NPL
National Physical Laboratory

NPL REPORT
DQL-RN 012

Comparison of Strontium-89 Solution Sources in UK Hospitals, 2003

D.K. Tyler, M.I. Baker, M.J. Woods

NOT RESTRICTED

May 2005

FUNDED BY THE DTI

National Physical Laboratory | Hampton Road | Teddington | Middlesex | United Kingdom | TW11 0LW
Switchboard 020 8977 3222 | **NPL Helpline** 020 8943 6880 | **Fax** 020 8943 6458 | **www.npl.co.uk**

dti

The DTI drives our ambition of 'prosperity for all' by working to create the best environment for business success in the UK. We help people and companies become more productive by promoting enterprise, innovation and creativity.

We champion UK business at home and abroad. We invest heavily in world-class science and technology. We protect the rights of working people and consumers. And we stand up for fair and open markets in the UK, Europe and the world.

The National Physical Laboratory is operated on behalf of the DTI by NPL Management Limited, a wholly owned subsidiary of Serco Group plc

Comparison of Strontium-89 Solution Sources in UK Hospitals, 2003.

Dagmara K Tyler, Michaela I Baker, Michael J Woods*
Quality of Life Division
National Physical Laboratory
Teddington, Middlesex, TW11 0LW
United Kingdom

*Ionising Radiation Metrology Consultants Ltd
152 Broom Road
Teddington, Middlesex, TW11 9PQ
United Kingdom

Abstract

Concerns have been raised within the nuclear medicine field about the accuracy of measurements of the activity of ^{89}Sr. Measurements of ^{89}Sr activity at NPL have found that the ^{85}Sr impurity, that is present in the ^{89}Sr solution, has a significant effect on the response of radionuclide calibrators routinely used in UK hospitals.

To assess the magnitude of these effects on the accuracy of clinical measurements of the activity of ^{89}Sr, a comparison was conducted between the National Physical Laboratory (NPL) and the UK hospital physics community.

93 results were reported for this comparison. Only 58 % of these results were within 5 % of the NPL value. There were also a small number of results reported with large discrepancies (up to 82 % in error). All results are for 10 R Schott vials only.

This comparison has revealed that there is still room for improvement in measuring this radionuclide and, to this end, NPL has derived correction factors for the NPL secondary standard radionuclide calibrator and Capintec systems.

ISSN 1744-0629

National Physical Laboratory
Teddington, Middlesex, TW11 0LW
United Kingdom

Approved on behalf of Managing Director, NPL, by
Dr Desmond MacMahon, Knowledge Leader
Radioactivity and Neutron Metrology Team
Quality of Life Division

CONTENTS

TABLES

ILLUSTRATIONS

APPENDICES

1 INTRODUCTION

Radioactive materials are widely used in hospitals for therapeutic, diagnostic and research purposes. The choice of radionuclide depends on the type of radiation emitted as well as its expected pathway through the body. The activity of a particular radionuclide should be determined accurately prior to administration to the patient. Radionuclide calibrators are the most commonly used instrument for radionuclide activity assay; they are normally based on high pressure, re-entrant ionisation chambers. Calibration factors for solution formats are determined directly by measuring the ionisation chamber response to solutions that have been standardised using absolute methods. The operation of such radionuclide calibrators is relatively straightforward and, if used correctly in conjunction with a recognised quality assurance system, the relevant levels of accuracy can be achieved. A protocol for such a QA system has been recommended for use in UK hospitals[(1)].

As part of its ongoing programme, supported by the National Measurement System Policy Unit of the Department of Trade and Industry, the National Physical Laboratory's Radioactivity Metrology Group is conducting a series of comparisons and workshops concerned with the use of radionuclide calibrators in practice. This continues the very well-subscribed comparisons conducted in previous years [(2-9)]. The aim is to determine the overall level of measurement performance in UK hospitals, to identify and discuss problems and to facilitate the exchange of information.

^{89}Sr behaves like calcium in the body and it is used for therapeutic purposes. Concerns have been raised at the UK Radionuclide Calibrator Users Forum by the nuclear medicine community about the accuracy of activity measurements for this radionuclide. Measurements of the activity of ^{89}Sr at NPL have found that the ^{85}Sr impurity, that is present in the ^{89}Sr solution, has a significant effect on the response of radionuclide calibrators routinely used in UK hospitals. Different impurity levels of ^{85}Sr between batches mean that it is more difficult to apply conventional calibration techniques based on the derivation of a new calibration factor.

A comparison was conducted, between NPL and the UK hospital physics community, to assess the current situation regarding ^{89}Sr activity measurements and to provide

hospitals with a traceable standard, which enables them to re-calibrate their systems. Initially it was envisaged that it would be possible to provide each participant with a response factor for their particular calibrator. However, as the comparison progressed it became apparent that this would only be possible for the NPL secondary standard radionuclide calibrator systems (SSRC, NPL-CRC, 671/271, Isocal IV), as the manufacturing tolerances for the other chambers are not sufficiently known. This calibration procedure could only be used to re-calibrate chambers used in this comparison: it cannot be applied to any other calibrator. Correction formulae have been derived for the NPL SSRC, Isocal III and Capintec systems. These can be used by anyone with these types of calibrator to improve their measurements.

2 PARTICIPANTS

Participation was open to all UK hospitals. A total 36 hospitals took part in the comparison, with 32 reporting results, with 25 reporting more than one result.

A list of the participants is given in Appendix 1.

3 COMPARISON SAMPLES

The stock solution was procured from Nycomed Amersham and accurately subdivided into 10R Schott vials. The samples, each comprising approximately 4 ml of solution, were then assayed at NPL and dispatched to participants. At 12.00 GMT on 23rd June, the mean activity concentration of the solution was 38.15 MBq g^{-1}. For this comparison, the activity of each sample is given in Table 1. A total of five sources were dispatched, with each one being assayed by several participants. The samples comprised ^{89}Sr, as chloride with 30 μg g^{-1} of inactive Sr in 0.1M HCl.

4 NPL MEASUREMENTS OF COMPARISON SAMPLES

The activity concentration of each sample was determined by assay on NPL's master SSRC (it should be noted that this system has also been known in the past as the NPL-CRC, 671/271 chamber and Isocal IV). This system has been previously calibrated for ^{89}Sr using solutions which have been standardised absolutely using the primary standardisation facilities and techniques available at NPL. One absolute method employed was 4πβ (atmospheric pressure, proportional counter) counting. The efficiency of the proportional counter is 99 % ± 0.5 % (*k = 1*). The other technique employed was the absolute 4πβ-γ coincidence tracer efficiency technique using ^{86}Rb and ^{24}Na as the tracers. These standards are supported by results from comparisons with other National Metrology Institutes.

The samples were measured by gamma spectrometry to identify and quantify any contaminant in the sample. The presence of ^{85}Sr was confirmed with its activity being ~ 0.17 % of the ^{89}Sr activity at reference time. Table 1 shows the values for each sample. This contaminant level was taken into account when calculating the activity of the ^{89}Sr samples.

The uncertainties on the NPL ^{89}Sr and ^{85}Sr activity measurements were ± 1.7 % and ± 2.2 % respectively (*k=2*).

5 MEASUREMENT AND REPORTING PROTOCOL

There was a change in the measurement protocol of this comparison compared to previous years. This was due to the original concept of providing participants with individual response factors. The participants were asked to assay the ^{89}Sr solution on their calibrators and to report their results back to NPL. The participants were asked to report both ^{89}Sr activity uncorrected for the ^{85}Sr impurity, and the ^{89}Sr activity corrected for ^{85}Sr (if any such corrections were made). The participants were asked not to re-set or to derive new calibration factors for the comparison samples.

The only measurement format that could be performed for this comparison was the 10R Schott vial. No solution transfer was possible as the sources had to be sent to other participants. The participants were asked to report the details of their radionuclide calibrator and the ^{89}Sr calibration or dial factor setting used. Information was also sought on the origin of the calibration setting as to whether it was self derived or obtained from the manufacturer, and on any corrections applied to account for the ^{85}Sr impurity. Estimates on uncertainty calculations were also asked for. A standard reporting form was provided: a copy is shown in Appendix 2.

The results were collated and analysed by NPL. Each participant was sent their results in the form of a ratio, namely, Reported ^{89}Sr activity / NPL ^{89}Sr activity. If participants applied a correction for ^{85}Sr, then these values were used.

6 CONFIDENTIALITY

All results were reported directly to NPL. Each reported result was given a code number by NPL and the results in this report are tabulated against those code numbers. The correlation between code number and the participant remains confidential to NPL.

7 ANALYSIS OF RESULTS

Of the 36 hospitals that took part in the comparison, 32 returned results and 25 returned multiple results. The multiple results ranged from using different dial factors for the same calibrator to using different calibrators. 93 results were returned in total, representing 6 different calibrator manufacturers with a total of 19 different models used for the measurements.

Table 1 shows the individual sample activities at the NPL reference time of 23 June 2003 12:00 GMT. In contrast to previous comparisons, the NPL measurement results were decayed to the participants' measurement times. The half lives used are listed in

Table 6. There was no transfer of solution to different containers in this comparison and all results refer to 10R Schott vials.

Table 2 shows all the results and they have been tabulated as ratios of the reported ^{89}Sr activity to the NPL ^{89}Sr activity. The reported activity is also shown in the table. An asterisk (*) in the settings/dial factor column denoted that the participant applied a self-derived dial factor.

Table 3 shows a summarised breakdown of results by calibrator model. The results are selectively displayed in both scatter plot and histogram form in Figures 1 - 9.

The uncertainties reported by the participants are shown in Table 4.

Table 5 shows the distribution of results from this and previous comparisons expressed as a percentage of results within 5 and 10 % of the NPL value. It should be noted of course that ^{89}Sr is a therapeutic nuclide and as such it would be better to judge performance by looking at the 3 and 5% distributions rather than those for 5 and 10%.

The distribution of results is as follows:

Within ± 3 % of the NPL value:	44%
Within ± 5 % of the NPL value:	58%
Within ± 10 % of the NPL value:	86%

8 DISCUSSION

There were two main aims of this exercise. The first was to assess the current accuracy of ^{89}Sr activity measurements in hospitals using typical radionuclide calibrators; the second was to provide participants with a traceable standard which

enables them to check the performance of their systems and to recalibrate their systems, if necessary.

In addition, NPL has provided a procedure (correction formulae) which participants can follow. The formulae will allow the accurate determination of ^{89}Sr taking into account the ^{85}Sr contaminant. This procedure requires the ratio of the ^{85}Sr activity to the ^{89}Sr activity to be known and this is easily obtainable from the supplier of the ^{89}Sr solution.

The accurate assay of this radionuclide is problematic since the relative response of calibrators for β-emitters is very small compared to that for γ-emitters. This means that any γ-emitting impurity will have a large effect on the response of the chamber. This is acknowledged by manufacturers and Capintec state that, for their CRC calibrator series, the response for pure β-emitters is of the order of 1 % of a γ-emitter and that the contamination of a small faction of γ-emitters in a ^{89}Sr sample will have a large influence on the attainable precision of ^{89}Sr measurements. Capintec quantify this by stating that a contaminant level of 0.1 % will generate an error of approximately 5 % on the ^{89}Sr activity[12]. Typically, the contaminant level for ^{85}Sr in a ^{89}Sr sample has been of the order of 0.2 %: this will produce an error of about 10 % on the ^{89}Sr value when using a Capintec system, if an appropriate correction is not made. For the NPL SSRC, ^{85}Sr has a much larger relative response, of the order of 200 times that of ^{89}Sr.

8.1 ALL RESULTS

The overall received data, represented graphically in Figure 2 (scatter) and Figure 3 (distribution), show that there is a general spread of results of about ± 20 %. There are however 4 outliers which all underestimate the ^{89}Sr activity, 3 are ~ 50 % below the target value and 1 result showed a deviation of 82 % below the target value. The results, including the outliers, are discussed in more detail under both calibrator and calibration factor results.

Some 86 % of the results lie within 10 % of the NPL value, and 58 % lie within 5 % of the NPL value. It is generally assumed that hospitals need to measure to an accuracy of ± 10 % for diagnostic purposes and ± 5 % for therapeutic purposes. It should be stressed however that the therapeutic ± 5 % accuracy requirement refers to the overall treatment regime and not just the radioactivity assay, so it is important to improve this level of accuracy to below ± 5 % (± 3% is a typical target). Taking the ± 3% level, less than half (44%) of the reported results meet this strict requirement

When the four outliers are ignored, the remaining results show that there is a bias in the results towards overestimating the activity with 59 of the residual 89 results being above the target value and 30 below.

There are several possible reasons for the large spread of the results.

(a) The accuracy of the calibration factors, dial factors or settings may be in error for the containers being assayed. With the exception of the NPL SSRC calibrator, the accuracy and traceability of the calibration factors for most commercially available calibrators are not known. Also, the calibrator factors supplied by the calibrator manufacturer are for specific container formats, which may not be the same as the ones used in practice. For Capintec systems, the ^{89}Sr setting is not well known and the corresponding ^{85}Sr setting is for a 5 ml solution in a 5 ml NBS ampoule. For this comparison, the container was the 10 R Schott vial which is significantly different to the Capintec reference container. This container and volume effect is more significant for low energy gamma emitters and pure beta emitting radionuclides. The best way to avoid this situation is to follow the UK protocol for maintaining the quality of radionuclide calibrator performance. This report recommends that calibration figures should be checked at installation, for the preferred container format, and then rechecked on a regular basis.

(b) The tolerances for the dimensions and the gas filling of radionuclide calibrators made by the same manufacturers may not be sufficiently controlled or specified. Often, the calibrator is set up using a radioactive reference source but, typically, the lowest energy gamma emitter that would be used would be ^{57}Co.

Although this is adequate for most purposes, the principal photon energy is 122 keV and small variations in response at this energy could correspond to significantly larger variations at lower energies. Thus, small variations in the thickness of the inner wall of calibrators of the same type would generate considerable differences in response to both low energy gamma emitters and pure beta emitters. The exception to this is the NPL SSRC, which is required to meet strict production tolerance requirements even at 30 keV.

(c) The introduction of extra fittings such as PVC liners, which are used to avoid contamination, lower the response of calibrators. These liners produce extra attenuation and for low energy radionuclides this can have a significant effect. Calibrators using these liners should be re-calibrated for ^{89}Sr.

(d) If shielding is used on the calibrators or if there are any deviations from the normal measurement regime for which the factors are valid, then the radionuclide calibrator needs to be re-calibrated.

8.2 CALIBRATION FACTORS

The calibration factors are categorised into three types:

manufacturer - which encompasses presets, manufacturer recommended dial settings or calibration factors and internal library settings for ^{89}Sr;

self derived – including deriving factors after having the solution measured at NPL (NPL hospital calibration);

others (this includes those using presets other than for ^{89}Sr and those where no information was supplied by the participant).

The spread of all results categorised by dial factors is represented in Figures 6 and 7.

Several participants also reported using different factors for the same calibrator types but no explanations were given for the reasoning behind this. There are two possible explanations that could account for this: the factors were derived at different times or different factors were derived for different impurity levels. Without more details, it is not possible to draw any conclusions from the data currently available.

8.2.1 Manufacturers recommended factors

38 % of all the results were made using factors or settings provided by the manufacturer. Within that group, 69 % of these measurements fall within 5 % of the NPL value and only 46 % fall within 3 % of the NPL value. There is no significant evidence of overall bias in this group. The two obvious outliers were those obtained from the Capintec CRC β counter.

8.2.2 Self derived factors.

In general, very little information was provided by participants on the derivation methodology of these factors. A few participants did state that they derived their factors after carry out a source calibration with NPL.

54 % of all the participants derived their own factors. There was a distinct bias for overestimation within this group, with almost three times as many results being higher than the NPL value compared with those being lower. 75 % of results overestimated the activity although 88 % of the results fell within 10 % of the NPL result. There was one outlier for this group, which was 45 % below the NPL value. The uncertainty on this result is 15 % at k=2. The calibrator used, as in the previous group, was the Capintec CRC β counter.

Within this group, 60 % of these measurements fall within 5 % of the NPL value and only 44 % fall within 3 % of the NPL value. It will be noted that these numbers are very similar to those in the manufacturers recommended factors group (8.2.1).

8.2.3 Other factors

There were eight other results submitted that did not clearly fit into the other two groups discussed above.

Two results were submitted which used factors which were appropriate to other nuclides.. One was for the Capintec CRC β calibrator, its γ-chamber and a setting for ^{90}Y was used. The participant reported that this setting was selected because it gave the closest reading to the β counter and the highest reading. This result was 48 % below the NPL value. The second result was for the Siel Bic 1 chamber and a setting for ^{99}Mo was used, again as it was the most sensitive setting, this result was also an outlier being 82 % below the NPL value. The result from the Capintec chamber was most likely due to using an incorrect dial setting for the chamber but this participant also had additional problems relating to the container holder (discussed further under the calibrator section), and that would also account for a deviation from the target value. These effects combined would certainly account for the high deviation seen from the target value.

A third result uses a Isocal IV chamber but a calibration factor for the Isocal III chamber. This result is within 2 % of the target value. This is easily explained as these two chambers are almost identical and hence the calibration figures are similar. The Isocal IV chamber is a secondary standard, whereas depending on its age the Isocal III may be the same chamber as the Isocal IV (but it did not meet the stringent requirements for a secondary chamber).

The other five results in this category were submitted with no information about the origin of the dial factors. All five were within 6 % of the target value.

8.3 CALIBRATORS

There were several different types of radionuclide calibrators and models used for this comparison. In many cases, the different model identifiers relate to the electronics,

with the same ionisation chambers being used. In these cases the same chambers have been grouped together.

The Capintec systems were most commonly used with ~78 % of the results being assayed on the Capintec calibrators.

8.3.1 NPL Secondary Standard Radionuclide Calibrator (NPL SSRC)

The NPL SSRC has been marketed under a variety of names, principally the NPL-CRC, Isocal IV and the 671/271. In each case, the ionisation chamber is identical and it is only the electronics which varies. Each production chamber is calibrated directly against the master chamber held at NPL and the master chamber itself is calibrated against absolute standards of radioactivity. Hence, all calibration factors including the ^{89}Sr and ^{85}Sr are directly traceable to national and international standards of radioactivity. The manufacturing tolerances on these calibrators are very strictly controlled, so that the variation of response between chambers is minimal, even in the case of ^{89}Sr in which the chamber is responding to the bremsstrahlung and this is very sensitive to the differences in the inner wall thickness of the calibrator. The calibration factors for these systems were originally derived for the P6 vials but, more recently, factors have also been derived for 10 R Schott vials. However, because of these strict tolerances, these chambers are very expensive and hence are not widely used in the field.

Five results were measured on these systems, which represents ~ 5% of the total results. One result was measured on the Isocal IV chamber with shield but this has not affected the result, which was 3% higher than the target value. The results are displayed in Figure 4. Four of the five results are within 3 % of the target value with there being no bias towards over or under estimating. One result is 18 % high but the calibration figure used was self derived. This result suggests that the calibration figure needs be re-checked. For these chambers it is best to use the calibration figures supplied by the manufacturers but if self derived figures are used than they should be determined using sources traceable to national standards. (NPL offers a calibration service for medical nuclides). Three of the other results used factors from the manual

but it should be noted that these factors refer to P6 vials and 10R Schott vial factors should be used. The 10R Schott vial factors are shown in Table 7 and have been published[13]. One participant used figures for the Isocal III; depending on the age of the Isocal III it may be the same chamber as the Isocal IV and so the same calibration figures can be used but again these would have been for a P6 vial.

In order to take into account the effect of the ^{85}Sr impurity, a correction needs to be applied and the method and data necessary for this are provided in the user manual and in relevant publications. For convenience, this is repeated below and explained in Section 10.

8.3.2 Capintec systems.

Capintec's represented the vast majority of the results. These systems have been split into 3 catagories since many of the different models have the same ionisation chamber but differ in their electronics.

8.3.2.1 Capintec CRC 15R system.

The systems under this section are: CRC 15R and from the CRC 15R β counter system, the γ chamber component results.

The Capintec CRC 15R series is the most popular system used and this is confirmed by the fact that 58 % of the results returned used this system. 57 % of these results were within 5 % of the target value and 41 % were within 3 %. There is a wide spread of results and there is also a bias towards overestimating the activity, 75 % of the results returned were higher than the target value.

66 % of these results used self-derived factors, 27 % used manufacturers factors. The rest had either no information or used different radionuclide presets. Again it should be stated that the manufacturers factors will be for P6 vials or other containers and

that each calibrator will need to be recalibrated for 10 R Schott vials. No information was provided by the participants as to whether the self-derived factors were derived for 10 R Schott vials. Indeed, the calibrator factors should be derived for the routinely used container type, whatever it may be. One participant used the ^{90}Y calibration factor and this returned a result that was 48 % below that target value. This participant also had problems with their container holder, the 10 R Schott vial did not fit into the holder.

8.3.2.2 CRC 15R β Counter

The systems under this section are: from the CRC 15R β Counter, the β counter results and Capintec Beta C Counter results.

11 results were returned using these systems. 9 (~72 %) results were within 10 % of the target value. There were two outliers from this group; one used a self derived calibration factor and the other used the ^{89}Sr preset. Both were well below the target value, being 45 % and 43 % low respectively. For the self-derived factor result, the factor needs to be re-checked. For the preset it is difficult to say what has caused this outlier without having more information. There does appear to be a general low bias for this group.

8.3.2.3 Other Capintec systems.

The systems under this section are:

a) CRC-10, CRC-120, CRC-10B, ARC 120, ARC 120R and Amersham 120.

10 results were returned using these systems. Half of the results fell within 3 % of the target value, with the maximum difference being 6%. Care needs to be taken when using these calibrators as they are old (in the case of the CRC 10 and CRC 10 B they are over 20 years old) and these are analogue units which means that there is no

quality control on the calibration factor settings. There is a slight bias towards overestimating the activity for these chambers. Six participants derived their own calibration factors and two did not provide any information about their factors.

b) CRC-15R PET.

Only one participant used the Capintec CRC 15R PET system. This chamber needs to be considered separately as it is filled to 5 atmospheres instead of 10 compared with the other chambers. The calibration factor was self derived and the result was within 4 % of the target value. No conclusions can be drawn from one result.

8.3.3 Isocal II and III systems.

Only four and two results were reported for the Isocal II and III systems respectively, which makes it difficult to draw any conclusions for either system.

For the Isocal II, two results used manufacturer's data and both were high (8 % and 12 %). One self derived figure was within 3 % of the target value and one offered no information and was 7 % low.

For the Isocal III, one result used self derived calibration factors and was 20 % below the target value which suggests that this factor should be re-evaluated.

8.3.4 Atomlab.

Six results were returned using these chambers with four different models being used. As with the Capintec's, the actual ionisation chambers are the same design and only the electrometers are different, so they have been considered together. Once again it is difficult to draw conclusions from the limited data available. Four results used the manufacturers factors and they have a low bias, with 3 being 15 % below the target value. The containers that these chambers were calibrated for are not known to the authors but this does suggest that any participants using these chambers should

recalibrate their systems. Two results which used self derived figures fall well within 4 % of the target value.

8.3.5 Pitman 270, Siel and Veenstra

Only one result per chamber was returned and this makes it impossible to draw any conclusions on the performance of these chambers. However the result returned for the Siel Bic-1 chamber was 82 % below the NPL value, the preset used was ^{99}Mo and the container is unknown. Users of these systems are advised to recalibrate their systems directly for ^{89}Sr and for their routinely used containers.

9 CORRECTIONS FOR ^{85}Sr IMPURITIES

The accuracy of activity assays of radionuclides used for therapeutic reasons should be ideally better than ± 5 %. For ^{89}Sr, the effect of the ^{85}Sr impurity is such that the additional response produced by the contaminant may be up to several or even tens of percent of the ^{89}Sr response. If it is not corrected for properly, it may mean that it will be impossible to meet the accuracy requirement.

In some cases, users have recognised this problem and have attempted to resolve it by finding an artificial calibration setting which produces an instrument response that indicates the same activity as provided by the ^{89}Sr supplier on the vial label. It must be noted that this activity is often only a nominal value and the true activity may well be up to 10% different. In addition, the self-derived artificial calibration setting is only applicable to those samples with the same level of impurity. If another sample is assayed that has a different impurity level, this derived calibration setting may well produce errors of several or even tens of percent.

In practice, ^{89}Sr production techniques have changed with time and impurity levels have ranged from about 0.05 % up to almost 0.2 %. When this is translated into relative calibrator responses, assays at both ends of this impurity range could result in

errors of up to 30 % in the assay, depending on the calibrator being used. It is dangerous therefore to attempt to find a “fudge factor”/artificial calibration setting which applies to all samples. The correct solution is to apply a specific correction factor which depends on the impurity level and the specific calibrator type. The impurity level is measured accurately by the supplier and is readily available to the user and the correction formula is simple. The application of this approach, therefore, is not onerous. Indeed, look-up tables can be set up to cover the typical impurity levels.

The correction procedure is described below for the NPL SSRC and Capintec systems..

9.1 NPL SSRC and ISOCAL III Corrections.

As stated above, the Isocal III systems use ionisation chambers that failed to meet the very strict manufacturing and response tolerances required for an NPL SSRC. However, the differences between the observed and required responses have always been minimal and hence the correction factors (which are relative in nature) for the Isocal III will be the same as for the NPL SSRC.

The correction formulae for these chambers have been established for both P6 and 10R Schott vials. The true activity of a sample of ^{89}Sr which contains ^{85}Sr impurity, when it is assayed in the NPL SSRC or Isocal III using the appropriate ^{89}Sr calibration factor, is given by the following equation:

$$True\ activity = \frac{Indicated\ activity}{\left\{1 + \frac{CF_{85}}{CF_{89}} \times f\right\}}$$

where:

f = activity of ^{85}Sr / activity of ^{89}Sr (available from supplier)

CF_{85} = calibration factor for ^{85}Sr

CF_{89} = calibration factor for ^{89}Sr

CF_{85}/CF_{89} = NPL determined value

From the experimental work done at NPL to determine calibration factors for P6 and 10 R Schott vials, the CF_{85}/CF_{89} values are now established[13]. Table 7 shows the calibration figures for both P6 and 10 R Schott vials and the corresponding CF_{85}/CF_{89} values.

9.2 Capintec Corrections.

The correction formula for the Capintec systems is more complicated to establish because the tolerances are not as stringent and each chamber will have a slightly different response. Also the ^{89}Sr calibration setting is not well known for the Capintec systems and the ^{85}Sr calibration figure relates to a 5 ml NBS ampoule. The matter is further complicated by the complex relationship between calibration settings. However, following the comparison, work was carried out at NPL to determine the relationship for 10R Schott vials between the relative responses of Capintec ionisation chambers (of the type used in the large majority of Capintec systems. It was necessary of course to establish also the best factor for pure ^{89}Sr. This should apply to the "15" and "120" types.). From the experimental data, the general formula has been established in the same way as for the NPLSSRC. Again, it assumes that the factor that has been set for the measurement is that for pure ^{89}Sr. The corresponding equation is represented by:

$$True\ activity = \frac{Indicated\ activity}{\left(1 + \frac{^{85}Sr\ sensitivity}{^{89}Sr\ sensitivity} \times f\right)}$$

where

f = activity of ^{85}Sr / activity of ^{89}Sr (available from supplier)

^{85}Sr sensitivity/^{89}Sr sensitivity = 40.0

^{89}Sr calibration setting: 565 x 100.

The recommended procedure then to assay ^{89}Sr using Capintec systems is:

- Set the calibration factor to 565 x 100
- Assay the sample using 10 R Schott vial with a nominal value of 4 ml, with no liner in the chamber. Record the result time.
- Calculate the relative ^{85}Sr activity at the measurement time. (The ^{89}Sr/^{85}Sr activity ratio is available by telephone from the manufacturer but is not normally stated in the pack insert)
- Calculate the corrected activity at the measurement time from the formula

Figure 8 shows all the reported results as measured on the Capintec systems: all of the values are uncorrected for the ^{85}Sr activity. The spread is approximately ± 20 %. Many participants did make corrections for the ^{85}Sr impurity and these are shown in Figure 9, the spread is then reduced to approximately ± 10 %.

From the reported data on calibration settings, each of the uncorrected participants results was converted from the response at the measured setting to a response at a setting of 584 x 100, and this was then subsequently corrected using the formula above to take account of the ^{85}Sr impurity. These results are also shown in Figure 9, It is reasonable, for the reasons given above, to exclude the CRC10 results from the

discussion. If the one outlier at the highest end of the distribution of results is also ignored, it is seen that the spread is now reduced to about ± 3 %.

For convenience, Table 8 presents the correction factors for NPL SSRC and Capintec systems covering a typical range of impurity levels.

10 UNCERTAINTIES

Over half of the participants reported an uncertainty on their results. However, very little information was given about the uncertainty budgets. In most cases only type A uncertainties were quoted (statistical) and for the majority who reported type B uncertainties, no explanation was given about the method of estimation or what the individual components were. There was also no information about how the uncertainty components were combined.

The uncertainties reported in Table 4 do not account for the spread of results seen in this comparison.

11 CONCLUSIONS

This comparison has determined the accuracy of ^{89}Sr measurements in UK hospitals. It has identified possible sources of error and sought to explain them. Correction formulae have determined for the NPL chambers and the Capintec chambers.

(a) Less than 60 % of the original results fell within ± 5 % of the NPL value while the corresponding figure for ± 3 % was only 44 %.

(b) If appropriate impurity corrections are applied to Capintec systems, over 70 % of all results now fall within ± 3 % of the NPL value.

(c) In the absence of appropriate corrections, there is a general tendency to overestimate the activity.

(d) The ^{85}Sr impurity will greatly affect the response of all calibrators. The effects will be different for each calibrator.

(e) A procedure using the correction formulae for the NPL SSRC and the Capintec chambers should be adopted to further improve results.

(f) Radionuclide calibrators should be recalibrated individually using traceable standards, in the preferred format i.e. 10 R schott vial.

(g) If any liner or shielding is used then new calibration factors need to be derived.

(h) Variations in results between chambers of the same type is most likely due to variations in the thickness of the inner wall. This will have a significant effect on the response of the chamber to ^{89}Sr.

(i) When manufacturers calibration factors are used, care should be taken to ensure that the container formats are the same.

(j) Users should ensure that the recommended quality assurance procedures are established and maintained on a regular basis.

(k) NPL should continue the ongoing programme of comparison exercises.

12 ACKNOWLEDGEMENTS

The authors acknowledge the financial support of the UK Department of Trade & Industry (National Measurement System Directorate).

The participants are thanked for the time and effort they have put into this exercise.

Thanks are also due to many members of the Radioactivity Metrology Group, in particular Hiliary Phillips, Sean Collins and Kalyani Chari for their support.

13 REFERENCES

(1) A Parkin, J P Sephton, E G A Aird, J Hannan, A E Simpson, M J Woods.
Protocol for Establishing and Maintaining the Calibration of Medical Radionuclide Calibrators and their Quality Control.
Proceedings of their joint IPMS/BIR Meetings on Quality Standards in Nuclear Medicine, BIR, London, February 1992. Institute for Physical Sciences in Medicine Report No. 65 (1992) 60.

(2) M J Woods.
Intercomparison of ^{57}Co and ^{125}I in U.K. Hospitals 1980/81.
NPL Report RS56 (1981).

(3) M J Woods.
Intercomparison of ^{99m}Tc and ^{131}I by Radionuclide Calibrators in U.K. Hospitals, 1986.
NPL Report RS(EXT)88 (1987).

(4) M J Woods, J D Keightley, M Ciocanel.
Intercomparison of ^{67}Ga Solution Sources in U.K. Hospitals, 1996.
NPL Report CIRA(EXT)012.

(5) M J Woods, M Ciocanel, J D Keightley.
Intercomparison of ^{123}I Solution Sources in U.K. Hospitals, 1996.
NPL Report CIRA(EXT)017 (1997).

(6) M J Woods, M Ciocanel, J D Keightley.
Intercomparison of ^{111}In Solution Sources in U.K. Hospitals, 1997.
NPL Report CIRM 001 (1997).

(7) M Ciocanel, J D Keightley, C J Scott and M J Woods.
Intercomparison of ^{131}I Solution and Capsule Sources in U.K. Hospitals, 1999.
NPL Report CIRM 31 (1999).

(8) M Baker and M J Woods.
Intercomparison of ^{123}I Solution Sources in U.K. Hospitals, 2000.
NPL Report CIRM 38 (2000).

(9) M Baker and M J Woods.
Intercomparison of ^{201}Tl Solution Sources in U.K. Hospitals, 2001.
NPL Report CIRM 47 (2001).

(10) D Smith, S A Woods.
Recommended Nuclear Decay Data.
NPL Report RSA(EXT)53 (1995).

(11) *Radioisotope Calibrator Owner's Manual for Models CRC-7, CRC-12 and CRC-120.*
Capintec, Inc. Pittsburgh, PA 15238, U.S.A. (1983).

(12) *βeta C - βeta Counter Owner's manual. Capintec, Inc. Pittsburgh, PA 15238, U.S.A. (1983).*

(13) M Baker
Calibration of the NPL secondary standard radionuclide calibrator for the new 10R Schott, Type 1+ vials
Appl. Radiat. Isot., **63**, 71-77 (2005)

Table 1 - Activity of individual samples on 23 June 2003 12:00 GMT

Source identifier	**Mass of solution**	**^{89}Sr results:**		**^{85}Sr results:**	
		Activity	**Expanded uncertainty *(k=2)***	**Activity**	**Expanded uncertainty *(k=2)***
X31/03	4.0364 g	154.0 MBq	± 1.7 %	259 kBq	± 2.2 %
X32/03	4.0433 g	154.3 MBq	± 1.7 %	260 kBq	± 2.2 %
X33/03	4.0052 g	152.8 MBq	± 1.7 %	257 kBq	± 2.2 %
X34/03	4.0059 g	152.8 MBq	± 1.7 %	257 kBq	± 2.2 %
X35/03	3.8146 g	145.5 MBq	± 1.7 %	245 kBq	± 2.2 %
X36/03	3.9858 g	152.1 MBq	± 1.7 %	256 kBq	± 2.2 %

Table 2 – ^{89}Sr solution reported results

Soln code	NPL ident.	Calibrator Manufacturer	Model	Settings / dial factor	Reported activity [1] (MBq)	Reported ^{89}Sr activity / NPL ^{89}Sr activity[2]
1	X32/03	Capintec	CRC-15R	565 x 100*	115.7	1.05
2[a]	X35/03	Capintec	CRC-15 Beta (γ chamber)	595 x 100	111.4	1.02
2[a]	X35/03	Capintec	CRC-15 Beta Counter	IL[3]	111.2	1.02
2[b]	X35/03	Capintec	CRC-15R	595 x 100	109.5	1.01
2[c]	X35/03	Capintec	CRC-15 Beta Counter	IL[3]	111	1.02
2[c]	X35/03	Capintec	CRC-15 Beta (γ chamber)	595 x 100	109.9	1.01
3[a]	X34/03	Atomlab	100	851*	150.1	1.04
3[b]	X34/03	Capintec	CRC-15R	575 x 100*	150	1.04
4[a]	X34/03	Capintec	CRC-15R	640 x 100*	134.6	0.99
4[b]	X34/03	Capintec	CRC-15R	680 x 100*	123.1	0.90
4[c]	X34/03	Capintec	CRC-15R	650 x 100*	128.8	0.94
4[d]	X34/03	Capintec	CRC-15R	680 x 100*	121.4	0.89
4[e]	X34/03	Capintec	CRC-15R	680 x 100*	123.4	0.90
5	X34/03	Capintec	CRC-15R β Counter	Preset	66.6	0.55
6	X34/03	Capintec	CRC-15R	555 x 100*	123.6	1.08
7[a]	X33/03	Capintec	CRC-10B	574 x 100	104.54	0.95
7[b]	X33/03	Capintec	CRC-15R	574 x 100	109.82	1.00
7[c]	X33/03	Capintec	CRC-15R	574 x 100	108.91	0.99
8[a]	X33/03	Capintec	CRC-15R	574 x 100	104.8	1.03
8[b]	X33/03	Capintec	CRC-15R	574 x 100	106.8	1.05
9[a]	X33/03	Capintec	ARC-120	575 x 100*	99.3	1.06
9[b]	X33/03	Capintec	CRC-15R	575 x 100*	98.9	1.06
9[c]	X33/03	Capintec	CRC-15R	575 x 100*	99.9	1.07
9[d]	X33/03	Capintec	CRC-15R	575 x 100*	100	1.06
10[a]	X35/03	Vinten	ISOCAL II	0022	99	1.12
10[b]	X35/03	Vinten	ISOCAL II	0024	96	1.08
10[c]	X35/04	Capintec	CRC-15R	556 x 100*	97.9	1.09
10[d]	X35/03	Capintec	CRC-15R	556 x 100*	99.2	1.12
11[a]	X35/04	Capintec	Beta C		100.2	1.04
11[b]	X35/04	Vinten	ISOCAL III	0115 x 10	99.1	0.99
11[c]	X35/03	Vinten	ISOCAL IV	0115 x 10	94.2	0.98
12[a]	X35/03	Atomlab	200	680	85.4	0.82
12[b]	X35/03	Atomlab	201	680	84.6	0.81
12[c]	X35/03	NE Technology	ISOCAL III	0012*	83.8	0.80
13[a]	X32/03	Capintec	CRC-15R	530 x 100*	129.6	1.05
13[b]	X32/03	Capintec	CRC-15R	530 x 100*	132.9	1.07
14[a]	X32/03	Capintec	CRC-15 R Beta	^{89}Sr preset	75.97	0.57
14[b]	X32/03	Capintec	CRC-15R Beta (γ chamber)	^{90}Y (48 x 10)	68.8	0.52
14[c]	X32/03	SIEL	BIC-1	^{99}Mo preset	23.66	0.18
15[a]	X32/03	Capintec	CRC-15R Beta	^{89}Sr preset	135.1	0.99
15[b]	X32/03	Capintec	CRC-15R Beta (γ chamber)	600 x 100*	137	1.01
15[c]	X32/03	Capintec	CRC-15R Beta	*	133.3	0.98
16	X32/03	Capintec	CRC-15R	630 x* 100	138.3	0.99
17[a]	X31/03	Vinten	ISOCAL IV	0010*	112.248	1.18
17[b]	X31/03	Capintec	ARC-120R	630 x 100*	98.803	1.00
17[c]	X31/03	Capintec	CRC-15R	630 x 100*	91.486	0.98
17[d]	X31/03	Capintec	CRC-15R	630 x 100*	93.988	0.99
17[e]	X31/03	Capintec	CRC-15R	630 x 100*	92.578	0.97

17[f]	X31/03	Capintec	CRC-15R	630 x 100*	99.503	1.00
17[g]	X31/03	Capintec	CRC-15R PET	630*	90.97	0.97
18	X31/03	Capintec	CRC-15R	574 x 100	110	1.08
19[a]	X31/03	Capintec	CRC-15R Beta	^{89}Sr preset	111	1.02
19[b]	X31/03	Capintec	CRC-15R Beta (γ chamber)	574 x 100	117.6	1.08
20[a]	X33/03	Capintec	CRC-15R	560 x 100*	122.7	1.07
20[b]	X33/03	Capintec	CRC-15R	560 x 100*	121.18	1.07
20[c]	X33/03	Capintec	CRC-15R	560 x 100*	122.45	1.08
20[d]	X33/03	Capintec	CRC-15R		117.55	1.03
21[a]	X33/03	Capintec	CRC-15R	48.03	119.8	0.98
21[b]	X33/03	Capintec	CRC-15R Beta (γ chamber)	584 x 100	126.9	1.04
22[a]	X33/03	Capintec	CRC-15R Beta	48.03/1.20	127.12	1.01
22[b]	X33/03	Capintec	CRC-15R Beta (γ chamber + liner)	585 x 100	130.79	1.04
23[a]	X33/03	Capintec	CRC-15R	574 x 100	142.3	1.06
23[b]	X33/03	Capintec	CRC-15R	574 x 100	128.8	0.96
23[c]	X33/03	Capintec	CRC-15R	574 x 100	129.4	0.96
23[d]	X33/03	Capintec	CRC-15R	574 x 100	139.6	1.04
24[a]	X33/03	Atomlab	100 Plus	680	123.2	0.85
24[b]	X33/03	Atomlab	100 Plus	768	139.2	0.96
24[c]	X33/03	NE Technology	Isocal IV + shield	0.0300/0.0279*	149.5	1.03
24[d]	X33/03	NE Technology	Isocal IV	0.0300/0.0279*	147.6	1.02
25[a]	X31/03	Capintec	CRC-15R	600 x 100*	159	1.09
25[b]	X31/03	Capintec	CRC-15R	600 x 100*	152.4	1.05
26[a]	X31/03	Capintec	CRC-15R	600 x 100*	139.3	1.01
26[b]	X31/03	Vinten	Isocal II	0026*	140.6	1.03
26[c]	X31/03	Capintec	ARC-120	600 x 100*	137.8	1.00
26[d]	X31/03	Capintec	CRC-15R	600 x 100*	139.8	1.01
26[e]	X31/03	Capintec	CRC-15R	600 x 100*	141	1.03
27	X31/03	Veenstra	VDC 404	^{89}Sr preset	123	0.97
28[a]	X31/03	Capintec	Beta C	^{89}Sr preset	109.8	0.90
28[b]	X31/03	Vinten	Isocal II	2600 x 100	113.4	0.93
28[c]	X31/03	Capintec	CRC-10	750 x 100	115	0.94
28[c]	X31/03	Capintec	CRC-10	750 x 100	122.5	1.01
29[a]	X31/03	Pitman	270	10103 x 10*	127.7	1.10
29[b]	X31/03	Capintec	CRC-15R	519 x 100*	127.9	1.12
29[c]	X31/03	Capintec	CRC-120	545 x 100*	121	1.05
30	X34/03	Atomlab	100	870*	111.9	1.03
31[a]	X34/03	Capintec	CRC-15R	584 x 100*	104.7	1.03
31[b]	X34/03	Capintec	CRC-15R	586 x 100*	104.75	1.04
31[c]	X34/03	Capintec	CRC-120	600 x 100*	104.3	1.03
31[d]	X34/03	Capintec	CRC-15R	600 x 100*	104.1	1.03
31[e]	X34/03	Capintec	CRC-120	600 x 100*	104.9	1.04
32[a]	X32/03	Amersham	ARC-120	600 x 100*	96.7	1.01
32[b]	X32/03	Capintec	CRC-15R	600 x 100*	96.3	1.01
33	X33	Vinten	Isocal IV	0.0300/0.0279	111.02	0.97

1 Reported ^{89}Sr activity corrected for ^{85}Sr at measurement time

2 At measurement time

3 IL – internal library settings

Table 3 Results summarised by calibrator
(Numbers in cells represent the number of results where the ratio of the reported value to the NPL value falls within the range of values at the top of the column)

^{89}Sr DATA GROUPS	**0.10 to 0.50**	**0.50 to 0.60**	**0.60 to 0.70**	**0.70 to 0.80**	**0.80 to 0.84**	**0.84 to 0.86**	**0.86 to 0.88**	**0.88 to 0.90**	**0.90 to 0.92**	**0.92 to 0.94**	**0.94 to 0.96**	**0.96 to 0.98**	**0.98 to 1.00**	**1.00 to 1.02**	**1.02 to 1.04**	**1.04 to 1.06**	**1.06 to 1.08**	**1.08 to 1.10**	**1.10 to 1.12**	**1.12 to 1.14**	**1.14 to 1.16**	**1.16 to 1.18**
ALL DATA (93)	1	3	0	0	3	1	0	2	2	1	4	10	7	14	20	7	9	4	3	1	0	1
ISOCAL II	~	~	~	~	~	~	~	~	~	~	~	~	~	~	1	~	~	1	1	~	~	~
ISOCAL III	~	~	~	~	1	~	~	~	~	~	~	~	1	~	~	~	~	~	~	~	~	~
ISOCAL IV	~	~	~	~	~	~	~	~	~	~	~	2	~	~	2	~	~	~	~	~	~	1
CAPINTEC CRC-15R	~	1	~	~	~	~	~	1	1	2	2	3	4	8	11	6	8	3	1	1	~	~
CAPINTEC CRC-15R β Counter	~	2	~	~	~	~	~	1	1	~	~	2	1	3	2	~	~	~	~	~	~	~
CAPINTEC other	~	~	~	~	~	~	~	~	~	~	2	0	1	3	2	1	1	~	~	~	~	~
CAPINTEC CRC-15R PET	~	~	~	~	~	~	~	~	~	~	~	1	~	~	~	~	~	~	~	~	~	~
VEENSTRA VDC 404	~	~	~	~	~	~	~	~	~	~	~	1	~	~	~	~	~	~	~	~	~	~
SIEL BIC-1	1	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~
ATOMLAB	~	~	~	~	2	1	~	~	~	~	~	1	~	~	2	~	~	~	~	~	~	~
PITMAN 270	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	1	~	~	~

Table 4 - Reported uncertainties

Participant	Type A uncertainty (%)	Type B uncertainty (%)	Overall uncertainty (%)
2[a]	0.16	-	-
2[a]	2.04	-	-
2[b]	0.20	-	-
2[c]	0.88	-	-
2[c]	0.14	-	-
3[a]	0.50	3.6	4.1
3[b]	0.50	2.5	3
5	0.30	7.3	7.3
6	0.23	1.5	1.5
7[a]	0.22	10.3	10.3
7[b]	0.1	10.3	10.3
7[c]	0.03	10.3	10.3
8[a]	0.5	-	0.5
8[b]	0.5	-	0.5
9[a]	0.5	-	0.5
9[b]	0.5	-	0.5
9[c]	0.5	-	0.5
9[d]	0.5	-	0.5
10[a]	1.5	-	-
10[b]	1.5	-	-
10[c]	1	-	-
10[d]	0.8	-	-
11[a]	0.2	-	-
11[b]	0.4	-	-
11[c]	0.4	-	-
12[a]	0.5	5	5
12[b]	-	-	5
12[c]	-	-	5
15[a]	0.35	2	2.03
15[c]	0.35	2	2.003
16	0.14	2	2
17[a]	2	-	-
17[b]	2	-	-
17[c]	2	-	-
17[d]	2	-	-
17[e]	2	-	-
17[f]	2	-	-
17[g]	2	-	-
18	1	5	6
19[a]	0.2	-	-
19[b]	0.2	-	-
20[a]	0.3	-	0.3
20[b]	0.2	-	0.2

Participant	Type A uncertainty (%)	Type B uncertainty (%)	Overall uncertainty (%)
20[c]	0.4	-	0.4
20[d]	0.4	-	0.4
21[a]	0.3	-	-
21[b]	0.3	-	-
22[a]	0.2	4.1	4.3
22[b]	0.12	-	10
23[a]	2	-	2
23[b]	2	-	2
23[c]	2	-	2
23[d]	2	-	2
24[a]	0.5	-	-
24[b]	0.5	-	-
24[c]	0.5	2	2.5
24[d]	0.5	2	2.5
26[a]	0.2	1.8	2
26[b]	1	2	3
26[c]	0.5	1.5	2
26[d]	0.2	1.8	2
26[e]	0.2	1.8	2
27	4	-	4
29[a]	3.2	5	6
29[b]	0.4	5	5
29[c]	0.4	5	5
30	3	3	6
32[a]	0.05	0.31	0.31

Table 5 - Distribution of results from previous intercomparisons
(expressed as percentage of results within given range of NPL value)

		Range	
Year	**Nuclide**	0.95 - 1.05	0.90 - 1.10
1981	^{125}I	13%	26%
1981	^{57}Co	52%	76%
1986	^{99m}Tc	73%	94%
1986	^{131}I	88%	95%
1996	^{67}Ga	91%	95%
1996	^{123}I	28%	62%
1997	^{111}In	84%	92%
1999	^{131}I solution ^{131}I capsule	90% 79%	100% 100%
2000	^{123}I	29 %	66 %
2001	^{201}Tl	55 %	90 %
2003	^{89}Sr	58 %	86 %

Table 6 Half-lives and the 10R Schott vial calibration figures for ^{89}Sr and its impurities, for the NPL calibrator

Radionuclide	**Half-life** (days)	**10 R Schott vial calibration figure for the NPL calibrator (pA/MBq)**
^{89}Sr	50.52 ± 0.08	0.0284 ± 0.70 %
^{85}Sr	64.849 ± 0.004	5.286 ± 0.85 %

Table 7 – Calibration factors for ^{85}Sr, ^{89}Sr and their ratios for the NPL SSRC.

Container	Calibration factors (pA/MBq)		CF_{85}/CF_{89}
	CF_{89}	CF_{85}	
10R Schott vial	0.0284	5.286	186
P6 vial	0.0279	5.258	188

Table 8 Look-up table for impurity corrections for NPL SSRC and Capintec systems for 10R Schott and P6 vials

Correction factor, A, to be applied to indicated activity to give true activity of ^{89}Sr

NPL SSRC Calibration factor for ^{89}Sr in 10R Schott vial = 0.0284 pA/MBq

NPL SSRC Calibration factor for ^{89}Sr in P6 vial = 0.0279 pA/MBq

Capintec calibration setting for ^{89}Sr in 10R Schott vial = 584 x 100

When calibration setting for ^{89}Sr is used, true activity = A * indicated activity

	Correction factor, A		
Impurity level ^{85}Sr/^{89}Sr (%)	NPL SSRC and Isocal III		Capintec
	10R Schott vial	P6 vial	10R Schott vial
0.00	1.000	1.000	1.000
0.01	0.982	0.982	0.996
0.02	0.964	0.964	0.992
0.03	0.947	0.947	0.988
0.04	0.931	0.930	0.984
0.05	0.915	0.914	0.980
0.06	0.900	0.899	0.976
0.07	0.885	0.884	0.972
0.08	0.870	0.869	0.968
0.09	0.857	0.855	0.965
0.10	0.843	0.842	0.961
0.11	0.830	0.829	0.957
0.12	0.818	0.816	0.953
0.13	0.805	0.804	0.950
0.14	0.793	0.792	0.946
0.15	0.782	0.780	0.942
0.16	0.771	0.769	0.939
0.17	0.760	0.758	0.935
0.18	0.749	0.747	0.932
0.19	0.739	0.737	0.928
0.20	0.729	0.727	0.925

Figure 1 - Variation of the % of Sr-85 impurity to Sr-89 with time during hospital measurements.

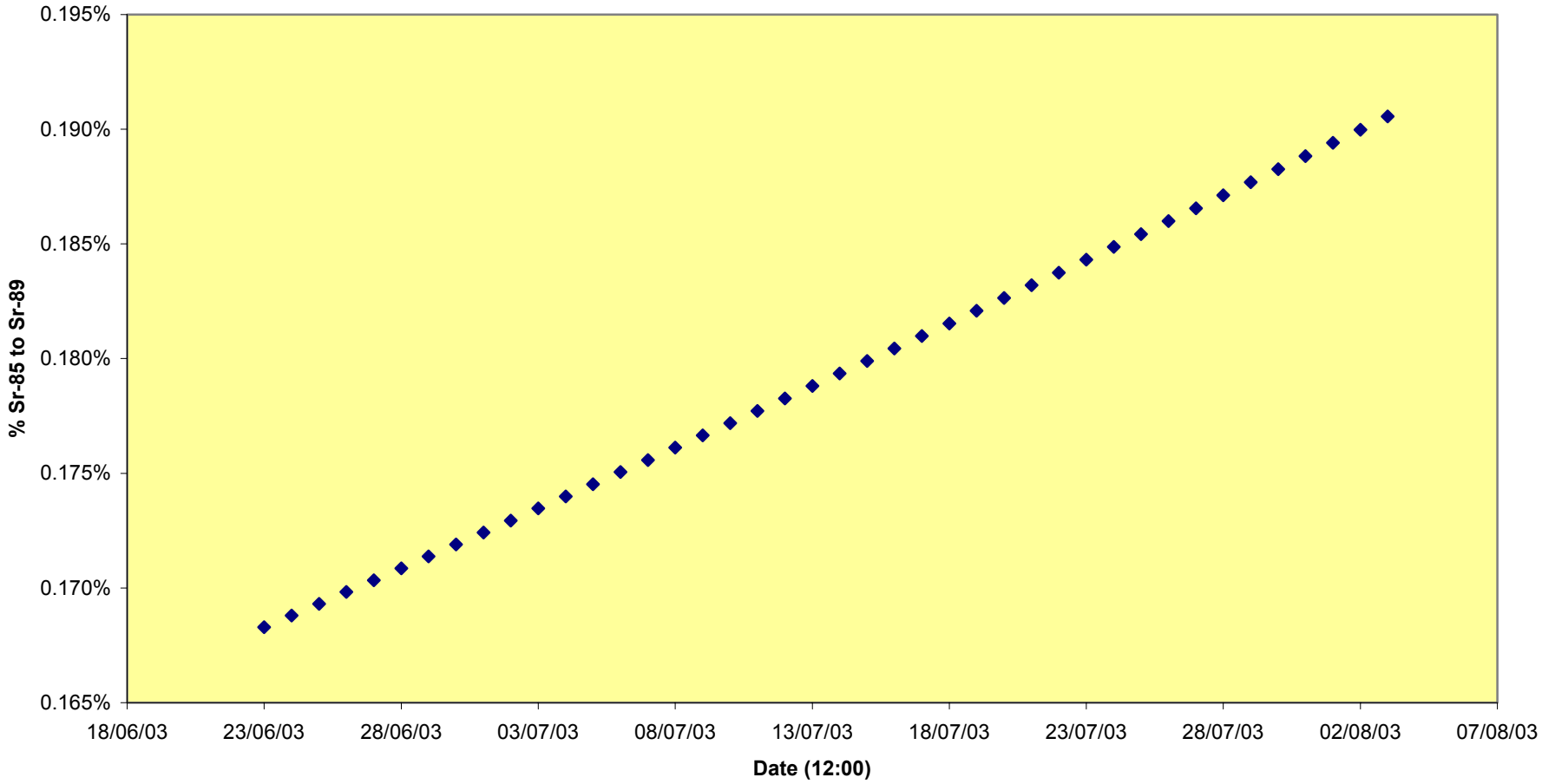


Figure 2 - Variation of all results

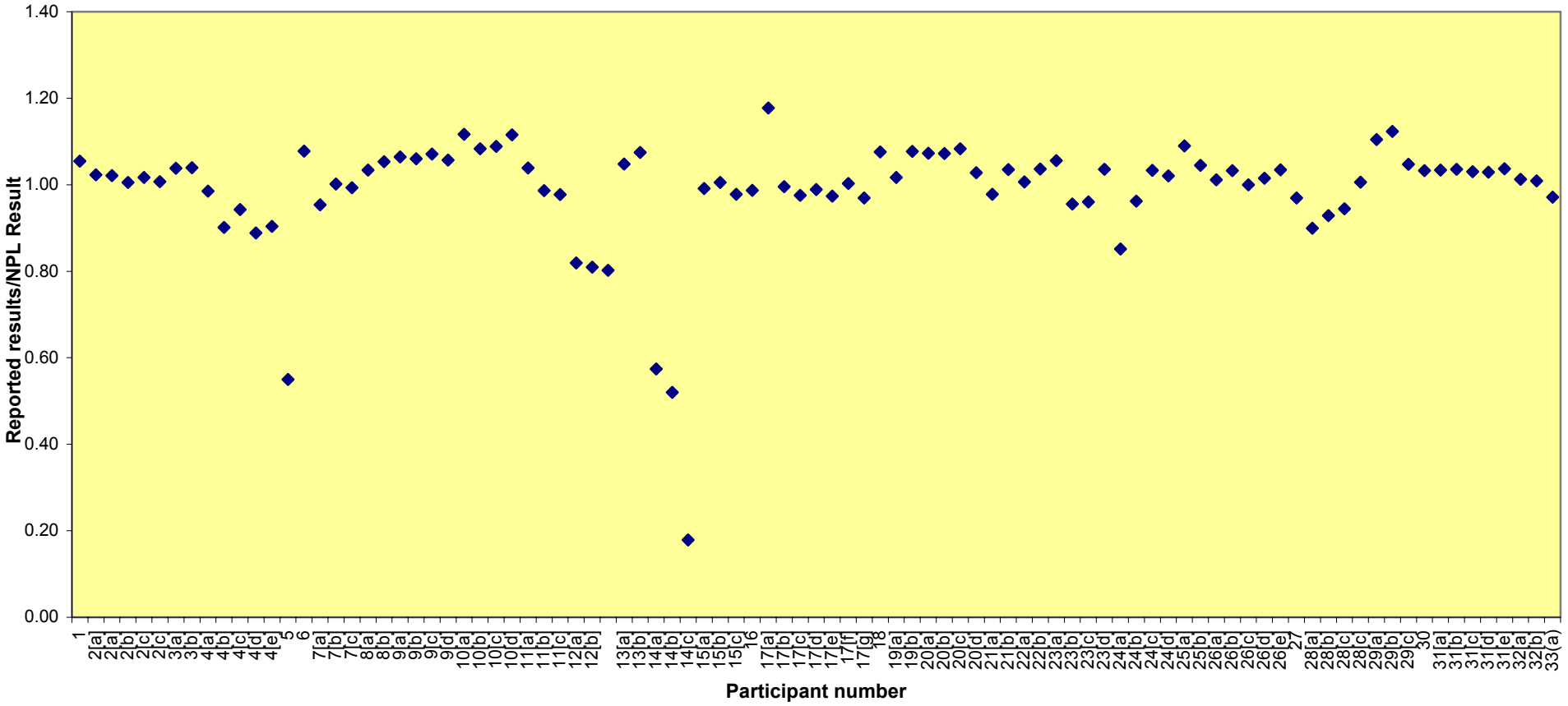


Figure 3 - Distribution of all results

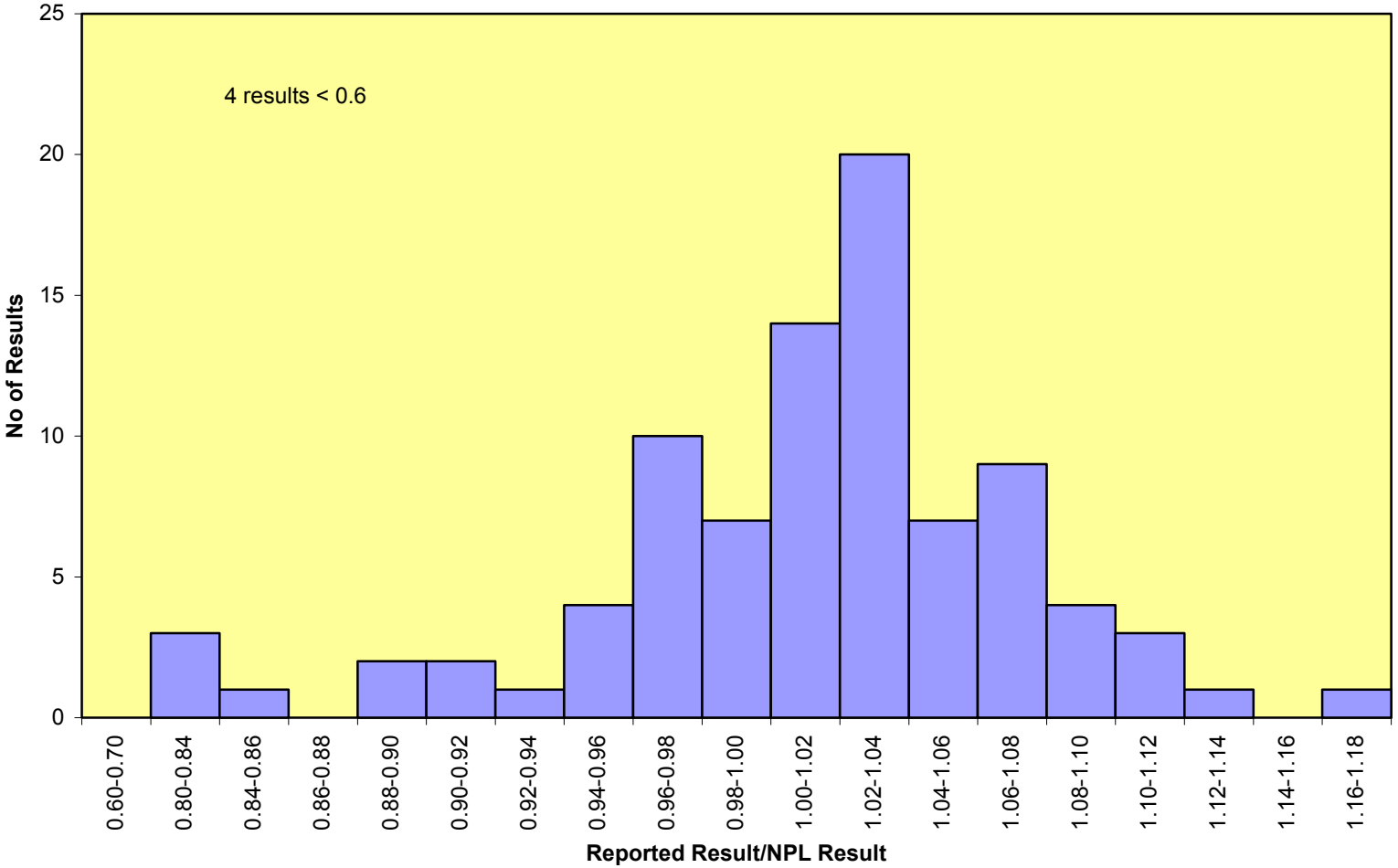


Figure 4 - Variation in response by calibrator type

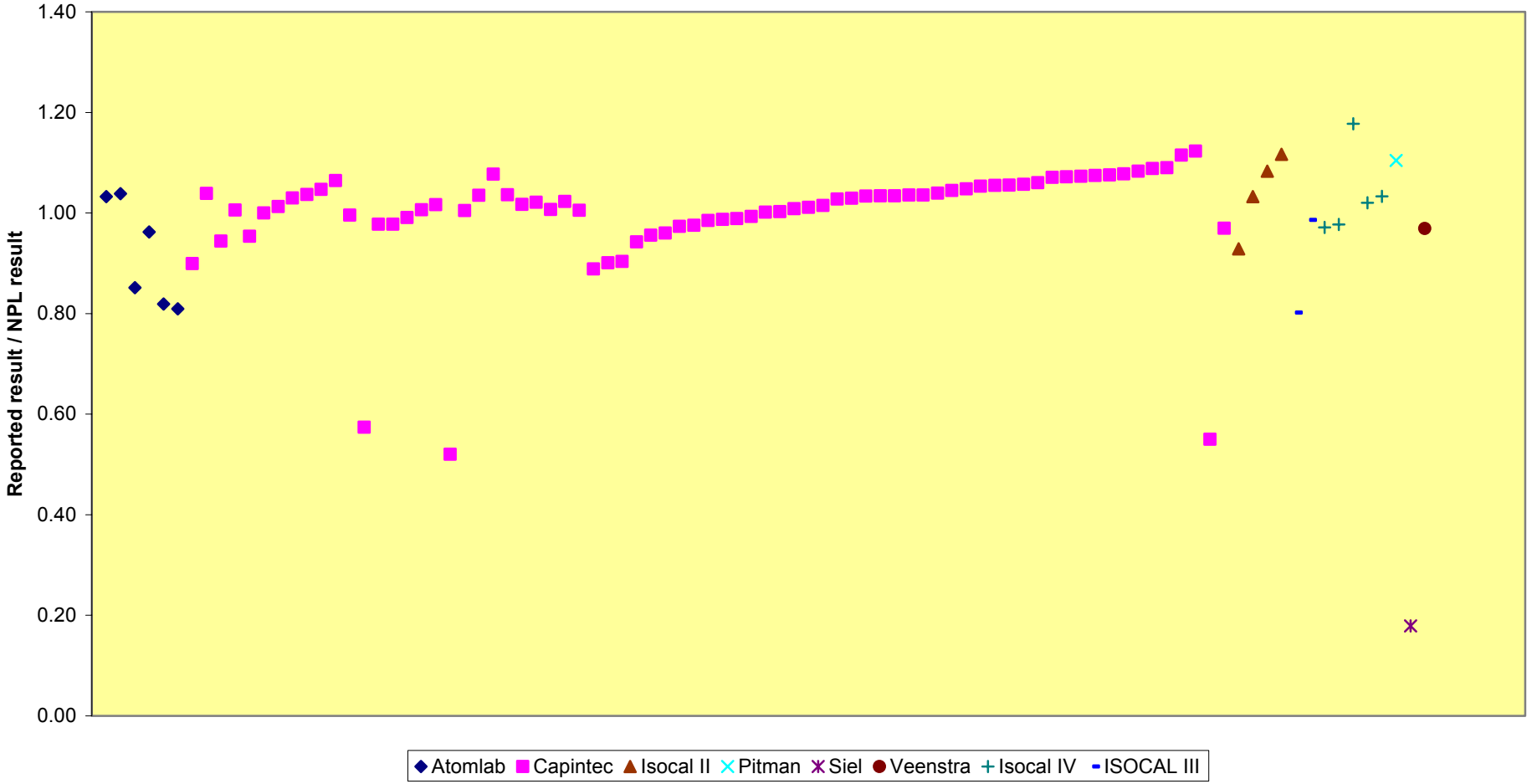


Figure 5 - Distribution of results by calibrator

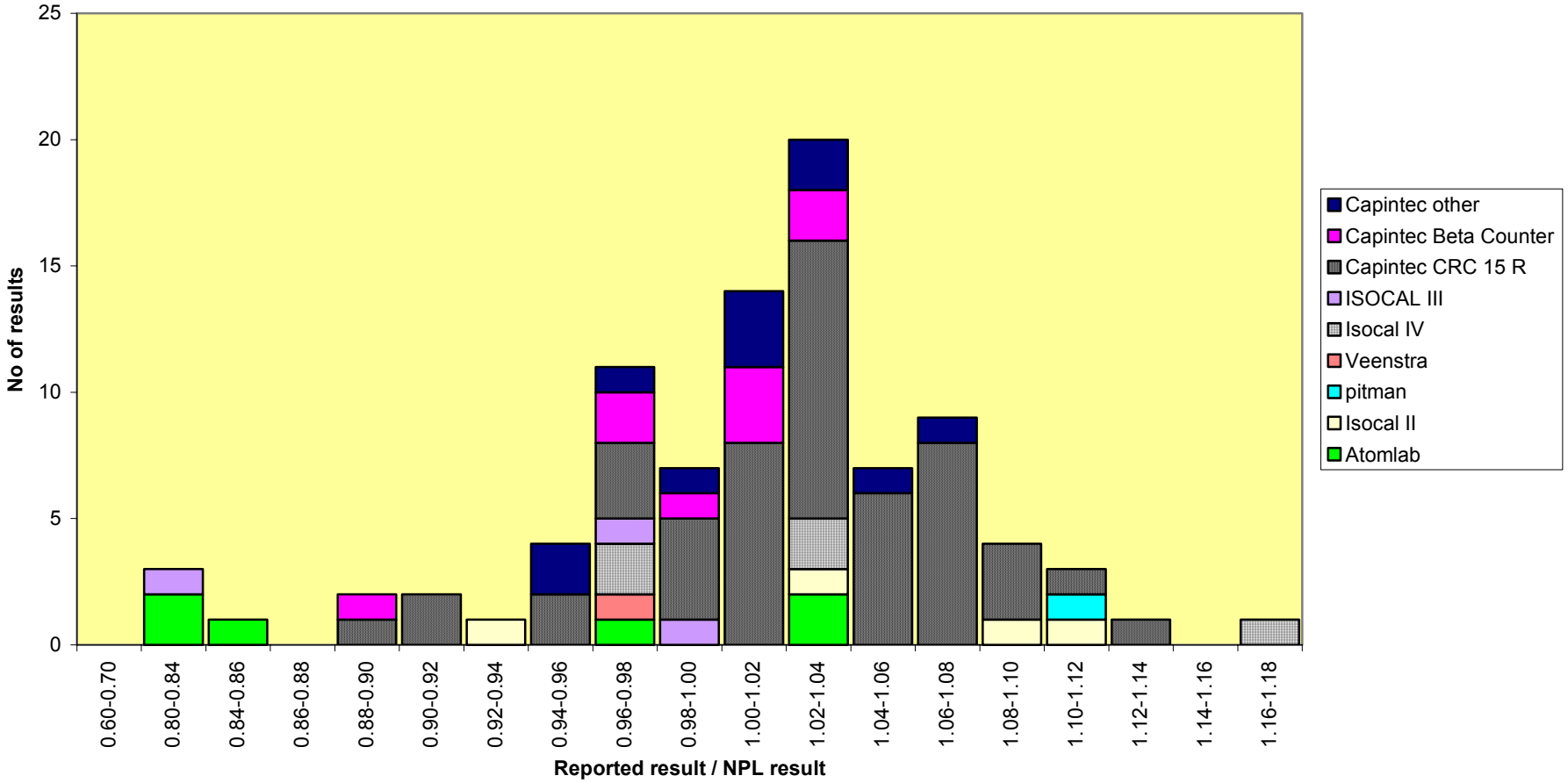


Figure 6 - Variation in response to Dial Factors

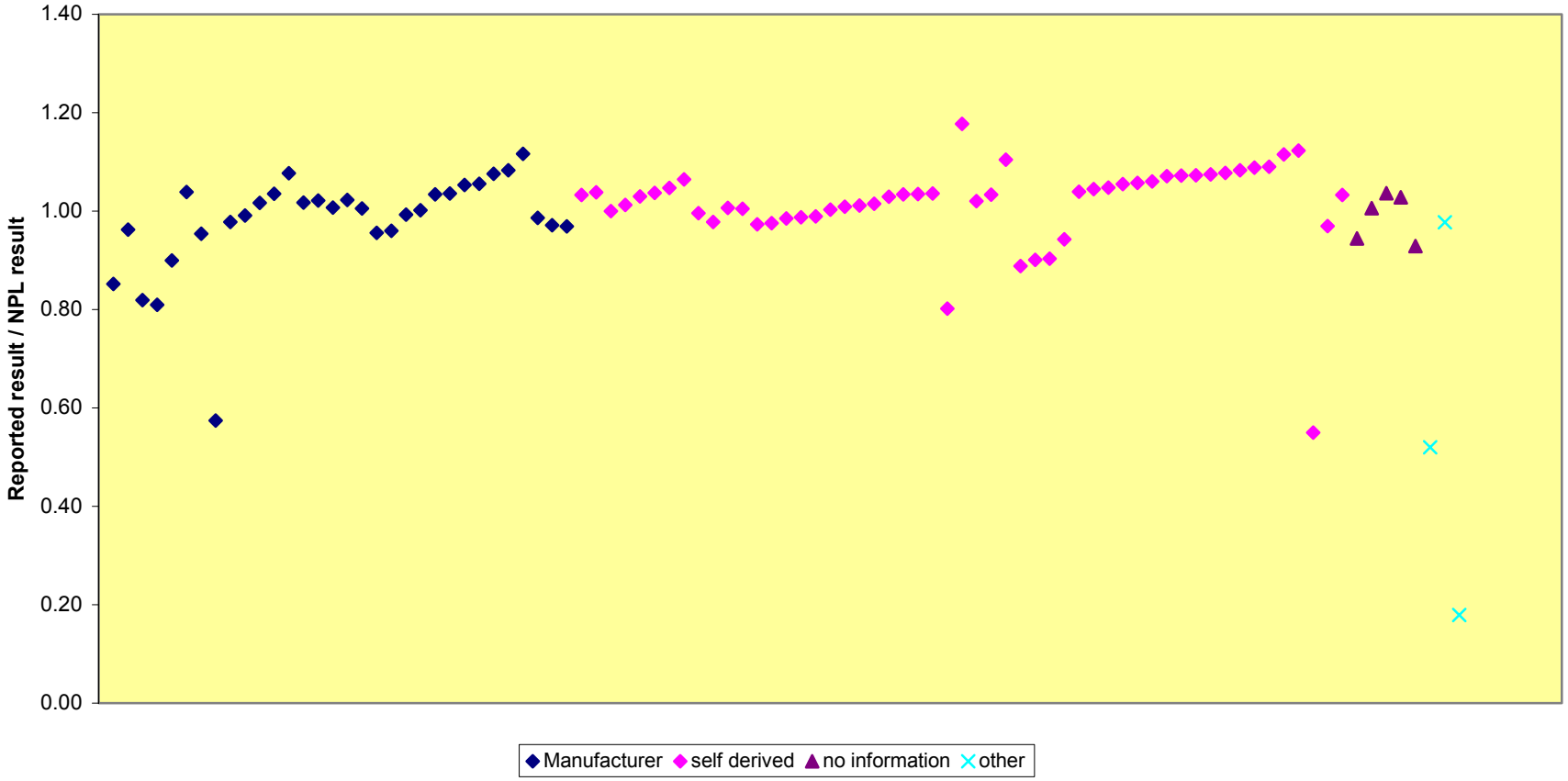


Figure 7 - Distribution of results by dial factor

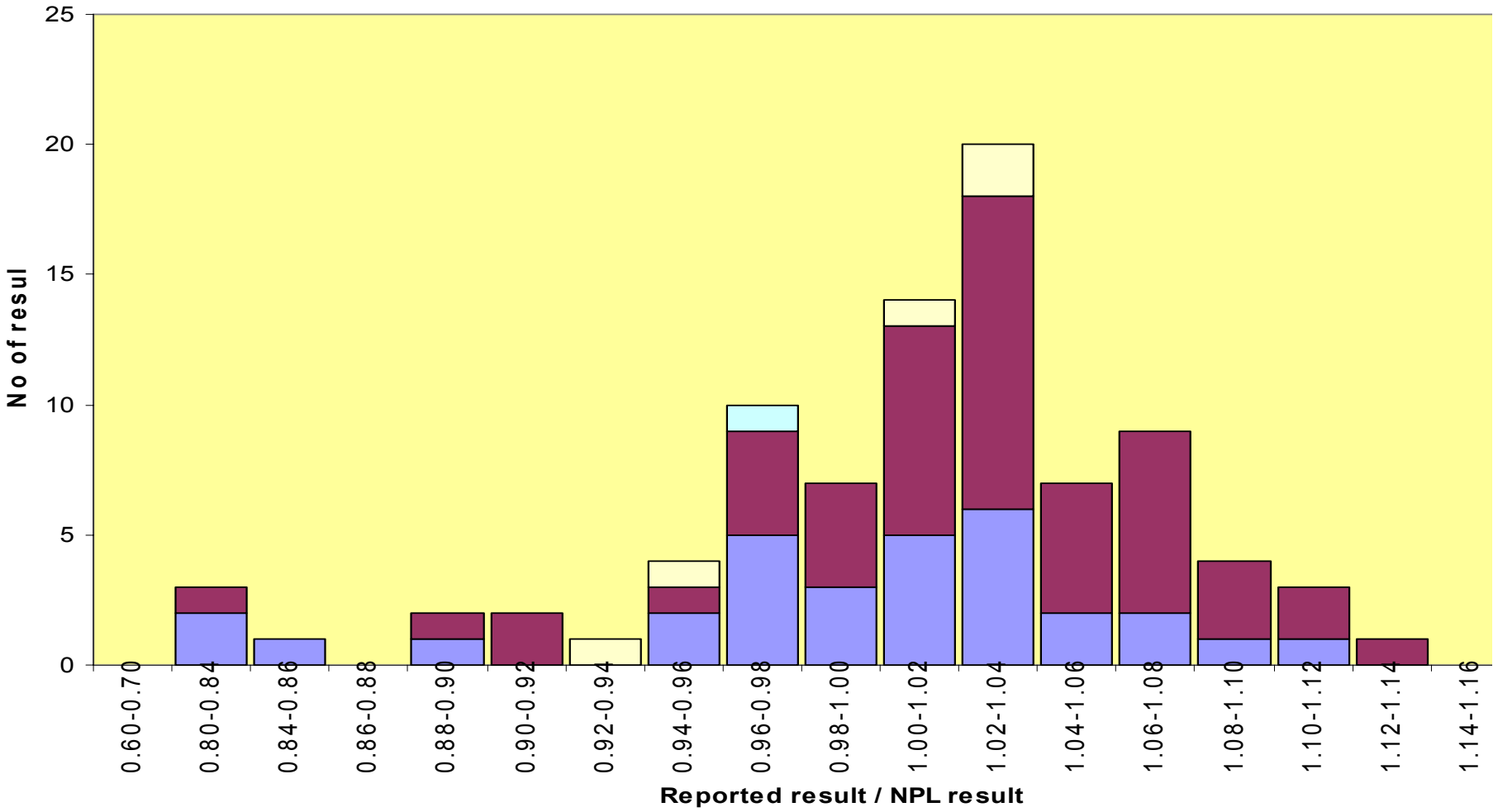


Figure 8 - Uncorrected Capintec results

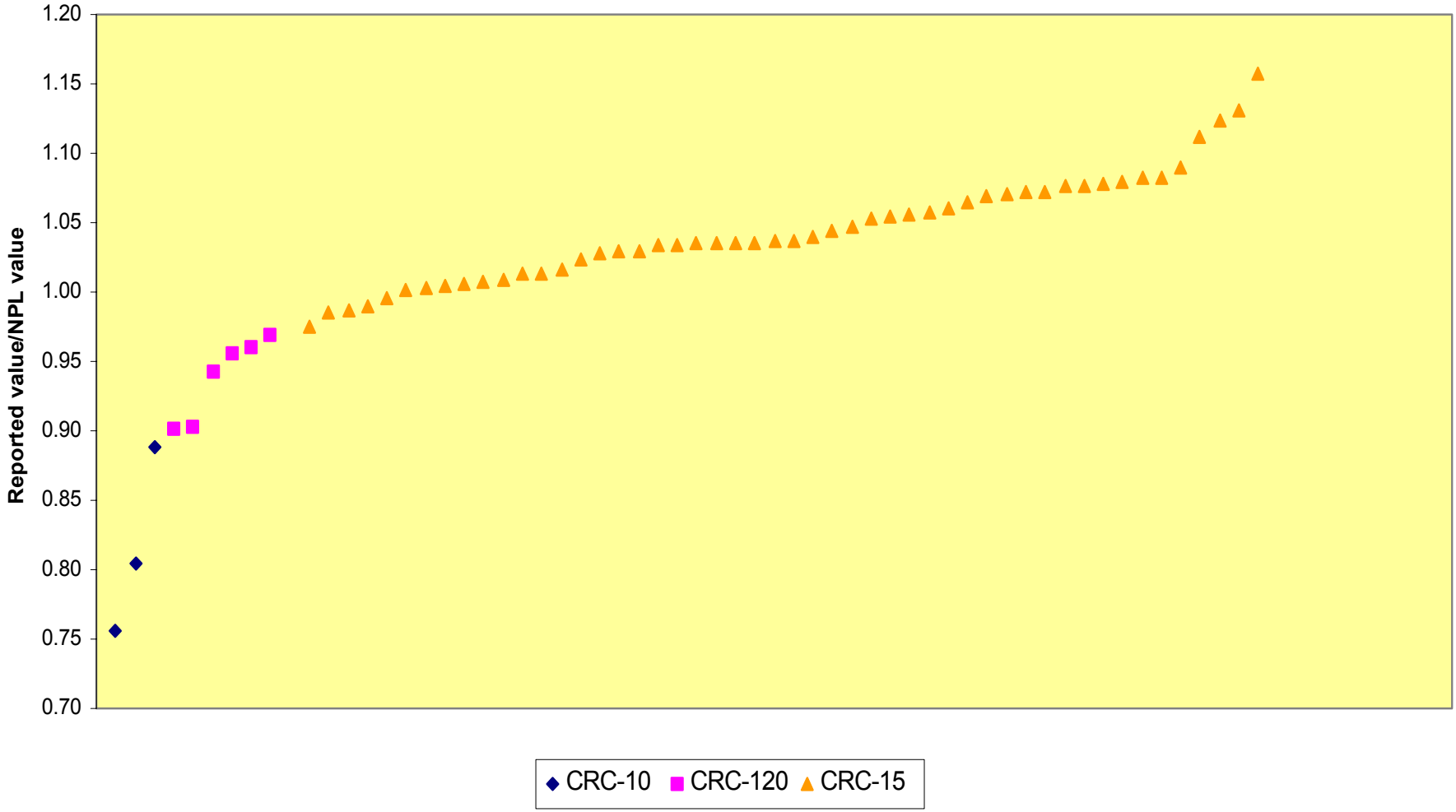
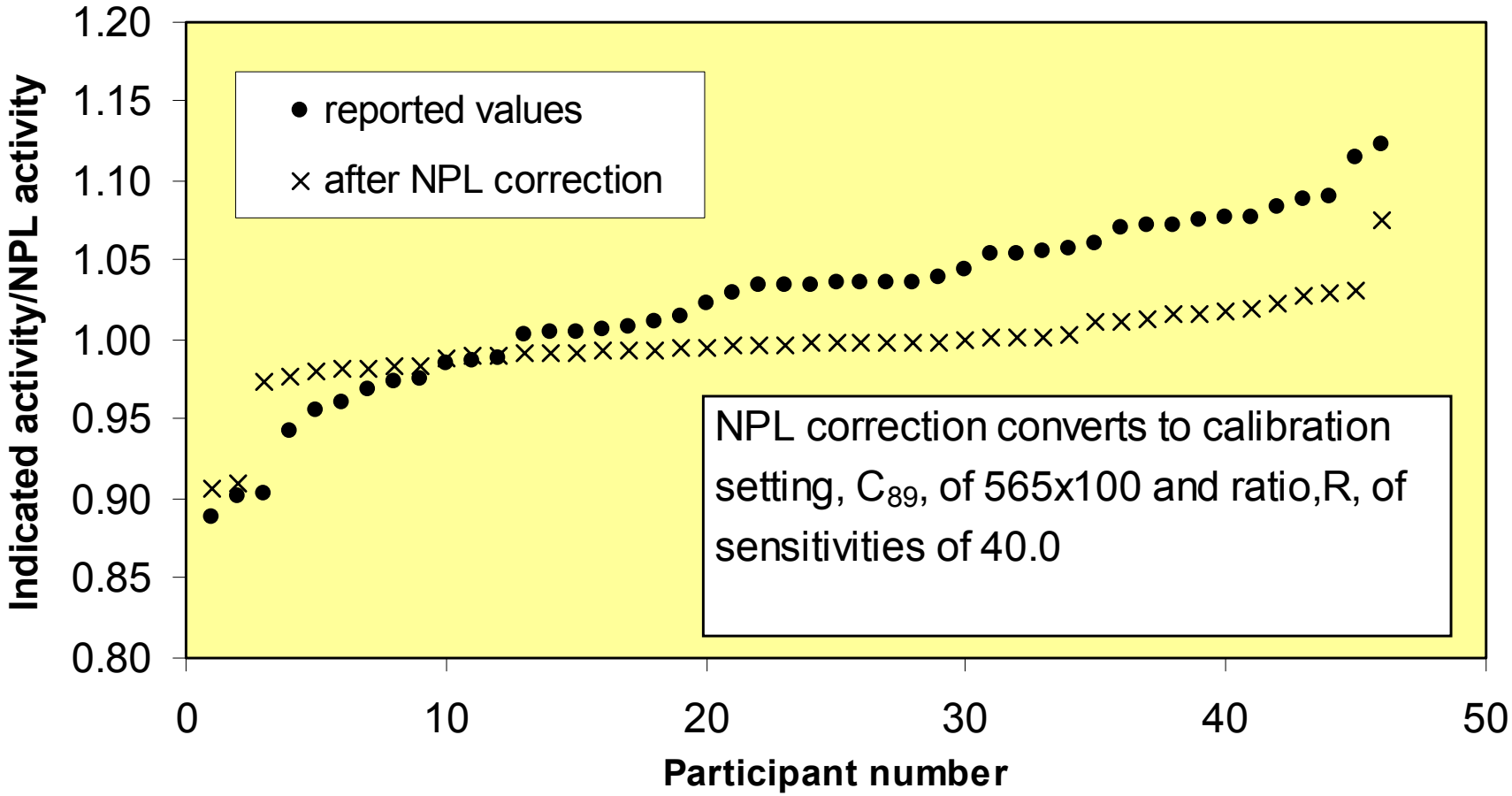


Figure 9 Corrected Capintec results



APPENDIX 1

List of participants.

Participant	Hospital
Mr A Aldous	Ipswich Hospital NHS Trust, Ipswich
Ms S Anderson	Mount Vernon Hospital, Northwood
Mr B Baily	Cromwell Hospital, London
Mr B Barber	Addenbrookes Hospital, Cambridge
Mr S Brown	Southend Hospital, Westcliff-on-Sea
Mr I Coles	Charing Cross Hospital , London
Mr I Driver	Cookridge Hospital, Leeds
Mr M Early	Leicester Royal Infirmary, Leicester
Mr T Elkerton	Royal Devon and Exeter Hospital, Exeter
Mr M Evans	Royal United Hospital, Bath
Mr R Gadd	University Hospital of North Staffordshire, Stoke-on-Trent
Dr C Green	Aberdeen Royal Infirmary, Aberdeen
Mr A Harris	Northern General Hospital, Sheffield
Dr T Hilditch	Western Infirmary, Glasgow
Mr E Hockaday	Ninewells Hospital, Dundee
Ms S Hooper	Velindre NHS Trust, Cardiff
Mr D Ibbett	Derbyshire Royal Infirmary, Derby
Mr L Jansson	Poole Hospital, Poole
Mr S Jeans	Christie Hospital NHS Trust, Manchester
Dr J MacDonald	Glan Clwyd Hospital, Bodelwyddan
Mr P Maltby	The Royal Liverpool University Hospitals, Liverpool
Mr C Marshall	Lincoln County Hospital, Lincoln
Mr D Marshall	Medway Maritime Hospital, Gillingham
Mr C Nottage	Essex County Hospital, Colchester
Mr A O'Brien	Raigmore Hospital, Inverness
Mr P Ormsby	Derriford Hospital, Plymouth
Mr R Patel	Gloucester Royal Hospital, Gloucester
Mr D Pears	Diana, Princess of Wales Hospital, Grimsby
Ms B Pratt	Royal Marsden Hospital, Sutton, Surrey
Mr A Przeslak	Nottingham City Hospital, Nottingham
Mr P Tapper	The Harley Street Clinic, London
Mr M Wisbey	Maidsone Hospital, Maidstone
Ms M Zinvanovic	Southampton General Hospital, Southampton

APPENDIX 2

Comparison Exercise for ^{89}Sr Measurements in UK Hospitals, July 2003

REPORTING FORM

Organisation ..... **Participant**
.....….

Address ..... **Tel No.**
.....
…..

..... **Fax No.**
.....…..

..... **E-mail**
.....….

.....

SAMPLES DETAILS:

- Vial identifier: .....

- Container type: 10R type 1+ Schott vial

- % ^{85}Sr of the ^{89}Sr activity will be provided by NPL

DETAILS OF RADIONUCLIDE CALIBRATOR:
(If more than one calibrator is used, please photocopy this reporting form and use a separate form for each calibrator):

- Manufacturer: …….

- Model/Type: …….

- Serial No: …….

NPL RECOMMENDED HALF-LIVES:

^{89}Sr: 50.52 days ± 0.08 days (at k=1)
^{85}Sr: 64.849 days ± 0.004 days (at k=1)

^{89}Sr ACTIVITY MEASUREMENTS:

- ^{89}Sr Calibration factor/dial setting used: ……...……...

Please give details of the origin of dial/preset factor (eg: users' manual, self-derived, etc)

- Date and time of measurement (GMT): Month .....… Day .....… Hour .....… Min .....…

- Measured background: ……. MBq

- ^{89}Sr displayed activity (no corrections for ^{85}Sr applied): …… MBq
NOTE: This result is absolutely necessary!
Please specify whether background has been subtracted from the above reading: **YES / NO**

- ^{89}Sr activity (after bkg. subtraction and correction for ^{85}Sr): .....…….. MBq

Please give details of the correction applied to account for the ^{85}Sr impurity:

- If individual impurity checks are performed routinely, please specify method:

UNCERTAINTIES:

Please provide an estimate of the uncertainty (at k = 1) on your measurements:

- Random (Type A): ± .....%

- Non-random (Type B): ± .....%

- Overall: ± .....%

It would be useful if you could indicate below how these values were estimated.

ADDITIONAL COMMENTS:

Please return this form to:

Michaela Baker
Centre for Acoustics and Ionising Radiation
National Physical Laboratory
Teddington, Middlesex, TW11 0LW
Tel: 020 8943 6579
Fax: 020 8943 8700
E-mail: michaela.baker@npl.co.uk