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Third IRMF Comparison of Calibrations of Neutron Area Survey Monitors, 2001 - 2002

V E Lewis

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V E Lewis

Centre for Acoustics and Ionising Radiation
National Physical Laboratory, Teddington, Middlesex

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National Physical Laboratory

Teddington, Middlesex, United Kingdom, TW11 0LW

Website: www.npl.co.uk

Approved on behalf of Managing Director, NPL, by
Dr Martyn Sené, Head, Centre for Acoustics and Ionising Radiation

ABSTRACT

The Ionising Radiations Metrology Forum organised a comparison of calibrations of neutron area survey instruments in which five establishments in the UK participated. The exercise involved the circulation of two neutron area survey monitors for calibration in fields produced using ^{252}Cf and ^{241}Am-Be sources. The instruments used were a model Mark 7 NRM and a model NM2B.

All results were submitted to the author for analysis. Responses relative to neutron fluence, as stated by the individual participants, were calculated. The results are compared and generally demonstrate reasonable agreement between establishments.

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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 the need for traceability to national standards, through the organisation of regular comparisons of calibrations of monitoring in areas of ionising radiation metrology. To this end, comparisons are held in each area (neutron, gamma-ray and surface contamination monitoring) at approximately three-year intervals. The main objective of the comparisons is to assess the ability of calibration laboratories to perform routine calibrations of instrumentation in pursuance of the Ionising Radiations Regulations 1999 [1].

The first and second IRMF comparisons of calibrations of neutron area survey monitors were held in 1995/6 [2] and 1998/1999 [3] respectively. As in those exercises, the present comparison involved the circulation of two area survey neutron monitors for participants to calibrate in two neutron fields that were produced using radionuclide sources. The participants generally carried out their measurements in the neutron fields and at dose-rates normally used for routine instrument calibrations, employing the same methods to calibrate the two transfer instruments as are routinely used within their organisation.

The calibration quantity for this comparison was the quotient of the instrument reading and neutron fluence at the position of the effective centre of the instrument.

The present comparison was planned by a working party comprised of representatives from all participating laboratories (see below) along with a representative from BNFL, Berkeley. The organisation and coordination of the exercise were funded under the National Measurement System Programme in Ionising Radiation Metrology and were carried out by NPL.

All results were submitted for analysis to the author, who was not involved in any of the calibrations carried out at NPL. Instrumentation matters were referred to Graeme Taylor, NPL.

2 PARTICIPANTS

The establishments (and contact persons) participating in the comparison were -

*RWE NUKEM, Harwell	R Bosley
** Dosimetry and Radiation Metrology Service, Aldermaston	P Danyluk
National Physical Laboratory, Teddington	G C Taylor
National Radiological Protection Board, Chilton	D R McClure
BAE Systems Marine, Barrow-in-Furness	S Marriott, J Silvie

(* Previously AEA Technology

(** Previously DRaStaC)

Prior to the comparison, the Working Party agreed that participants would not be allowed to withdraw results.

All participants chose to identify their results in any presentation or report associated with the exercise.

3 PROTOCOL

A protocol for the comparison, based on that employed in the second IRMF comparison [3], was produced by the working party. This provided guidance and included pro forma for reporting various information and the results of measurements to the evaluator. Instructions were given for mounting and operating the instruments. Deviation from the specified orientations was discouraged unless it was physically impossible to achieve those orientations in the participant's facility.

3.1 INFORMATION REPORTED BY PARTICIPANTS

The following pro-forma were provided:

3.1.1 Form IRMF/N3/1 Calibration measurement details

This form was used for reporting results obtained using the routine calibration technique. The reported data included -

- source used,
- distance between source and centre of dose meter,
- fluence rate and approximate dose equivalent rate,
- monitor responses (pulse output and, if desirable, analogue and digital),
- scatter correction,
- calculated fluence rate response.

These details were sufficient to enable the evaluator to calculate the calibration value and check those calculated by the participant. The appropriate uncertainties were also requested.

3.1.2 Form IRMF/N3/2 Details of neutron sources

Participants were asked to supply information about their sources including -

- emission rate,
- anisotropy factor,
- air attenuation factor,
- encapsulation and dimensional details.

3.1.3 Forms IRMF/N3/3, IRMF/N3/4 Accelerator- produced fields

These forms were for use in a parallel, bi-lateral exercise.

3.1.4 Form IRMF/N3/5 Details of calibration facilities

The following details of calibration rooms were requested -

- approximate dimensions of the exposure room,
- source height above floor and distance from walls,
- source - instrument separation distance,
- wall/floor/ceiling material.

The dimensions of the calibration rooms, shown in Table 1, varied considerably.

3.1.5 Form IRMF/N3/6 Uncertainties

Participants were asked to provide sample uncertainty budgets, giving details of the estimated uncertainties in the neutron fluence, instrument output and scatter correction.

4 RADIATION FIELDS

Neutron fields produced using ^{252}Cf and ^{241}Am-Be sources were selected for this comparison. All participants reported results for ^{241}Am-Be fields and ^{252}Cf fields with neutron fluence rates traceable to national standards.

The participants usually possessed only one or two sources of each radionuclide. A range of distance between source and monitor was therefore used to give a range of dose rates. Overall, ranges of neutron dose equivalent rates from about 5 to 4,800 μSv h^{-1} and 1.5 to 3,200 μSv h^{-1} were covered for ^{241}Am-Be and ^{252}Cf fields respectively.

5 INSTRUMENTATION

Two types of widely-used neutron dose-equivalent rate meters were used as transfer instruments. The electronics were not deliberately off-set.

5.1 Mark 7 NRM

The NE Technology (now Thermo Electron Corporation) monitor type Mark 7 NRM was loaned by BAE Systems. It has a ^{3}He tube thermal neutron detector at the centre of a spherical polyethylene moderator. The effective centre was assumed to be the sphere's geometrical centre.

The monitor has two modes of output -

- an external pulse output,
- a logarithmic display from 1 μSv/h to 10 mSv/h in four decades.

5.2 NM2B

The NE Technology monitor type NM2B was loaned by BNFL, Berkeley. It has a cylindrical polyethylene moderator with a BF_3 detector with its axis on the axis of cylindrical symmetry. The effective centre was assumed to be on the cylindrical axis at 125 mm from the end of the moderator.

The monitor has three modes of output -

- an external pulse output,
- a digital display with four ranges,
- a logarithmic display from 1 μSv/h to 100 mSv/h in five decades.

The monitor was positioned with its axis normal to the incident neutrons.

6 MEASUREMENTS

6.1 PROGRAMME

Initial checks on the instruments were carried out by NPL in September 2001. These included a check of response of the instruments using an ^{241}Am-Be check-source in a fixed geometry. This was done using the pulse output.

The participants' measurements started in October 2001. Each participant was allotted one month to receive the instruments, carry out the calibrations and then send them on to the next participant. It was planned to carry out response checks only when the instruments were at NPL for calibrations there and at the end of the measurement phase.

The NM2B suffered damage in transit between the establishments of the first participant (DRMS) and second participant (BAE Systems). It was immediately returned to NPL for inspection and checks. The damage was found to be superficial (the glass cover of the display meter was broken) and readily repaired. The instruments were retained at NPL to enable NPL's calibrations to be carried out. They were then circulated to the remaining participants.

The next participant, NRPB, reported a problem with the movement of the needle of the analogue display of the NM2B. This was remedied by replacing the display drive unit. It is not known whether this affected the calibration for readings taken in this mode.

The final calibrations were made by NPL in mid-July 2002. These were followed by the final stability tests using the check-source. The tests included measurements of the quotients of the response in the different modes of operation.

The programme is summarised in Appendix 1.

6.2 CALIBRATIONS

6.2.1 Method

The two instruments were placed at selected distances from the radionuclide sources and their responses (monitor indication per unit fluence rate) were measured.

The monitor indication was -

- pulse output, integrated on a scaler; both monitors, mandatory,
- analogue display of ambient dose equivalent rate; both monitors, optional,
- digital display of ambient dose equivalent rate; NM2B only, optional.

The fluence rate was determined from the measured value of the source emission rate, the source anisotropy factor and the distance between source and the effective centre of the monitor. An attenuation correction, dependent on the distance between source and front face of the monitor was applied for each position.

The reading, *M(r)*, of a monitor in a neutron field produced by a radionuclide source may be expressed -

$$M(r) = R \frac{E}{4\pi r^2} f_g(r) f_A f_{aa}(d) f_{sc}(r) + M_B(r)$$

where
R - response (defined as the reading per unit fluence) for source spectrum,
E - emission rate of source,
r - distance between source and effective centre of monitor.
$f_g(r)$ - geometrical correction
f_A - anisotropy factor
$f_{aa}(d)$ - air attenuation correction at distance d
d - distance between the source and front face of the monitor
$f_{sc}(r)$ - room-scatter correction
$M_B(r)$ - background

6.2.2 Corrections

With the exception of the correction for room scatter, the above corrections are readily determined with appropriate accuracy.

- For a sphere with radius ρ, the geometrical correction, $f_g(r)$ [4], is less than 1% for distance r greater than 4ρ. This effect is insignificant at distances greater than 40 cm for the monitors used in this exercise.
- The anisotropy of the source, represented by the factor f_A,, can be as high as 4% for physically large ^{241}Am-Be sources, but is closer to 1% for ^{252}Cf sources.
- The air attenuation correction, $f_{aa}(d)$, for the distance, d, between the source and front face of the monitor is calculated using published values of 0.88 % m^{-1} and 1.06 % m^{-1} for the attenuation coefficients for ^{241}Am-Be and ^{252}Cf neutrons respectively.
- The background effect, $M_B(r)$, is generally insignificant.

6.2.3 Room-scatter correction, $f_{sc}(r)$

Participants were asked to report the magnitude of the correction for neutrons scattered from the air, walls, floor and ceiling of the calibration room. This correction is generally expressed as a percentage increase of the reading of a monitor relative to that due to direct neutrons or relative to the total reading. Sometimes it is expressed as an additional component of fluence rate or dose equivalent rate.

Although the reading due to the direct component varies according to an inverse square relation with distance (allowing for air-attenuation), the room-scatter component is fairly constant and the air-scatter component varies inversely with distance. Thus, the combined effect of scatter is an increase with distance relative to the direct component. The room-scatter correction depends markedly on room dimensions and structural materials.

One participant (NPL) measured the room-scatter component at each distance for each monitor/ source calibration. Another participant (NRPB) assumed that the absolute magnitude of the room-scatter component was constant and used linear regression analysis to fit the responses at different distances. Other participants used corrections that had been derived from previous series of measurements made for the two types of monitor used in ^{241}Am-Be and ^{252}Cf fields.

For comparison between participating laboratories, values are shown in Table 1 for a standard distance from source of one metre.

6.2.4 Correction for decay of radionuclide source

The source emission rates were derived from a measured value multiplied by a decay factor for the period between the measurement and the day of the calibration for the comparison. The uncertainty in this factor depended on that of the half life value used. This was negligible for all ^{241}Am-Be sources used. However, older ^{252}Cf sources could contain a significant fraction of the longer-lived ^{250}Cf, and this required further consideration.

6.3 FURTHER MEASUREMENTS

At the end of the comparison, NPL measured the quotients of pulse, analogue and digital display readings using the test rig.

6.4 CALCULATION OF RESPONSE VALUES

For each monitor/source/distance configuration, participants reported the calculated fluence rate and corresponding monitor reading, using the pro-forma report forms provided with the protocol (see Section 3 above). The participants were asked to calculate the corresponding response values and to derive a weighted mean value for each monitor/source configuration. The pro-forma report forms were sent to the Evaluator for checking and analysis at NPL.

The responses were calculated in terms of fluence rate rather than ambient dose equivalent rate.

7 RESULTS AND ANALYSIS

7.1 GENERAL

The responses measured by the participants for each source/monitor configuration, at fluence rates they selected, are shown in Figures 1, 2, 3 and 4, for the pulse mode of operation. For ease of comparison between the results for the different configurations, the range of fluence rate (abscissa) is the same for all four figures; the range of response (ordinate) is the same for the Mark 7 NRM ^{241}Am-Be and ^{252}Cf results (Figures 1,2) and for NM2 ^{241}Am-Be and ^{252}Cf results (Figures 3,4). The limits for the ordinate ranges are the same for both sources for each monitor and have the same proportions for both monitors with the upper limits being a factor of 1.6 that of the lower limits. Some NRPB ^{241}Am-Be data that lie outside these limits are not plotted.

The responses for the analogue mode of operation are shown in Figures 5, 6, 7 and 8. Four participants recorded data using this mode of operation, which was optional. The NM2B data are from measurements made after the change of the meter unit.

The responses for the digital mode of operation (NM2B only) are shown in Figures 9 and 10. Only two participants recorded data using this mode. One participant, RWE NUKEM, took readings using four ranges of sensitivity; the responses are plotted separately for each.

Measurements in accelerator-produced neutron fields with strengths much higher than those obtained using radionuclide sources had previously indicated that the type of monitor used in this comparison did not suffer from dose rate effects.

The principal means of varying dose rate was to vary distance between source and monitor, and this produced a change in the room scatter correction that could easily hide any dose rate effect or give the appearance of an effect. It could be assumed therefore that any trend with dose rate in the radionuclide fields used was likely to be due to room scatter effects.

7.2 CALCULATION OF MEAN VALUES

For each source/monitor configuration the weighted mean value was calculated for each set of response values obtained over the range of distance used by each participant. Sometimes this was done by the participant and at other times by the Evaluator. The weighting factors were derived as the inverse of the combined random plus room scatter uncertainties for each individual value. Each participant submitted sample uncertainty budgets for individual data points; a selection is shown in Tables 6 to 10. The main random (type A) uncertainty was statistical (recorded events or fluctuation of display). Correlations in the room-scatter corrections for different distances were ignored because they were not always known. The type B components due to the source emission rate and anisotropy were excluded.

The weighted mean values for the sets of results from each participant are given in Tables 2 & 3 for the pulse output and analogue reading modes of operation respectively. The values are quoted in terms of the reading per unit fluence rate.

For information, the coefficients for converting fluence rate to ambient dose equivalent rate are also given in Table 3. (Ideally, the analogue response values should be equal to these values.) These have been derived using the conversion coefficients based on ICRU 57 [5].

Not all of the participants calculated the uncertainties of the mean values. These are very difficult to derive in a consistent manner because information is required on, for example, the correlations in the corrections for room scatter. Where necessary the Evaluator calculated the uncertainties as a combination of the standard deviation of the mean of each set of values and the Type B uncertainties due to emission rate, anisotropy, etc. These values tend to underestimate the uncertainties very slightly.

To aid comparison, the mean response values of each participant (Table 4) have been normalised to those of BAE Systems, who carried out calibrations in all source/monitor/mode of operation configurations.

7.3 Mark 7 NRM CALIBRATIONS

7.3.1 Pulse mode of operation

The ^{241}Am-Be pulse mode responses of four participants (Figures 1) lie in a band of ± 6.3 % about the median value. The sets of values of those individual participants are reasonably constant with fluence rate; this indicates consistent room scatter corrections. On the other hand, the NRPB responses vary enormously; the value agreeing most closely with the consensus of the other participants is that obtained at the shortest distance from source. The values at the two greatest distances are in fact negative, indicating that the scatter correction, equivalent to 64% at one metre (Table 1), is excessive. These two values were excluded from the calculation of the mean value.

The observed 9% range of mean values (Table 2) is not consistent within the uncertainties (at 95% confidence level), with disagreement between RWE NUKEM and NPL.

Four participants submitted values for the ^{252}Cf response using the monitor in the pulse mode of operation (Figure 2). The values lie in a band of ± 10.8 % about the median value and are reasonably constant with fluence rate. The highest RWE NUKEM value (at the lowest fluence rate) has a large 12% uncertainty and is consistent with the other values.

The reported uncertainties are similar to those for the ^{241}Am-Be values but the range of mean values (15 %) is significantly higher. The highest mean value (RWE NUKEM) is about 15% higher than the lowest (NPL) although the uncertainties are 4% and 2.2% respectively. It is thought that this worsening of agreement by some 5% may be explained by growing proportion of ^{250}Cf in the RWE NUKEM sources which were last calibrated about eleven years previously. This would give rise to an enhancement of emission rate of about 3.5% compared with a pure ^{252}Cf source.

7.3.2 Analogue reading mode

Four participants submitted values for the ^{241}Am-Be response using the analogue reading mode of operation (Figure 5). All values but one lie in a band of ± 10 % about the median value. One outlier, the NRPB value obtained at the greatest distance is consistent with the next lowest value within the uncertainties.

The reported uncertainties were greater than those for the pulse output due to the larger uncertainty in reading the needle indication compared with counting pulses. The uncertainties were greater at the lower fluence rates because the needle fluctuations were greater. This is reflected in the greater spread of response values at lower rates. At higher rates the consistency is very good. The mean values (Table 3) agree within the uncertainties because the lower fluence rate values have less weight.

Most of the values for the ^{252}Cf response for the monitor in the analogue mode (Figure 6) lie in a band of ± 12 % about their median value. These responses were measured at lower fluence rates than for the ^{241}Am-Be responses and the spread is greater as would be expected.

Outside of this band, the RWE NUKEM value obtained at the greatest distance is again slightly high. Also, the two large-distance NRPB values are outliers again; this time they are high, suggesting that the scatter correction, equivalent to 0.1% at one metre (Table 1), is low. These two values were omitted from the calculation of the mean. The mean values are reasonably consistent within the uncertainties but the spread is greater than for the ^{241}Am-Be values. Some of this may be due to the age of the sources used by RWE NUKEM (see 7.3.1 above).

7.3.3 Consistency between reading modes

For each participant, the quotient of mean responses in the two modes is the same for both ^{241}Am-Be and ^{252}Cf calibrations. The mean quotients for both fields (Table 5) of all participants lie in a 4.5 % range. This is reasonably consistent within the statistical uncertainties and indicates that the monitor electronics were stable throughout the exercise.

7.4 NM2B CALIBRATIONS

7.4.1 Pulse mode of operation

Nearly all the ^{241}Am-Be pulse mode responses of the five participants (Figure 5) lie in a band of ± 6.8 % about the median value and are reasonably constant with fluence rate. The exceptions are the NRPB values at the two greatest distances that are much lower, suggesting that the scatter correction of around 11% at one metre (Table 1) is high. The weighted mean values (Table 2) are consistent within the uncertainties.

Four participants submitted values for the ^{252}Cf response using the monitor in the pulse mode of operation (Figure 6). The figure is very similar to the corresponding one for the Mark 7 NRM monitor (Figure 2) except that the values lie in a narrower band of ± 6.0 % about the median value. The highest RWE NUKEM value (at the lowest fluence rate) is consistent with the other values within its 15% uncertainty. As with the Mark 7 NRM results, there is disagreement between the highest and lowest mean values that could be due in part to the age of the RWE NUKEM source (see 7.3.1).

7.4.2 Analogue reading mode

Three participants submitted values for the ^{241}Am-Be response using the analogue reading mode (Figure 7). Most values lie in a band of ± 7.5 % about a median value, but the NRPB values show an upward trend with distance, suggesting that the scatter correction of about 1.2% at one metre is low. The mean values (Table 3) are consistent within the uncertainties.

Most of the values for the ^{252}Cf response in the analogue mode (Figure 8) lie in a band of ± 10 % about their median value. The NRPB values at the two largest distances deviate markedly from the other values. These are omitted from calculation of the mean value.

7.4.3 Digital reading mode

Only two participants reported values for the digital reading mode (Figure 9 and 10).

RWE NUKEM measured comprehensive sets of values using at least three sensitivity ranges for each value. Some ranges are inappropriate for some fluence rates and would not be used routinely. All values measured at the same distance are consistent. There are no trends with distance for both ^{241}Am-Be and ^{252}Cf fields. The apparent outlier at the greatest distance and lowest sensitivity range for ^{252}Cf has a large uncertainty and is consistent with other values.

The BAE Systems values are more constant with fluence rate than those of RWE NUKEM but, however, over a much smaller range of fluence rate for the ^{252}Cf calibrations. They are slightly lower than the latter for the ^{252}Cf calibrations and for the ^{241}Am-Be calibrations at low fluence rates, but consistent within the uncertainties.

7.4.4 Consistency between reading modes

The mean quotients (analogue/pulse), (digital/pulse) and (analogue/digital) for both ^{241}Am-Be and ^{252}Cf calibrations (Table 5) of three participants each lie in a 1.5 % range. This is very consistent within the statistical uncertainties and indicates that the monitor electronics were stable following the change of meter display drive unit.

7.5 ABSOLUTE ACCURACY AND VARIATION WITH ENERGY

7.5.1 Absolute accuracy

The analogue responses measured for the NM2B are within ± 8% of the conversion coefficients ^{241}Am-Be and ^{252}Cf given in Table 3 except for one value; this is within 14% which is consistent within the uncertainty. The Mark 7 NRM responses are generally between 30% and 20% lower for ^{241}Am-Be and ^{252}Cf respectively. This does not affect the validity of the comparison.

Although the NM2B digital responses (Figures 9, 10) are expressed in the same units as those for the analogue mode, i.e. in µSv h^{-1} per cm^{-2} s^{-1}, but the values are 50% higher than those of the analogue mode and thus 50% higher than the conversion coefficient. It obviously needs some adjustment to the electronics. The Mark 7 NRM has no digital mode of response.

7.5.2 Variation with neutron field

The Mark 7 NRM has a ^{241}Am-Be neutron response that is about 11% higher than that for ^{252}Cf neutrons (Tables 2 & 3). For the NM2B the ^{241}Am-Be neutron response that is about 5% higher than that for ^{252}Cf.

8 UNCERTAINTIES

8.1 UNCERTAINTY BUDGETS

The uncertainty budgets shown in Tables 6, 7, 8, 9 and 10 are for individual calibrations carried out at chosen distances. They have been selected from sets of uncertainty budgets submitted by all participants. The uncertainties have been treated in accordance with UKAS, 1997 [6] and GPG 49 [7]. The expanded uncertainties at 95 % confidence level were calculated by combining the standard uncertainties of the various components in quadrature and multiplying by a k-factor ($k = 2$). A few changes have been made by the Evaluator to achieve better consistency of presentation.

8.2 COMPONENTS

All uncertainties quoted below are for a 95% confidence level unless specified otherwise.

8.2.1 Instrument reading

For pulse counting mode, the random uncertainty for the observed reading was derived from the standard deviation of the total number of events observed (taken as the square root of total) or the standard deviation of the mean of a series of readings. This was normally between about 10,000 to 40,000 events, yielding a standard uncertainty of between 0.5 to 1%. For most situations this was not a major uncertainty.

Most participants derived the uncertainty for the analogue reading mode was from a series of reading of the needle rather than from the minimum and maximum values. This could not be as precise as recording the number of events, and the uncertainties were higher and sometimes dominant at low fluence rates where the needle was making large swings. The minimum value reported was about 1% and the maximum around 23%.

The situation was similar for the digital reading mode where the largest uncertainty was 46%.

8.2.2 Neutron source emission rate

The source emission rate used was usually that measured absolutely at NPL using the manganese bath method. The associated uncertainty has a value of at least 1.2%, at a confidence level of 95% ($k = 2$). This uncertainty is produced by the combination of several components and has a normal distribution. Some participants used sources that had been calibrated by comparison with sources whose emission rates had traceability to national standards. The uncertainties included an additional component of the counting statistics, and the overall uncertainty could be several percent. NRPB put a value of 10% for the uncertainty of all their sources.

The uncertainty due to that in the half life of ^{241}Am ($1.5785 \pm 0.0024 \times 10^5$ day) has negligible effect for measurements are made within ten years of calibration of the source.

The decay correction for a ^{252}Cf source depends on the amount of ^{250}Cf present at the time of its calibration. The latter isotope has a half life of 4,777 day compared with 966 day for the former. Measurements at NPL suggest that the effect could amount to an increase in neutron emission of around 3.5% over ten years from manufacture. Derivation of the uncertainty involves calculation of the covariance between the uncertainties for both half lives (see Table 10 as an example). The effect is less than 0.5% for sources within one half life of calibration.

8.2.3 Neutron source anisotropy

Generally, the anisotropies had been measured previously by NPL. For the ^{252}Cf sources used in this exercise the value was around 1% and up to about 4% for ^{241}Am-Be sources. The uncertainty was up to 0.5% for the ^{252}Cf sources and around 1% to 2% for the ^{241}Am-Be sources. NRPB assigned a value of 3.6% for the uncertainty for both types of source; this is approximately equal to the anisotropy for the larger type of ^{241}Am-Be source used.

8.2.4 Distance of the effective centre of monitor from neutron source

The uncertainty in the distance between detector and source centre is comprised of the three possible components listed. Generally these were of the order of 1 mm and therefore made an insignificant contribution to the overall uncertainty except at very close distances.

8.2.5 Room- and air-scatter correction

The fractional room- and air-scatter component varies markedly with distance and from one facility to another. The uncertainty is typically around 10% to 20% of the correction (at 95% confidence level) and can be the largest contribution to the overall uncertainty. For example, DRMS had the largest room scatter component (Table 1) with an uncertainty of 3.5% at 1 m. In contrast, BAE Systems, with lower room scatter, quoted about 2% at 1 m.

8.2.6 Air attenuation correction

The air attenuation correction is of the order of 1% at one metre and the associated uncertainty is insignificant.

8.2.7 Spectral effects

There could be differences between the spectra of different sources due to differences in the physical properties. The spectra for the ^{241}Am-Be sources used in this comparison were assumed to be similar because the encapsulations were not massive for sources of the strengths employed. No participants incorporated an uncertainty in the budgets to cover this effect.

8.3 COMMENTS

There are three main uncertainties –

- Emission rate (plus decay factor) and anisotropy
  For each participant this is constant for all measurements with a given source.
- Room scatter
  This depends on the facility and increases with increasing distance from source.
- Instrument reading
  This depends on various parameters such as fluence rate and the time interval over which the reading is taken.

All other uncertainties are smaller and more accurately known.

At the reasonably high fluence rates (i.e. at shorter distances), the uncertainty budgets do not tend to be dominated by any single component and expanded uncertainties of around 5% may be readily obtained. At lower fluence rates and/or greater distances, the uncertainty of the reading can dominate and that due to room scatter also increases.

9 DISCUSSION

The current exercise was similar in scope to the previous comparison [2], employing the same neutron fields but different models of monitor. The range of calibrations undertaken was wider, with all participants calibrating both monitors and both radionuclide fields. In some cases this required a facility to perform calibrations that were not carried out routinely. There has also been greater emphasis on the derivation and expression of uncertainties with all participants submitting examples of uncertainty budgets.

The exercise took longer than planned due partly to one monitor being damaged (slightly) in transit and also to delays with the submission of results by NPL.

The participants' internal consistency was generally very good, indicating that the large correction due to room scatter had been determined fairly accurately. There are problems with the NRPB linear regression approach, as may be seen by the range of values obtained in Table 1. Subsequent investigations have shown that the technique works better when calculating a single response factor from all the points, which is the normal NRPB procedure, but not for calculating individual response factors for each point as presented in this comparison.

The agreement between participating laboratories is not as good as in the previous two exercises. (This can be judged only by examining the results obtained using the pulse mode of reading.) This could be due to different makes of monitor being used this time, the ageing of some of the sources that were employed and participants carrying out non-routine calibrations. Another possibility is that the output pulses of the Mark 7 NRM were very noisy and spurious events could be recorded.

10 CONCLUSIONS

The consensus of calibration values is satisfactory, although not as good as in previous exercises.

The uncertainties that have been given by participating laboratories are adequate for the accuracy required. The participants' approach to the treatment and expression of uncertainty in this area is generally consistent.

The comparison has demonstrated that the calibrating facilities could meet the requirements of the IRRs [1] and the associated codes of practice [8].

11 ACKNOWLEDGEMENTS

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The Mark 7 NRM was loaned by BAE Systems and the NM2B by BNFL, Berkeley.

The help of the participants in the production of this report is gratefully acknowledged.

The work of Graeme Taylor (NPL) in checking the instrumentation and that of Nicky Horwood (NPL) in producing the figures is much appreciated.

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APPENDIX 1 PROGRAMME

2001	
September	Initial checks at NPL
October	DRMS calibrations using ^{241}Am-Be and ^{252}Cf fields
November	NM2B damaged in transit and returned to NPL
December	Checks at NPL
2002	
January	NPL calibrations using ^{241}Am-Be and ^{252}Cf fields
February	NM2B meter unit replaced at NRPB
March	NRPB calibrations using ^{241}Am-Be and ^{252}Cf fields
April	RWE NUKEM calibrations using ^{241}Am-Be and ^{252}Cf fields
May	BNFL calibrations using 2.7 MeV neutron field
June	BAE Systems calibrations using ^{241}Am-Be and ^{252}Cf fields
July	Further NPL calibrations using ^{241}Am-Be and ^{252}Cf fields
August	NPL calibrations using 2.7 MeV neutron field
September	Checks and further measurements at NPL
October	
November	
December	Final results received (from NPL)

Table 1 Room dimensions and room scatter corrections

The room scatter correction is expressed as percentage of direct field

	Dimensions of room			Scatter correction normalised to 1 metre distance			
	Length	Width (m)	Height	Mk 7 NRM		NM2B	
				^{241}Am - Be	^{252}Cf	^{241}Am - Be	^{252}Cf
DRMS, Aldermaston	9.1	5.5	4.4	19.2	19.8	16.0	16.4
NRPB, Radiation. Metrology, Chilton	8	5	2.5 *	64, 9.7 #	0.1	10.7, 1.2 #	8.3
RWE NUKEM, Harwell	5.5	5.4	3.1	6	6	6	6
NPL, Teddington	25	18	18	7.2	7.6	5.0	6.8
BAE Systems, Barrow in Furness	11.7	6.6	4.5 **	12.1	12.1	12.1	12.2

* “PREMADEX” lining over concrete

** Lightweight roof

\# Measured separately in pulse and analogue output modes respectively

Table 2 Measured responses: pulse output mode of operation

Expressed as detected events per unit neutron fluence (cm^2)

	Mark 7 NRM			NM2B			Ratio (NRM / NM2B)	
	^{241}Am - Be (Figure 1)	Cf-252 (Figure 3)	Ratio	^{241}Am - Be (Figure 2)	Cf-252 (Figure 4)	Ratio	^{241}Am - Be	Cf-252
DRMS, Aldermaston	0.241 (14)	0.254 (13)	1.054	0.390 (25)	0.393 (19)	1.008	0.618	0.646
NRPB, Chilton #	0.235 (25)	- - -	n/a	0.365 (40)	- - -	n/a	0.644	n/a
RWE NUKEM, Harwell	0.244 (10)	0.285 (11)	1.168	0.390 (16)	0.418 (16)	1.070	0.625	0.680
NPL, Teddington	0.223 (4)	0.246 (5)	1.103	0.379 (6)	0.383 (7)	1.010	0.588	0.642
BAE Systems, Barrow-in-Furness	0.230 (5)	0.268 (5)	1.165	0.373 (8)	0.398 (8)	1.067	0.617	0.673

Data for distances greater than 1.5 m omitted.

All uncertainties (in parentheses) are for 95% confidence level.

Table 3 Measured responses: analogue reading mode of operation

Expressed as indication per unit neutron fluence rate ($\mu Sv\ h^{-1} / cm^{-2}\ s^{-1}$)

	Mark 7 NRM			NM2B			Ratio (NRM / NM2B)	
	^{241}Am - Be (Figure 5)	Cf-252 (Figure 6)	Ratio	^{241}Am - Be (Figure 7)	Cf-252 (Figure 8)	Ratio	^{241}Am - Be	Cf-252
DRMS, Aldermaston	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -
NRPB, Chilton	0.98 (11)	1.11 (15)	1.13	1.49 (16)	1.58 (25)#	1.06	0.66	0.70
RWE NUKEM, Harwell	1.040 (40)	1.160 (50)	1.115	1.350 (55)	1.445 (60)	1.070	0.770	0.805
NPL, Teddington	0.990 (35)	1.065 (40)	1.075	- - -	- - -	- - -	- - -	- - -
BAE Systems, Barrow-in-Furness	1.010 (50)	1.146 (45)	1.135	1.305 (65)	1.350 (65)	1.035	0.775	0.850
*** $\mu Sv\ h^{-1} / cm^{-2}\ s^{-1}$**	**1.408**	**1.386**		**1.408**	**1.386**			

\# Data for distances greater than 1.5 m omitted.

All uncertainties (in parentheses) are for 95% confidence level.

* Fluence-to-ambient dose equivalent conversion coefficient [4]: ^{241}Am-Be: 391 pSv cm^2; ^{252}Cf : 385 pSv cm^2

Table 4 Normalised responses

	Mark 7 NRM				NM2B			
	Pulse		Analogue		Pulse		Analogue	
	Am-Be	Cf-252	Am-Be	Cf-252	Am-Be	Cf-252	Am-Be	Cf-252
DRMS, Aldermaston	1.048 (60)	0.948 (50)	- - -	- - -	1.045 (65)	0.987 (48)	- - -	- - -
NRPB, Chilton	1.02 (11)	- - -	1.00 (12)	0.97 (15)	0.98 (11)	- - -	1.14 (11)	1.17 (17)
RWE NUKEM, Harwell	1.060 (40)	1.063 (40)	1.031 (40)	1.012 (40)	1.045 (40)	1.050 (40)	1.035 (40)	1.070 (40)
NPL, Teddington	0.970 (15)	0.918 (20)	0.980 (35)	0.930 (40)	1.016 (15)	0.962 (20)	- - -	- - -
BAE Systems, Barrow-in-Furness	1.000 (20)	1.000 (20)	1.000 (50)	1.000 (50)	1.000 (20)	1.000 (20)	1.000 (50)	1.000 (50)

To aid comparison, all results are normalised to BAE Systems values

All uncertainties (in parentheses) are for 95% confidence level.

Table 5 Consistency of monitor readings

Ratio of responses in different modes of operation

	Mark 7 NRM	NM2B		
	Analogue / Pulse	Analogue / Pulse	Digital / Pulse	Digital / Analogue
NRPB, Chilton	4.38	4.09	- - -	- - -
RWE NUKEM, Harwell	4.19	3.46	4.94	1.43
NPL, Teddington	4.38	- - -	- - -	- - -
NPL, check source	4.26	3.48	5.01	1.44
BAE Systems Barrow-in-Furness	4.38	3.45	4.97	1.44

Table 6 Sample uncertainty budget: DRMS

^{252}Cf	Distance: 1009 mm	Mk7 NRM	Pulsed output

Quantity	Value	Uncertainty (∂x_i)	Probability distribution	Confidence level	Divisor	c_i / y	$u_i(y)$ (%)	v_i or v_{eff}
# Mean monitor reading, M	22,254 x 3	0.4 %	normal	1 σ	1	1	0.4	∞
Period	600 s	0.01 s	rectangular	- - -	√3	100/600	< 0.01	∞
Mean background reading, M_B	negligible	- - -						
Emission rate; corrected for decay	21.1 10^6 s^{-1}	3.0 %	normal	95%	2	1	1.50	∞
Distance, r: calibration repeatability position of effective centre	1009 mm	 0.02 mm 2.0 mm - - -	rectangular	- - -	√3	200 /1001	0.23	∞
Anisotropy, f_A	1.01	0.005	normal	95%	2	100	0.25	∞
Attenuation correction, f_{aa}	- - -	- - -						
Source half life	2.645 y	- - -						
Room scatter, f_{sc}	0.198	0.035	normal	95%	2	100 / 1.20	1.46	
Scatter model accuracy	- - -	1.1 %	rectangular	- - -	√3	1 / 1.20	0.53	∞
Combined uncertainty			normal				2.33	∞
Expanded uncertainty (k = 2.0)			normal				4.7	∞

$$u_i(y) = (\partial \boldsymbol{x_i} / \text{divisor}) \times (c_i / y)$$

Mean measured over 3 periods

Table 7 Sample uncertainty budget: NRPB

^{241}Am/^{9}Be	Distance: 1000 mm	Mk7 NRM	Pulsed output

Quantity	Value	Uncertainty ($\partial \boldsymbol{x_i}$)	Probability distribution	Confidence level	Divisor	c_i / y	$u_i(y)$ (%)	v_i or v_{eff}
Monitor reading, M	27,420	1 %	normal	1 σ	1	1	1.0	∞
Period	600 s	0.1 %	rectangular	- - -	√3	1	< 0.01	∞
Mean background reading, M_B	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -
Emission rate; corrected for decay	10.63 10^6 s^{-1}	10 %	normal	95%	2	1	5.0	∞
Distance, r: calibration repeatability position of effective centre	1000 mm	- - - 0.1 % 0.1 %	rectangular	- - -	√3	1	0.06 0.06	∞
Anisotropy, f_A	- - -	3.6 %	normal	95%	2	1	1.8	∞
Attenuation correction, f_{aa}	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -
Room scatter, f_{sc}	- - -	9 %	normal	95%	2		4.5	∞
Combined uncertainty			normal				7.0	∞
Expanded uncertainty (k = 2.0)			normal				14	∞

$$u_i(y) = (\partial \boldsymbol{x_i} / \text{divisor}) \times (c_i / y)$$

Table 8 Sample uncertainty budget: RWE NUKEM

$^{241}Am/^{9}Be$	Distance: 130 mm	Mk7 NRM	Pulsed output

Quantity	Value	Uncertainty (∂x_i)	Probability distribution	Confidence level	Divisor	c_i / y	$u_i(y)$ (%)	v_i or v_{eff}
Transfer instrument reading, T_1	30,000	0.6 %	normal	1 σ	1	1	0.35	∞
Period	2,000 s	0.5	rectangular	- - -	√3	100/2000	0.02	∞
Emission rate; corrected for decay	$2.30\ 10^6\ s^{-1}$	1.2 %	normal	95%	2	1	0.6	∞
Anisotropy, f_A	1.02	0.5 %	normal	95%	2	1	0.25	∞
Room scatter, f_{sc} (at 1.0 m)	1.06	0.007	normal	95%	2	100	0.35	∞
Attenuation correction, f_{aa}	0.989	0.002	normal	95%	2	100	0.10	∞
Transfer instrument reading, T_2	10,000	1.0 %	normal	1 σ	1	1	1.0	∞
Period	100 s	0.5	rectangular	- - -	√3	100/100	0.29	∞
Distance: calibration repeatability position of effective centre	130 mm	0.5 mm 1 mm 1 mm	rectangular normal rectangular	- - - 95% - - -	√3 2 √3	200 /130	0.45 0.77 0.90	∞
Monitor reading, M	10,000	1.0 %	normal	1 σ	1	1	1.0	∞
Period	1,000 s	0.5	rectangular	- - -	√3	100/1000	0.03	∞
Distance, r: calibration repeatability position of effective centre	130 mm	0.4 mm 0.8 mm 0.8 mm	rectangular normal rectangular	- - - 95% - - -	√3 2 √3	200 /130	0.45 0.77 0.90	∞
Combined uncertainty			normal				2.44	∞
Expanded uncertainty ($k = 2.0$)			normal				4.9	∞

Table 9 Sample uncertainty budget: BAE Systems Marine

^{241}Am/^{9}Be (185 GBq)	Distance: 836 mm	Mk7 NRM	Pulsed output

Quantity	Value	Uncertainty (∂x_i)	Probability distribution	Confidence level	Divisor	c_i / y	$u_i(y)$ (%)	v_i or v_{eff}
Reading of monitor, M	9778	1.0 %	normal	1 σ	1	1	1.0	∞
Period	300 s	1.26 s	normal	95%	2	100/300	0.20	∞
Background reading, M_B	37	0.06 %	normal	1 σ	2	1	0.06	∞
Emission rate	10.96 10^6 s^{-1}	1.2 %	normal	95%	2	1	0.60	∞
Distance, r: calibration repeatability position of effective centre	836 mm	 3.0 mm 1.0 mm 1.0 mm	rectangular	- - -	√3	200 /836	0.23	∞
Anisotropy, f_A	1.046	0.7 %	normal	95%	2	1 / 1.05	0.34	∞
Attenuation correction, f_{aa}	0.990	0.002	normal	95%	2	100 / 0.99	0.10	∞
Source half life	432.2 y	0.15%	normal	95%	2	0.02	< 0.01	∞
Room scatter, f_{sc}	1.090	0.018	normal	95%	2	100 / 1.09	0.83	∞
Combined uncertainty			normal				1.51	∞
Expanded uncertainty (k = 2.0)			normal				3.1	∞

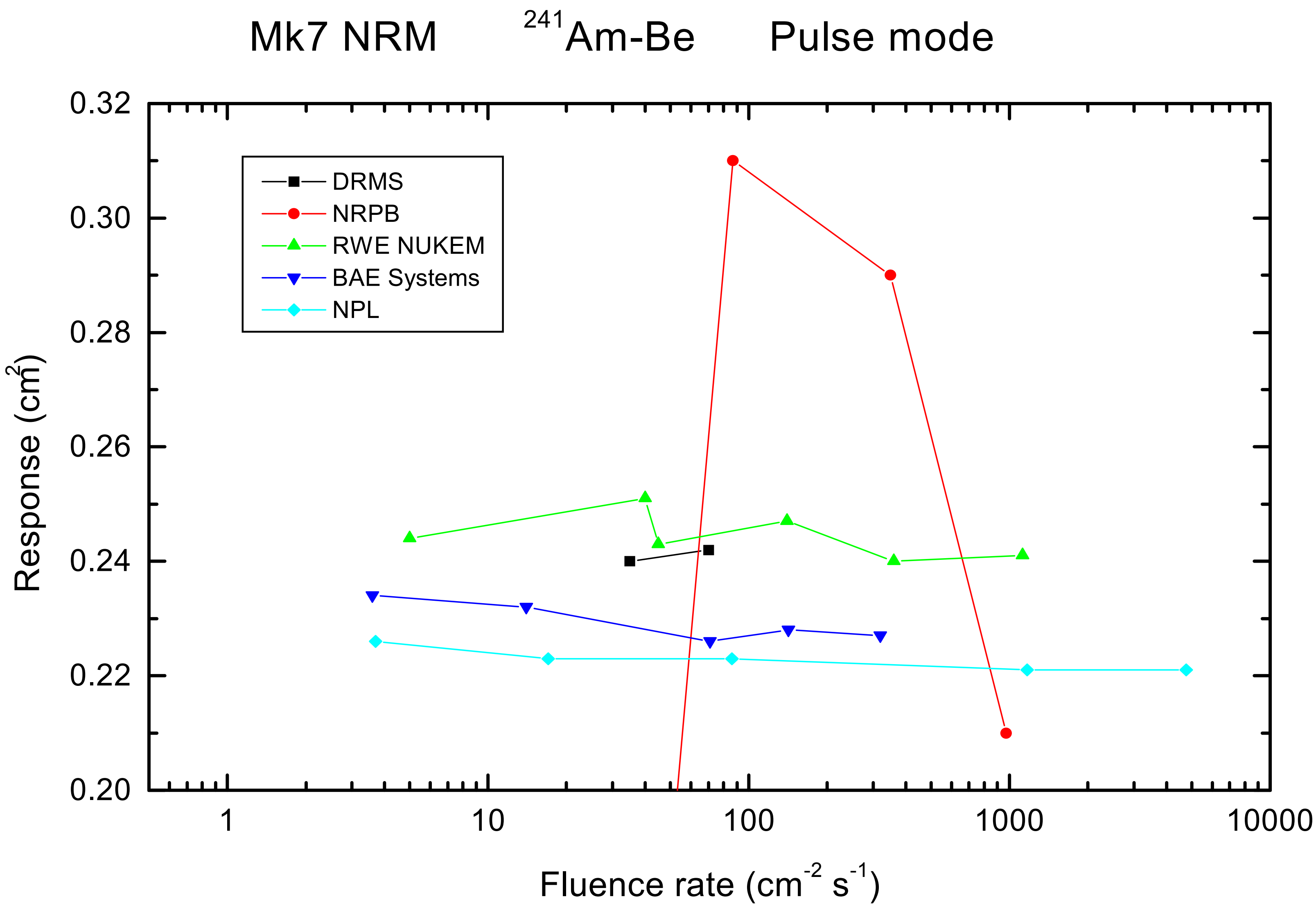
$$u_i(y) = (\partial x_i / \text{divisor}) \times (c_i / y)$$

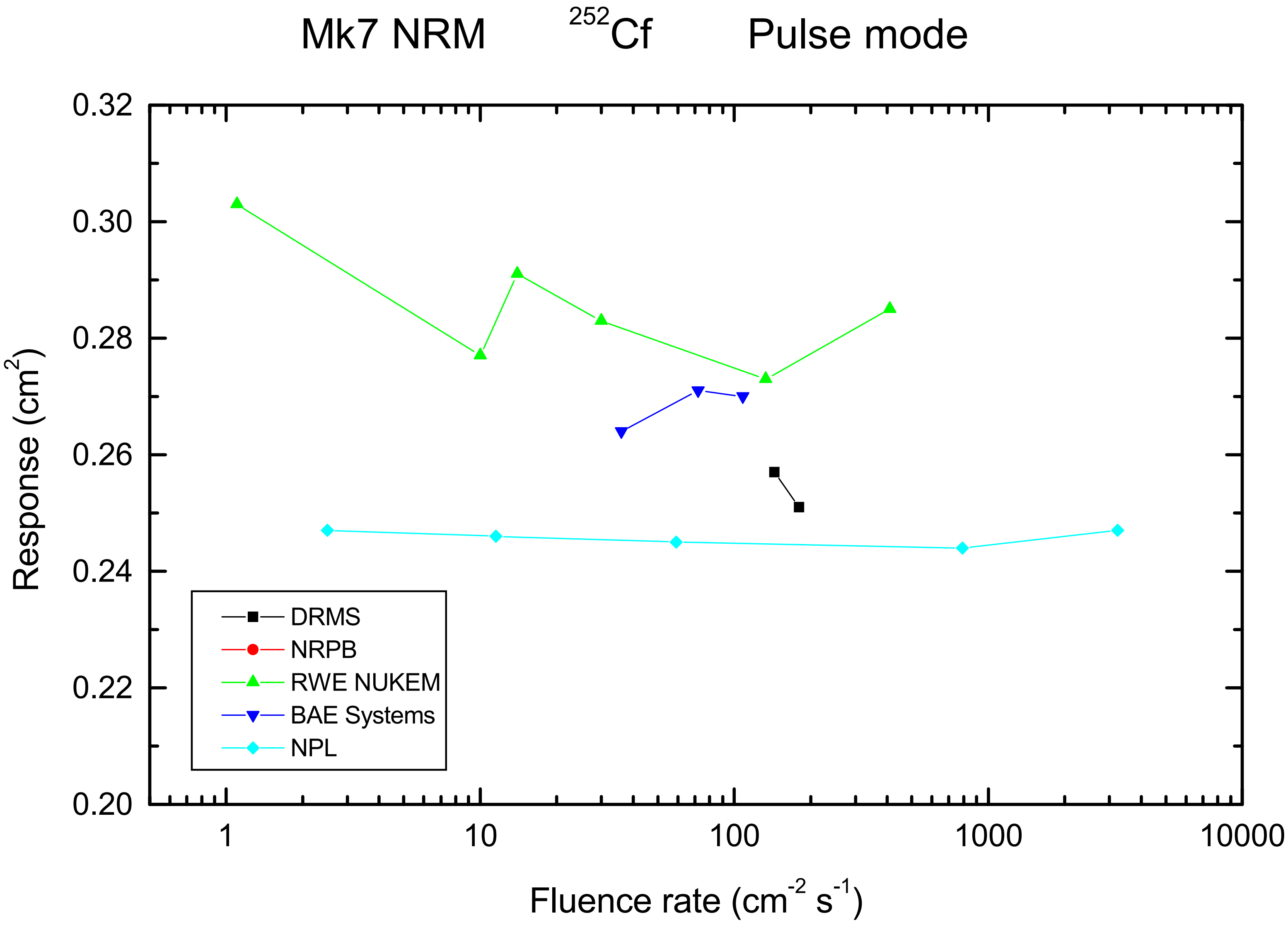
Table 10 Sample uncertainty budget: NPL

^{252}Cf	Distance: 2290 mm	Mk7 NRM	Pulsed output

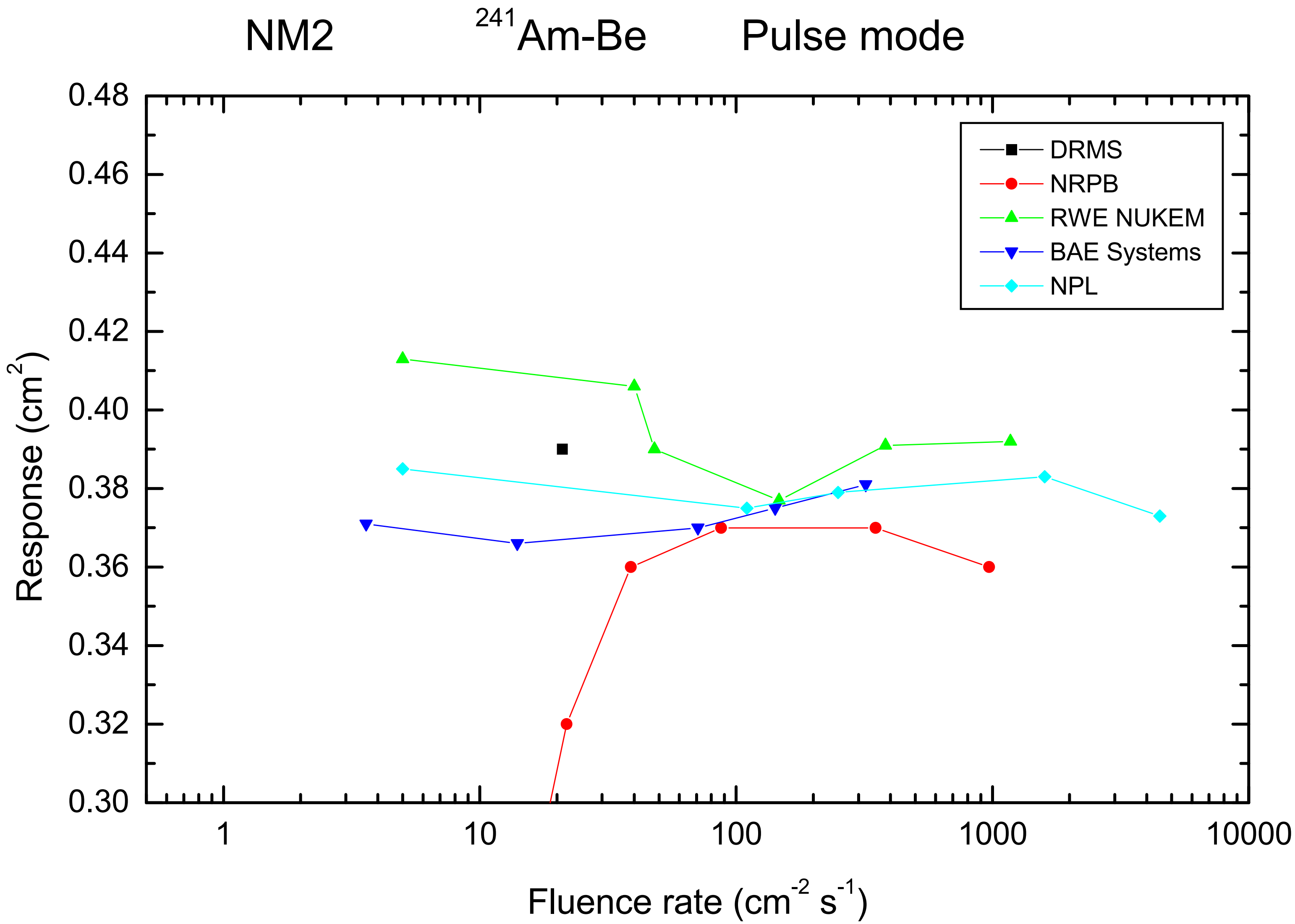
Quantity	Value	Uncertainty (∂x_i)	Probability distribution	Confidence level	Divisor	c_i / y	$u_i(y)$ (%)	v_i or v_{eff}
Mean reading of monitor, M	50,192	0.57 %	normal	68%	1	1	0.57 **	7
Period	64,000 s	negligible	-	-	-	-	-	-
Mean background reading, M_B	negligible	negligible	-	-	-	-	-	-
Emission rate: total Cf-252 Cf-250 Covariance	**1.67x10^6 s^{-1}** 1.58x10^6 s^{-1} 9.41x10^4 s^{-1}	**1.6 %** 1.0 % 39.6 % 6.3 %	normal	95%	2	**1** 0.9438 0.0562 0.2887	**0.80** (0.47) (1.11) (0.91)	∞
Distance, r: calibration repeatability position of effective centre	2290 mm	2 mm 2 mm 2 mm	rectangular normal rectangular	- - - 68% - - -	√3 1 √3	200 / 2300 200 / 2300 200 / 2300	0.10 0.18 0.10	∞
Anisotropy, f_A	1.021	0.0025	normal	95%	2	100 / 1.02	0.13	∞
Attenuation correction, f_{aa}	0.976	1.5%	normal	68%	1	0.024	< 0.01	∞
Source half life: Cf-252 Cf-250	2.645 y 13.08 y	0.30% 0.70%	rectangular	- - -	√3	0.341 0.004	0.06 0.002	∞
Room scatter, f_{sc}	1.254	0.71%	normal	68%	1	1	0.71	∞
Combined uncertainty			normal				1.23	∞
Expanded uncertainty (k = 2.0)			normal				2.5	∞

** Derived from SDOM of 8 cycles of 8000 s

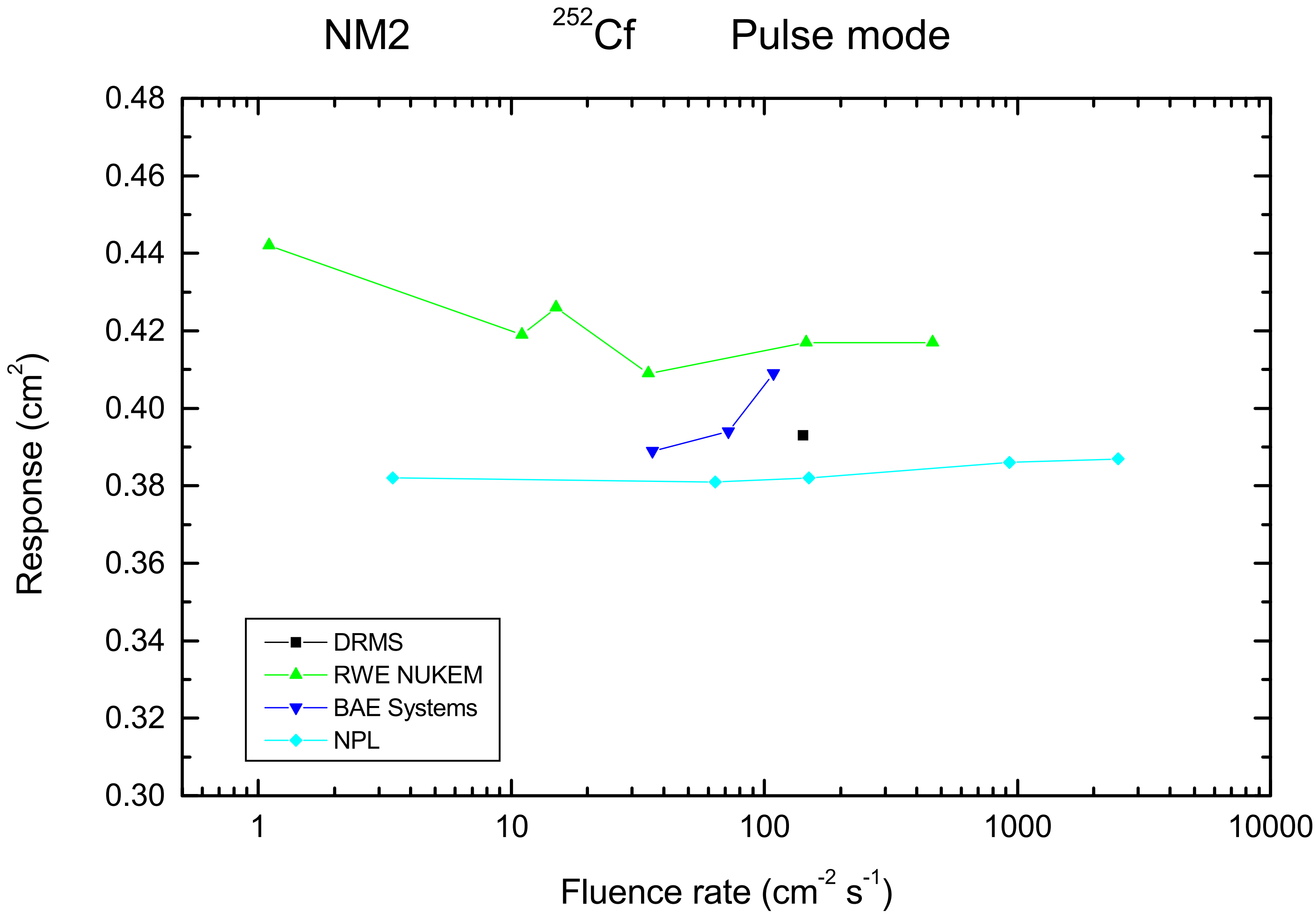

Mk7 NRM
241Am-Be
Pulse mode
Response (cm2)
Fluence rate (cm-2 s-1)
0.32
0.30
0.28
0.26
0.24
0.22
0.20
1
10
100
1000
10000
DRMS
NRPB
RWE NUKEM
BAE Systems
NPL

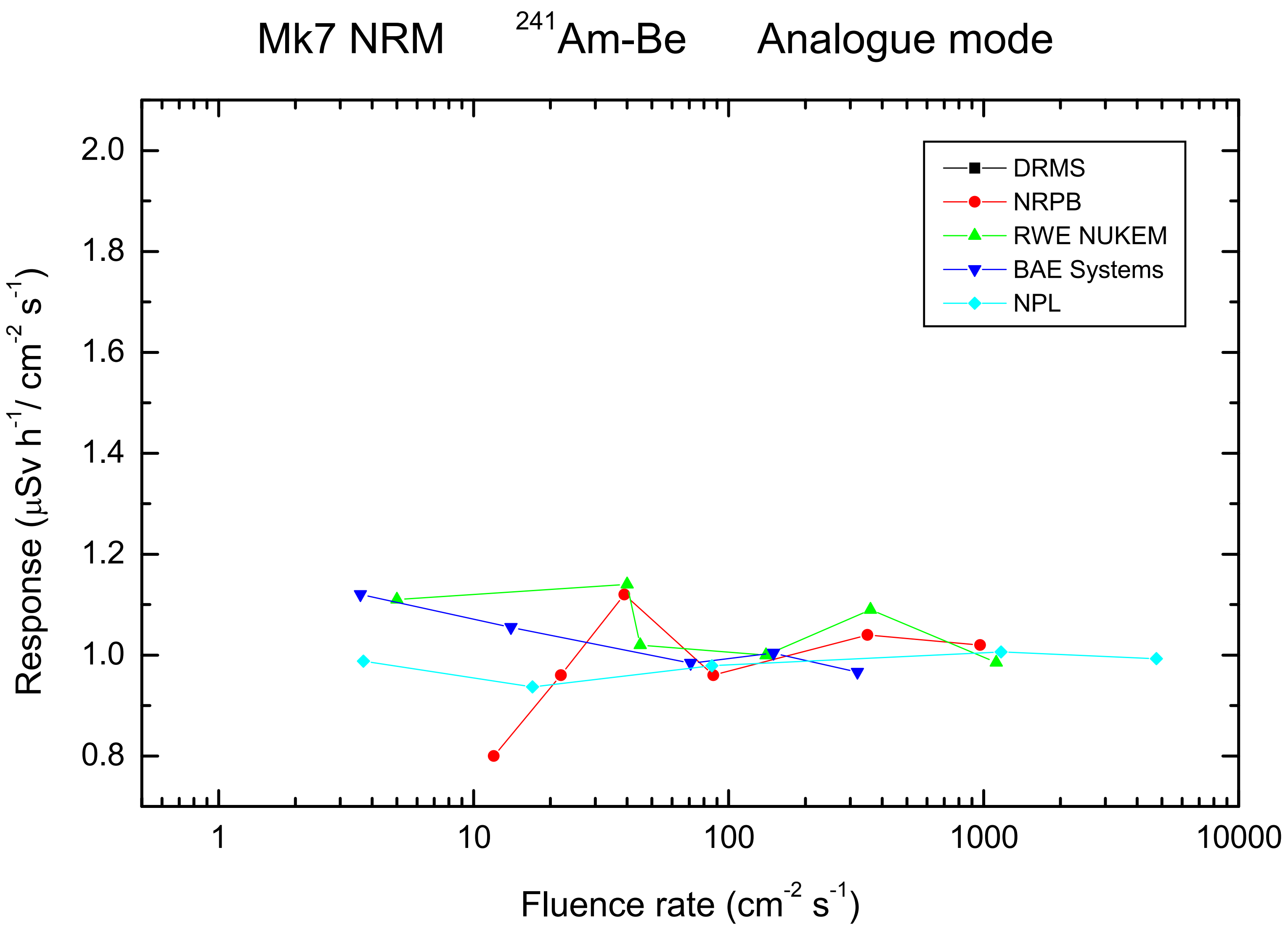


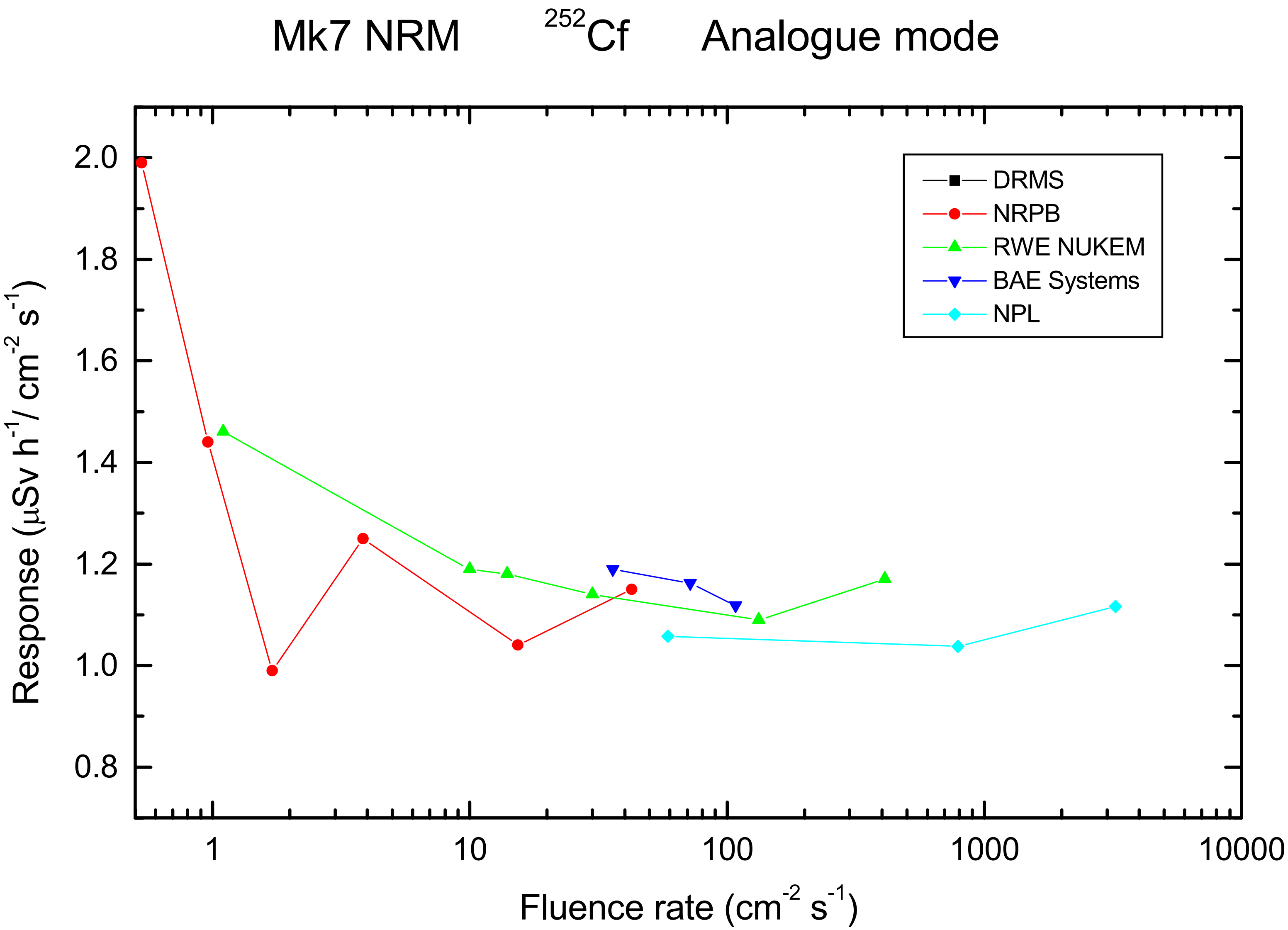
Mk7 NRM
252Cf
Pulse mode
0.32
0.30
0.28
0.26
0.24
0.22
0.20
Response (cm2)
1
10
100
1000
10000
Fluence rate (cm-2 s-1)
DRMS
NRPB
RWE NUKEM
BAE Systems
NPL

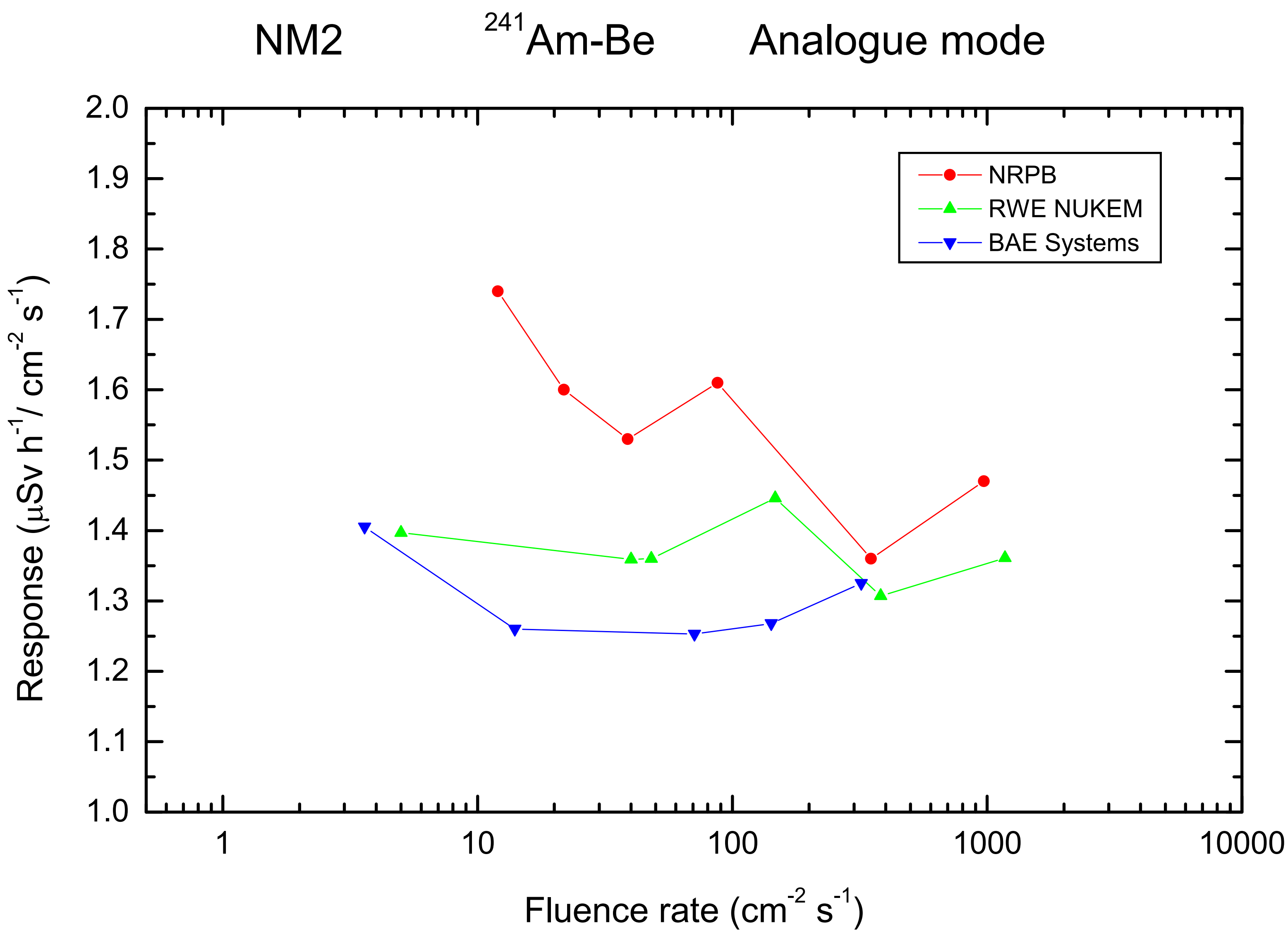


NM2
241Am-Be
Pulse mode
Response (cm2)
Fluence rate (cm-2 s-1)
0.48
0.46
0.44
0.42
0.40
0.38
0.36
0.34
0.32
0.30
1
10
100
1000
10000
DRMS
NRPB
RWE NUKEM
BAE Systems
NPL

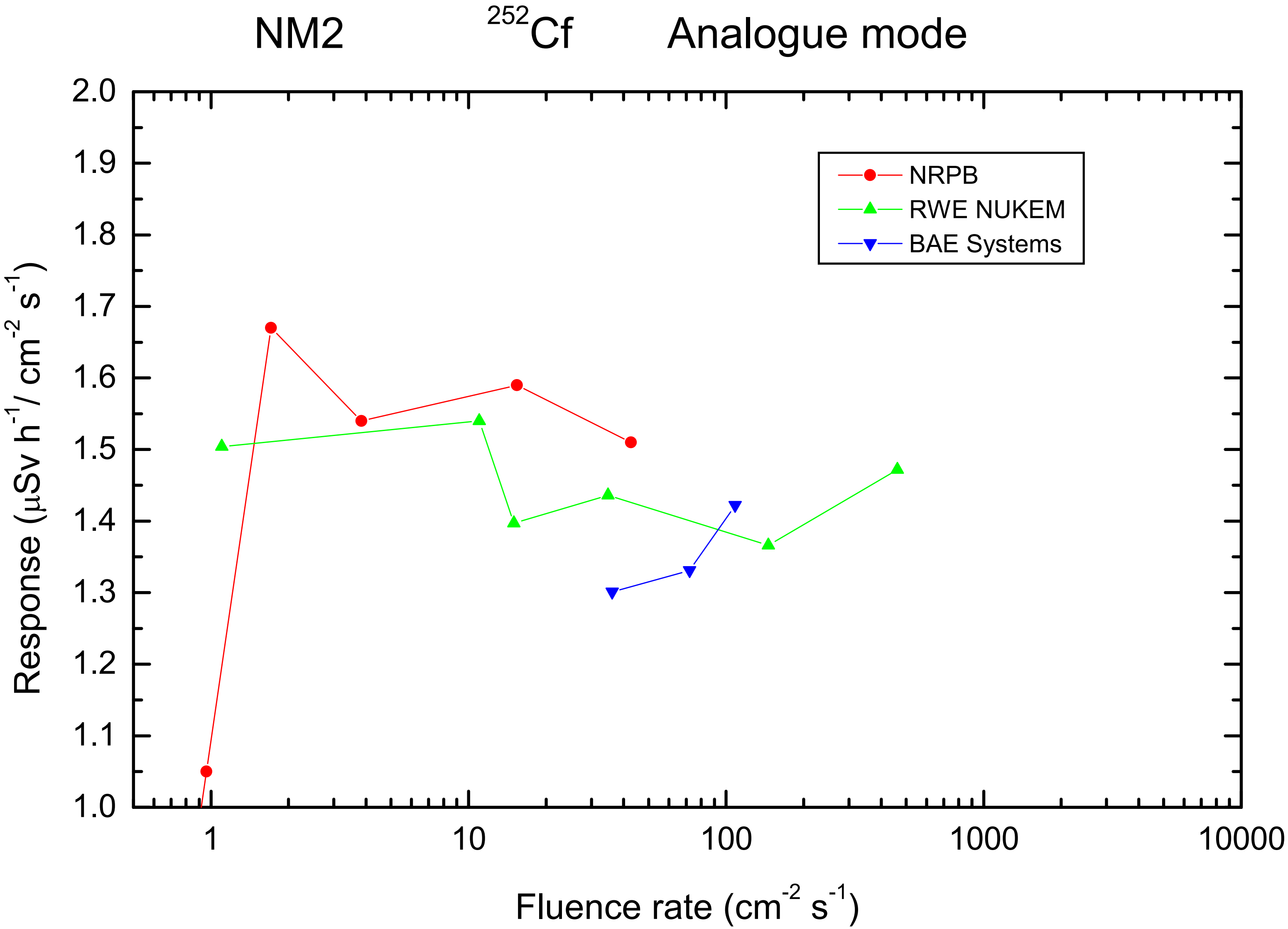

NM2
^{252}Cf
Pulse mode
Response (cm^2)
0.48
0.46
0.44
0.42
0.40
0.38
0.36
0.34
0.32
0.30
1
10
100
1000
10000
Fluence rate (cm^{-2} s^{-1})
DRMS
RWE NUKEM
BAE Systems
NPL


Mk7 NRM
241Am-Be
Analogue mode
Response (μSv h-1 / cm-2 s-1)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
1
10
100
1000
10000
Fluence rate (cm-2 s-1)
DRMS
NRPB
RWE NUKEM
BAE Systems
NPL

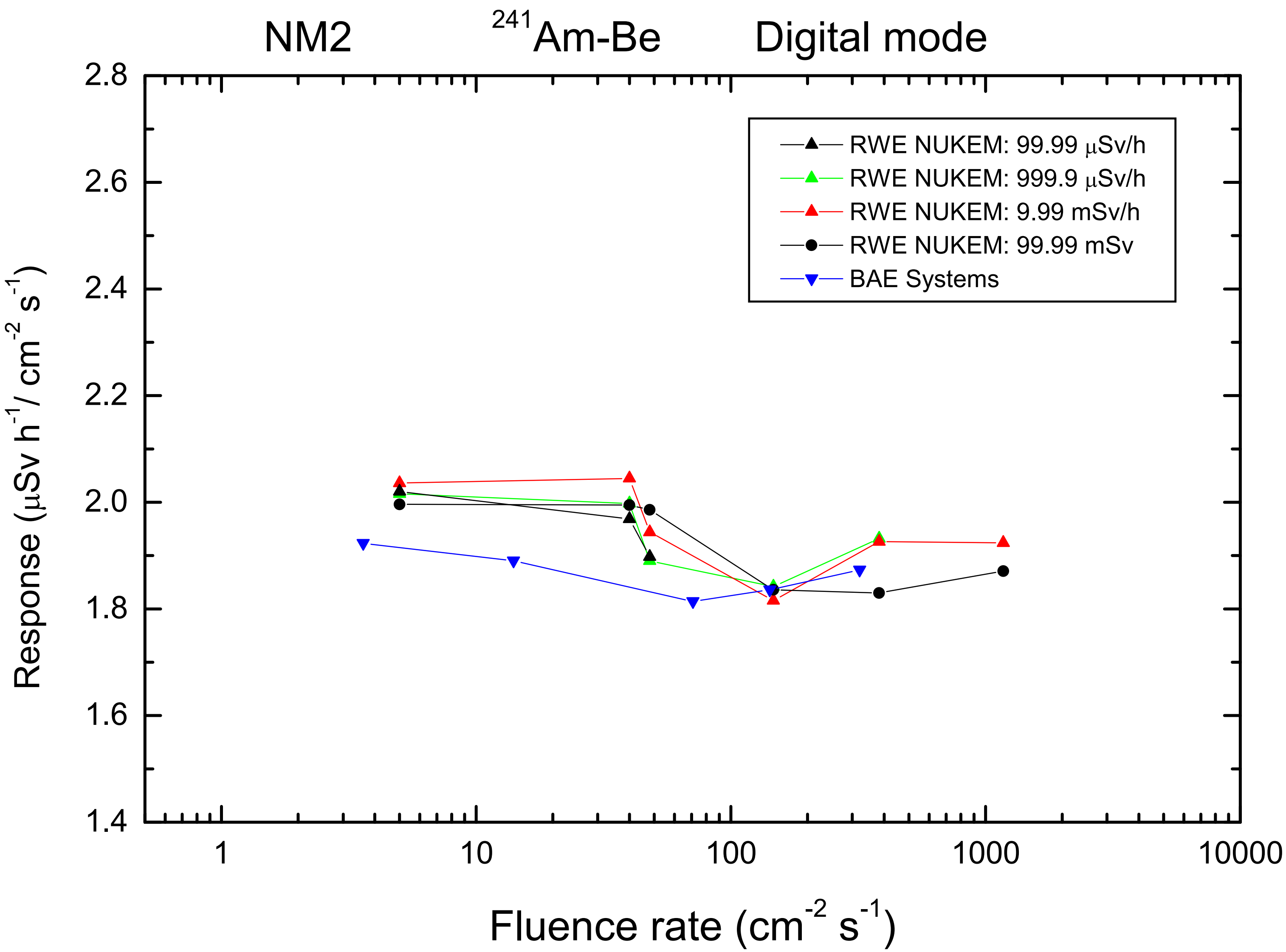

Mk7 NRM
252Cf
Analogue mode
Response (µSv h-1/ cm-2 s-1)
0.8
1.0
1.2
1.4
1.6
1.8
2.0
1
10
100
1000
10000
Fluence rate (cm-2 s-1)
DRMS
NRPB
RWE NUKEM
BAE Systems
NPL



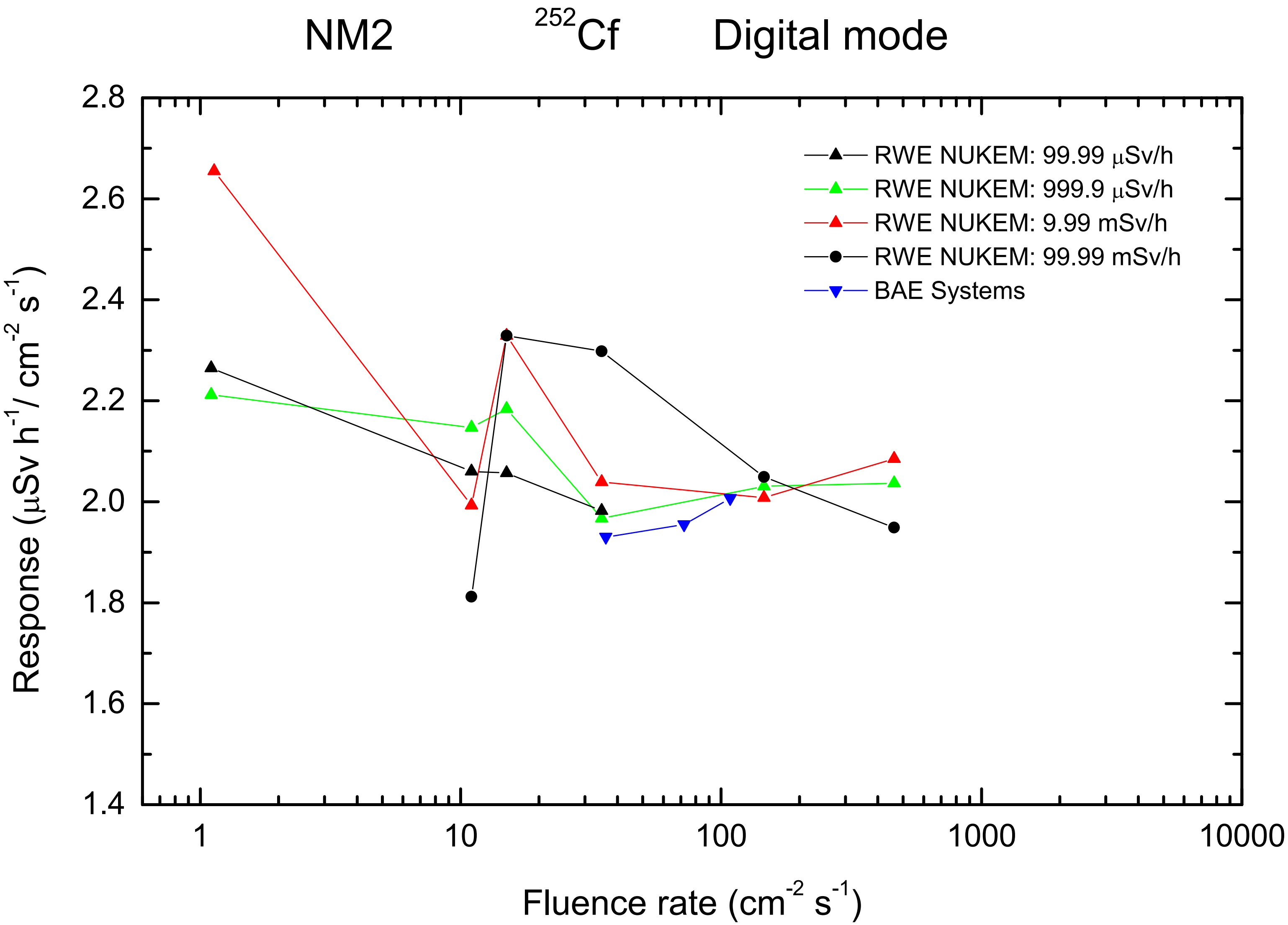
NM2
241Am-Be
Analogue mode
NRPB
RWE NUKEM
BAE Systems
Response (µSv h-1 / cm-2 s-1)
Fluence rate (cm-2 s-1)
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
1
10
100
1000
10000



NM2
252Cf
Analogue mode
Response (μSv h-1 / cm-2 s-1)
Fluence rate (cm-2 s-1)
NRPB
RWE NUKEM
BAE Systems
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
1
10
100
1000
10000



NM2
241Am-Be
Digital mode
RWE NUKEM: 99.99 µSv/h
RWE NUKEM: 999.9 µSv/h
RWE NUKEM: 9.99 mSv/h
RWE NUKEM: 99.99 mSv
BAE Systems
Response (µSv h-1 / cm-2 s-1)
Fluence rate (cm-2 s-1)
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1
10
100
1000
10000



NM2
^{252}Cf
Digital mode
RWE NUKEM: 99.99 μSv/h
RWE NUKEM: 999.9 μSv/h
RWE NUKEM: 9.99 mSv/h
RWE NUKEM: 99.99 mSv/h
BAE Systems
Response (μSv h^{-1}/ cm^{-2} s^{-1})
Fluence rate (cm^{-2} s^{-1})
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1
10
100
1000
10000

ANNEX PROTOCOL

PROTOCOL

1 INTRODUCTION AND AIMS

The Ionising Radiations Metrology Forum (IRMF) aims to encourage good practice in radiological measurements through the organisation of regular comparisons. Following the completion of two successful comparisons of neutron area survey dose equivalent monitors, the IRMF agreed to organise a third exercise. The aim is to assess the present calibration capabilities of the laboratories within the United Kingdom to perform routine calibrations of survey instruments in pursuance of the Ionising Radiations Regulations 1999.

The comparison will involve the circulation of two commercially-available instruments, both of which are extensively used in the UK, to the participating laboratories. To keep the exercise as simple as possible and to ensure that a meaningful comparison can be made between results from different laboratories, the quantity measured will be the free-field response of the instruments in designated neutron fields. In order that the exercise and its conclusions reflect the routine calibration capabilities it is essential that participants employ the same techniques to calibrate the two transfer instruments as those used routinely within their organisations.

It is quite acceptable for laboratories to take advantage of the opportunity to make additional measurements, provided they do not in any way modify the results obtained using the routine techniques, and provided they do not prejudice the time scales agreed for the overall exercise.

2. PARTICIPANTS

The participants are:

AEA Technology, Harwell	(Reg Bosley)
BAE Systems, Barrow-in Furness	(Jon Silvie)
BNFL, Berkeley	(Barbara Gallani)
DRaStaC, AWE Aldermaston	(Peter Danyluk)
NPL, Teddington	(Graeme Taylor)
NRPB, Chilton	(Duncan McClure)

3 QUANTITY TO BE MEASURED

The definitive quantity to be measured will be the quotient of the instrument pulse output by neutron fluence at the position of the effective centre of the instrument. The result will be quoted in terms of counts per unit fluence and will have the dimensions, cm^2.

The dial-reading response will also be measured.

It is not necessary to convert fluence to dose equivalent response.

4 NEUTRON FIELDS

The neutron fields to be used will be those produced using

- ^{241}Am-Be and ^{252}Cf sources
- accelerator-produced, monoenergetic 2.7 MeV neutron field.

5 INSTRUMENTS

The two area survey instruments to be used in the comparison are:

(a) Mark 7 NRM neutron dose rate meter
Spherical monitor supplied by BAE Systems
Serial number: N221
Analogue meter; log display from 1 μSv/h to 10 mSv/h in 4 decades
Pulse output: negative-going pulses

(b) NM2 neutron dose rate meter
Cylindrical monitor supplied by BNFL, Berkeley
Serial number: NM2B 283
Digital display: 4 digit from 0.01 μSv/h to 99.99 mSv/h
Analogue meter: log display from 1 μSv/h to 100 mSv/h in 5 decades
Pulse output: 2 V minimum amplitude, 2 μs width
External recorder output: 100 mV corresponds to fsd on internal meter

User manual/data sheets will be included in the transport case with each instrument.

These are accompanied by a model UC106 universal counter (serial number 0117).

6 DOSE EQUIVALENT RATE RANGES

Participants may choose the appropriate fluence rates for their measurements by positioning the monitors at various distances from the sources.

It is anticipated that the ^{241}Am-Be neutron fields to be used could have dose rates of up to 1500 μSv h^{-1}. In order to investigate the influence of possible rate effects, it is proposed that at least one participant using the accelerator-produced fields should make some measurements at up to 5 mSv h^{-1}.

7 ORGANISATIONAL DETAILS

The instruments will be circulated to each participant in turn according to the agreed timetable; version 1 is attached.

- The measurements by a participant and subsequent transportation to the next participant should be completed within one calendar month.

- It will be the responsibility of each participant to arrange for both collection and despatch of the instrumentation with the preceding and following participants.

Before and after the measurements by the participants the response of the monitors will be checked at NPL using a fixed geometry arrangement and an ^{241}Am-Be source.
Another check will be made halfway through, when the instruments are at NPL.

8 MEASUREMENT DETAILS

The definitive measurement is that of pulse count rate per unit fluence rate (events cm^2). This provides the best precision with good counting statistics for sufficiently long counting periods. For participants who do not routinely measure the pulse output rate, BAE Systems have kindly lent a small stand-alone scaler system that can be used close to the instrument.

It is important to also calibrate the dial or analogue meter reading as this is what the end-user requires.

- For an analogue meter with a scale calibrated in dose equivalent rate, the reported meter response will be in dose equivalent rate per unit fluence rate (mSv h^{-1} cm^2 s).
- For a digital dial reading calibrated in dose equivalent rate, the reported dial response will also be in dose equivalent rate per unit fluence rate (mSv h^{-1} cm^2 s). This may be measured using the integral mode of operation if available.

8.1 Instrument adjustments

There will be no deliberate off-set because there is no universally recognised 'correct' value for these instruments. Some calibration laboratories routinely adjust instrument responses on receipt, for example, to ensure complete gamma rejection in all measurement situations. **This should not be done in this case** since it would invalidate the exercise as a comparison of identical instruments. For the radionuclide sources there will be no gamma rejection problems.

8.2 Calibration technique

The exercise is meant to be a comparison of results obtained using the calibration techniques routinely employed by each participant. This is a good opportunity to try other techniques; if other measurements are made, the results should be reported separately.

8.3 Instrument orientation

The instruments should be mounted as shown in the accompanying figure.

- Mark 7 NRM with the electronics on the side away from the source of neutrons
- NM2 with the axis of cylindrical symmetry vertical with the electronics on top and the dial facing away from the source.

The effective centre of the Mark 7 NRM may be assumed to be the centre of the polyethylene moderating sphere.

The effective centre of the NM2 may be assumed to be on the axis of cylindrical symmetry at a distance of 12.5 cm from the semi-rounded end of the polyethylene moderator (see figure).

8.4 Power supplies for the instruments

The battery life of the Mark 7 NRM is about 150 hours.

Following the problems encountered in the previous comparisons, various aspects of the power supply situation will be checked by NPL before the measurement phase. This protocol will be revised as necessary.

9 INFORMATION REQUIRED FROM PARTICIPANTS

Pro-forma report sheets must be used to detail the information required when reporting results. Copies will be distributed in electronic form.

- Form IRMF/N3/1 is for results obtained using radionuclide sources.

  The response must be calculated for each distance (fluence rate) used and a mean value calculated. The former values will be plotted in the report and the latter tabulated.
  The main correction will be for the response of the instrument to scattered neutrons; the technique used to perform these corrections should briefly be described.

  Define also what is meant by the value of the scattering correction: ie. whether it is a fraction of the direct (unscattered component) of the reading or a fraction of the total reading or an absolute value.

- Form IRMF/N3/2 asks for details about the radionuclide sources

- Form IRMF/N3/3 is for the results obtained using accelerator-produced fields.

  See comments for IRMF/N3/1.

- Form IRMF/N3/4 asks for details about the accelerator-produced fields

  These will enable target interaction corrections to be derived if required.

- Form IRMF/N3/5 covers source and detector mounting, and calibration room details.

- Form IRMF/N3/6 contains a table to be used for details of uncertainties.

  The quantities given are suggestions and may by changed by the participant.
  The confidence level used must be specified.
  A confidence level of 95% (coverage factor $k = 2$) is recommended.
  Participants must estimate the uncertainty in:
  - instrument reading
  - neutron fluence (or fluence rate) at the instrument
  - scatter correction

  The total (expanded) uncertainty for derived response must be calculated.

  For the pulse measurements the uncertainty in the instrument output can be derived from counting statistics, for dial readings from repeat readings.

Separate forms IRMF/N3/1,2,3,4,6 must be completed for each and every combination of neutron field and instrument.

10 COLLATION OF RESULTS AND REPORT

Participants must send completed pro-forma report sheets and send them within four weeks of completing their measurements to the evaluator, Vic Lewis (NPL; 020 8943 6851).
Participants who fail to do so will be named in the report.

A summary report will be prepared and distributed to all participants prior to holding a meeting to finalise the report and agree conclusions to be drawn from the comparison.
The final report will be produced as an open NPL report.