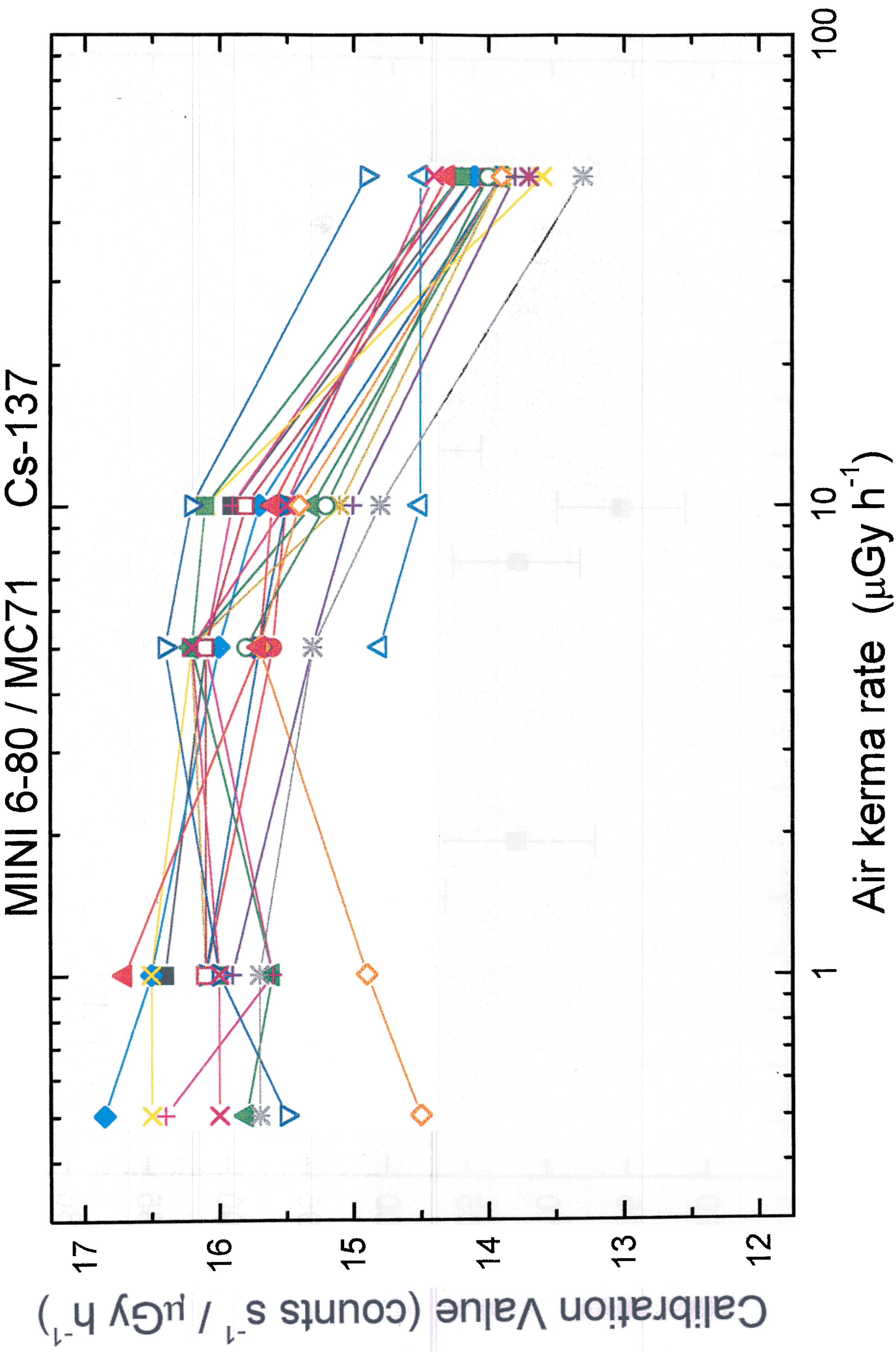


Figure 18 ^{137}**Cs calibrations of Mini 6-80/MC71**

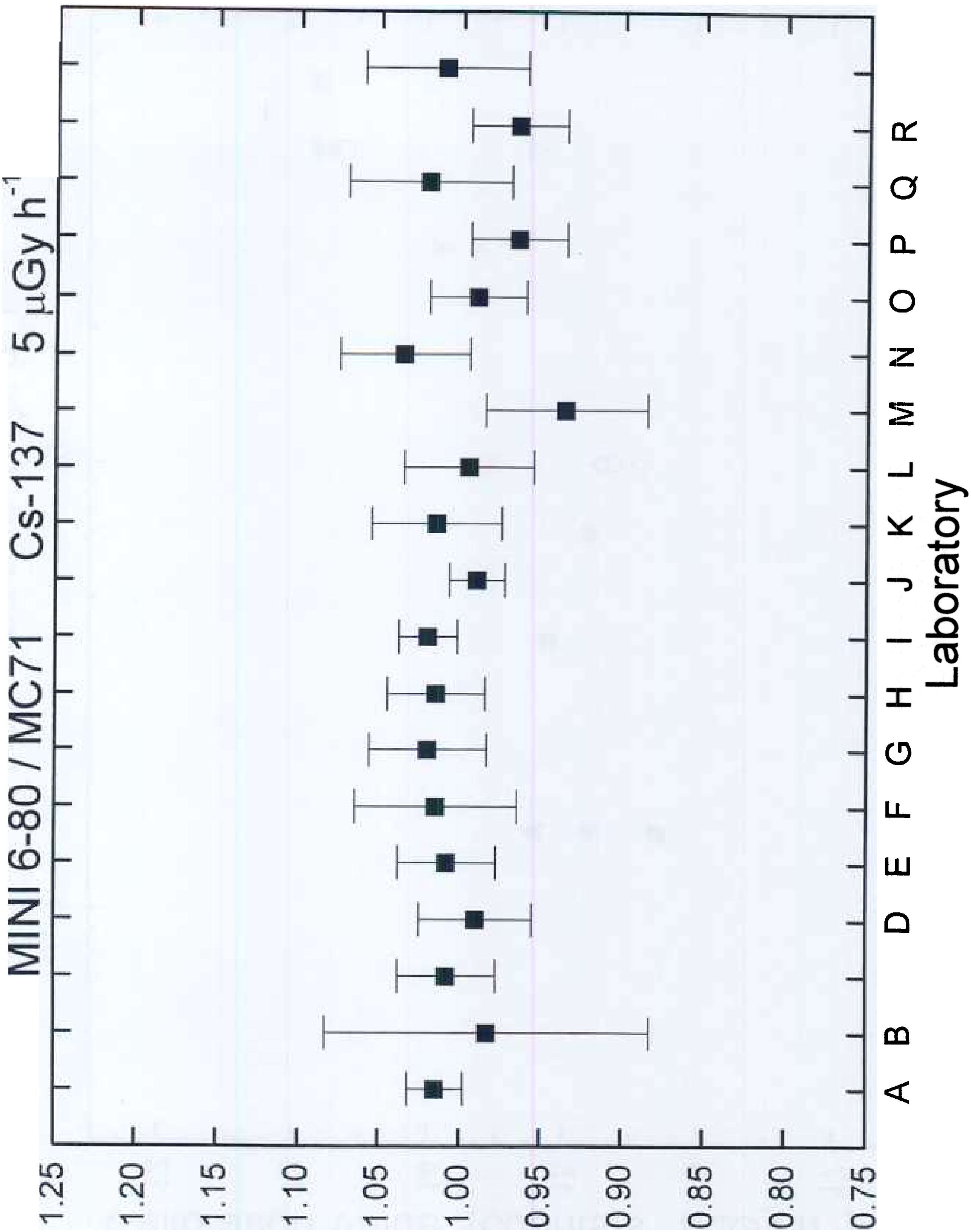


Figure 19 ^{137}Cs **calibrations of Mini 6-80/MC71 at 5 μGy h^{-1} ; normalised values**

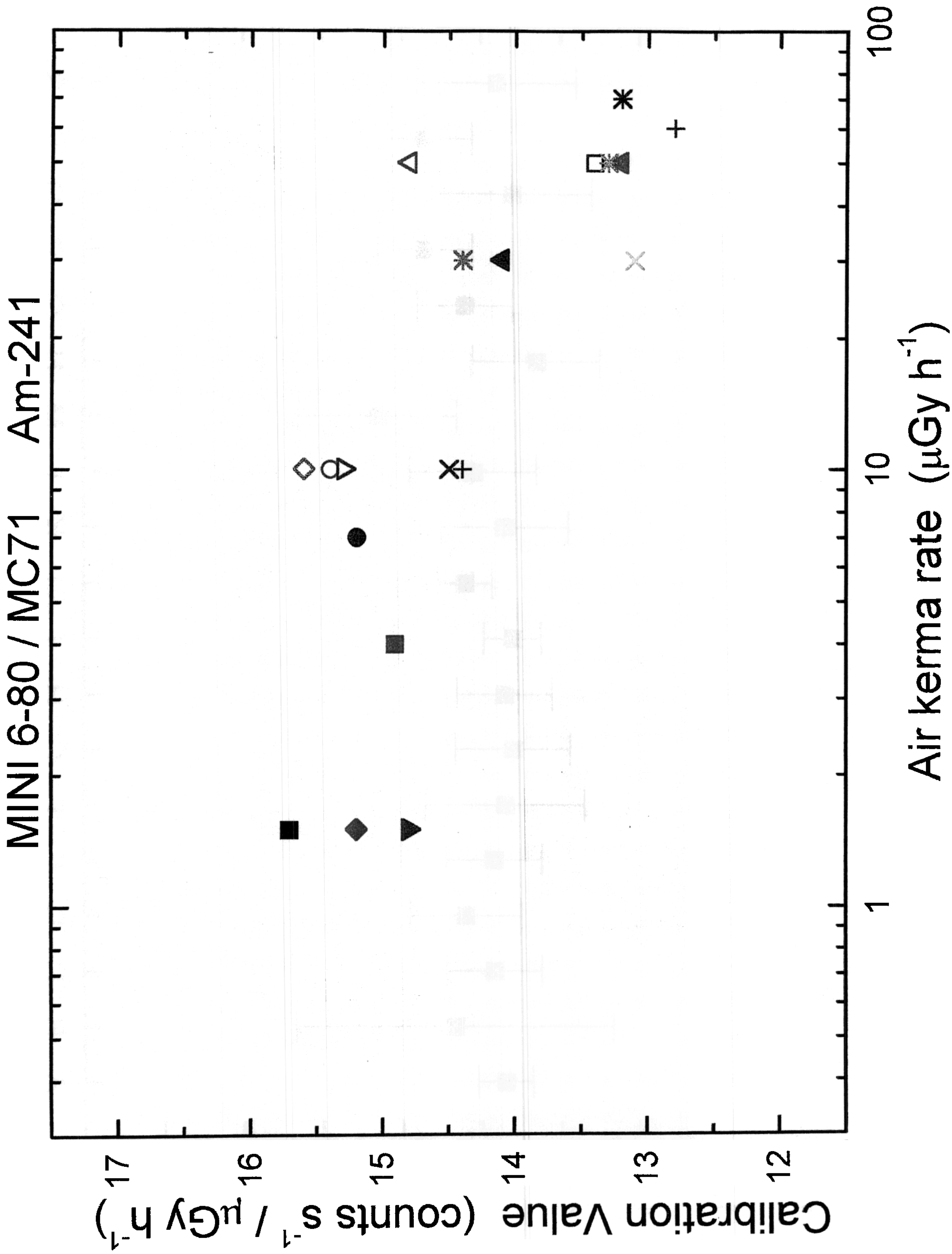


Figure 20 ^{241}**Am calibrations of Mini 6-80/MC71**

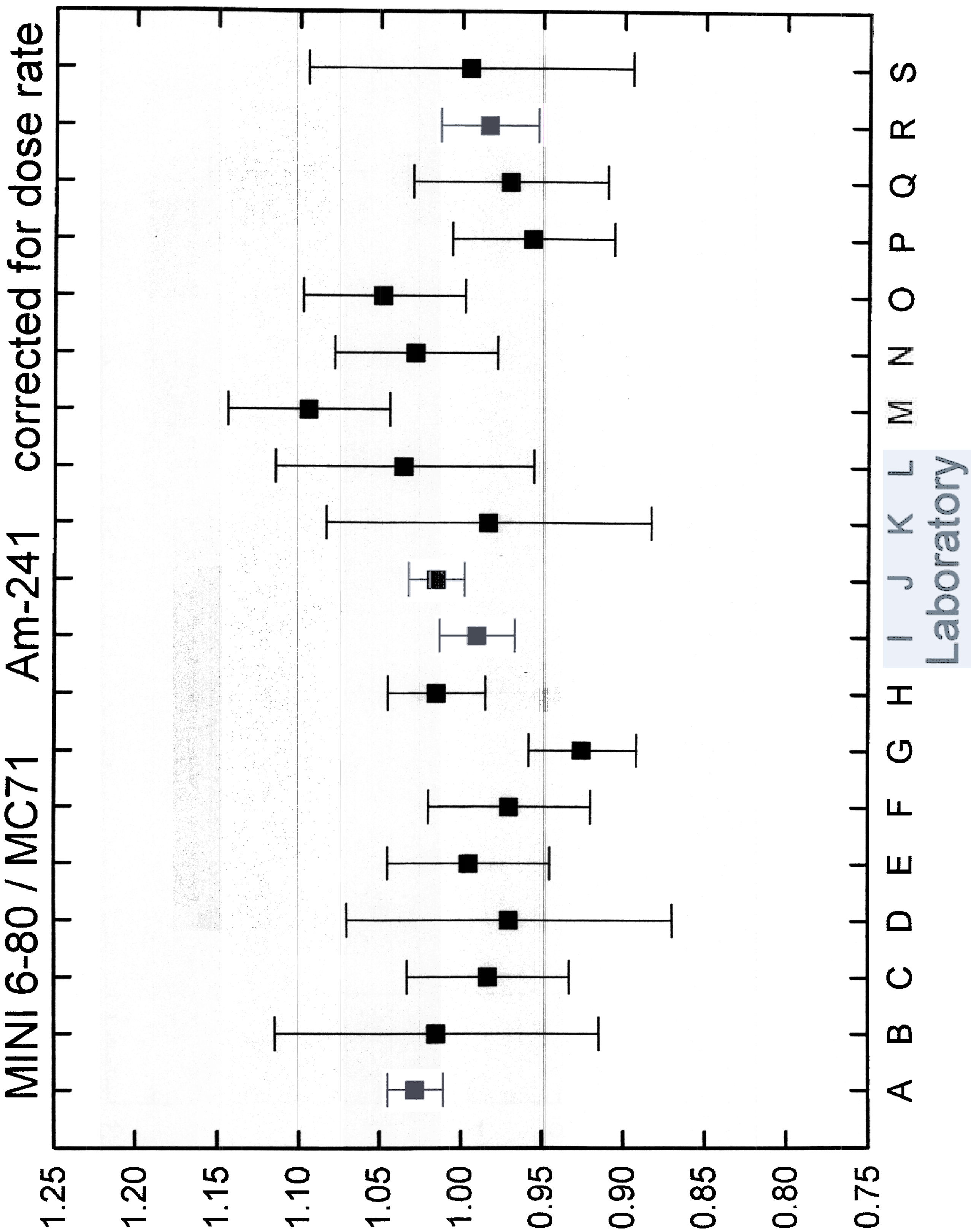


Figure 21 ^{241}**Am calibrations of Mini 6-80/MC71 corrected for air kerma rate**

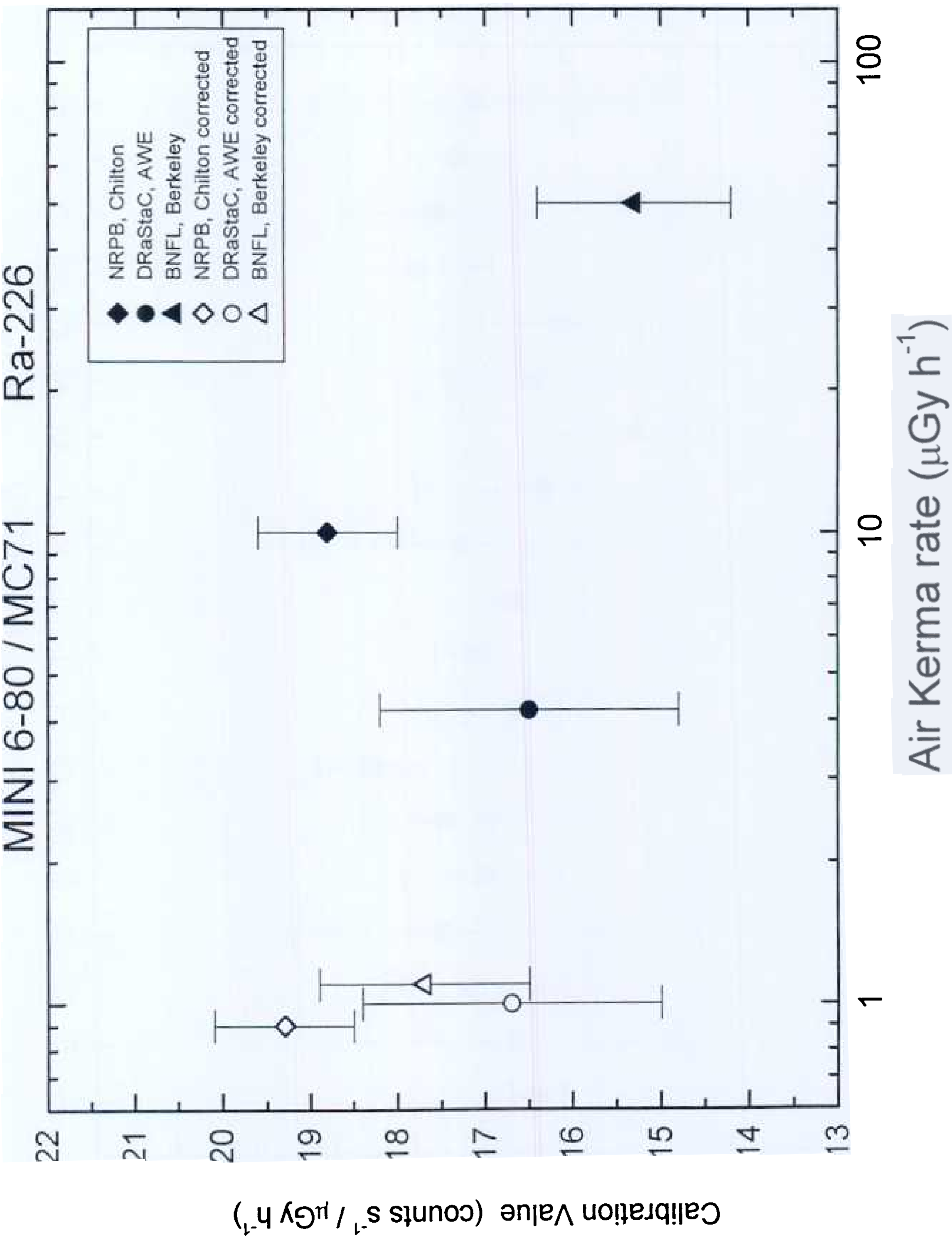


Figure 22 ^{226}Ra calibrations of Mini 6-80/MC71