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Comparison of ^{201}Tl Solution Sources in UK Hospitals, 2001

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ABSTRACT

During recent years, concerns have been raised within the nuclear medicine field about the accuracy of activity measurements for ^{201}Tl. And indeed, NPL calibrations repeatedly indicated that the level of impurities present in such samples and the significant amount of activity adsorbed onto the glass wall of the container could produce erroneous results. In addition, the standard P6 vials, in which ^{201}Tl solution had been previously supplied, were recently replaced with the new "10R Type 1 plus" Schott vials.

To assess the magnitude of these effects on the accuracy of clinical measurements of the activity of ^{201}Tl, an intercomparison exercise was conducted between the National Physical Laboratory (NPL), Nycomed-Amersham (NA) and the UK hospital physics community.

The majority of the 273 reported results were within the ± 10 % limit of accuracy that hospitals aim to achieve for diagnosis, biased high. The tendency to overestimate the activity was more evident for syringe measurements.

The exercise also revealed that the adsorption losses experienced with P6 vials had been solved by the introduction of the 10R vials, but individual calibrators need to be recalibrated for this new container.

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1. INTRODUCTION

Various radionuclides are used in UK hospitals for therapy, diagnosis or research purposes. The choice of radioisotope depends on its half-life, on the type of the radiation emitted as well as on its expected pathway through the body. To ensure that these radionuclides are correctly administered to the patient, their activity should be accurately determined. Radionuclide calibrators are the instruments commonly used for this purpose. Their principle of operation is relatively simple and, used correctly via a quality assurance system, they can ensure the desired accuracy of the administered activities. A protocol for establishing and maintaining such a quality 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 has been 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 [2-8]. 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 between hospital physicists.

^{201}Tl is routinely used to provide diagnostic information about the functioning of the heart. During recent years, concerns have been raised within the nuclear medicine field about the accuracy of activity measurements for this radionuclide. These concerns seemed well founded as NPL calibrations of ^{201}Tl solutions repeatedly indicated that the level of contaminants present in such samples could significantly affect the response of typical radionuclide calibrators commonly used in UK hospitals. Also the transfer of these solutions revealed that a considerable amount of activity was usually adsorbed onto the glass wall of the container. In addition, the standard P6 vials, in which ^{201}Tl solution had been previously supplied, were recently replaced with the new “10R Type 1 plus” Schott vials.

To assess the magnitude of these effects on the accuracy of clinical measurements of the activity of ^{201}Tl, an intercomparison exercise was conducted between the National Physical Laboratory (NPL), Nycomed-Amersham (NA) and the UK hospital physics community.

2. PARTICIPANTS

Participation was open to all UK hospitals and the exercise was publicised via the contact mailing lists maintained by AEA, NA and NPL.

Several participants took the opportunity to share their samples by circulating them amongst other hospital departments in their region.

A list of the participants is given in Appendix 1.

3. COMPARISON SAMPLES

The comparison samples were supplied by NA, via AEA, from a stock solution of ^{201}Tl which was accurately sub-divided into a series of 4 ml aliquots, dispensed into 10R vials, and dispatched to each participant. Three of these samples were sent to NPL for activity assay along with two additional 5 ml BS ampoules, each containing about 3 ml of the same ^{201}T stock solution.

At 12:00 GMT on 18 October 2000, the mean activity concentration of the ^{201}T comparison solution, as determined by NPL from all five samples received, was approximately 2.41 MBq g^{-1}. The chemistry of the solution was not specified by the supplier.

4. NPL MEASUREMENTS OF COMPARISON SAMPLES

The three 10R vial samples as well as the two 5 ml BS ampoules sent to NPL were assayed using the NPL secondary standard radionuclide calibrator. This system is a sealed, high pressure, re-entrant ionisation chamber, also known variously as the 671/271, the ISOCAL IV and the NPL-CRC. This chamber had been previously calibrated for ^{201}Tl solution in such a way that direct traceability was maintained to the absolute standards of ^{201}Tl using the primary standardisation facilities and techniques available at NPL.

As the new 10R vials have only relatively recently been introduced for the distribution of ^{201}Tl solutions, replacing the standard P6 vials, at present no calibration factor is available for the NPL system, for this container. Therefore, to assay the activity content of these three samples, the solution from each 10R vial was transferred accurately into 2 ml and 5 ml BS ampoules and measured using the NPL secondary standard high pressure, re-entrant ionisation chamber, type TPA MkII. Each 10R vial was also measured prior to, as well as after, the solution transfer to estimate and account for any residual activity - these measurements indicated only an insignificant level of activity adsorption onto the inner wall of the 10R vials. The principal reason for introducing the 10R vial was to reduce the level of adsorption onto the walls of the container: any adsorption will reduce the activity concentration below that which was initially dispensed into the vial.

Similarly, the two 5 ml BS ampoules also containing the ^{201}Tl intercomparison solution were measured as received. Then, to confirm the validity of the activity measured, the solution from each ampoule was dispensed accurately into another 5 ml BS ampoule and re-measured using the NPL secondary standard high pressure, re-entrant ionisation chamber, type TPA MkII. The activity concentration of the transferred solution agreed with the initial measured value to better than 0.3%.

The NPL-determined activity concentration of the ^{201}Tl intercomparison solution was calculated from the mean of all the results obtained from measurements made in the ampoules.

The presence of any photon emitting radioactive impurities in the solution was checked by gamma spectrometry. This identified the presence, at the reference time, of ^{200}Tl, at an activity level of about 0.3 % of that of ^{201}Tl, and ^{202}Tl, at an activity level of about 0.04 % of that of ^{201}Tl. These levels may seem insignificant but, because the response factor of ^{200}Tl in the NPL calibrator is about 14 times higher that that of ^{201}Tl and the response factor of ^{202}Tl in the NPL calibrator is about 5 times higher that that of ^{201}Tl (see Table 7), the effect of the contaminant was taken into account when determining the activity concentration of ^{201}Tl in the intercomparison sample. For the measurements made using the NPL calibrator, the activity concentration corrected for contaminants was about 2 % lower than the uncorrected value, at the reference time.

5. FURTHER NPL MEASUREMENTS USING THE NPL CALIBRATOR AND A CAPINTEC 120 SYSTEM

To estimate the variation in response of the NPL radionuclide calibrator and that of the Capintec 120 system available at NPL with the type of container used, some additional measurements were made using a stock solution of ^{201}Tl. As Capintec radionuclide calibrators are predominantly used in the UK hospitals, it was useful to check their performance for ^{201}Tl activity measurements.

Minimal volumes of a ^{201}Tl stock solution were accurately dispensed to various syringes routinely used in UK hospitals and to the new 10R vials. Aliquots of 1 ml of the same solution were also dispensed to some standard 2 ml BS ampoules. Each syringe and 10R vial was subsequently topped up in stages with inactive carrier to its nominal volume and measured at each stage in both calibrators.

For the Capintec system, no significant variation in response between the two “pre-set” and “dial 205” setting options for ^{201}Tl was noticed.

Details of the containers used, their nominal volumes and wall thickness are given in Table 6.

The activity concentration of this solution was determined from measurements of the 2 ml BS ampoules in the NPL secondary standard ionisation chamber and corrected for the effect of the ^{200}Tl and the ^{202}Tl contaminants identified in this solution by gamma spectrometry. The activity concentrations of the syringes and the 10R vial were compared to this corrected value.

The results obtained from the NPL secondary standard radionuclide calibrator are displayed in Figure 2, while those from the Capintec 120 system are presented in Figure 3. It is immediately evident that, using the P6 vial ^{201}Tl calibration factor for the NPL calibrator to determine the activity in the 10R vials, and without correcting for the effect of impurities present in this solution, this produced results that overestimate the activity by about 5 %.

The User Manual [9] for Capintec calibrators states for the ^{201}Tl radionuclide that:

a) The Calibration Setting Numbers are given for approximately 5 grams of radioactive solution in a standard source ampoule made of about 0.6 mm thick borosilicate glass. The standard radioactive source in the ampoule is, however, a good approximation for a radiopharmaceutical in a plastic syringe (wall thickness of about 1.2 mm), for most radioisotopes;

b) The correction factor for syringe is 2 %.

The ^{201}Tl factor recommended in the Capintec User Manual, although intended for a container that is never used in practice, coincidentally produced reasonably good results, of just less than 1 % high (for measurements made with 4 ml of solution in the vial).
It is, however, difficult to accurately estimate the correction needed for the new 10R vial, for each calibrator, because:

- the level of impurities usually varies from sample to sample.

Indeed, NPL calibrations of ^{201}Tl solutions repeatedly indicated that the level of impurities present in the solution samples received from customers varied significantly. The contaminant-corrected activity of such calibration samples was found to be, on average, between 2 and 5 % lower than the uncorrected value, at the reference time of the particular calibration, and for one particular solution the difference was as high as 19 %.

- the ratio of the activity of contaminants to that of the ^{201}Tl will change in time.

As the half-lives of ^{200}Tl and ^{201}Tl are significantly smaller than that of ^{202}Tl (see Table 7), the ratios of contaminants to the main radionuclide will not remain constant in time. To estimate how the effect of the two contaminants on the response of the NPL radionuclide calibrator changes with time, one of the 2 ml BS ampoule was repeatedly measured until almost completely decayed and the results are presented in Figure 4. These measurements indicated that the correction for the contribution of the contaminants to the overall response of the ionisation chamber has to be done at the measurement time, as the

uncorrected for contaminants activity of the ampoule was only about 1 % higher than the true value in the first day of measurement but it became about 6 % higher ten days later.

For the syringe results, the response of the NPL calibrator is clearly more sensitive to variations in the volume of solution in the syringe containers, and it decreases by up to 10 % as the syringe is completely filled.

The syringe results from measurements made in the Capintec 120 system centre about 5 to 7 % higher than the true value (at least for the syringe types chosen for this exercise), and the response of this calibrator seems less volume dependant. The 2 % correction recommended by the Capintec User Manual is evidently inaccurate.

6. INTERNATIONAL EQUIVALENCE OF NPL PRIMARY STANDARDS

All the measurements on which the results of this exercise were based, as well as the additional NPL measurements to investigate possible sources of errors associated with the activity assay of ^{201}Tl, were made using the NPL secondary standard ionisation chambers. These systems had been previously calibrated using primary standards of ^{201}Tl produced at NPL. The accuracy of such standards had been confirmed by an international comparison exercise conducted in 1990 between the National Metrology Institutes from the United States (NIST), Germany (PTB), United Kingdom (NPL) and Nycomed Amersham plc. The results of that comparison are shown in Table 1 and Figure 1.

7. MEASUREMENTS AND REPORTING PROTOCOL

Participants were invited to assay their samples in each of their radionuclide calibrators and to report their results directly to NPL. Subsequently the NA certificates of calibrations were sent to each participant, stating the activity content of their solution samples based on the NPL determined activity concentration of the ^{201}Tl comparison solution.

Participants were encouraged to provide additional information for this exercise by making measurements using both pre-set and dial settings, by transferring the solution to other

containers routinely used, such as syringes, and reporting their results on these. They were also invited to check the presence of any possible radioactive impurities in their samples and to correct for their contribution.
Estimates of measurement uncertainties were also sought. A standard reporting form was provided.

8. CONFIDENTIALITY

All results were reported directly to NPL. Each result was given a code by NPL, consisting of a number indicating the individual participating hospital or group of hospitals within a NHS Trust and a letter indicating the particular calibrator in that hospital/Trust. This code system both preserves the anonymity of individual participants and allows the comparison of results from individual calibrators within a hospital.

9. ANALYSIS OF RESULTS

28 of the 29 possible participants reported a total of 273 results, from measurements made on 120 calibrators from 34 hospitals. All results have been decayed to the same reference time of 12:00 GMT on 18 October 2000 (the half-lives used are listed in Table 7).

The activity content of each sample was determined from the activity concentration measured and corrected for impurities by NPL (as described in Chapter 4) and the masses of solution dispensed by NA. For those samples that were subsequently transferred by the participants to other container types (in most cases syringes), the activities were determined from the participants' declared dispensings and the NPL measured activity concentrations. The reported activities of the comparison samples and of the transferred solutions were compared to these NPL calculations.

The results have been tabulated as ratios of reported activity to the NA certificated value (based on the activity concentration determined by NPL) and are presented in Table 2. An asterisk (*) in the "setting" column of this table indicates that the participant applied a self-determined correction factor or a self-derived dial factor.

Only one of the participants reported any evidence of contaminant checks and corrections for their effect.

Summarised breakdowns of the results by container and calibrator type are given in Table 3. In the breakdown by calibrator type, the original 10R vial results and the syringe results were considered separately, while in the summary by container all reported results were included. The results are also selectively displayed in histogram form in Figures 5 to 10.

The reported uncertainties associated with the individual results sent by the participants are listed in Table 4.

10. DISCUSSION

The main aim of this exercise was to assess the accuracy of ^{201}Tl activity measurements using typical radionuclide calibrators and containers available in UK hospitals, in particular since the replacement of the standard P6 vial with the new 10R vial.

In addition, the participants were provided with a traceable standard which enabled them to check and recalibrate their systems, if and when necessary, for this particular radionuclide.

From all the reported results, some of the residue values need to be regarded with some reservation because the estimation of the mass remaining after transfer is not accurate and this could lead to a distortion of the related results. The discussion, as it relates to containers, is confined to those results from measurements made using the 10R vials (in which the solution was sent to the participants) and various syringes.

10.1. REPLACEMENT OF P6 VIALS WITH "10R TYPE 1 plus" VIALS

As P6 vials have been used for the distribution of radioactive solutions for a long period of time, most of the radionuclide calibrators used in hospitals have been calibrated for this particular container. Indeed, NPL provides an extensive list of calibration factors for the P6 vial, for the NPL system, including all the photon emitting radionuclides, the positron

emitters recently used for diagnosis as well as for some of the pure beta emitters used for therapeutic purposes. This container has been recognised as the standard container for activity measurements of radioactive solution and therefore was always used in national comparison exercises and for NPL calibrations of radionuclide calibrators.

Recently the 10R "Type 1 plus" Schott vial was introduced as a replacement for the P6 vial. This new vial also has a nominal volume of 10 ml, but it is shorter and wider that the P6 vial. Its wall thickness is 0.2 mm thinner than that of the P6 vial.

The vial has an inner coating of pure silica; the inertness of this coating reduces significantly the adsorption onto the glass container of radionuclides such as ^{201}Tl and ^{67}Ga from their carrier-free solutions. Indeed, all previous NPL calibrations of ^{201}Tl solution in P6 vials revealed that a considerable amount of activity was usually adsorbed onto the glass wall of the container, varying between 5 to as much as 19 % of the total activity. However, the NPL measurements performed for this comparison showed no significant activity adsorption onto the inner wall of the 10R Schott vials.

Although the new 10R vial eliminates adsorption losses, the responses of radionuclide calibrators are container-dependent and new calibration factors should be derived for individual radionuclides and calibrators. The supplier suggested that: "this change in dimension (from that of P6 vial to the 10R vial) showed no significant effect on total activity measurements". NPL measurements indicated that this is not true for each radionuclide calibrator type, in particular for the NPL system, as the existing P6 vial calibration factors produced erroneous results. Therefore, recalibration for the new container is required for individual radionuclides and in particular for the low energy emitters.

The other disadvantage of the new 10R vial is that it does not fit in the standard holder of the NPL calibrator. A new holder has been designed by Southern Scientific to accommodate both the P6 and the 10R vials; the response of the NPL calibrator using the new holder was checked by NPL and was found to be similar to that of the standard holder.

10.2. ALL RESULTS

The overall received data, displayed in Figure 5, show a spread of about ± 20 % from the NPL determined activity, but most of the results (about 89%) lie within the ± 10 % limit of accuracy that hospitals aim to achieve for diagnosis, with about half of them within ± 4 % of the true value. There is, however, a distinct bias towards overestimation.
The 4 outliers, positioned about 30 % low, are from residue measurements and they have been excluded from the data analysis.

Possible reasons for the tendency to overestimate the activity and for the relatively wide spread of results are:

- the use of ^{201}Tl P6 vial calibration factors to determine the activity of the comparison solution in the 10R vials. Measurements conducted at NPL for this exercise (see Chapter 5 and Figures 2 and 3) show that the existing P6 vial factor produces results which overestimate the activity to different degrees, depending on the type of radionuclide calibrator used. This confirms the need to recalibrate individual systems for the new container.

- the levels of ^{200}Tl and ^{202}Tl impurities present in the sample. Present measurements at NPL, as well as previous NPL calibrations of ^{201}Tl solutions (see Chapter 5), indicated that the level of impurities can significantly affect the accuracy of the ^{201}Tl activity assay and also that the ratio of the activity of contaminants to that of the ^{201}Tl varies from sample to sample. The presence of impurities in the comparison solution would have affected the accuracy of all the results, and especially those performed at a later date than the reference time.

- small variations in the thickness of the inner wall of calibrators of the same type could generate differences in response. With the exception of the NPL calibrator, it is not known how tightly controlled or specified the tolerances for the dimensions and the gas filling of radionuclide calibrators made by the same manufacturer are. Such variations in response are evidenced in Figure 11, which displayed the results from participant number 3. All these results are from measurements made in various Capintec systems within the

particular Trust. Most of the calibrators used produced results between 1 to 6 % higher than the true activity, while the results from two particular systems are about 5 % and 8 % low respectively.

- extra fittings such as inner PVC liners lower the response of calibrators. It is possible that the systems, which produced low results, were fitted with extra protective liners to avoid contamination, hence the low response. This is often a source of error due to the added attenuation and calibrators fitted with such liners should be recalibrated, in particular when used to measure low-energy, gamma-ray emitting radionuclides.

The UK protocol [1] for maintaining the quality of radionuclide calibrator performance is in the process of being revised and the aim is to emphasise these possible sources of errors associated with the use of typical radionuclide calibrators and to support this with practical examples.

The effect of these possible sources of error on the accuracy of ^{201}Tl activity measurements is better revealed in the analysis of the data summarised by container type and calibrator type.

The overall data indicated that, for the majority of calibrators, there are no significant differences in response between the “dial” and the “preset” settings for ^{201}Tl, for either 10R Schott vial or syringe results.

10.3. 10R VIAL RESULTS

The spread of results from measurements made in the 10R vials are presented in Figure 6. As these results represent the majority of the reported values, their distribution is similar to that described for all results: biased high – about 85 % of results are up to 7 % high and centred about 2.5 % higher than the true value.

About 6 % of all the 10R vial results are outside the ± 10 % limit.

Some participants have also reported results to which they applied self-determined correction factors, although the method or the traceability of their recalibrations was not specified. These particular results are highlighted in Figure 6 and their distribution reveal a high bias and a relatively wide spread. This may be due, in part, to the fact that the initial recalibration was probably performed with standard P6 vials and not revised for the newly introduced 10R vial. The spread of results is a reflection of the performance of individual calibrators and is discussed next.

10.3.1. CAPINTEC SYSTEMS

The results from Capintec systems, which represent about 75 % of the entire 10R vial reported results, are displayed in Figure 8. The majority of these results are from the Capintec 120 and Capintec 15 systems and they all show the same trend: most of them about 1 to 6 % high, with some outliers up to ± 16 % from the true value. The NPL measurements made with a Capintec 120 system (see Chapter 5 and Figure 3) seem to indicate that only a very minimal correction is needed when the ^{201}Tl manufacturer recommended factor is used for measurements made in the 10R vial. The relatively high bias and the spread of these results suggests that the response of Capintec systems is not constant, possibly due to variations in the thickness of the inner wall of these chambers which will considerably affect the response of individual calibrators.

As a new 10R vial was introduced for the distribution of ^{201}Tl solutions, best practice is to recalibrate these systems individually for this vial or indeed, for the container type routinely used to measure this radionuclide.

10.3.2. ISOCAL IV SYSTEMS

This is the NPL secondary standard radionuclide calibrator. Its design tolerances are tightly controlled to ensure that the variations in response between these systems are minimal. To confirm their expected accuracy, each system is calibrated by NPL directly against the NPL secondary standard ionisation chamber, over a wide range of energy. The existing ^{201}Tl calibration factor for these systems is valid for the P6 vial format only, but the measurements conducted at NPL for this exercise will be used to derive a new calibration factor and to

determine the volume correction for the newly introduced 10R vial, which will then be made available to the users.

The reported results are displayed in Figure 7 and they show a tendency to overestimate the activity by about 4 to 8%. This is a consequence of the fact that the P6 vial factor was used to determine the activity rather than a reflection of the level of accuracy of calibration of these systems. Indeed, the measurements carried out at NPL for this exercise suggested an overestimation of about 5 % if the P6 vial factor is used for measurements of solution in 10R vials. Also, for measurements made close to the reference time, the correction for the presence of impurities would have lowered the results by about 2 %. If these corrections are applied, the results improve significantly, with the exception of result number 20[a], which deserves some attention: this measurement was performed 9 days after the reference time, by which time the level of ^{202}Tl became more dominant compared with the amount of ^{201}Tl left in the sample. This just confirms the findings from the NPL measurements presented in Figure 7 and discussed in Chapter 5.

10.3.3. ISOCAL III SYSTEMS

Only four results were reported for this system. Their random distribution makes it difficult to come to a definitive conclusion on the performance of these calibrators, although the wide spread suggests that a new factor for the 10R vial should be derived.

10.3.4. ISOCAL II/PITMAN 238 SYSTEMS

About 67 % of the ISOCAL II results are up to 8 % higher than the NPL determined activity (Figure 7). This high bias was expected, as the P6 vial calibration factor was used. However, the wider spread of all the ISOCAL II results, between ± 18 % from the true value, indicates once again that the performance of these systems is poor. This is mainly because these chambers are unsealed and therefore subject to pressure and temperature variations and possibly because of suspected errors in the initial calibration.

It is therefore recommended that these systems should be re-calibrated individually for the new 10R vial.

10.3.5. OTHER SYSTEMS

With only a few results reported from measurements made in other calibrators, it is difficult to assess the general performance of these systems.

The results from Atomlab calibrators, presented in Table 5, seem to have a wider spread, possibly due to variations in its dimensions.

Although only one result for a Pitman 270 calibrator was reported, it seem to suggest that the recommended calibration factor for this system may be overestimating the activity by about 16 %. It is difficult to conclude if this is the case based on a single reported result, but it appears to confirm the inaccuracy of the calibration factors available for these systems, which was also highlighted in previous intercomparison exercises.
The users of these calibrators are well advised to check their calibrations.

As explained in Chapter 5, the presence of impurities would have affected the response of all the calibrators discussed above, to various degrees.

10.4. SYRINGE DATA

The syringe results reported for this exercise are displayed in Figure 9. Around 75 % of them are between 2 % and 12 % higher than the NPL determined value. The spread of results is possibly a reflection of the performance of individual calibrators, but also due to the fact that different syringe types and sizes were used, containing varying volumes of solution. The high bias can be attributed to the use of ^{201}Tl calibration factors recommended for glass containers to assay the activity of syringes.

The performance of individual systems is revealed in the breakdown of syringe results by calibrator type and presented in Figure 10.

10.4.1. CAPINTEC SYSTEMS

In Figure 10, the syringe results for these calibrators reveal a relatively wide spread and a high bias, as most of them are between 2 and 16 % higher than the true value. The 2 % syringe correction recommended in the Capintec user manual is evidently not accounting for all the syringe types in use or for the volume effect. The relatively wide spread of results can be attributed to the already identified variations in the wall thickness of these calibrators.

Only two participants (producing 5 results) applied self-determined corrections to their syringe measurements (see Figure 9) and they deserve some attention. The Capintec recommended 2 % correction for syringe measurements was applied to result no. 11. This confirmed once again that the recommended correction is not sufficient, as the uncorrected result was 8 % high.
The four outliers, two each from calibrators 17[a] and 17 [b], are biased about 12 % low.They are corrected syringe results from measurements made on two different Capintec system within the same hospital. The consistent low bias may be a consequence of an incorrectly derived syringe factor or possibly because the particular calibrator was fitted with an extra inner liner.

10.4.2. ISOCAL SYSTEMS

Only three syringe results were reported for this exercise, from measurements made in one ISOCAL III and one ISOCAL IV fitted with lead shielding, and they were about 12 to 14 % high. With such a limited number of results, it is difficult to draw any conclusions.

For the ISOCAL IV systems, syringe factors have not been published as yet. NPL is in the process of determining calibration factors and volume correction factors for the most commonly used syringe types, for a wide range of radionuclides routinely used in medicine. These will then be made available to the users of these systems.
An indication of the degree of inaccuracy expected for ^{201}Tl syringe measurements in the NPL calibrator using the existing P6 vial factor is given in Figure 2.

11. UNCERTAINTIES

The response to the request for estimates of uncertainty produced fewer contributions than the previous exercises, but the same comments apply as before: the methods of estimation and combination of individual contributions show no consistency.

The reported uncertainties are listed in Table 4 and show that generally only the standard deviation of the measurement (the Type A uncertainty arising from counting statistics) was quoted. It is important to note, however, that there is at least a factor of 10 between the largest and smallest Type A estimates. When the Type B uncertainties are considered, there is a similar spread between estimated values: this may indicate that many users may be unaware of the totality of the Type B uncertainties.

12. CONCLUSIONS

This comparison sought to provide a true reflection of the accuracy of ^{201}Tl activity measurements in UK hospitals and to identify possible sources of error. It was a good opportunity to check if the adsorption losses experienced with the P6 vials had been solved by the introduction of the new 10R vials and to highlight that, although the supplier suggested no corrections for measurements in the new container, the response of some calibrators is clearly affected.

The authors propose the following conclusions:

(a) The spread of 10R vial results is generally within the ± 10 % limit, biased high.

(b) The syringe measurements produce results which overestimate the activity.

(c) The presence of impurities in the intercomparison sample would have affected the response of all the calibrators to various degrees.

(d) ^{201}Tl activity adsorption in the new 10R vials is insignificant.

(e) The relatively wide spread of both the 10R and syringe results is possibly due to variations in the thickness of the inner wall of the chambers of the same type.

(f) Calibration factors for the new 10R "Type 1 plus" Schott vial should be derived for all calibrators, using traceable standards.

(g) Users of Pitman 270 and Isocal II systems should check the accuracy of their supplied calibration factors for ^{201}Tl.

(h) Calibrators with any additional fittings such as inner PVC protective liner, lead shielding, etc. should be individually recalibrated for the preferred measurement format.

(i) NPL should provide calibration factors for the NPL calibrator, for the 10R vial and for the most commonly used syringe types.

(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 intercomparison exercises.

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Table 1 Comparison of primary standards from National Metrology Institutes (NMIs)

Country	**NMI Acronym**	**NMI Value (Bq/mg)**	**Uncertainty (k=1) (Bq/mg)**
United States	NIST	7.207	0.033
Germany	PTB	7.197	0.027
UK	NPL	7.116	0.050
Amersham	N-A	7.18	0.11

Table 2 ^{201}Tl solution reported results.

Solution Code	Calibrator Manufacturer	Model	Container Type	Settings	Reported Activity (MBq)	Reported/NA
1[a]	VEENSTRA	VDC404	10R Schott vial	^{201}Tl preset	9.93	1.024
1[a]	VEENSTRA	VDC404	10R Schott vial	dial 552	9.94	1.025
1[b]	NPL-CRC (shielding)	ISOCAL IV	10R Schott vial	dial 0.8682	10.42	1.074
1[c]	VINTEN	ISOCAL II	10R Schott vial	dial 1043	10.37	1.069
1[c]	VINTEN	ISOCAL II	10R Schott vial	dial 1043+cor*	10.55	1.088
1[d]	VINTEN	ISOCAL II	10R Schott vial	dial 1043	10.05	1.036
1[d]	VINTEN	ISOCAL II	10R Schott vial	dial 1043+cor*	10.19	1.050
1[e]	VINTEN	ISOCAL II	10R Schott vial	dial 1043	10.26	1.057
1[e]	VINTEN	ISOCAL II	10R Schott vial	dial 1043+cor*	10.40	1.072
1[f]	CAPINTEC	ARC-120	10R Schott vial	^{201}Tl preset	10.71	1.104
1[f]	CAPINTEC	ARC-120	10R Schott vial	dial 205	10.42	1.074
1[g]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	10.08	1.039
1[g]	CAPINTEC	CRC-15R	10R Schott vial	dial 205	10.08	1.039
1[h]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	10.06	1.037
1[h]	CAPINTEC	CRC-15R	10R Schott vial	dial 205	10.06	1.038
1[i]	CAPINTEC	ARC-120	10R Schott vial	^{201}Tl preset	9.87	1.018
1[i]	CAPINTEC	ARC-120	10R Schott vial	dial 205	10.04	1.035
1[j]	VEENSTRA	VDC 404	10R Schott vial	^{201}Tl preset	9.79	1.009
1[j]	VEENSTRA	VDC 404	10R Schott vial	dial 552	9.79	1.009
1[k]	CAPINTEC	ARC-120	10R Schott vial	^{201}Tl preset	10.29	1.060
1[k]	CAPINTEC	ARC-120	10R Schott vial	dial 205	10.26	1.058
1[l]	SIEL		10R Schott vial	dial 240.05	9.75	1.006
1[m]	VEENSTRA	VDC 404	10R Schott vial	^{201}Tl preset	10.01	1.032
2[a]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	9.71	1.008
2[a]	CAPINTEC	CRC-15R	10R Schott vial	dial 205	9.72	1.008
2[b]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	9.90	1.027
2[b]	CAPINTEC	CRC-15R	10R Schott vial	dial 205	9.90	1.027
2[c]	CAPINTEC	ARC-120R	10R Schott vial	^{201}Tl preset	9.92	1.029
3[a]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	8.89	0.922
3[a]	CAPINTEC	CRC-15R	10R Schott vial	dial 205	8.90	0.923
3[b]	AMERSHAM	ARC-120	10R Schott vial	^{201}Tl preset	9.89	1.026
3[b]	AMERSHAM	ARC-120	10R Schott vial	dial 205	10.13	1.051
3[c]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	9.86	1.023
3[c]	CAPINTEC	CRC-15R	10R Schott vial	dial 205	9.85	1.021
3[d]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	10.02	1.040
3[d]	CAPINTEC	CRC-15R	10R Schott vial	dial 205	10.00	1.037
3[k]	AMERSHAM	ARC-120	10R Schott vial	^{201}Tl preset	9.97	1.034
3[e]	AMERSHAM	ARC-120	10R Schott vial	^{201}Tl preset	9.83	1.020
3[e]	AMERSHAM	ARC-120	10R Schott vial	dial 205	9.83	1.020
3[f]	AMERSHAM	ARC-120	10R Schott vial	^{201}Tl preset	9.17	0.951
3[f]	AMERSHAM	ARC-120	10R Schott vial	dial 205	9.21	0.956
3[g]	CAPINTEC	CRC-120	10R Schott vial	^{201}Tl preset	9.79	1.016
3[g]	CAPINTEC	CRC-120	10R Schott vial	dial 205	9.75	1.012
3[h]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	9.86	1.023

Solution Code	Calibrator Manufacturer	Model	Container Type	Settings	Reported Activity (MBq)	Reported/NA
3[h]	CAPINTEC	CRC-15R	10R Schott vial	dial 205	9.87	1.024
3[i]	CAPINTEC	CRC-712M	10R Schott vial	dial 205	9.95	1.033
3[j]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	10.02	1.040
3[j]	CAPINTEC	CRC-15R	10R Schott vial	dial 205	10.03	1.041
4[a]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	9.87	1.023
4[a]	CAPINTEC	CRC-15R	10R Schott vial	dial 205	9.89	1.025
4[a]	CAPINTEC	CRC-15R	2 ml syringe	^{201}Tl preset	5.08	1.056
4[a]	CAPINTEC	CRC-15R	2 ml syringe	dial 205	5.08	1.056
4[a]	CAPINTEC	CRC-15R	residue	^{201}Tl preset	4.83	0.999
4[a]	CAPINTEC	CRC-15R	residue	dial 205	4.83	0.999
4[b]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	10.03	1.039
4[b]	CAPINTEC	CRC-15R	10R Schott vial	dial 205	10.03	1.040
4[b]	CAPINTEC	CRC-15R	2 ml syringe	^{201}Tl preset	5.18	1.077
4[b]	CAPINTEC	CRC-15R	2 ml syringe	dial 205	5.18	1.077
4[b]	CAPINTEC	CRC-15R	residue	^{201}Tl preset	4.92	1.016
4[b]	CAPINTEC	CRC-15R	residue	dial 205	4.92	1.017
5[a]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	9.98	1.038
5[a]	CAPINTEC	CRC-15R	10R Schott vial	dial 205	9.98	1.039
5[b]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	9.90	1.030
5[b]	CAPINTEC	CRC-15R	10R Schott vial	dial 205	9.89	1.030
5[b]	CAPINTEC	CRC-15R	5 ml syringe	^{201}Tl preset	9.06	1.106
5[b]	CAPINTEC	CRC-15R	5 ml syringe	dial 205	9.06	1.107
5[b]	CAPINTEC	CRC-15R	residue	^{201}Tl preset	0.95	0.667
5[b]	CAPINTEC	CRC-15R	residue	dial 205	0.96	0.671
5[c]	CAPINTEC	ARC-120	10R Schott vial	dial 205	9.95	1.036
5[c]	CAPINTEC	ARC-121	5 ml syringe	^{201}Tl preset	8.52	1.040
5[c]	CAPINTEC	ARC-122	5 ml syringe	dial 205	9.40	1.148
5[c]	CAPINTEC	ARC-123	residue	^{201}Tl preset	0.90	0.634
5[c]	CAPINTEC	ARC-124	residue	dial 205	0.99	0.693
6[a]	CAPINTEC	CRC-10	10R Schott vial	^{201}Tl preset	10.09	1.038
6[b]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	9.88	1.016
7[a]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	9.70	1.014
7[a]	CAPINTEC	CRC-15R	10R Schott vial	dial 205	9.70	1.014
7[a]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	9.80	1.024
7[a]	CAPINTEC	CRC-15R	10R Schott vial	dial 205	9.81	1.025
7[a]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	9.85	1.030
7[a]	CAPINTEC	CRC-15R	10R Schott vial	dial 205	9.87	1.031
7[a]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	9.85	1.030
7[a]	CAPINTEC	CRC-15R	10R Schott vial	dial 205	9.85	1.030
7[b]	AMERSHAM	ARC-120R	10R Schott vial	^{201}Tl preset	9.83	1.027
7[b]	AMERSHAM	ARC-120R	10R Schott vial	dial 205	9.90	1.035
7[b]	AMERSHAM	ARC-120R	10R Schott vial	^{201}Tl preset	9.85	1.029
7[b]	AMERSHAM	ARC-120R	10R Schott vial	dial 205	9.91	1.035
7[b]	AMERSHAM	ARC-120R	10R Schott vial	^{201}Tl preset	9.85	1.029
7[b]	AMERSHAM	ARC-120R	10R Schott vial	dial 205	9.92	1.036
7[b]	AMERSHAM	ARC-120R	10R Schott vial	^{201}Tl preset	9.86	1.030

Solution Code	Calibrator Manufacturer	Model	Container Type	Settings	Reported Activity (MBq)	Reported/NA
7[b]	AMERSHAM	ARC-120R	10R Schott vial	dial 205	9.92	1.037
7[c]	AMERSHAM	ARC-120	10R Schott vial	^{201}Tl preset	9.81	1.025
7[c]	AMERSHAM	ARC-120	10R Schott vial	dial 205	9.78	1.021
7[c]	AMERSHAM	ARC-120	10R Schott vial	^{201}Tl preset	9.74	1.018
7[c]	AMERSHAM	ARC-120	10R Schott vial	dial 205	9.76	1.020
7[c]	AMERSHAM	ARC-120	10R Schott vial	^{201}Tl preset	9.82	1.026
7[c]	AMERSHAM	ARC-120	10R Schott vial	dial 205	9.84	1.028
7[c]	AMERSHAM	ARC-120	10R Schott vial	^{201}Tl preset	9.80	1.024
7[c]	AMERSHAM	ARC-120	10R Schott vial	dial 205	9.87	1.031
7[d]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	9.85	1.029
7[d]	CAPINTEC	CRC-15R	10R Schott vial	dial 205	9.85	1.029
8[a]	CAPINTEC	CRC-35R	10R Schott vial	^{201}Tl preset	10.43	1.074
8[a]	CAPINTEC	CRC-35R	2.5 ml syringe	^{201}Tl preset	5.22	1.056
8[a]	CAPINTEC	CRC-35R	residue	^{201}Tl preset	4.93	1.034
8[b]	CAPINTEC	CRC-35R	10R Schott vial	^{201}Tl preset	9.71	1.000
8[b]	CAPINTEC	CRC-35R	2.5 ml syringe	^{201}Tl preset	4.82	0.974
8[b]	CAPINTEC	CRC-35R	residue	^{201}Tl preset	4.72	0.992
9[a]	VINTEN	ISOCAL III	10R Schott vial	dial 1690	9.41	0.979
9[b]	VINTEN	ISOCAL II	10R Schott vial	dial 1218	8.30	0.863
9[c]	NE Technology	ISOCAL IV	10R Schott vial	dial 0257	9.51	0.988
10[a]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	10.18	1.058
10[a]	CAPINTEC	CRC-15R	10R Schott vial	dial 211*	9.96	1.036
10[b]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	9.93	1.032
10[b]	CAPINTEC	CRC-15R	10R Schott vial	dial 211*	9.71	1.010
10[c]	NPL-CRC	ISOCAL IV	10R Schott vial	^{201}Tl preset	9.22	0.958
10[c]	NPL-CRC	ISOCAL IV	10R Schott vial	dial 0.8500	9.74	1.013
11	CAPINTEC	CRC-15R	10R Schott vial	dial 205	10.02	1.040
11	CAPINTEC	CRC-15R	10R Schott vial	dial 175 *	11.22	1.163
11	CAPINTEC	CRC-15R	5 ml syringe	dial 205	4.85	1.084
11	CAPINTEC	CRC-15R	5 ml syringe	dial 212 *	4.76	1.062
11	CAPINTEC	CRC-15R	residue	dial 205	5.32	1.031
12[a]	VINTEN	ISOCAL III	10R Schott vial	^{201}Tl preset	10.60	1.097
12[b]	VINTEN	ISOCAL II	10R Schott vial	^{201}Tl preset	9.85	1.019
12[c]	VINTEN	ISOCAL II	10R Schott vial	^{201}Tl preset	9.67	1.002
12[c]	VINTEN	ISOCAL II	10R Schott vial	dial 1033	9.68	1.002
12[d]	VINTEN	ISOCAL II	10R Schott vial	^{201}Tl preset	10.16	1.052
12[d]	VINTEN	ISOCAL II	10R Schott vial	dial 1033	10.16	1.052
12[e]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	9.76	1.010
12[f]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	9.99	1.034
12[g]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	10.07	1.042
12[h]	VINTEN	ISOCAL II	10R Schott vial	^{201}Tl preset	10.82	1.120
12[i]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	9.69	1.003
12[j]	VINTEN	ISOCAL II	10R Schott vial	^{201}Tl preset	9.93	1.028
12[k]	VINTEN	ISOCAL II	10R Schott vial	^{201}Tl preset	10.06	1.041
12[k]	VINTEN	ISOCAL II	10R Schott vial	dial 1033	10.05	1.041
12[l]	NE Technology	ISOCAL IV	10R Schott vial	^{201}Tl preset	10.16	1.051

Solution Code	Calibrator Manufacturer	Model	Container Type	Settings	Reported Activity (MBq)	Reported/NA
12[l]	NE Technology	ISOCAL IV	10R Schott vial	dial 0257	10.16	1.052
13[a]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	10.20	1.053
13[a]	CAPINTEC	CRC-15R	10R Schott vial	dial 205	10.20	1.053
13[a]	CAPINTEC	CRC-15R	2 ml syringe	^{201}Tl preset	2.21	1.033
13[a]	CAPINTEC	CRC-15R	2 ml syringe	dial 205	2.21	1.034
13[a]	CAPINTEC	CRC-15R	residue	^{201}Tl preset	7.92	1.050
13[a]	CAPINTEC	CRC-15R	Amersham vial	^{201}Tl preset	4.95	1.034
13[a]	CAPINTEC	CRC-15R	Amersham vial	dial 205	4.95	1.035
13[a]	CAPINTEC	CRC-15R	residue (2nd)	^{201}Tl preset	2.91	1.060
13[b]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	10.12	1.045
13[b]	CAPINTEC	CRC-15R	10R Schott vial	dial 205	10.12	1.046
13[b]	CAPINTEC	CRC-15R	2 ml syringe	^{201}Tl preset	2.28	1.063
13[b]	CAPINTEC	CRC-15R	2 ml syringe	dial 205	2.28	1.063
13[b]	CAPINTEC	CRC-15R	residue	^{201}Tl preset	7.92	1.050
13[b]	CAPINTEC	CRC-15R	Amersham vial	^{201}Tl preset	4.94	1.031
13[b]	CAPINTEC	CRC-15R	Amersham vial	dial 205	4.94	1.032
13[b]	CAPINTEC	CRC-15R	residue (2nd)	^{201}Tl preset	2.91	1.060
13[c]	VINTEN	ISOCAL III	10R Schott vial	^{201}Tl preset	11.36	1.174
13[c]	VINTEN	ISOCAL III	10R Schott vial	dial 244	11.37	1.175
13[c]	VINTEN	ISOCAL III	2 ml syringe	^{201}Tl preset	2.44	1.142
13[c]	VINTEN	ISOCAL III	2 ml syringe	dial 244	2.45	1.143
13[c]	VINTEN	ISOCAL III	Amersham vial	^{201}Tl preset	5.53	1.156
13[c]	VINTEN	ISOCAL III	Amersham vial	dial 244	5.54	1.157
14[a]	CAPINTEC	CRC-15R	10R Schott vial	dial 205	10.08	1.044
14[b]	VINTEN	ISOCAL II	10R Schott vial	dial 244	10.64	1.101
14[b]	VINTEN	ISOCAL II	10R Schott vial	dial 252 *	10.30	1.066
14[c]	ATOMLAB	200	10R Schott vial	dial 18.8	9.22	0.954
14[c]	ATOMLAB	200	10R Schott vial	dial 21.1 *	10.37	1.074
14[d]	VEENSTRA		10R Schott vial	dial 552	8.70	0.901
14[e]	CAPINTEC	CRC-15R	10R Schott vial	dial 205	10.09	1.044
14[f]	CAPINTEC	CRC-7B	10R Schott vial	^{201}Tl preset	9.65	0.999
14[g]	CAPINTEC	CRC-15R	10R Schott vial	dial 205	9.89	1.024
14[h]	CAPINTEC	CRC-15R	10R Schott vial	dial 205	10.15	1.050
15[a]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	9.96	1.033
15[b]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	9.90	1.026
15[c]	CAPINTEC	ARC-120	10R Schott vial	^{201}Tl preset	9.92	1.028
15[c]	CAPINTEC	ARC-120	10R Schott vial	dial 205	9.88	1.024
15[d]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	9.92	1.028
16[a]	SIEL	BIC-1	10R Schott vial	dial 250	9.63	0.998
16[b]	CAPINTEC	CRC-10BETA	10R Schott vial	^{201}Tl preset	10.07	1.043
16[b]	CAPINTEC	CRC-10BETA	10R Schott vial	dial 205	10.07	1.044
17[a]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	10.14	1.052
17[a]	CAPINTEC	CRC-15R	10R Schott vial	dial 205	10.14	1.052
17[a]	CAPINTEC	CRC-15R	5 ml syringe	^{201}Tl preset *	8.60	0.894
17[a]	CAPINTEC	CRC-15R	5 ml syringe	dial 233 *	8.59	0.892
17[b]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	9.72	1.008

Solution Code	Calibrator Manufacturer	Model	Container Type	Settings	Reported Activity (MBq)	Reported/NA
17[b]	CAPINTEC	CRC-15R	10R Schott vial	dial 205	9.72	1.009
17[b]	CAPINTEC	CRC-15R	5 ml syringe	^{201}Tl preset *	8.54	0.888
17[b]	CAPINTEC	CRC-15R	5 ml syringe	dial 233 *	8.54	0.888
17[c]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	9.67	1.003
17[c]	CAPINTEC	CRC-15R	10R Schott vial	dial 205	9.67	1.003
18[a]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	9.91	1.016
18[a]	CAPINTEC	CRC-15R	10R Schott vial	dial 205	9.88	1.014
18[a]	CAPINTEC	CRC-15R	5 ml syringe	^{201}Tl preset	5.08	1.055
18[a]	CAPINTEC	CRC-15R	residue	^{201}Tl preset	5.10	1.035
18[b]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	10.37	1.064
18[b]	CAPINTEC	CRC-15R	10R Schott vial	dial 205	10.37	1.064
19[a]	BIODEX ATOMLAB	100	10R Schott vial	dial 18.8	9.64	0.988
19[a]	BIODEX ATOMLAB	100	10R Schott vial	dial 18.8	9.60	0.983
19[b]	AMERSHAM	ARC-120	10R Schott vial	dial 205	10.20	1.045
19[b]	AMERSHAM	ARC-120	10R Schott vial	dial 205	10.18	1.043
19[c]	CAPINTEC	CRC-15R	10R Schott vial	dial 205	10.21	1.046
19[c]	CAPINTEC	CRC-15R	10R Schott vial	dial 205	10.20	1.045
19[d]	CAPINTEC	CRC-15R	10R Schott vial	dial 205	10.31	1.056
19[d]	CAPINTEC	CRC-15R	10R Schott vial	dial 205	10.32	1.057
20[a]	NPL-CRC	ISOCAL IV	10R Schott vial	^{201}Tl preset	10.86	1.121
20[b]	ISOCAL II	ISOCAL II	10R Schott vial	^{201}Tl preset	10.07	1.039
20[c]	ISOCAL II	ISOCAL II	10R Schott vial	^{201}Tl preset	11.17	1.153
20[d]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	10.20	1.052
20[e]	CAPINTEC	CRC-10BC	10R Schott vial	^{201}Tl preset	9.99	1.031
20[f]	CAPINTEC	CRC-10B	10R Schott vial	^{201}Tl preset	9.95	1.027
20[g]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	10.23	1.055
20[h]	CAPINTEC	ARC-120R	10R Schott vial	^{201}Tl preset	9.88	1.020
20[i]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	10.12	1.044
20[j]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	10.07	1.039
20[k]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	10.15	1.047
20[l]	CAPINTEC	CRC-12	10R Schott vial	^{201}Tl preset	9.94	1.026
20[m]	CAPINTEC	CRC-10RB	10R Schott vial	^{201}Tl preset	9.85	1.016
20[n]	CAPINTEC	ARC-120R	10R Schott vial	^{201}Tl preset	9.95	1.027
20[o]	PITMAN	270	10R Schott vial	^{201}Tl preset	11.09	1.144
21[a]	NE Technology	ISOCAL IV	10R Schott vial	^{201}Tl preset	10.36	1.072
21[a]	NE Technology (shielding)	ISOCAL IV	10R Schott vial	^{201}Tl preset	10.47	1.083
21[a]	NE Technology	ISOCAL IV	10R Schott vial	dial 0257	10.38	1.074
21[a]	NE Technology (shielding)	ISOCAL IV	2 ml syringe	^{201}Tl preset	5.74	1.117
21[a]	NE Technology (shielding)	ISOCAL IV	residue	^{201}Tl preset	4.94	1.094
21[b]	ATOMLAB	100 plus	10R Schott vial	^{201}Tl preset	10.54	1.092
21[b]	ATOMLAB	100 plus	10R Schott vial	dial 20.4 *	10.52	1.089
21[b]	ATOMLAB	100 plus	10R Schott vial	dial 18.8	9.69	1.004

Solution Code	Calibrator Manufacturer	Model	Container Type	Settings	Reported Activity (MBq)	Reported/NA
21[b]	ATOMLAB	100 plus	2 ml syringe	^{201}Tl preset	5.84	1.137
21[b]	ATOMLAB	100 plus	residue	^{201}Tl preset	4.88	1.080
21[c]	VEENSTRA	VDC304	10R Schott vial	dial 552	9.48	0.981
22[a]	CAPINTEC	CRC-15R	10R Schott vial	dial 205	9.81	1.019
22[b]	CAPINTEC	CRC-15R	10R Schott vial	dial 205	9.97	1.035
22[b]	CAPINTEC	CRC-15R	5 ml syringe	dial 205	10.13	1.074
22[b]	CAPINTEC	CRC-15R	residue	dial 205	0.21	1.042
22[c]	CAPINTEC	CRC-15R	10R Schott vial	dial 205	10.05	1.043
22[c]	CAPINTEC	CRC-15R	5 ml syringe	dial 205	10.11	1.072
22[c]	CAPINTEC	CRC-15R	residue	dial 205	0.21	1.042
23[a]	CAPINTEC	CRC-15R	10R Schott vial	dial 205	9.89	1.029
23[b]	CAPINTEC	CRC-10B	10R Schott vial	dial 205	9.50	0.989
24[a]	VEENSTRA	VDC 304	10R Schott vial	dial 552	9.53	0.991
24[b]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	8.09	0.841
24[c]	VINTEN	ISOCAL II	10R Schott vial	dial 1218	7.73	0.804
24[c]	VINTEN	ISOCAL II	10R Schott vial	dial 1033	9.16	0.952
24[d]	VINTEN	ISOCAL II	10R Schott vial	dial 1218	8.73	0.907
24[d]	VINTEN	ISOCAL II	10R Schott vial	dial 1033	10.29	1.070
24[e]	CAPINTEC	CRC-35R	10R Schott vial	^{201}Tl preset	9.81	1.020
24[f]	CAPINTEC	CRC-12	10R Schott vial	^{201}Tl preset	9.76	1.015
25[a]	CAPINTEC	CRC-10RB	10R Schott vial	dial 205	10.10	1.042
25[a]	CAPINTEC	CRC-10RB	10R Schott vial	^{201}Tl preset	10.10	1.042
25[a]	CAPINTEC	CRC-10RB	5 ml syringe	dial 205	10.18	1.079
25[a]	CAPINTEC	CRC-10RB	5 ml syringe	^{201}Tl preset	10.18	1.079
25[a]	CAPINTEC	CRC-10RB	residue	^{201}Tl preset	0.26	1.030
25[b]	CAPINTEC	CRC-120R	10R Schott vial	dial 205	10.08	1.040
25[b]	CAPINTEC	CRC-120R	10R Schott vial	^{201}Tl preset	10.05	1.038
25[b]	CAPINTEC	CRC-120R	5 ml syringe	dial 205	10.21	1.083
25[b]	CAPINTEC	CRC-120R	5 ml syringe	^{201}Tl preset	10.22	1.083
25[b]	CAPINTEC	CRC-120R	residue	^{201}Tl preset	0.26	1.034
26[a]	CAPINTEC	CRC-120R	10R Schott vial	dial 205	9.98	1.039
26[a]	CAPINTEC	CRC-120R	5 ml syringe	dial 205	10.07	1.087
26[a]	CAPINTEC	CRC-120R	residue	dial 205	0.34	1.019
26[b]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	9.96	1.037
26[b]	CAPINTEC	CRC-15R	5 ml syringe	^{201}Tl preset	9.88	1.066
26[c]	CAPINTEC	CRC-120R	10R Schott vial	^{201}Tl preset	10.05	1.046
26[c]	CAPINTEC	CRC-120R	5 ml syringe	^{201}Tl preset	10.15	1.095
26[d]	CAPINTEC	CRC-15R	10R Schott vial	^{201}Tl preset	9.97	1.039
26[d]	CAPINTEC	CRC-15R	5 ml syringe	^{201}Tl preset	9.61	1.037
27[a]	NE Technology	ISOCAL IV	10R Schott vial	dial 268	9.97	1.028
27[b]	CAPINTEC	ARC-120	10R Schott vial	dial 212 *	9.90	1.021
27[c]	CAPINTEC	CRC-15R	10R Schott vial	dial 214 *	9.70	1.000
27[d]	CAPINTEC	CRC-15R	10R Schott vial	dial 215 *	9.77	1.008
27[e]	CAPINTEC	CRC-12R	10R Schott vial	dial 204 *	9.87	1.017
27[f]	CAPINTEC	CRC-35R	10R Schott vial	dial 218 *	9.94	1.025
27[g]	CAPINTEC	CRC-35R	10R Schott vial	dial 216 *	10.01	1.032
27[h]	CAPINTEC	CRC-35R	10R Schott vial	dial 217 *	10.00	1.031

Solution Code	Calibrator Manufacturer	Model	Container Type	Settings	Reported Activity (MBq)	Reported/NA
28	CAPINTEC	CRC-120R	10R Schott vial	dial 205	10.09	1.049
28	CAPINTEC	CRC-120R	10R Schott vial	^{201}Tl preset	10.06	1.046

Table 3 Results summarised by calibrator and container

^{201}Tl DATA GROUPS	**0.60 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 (273)	4	1	1	1	4	2	2	5	2	12	38	96	52	24	11	5	3	7	3
Container data:																			
10R SCHOTT VIAL	0	1	1	1	0	2	2	5	1	9	35	84	41	13	5	2	2	2	3
SYRINGE DATA	0	0	0	0	4	0	0	0	1	0	0	3	5	10	5	3	1	3	0
OTHER CONTAINERS	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	2	0
RESIDUE DATA	4	0	0	0	0	0	0	0	0	3	3	5	6	1	1	0	0	0	0
Chamber data (10R Schott vial):																			
ISOCAL II/PITMAN238	0	1	0	1	0	1	0	1	0	0	3	3	6	4	1	1	1	1	0
ISOCAL III	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	2
ISOCAL IV	0	0	0	0	0	0	0	1	0	1	1	1	2	3	1	0	1	0	0
CAPINTEC 120	0	0	0	0	0	0	0	2	0	0	6	27	8	2	0	1	0	0	0
CAPINTEC 35	0	0	0	0	0	0	0	0	0	1	1	3	0	1	0	0	0	0	0
CAPINTEC 15	0	0	1	0	0	0	2	0	0	0	17	42	21	2	0	0	0	0	1
CAPINTEC 12	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0
CAPINTEC 10	0	0	0	0	0	0	0	0	0	1	1	3	4	0	0	0	0	0	0
CAPINTEC 7	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
CAPINTEC 712	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
VEENSTRA	0	0	0	0	0	1	0	0	0	2	2	3	0	0	0	0	0	0	0
SIEL	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
ATOMLAB	0	0	0	0	0	0	0	1	0	2	1	0	0	1	2	0	0	0	0
PITMAN 270	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Chamber data (syringe):																			
CAPINTEC	0	0	0	0	4	0	0	0	1	0	0	3	5	10	5	2	0	1	0
ISOCAL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	0
OTHER SYSTEMS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0

Table 4

Reported uncertainties

Participant	Type A uncertainty (random)	Type B uncertainty (non-random)	Overall uncertainty
1[b]	0.1%	1.1%	1.2%
1[c]	0.2%	5.9%	5.9%
1[d]	0.7%	6.0%	6.0%
1[e]	0.7%	6.0%	6.0%
8[a]	0.36%	-	-
8[b]	0.40%	-	-
9[b]	0.6%	10%	15%
12[e]	0.5%	-	-
12[f]	0.5%	-	-
12g]	0.6%	-	-
12[h]	1.1%	-	-
12[i]	0.5%	-	-
13[a]	0.4%	0	0.4%
13[b]	0.38%	0	0.38%
13[c]	0.5%	0	0.5%
15[a]	0.54%	-	-
15[b]	0.7%	-	-
15[c]	0.2%	-	-
15[d]	0.08%	-	-
17[a]	1.0%	3.5%	3.6%
17[b]	1.0%	3.5%	3.6%
20[a]	1%	-	-
20[b]	0.8%	-	-
20[c]	0.8%	-	-
20[d]	0.8%	-	-
20[e]	0.3%	-	-
20[f]	0.3%	-	-
20[g]	1.0%	-	-
20[h]	0.3%	-	-
20[i]	0.3%	-	-
20[j]	0.3%	-	-
20[k]	0.3%	-	-
20[l]	0.3%	-	-
20[m]	0.3%	-	-
20[n]	0.3%	-	-
20[o]	0.7%	-	-
21[a]	1.0%	1.0%	2.0%
21[b]	1.0%	-	1.2%
21[c]	1.0%	1.0%	1.0%
23[a]	0.15%	2.0%	2.0%
23[b]	0.3%	2.0%	2.0%

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 %

Table 6

Details of containers used in experimental work at NPL

Container	Nominal volume (ml)	Wall thickness (mm)
BS glass ampoule	2	0.45
BS glass ampoule	5	0.55
NBS glass ampoule	5	0.6
P6 glass vial	10	1.2
10R Type 1 plus glass vial	10	1
B-D Luer Slip plastic syringe (A)	1	1
B-D Luer Lok plastic syringe (B)	1	2.3
B-D Luer Slip plastic syringe	2.5	0.7
B-D Luer Slip plastic syringe	5	0.8

Table 7 Half-lives and the P6 vial calibration figures for ^{201}Tl and its impurities, for the NPL calibrator

Radionuclide	**Half-life**	**P6 vial calibration figure for the NPL calibrator**	**Contaminant factor ^{201}Tl factor**
^{200}Tl	26.1(1) hours	12.5(12) pA/MBq	14.6
^{201}Tl	72.912(17) hours	0.8557(42) pA/MBq	
^{201}Tl	12.23(2) days	4.29(43) pA/MBq	5.0

Figure 1 Comparison of primary standards from National Metrology Institutes

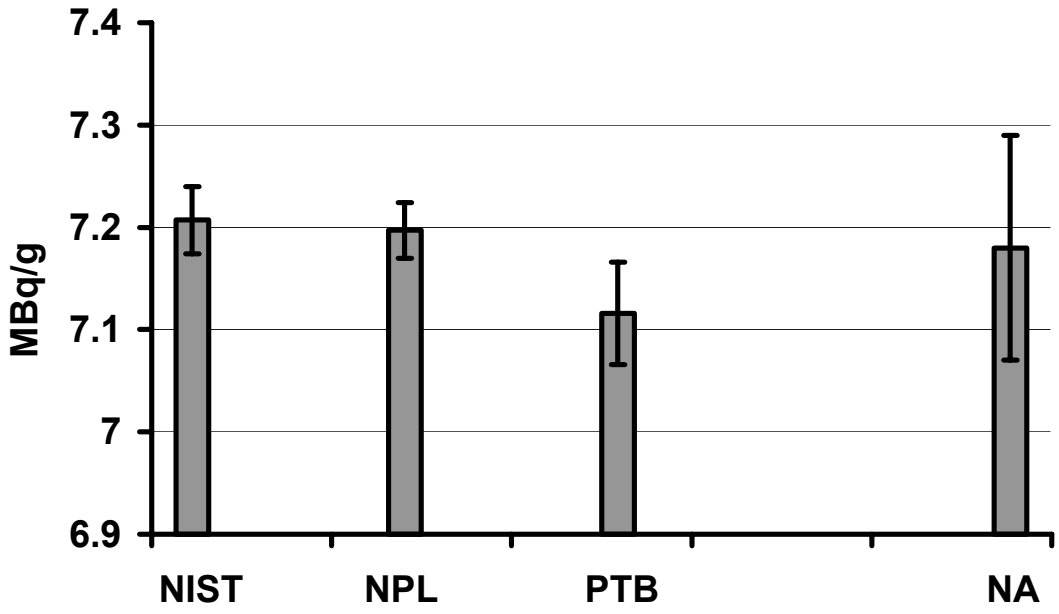


Figure 2 Variation in response with container type for the ISOCAL IV (NPL secondary standard calibrator)

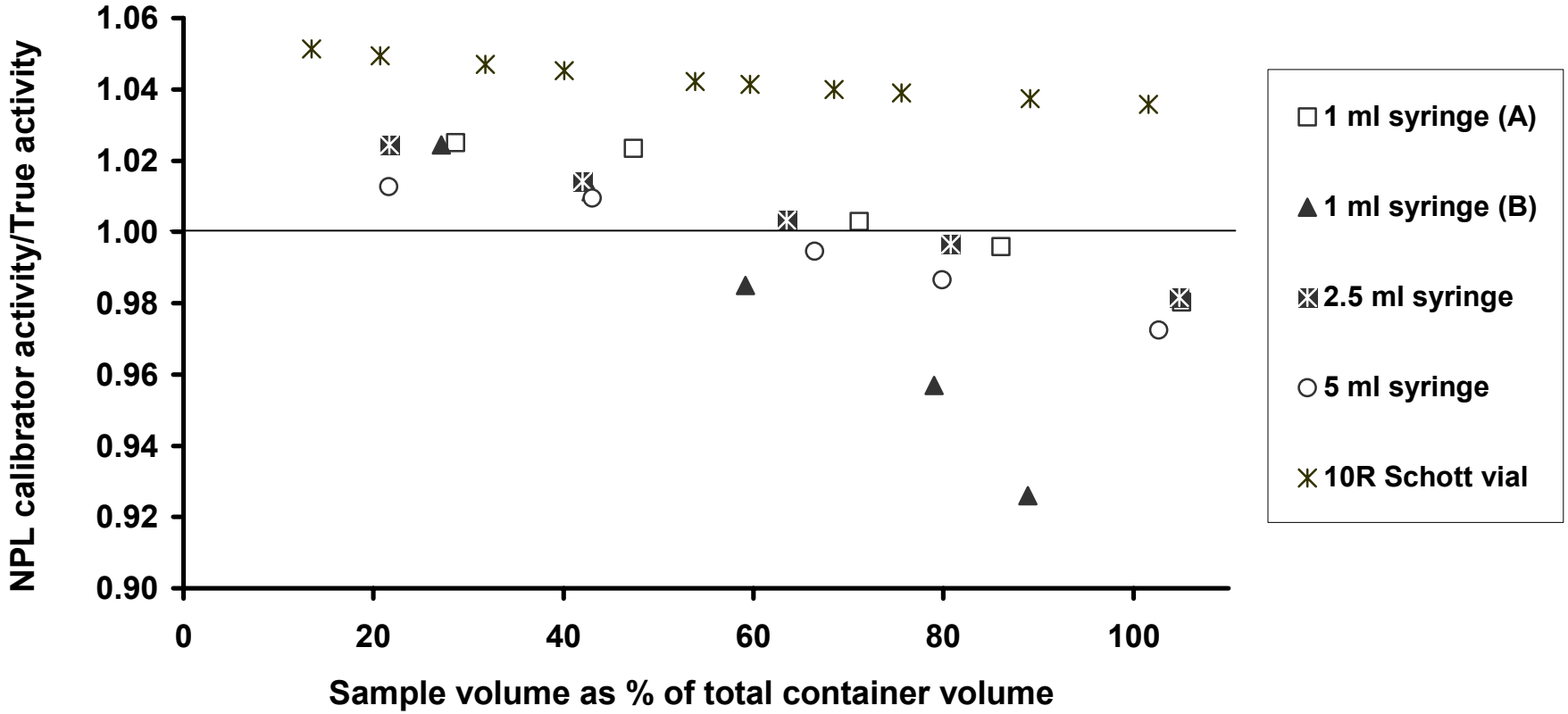


Figure 3 Variation in response with container type for the CAPINTEC 120 calibrator

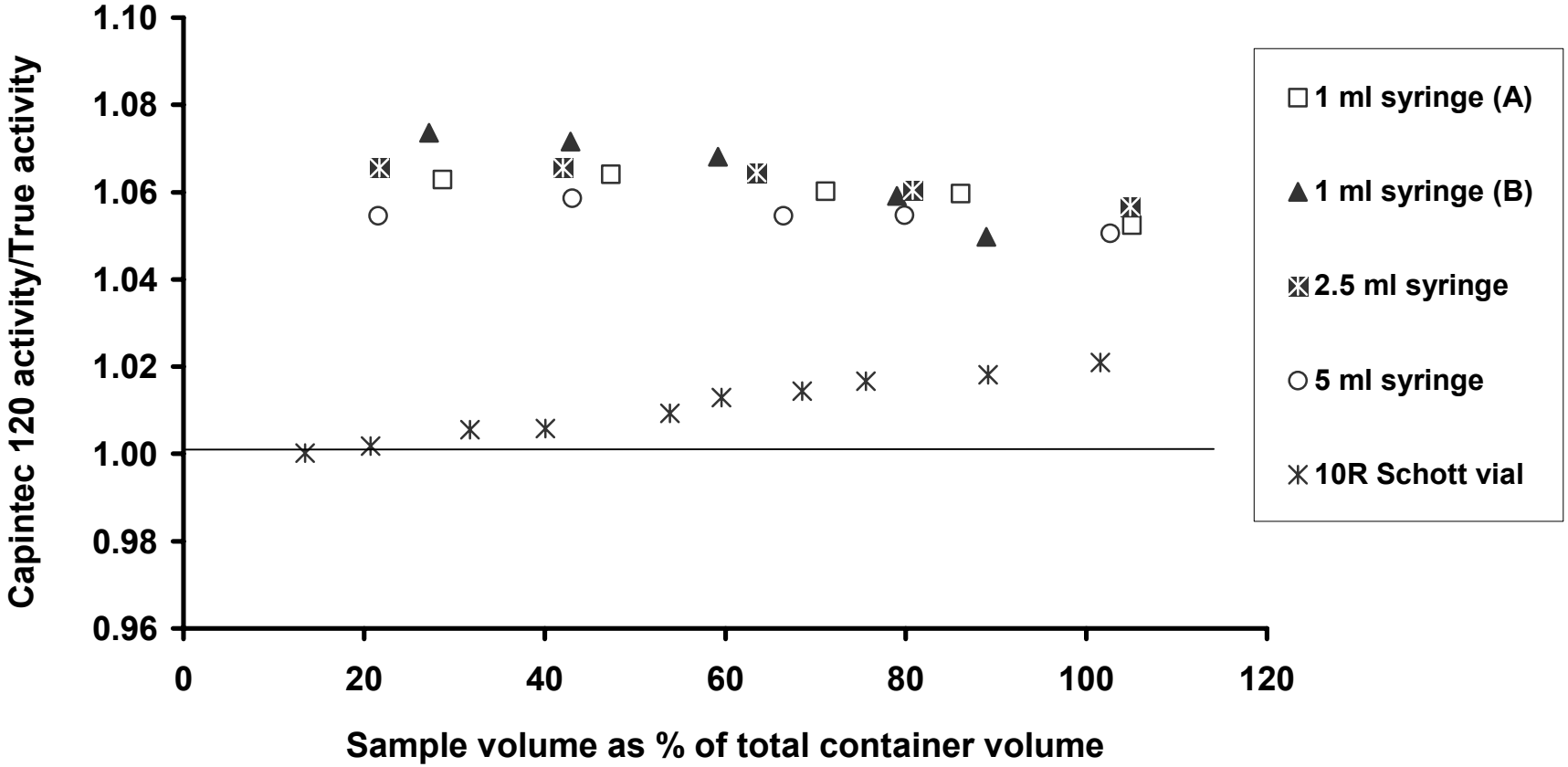


Figure 4 Variation in the ratio of contaminants to the ^{201}Tl with time, for the NPL calibrator.

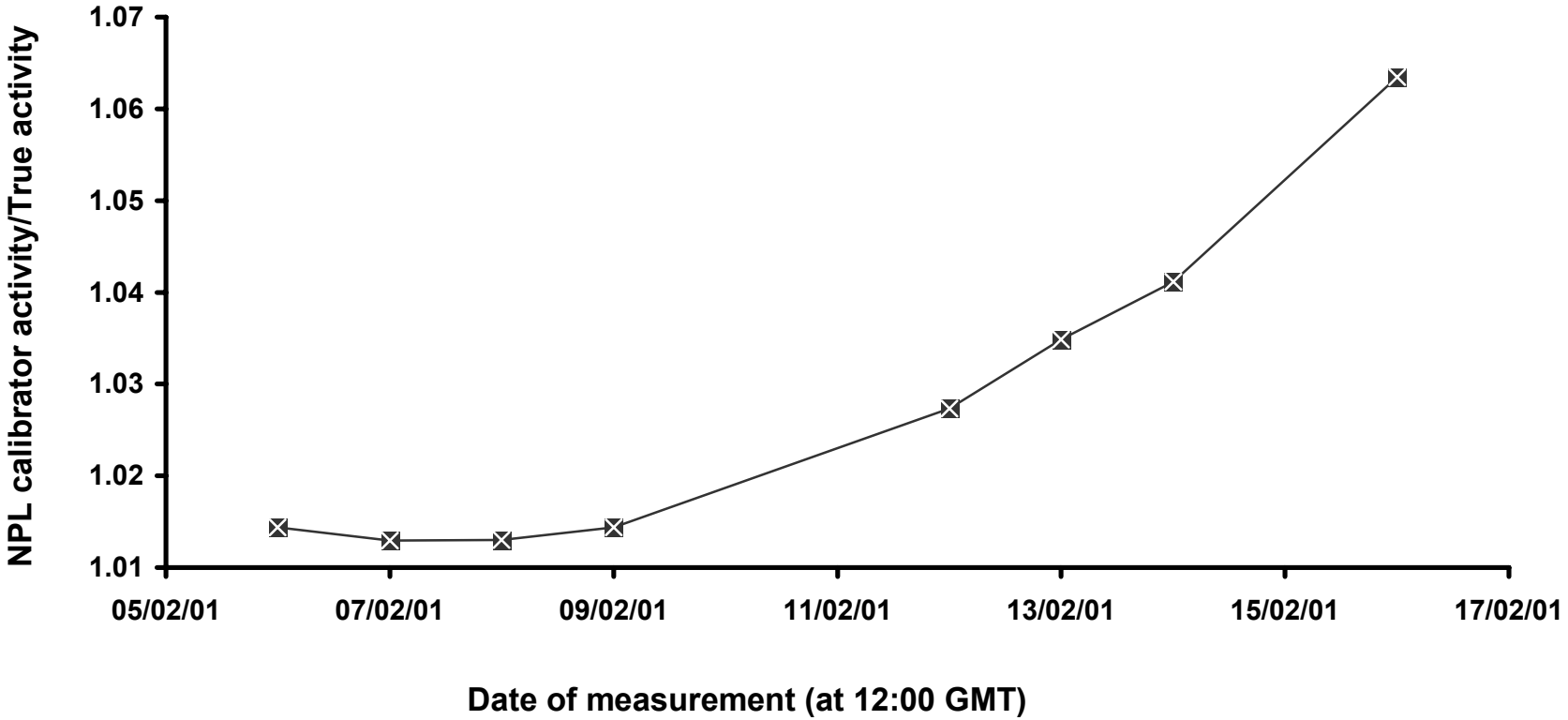


Figure 5 Distribution of results – all systems, all containers

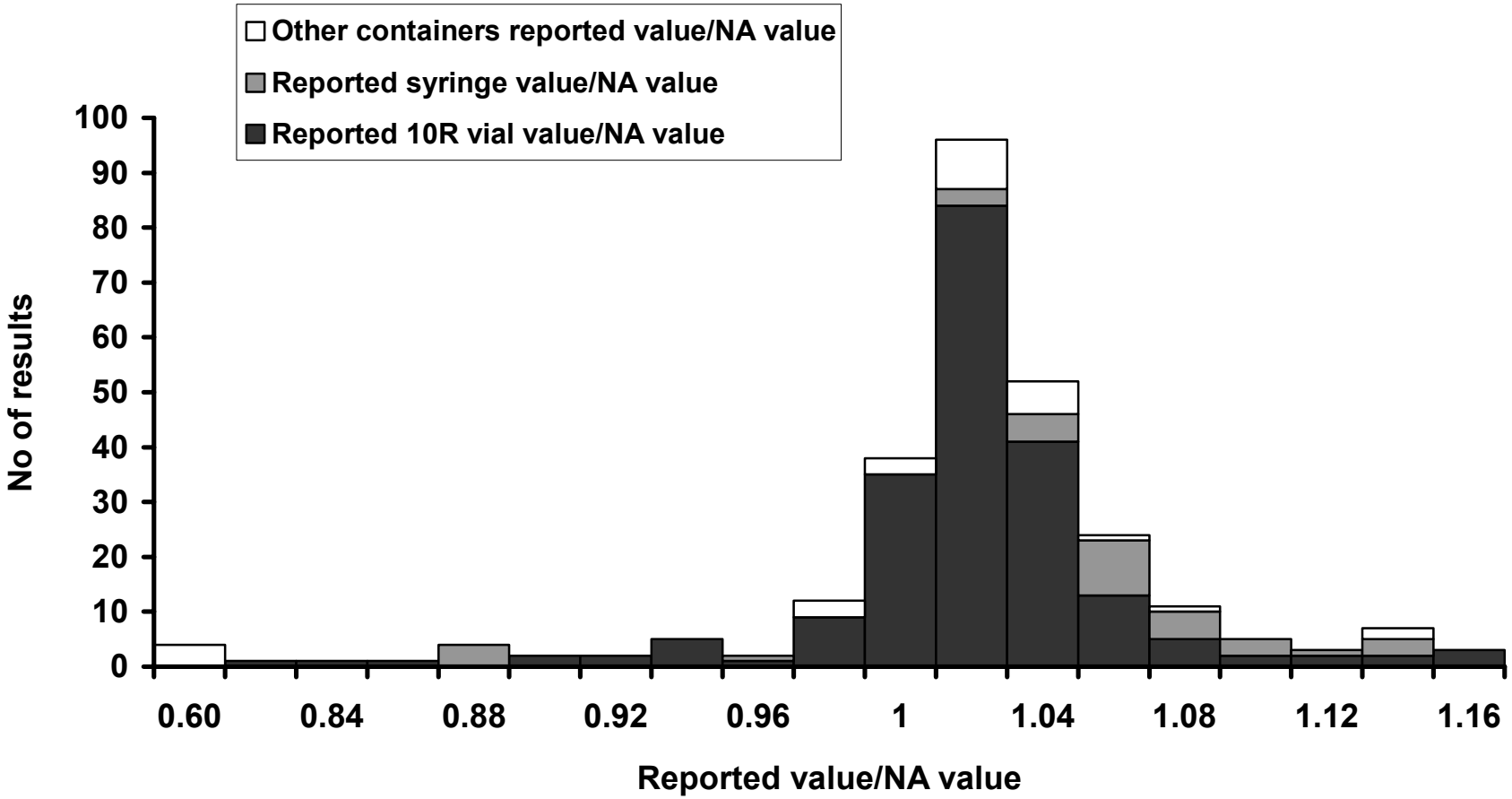


Figure 6 Distribution of 10R vial results – all systems

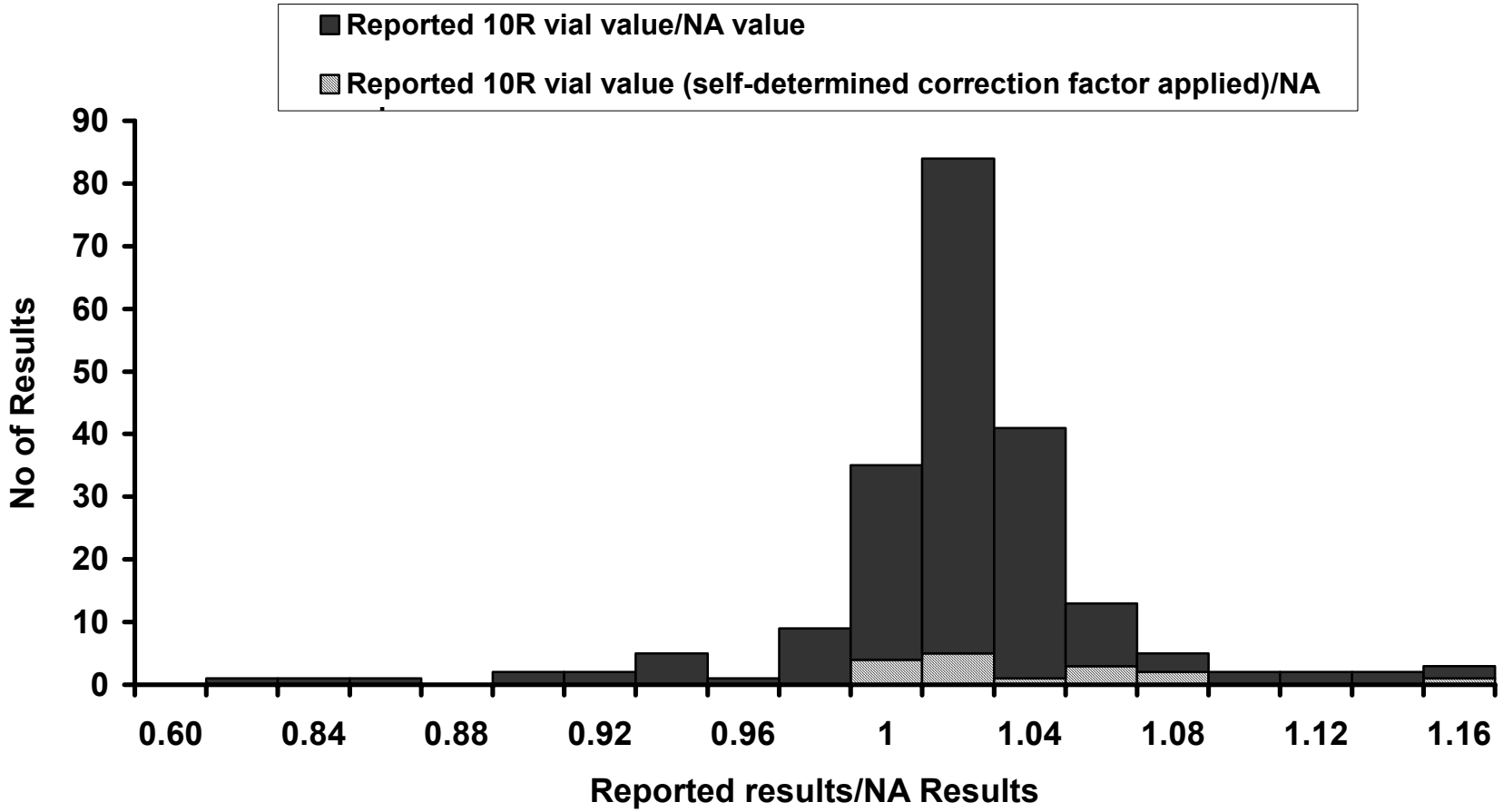


Figure 7 Distribution of 10R vial results – ISOCAL systems

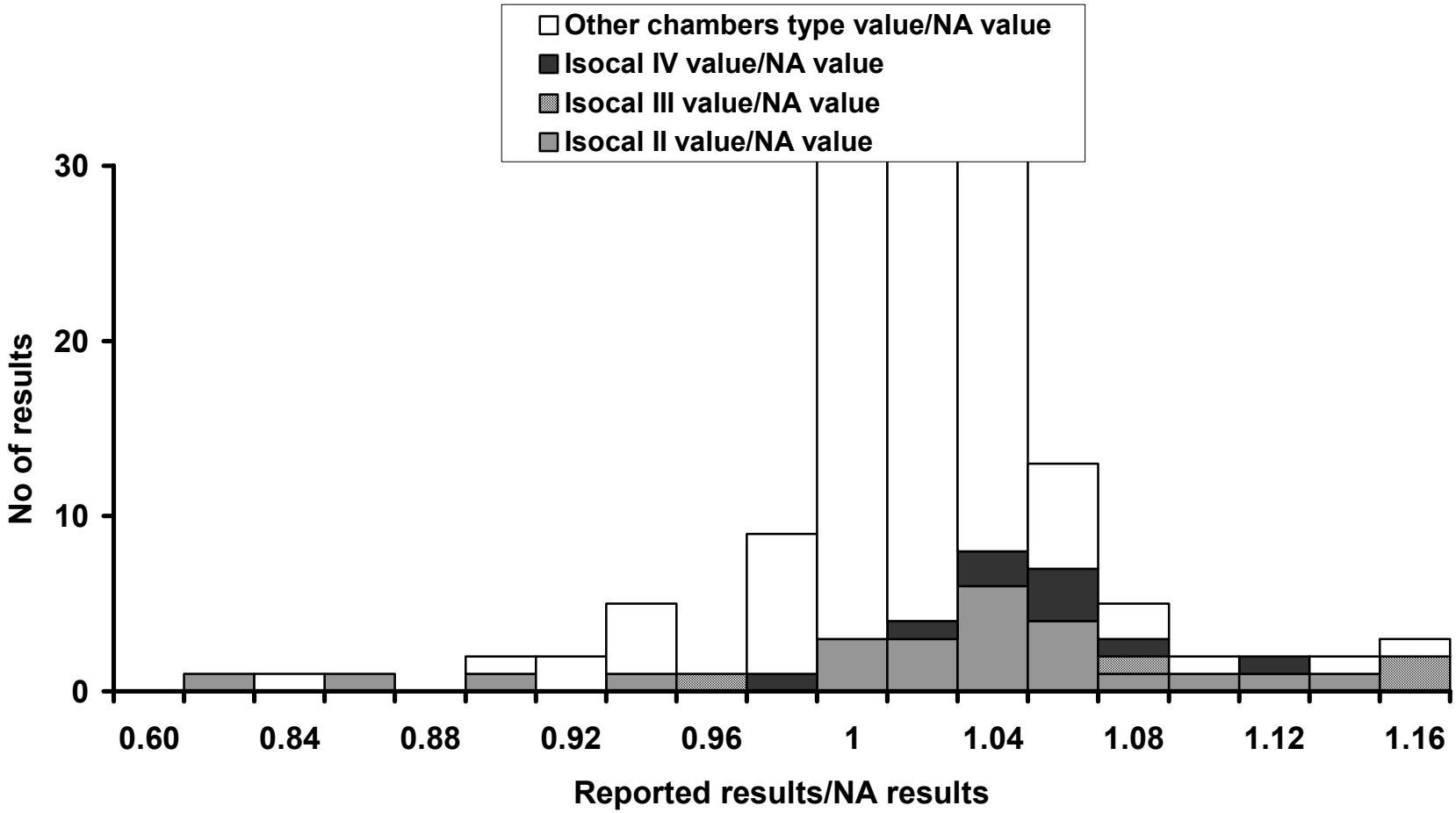


Figure 8 Distribution of 10R vial results – CAPINTEC systems

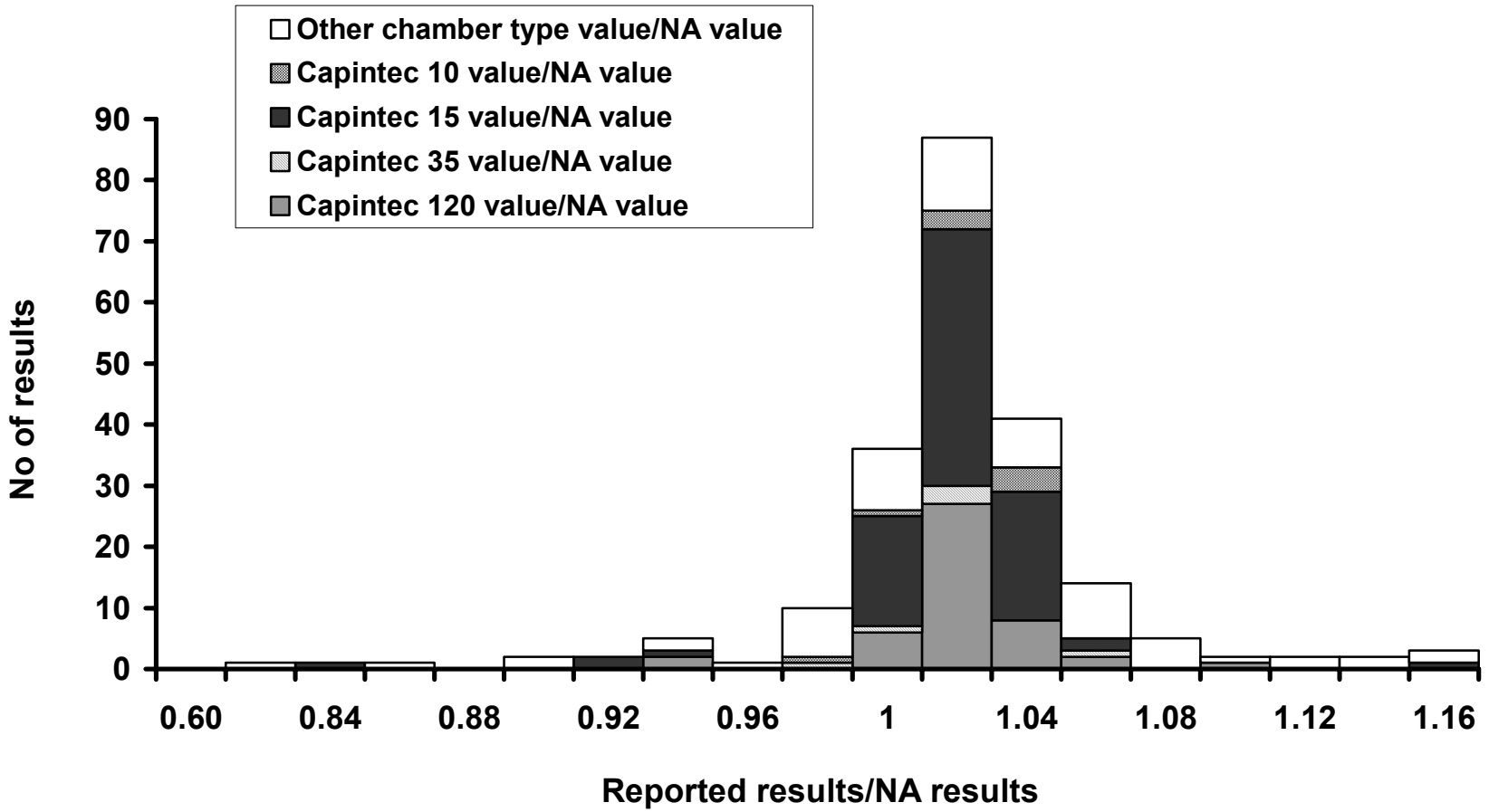


Figure 9 Distribution of syringe results – all systems

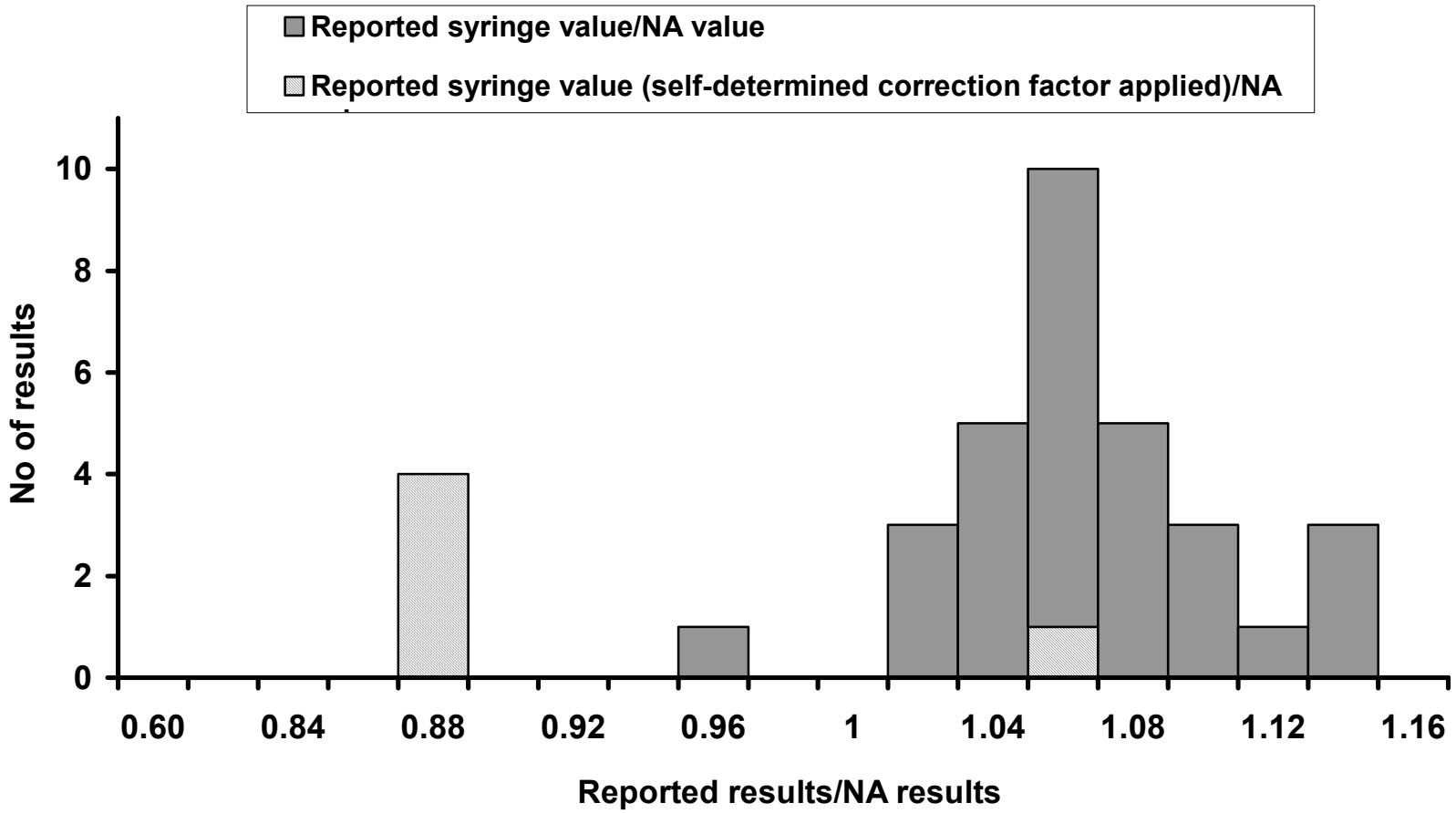


Figure 10 Distribution of syringe results – ISOCAL and CAPINTEC systems

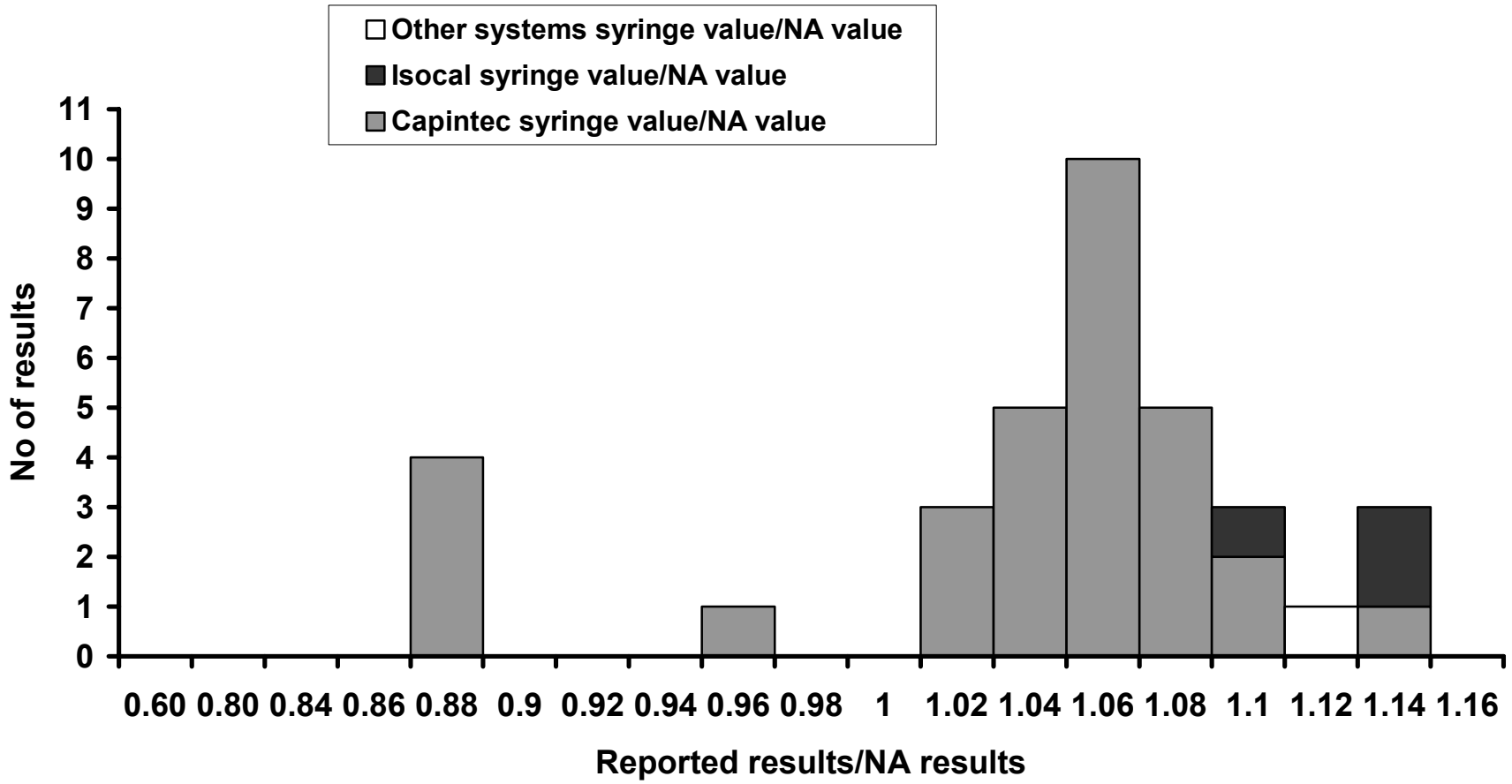
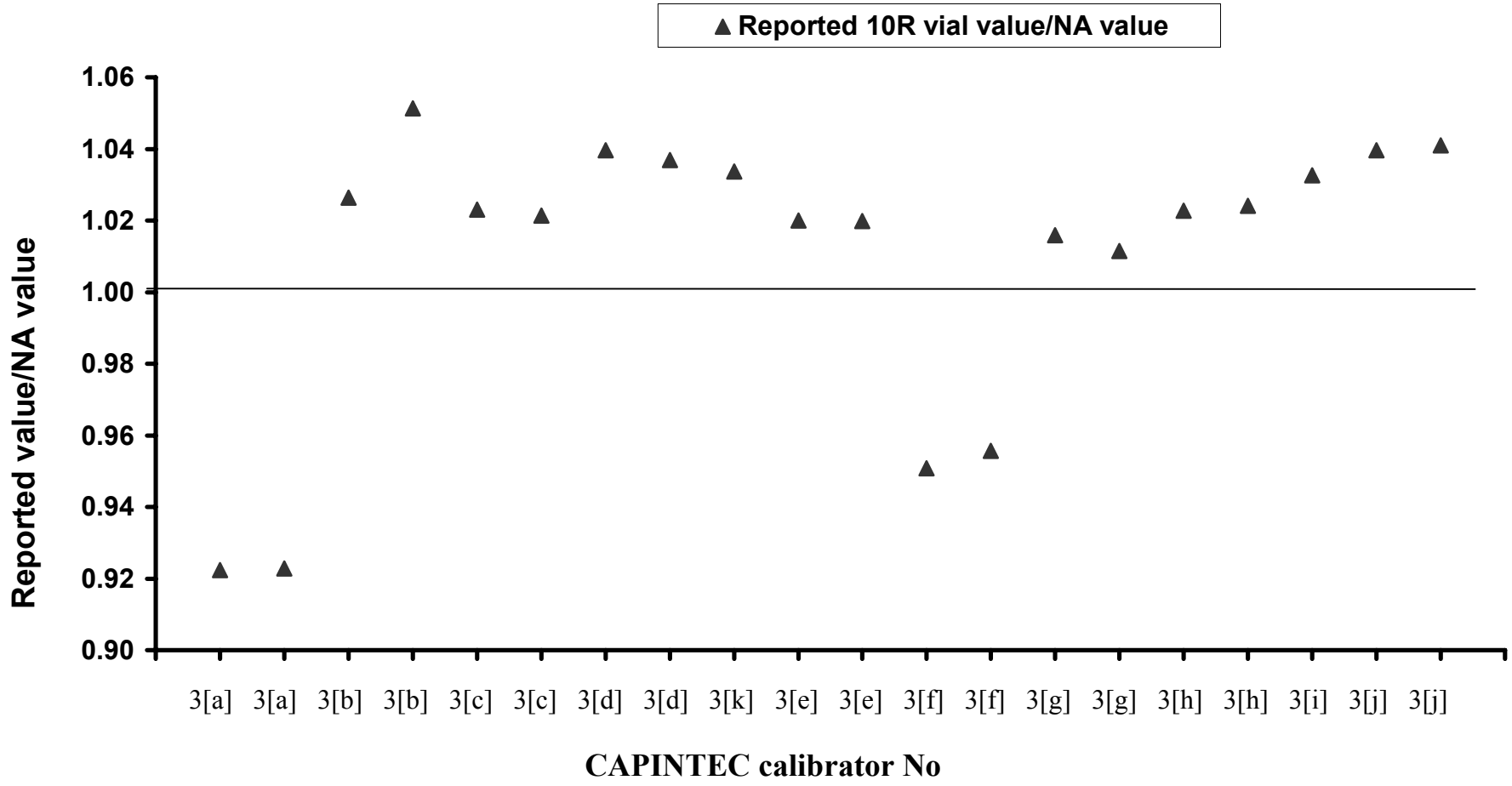


Figure 11 Distribution of 10R vial results from participant No 3



PARTICIPANTS

Participant	Hospital
K Ashley	Good Hope, West Midlands
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P Anderson	Queen Elizabeth Hospital, Birmingham
J Glennon	The Priory Hospital, Birmingham
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K Adamsom	Guy's Hospital, London
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	Leicester Royal Infirmary
J Povedz	Nottingham City Hospital
A Bradley	Manchester Royal Infirmary
R Gadd	North Staffordshire Hospital, Stoke-on-Trent
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B Baily	Cromwell Hospital, London
R J Ward	Royal Devon & Exeter Hospital
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A Maxwell	Bradford Royal Infirmary
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	Belvoir Park Hospital, Belfast
	Belfast City Hospital
	Altnagelvin Hospital, L'Derry
	Antrim Area Hospital
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