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COMPARISON OF ^{90}Y MEASUREMENTS IN UK HOSPITALS, 2009

ANDREW FENWICK
JOHN KEIGHTLEY
MICHAELA BAKER
LENA JOHANSSON
ARVIC HARMS

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Andrew Fenwick
John Keightley
Michaela Baker
Lena Johansson
Arvic Harms

Acoustics and Ionising Radiation Division

ABSTRACT

This report presents the results from a comparison exercise involving ^{90}Y performed in October 2009 to assess the measurement capability of Medical Physics Departments in the UK and Ireland. The report shows discrepancies of up to 20 % from the NPL certificated value and highlights issues with measuring ^{90}Y in different geometries.

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National Physical Laboratory
Hampton Road, Teddington, Middlesex, TW11 0LW

Approved on behalf of NPLML by Bajram Zeqiri, Knowledge Leader (AIR)

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INTRODUCTION

Radioactive isotopes are widely used in the medical physics community for both diagnosis and treatment of various ailments. When used for diagnostic purposes, the nuclide used is dependent on which organ or area you are interested in looking at and the equipment you are using. In radionuclide therapy, the nuclide and activity used is dependent on which organ or area is being targeted and the effect you wish the treatment to have. The activity to be administered is normally decided in advance of treatment and is equally dependent on the particulars of each case. Ionisation chambers in the form of Radionuclide Calibrators are often employed as the main method of measuring activity prior to administration. These instruments are commonly high-pressure, re-entrant type ionisation chambers complete with calibration factors derived by measurement of known activities of specific nuclides. Due to the wide range of nuclides used in the clinical environment, it is very difficult to provide a calibration factor directly linked to a national standard for every nuclide. Manufacturers often use energy response curves or Monte Carlo models to predict calibration factors for less common radionuclides. The operation of these calibrators is very straightforward, and provided an approved QA protocol is maintained can produce results at an acceptable level of accuracy. A QA protocol is suggested in the NPL Good Practice Guide (GPG) No 93[(i)].

The Radionuclide Calibrator Users Forum (RCUF) is a forum run annually at NPL to discuss measurement issues within the nuclear medicine community. At the last forum (held in May 2009) the point was raised that ^{90}Y, along with several other pure beta-emitting radionuclides, was proving difficult to measure consistently using a radionuclide calibrator. This led to the organisation of this comparison in order to identify the severity of the problem, and what specifically was causing the problem. The aim was to identify the overall measurement performance level within the UK hospital community, to identify problems, and to exchange information on how to improve measurements. Previous comparisons [(iii-xi)] have proven very successful at doing this. This comparison is entirely self-funded by the participants, showing the commitment by the community to assess and improve their measurement capabilities. Due to the cost, the number of participants was fewer than in previous comparison exercises, which perhaps shows the need for more funding in this area.

^{90}Y is used for the treatment of various cancers such as ovarian, colorectal, pancreatic, bone cancer and leukaemia, as well as being used to treat inflamed joints, especially for patients suffering from rheumatoid arthritis. ^{90}Y is used mainly in three different forms; liquid, colloidal, and resin spheres. This causes a measurement issue in itself, as NPL has only developed factors for liquid forms of ^{90}Y and a lot of work needs to be done in the development of measurement techniques for the other forms of the nuclide. Further work, not within the scope of this comparison, will be performed in the future to address these issues.

In 2003, a solution of ^{90}Y in 1 mol dm^{-3} hydrochloric acid, and also containing approximately 50 μg g^{-1} yttrium chloride as YCl_3 was prepared by the National Institute of Science and Technology (NIST) in the USA. This solution was distributed under the instruction of the International Atomic Energy Authority (IAEA) to seven National Measurement Institutes (NMI's) worldwide, and the Bureau International des Poids et Mesures (BIPM) in France. The participants submitted results back to the BIPM and a Key Comparison Reference Value (KCRV) was calculated. The results from this comparison are reported under the key comparison reference code CCRI (II)-K2.Y-90[(ii)], and show a good agreement between the NMI's and the KCRV. This shows this radionuclide is relatively easy to standardise by primary methods, thus giving confidence in our standardisation techniques. An aliquot of the solution used in this comparison was also submitted to the Système International de Référence (SIR) ionisation chamber, in preparation for the upcoming key comparison exercise involving yttrium-90 microspheres.

This report presents the results from the ^{90}Y comparison exercise, performed in October 2009, to assess the measurement capabilities of Medical Physics Departments in the UK and Ireland. Further work to compare primary counting methods at ANSTO and NPL were carried out and are also briefly summarised in this report.

PARTICIPANTS

A total of 27 hospitals and 1 NMI took part in the comparison, reporting a total of 244 individual measurement results. A list of participants is given in Appendix IV.

COMPARISON SAMPLES

A stock solution was prepared for the comparison by Perkin Elmer (USA) and subdivided into 33 Type 1+ coated Schott Vials (DIN 10R). This supplier is registered under *ISO 9001:2008* and the yttrium-90 group operates consistently with Q7 *Good Manufacturing Practice Guidance for Active Pharmaceutical Ingredients, August 2001.* The samples were weighed to an accuracy of ± 1 μg and the mass determined by the supplier was rounded to ± 10 μg at NPL before final certification. The samples were weighed using calibrated balances with an appropriate QA/QC system in place to ensure maintenance of calibration. The masses were corrected for buoyancy using a correction factor of 1.001. The sample mass ranged from 4.0 g to 4.5 g and all the values were sent to NPL.

As the samples were distributed directly to the hospitals, a random sample of six vials was sent to NPL for analysis. These samples were all assayed using the NPL secondary standard system, and 4 of the vials were assayed using liquid scintillation counting and 4πβ proportional counting. The results from the liquid scintillation method proved that the homogeneity of the solution was consistent to within ± 0.3 %. The results from all the NPL measurements are included in Appendix I. The activity of the individual vials, supplied to the hospitals, was determined by multiplying the activity concentration derived by primary methods by the corrected mass supplied by Perkin Elmer (USA). All NPL results were decay corrected to 12:00 UTC (Universal Time, Coordinated), Monday 5th October 2009. This reference time was also used for the certification. For the convenience of the participants, NPL did not ask them to decay correct their result and instead the correction was subsequently done at NPL. A list with all the sample information (excluding recipient details) is available in Appendix II.

NPL MEASUREMENTS AND INTERNATIONAL EQUIVALENCE

The activity concentration of the distributed solution was assayed at NPL using four different measurement techniques; ionisation chamber, liquid scintillation counting, 4πβ proportional counting and Triple to Double Coincidence Ratio (TDCR) counting. Efficiency for the liquid scintillation counter had previously been derived for this nuclide using CIEMAT/NIST efficiency tracing, and the 4πβ counter efficiency had previously been determined using 4πβ-γ coincidence counting with an appropriate efficiency tracer nuclide. A weighted mean of the results from 4πβ proportional counting and liquid scintillation counting was used for the certificates that were distributed to the participants.

Gamma-emitting impurities were assayed using high-resolution gamma spectrometry with a high purity germanium detector (a full description is included in Appendix III). Four 1ml ampoules were checked over a period of two months. This was to ensure the large bremsstrahlung continuum caused by the beta emission of the ^{90}Y was not swamping the detector and masking impurities in the gamma spectrum. No gamma-emitting impurities were detected in the samples.

Beta-emitting impurities were checked by continued measurement of the solution by liquid scintillation counting. It was found that ^{90}Sr was present and the Sr-90 activity concentration at 1200 UTC on the reference date of 5 October 2009 was less than 3 Bq g^{-1}. This level of impurity was not considered to cause any measurement issues on an ionisation chamber as the response of the instrument and the activity present would be too low. No further impurities were detected.

TDCR measurements were carried out using the NPL experimental TDCR detector. TDCR measurements were also carried out at the Australian National Science and Technology Organisation (ANSTO) and these results are also shown in this report.

Results from previous key comparison exercises show a good agreement between the participating NMI's. The most recent comparison in 2003 showed the NPL value agreed to within 0.1 % of the Key Comparison Reference Value.

MEASUREMENT AND REPORTING PROTOCOL

Participants were asked to assay the supplied ^{90}Y sample using their radionuclide calibrators and report results directly back to NPL. Participants were allowed to report as many measurements as possible in whatever geometry they like, however each centre was asked to identify a 'preferred' result which they deem to be their best measurement.

The participants were each sent a generic reporting form, an example of which can be found in Appendix V. This form asked for details of the calibrator (such as make and serial number) and also details of calibration factors or dial settings used, alongside the usual activity and reference date information needed. Participants were also asked to perform an uncertainty evaluation where possible and give reasons for why their 'preferred' value was chosen.

The results were collated and analysed by NPL. The deadline for submission was the 1st November 2009 and most results were received by this time. Certificates were issued on 30th November and were sent to participants once purchase orders or signed quotes were received. All results received after the certificates were released were discounted. Each participant received a certificate specific to their vial showing total activity, and also a certificate for activity concentration of the original stock solution.

CONFIDENTIALITY

All results were reported directly to NPL. Each centre was assigned a unique code and only NPL and the individual participant know the identity of the code for that participant.

RESULTS

A total of 244 individual measurement results were returned from 28 participants (excluding NPL). This represented 5 chamber manufacturers, 18 models, 21 geometries and 39 calibration dial settings. All results are shown in Figure 1 including any uncertainties quoted and the raw data is shown in Table 4. This table includes data on: -

- Calibrator used
- Geometry
- Dial Setting
- Mass of solution
- Hospital reported value
- Hospital value after decay correction to reference time
- Hospital uncertainty
- % Deviation from NPL value
- Ratio of Hospital Value/NPL calculated value

All decay corrections were made using 2.6684 (13) days as the half-life of ^{90}Y. This is taken from the evaluations of the '*Decay Data Evaluations Project'* (xii)

Figure1 shows all of the submitted results plotted as % deviation from the NPL value. This includes any uncertainties quoted by the participants.

Figure 2 shows the 'preferred' results as submitted by the participants. This includes any uncertainties quoted by the participants.

Figure 3 shows results as a histogram of Hospital Value / NPL value.

Figure 4 shows preferred values plotted as % deviation against vial mass to identify volume effects.

Figure 5 shows all reported syringe results, and Figure 6 shows specific 'Becton Dickson' syringe results.

Figure 7 identifies 'P6' Vial results and Figure 8 shows other vial types (excluding 'P6' and '10R' Schott vials).

Figure 9 shows preferred results obtained using a Capintec CRC 15R chamber (in a 10ml Schott vial) and Figure 10 shows Capintec CRC 15R results in a P6 vial.

Figure 11 shows results obtained using Atomlab chambers.

Figure 12 shows results obtained using Fidelis, NPL CRC and Vinten Isocal IV chambers.

Figure 13 shows NPL samples measured on the NPL 'Vinten 671' system, which is the chamber to which all 'Fidelis' and 'NPL CRC' chambers have been compared to during calibration.

DISCUSSION

8.1 NPL VALUES

The NPL results from the liquid scintillation, TDCR and 4πβ counting show that the solution was homogenous. The NPL TDCR result and the ANSTO TDCR result also agree well and this adds further confirmation that the solution supplied by Perkin Elmer (USA) was indeed homogenous. The 6 NPL vials measured using the 'Vinten 671' ionisation chamber agreed within 1.3 % of the certificated value, which is within the uncertainty quoted for the system. This is not as good as had been hoped; however only one value deviates by more than 0.8 % from the certificated value. Further work will be done to refine NPL's in-house calibration factors and associated volume correction factors.

The certificates were prepared using a value obtained using a weighted mean of the liquid scintillation and 4πβ results. The TDCR result agreed with this weighted mean to within 0.53 % and this is within the uncertainty of the results. The slight variance is likely to be due to the efficiencies used for the 4πβ and liquid scintillation systems.

8.2 NPL MEASUREMENTS IN COMMERCIAL CALIBRATORS

These measurements are useful in that one can see how certain calibrators perform when using both derived factors and presets. Unfortunately at the time of the exercise NPL only had access to three commercial calibrators. Measurements were made on three different occasions and results decay corrected to the reference time.

i) 'NPL Fidelis' measurements at NPL

Two vials were measured on this system using the electrometer mode and manually calculating activity using the factor 0.0721 pA MBq^{-1}. Since the system uses the same factor to derive activity it was deemed that measuring using the built-in factor would be unnecessary. It can be seen from the analysed results in Figure 2 that the results agreed well, with the greatest deviation being 1.6 % below the certificated value. The mean deviation of the chamber was 1.3 % below the certificated value. NPL would normally expect this chamber to be within 2 % of the certificated value for gamma emitters, and 2-5 % for beta emitters, so for a pure beta to be within 1.6 % confirms this chamber is performing as expected.

ii) 'Atomlab 500' measurements at NPL

Again two vials were measured on this system using both the preset factor for a vial, and an NPL derived factor. It is important to note that this system does not specify which vial the preset factor is attributed to and so it is not surprising the results do not agree very well. The greatest deviation using the preset value was 16.4 % below the certificated value and the average was 15.8 % below the certificated value. NPL derived an initial custom factor for this chamber and that brought the result to 2.5 % above the certificated value however the chamber had to be returned before the final results were available and no further adjustments were possible. The large deviation of the preset value is of concern, and anyone using these chambers regularly would be advised to re-calibrate for all nuclides they use in their own vial type.

iii) 'Capintec ARC 120' measurements at NPL

Only one vial was measured on this chamber, as it is no longer a widely used chamber and it was deemed less relevant to obtain data on it. However the data gathered showed an average reading of 8.3 % below the certificated value when using the preset factor. The NPL derived factor showed a deviation of 0.1 % above the certificated value and this again shows the importance of adjusting dial settings especially for beta emitters. From the main data which will be discussed later it is interesting to note that the '048 x 10' factor used on the ARC 120 chamber is the same factor issued with the CRC 15R chamber.

8.3 PARTICIPANTS 'PREFERRED' VALUES

As part of the exercise each of the participants was asked to identify and report a 'preferred' value for the vial measurement. The plot of 'preferred values' gives the following breakdown:

Within ±2 % of NPL Value:	11 %
Within ±5 % of NPL Value:	40 %
Within ±10 % of NPL Value:	89 %
Within ±20 % of NPL Value:	96 %

One participant reported a value that was 23 % below the NPL value.

IPEM recommend that when hospitals perform calibration checks of their equipment they should operate to within ±5 % of the certificated value. This value is also attributed to therapy dose administration. Further to this the generally accepted tolerance for administering dose to a patient is ±10 %. This report clearly shows that most participants that took part can deliver to within ±10 % however less than half can measure to within the recommended limits of ±5 %.

8.4 ALL SUBMITTED VALUES DATA

This data is all of the accepted result submissions including any uncertainties reported. This is useful as it shows the vast range not only in reported values but also in the uncertainty calculations performed. Also of interest is the apparent skew in the data shown quite clearly in the histograms. The breakdown of this data is shown below, however it should be noted that some of the data has been collected with no prior knowledge of the factors needed to derive activity in certain geometries and does not necessarily reflect the participants' ability to measure the activity in a known geometry.

Within ±2 % of NPL Value:	22 %
Within ±5 % of NPL Value:	42 %
Within ±10 % of NPL Value:	84 %
Within ±20 % of NPL Value:	93 %
More than ±20 % of NPL Value:	7 %

Whilst these results show that a greater number of participants are within 2 % and 5 % of the NPL value, it also shows that more are outside the 10 % range recommended by protocol. However as mentioned previously this is likely to be due to participants using this exercise to determine new factors for their calibrators.

8.5 UNCERTAINTIES

Data that was submitted with an associated uncertainty was analysed using three tests, the ζ (zeta) test, the z-test and the IQR outlier test using the method described by Harms, 2009(xiii).

Zeta test:
$$\zeta = \frac{L-N}{\sqrt{u_L^2 + u_N^2}} \quad [1]$$

z-test:
$$z = \frac{L-N}{R_{med} N} \quad [2]$$

Relative uncertainty:
$$R_L = \frac{u_L}{L} \quad [3]$$

where:

ζ	- zeta score
L	- participant value
N	- NPL assigned value
u_L	- standard uncertainty of the participant value
u_N	- standard uncertainty of the NPL assigned value
z	- z-score
R_{med}	- median of the R_L values
R_L	- relative uncertainty of the participant value

The Interquartile Range (IQR) outlier test was used to assess whether the relative uncertainty assigned to a participant's value was significantly larger than others in the data set. In this comparison all of the participants passed this test.

The z-score and zeta score assess whether the difference between a participants submitted values and the NPL assigned value is much greater than zero. In order to pass these tests, the zeta and z-score must lie between –2.576 and +2.576. If either one of these tests is failed the result is marked as 'questionable' and if both are failed the result is marked as 'discrepant'.

In Agreement:	8 participants (including NPL):	H2, H3, H6, H14, H15, H23, H27, NPL
Questionable:	4 participants:	H4, H8, H9, H10
Discrepant:	4 participants:	H11, H13, H26, H7
Total:	16 participants (including NPL)	

The range of uncertainties reported by the participants was very high, with some reporting values as low as 0.2 %. Uncertainties this low on an ionisation chamber are unrealistic, especially for pure beta emitting nuclides, and so it is clear not all contributing factors were considered when calculating the uncertainty budget. The NPL Vinten chamber calibration factor, which is derived by direct nuclide measurement, has an uncertainty between 0.7 % - 3 % for ^{90}Y, depending on container type. This leads NPL to recommend that the lowest uncertainty level for a hospital instrument should be of the order of 2 % (@ $k=1$), however it is entirely dependent on the chamber and geometry used and may therefore be higher.

8.6 SYRINGE DATA

Several participants submitted values for different syringes and it is interesting to note the vast range of factors used (some having greater effects than others). The plots show that the majority lie within the ±10 % range, however the spread of results is ±40 % showing once again that the effect of geometry on these measurements is important to note, even with syringes that may look similar or hold similar volumes.

8.7 P6 VIAL DATA

The relatively common ‘P6’ type vial was assayed by some participants and the results provided show that even this most common of vial types does not perform very well when measuring pure betas. NPL have noticed over the past few years that the design of the ‘P6’ has been modified slightly depending on which supplier it is purchased from. The modifications are in the wall thickness, and whilst for a gamma emitter it is not very noticeable, when a pure beta is measured the effects can be quite pronounced. It is recommended that participants obtain data sheets for their ‘P6’ vials and ensure their specifications are consistent with the original specification.

8.8 OTHER VIAL DATA

Several participants provided results in different vials and these show once again a large range in reported values. The results from these vials may be biased by attempts to derive custom factors.

8.9 CAPINTEC CRC 15R ‘PREFERRED’ RESULTS

Many participants reported their ‘preferred’ value using a Capintec CRC 15R system. Whilst most participants had corrected the standard ‘048 x 10’ factor provided by the manufacturer several other have not and the effects of this can be seen by the plateau effect on the graph. The range of difference is quite large, however 82 % of the values lie within ±10 % of the NPL value. 65 % of the results lie within ±5 %.

8.10 CAPINTEC CRC 15R ‘P6’ VIAL RESULTS

Several results were reported on this system using ‘P6’ vials and these show a much smaller deviation from the NPL value. Most of the results lay between 0 % and –10 % and there could be two reasons for this: the ‘048 x 10’ factor provided with the Capintec chamber works better with a ‘P6’ vial than a 10R Schott© vial, and the factors have been determined by the centres themselves, giving them greater accuracy; or it may be a combination of both reasons. One centre submitted a result at –56 % and this is assumed to be due to either a submission error or due to their attempts to derive a custom factor.

8.11 ATOMLAB VALUES

Few participants use Atomlab chambers, but the results show these chambers have reasonable measurement capabilities. With the limited number of results it is difficult to draw definite conclusions.

8.12 NPL FIDELIS, NPL-CRC, AND VINTEN ISOCAL IV SYSTEMS

The results from these systems are a little disappointing, although almost all the results lie within ±10 % of the calibrated value (with only 1 lying outside this range).
The breakdown is:

Within ±2 % of NPL Value:	35 %
Within ±5 % of NPL Value:	47 %
Within ±10 % of NPL Value:	94 %

1 Value lay at 10.77 % from certificated value

This big variance in these systems has not been noticed in previous exercises and it was not noticed in the NPL testing of the Fidelis system, which leads NPL to believe it is due to operator error, or volume correction issues. NPL has launched a full investigation into this problem and users will be informed of results.

8.13 COMPARISON TO PREVIOUS EXERCISES

The results seem to imply a that centres have performed less well compared with previous exercises, however this would be an unfair assessment as ^{90}Y is far more difficult to measure than many of the nuclides previously examined. In Table 3 a breakdown of the past 6 exercises is shown, and the pure-β emitting nuclides are highlighted in blue (the remainder are β/γ emitting nuclides). This shows the difficulty in measuring pure beta emitting nuclides very clearly.

CONCLUSIONS

9.1 COMPARISON METHOD

The number of participants in this comparison was limited by cost. It is hoped that funding may be made available in future to allow more centres to participate, and the results of this comparison should help raise awareness of this issue. This comparison is the first to be run in this manner and although it is the most cost effective and simple way of running the comparison, NPL has no control over each individual vial. However, through its measurements of a subset of samples, NPL was satisfied that the production and weighing procedures used by the supplier were robust. This comparison has proved beneficial in identifying measurement problems nationwide and will help NPL draw attention to the measurement difficulties associated with this nuclide and to hopefully obtain funding into further study of not only this nuclide, but other pure beta emitters also.

9.2 OVERALL PERFORMANCE (PREFERRED VALUES)

The overall performance of the participants varied greatly. The participants that calculated their own factors generally performed very well, and indeed the majority of participants in the ±5 % region had developed custom factors.

The participants using the Capintec supplied '048 x 10' factor submitted results lying between –2 % and –23 % with the majority grouped around the –6 % and –7 % region. This would suggest that a simple correction factor of 1.06 should be applied when measuring ^{90}Y liquid in a 10ml Schott vial on this type of instrument. This is of course also dependent on volume corrections and in-house studies should be done in each centre to derive new factors. It is strongly recommended that anyone regularly using any pure beta emitting nuclide perform a direct calibration and determine a custom factor for each chamber and geometry in use. It is also recommended some procedures are put in place to minimise possible confusion in the use of these factors.

9.3 OVERALL PERFORMANCE (ALL VALUES)

It is clear from the range of results obtained that much work is still to be done on the development of factors in all the various geometries, which also includes volume corrections in each container. Even the spread of results observed with similar container types shows every container is unique when it comes to pure beta emitters and much care should be taken to ensure the correct factors are being used. Comments mentioned above also apply regarding determination of new factors.

9.4 UNCERTAINTIES

The number of participants submitting uncertainty information was similar to previous exercises. The methods used to determine uncertainties shows huge amount of inconsistency, and as noted in most previous exercises more work needs to be done in this area. A discussion on this issue will be raised at the next RCUF meeting and proposals will be considered. It is recommended that a training course be developed that addresses possible sources of uncertainties when using a radionuclide calibrator.

9.5 FACTOR DETERMINATION

Although most of the custom factors used in this comparison helped in the determination of activity, several did not agree very well with the NPL value. This may be because either the factors used were determined for a different geometry, or the method for obtaining this factor was incorrect. An approved method for deriving custom factors will be developed by NPL (with input from users) and presented at an upcoming RCUF meeting.

9.6 FUTURE WORK

From this comparison, difficulties encountered when measuring ^{90}Y have become apparent and a similar trend has been noticed with other pure-β emitting nuclides (such as Sr-89 and P-32). This, along with the different forms of ^{90}Y currently available (e.g. colloids and SIR spheres) has led NPL to seek funding to help to improve measurement capabilities for these nuclides. NPL has also been invited to participate in an international comparison (organised by the BIPM) of SIR spheres taking place later this year and early next year. It is planned to develop a factor for this form of the nuclide, which will then be disseminated to the 'Fidelis' user community. Should the funding be secured, NPL would hope to also offer private calibrations to individual centres to help them develop new factors and techniques on other commercially available systems.

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TABLES

TABLE 1 - CLASSIFICATION CRITERIA

Zeta test	IQR test	z test	Classification
pass	pass	pass	in agreement
pass	fail	pass	questionable
fail	pass	pass	questionable
pass	pass/fail	fail	questionable
fail	pass/fail	fail	discrepant

TABLE 2 – PARTICIPANT CLASSIFICATION

Participant code	Result of zeta test	Result of IQR test	Result of z-test	Classification
H11	Fail	Pass	Fail	discrepant
H9	Fail	Pass	Pass	questionable
H8	Fail	Pass	Pass	questionable
H10	Fail	Pass	Pass	questionable
H7	Fail	Pass	Fail	discrepant
H23	Pass	Pass	Pass	in agreement
NPL	Pass	Pass	Pass	in agreement
H2	Pass	Pass	Pass	in agreement
H6	Pass	Pass	Pass	in agreement
H15	Pass	Pass	Pass	in agreement
H26	Fail	Pass	Fail	discrepant
H27	Pass	Pass	Pass	in agreement
H3	Pass	Pass	Pass	in agreement
H14	Pass	Pass	Pass	in agreement
H4	Pass	Pass	Fail	questionable
H13	Fail	Pass	Fail	discrepant

TABLE 3 – ROUNDUP OF RESULTS FROM PREVIOUS COMPARISON EXERCISES.

Year	Nuclide	Within 5 %	Within 10 %
1996	^{67}Ga	91 %	95 %
1997	^{111}In	84 %	92 %
2001	^{201}Tl	70 %	94 %
2003	^{89}Sr	58 %	86 %
2006	^{99m}Tc	96 %	99.5 %
2009	^{90}Y	40 %	89 %

TABLE 4 – ALL SUBMITTED VALUES

Code	Calibrator	Geometry	Dial Setting	Reported Activity	Uncertainty	Corrected Activity	Mass	NPL Activity	% Deviation	Ratio
H1	Capintec CRC 15R	10R Schott	048 x 10	540		541.1702	4.1038	597.513	-9.43	0.906
H2	Capintec CRC 15R	10R Schott	048 x 10	479	2.7	614.3953	4.3730	636.704	-3.50	0.965
H2	Capintec CRC 15 Beta	10R Schott	048 x 10	208.8	0.4	583.8236	4.3730	636.704	-8.31	0.917
H2	Capintec CRC 15 Beta	10R Schott	048 x 10	272.1	0.11	586.7685	4.3730	636.704	-7.84	0.922
H2	Capintec CRC 15 Beta	10R Schott	048 x 10	353	0.3	587.0837	4.3730	636.704	-7.79	0.922
H2	Capintec CRC 15 Beta	10R Schott	048 x 10	458.8	0.3	588.4855	4.3730	636.704	-7.57	0.924
H2	Capintec CRC 15 Beta	10R Schott	048 x 10	460	2	590.0247	4.3730	636.704	-7.33	0.927
H2	Capintec CRC 15 Beta	10R Schott	048 x 10	44.7	0.83	593.9313	4.3730	636.704	-6.72	0.933
H2	Capintec CRC 15 Beta	10R Schott	048 x 10	97.5	0.32	594.2847	4.3730	636.704	-6.66	0.933
H2	Capintec CRC 15 Beta	10R Schott	048 x 10	75.2	0.24	594.3205	4.3730	636.704	-6.66	0.933
H2	Capintec CRC 15 Beta	10R Schott	048 x 10	58	0.35	594.352	4.3730	636.704	-6.65	0.933
H2	Capintec CRC 15 Beta	10R Schott	048 x 10	15.9	0.94	597.1419	4.3730	636.704	-6.21	0.938
H2	Capintec CRC 15R	10R Schott	048 x 10	215.9	0.4	603.6758	4.3730	636.704	-5.19	0.948
H2	Capintec CRC 15R	10R Schott	048 x 10	281.4	0.11	606.8234	4.3730	636.704	-4.69	0.953
H2	Capintec CRC 15R	10R Schott	048 x 10	365.8	0.3	608.3717	4.3730	636.704	-4.45	0.956
H2	Capintec CRC 15R	10R Schott	048 x 10	476.6	2	611.3169	4.3730	636.704	-3.99	0.960
H2	Capintec CRC 15R	10R Schott	048 x 10	102.1	0.22	622.3227	4.3730	636.704	-2.26	0.977
H2	Capintec CRC 15R	10R Schott	048 x 10	60.8	0.52	623.0449	4.3730	636.704	-2.15	0.979
H2	Capintec CRC 15R	10R Schott	048 x 10	16.6	1.25	623.4311	4.3730	636.704	-2.08	0.979
H2	Capintec CRC 15R	10R Schott	048 x 10	78.9	0.52	623.5623	4.3730	636.704	-2.06	0.979
H2	Capintec CRC 15R	10R Schott	048 x 10	47	0.83	624.4915	4.3730	636.704	-1.92	0.981
H2	Capintec CRC 15R	10R Schott	048 x 10	36.4	0.75	627.109	4.3730	636.704	-1.51	0.985
H3	Capintec CRC 25R	10R Schott	048 x 10	347		559.6759	4.1239	600.443	-6.79	0.932
H3	Capintec CRC 25R	10R Schott	048 x 10	349		561.3806	4.1239	600.443	-6.51	0.935
H3	Atomlab 100	10R Schott	440	375		602.9851	4.1239	600.443	0.42	1.004
H3	Atomlab 100	10R Schott	436	381	5	614.182	4.1239	600.443	2.29	1.023
H3	Atomlab 100	10R Schott	429	388		625.015	4.1239	600.443	4.09	1.041
H4	Capintec CRC 15R	1ml BD Luer Lok Syringe	53	14.04	7	117.491	0.8000	116.480	0.87	1.009
H4	Capintec ARC 120R	CIS BIO 10ml YMM1	37	18.82	6.5	157.7758	0.9800	142.688	10.57	1.106
H4	Capintec CRC 15R	CIS BIO 10ml YMM1	37	19.6	6.5	158.1782	0.9800	142.688	10.86	1.109
H4	Capintec CRC 15R	10ml BD Luer Lok Syringe	47	37.65	6	302.5894	2.1300	310.128	-2.43	0.976
H4	Capintec ARC 120R	10ml BD Luer Lok Syringe	47	36.69	6	304.8806	2.1300	310.128	-1.69	0.983
H4	Capintec ARC 120R	10R Schott	041 x 10	98.5	6	612.8542	4.2808	623.284	-1.67	0.983
H4	Capintec CRC 15R	10R Schott	041 x 10	79.8	6	621.527	4.2808	623.284	-0.28	0.997
H4	NPL Fidelis	10R Schott	Preset 10R	106.149	6	673.1954	4.2808	623.284	8.01	1.080
H5	Capintec CRC 15R	1ml BD Plastipak Syringe	051 x 10	17.35		23.37335	0.2288	33.313	-29.84	0.702
H5	Capintec CRC 15R	1ml BD Plastipak Syringe	051 x 10	111.7		149.8285	1.0638	154.889	-3.27	0.967
H5	Capintec CRC 15R	20ml BD Plastipak Syringe	051 x 10	138.6		185.1076	2.0338	296.121	-37.49	0.625
H5	Capintec CRC-15R	10ml BD Plastipak Syringe	051 x 10	20.23		366.3194	2.4875	362.180	1.14	1.011
H5	Capintec CRC 15R	20ml BD Plastipak Syringe	051 x 10	343.1		456.4133	3.1191	454.141	0.50	1.005

Code	Calibrator	Geometry	Dial Setting	Reported Activity	Uncertainty	Corrected Activity	Mass	NPL Activity	% Deviation	Ratio
H5	Capintec ARC 120R	10R Schott	048 x 10	539.3		553.7921	4.1219	600.151	-7.72	0.923
H5	Capintec CRC 15R	10R Schott	048 x 10	542.1		554.2625	4.1219	600.151	-7.65	0.924
H5	Capintec CRC 15R	10R Schott	048 x 10	542.2		555.6663	4.1219	600.151	-7.41	0.926
H5	Capintec CRC 15R	10R Schott	048 x 10	546.8		557.6578	4.1219	600.151	-7.08	0.929
H5	Capintec CRC 15R	10R Schott	048 x 10	546		560.9756	4.1219	600.151	-6.53	0.935
H5	Capintec CRC 15R	10R Schott	048 x 10	548.7		563.1398	4.1219	600.151	-6.17	0.938
H6	Capintec CRC 15R	P6 Vial (N46)	048 x 10	309.1	2.95	522.2039	3.9440	574.246	-9.06	0.909
H6	Capintec CRC 25R	P6 Vial (N46)	048 x 10	314.4	2.95	531.829	3.9440	574.246	-7.39	0.926
H6	NPL Fidelis	P6 Vial (N46)	Preset P6	444.9	1.77	601.304	4.1140	598.998	0.38	1.004
H6	Capintec CRC 15R	10R Schott	048 x 10	573.5	3.19	554.9772	4.2402	617.379	-10.11	0.899
H6	Capintec CRC 15R	10R Schott	044 x 10	591.6	3.19	572.8025	4.2402	617.379	-7.22	0.928
H6	Capintec CRC 25R	10R Schott	048 x 10	563.8	2.89	577.6986	4.2402	617.379	-6.43	0.936
H6	NPL Fidelis	10R Schott	Preset 10R	630.7	0.88	613.5309	4.2402	617.379	-0.62	0.994
H7	Capintec CRC 25R	10R Schott	048 x 10	566.55	10	585.0368	4.2952	625.380	-6.45	0.935
H7	Capintec CRC 15R	10R Schott	048 x 10	576.85	10	586.9266	4.2952	625.380	-6.15	0.939
H7	Capintec CRC 15R	10R Schott	048 x 10	276	10	587.3924	4.2952	625.380	-6.07	0.939
H7	NPL Fidelis	10R Schott	Preset 10R	678.42	1	686.6692	4.2952	625.380	9.80	1.098
H8	Capintec CRC 15R	2.5ml Terumo Syringe	058 x 10	30.5		86.86442	0.5710	83.138	4.48	1.045
H8	Capintec CRC 15R	2.5ml Terumo Syringe	065 x 10	52.6		149.0777	0.9840	143.270	4.05	1.041
H8	Capintec CRC 15R	5ml Terumo Syringe	057 x 10	72.5		160.2541	1.0560	153.754	4.23	1.042
H8	Capintec CRC 15R	5ml Terumo Syringe	055 x 10	151.4		333.3894	2.1880	318.573	4.65	1.047
H8	Capintec CRC 15R	5ml Terumo Syringe	052 x 10	221		483.7633	3.1880	464.173	4.22	1.042
H8	Capintec CRC 15R	P6 Vial	040 x 10	395		528.4958	3.6630	533.333	-0.91	0.991
H8	NPL Fidelis	P6 Vial	Preset P6	416.46	0.38	558.416	3.6630	533.333	4.70	1.047
H8	NPL Fidelis	P6 Vial	Preset P6	418.76	0.46	561.6013	3.6630	533.333	5.30	1.053
H8	NPL Fidelis	10R Schott	Preset 10R	478.65	0.43	619.7325	4.0795	593.972	4.34	1.043
H9	Capintec CRC 15R	P6 Vial (N46)	034 x 10	8.65	2.51	116.3935	0.8000	116.480	-0.07	0.999
H9	Capintec CRC 15R	10R Schott	034 x 10	449.2	0.48	572.959	4.0766	593.549	-3.47	0.965
H9	Capintec CRC 15 Beta	10R Schott		429.2	0.38	575.4986	4.0766	593.549	-3.04	0.970
H9	Capintec CRC 15R	10R Schott	034 x 10	458.1	0.25	580.6335	4.0766	593.549	-2.18	0.978
H9	Capintec CRC 15 Beta	10R Schott	034 x 10	453.9	0.22	609.6069	4.0766	593.549	2.71	1.027
H9	Capintec CRC 15 Beta	10R Schott	034 x 10	461.1	0.33	611.5062	4.0766	593.549	3.03	1.030
H9	Capintec CRC 15 Beta	10R Schott		486.6	0.59	644.8585	4.0766	593.549	8.64	1.086
H10	Capintec CRC 25R	5ml BD Syringe	048 x 10	134.3	2.6	297.2856	1.9000	276.640	7.46	1.075
H10	Capintec CRC 25R	10R Schott	048 x 10	441.1	0.34	593.8068	4.3670	635.830	-6.61	0.934
H10	Capintec CRC 25R	10R Schott	048 x 10	442.9	0.45	596.23	4.3670	635.830	-6.23	0.938
H10	Capintec CRC 15R	10R Schott	048 x 10	444.3	0.41	598.1146	4.3670	635.830	-5.93	0.941
H11	Capintec CRC 15R Enhanced	2.5ml Terumo Syringe	048 x 10	27.59	0.2	304.2656	2.0500	298.480	1.94	1.019
H11	Capintec CRC 15R	2.5ml Terumo Syringe	048 x 10	22.85	0.2	312.7817	2.0500	298.480	4.79	1.048
H11	Capintec CRC 15R	2.5ml Terumo Syringe	048 x 10	28.99	0.3	318.611	2.0500	298.480	6.74	1.067
H11	Capintec CRC Beta-C	2.5ml Terumo Syringe	048 x 10	29.63	0.4	327.4119	2.0500	298.480	9.69	1.097

Code	Calibrator	Geometry	Dial Setting	Reported Activity	Uncertainty	Corrected Activity	Mass	NPL Activity	% Deviation	Ratio
H11	Vinten Isocal IV	2.5ml Terumo Syringe	22	33.97	0.3	373.8148	2.0500	298.480	25.24	1.252
H11	Vinten Isocal IV	P6 Vial	22	3.26	2.3	276.9472	2.0800	302.848	-8.55	0.914
H11	Capintec CRC 15R	P6 Vial	048 x 10	3.35	0.4	281.7833	2.0800	302.848	-6.96	0.930
H11	Capintec CRC 15R	P6 Vial	048 x 10	3.36	0.9	284.4145	2.0800	302.848	-6.09	0.939
H11	Capintec CRC 15R	P6 Vial	048 x 10	3.4	0.8	286.8157	2.0800	302.848	-5.29	0.947
H11	Capintec CRC 15R	P6 Vial	048 x 10	3.41	0.4	287.1926	2.0800	302.848	-5.17	0.948
H11	Capintec CRC 15R	P6 Vial	048 x 10	3.46	0.8	291.8245	2.0800	302.848	-3.64	0.964
H11	Vinten Isocal IV	P6 Vial	22	3.52	2.3	298.7654	2.0800	302.848	-1.35	0.987
H11	Capintec CRC Beta-C	5ml Terumo Syringe	048 x 10	29.68	0.4	413.2964	2.8600	416.416	-0.75	0.993
H11	Capintec CRC 15R Enhanced	5ml Terumo Syringe	048 x 10	30.09	0.2	419.0812	2.8600	416.416	0.64	1.006
H11	Capintec CRC 15R	5ml Terumo Syringe	048 x 10	30.97	0.2	427.2333	2.8600	416.416	2.60	1.026
H11	Capintec CRC 15R	5ml Terumo Syringe	048 x 10	31.51	0.4	433.821	2.8600	416.416	4.18	1.042
H11	Vinten Isocal IV	5ml Terumo Syringe	22	41.82	0.2	576.7017	2.8600	416.416	38.49	1.385
H11	Capintec CRC Beta-C	10ml Terumo Syringe	048 x 10	34.25	0.6	483.256	3.6400	529.984	-8.82	0.912
H11	Capintec CRC 15R Enhanced	10ml Terumo Syringe	048 x 10	37.21	0.2	525.684	3.6400	529.984	-0.81	0.992
H11	Capintec CRC 15R Enhanced	10ml Terumo Syringe	048 x 10	37.63	0.4	532.5774	3.6400	529.984	0.49	1.005
H11	Capintec CRC 15R	10ml Terumo Syringe	048 x 10	38.49	0.2	541.9067	3.6400	529.984	2.25	1.022
H11	Capintec CRC 15R	10ml Terumo Syringe	048 x 10	38.81	0.1	543.7571	3.6400	529.984	2.60	1.026
H11	Vinten Isocal IV	10ml Terumo Syringe	22	47.05	0.5	660.3959	3.6400	529.984	24.61	1.246
H11	Vinten Isocal IV	5ml Plastic V-Vial (Sirtex)	22	47.79	0.3	493.8953	3.7400	544.544	-9.30	0.907
H11	Capintec CRC 15R	5ml Plastic V-Vial (Sirtex)	048 x 10	51.41	0.1	532.0742	3.7400	544.544	-2.29	0.977
H11	Capintec CRC 15R Enhanced	5ml Plastic V-Vial (Sirtex)	048 x 10	62.62	0.1	534.7179	3.7400	544.544	-1.80	0.982
H11	Capintec CRC 15R Enhanced	5ml Plastic V-Vial (Sirtex)	048 x 10	63.28	0.2	539.0881	3.7400	544.544	-1.00	0.990
H11	Capintec CRC 15R	5ml Plastic V-Vial (Sirtex)	048 x 10	52.9	0.3	548.2858	3.7400	544.544	0.69	1.007
H11	Capintec CRC 15R	5ml Plastic V-Vial (Sirtex)	048 x 10	52.27	0.2	565.7258	3.7400	544.544	3.89	1.039
H11	Capintec CRC Beta-C	5ml Plastic V-Vial (Sirtex)	048 x 10	68.5	0.3	585.7725	3.7400	544.544	7.57	1.076
H11	Capintec CRC 15R	P6 Vial	048 x 10	60.82	0.1	501.487	3.8200	556.192	-9.84	0.902
H11	Capintec CRC 15R Enhanced	P6 Vial	048 x 10	60.23	0.2	507.0322	3.8200	556.192	-8.84	0.912
H11	Vinten Isocal IV	P6 Vial	22	61.19	0.2	511.7794	3.8200	556.192	-7.99	0.920
H11	Capintec CRC 15R Enhanced	P6 Vial	048 x 10	60.67	0.1	512.8596	3.8200	556.192	-7.79	0.922
H11	Capintec CRC 15R	P6 Vial	048 x 10	63.07	0.1	517.6993	3.8200	556.192	-6.92	0.931
H11	Capintec CRC 15R	P6 Vial	048 x 10	63.21	0.2	520.1604	3.8200	556.192	-6.48	0.935
H11	Capintec CRC Beta-C	P6 Vial	048 x 10	76.16	0.2	641.7137	3.8200	556.192	15.38	1.154
H11	Capintec CRC 15R Enhanced	10R Schott	048 x 10	315.6	0.2	548.8974	4.1239	600.443	-8.58	0.914
H11	Capintec CRC 15R Enhanced	10R Schott	048 x 10	314.6	0.2	549.1358	4.1239	600.443	-8.54	0.915
H11	Capintec CRC 15R Enhanced	10R Schott	048 x 10	244.6	0.2	549.811	4.1239	600.443	-8.43	0.916
H11	Capintec CRC 15R Enhanced	10R Schott	048 x 10	321.3	0.2	557.2004	4.1239	600.443	-7.20	0.928
H11	Capintec CRC 15R	10R Schott	048 x 10	267	0.2	559.6928	4.1239	600.443	-6.79	0.932
H11	Vinten Isocal IV	10R Schott	22	537.5	0.1	561.9906	4.1239	600.443	-6.40	0.936

Code	Calibrator	Geometry	Dial Setting	Reported Activity	Uncertainty	Corrected Activity	Mass	NPL Activity	% Deviation	Ratio
H11	Capintec CRC 15R	10R Schott	048 x 10	546.4	0.2	563.924	4.1239	600.443	-6.08	0.939
H11	Capintec CRC 15R	10R Schott	048 x 10	545.7	0.1	565.0333	4.1239	600.443	-5.90	0.941
H11	Capintec CRC 15R	10R Schott	048 x 10	545.7	0.2	565.5431	4.1239	600.443	-5.81	0.942
H11	Capintec CRC 15R	10R Schott	048 x 10	271.3	0.2	567.5793	4.1239	600.443	-5.47	0.945
H11	Capintec CRC 15R	10R Schott	048 X 10	548.1	0.1	568.4404	4.1239	600.443	-5.33	0.947
H11	Capintec CRC Beta-C	10R Schott	048 x 10	296.6	0.2	665.6149	4.1239	600.443	10.85	1.109
H12	Capintec CRC 15R	10R Schott	048 x 10	217.2		603.8152	4.4012	640.814	-5.77	0.942
H12	Capintec CRC 35R	10R Schott	048 x 10	222		615.7136	4.4012	640.814	-3.92	0.961
H13	Capintec NPL CRC	P6 Vial (N46)	0.08 pA/MBq	84.3	8	526.4943	3.9500	575.120	-8.45	0.915
H13	Capintec NPL CRC	P6 Vial (N46)	Preset 10R	99.47	8	621.2383	3.9500	575.120	8.02	1.080
H13	Capintec CRC 15R	P6 Vial (N46)	048 x 10	448	8	583.6169	4.0700	592.592	-1.51	0.985
H13	Capintec CRC 15R	10R Schott	056 x 10	538.6	7	530.1176	4.4484	647.693	-18.15	0.818
H13	Capintec CRC 15R	10R Schott	048 X 10	577.15	7	583.9571	4.4484	647.693	-9.84	0.902
H13	Capintec CRC 15R	10R Schott	048 x 10	615	7	605.2052	4.4484	647.693	-6.56	0.934
H13	Capintec CRC 15R	10R Schott	056 X 10	545.06	7	551.4886	4.4484	647.693	-14.85	0.851
H13	Capintec CRC 25R	10R Schott	056 X 10	561.92	7	575.1494	4.4484	647.693	-11.20	0.888
H13	Capintec NPL CRC	10R Schott	0.08 pA/MBq	563	1	577.9204	4.4484	647.693	-10.77	0.892
H13	Capintec CRC 25R	10R Schott	048 X 10	595.92	7	609.9498	4.4484	647.693	-5.83	0.942
H13	Capintec NPL CRC	10R Schott	Preset 10R	625	1	641.5635	4.4484	647.693	-0.95	0.991
H14	Capintec CRC 25R	10R Schott	048 x 10	583	5.7	593.291	4.3993	640.537	-7.38	0.926
H14	Capintec CRC 15R	10R Schott	048 x 10	73.9	3	603.3216	4.3993	640.537	-5.81	0.942
H14	Capintec CRC 15R	10R Schott	048 x 10	596	3	605.7551	4.3993	640.537	-5.43	0.946
H14	Capintec CRC 15R	10R Schott	040 x 10	617.9	3	638.2926	4.3993	640.537	-0.35	0.996
H14	Capintec CRC 15R	10R Schott	040 x 10	657.15	5.7	678.838	4.3993	640.537	5.98	1.060
H15	Capintec CRC 15R	P6 Vial (N46)	031 x 10	188.7	3.9	248.2288	3.8780	564.637	-56.04	0.440
H15	Capintec CRC 15R	10R Schott	033 x 10	477.5	3.6	625.6481	4.1649	606.404	3.17	1.032
H15	Capintec CRC 15R	10R Schott	034 x 10	483.5	3.6	629.1819	4.1649	606.404	3.76	1.038
H16	Capintec CRC 15R	10R Schott	055 x 10	418		555.4484	4.0580	590.838	-5.99	0.940
H17	Capintec ARC 120	10R Schott	048 x 10	495.575		491.3025	4.3670	635.830	-22.73	0.773
H17	Capintec CRC 15R	10R Schott	048 x 10	500		492.8362	4.3670	635.830	-22.49	0.775
H17	Capintec CRC 15R	10R Schott	048 x 10	497.345		493.6802	4.3670	635.830	-22.36	0.776
H17	Capintec CRC 15R	10R Schott	052 x 10	519		511.8409	4.3670	635.830	-19.50	0.805
H17	Capintec CRC 15R	10ml BD Luer Lok Syringe	048 x 10	518		535.3852	4.3670	635.830	-15.80	0.842
H17	Capintec ARC 120	10ml BD Luer Lok Syringe	048 x 10	523		541.2361	4.3670	635.830	-14.88	0.851
H17	Capintec CRC 15R	10ml BD Luer Lok Syringe	048 x 10	529		543.4113	4.3670	635.830	-14.54	0.855
H17	Capintec CRC 15R	10ml BD Luer Lok Syringe	052 x 10	532		547.0849	4.3670	635.830	-13.96	0.860
H18	Capintec CRC 15R	10R Schott	064 x 10	299		483.9998	4.0718	592.849	-18.36	0.816
H18	Capintec CRC 15 Beta	10R Schott	048 x 10	333		543.332	4.0718	592.849	-8.35	0.916
H18	Capintec CRC 15R	10R Schott	048 x 10	332.7		543.6264	4.0718	592.849	-8.30	0.917
H18	Capintec CRC 15 Beta	10R Schott	048 x 10	41.25		546.8072	4.0718	592.849	-7.77	0.922
H18	Capintec CRC 15R Beta	10R Schott	048 x 10	338.1		550.7584	4.0718	592.849	-7.10	0.929
H18	Capintec CRC 15R	10R Schott	048 x 10	330		571.0506	4.0718	592.849	-3.68	0.963
H18	Capintec CRC 15R	10R Schott	048 x 10	335.7		580.9142	4.0718	592.849	-2.01	0.980
H18	Capintec CRC VD 505	10R Schott	902 x 100	337.6		585.2568	4.0718	592.849	-1.28	0.987
H19	Capintec CRC 15R	10R Schott	063 x 10	356.8		476.3533	4.1097	598.373	-20.39	0.796
H19	Capintec CRC 15R	10R Schott	063 x 10	371.09		500.8229	4.1097	598.373	-16.30	0.837
H19	Capintec CRC 15R	10R Schott	047 x 10	400		534.0284	4.1097	598.373	-10.75	0.892
H19	Capintec CRC 15R	10R Schott	048 x 10	414.19		557.078	4.1097	598.373	-6.90	0.931

Code	Calibrator	Geometry	Dial Setting	Reported Activity	Uncertainty	Corrected Activity	Mass	NPL Activity	% Deviation	Ratio
H19	Capintec CRC 15R	10R Schott	040 x 10	458.19		593.2419	4.1097	598.373	-0.86	0.991
H20	Atomlab 200	1ml Becton Dickinson Syringe	480	68		90.81759	0.6000	87.360	3.96	1.040
H20	Capintec CRC 15R	1ml Becton Dickinson Syringe	053 x 10	69.372		92.58314	0.6000	87.360	5.98	1.060
H20	Atomlab 200	2ml CIS Bio Vial	480	100.5		134.7082	0.8000	116.480	15.65	1.156
H20	Capintec CRC 15R	2ml CIS Bio Vial	048 x 10	105.96		141.9242	0.8000	116.480	21.84	1.218
H20	Atomlab 200	10ml Becton Dickinson Syringe	480	381.65		510.634	3.0000	436.800	16.90	1.169
H20	Capintec CRC 15R	10ml Becton Dickinson Syringe	049 x 10	387.97		518.5284	3.0000	436.800	18.71	1.187
H20	Atomlab 200	10R Schott	480	404.7		537.9691	4.0539	590.255	-8.86	0.911
H20	Atomlab 200	10R Schott	480	530.867		546.9054	4.0539	590.255	-7.34	0.927
H20	Capintec CRC 15R	10R Schott	U3 (# 370)	456.97		607.2327	4.0539	590.255	2.88	1.029
H20	Capintec CRC 15R	10R Schott	U3 (# 370)	597.975		608.7499	4.0539	590.255	3.13	1.031
H21	Capintec CRC 15R	10ml BD Plastipak Syringe	049 x 10	338.62		583.3305	4.1093	598.314	-2.50	0.975
H21	Capintec CRC 15R	10ml BD Plastipak Syringe	049 x 10	261		584.773	4.1093	598.314	-2.26	0.977
H21	Capintec CRC 15R	10ml BD Plastipak Syringe	049 x 10	262		585.5329	4.1093	598.314	-2.14	0.979
H21	Capintec CRC 15R	10ml BD Plastipak Syringe	049 x 10	344.42		593.001	4.1093	598.314	-0.89	0.991
H21	NPL Fidelis	10ml BD Plastipak Syringe	0.3826 pA/MBq	343		593.0114	4.1093	598.314	-0.89	0.991
H21	Capintec CRC 15R	10ml BD Plastipak Syringe	049 x 10	266		594.5796	4.1093	598.314	-0.62	0.994
H21	Capintec CRC 15R	10ml BD Plastipak Syringe	049 x 10	266		596.0831	4.1093	598.314	-0.37	0.996
H21	Capintec CRC 15R	10ml BD Plastipak Syringe	049 x 10	347.06		597.0076	4.1093	598.314	-0.22	0.998
H21	Capintec CRC 15R	10ml BD Plastipak Syringe	049 x 10	267		597.1379	4.1093	598.314	-0.20	0.998
H21	Capintec CRC 15R	10ml BD Plastipak Syringe	049 x 10	266		597.1593	4.1093	598.314	-0.19	0.998
H21	Capintec CRC 15R	10ml BD Plastipak Syringe	049 x 10	348.16		600.3059	4.1093	598.314	0.33	1.003
H21	Capintec CRC 15R	10ml BD Plastipak Syringe	049 x 10	268		600.3483	4.1093	598.314	0.34	1.003
H21	Capintec CRC 15R	10ml BD Plastipak Syringe	049 x 10	269		601.0685	4.1093	598.314	0.46	1.005
H21	NPL Fidelis	10ml BD Plastipak Syringe	0.37057 pA/MBq	349		604.2561	4.1093	598.314	0.99	1.010
H21	Capintec CRC 15R	10ml BD Plastipak Syringe	049 x 10	353.88		610.3887	4.1093	598.314	2.02	1.020
H21	Capintec CRC 15R	10ml BD Plastipak Syringe	049 x 10	274		613.8996	4.1093	598.314	2.60	1.026

Code	Calibrator	Geometry	Dial Setting	Reported Activity	Uncertainty	Corrected Activity	Mass	NPL Activity	% Deviation	Ratio
H21	Capintec CRC 15R	10ml BD Plastipak Syringe	049 x 10	275		614.4752	4.1093	598.314	2.70	1.027
H21	NPL Fidelis	10ml BD Plastipak Syringe	0.37057 pA/MBq	319.8		717.1615	4.1093	598.314	19.86	1.199
H21	NPL Fidelis	10ml BD Plastipak Syringe	0.37057 pA/MBq	324.5		726.2589	4.1093	598.314	21.38	1.214
H21	Capintec CRC 15R	10R Schott	048 x 10	431.84		569.5082	4.2392	617.233	-7.73	0.923
H21	Capintec CRC 15R	10R Schott	048 x 10	438.18		576.8279	4.2392	617.233	-6.55	0.935
H21	Capintec CRC 15R	10R Schott	048 x 10	443.99		585.2147	4.2392	617.233	-5.19	0.948
H21	NPL Fidelis	10R Schott	Preset 10R	464.4		613.6646	4.2392	617.233	-0.58	0.994
H21	NPL Fidelis	10R Schott	Preset 10R	472.65		626.0326	4.2392	617.233	1.43	1.014
H22	Capintec CRC 15R	10R Schott	051 x 10	540.47		555.795	4.1310	601.478	-7.60	0.924
H22	Capintec CRC 15R	10R Schott	050 x 10	539.26		557.5599	4.1310	601.478	-7.30	0.927
H22	Capintec CRC 15R	10R Schott	048 x 10	547.5		565.5692	4.1310	601.478	-5.97	0.940
H22	Capintec CRC 15R	10R Schott	048 x 10	553.09		568.2601	4.1310	601.478	-5.52	0.945
H23	TPA Ion Chamber	12ml Wheaton Vial		3.842	1.14	147.448		145.600	1.27	1.013
H24	Capintec CRC 15R	10R Schott	047 x 10	362		611.906	4.4776	651.935	-6.14	0.939
H25	Capintec CRC 15R	10ml BD Plastipak Syringe	049 x 10	328.38		581.6255	4.1093	598.314	-2.79	0.972
H25	Capintec CRC 15R	10ml BD Plastipak Syringe	049 x 10	260		588.9779	4.1093	598.314	-1.56	0.984
H25	Capintec CRC 15R	10ml BD Plastipak Syringe	049 x 10	33.77		594.2083	4.1093	598.314	-0.69	0.993
H25	Capintec CRC 15R	10ml BD Plastipak Syringe	049 x 10	337.67		598.4037	4.1093	598.314	0.01	1.000
H25	Capintec CRC 15R	10ml BD Plastipak Syringe	049 x 10	265		600.3044	4.1093	598.314	0.33	1.003
H25	Capintec CRC 15R	10ml BD Plastipak Syringe	049 x 10	34.47		605.4322	4.1093	598.314	1.19	1.012
H25	Capintec CRC 15 Beta	10ml BD Plastipak Syringe	049 x 10	282		639.391	4.1093	598.314	6.87	1.069
H25	Capintec CRC 15 Beta	10ml BD Plastipak Syringe	049 x 10	361.36		640.9639	4.1093	598.314	7.13	1.071
H25	Capintec CRC 15R	10R Schott	048 x 10	538.99		574.3243	4.2392	617.233	-6.95	0.930
H25	Capintec CRC 15R	10R Schott	048 x 10	463.95		575.4557	4.2392	617.233	-6.77	0.932
H25	Capintec CRC 15 Beta	10R Schott	Preset Y-90	616.63		657.1727	4.2392	617.233	6.47	1.065
H25	Capintec CRC 15 Beta	10R Schott	Preset Y-90	492.91		673.3199	4.2392	617.233	9.09	1.091
H25	Capintec CRC 15 Beta	10R Schott	Preset Y-90	500.51		691.7654	4.2392	617.233	12.08	1.121
H26	Capintec CRC 15R	Sirtex Vial	048 x 10	19.32	5	42.94443	0.3900	56.784	-24.37	0.756
H26	Capintec CRC 15R	Sirtex Vial	048 x 10	21.62	5	48.0482	0.3900	56.784	-15.38	0.846
H26	Capintec CRC 15R	1ml BD Luer Lok Syringe	041 x 10	40.79	5	71.32769	0.4770	69.451	2.70	1.027
H26	Capintec CRC 15R	1ml BD Luer Lok Syringe	041 x 10	41.02	5	72.17117	0.4770	69.451	3.92	1.039
H26	Capintec CRC 15R	10ml BD Luer Lok Syringe	033 x 10	86.82	5	152.5871	1.0015	145.818	4.64	1.046
H26	Capintec CRC 15R	10ml BD Luer Lok Syringe	033 x 10	90.09	5	157.366	1.0015	145.818	7.92	1.079
H26	Capintec CRC 15R	1ml Zevalin Vial	038 x 10	78.02	5	137.4182	1.0080	146.765	-6.37	0.936
H26	Capintec CRC 15R	1ml Zevalin Vial	038 x 10	85.09	5	149.0081	1.0080	146.765	1.53	1.015

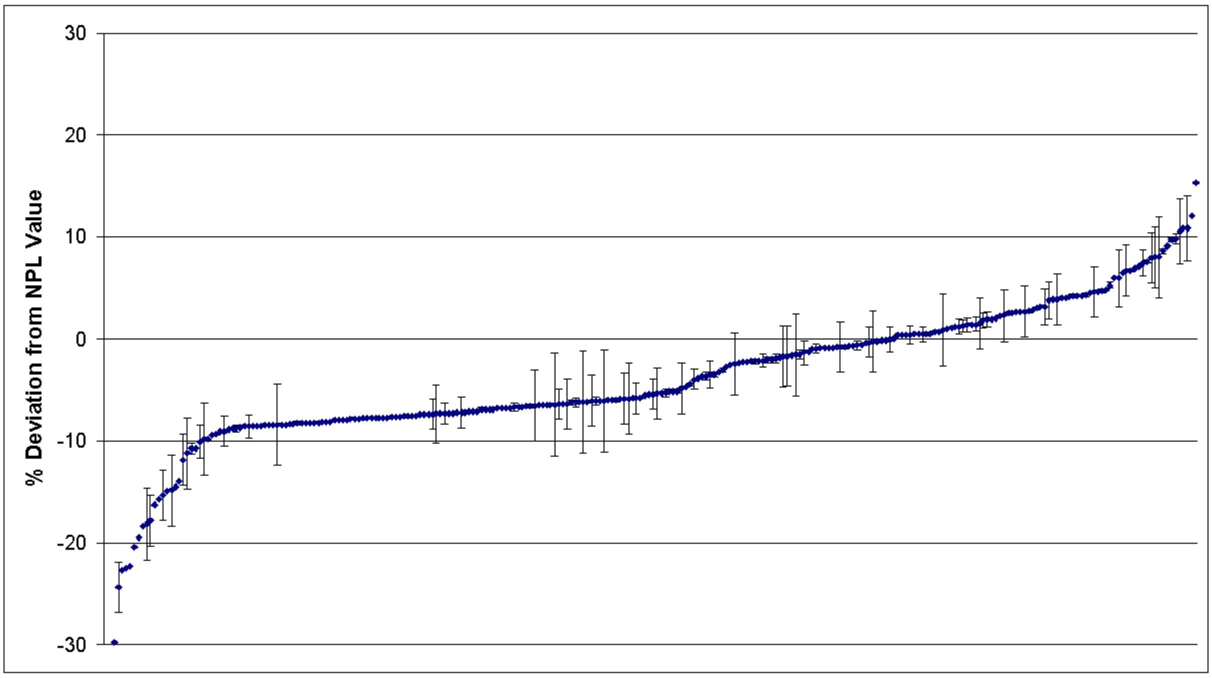
Code	Calibrator	Geometry	Dial Setting	Reported Activity	Uncertainty	Corrected Activity	Mass	NPL Activity	% Deviation	Ratio
H26	Capintec CRC 15R	10ml Zevalin Vial	027 x 10	95.22	5	167.9551	1.1623	169.231	-0.75	0.992
H26	Capintec CRC 15R	10ml Zevalin Vial	027 x 10	102.99	5	180.5169	1.1623	169.231	6.67	1.067
H26	Capintec CRC 15R	10R Schott	048 x 10	287	5	491.7379	4.1083	598.168	-17.79	0.822
H26	Capintec CRC 15R	10R Schott	048 x 10	305.01	5	527.2355	4.1083	598.169	-11.86	0.881
H27	Capintec CRC 25R	10R Schott	048 x 10	55.7	5	601.8713	4.4024	640.989	-6.10	0.939
H27	Capintec CRC 25R	10R Schott	048 x 10	55.6	5	603.3974	4.4024	640.989	-5.86	0.941
H27	Capintec CRC 25R	10R Schott	048 x 10	55.8	5	606.4424	4.4024	640.989	-5.39	0.946
H27	Capintec CRC 25R	10R Schott	048 x 10	56.1	5	610.253	4.4024	640.989	-4.80	0.952
H29	Capintec CRC 15R	10R Schott	48 x 10	518.4843		541.4244	4.0539	590.255	-8.27	0.917
H29	Capintec CRC 15R	10R Schott	48 x 10	521.4136		544.4833	4.0580	590.838	-7.85	0.922
H29	Capintec CRC 15R	10R Schott	48 x 10	527.2722		550.601	4.0718	592.849	-7.13	0.929
H29	Capintec CRC 15R	10R Schott	48 x 10	525.3193		548.5618	4.0766	593.549	-7.58	0.924
H29	Capintec CRC 15R	10R Schott	48 x 10	523.3665		546.5225	4.0795	593.972	-7.99	0.920
H29	Capintec CRC 15R	10R Schott	48 x 10	522.3901		545.5029	4.0858	594.890	-8.30	0.917
H29	Capintec CRC 15R	10R Schott	48 x 10	524.3429		547.5421	4.0860	594.919	-7.96	0.920
H29	Capintec CRC 15R	10R Schott	48 x 10	527.2722		550.601	4.1038	597.513	-7.85	0.921
H29	Capintec CRC 15R	10R Schott	48 x 10	528.2486		551.6207	4.1083	598.169	-7.78	0.922
H29	Capintec CRC 15R	10R Schott	48 x 10	530.2015		553.6599	4.1097	598.373	-7.47	0.925
H29	Capintec CRC 15R	10R Schott	48 x 10	524.3429		547.5421	4.1100	598.417	-8.50	0.915
H29	Capintec CRC 15R	10R Schott	48 x 10	526.2958		549.5814	4.1219	600.151	-8.43	0.916
H29	Capintec CRC 15R	10R Schott	48 x 10	533.1308		556.7188	4.1239	600.443	-7.28	0.927
H29	Capintec CRC 15R	10R Schott	48 x 10	534.1072		557.7385	4.1310	601.478	-7.27	0.927
H29	Capintec CRC 15R	10R Schott	48 x 10	533.1308		556.7188	4.1629	606.112	-8.15	0.919
H29	Capintec CRC 15R	10R Schott	48 x 10	537.0365		560.7974	4.1649	606.404	-7.52	0.925
H29	Capintec CRC 15R	10R Schott	48 x 10	534.1072		557.7385	4.1703	607.191	-8.14	0.919
H29	Capintec CRC 15R	10R Schott	48 x 10	541.9187		565.8955	4.2071	612.554	-7.62	0.924
H29	Capintec CRC 15R	10R Schott	48 x 10	539.9658		563.8563	4.2337	616.431	-8.53	0.915
H29	Capintec CRC 15R	10R Schott	48 x 10	550.7065		575.0722	4.2392	617.233	-6.83	0.932
H29	Capintec CRC 15R	10R Schott	48 x 10	540.9422		564.8759	4.2402	617.378	-8.50	0.915
H29	Capintec CRC 15R	10R Schott	48 x 10	541.9187		565.8955	4.2552	619.550	-8.66	0.913
H29	Capintec CRC 15R	10R Schott	48 x 10	544.8479		568.9544	4.2641	620.847	-8.36	0.916
H29	Capintec CRC 15R	10R Schott	48 x 10	547.7772		572.0133	4.2808	623.281	-8.23	0.918
H29	Capintec CRC 15R	10R Schott	48 x 10	553.6358		578.1311	4.2952	625.380	-7.56	0.924
H29	Capintec CRC 15R	10R Schott	48 x 10	554.6122		579.1507	4.3313	630.641	-8.16	0.918
H29	Capintec CRC 15R	10R Schott	48 x 10	558.518		583.2293	4.3670	635.830	-8.27	0.917
H29	Capintec CRC 15R	10R Schott	48 x 10	561.4473		586.2881	4.3730	636.704	-7.92	0.921
H29	Capintec CRC 15R	10R Schott	48 x 10	561.4473		586.2881	4.3993	640.537	-8.47	0.915
H29	Capintec CRC 15R	10R Schott	48 x 10	568.2823		593.4256	4.4012	640.814	-7.40	0.926
H29	Capintec CRC 15R	10R Schott	48 x 10	566.3294		591.3863	4.4024	640.989	-7.74	0.923
H29	Capintec CRC 15R	10R Schott	48 x 10	567.3058		592.4059	4.4484	647.693	-8.54	0.915
H29	Capintec CRC 15R	10R Schott	48 x 10	567.3058		592.4059	4.4776	651.935	-9.13	0.909

TABLE 5 – NPL RESULTS ON COMMERCIAL CALIBRATORS

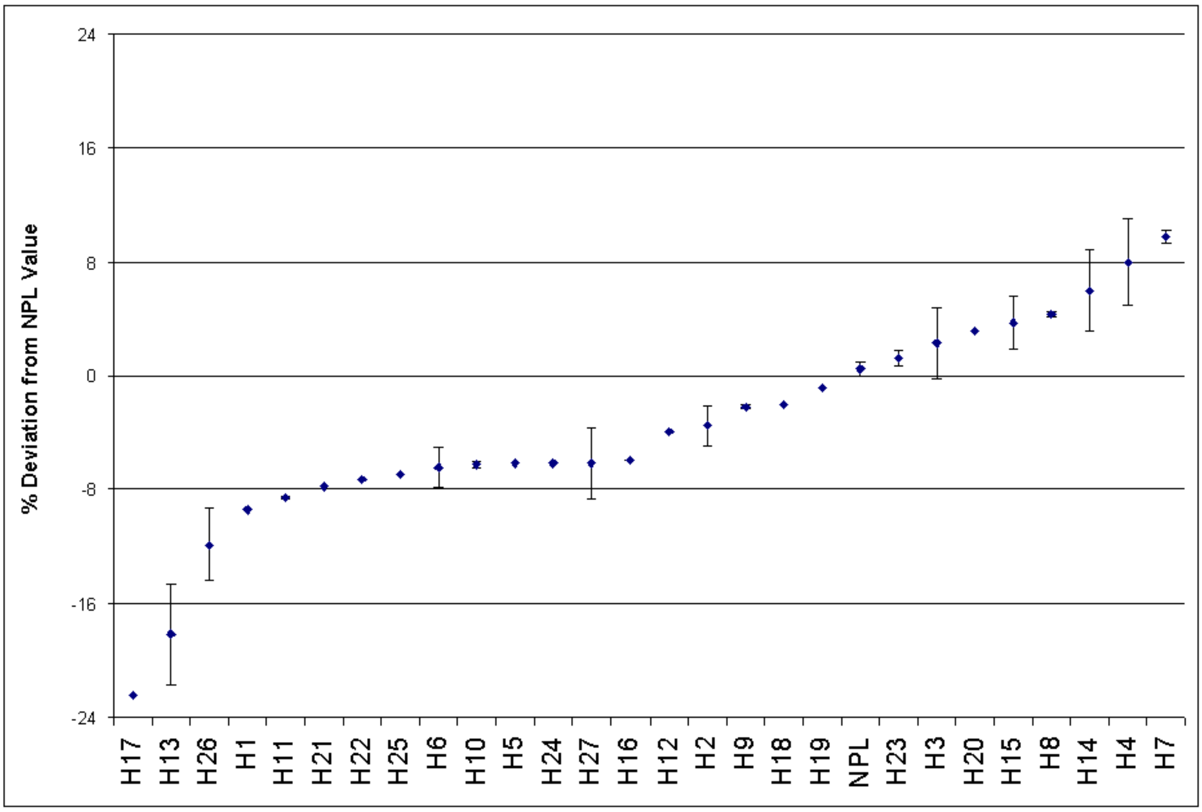
Calibrator	Vial ID	Dial Setting	Activity at ref. time	Certificated Value	% Difference
Fidelis	(No 1) J09174	Y90 10R vial preset	622	630.637	-1.4%
Fidelis	(No 2) J09175	Y90 10R vial preset	613	620.853	-1.3%
Fidelis	(No 1) J09174	Y90 10R vial preset	621	630.637	-1.6%
Fidelis	(No 1) J09174	Y90 10R vial preset	628	630.637	-0.4%
Atomlab 500	(No 1) J09174	preset dial 375	550	630.637	-14.7%
Atomlab 500	(No 1) J09174	preset dial 375	542	630.637	-16.4%
Atomlab 500	(No 1) J09174	preset dial 375	543.6	630.637	-16.0%
Atomlab 500	(No 1) J09174	NPL derived dial 441	647	630.637	2.5%
Atomlab 500	(No 2) J09175	preset dial 375	534.5	620.853	-16.2%
ARC120	(No 1) J09174	dial 48 x 10	582.5	630.637	-8.3%
ARC120	(No 1) J09174	dial 48 x 10	583.6	630.637	-8.1%
ARC120	(No 1) J09174	NPL derived dial 45 x 10	596.6	630.637	-5.7%
ARC120	(No 1) J09174	NPL derived dial 42 x 10	611.4	630.637	-3.1%
ARC120	(No 1) J09174	NPL derived dial 40 x 10	621	630.637	-1.6%
ARC120	(No 1) J09174	NPL derived dial 38x10	631	630.637	0.1%

GRAPHS

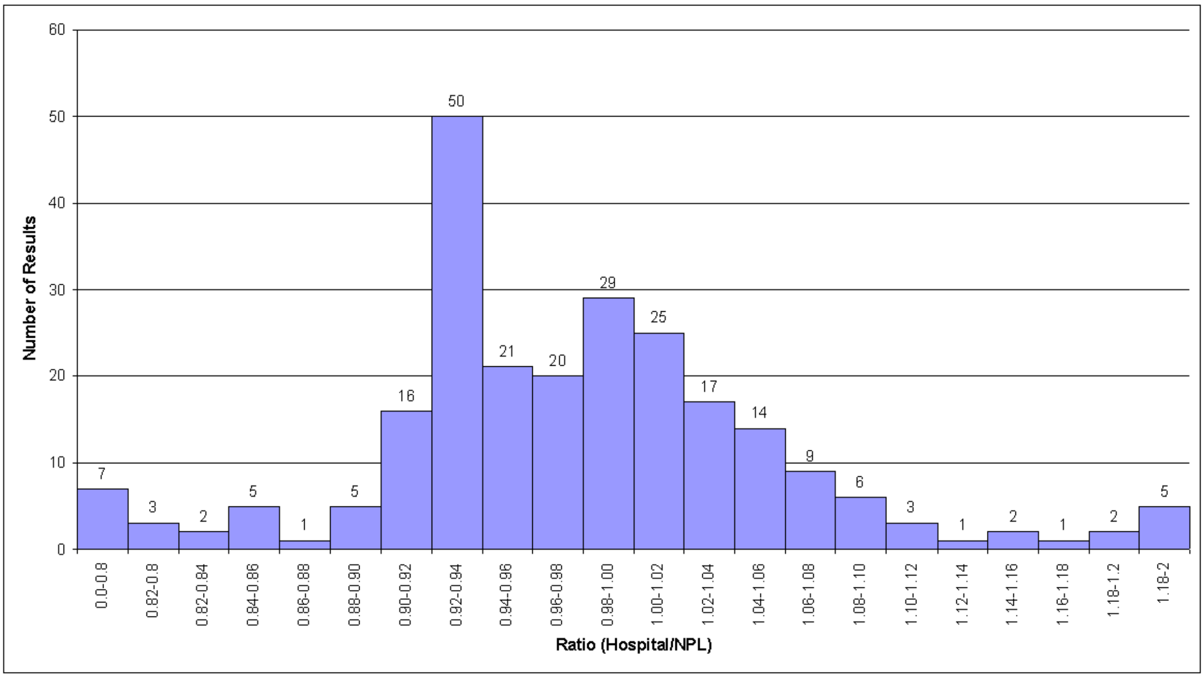
GRAPH 1 (all results):



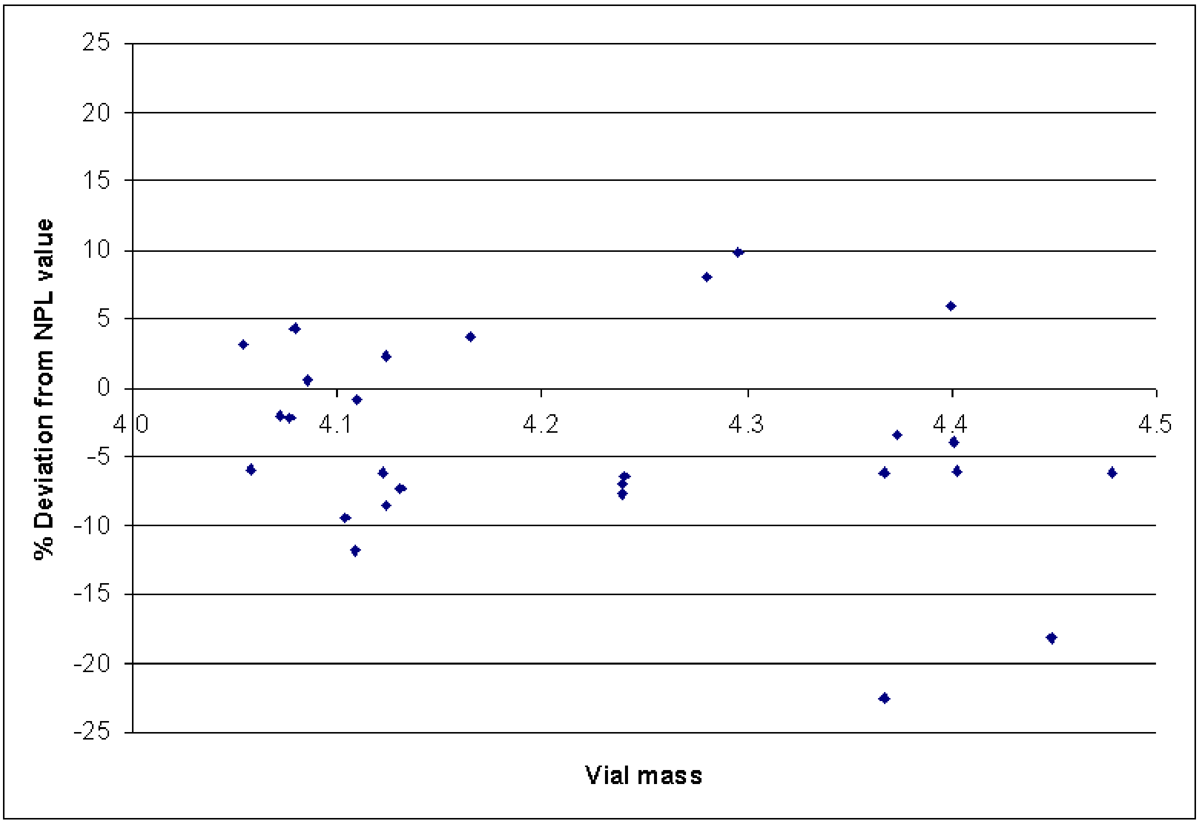
GRAPH 2 (Preferred Values):



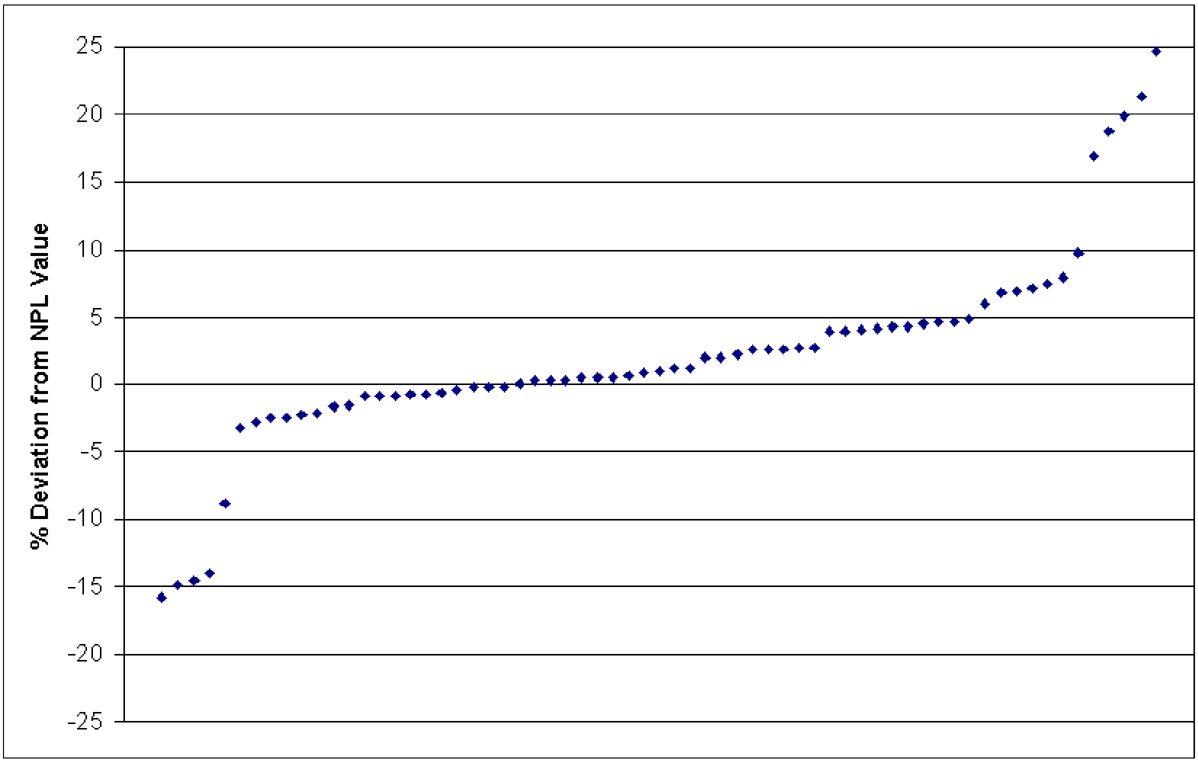
GRAPH 3 (Results ordered by Ratio [Hospital/NPL]):



GRAPH 4 (Preferred values % deviation against vial weight):

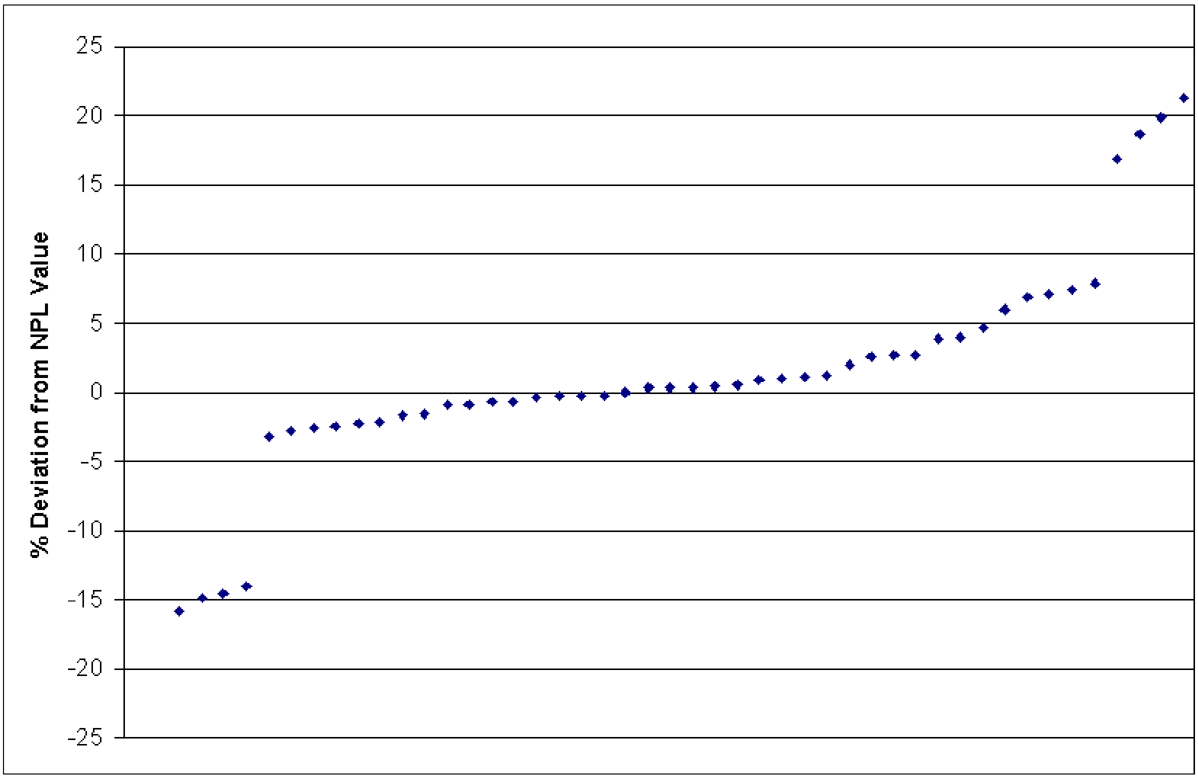


GRAPH 5 (All Syringe Values against NPL Value*)



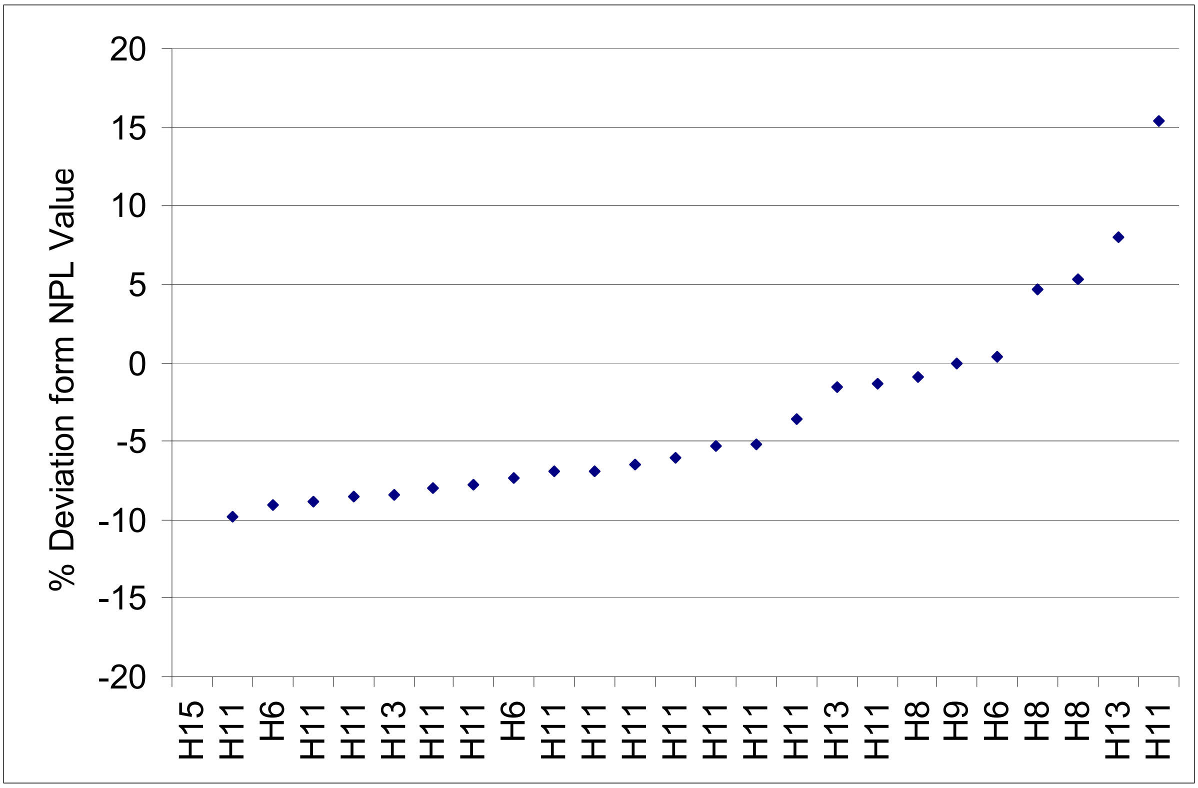
*NPL value derived using masses supplied by participant

GRAPH 6 (Becton Dickson Syringe Values against NPL Values*)



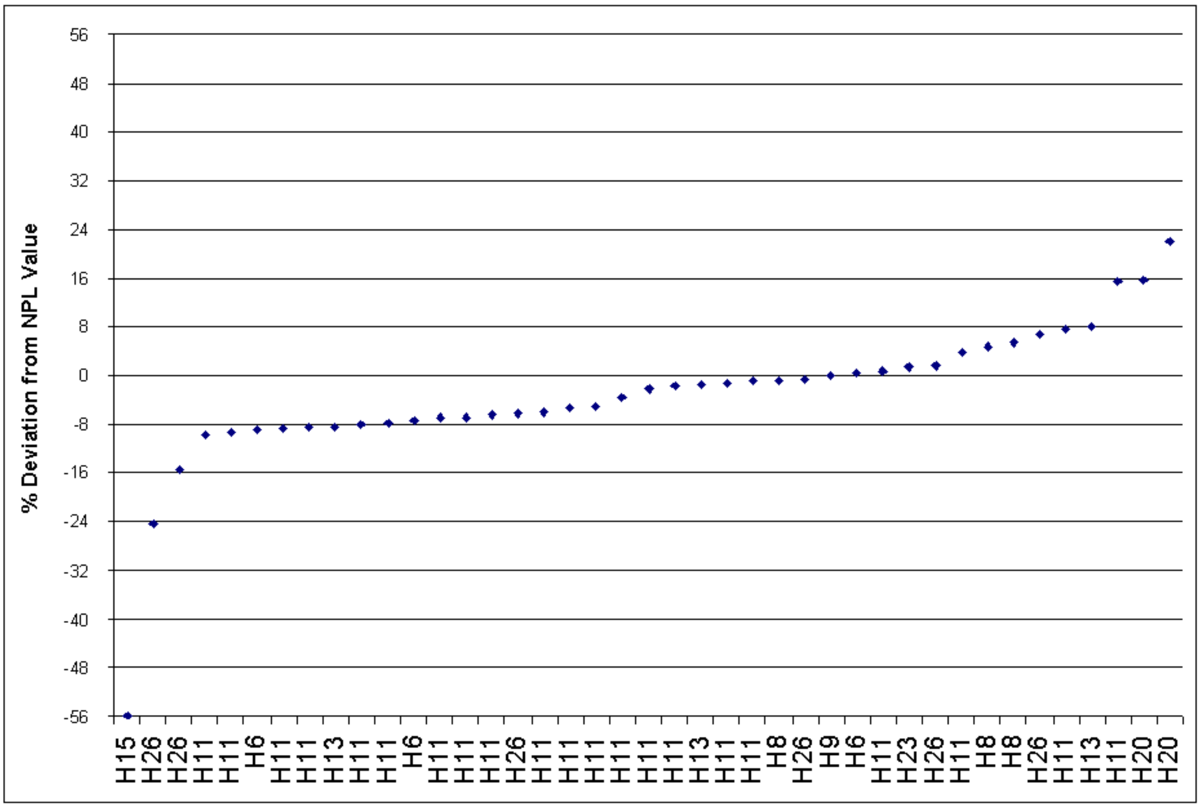
*NPL value derived using masses supplied by participant

GRAPH 7 (P6 Vial Values against NPL Value*)



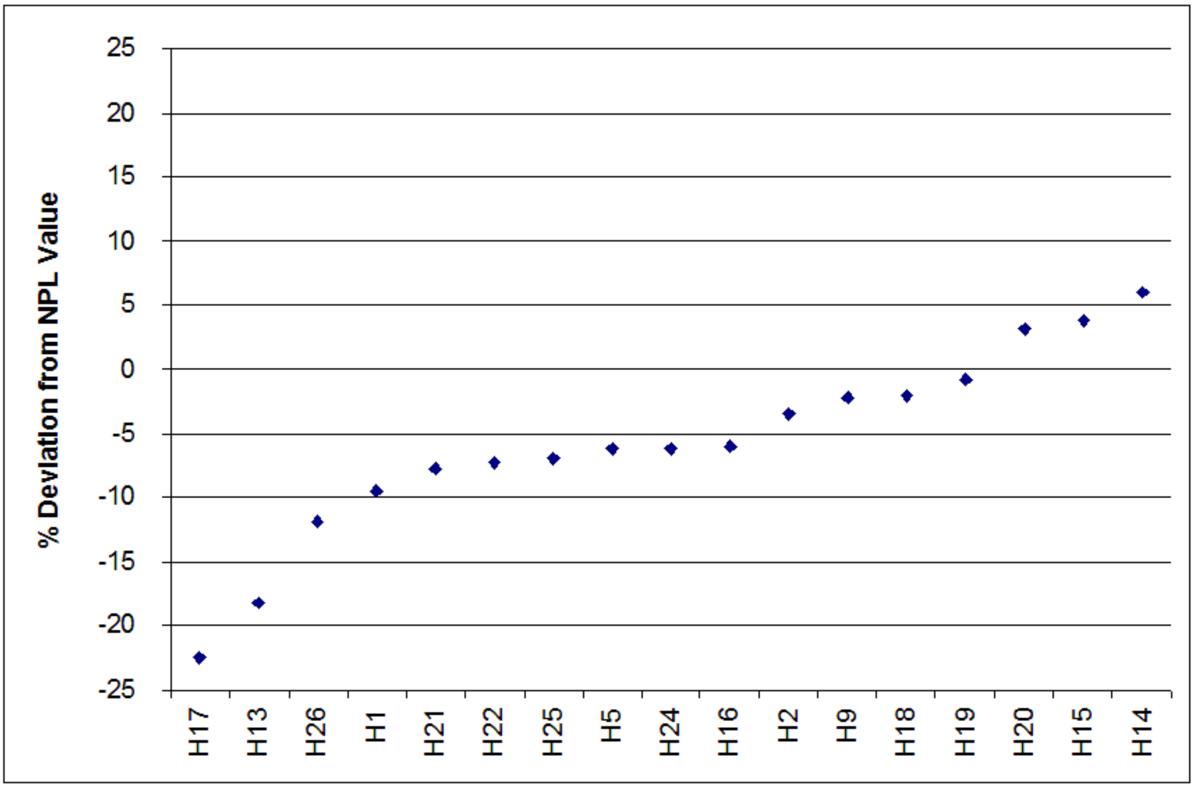
*NPL value derived using masses supplied by participant
*H15 value lies at -56 % and not shown on graph

GRAPH 8 (Other Vial Values against NPL Value*)

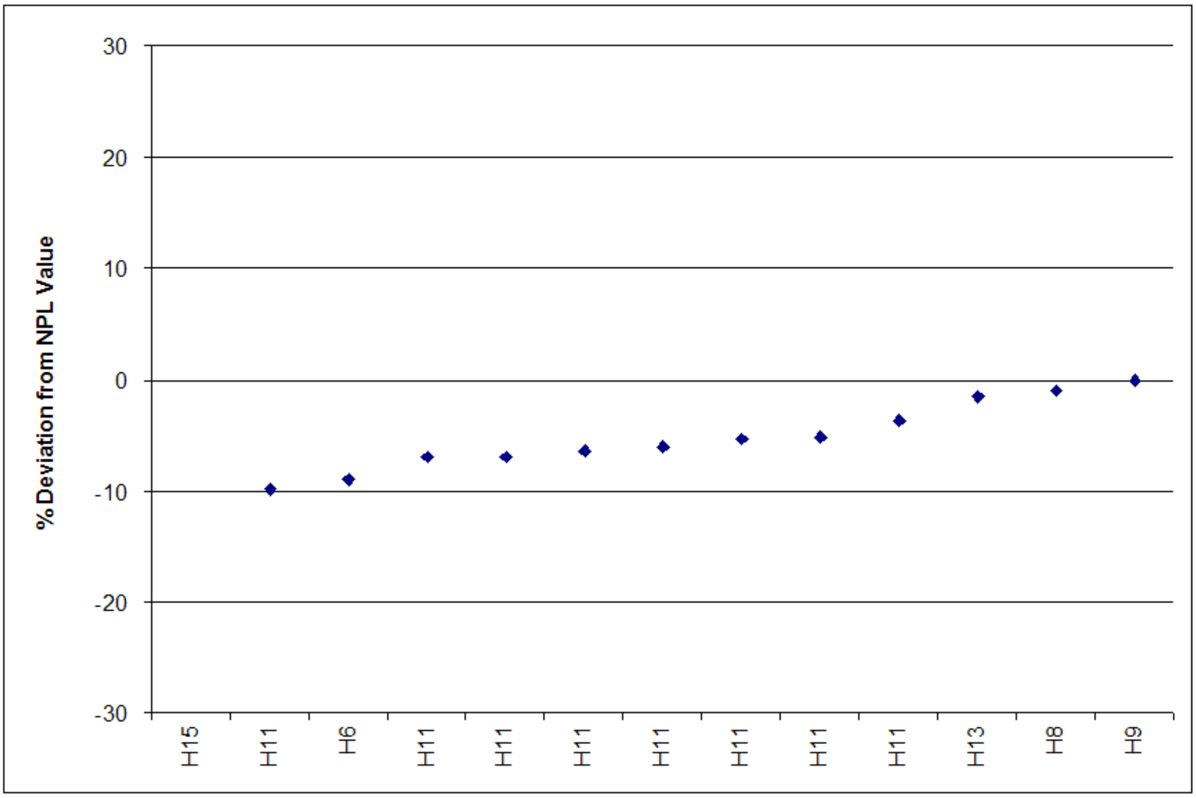


*NPL value derived using masses supplied by participant

GRAPH 9 (Capintec CRC 15R 'Preferred' Values against NPL Value)

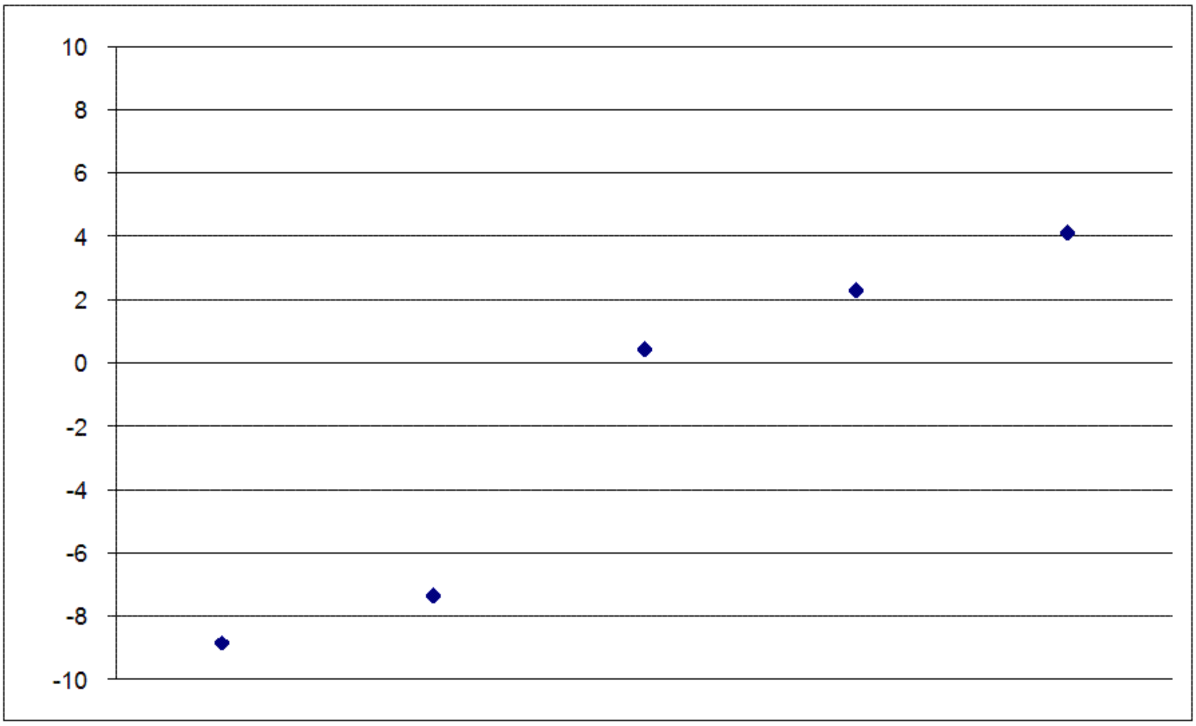


GRAPH 10 (P6 vials measured on Capintec CRC 15R against NPL Value*)



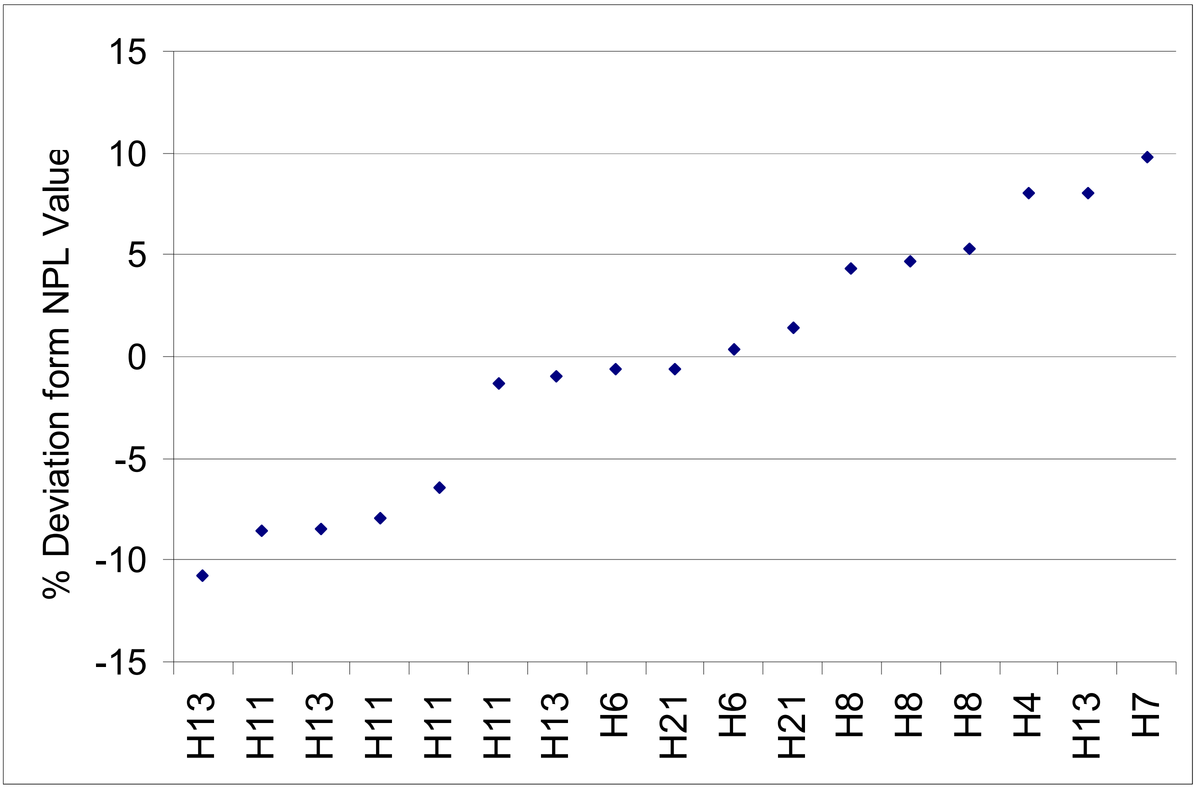
*NPL value derived using masses supplied by participants
('H15' value not shown on graph as it lies at –56% deviation from NPL Value)

GRAPH 11 (Atomlab values against NPL Value*)



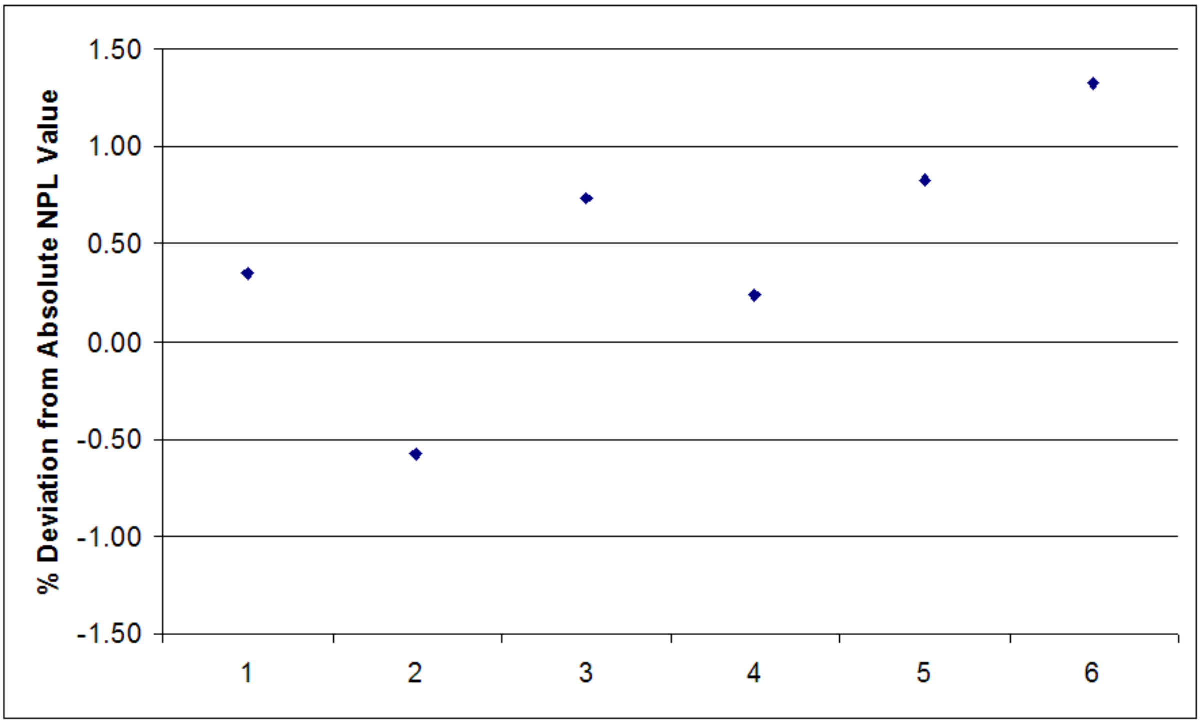
*NPL value derived using masses supplied by participants

GRAPH 12 (Fidelis, NPL CRC and Vinten Isocal IV against NPL Value*)



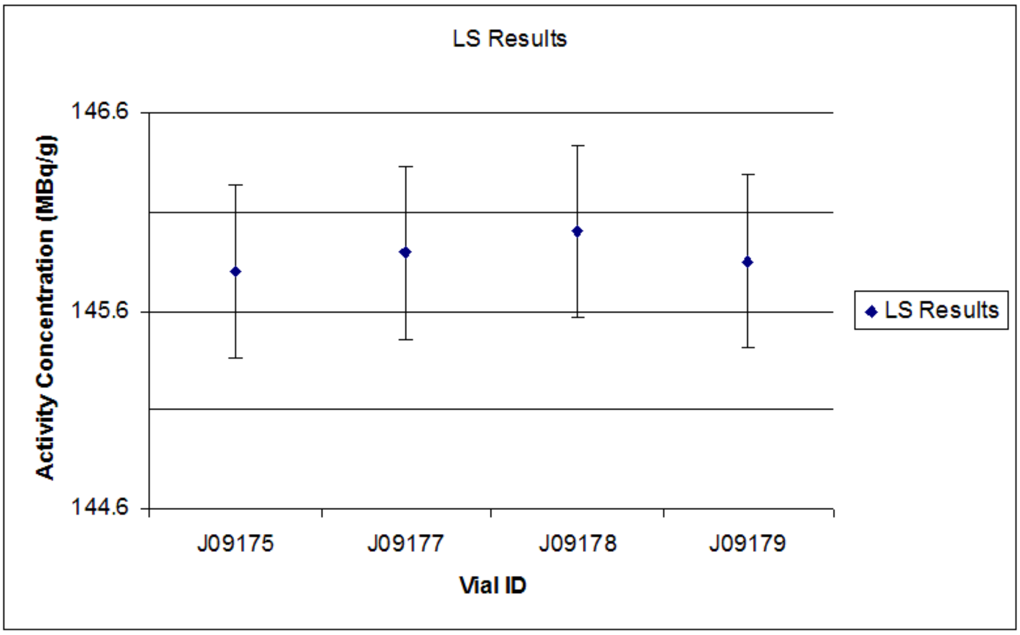
*NPL value derived using masses supplied by participants

GRAPH 13 (NPL vials measured on secondary system (Vinten 671), against certificated value)



APPENDIX I – NPL RESULTS & BIPM SUBMISSION

The results from the NPL measurements using liquid scintillation and 4πβ counting are shown in the graphs and table below. The scale on the Y-axis of the graphs refers to activity concentration, with the weighted mean of both LS and 4πβ systems in the centre. The maximum and minimum on the Y-axis is the uncertainty assigned to the final value. The table shows weighted mean results from each system and the final result.



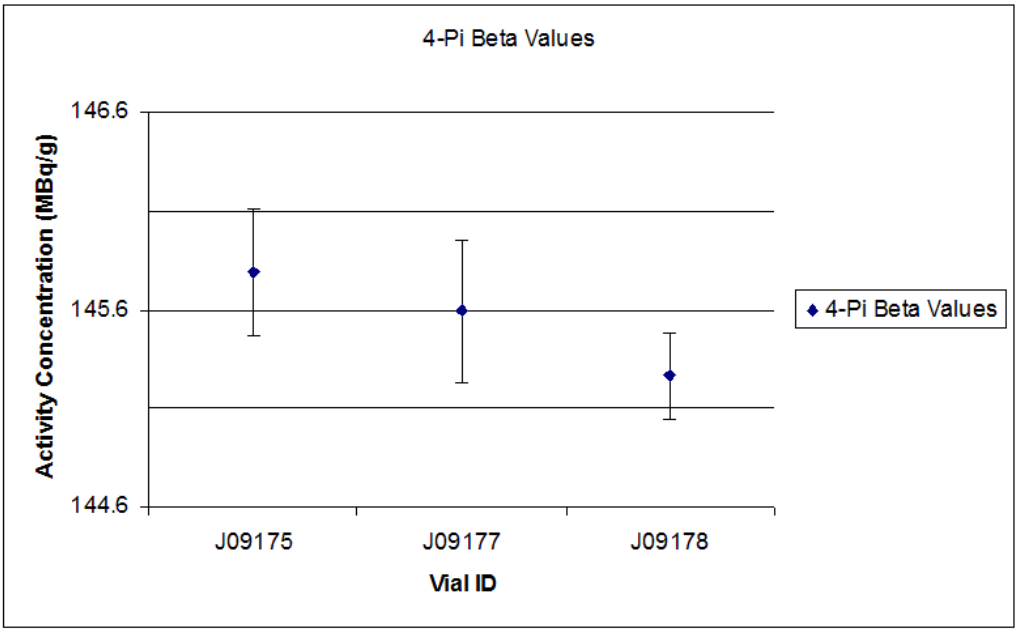


Table 6:

	Activity Conc. MBq/g	% Uncertainty
Liquid Scintillation Value	145.8996269	0.7
4-pi Beta Value	145.3952337	0.7
Arithmetic mean	145.6474303	0.7
Weighted Mean	145.6474303	0.7

BIPM SUBMISSION

The result from the TDCR measurements taken at NPL is shown below. This result was submitted to the international reference system at BIPM and we are awaiting the results from this submission. This result also includes our associated uncertainty (shown on the next page).

BUREAU INTERNATIONAL DES POIDS ET MESURES
International Reference System
for activity measurements of gamma-ray emitting nuclides (SIR)

Participating laboratory : NATIONAL PHYSICAL LABORATORY

Radionuclide (main contribution) ^{90}Y $T_{1/2}$: 2.6684(*13*) days

Chemical composition of the solution :

Solvent : nitric acid and its concentration : 0.1 mol per dm^3 of solution

Carrier : $Y(NO_3)_3$ and its concentration : 13 mg g^{-1}

Density of the solution: = 1.046 g ml^{-1}

Ampoule number : A09843 Mass of solution (corrected for buoyancy) : 3.60289 g

Activity per gram of solution (main radionuclide) : 146.08 MBq g^{-1}

Reference date: 2009 year 10 month 05 day 12:00 h UTC*

Measurement date : 6 October 2009 – 1 November 2009

Uncertainties (in the form of standard uncertainties). **Please join also a detailed uncertainty budget :**

Category A (evaluated applying statistical methods) : 0.1461 MBq g^{-1}

Number of degrees of freedom : 7

Category B (evaluated by other means) : 0.3720 MBq g^{-1}

Method(s) of measurement :
Triple to Double Coincidence Ratio Counting system (4P-LS-BP-00-00-TD)

For relative methods, please indicate the methods and the standards used to calibrate your experimental setup :_ _ _ _ _ _ _ _ _ _ _ _ and also the date of calibration :_ _ _ _ _ _ _ _ _ _ _ _ _ _ _

	Nuclide	Ratio of activity of impurity to activity of main radionuclide at reference date
Radionuclide impurities:	^{90}Sr	$(2 \pm 1) \times 10^{-6}$

Your sample has been sent in the frame of a pilot study NO or to generate an equivalence value YES.

Date : 10 December 2009

Name of person responsible : Andrew Fenwick

Name of person(s) who carried out the measurements : Lena Johansson, Eleanor Bakhshandeiar

*UTC = coordinated universal time

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*Uncertainty components**, in % of the activity concentration, due to

		Remarks	Type (A or B)
counting statistics	0.10	std deviation of the mean of 8 sources	A
weighing	0.05	std uncertainty for balances incl. repeatability	B
dead time	0.03	comparison of high and low level measurements	B
background	0.004	std deviation on backgrounds measured	B
pile-up	0.01	_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _	B
counting time	0.001	uncertainty on frequency oscillator	B
adsorption	<0.001	not tested but typically less than this value	B
impurities	~ 1×10^{-6}	calculated by repeat mmts of LS sources	B
tracer	n.a.	_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _	_ _ _ _ _ _ _ _
input parameters and statistical model	0.004	kB value varied from 0.009 to 0.015	B
quenching	n.a.	_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _	_ _ _ _ _ _ _ _
interpolation from calibration curve	n.a.	_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _	_ _ _ _ _ _ _ _
decay-scheme parameters	n.a.	_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _	_ _ _ _ _ _ _ _
half life ($T_{1/2}$ = 2.6684 d; u = 0.0013 d)	0.17	data decayed back 14 days	B
self absorption	n.a.	_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _	_ _ _ _ _ _ _ _
extrapolation of efficiency	n.a.	_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _	_ _ _ _ _ _ _ _
other effects (if relevant) (explain)	0.18	Dilution of original solution (determined gravimetrically) including evaporation effects	B
combined uncertainty (as quadratic sum of all uncertainty components)	**0.27**	_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _	_ _ _ _ _ _ _ _

* The uncertainty components are to be considered as approximations of the corresponding standard deviations (see also *Metrologia*, 1981, **17**, 73 and *Guide to expression of uncertainty in measurement*, ISO, corrected and reprinted 1995).

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APPENDIX II - VIAL INFORMATION

Vial ID	Corrected Mass	Rounded Activity	Uncertainty
9022171800 1	4.079475	594	±8 MBq (±1.4 %)
9022171801 1	4.162859	606	±10 MBq (±1.4 %)
9022171804 1	4.057954	591	±8 MBq (±1.4 %)
9022171805 1	4.108304	598	±8 MBq (±1.4 %)
9022171834 1	4.239235	617	±10 MBq (±1.4 %)
9022171835 1	4.123920	600	±8 MBq (±1.4 %)
9022171836 1	4.295191	625	±10 MBq (±1.4 %)
9022171837 1	4.399295	641	±10 MBq (±1.4 %)
9022171838 1	4.164861	606	±10 MBq (±1.4 %)
9022171839 1	4.280777	623	±10 MBq (±1.4 %)
9022171840 1	4.372969	637	±10 MBq (±1.4 %)
9022171841 1	4.401197	641	±10 MBq (±1.4 %)
9022171842 1	4.170266	607	±10 MBq (±1.4 %)
9022171843 1	4.085982	595	±8 MBq (±1.4 %)
9022171844 1	4.071768	593	±8 MBq (±1.4 %)
9022171845 1	4.131027	601	±8 MBq (±1.4 %)
9022171853 1	4.053950	590	±8 MBq (±1.4 %)
9022171854 1	4.477573	652	±10 MBq (±1.4 %)
9022171903 1	4.366963	636	±10 MBq (±1.4 %)
9022171904 1	4.103800	598	±8 MBq (±1.4 %)
9022171905 1	4.402398	641	±10 MBq (±1.4 %)
9022171906 1	4.076573	594	±8 MBq (±1.4 %)
9022171907 1	4.109706	598	±8 MBq (±1.4 %)
9022172368 1	4.240236	617	±10 MBq (±1.4 %)
9022172371 1	4.448444	648	±10 MBq (±1.4 %)
9022172389 1	4.207103	613	±10 MBq (±1.4 %)
9022172403 1	4.121918	600	±8 MBq (±1.4 %)
9022171928 1	4.331327	631	±10 MBq (±1.4 %)
9022171928 2	4.264060	621	±10 MBq (±1.4 %)
9022171928 3	4.255151	620	±10 MBq (±1.4 %)
9022171928 4	4.085782	595	±8 MBq (±1.4 %)
9022171928 5	4.233730	616	±10 MBq (±1.4 %)
9022171928 6	4.110006	598	±8 MBq (±1.4 %)

APPENDIX III – HIGH PURITY GERMANIUM DETECTOR "MAGGIE"

"MAGGIE" is a calibrated detector with a high purity germanium n-type crystal with a relative efficiency of 11.1% at 1332 keV. It has a beryllium end cap to allow measurements at low energies. It is calibrated for aqueous solution, the geometry being 1 ml in a 2 ml ampoule. Calibration is achieved via ampoules containing single nuclide solutions which either:

a) Have been directly measured on the NPL ionization chambers.

b) Contain solutions standardized by absolute techniques at NPL. In this way the calibration is linked as closely to NPL primary standards as practicable.

"Maggie" was used to determine the gamma emitting impurity levels in five of the six-vial subset sent to NPL. No contaminants were detected.

APPENDIX IV – PARTICIPANT DETAILS

CONTACT NAME	COMPANY NAME	ADDRESS
Chris Nottage	Colchester Hospital University Foundation NHS Trust	Nuclear Medicine, Essex County Hospital, Lexden Road, Colchester, CO3 3NB
Dr WH Thompson	Sandwell and West Birmingham Hospitals NHS Trust	Physics & Nuclear Medicine City Hospital Dudley Road Birmingham B18 7QH
Andrew Harris	Sheffield Teaching Hospitals NHS Foundation Trust	Department of Medical Physics 1 Floor Royal Hallamshire Hospital Glossop Road Sheffield S10 2SJ
Allison Craig	St Georges Healthcare NHS Trust	St Georges Hospital Blackshaw Road London SW17 0QT
Matthew Talboys	University Hospital of Wales	Cardiff and Vale NHS Trust University Hospital of Wales Heath Park Cardiff CF14 4XW

CONTACT NAME	COMPANY NAME	ADDRESS
Jacqueline Roberts	St James Hospital, Leeds Teaching Hospitals NHS Trust	Department of Nuclear Medicine Level 1 Bexley Wing St James University Hospital Beckett Street Leeds Teaching Hospitals NHS Trust LS9 7TF
Steve Jeans	Christie NHS Foundation Trust	Radioisotope Department Christie NHS Foundation Trust Wilmslow Road Withington Manchester M20 4BX
Rosemary Thompson	Royal Devon & Exeter NHS Foundation Trust	Radiotherapy Physics Barrack Road Exeter EX2 5DW
Emma O'Shaughnessy	Poole Hospital NHS Foundation Trust	Longfleet Road Poole BH15 2JB
Dr Christopher Marshall	Belfast Health and Social Care Trust	Nuclear Medicine Northern Ireland Cancer Centre Belfast City Hospital Lisburn Road BELFAST
Ian Pitkin	Bupa Cromwell Hospital	Department of Medical Physics Bupa Cromwell Hospital Cromwell Road London SW5 0TU
Alistair Tarbuck	New Cross Hospital	Medical Physics Department New Cross Hospital Deanesly centre Wolverhampton WV10 0QP
Shona Anderson	Mount Vernon Hospital	Medical Physics Department Nuclear Medicine Mount Vernon Hospital Northwood Middlesex HA6 2RN

CONTACT NAME	COMPANY NAME	ADDRESS
Ian Hufton	Royal Liverpool University Hospital	Nuclear Medicine Department Royal Liverpool University Hospital Prescott Street LIVERPOOL L7 8XP
Brenda Pratt	The Royal Marsden NHS Foundation Trust	Radiopharmacy Downs Road Sutton Surrey SM2 5PT
James Thom	Southampton General Hospital	Tremona Road Southampton SO16 6YD
Jennie Cooke	St. James's Hospital	James's Street Dublin 8 Ireland
Zdzislaw Zuchora	University Hospital Galway Department of Medical Physics and Bioengineering	Newcastle Road Galway Co. Galway Republic of Ireland
Andy Bradley	Manchester Royal Infirmary	Nuclear Medicine Centre Central Manchester University Hospitals Oxford Road Manchester M13 9WL
Iain Murray	Barts & The London NHS Trust St Barts Hospital	West Smithfield London EC1A 7BE
Paul Hinton	Royal Surrey County Hospital	Medical Physics – Nuclear Medicine Egerton Road Guildford Surrey GU2 7XX

CONTACT NAME	COMPANY NAME	ADDRESS
Kay Pomeroy	Churchill Hospital (Oxford Radcliffe Hospitals NHS Trust)	Radiation Physics and Protection Level 2, Cancer and Haematology Centre Churchill Hospital Old Road Headington Oxford OX3 7LJ
Jeff Jones	The Royal Free Hampstead NHS Trust	Department of Medical Physics Pond Street Hampstead London NW3 2QG
Chandra Solanki	Cambridge University Hospital	JW2411 Nuclear Medicine Lvl 3 - 1 Cambridge University Hospitals, NHS Foundtaion Trust Addenbrookes Hospital Hills Road Cambridge Cambridgeshire CB2 0QQ
Richard Gadd	University Hospital of North Staffordshire	Nuclear medicine North Staffs Royal Infirmary Princes Road Stoke on trent Staffs
Dimitri Alexiev	ANSTO	Ionising Radiation Physics Group ANSTO PMB 1 Menai NSW 2234 Australia
Richard Fernandez	Guy's & St Thomas' NHS Foundation Trust	Department of Nuclear Medicine Imaging 1 Borough Wing Ground Floor Guy's Hospital Great Maze Pond London SE1 9RT

APPENDIX V

Radionuclide Calibrator Details			
Manufacturer	Model / Type	Serial Number	Dial Setting
Reason for Preference			

Y-90 Activity Measurements				
Dial Setting	Date and Time Of Measurement (DD/MM/YYYY hh:mm:ss) UTC (GMT)	Background	Displayed Activity	Corrected Activity
Preset (Specify):	00/00/0000 00:00:00			
Custom (specify):	00/00/0000 00:00:00			
Which setting is your preferred result obtained on:				

Uncertainty Measurements		
Random (Type A) % (k=1)	Non-random (Type B) % (k=1)	Overall % (k=1)
Notes / Origin of uncertainties		