Syringe Calibration Factors and Volume Correction Factors for the NPL Secondary Standard Radionuclide Calibrator.

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ABSTRACT

The activity assay of a radiopharmaceutical administration to a patient is normally achieved via the use of a radionuclide calibrator. Because of the different geometries and elemental compositions between plastic syringes and glass vials, the calibration factors for syringes may well be significantly different from those for the glass containers. The magnitude of these differences depends on the energies of the emitted photons. For some radionuclides variations have been observed of 70 %, it is therefore important to recalibrate for syringes or use syringe calibration factors.

Calibration factors and volume correction factors have been derived for the NPL secondary standard radionuclide calibrator, for a variety of commonly used syringes and needles, for the most commonly used medical radionuclide.

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1 INTRODUCTION.

As part of the DTI's National Measurement System (NMS) program to support measurement accuracy for the medical user community, NPL have derived syringe calibration factors for use with the NPL secondary standard radionuclide calibrator in hospitals. Volume correction factors have also been derived to correct for activity results for samples whose mass differs from the appropriate nominal mass.

Radionuclide administration to patients whether for diagnostic, therapeutic or research purposes, has become routine in hospitals. The activities of these radionuclides must be accurately known, firstly due to the nature and possible health effects of ionising radiation and secondly, to obtain the most effective treatment or imaging possible from the procedure, whilst keeping the dose to a minimum (ALARP).

A radionuclide calibrator is usually the instrument of choice for these measurements. The calibrator is essentially a well-type ionisation chamber, which has long term stability, a relatively simple principle of operation and can measure activity to the desired level of accuracy. These are all desirable characteristics for the calibrators: however, they are sensitive to even small changes in geometry, container type, density and volume of samples (not an exhaustive list). If any such changes occur, there will be an effect on the calibration factors for these instruments and an incorrect activity may be obtained. Therefore, any changes in these factors will require new calibration factors to be derived and applied.

The NPL secondary standard radionuclide calibrator (Figure 1) is supplied with a set of calibration factors, which relate to specific container types, volumes within such containers and specific geometries. A special Perspex holder is also provided with the calibrator to ensure good reproducibility of source placement within the calibrator (Figure 2).

Medical radionuclides are most commonly supplied in standard glass vials, which have a set of calibration factors already derived for the radionuclide calibrators. Before any activity is administered to the patient, the glass vial is measured in the calibrator to ascertain its activity. An aliquot of the radionuclide is withdrawn from the glass vial into a plastic syringe, which will be used to administer the radionuclide to the patient. In recent years, it has become standard procedure both as a confirmatory measurement and as good quality assurance purposes, to re-measure the activity in the syringe before administration to the patient. The activity, assumed to be given to the patient, relies on the final syringe measurement. Frequently, the calibration factors used for the syringe measurements are those derived for the glass vial and the activity obtained by using these calibration factors may differ significantly from the true activity of the radionuclide in question. The magnitude of the difference will depend upon the properties of the radionuclide being measured (energy, emission probabilities). These differences can be illustrated by looking at responses for ^{125}I and ^{131}I in glass vials and syringes. ^{125}I emits low energy photons (~30 keV) and any changes introduced to the measurement regime will have a significant effect on the activity assay. This can clearly be seen in Figure 3: the indicated syringe activity is ~ 70 % higher than the true activity when the glass vial calibration figure is used for the syringe measurement. ^{131}I emits several high energy photons (~364 keV) and changes to the measurement regime will have a much smaller effect on the activity assay (Figure 4). The ionisation chamber response will be much less sensitive to changes in container, volume and position within the chamber etc.

The purpose of this report is to identify any significant differences in measurement results from the radionuclide calibrators when using a syringe and to summarise these findings.

Calibration factors and volume correction factors for several syringe types have been experimentally derived for the NPL secondary standard radionuclide calibrator.

2 NPL SECONDARY STANDARD IONISATION CHAMBERS AND RADIONUCLIDE CALIBRATORS.

The ionisation chambers maintained by NPL have been previously calibrated for a series of radionuclides by comparing the results from the assay of radioactive sources in the ion chambers, with the results obtained by primary counting systems (absolute counting methods). Absolute standardisation is time consuming, labour intensive, requires a high level of operator expertise and is hence inappropriate for routine assay purposes. By calibrating ionisation chambers directly against primary standards, the chambers become secondary standards. The stability of these chambers is checked regularly by measurement of a reference source with a very long lived radionuclide (^{226}Ra in equilibrium with its daughters) and records of the response are kept to prove stability of the systems. The radium check source has been measured for over 35 years and no change in response has been observed within the limitations of the current measurement system.

The NPL produces a commercially available secondary standard radionuclide calibrator which is currently known as the NPL-CRC (it has previously been known as the 671/271 and the ISCOAL IV), presently manufactured by Southern Scientific Ltd (Worthing, UK). The NPL calibrator incorporates a pressurised well-type re-entrant ionisation chamber, has a low geometrical dependence, excellent linearity and there is a high consistency of performance between chambers. The NPL calibrator has well known and controlled dimensional tolerances, which allows reproducibility of calibrator factors between chambers and traceability to national standards for all calibrated nuclides. The magnitude of any calibration factor is a function of the physical characteristics of a particular ionisation chamber (wall thickness, chamber wall materials, gas filling, gas pressure, counting volume) as well as the physical nature of the radiation source (volume, container, position of source). All the chambers must pass stringent conformity checks against the NPL reference chamber to ensure transferability of calibration factors.

3 HOSPITAL RADIONUCLIDE CALIBRATORS.

There are several different radionuclide calibrators available commercially: the NPL-CRC, Capintec, Veenstra and PTW systems are those in most common use in the UK. Most hospitals have a range of different radionuclide calibrators and syringe measurements are made on some or all of these chambers.

In most nuclear medicine departments there is a general criteria that the activity administered to the patient should be within 10 % of the true value. However it should be noted that the activity assay is only a small part of the treatment regime and other sources of error may be introduced at different stages. It is therefore important that the activity assay uncertainties arising from the radionuclide calibrator measurements are reduced as much as possible so that they do not dominate the overall uncertainty budget for the treatment regime. By using calibration factors derived specifically for syringes, these uncertainties will be minimised.

4 PROBLEMS WITH DIRECT MEASUREMENTS OF SYRINGES.

Syringe measurements are becoming an important part of the treatment regime. The activity administered to the patient is commonly calculated on the basis of measurements of the syringe rather than on that of the glass vial, so it is important that this activity measurement is accurate.

NPL routinely organises radionuclide comparisons for UK hospitals [(1-9)]. It was during these exercises that problems with syringe measurements became apparent; this was especially evident with the comparisons of ^{111}In and ^{123}I (Figures 5 and 6). Both comparisons indicated that syringe measurements generally overestimate the activity. A review of the operating data retuned by the comparison participants showed that, although some had recognised this problem and derived new syringe-specific calibration factors, most used the same factor that they would use for glass vials. NPL than conducted some measurements on an ARC 120 calibrator comparing the indicated activities for a range of syringes (with varying volumes of solution) with those for a P6 vial. The results of these measurements are shown in (Figures 7,8) and serve to confirm the size of the problem. The syringe measurement results returned by the participants showed significant discrepancies between the reported value and the target value for all the calibrators. Some manufacturers recommend calibration factors for syringes, but the suggested corrections are sometimes underestimated so that significant errors (greater than 10 %) still exist even after these have been applied. The situation is made more complicated by there not being a 'standard' syringe and by the nuclear medicine departments rarely having control over the procurement of the syringes.

The differences between a glass vial and a syringe are fairly obvious: the container material, dimensions and shape as well as the source geometry within the radionuclide calibrator will be different. If the radionuclide calibrator is not re-calibrated so that these differences are taken into account, the activity obtained can vary significantly from the true activity. The magnitude of this difference is dependent upon the radionuclide, its energy and emission probabilities for both photons and beta particles.

5 IDENTIFICATION OF SYRINGES / NEEDLES.

It was necessary to identify the different types of syringes used in hospitals. A questionnaire (Appendix 1) was sent to a large number of hospitals, which asked for information on the types of syringes, needles (both length and gauge) routinely used, the range of volumes used, the radionuclides measured and whether the nuclear medicine departments had any control over the purchasing of the syringes. The response to the questionnaire was excellent, over 80 % of hospitals responded.

From the questionnaire it was possible to identify four main syringe manufacturers – Becton Dickinson (BD), Sherwood, Braun (both omnifix and inkjekt) and Terumo. The vast majority of hospitals (~85 %) used the Becton Dickinson syringes and over 95 % used the BD microlance needles. Due to time constraints it was decided that only the BD microlance needles would be investigated for this project. Two types of needles were used BD Microlance 3, 21 GA2 0.8mm x 50mm (green), and 23 x 1¼ 0.6 mm x 30 mm (blue). These are shown in Figure 9. Measurements were carried out initially to check whether the gauge size of the needles had any effect on assays; no significant effects were observed. The syringes sizes used were 1, 2, 3, 5, 6, 10, 12 ml: both luer lok and luer slip types were used. Figure 10 indicates the complexity of the problem, showing the range of syringes in common use.

6 SELECTION OF RADIONUCLIDES.

Initially 12 radionuclides were identified but this list was reduced due to time and measurement constraints as well as problems with procurement of the solutions. The radionuclide solutions were obtained from Nycomed Amersham plc. Obtaining the high activity solutions needed proved to be a problem for certain radionuclides. To achieve accurate calibration factors the radioactive solutions need to be pure or have small but accurately known levels of impurities. Corrections need to be made for any such impurities, especially if they are present in a significant amount.

The radionuclides that calibration factors have been obtained for are: ^{51}Cr, ^{67}Ga, ^{99m}Tc, ^{111}In, ^{123}I, ^{125}I, ^{131}I and ^{201}Tl. Measurements on ^{90}Y were carried out but problems with the carrier had a detrimental effect on the activity assay and no accurate calibration factors could be derived at present. The radionuclides that were not assayed in this project were: ^{89}Sr, ^{32}P, and ^{153}Sm. It may be possible to look at these radionuclides at a future date.

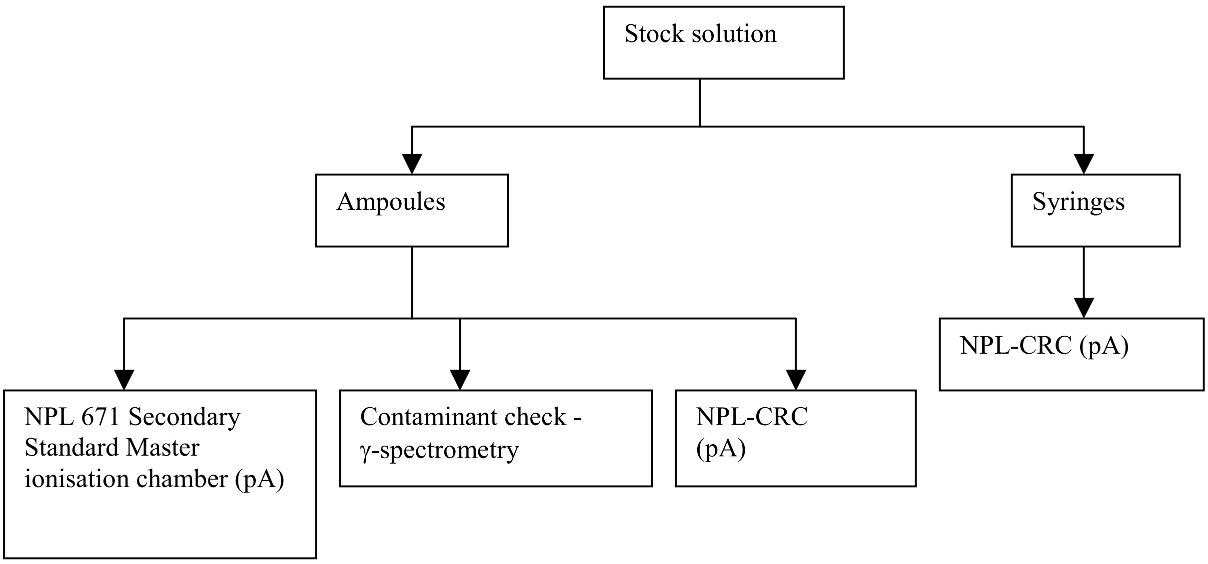
The details of the carriers are given in Appendix 2.

7 MEASUREMENTS.

For each radionuclide, a stock solution was dispensed into 2 ml and 5 ml ampoules and the syringes under investigation. The ampoules were measured in the master ionisation chamber of the NPL Secondary Standard radionuclide calibrator held at NPL, to accurately ascertain the activity concentration of the solution. These ampoules were also measured in a commercial NPL-CRC chamber and an ARC 120 Capintec chamber, both held at NPL. Gamma emitting impurities were assayed by high resolution gamma-spectrometry. The syringes were measured in the commercial chambers and their volume dependence was also investigated. For each syringe, the initial volume taken up depended on the syringe volume: 0.2 ml taken up into a 1 ml syringe; 0.5 ml into a 2 ml syringe; 1 ml into a 5 ml syringe; 2 ml into a 10 ml syringe. The volume dependence for each syringe was investigated by adding successive amounts of inactive carrier and re-measuring the syringe after each addition. After any uptake of either stock solution or carrier, air was sucked up into the syringe needle to ensure that all the solution was in the syringe cylinder. Ideally the needle would be changed between each measurement but, due to safety implications, this was not possible. In each case the measurements were carried out with the needle sheath in place. The volume of each carrier addition was approximately the same as the initial volume of active solution. The carriers were made up to be as near to the original solution as possible. The only problem encountered with the carrier was with ^{90}Y: the carrier became very viscous at low volumes and this had a significant effect on the results, which we were not able to correct for. Both the ampoules and syringes were weighed accurately both before and after dispensing, as was the solution container bottle. This gave a double check on the amounts of solution both in the ampoules and syringes.

Initially special holders for syringes were going to be designed to ensure that the syringe positioning within the chamber was reproducible. However, having several holders available and having to choose the right one for each syringe would prove to be impractical. Measurements with the current holder were made to see if the syringe position made a significant difference. Syringes of the same size were measured in the chamber several times, the syringe being taken out and than placed back in the holder randomly. There was no significant difference to the activity measurement if the tip of the syringe was always placed in the bottom trough (where the P6 vial is normally placed), in the NPL-CRC.

The figure below illustrates the measurement regime:



8 DERIVATION OF CALIBRATION FACTORS.

Calibration factors for the different types of syringes were derived from existing calibration figures for the 2 ml and 5 ml BS ampoules by direct comparison with the chamber responses for the different containers.

$$CF_{SYR}\ (\text{pA/MBq}) = CF_{AMP}\ (\text{pA/MBq}) \times \frac{R_{SYR}\ (\text{pA/g}) \times VC_{SYR}}{R_{AMP}\ (\text{pA/g}) \times VC_{AMP}}$$

where:

CF_{SYR} = Calibration figure for syringe
CF_{AMP} = Calibration figure for ampoule
R_{SYR} = Response per unit mass for syringe ampoule
R_{AMP} = Response per unit mass for syringe ampoule
VC_{SYR} = Volume correction factor for syringe
VC_{AMP} = Volume correction factor for syringe

Calibration factors are only valid for a particular volume of solution and corrections need to be made if the volume of the sample being measured on the radionuclide calibrator is different from the nominal value.

9 DERIVATION OF VOLUME CORRECTION FACTORS.

The calibration factors that have been determined are for specific chambers and containers. They have been adjusted to yield the response expected for a nominal volume of solution. If the volume within the container is varied, the self-absorption of the emitted radiation by the sample changes as will the geometry with respect to the chamber and this will yield a change in the current response from the chamber. The corrections that are needed are quantified by volume correction factors and these are radionuclide, container and geometry specific. The nominal values for each syringe are shown in Table 1.

Table 1. Nominal masses for different syringe sizes.

Syringe Size (ml)	***Nominal mass (g)***
1	0.1
2	0.5
3	0.5
5	1
6	1
10	2
12	2

The volume correction factors were determined by adding successive amounts of carrier and measuring the syringe in the ionisation chamber at each stage.

The measured current response (I_m) from the ionisation chamber was recorded for each volume, after making corrections for background and radioactive decay. If a graph is plotted of measured current (I_m) against mass of solution, it is then possible to determine the current at the nominal mass (I_o).

For solution volumes which are not equal to the nominal value, the measured current must be multiplied by the appropiate volume correction factor, in order for the Calibration Figure to be valid. Note that the "measured current" refers to the background corrected current. The volume corrected (I_0) current is obtained using the following equation :

$$I_0 = I_m \left[1 + a_1(m - m_{nom}) + a_2(m - m_{nom})^2\right]$$

where :

I_0	is the volume corrected current (pA)
I_m	is the measured current (corrected for background) (pA)
m	is the mass of solution (g)
m_{nom}	is the nominal mass (g) from appropriate Table.

a_1 and a_2 are the volume correction coefficients from appropriate Table.

The appropriate Calibration Figure (CF) may then be applied to this corrected current I_0 in the normal manner to yield the activity A of the sample, viz. $A = I_0 / CF$.

10 RESULTS.

Syringe calibration factors have been calculated for a variety of radionuclides which emit photons with energies ranging from 30 keV to 364 keV (decay scheme data for the radionuclides are given in Table 2). These factors are given in Tables 3 – 9. Generally, in the medical diagnostic field, radionuclides can be grouped as low, medium, and high photon energy emitters. The groupings are somewhat arbitrary but seek to reflect the penetrating power of the principal emissions. In effect, the transmission of photons of 'low energy' emitters is significantly altered by even small changes in the thickness and composition of the materials they are passing through (e.g. container and chamber walls). For 'high energy' emitters, the effect is minimal. A classification might be that low energy corresponds to less than 100 keV and high energy to greater than 300 keV. These classifications are arbitrary crude indicators of the degree of variation in response that might be expected due to variations in photon attenuation.

It was expected that the difference between the syringe calibration figure and that for the P6 glass vial, for a particular radionuclide, would be dependent on the energies of the photon emissions from the decay of that radionuclide: the lower the energies, the greaterr the difference. It was also expected that, for any individual radionuclide, the variation between calibration figures for the various syringes and volumes would also be photon energy dependent: the lower the energy, the larger the variation. This has been borne out in practice. If the radionuclides are ordered in terms of effective mean photon energy, there is a crude correspondence between the energy of the radionuclide and the difference between syringe factors to P6 vial factors, with the expected variations.

Initially, it was envisaged that calibration factors would be derived for each particular syringe type. However, as this project progressed it became apparent that this would not be possible, since the calibration factors within syringe manufacturers and within batches of syringes themselves vary significantly, in some cases (^{67}Ga and ^{99m}Tc) up to 30 %.

There are several factors that have been identified that may cause the sorts of variations seen. The degree of control over manufacturing tolerances that would be required to minimise activity measurement uncertainty e.g. wall thickness, length of barrel, etc, is not present because these types of variations do not affect the use of the syringe in everyday clinical use. The severity of this effect is dependent upon the radionuclide being measured: low energy radionuclides (^{125}I, ^{123}I) will be more severely affected than high energy radionuclides (^{131}I). Although these variations in syringe construction will have an effect they do not explain entirely the large differences that have been observed for the syringes.

The length of the needle also has an effect on the measurements. Two types of needle were used green (long) and blue (medium) (see section 5 – identification of syringes/needles). The length of the needle has an effect on the syringe height within the calibrator and the position within the chamber has an effect on the measurements. The effect due to position can be seen in the calibration factor results. The exact placement within the chamber is dependent upon the volume of the syringe. Again the severity of this effect is radionuclide dependant.

In general, the 1 ml syringes have a higher calibration figure than the other syringe volumes and the figures for P-6 glass vials. The 2 ml, 5 ml and 10 ml syringes have calibration factors closer to the P6 vial values. The luer slip type syringes tend to have lower calibration factors than the luer lok type. Visual comparisons of the luer lok/slip syringes to each other (for the same manufacturer) do not show any appreciable differences in the shape, size or structure of the syringe, except for the needle attachment and therefore this effect is difficult to explain.

The activity taken up into the syringe had a significant effect on the results. For the 1 ml syringes, only a small amount of stock solution was taken up into the syringe (0.2 ml), for the 10 ml syringe, 2 ml was taken up, in both cases this was diluted further. The 10 ml syringe calibration factors appear to be more stable, even when comparing manufacturer against manufacturer. This is expected since the response in the chamber is dependent upon the amount of activity, the higher the activity, the greater the ionisation current from the chamber. Even so, anomalies appear between the syringe manufacturers: the ‘luer slip green needle’ responses are significantly different to those for ‘luer slip blue needle’.

Checks were carried out to see whether the placement of the syringe within the chamber had an effect. The syringe was taken out and placed back into the holder several times with measurements taken at every stage, and no significant effect was seen even with low energy radionuclides.

The calibration factors for individual radionuclides are discussed below.

10.1 ^{67}Ga

^{67}Ga emits several gamma photons ranging from 93 to 300 keV, and hence it falls in the mid-energy range. Comparing the syringe calibration factors to the P6 vial calibration figure the values are similar. The percentage difference of the mean of the syringe calibration factors compared to the P6-vial factors is 0.8 %.

With the exception of the 1 ml BD syringes, all the calibration factors on all syringes with long needles are lower than for the medium needles by approximately 2-3 %. This confirms that the height and hence position of the syringe within the chamber has a significant effect on the measurements for this radionuclide. The 1 ml BD syringes show the opposite effect and the luer lok type syringe calibration factor is significantly reduced: this is most likely due to the outer casing on the 1 ml syringe which adapts the needle fixing from luer slip to luer lok. The outer casing will reduce the current produced by the chamber and this in turn will reduce the calibration figure.

Terumo have higher calibration factors for all their syringes suggesting that the container material is different to the other manufacturers.

For all syringes types the calibration factors show differences of only a few percent and therefore are relatively consistent with each other, and the P6 vial. The volume corrections for the 1 ml factors are higher than for the rest of the syringes. There is good consistency between the volume correction factors for the 3 ml, 5 ml, and 10 ml syringes. The uncertainty on the syringe calibration factors is 1.5 % (1σ).

10.2 ^{99m}Tc

Technetium-99m emits one gamma photon at 140.5 keV: there are other photon emissions but their emission probabilities are very low. The syringe factors are fairly consistent with the P6 vial factors, the P6 vial calibration figure is 1.227 and the syringe factors are in the range of 1.2 pA MBq^{-1}. The exceptions to this are discussed below.

The 1 ml syringe factors for all the syringe manufacturers are much higher than for the P6 vial ~20 %. All the 1 ml factors are consistent to each other and a trend is seen in that the green needle factors are generally lower than for the blue needle.

It is interesting to note that for all the manufacturers, the 3 ml luer lok calibration factors are 20 % higher than the luer slip values and they are also comparable to the 1 ml calibration factors. There are no visible differences in the syringes between the two fitting types and this effect was only seen with this radionuclide.

The 10 ml calibration factors are slightly lower than the P6 vial factors.

There is good consistency between the volume correction factors for all the syringes. The uncertainty for the syringe calibration factors is 1.1 % (1σ).

10.3 ^{111}In

^{111}In emits two photons at 171 and 245 keV. The P6 vial calibration figure is 4.088 pA MBq^{-1} and the syringe factors are also around 4 pA MBq^{-1}.

The 1 ml syringe factors are again higher than those for the rest of the syringes but the difference is not as great as for the other radionuclides. The factors decrease with increasing syringe size. There is one anomalous result for the 10 ml BD LS blue syringe. The factor works out as 3.8964 pA MBq^{-1}. This is considerably lower than expected. After re-examining all the raw data, no reason for this was evident. Nevertheless, it was decided to remove this value.

The syringes fitted with the green needles gave lower results than for the syringes fitted with blue needles except for Sherwood luer slip syringes where the opposite effect is seen. The difference is 1 %, which is outside the uncertainties. This is not consistent with the rest of the values.

There is good consistency between the volume correction factors for all the syringes. The uncertainty for the syringe calibration factors is 0.93 % (1σ).

10.4 ^{123}I

^{123}I emits a principal photon at 159 keV. It also has a significant number of other photons but with very low emission probabilities. However, there are also a significant number of X-ray emissions (30 keV) and because of this, any small changes in container thickness will generate large variations in responses. It is therefore especially important to use correct calibration factors for this radionuclide.

All of the calibration factors are approximately 7 % higher than the P6 vial result. The P6 vial calibration factor is 1.685 pA MBq^{-1} whilst the syringe calibration factors are in the range 1.8 pA MBq^{-1}. The calibration factors decrease with syringe volume as seen with the other radionuclides and the syringes with the green needles have lower values than the blue needles. Again there is one exception to this, the 1 ml BD luer slip syringes.

The 1 ml volume corrections are significantly higher than the rest of the syringes. The main reason for this will be due to the small amount taken up into the syringe combined with the low energy photons. Any change in volume will also change the effective position of the source with the syringe inside the chamber. The volume correction factors also decrease with increasing syringe volume. The uncertainty for the syringe calibration factors is 1.1 % (1σ).

It should be noted that all the measurements have been carried out without the copper insert.

10.5 ^{125}I

^{125}I only emits low energy photons (30 keV). As expected the calibration factors differed significantly when compared to the P6 vial. The calibration figure for the P6 vial is 0.3706 pA MBq^{-1}, whilst the syringe calibration factors are around 0.6 pA MBq^{-1}.

In contrast to other radionuclides, the 1 ml calibration factors are consistent with the rest of the syringes. A slight decrease in the calibration factors is seen with increasing syringe volume. The 10 ml luer lok syringe calibration factors are significantly lower than the 10 ml luer slip calibration factors, this effect is seen with all the manufacturers. The obvious explanation would be that there is a significant difference between the syringes but no differences can be observed visually. It should be noted that this effect is not observed with the other radionuclides.

The volume correction factors also decrease with increasing syringe volume. The uncertainty for the syringe calibration factors is 2.1 % (1σ).

10.6 ^{131}I

The principal photon of ^{131}I has a high energy (~364 keV) and therefore very small variations are expected between the calibration factors. The P6 vial calibration factor is 3.999 pA MBq^{-1} compared to the syringe factors which are in the range of 3.8108 - 4.1206 pA MBq^{-1}. Any changes in container, positioning, etc will have very little effect on the activity measurement.

An anomaly was observed for the 3 ml Braun inkjekt luer slip syringes. The calibration factor was 50 % lower than for the rest of the syringes. There is no apparent reason for this and by looking at the other radionuclides no similar variations are seen. If the syringes were of a different material or construction then a similar or greater variation with the other radionuclides, especially ones with low energies would be observed. Therefore it has been decided that these outliers would be removed from the data set and values for the luer lok should be used for the luer slip syringes. This is not an ideal solution but, since this is a high energy radionuclide and any changes have very small effects, it is reasonable to make this assumption.

The volume correction factors are small and there is little variation between the syringes. The uncertainty on the syringe calibration factors is 0.74 %.

10.7 ^{201}Tl

^{201}Tl is a mid range energy radionuclide with a photon at 167.4 keV, but it also emits a significant number of X-rays at ~ 80 keV and therefore it is expected that changes in container will have an effect on the measurements. The P6 vial calibration figure is 0.8557 pA MBq^{-1} and whilst the majority of syringe calibration factors are in the range of 0.8566-0.9047 there are some deviations to this.

The BD 1 ml calibration factors are consistent with the 2 ml, 5 ml and 10 ml syringes for all the manufacturers. The rest of the 1 ml syringes all showed calibration factors approximately 30 % lower than the P6 vial values. This is in contrast to the other radionuclides, which have shown the1 ml calibration factors to be higher than the other syringe values. The raw data and the source preparation procedures have been re-examined in depth but the is no obvious explanation for the magnitude of this anomaly. It is difficult therefore to justify these results and, in the absence of any other supporting measurements it would be reasonable to discard these results until such time as additional measurements can be made.

The thallium-201 solution was contaminated with thallium-200 and thallium-202. The overall contaminant contribution was 2.3 %. This contribution was taken into account in the uncertainty budget. The uncertainty on the syringe calibration factors is 2.6 %.

11 CONCLUSIONS.

The objective of this work was to provide calibration figures that would allow more accurate measurements to be made of the activities of a range of medically important radionuclides, when assayed in syringes. From both theoretical considerations and experimental evidence, it was clear that the use of calibration figures designed for glass vials would give increasingly inaccurate activity measurement results as the mean effective energy of the photon emissions from a radionuclide decreases. The results of this work have confirmed those assumptions and, in addition, have produced experimentally determined calibration factors for a range of syringes and radionuclides in common use in the nuclear medicine field.

The magnitude of the effort required to produce these figures was very large and it emphasises the difficulties faced by hospital physicists if they tackle this problem on an individual basis. On the other hand, the multiplicity of syringe types and volumes militates against collaborative efforts unless some action is taken to minimise the variety of syringes in current use.

In a number of cases during the correlation and analysis of the results of this work, it became apparent that some derived calibration figures should be regarded as anomalous. As and when the opportunities arise, these measurements will be repeated in order to fill the gaps. However, some of the anomalies cannot be explained by, for example, by measurement errors alone and the suspicion remains that production variations may have some part to play. It is important to remember that the syringe is normally regarded by the manufacturer only as a container and delivery device: its use as a calibration device does not enter into the setting of manufacturing tolerances. If accurate measurements are to be achieved with syringes on a routine basis, more consideration must be given by the user to the identification and supply of syringes that meet the more stringent tolerance requirements required.

The calibration figures produced during this work relate solely to the NPL secondary standard radionuclide calibrator. To this extent, the work was simplified by the knowledge that the variations between production models of this calibrator are very strictly controlled and that the calibration figures produced are equally applicable to all production models of the same type. The additional uncertainty that needs to be added arising from differences between the production model and the master chamber at NPL is insignificant but calculable. Other commercial calibrators are also in routine use in UK hospitals but the knowledge of their production tolerances is limited and generally empirical. Nevertheless, similar exercises need to be conducted to develop calibration figures for syringes when used in these other systems. This is no simple undertaking. It needs to be done but it may be beneficial to explore with the manufacturers the potential avenues for optimising the effort required.

In conclusion, this work has confirmed the concerns that led to its inception. It has produced more accurate calibration figures for syringe formats for the NPL secondary standard radionuclide calibrator. It has also indicated that additional work needs to be undertaken to cover those other radionuclide calibrators that are in common use in UK hospitals.

12 ACKNOWLEDGEMENTS.

The authors are indebted to the UK hospital physics community for their cooperation in identifying the wide range of syringe types and sizes in current use and prioritising the radionuclides investigated.

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Table 2 - Nuclear data for selected radionuclides[11, 12, 13]

Nuclide	Half-life	Principal Photon energy (keV)	Emission probability (E_γ) (0.1 limit)
^{67}Ga	3.261 days	93	0.42
		185	0.21
		209	0.02
		300	0.17
		393	0.05
^{99m}Tc	6.01 hours	141	0.890
^{111}In	2.8047 days	26	0.83
		171	0.90
		245	0.94
^{123}I	13.2 hours	30	0.87
		159.0	0.83
^{125}I	59.43 days	~ 30	1.39
		356	0.07
^{131}I	8.04 days	30	0.05
		80	0.03
		284	0.06
		365	0.82
		637	0.07
^{201}Tl	72.912 hours	~ 80	0.28
		135	0.03
		167	0.11

Table 3 – Calibration / Volume Correction factors for ^{67}Ga for all syringe types.

^{67}Ga	1 ml syringe			3 ml syringe			5 ml syringe			10 ml syringe		
Syringe type	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**
BD LS green	1.5935	0.0047	-0.006	1.5240	0.0013	0.0002	1.4795	0.0005	0.0001	1.4775	0.0002	0.0001
BD LS blue	1.5609	0.0774	-	1.5519	0.0007	-	1.5380	0.0002	-	1.5116	0.0001	-
BD LL green	1.5498	0.0172	-0.0081	1.5054	0.0016	0.0003	1.5119	0.0002	0.0001	1.4844	0.0001	0.0001
BD LL blue	1.5077	0.0055	-	1.5481	0.0007	-	1.5438	0.0004	-	1.5138	0.0001	-
Sherwood LS green	1.5233	0.0043	-	1.5259	0.001	-	1.4784	0.0003	-	1.5016	0.0001	-
Sherwood LS blue	1.5568	0.0668	-	1.5469	0.0006	-	1.5415	0.0003	-	1.5121	0.0001	-
Sherwood LL green	-	-	-	1.5264	0.0009	-	1.4847	0.0003	-	1.4849	0.0001	-
Sherwood LL blue	-	-	-	1.5459	0.0007	-	1.5497	0.0003	-	1.5176	0.0001	-
B Inkjekt LS green	1.5217	0.0042	-	1.5322	0.0005	-	1.4801	0.0002	-	1.5134	0.0001	-
B Inkjekt LS blue	1.5510	0.0053	-	1.5492	0.0006	-	1.5594	0.0003	-	1.5429	0.0001	-
B Inkjekt LL green	-	-	-	1.5280	0.001	-	1.5154	0.0004	-	1.5167	0.0001	-

^{67}Ga	1 ml syringe			3 ml syringe			5 ml syringe			10 ml syringe		
Syringe type	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)
B Inkjekt LL blue	-	-	-	1.5405	0.0012	-	1.5466	0.0003	-	1.5204	0.0001	-
B Omnifix LS green	-	-	-	1.5198	0.0007	-	-	-	-	1.5113	0.0001	-
B Omnifix LS blue	-	-	-	1.5557	0.0009	-	-	-	-	1.5414	0.0001	-
B Omnifix LL green	-	-	-	-	-	-	1.5225	0.0004	-	1.4947	0.0001	-
B Omnifix LL blue	-	-	-	-	-	-	1.5486	0.0002	-	1.5445	0.0001	-
Terumo LS green	1.5718	0.0046	-	1.5724	0.0002	-	-	-	-	1.5470	0.0001	-
Terumo LS blue	1.6093	0.0065	-	1.6075	0.001	-	-	-	-	1.5719	0.0001	-
Terumo LL green	-	-	-	-	-	-	-	-	-	1.5381	0.0001	-
Terumo LL blue	-	-	-	-	-	-	-	-	-	1.5592	0.0001	-

BD – Becton Dickinson
B Inkjekt – Braun inkjekt
B omnifix – Braun omnifix
LS - Luer slip
LL – Luer lok
Green- green microlance 3 needle
Blue- blue microlance 3 needle

Table 4 – Calibration factors for ^{99m}Tc for all syringe types.

^{99m}Tc	1 ml syringe			3 ml syringe			5 ml syringe			10 ml syringe		
Syringe type	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)
BD LS green	1.5466	0.0006	0.0001	1.2337	0.0012	0.0001	1.2166	0.0002	0.0001	1.1722	0.0004	0.0001
BD LS blue	1.5420	0.0003	-	1.2308	0.0005	-	1.2074	0.0002	-	1.1963	0.0002	-
BD LL green	1.5511	0.0018	0.0012	1.5463	0.0001	0.0001	1.2140	0.002	-	1.1783	0.0004	0.0001
BD LL blue	1.5774	0.0004	-	1.5734	0.0001	-	1.2357	0.0014	0.0001	1.1944	0.0001	-
Sherwood LS green	1.5529	0.0002	-	1.2247	0.0006	-	1.1824	0.0003	-	1.1853	0.0002	-
Sherwood LS blue	1.5771	0.0001	-	1.2449	0.0006	-	1.2089	0.0001	-	1.2050	0.0002	-
Sherwood LL green	-	-	-	1.5559	0.0001	-	1.2245	0.0004	-	1.1864	0.0002	-
Sherwood LL blue	-	-	-	1.5721	0.0001	-	1.2472	0.0004	-	1.2100	0.0001	-
B Inkjekt LS green	1.5640	0.0016	-	1.2192	0.0005	-	1.2400	0.0002	-	1.1821	0.0002	-
B Inkjekt LS blue	1.5830	0.0004	-	1.2328	0.0003	-	1.2136	0.0003	-	1.2495	0.0003	-
B Inkjekt LL green	-	-	-	1.5517	0.0001	-	1.2523	0.0007	-	1.1920	0.0002	-

^{99m}Tc	1 ml syringe			3 ml syringe			5 ml syringe			10 ml syringe		
Syringe type	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)
B Inkjekt LL blue	-	-	-	1.5800	0.0001	-	1.2512	0.0003	-	1.2149	0.0001	-
B Omnifix LS green	-	-	-	1.2217	0.0006	-	-	-	-	1.2214	0.0003	-
B Omnifix LS blue	-	-	-	1.2391	0.0005	-	-	-	-	1.2158	0.0002	-
B Omnifix LL green	-	-	-	-	-	-	1.2284	0.0004	-	1.1887	0.0002	-
B Omnifix LL blue	-	-	-	-	-	-	1.2529	0.0004	-	1.1742	0.0001	-
Terumo LS green	1.5620	0.0005	-	1.2122	0.0007	-	-	-	-	1.1991	0.0002	-
Terumo LS blue	1.5864	0.0004	-	1.2392	0.0005	-	-	-	-	1.2168	0.0002	-
Terumo LL green	-	-	-	-	-	-	-	-	-	1.1855	0.0001	-
Terumo LL blue	-	-	-	-	-	-	-	-	-	1.2600	0.0003	-

BD – Becton Dickinson
B Inkjekt – Braun inkjekt
B omnifix – Braun omnifix
LS - Luer slip
LL – Luer lok
Green- green microlance 3 needle
Blue- blue microlance 3 needle

Table 5 – Calibration factors for ^{111}In for all syringe types

^{111}In	1 ml syringe			3 ml syringe			5 ml syringe			10 ml syringe		
Syringe type	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)
BD LS green	4.2629	0.0039	-0.0007	4.1139	0.0002	-0.0001	4.0845	0.0001	-0.0001	4.0746	0.0001	0.0001
BD LS blue	4.2793	0.0035	-	4.2311	0.0003	-	4.1492	0.0001	-	-	-	-
BD LL green	4.2237	0.0101	0.0027	4.1034	0.0009	0.0001	4.0693	0.0002	0.0001	4.0841	0.0001	0.0001
BD LL blue	4.3380	0.0062	-	4.2117	0.0004	-	4.1501	0.0001	-	4.1338	0.0001	
Sherwood LS green	4.2588	0.0041	-	4.1699	0.0003	-	4.0479	0.0001	-	4.0558	0.0001	-
Sherwood LS blue	4.3000	0.0039	-	4.1274	0.0002	-	-	-	-	4.1079	0.0001	-
Sherwood LL green	-	-	-	4.0708	0.0005	-	4.0670	0.0001	-	4.0638	0.0001	-
Sherwood LL blue	-	-	-	4.1960	0.0005	-	4.1186	0.0001	-	4.1082	0.0001	-
B Inkjekt LS green	4.2941	0.0014	-	4.1646	0.0001	-	4.1094	0.0001	-	4.0556	0.0001	-
B Inkjekt LS blue	4.3480	0.0008	-	4.1872	0.0001	-	4.1833	0.0001	-	4.1360	0.0001	-
B Inkjekt LL green	-	-	-	4.1458	0.0001	-	4.0976	0.0001	-	4.0676	0.0001	-
B Inkjekt LL blue	-	-	-	4.2141	0.0001	-	4.1811	0.0001	-	4.1426	0.0001	-

^{111}In	1 ml syringe			3 ml syringe			5 ml syringe			10 ml syringe		
Syringe type	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**
B Omnifix LS green	-	-	-	4.0689	0.0004	-	-	-	-	4.0750	0.0001	-
B Omnifix LS blue	-	-	-	4.2199	0.0004	-	-	-	-	4.1175	0.0001	-
B Omnifix LL green	-	-	-	-	-	-	4.0655	0.0001	-	4.0742	0.0001	-
B Omnifix LL blue	-	-	-	-	-	-	4.1298	0.0001	-	4.1238	0.0001	-
Terumo LS green	4.1778	0.0014	-	4.1094	0.0001	-	-	-	-	4.0538	0.0001	-
Terumo LS blue	4.1703	0.0016	-	4.1851	0.0001	-	-	-	-	4.1216	0.0001	-
Terumo LL green		-	-	-	-	-	-	-	-	4.0748	0.0001	-
Terumo LL blue	-	-	-	-	-	-	-	-	-	4.1239	0.0001	-

BD – Becton Dickinson
B Inkjekt – Braun inkjekt
B omnifix – Braun omnifix
LS - Luer slip
LL – Luer lok
Green- green microlance 3 needle
Blue- blue microlance 3 needle

Table 6 - Calibration Factors for ^{123}I for all syringe types.

^{123}I	1 ml syringe			3 ml syringe			5 ml syringe			10 ml syringe		
Syringe type	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**
BD LS green	1.8384	0.0161	0.0024	1.8132	0.0016	-0.0001	1.7393	0.0001	0.0005	1.7486	0.0003	0.0001
BD LS blue	1.7550	0.0162	-	1.8310	0.0009	-	1.7766	0.0002	-	1.7593	0.0001	-
BD LL green	1.7438	0.2009	0.159	1.8040	0.001	-0.0003	1.7378	0.0004	0.0001	1.7556	0.0002	0.0001
BD LL blue	1.8734	0.0158	-	1.8308	0.0012	-	1.7660	0.0003	-	1.7832	0.0001	-
Sherwood LS green	1.8482	0.0203	-	1.8130	0.0022	-	1.7773	0.0005	-	1.7435	0.0002	-
Sherwood LS blue	1.9077	0.0191	-	1.8541	0.0014	-	1.8031	0.0004	-	1.7712	0.0002	-
Sherwood LL green	-	-	-	1.8514	0.0024	-	1.7830	0.0004	-	1.7703	0.0001	-
Sherwood LL blue	-	-	-	1.8822	0.0022	-	1.8198	0.0004	-	1.7634	0.0001	-
B Inkjekt LS green	1.8312	0.0196	-	1.7760	0.0017	-	1.7514	0.0006	-	1.7176	0.0002	-
B Inkjekt LS blue	1.8643	0.0125	-	1.7902	0.0013	-	1.7839	0.0005	-	1.7655	0.0002	-
B Inkjekt LL green	-	-	-	1.7718	0.002	-	1.7468	0.0007	-	1.7295	0.0002	-
B Inkjekt LL blue	-	-	-	1.7938	0.0016	-	1.7747	0.0004	-	1.7659	0.0001	-

^{123}I	1 ml syringe			3 ml syringe			5 ml syringe			10 ml syringe		
Syringe type	**Calibration figure**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**
	(pA MBq^{-1})			**(pA MBq^{-1})**			**(pA MBq^{-1})**			**(pA MBq^{-1})**		
B Omnifix LS green	-	-	-	1.8342	0.0015	-	-	-	-	1.7383	0.0002	-
B Omnifix LS blue	-	-	-	1.8661	0.0017	-	-	-	-	1.7813	0.0002	-
B Omnifix LL green	-	-	-	-	-	-	1.8136	0.0007	-	1.7564	0.0002	-
B Omnifix LL blue	-	-	-	-	-	-	1.8307	0.0004	-	1.7879	0.0002	-
Terumo LS green	1.8401	0.019	-	1.8087	0.0002	-	-	-	-	1.7322	0.0001	-
Terumo LS blue	1.8557	0.0135	-	1.8414	0.0001	-	-	-	-	1.7669	0.0001	-
Terumo LL green	-	-	-	-	-	-	-	-	-	1.7394	0.0001	-
Terumo LL blue	-	-	-	-	-	-	-	-	-	1.7560	0.0001	-

BD – Becton Dickinson
B Inkjekt – Braun inkjekt
B omnifix – Braun omnifix
LS - Luer slip
LL – Luer lok
Green- green microlance 3 needle
Blue- blue microlance 3 needle

Table 7 – Calibration factors for ^{125}I for all syringe types.

^{125}I	1 ml syringe			3 ml syringe			5 ml syringe			10 ml syringe		
Syringe type	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)
BD LS green	0.6387	0.0103	0.0058	0.6022	0.0013	0.0003	0.5536	0.0011	0.0001	0.5476	0.0012	0.0001
BD LS blue	0.6370	-0.0555	-	0.6124	0.001	-	0.5814	0.0003	-	0.5569	0.0005	-
BD LL green	0.6138	0.0124	0.007	0.5379	0.0057	0.0013	0.5637	0.0006	0.0001	0.4035	0.505	0.0069
BD LL blue	0.6222	0.0026	-	0.5460	0.0019	-	0.5618	0.0003	-	0.4081	0.0001	-
Sherwood LS green	0.6231	0.0052	-	0.6679	0.0017	-	0.5511	0.0006	-	0.5377	0.0006	-
Sherwood LS blue	0.6348	0.0036	-	0.6732	0.0009	-	0.5659	0.0004	-	0.5419	0.0002	-
Sherwood LL green	-	-	-	0.5769	0.0028	-	0.5514	0.0004	-	0.3912	0.0039	-
Sherwood LL blue	-	-	-	0.5873	0.0012	-	0.5607	0.0003	-	0.3868	0.0001	-
B Inkjekt LS green	0.6358	0.0095	-	0.5992	0.0028	-	0.5934	0.002	-	0.5678	0.0006	-
B Inkjekt LS blue	0.6423	0.0067	-	0.6088	0.0022	-	0.5976	0.0019	-	0.5778	0.0005	-
B Inkjekt LL green	-	-	-	0.6014	0.0034	-	0.5946	0.0015	-	0.4321	0.0058	-
B Inkjekt LL blue	-	-	-	0.6106	0.002	-	0.5926	0.0009	-	0.5760	0.0031	-

^{125}I	1 ml syringe			3 ml syringe			5 ml syringe			10 ml syringe		
Syringe type	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**
B Omnifix LS green	-	-	-	0.6571	0.0008	-	-	-	-	0.5584	0.0005	-
B Omnifix LS blue	-	-	-	0.6659	0.0007	-	-	-	-	0.5575	0.0004	-
B Omnifix LL green	-	-	-	-	-	-	0.5645	0.0007	-	0.5408	0.0021	-
B Omnifix LL blue	-	-	-	-	-	-	0.5754	0.0005	-	0.5638	0.0014	-
Terumo LS green	0.6307	0.0065	-	0.6005	0.0008	-	-	-	-	0.5622	0.0006	-
Terumo LS blue	0.6380	0.0056	-	0.6121	0.0007	-	-	-	-	0.5743	0.0005	-
Terumo LL green	-	-	-	-	-	-	-	-	-	0.5958	0.0186	-
Terumo LL blue	-	-	-	-	-	-	-	-	-	0.5911	0.0143	-

BD – Becton Dickinson
B Inkjekt – Braun inkjekt
B omnifix – Braun omnifix
LS - Luer slip
LL – Luer lok
Green- green microlance 3 needle
Blue- blue microlance 3 needle

Table 8 – Calibration factors for ^{131}I for all syringe types.

^{131}I	1 ml syringe			3 ml syringe			5 ml syringe			10 ml syringe		
Syringe type	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)
BD LS green	3.9974	0.0011	0.0001	3.9483	0.0004	0.0001	3.9508	0.0001	0.0001	3.8108	0.0004	0.0001
BD LS blue	4.0504	0.0009	-	4.0012	0.0003	-	4.0254	0.0002	-	3.9545	0.0003	-
BD LL green	3.9369	0.0028	0.0011	3.8632	0.0014	0.0004	3.9103	0.0003	0.0001	3.8793	0.0001	0.0001
BD LL blue	4.0032	0.0009	-	4.0081	0.0007	-	3.9863	0.0002	-	3.9415	0.0001	-
Sherwood LS green	3.9860	0.0009	-	3.9478	0.0002	-	3.9536	0.0002	-	3.8410	0.0002	-
Sherwood LS blue	4.0384	0.001	-	4.0041	0.0002	-	4.0134	0.0001	-	3.9081	0.0001	-
Sherwood LL green	-	-	-	3.9854	0.0011	-	3.9169	0.0001	-	3.8987	0.0001	-
Sherwood LL blue	-	-	-	4.0253	0.0006	-	3.9870	0.0001	-	3.9305	0.0001	-
B Inkjekt LS green	3.9672	0.0006	-	-	-	-	3.9838	0.0002	-	3.8517	0.0002	-
B Inkjekt LS blue	4.0711	0.0004	-	-	-	-	4.1206	0.0003	-	4.0381	0.0003	-
B Inkjekt LL green	-	-	-	3.9987	0.0007	-	3.9124	0.0001	-	3.9022	0.0001	-
B Inkjekt LL blue	-	-	-	3.9968	0.0048	-	-	-	-	3.9777	0.0001	-

^{131}I	1 ml syringe			3 ml syringe			5 ml syringe			10 ml syringe		
Syringe type	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)
B Omnifix LS green	-	-	-	3.9380	0.0002	-	-	-	-	3.8440	0.0002	-
B Omnifix LS blue	-	-	-	4.0334	0.0002	-	-	-	-	3.9339	0.0001	-
B Omnifix LL green	-	-	-	-	-	-	3.9152	0.0002	-	3.8790	0.0001	-
B Omnifix LL blue	-	-	-	-	-	-	3.9800	0.0001	-	3.9663	0.0001	-
Terumo LS green	3.9702	0.0012	-	3.7564	0.0003	-	-	-	-	3.9128	0.0001	-
Terumo LS blue	4.0275	0.0007	-	4.0006	0.0003	-	-	-	-	3.9702	0.005	-
Terumo LL green	-	-	-	-	-	-	-	-	-	3.9396	0.0001	-
Terumo LL blue	-	-	-	-	-	-	-	-	-	3.9756	0.0001	-

BD – Becton Dickinson
B Inkjekt – Braun inkjekt
B omnifix – Braun omnifix
LS - Luer slip
LL – Luer lok
Green- green microlance 3 needle
Blue- blue microlance 3 needle

Table 9 – Calibration factors for ^{201}Tl for all syringe types.

^{201}Tl	1 ml syringe			3 ml syringe			5 ml syringe			10 ml syringe		
Syringe type	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)
BD LS green	0.8868	0.0091	0.0033	0.8795	0.0012	0.0002	0.8564	0.0002	0.0001	0.8566	0.0002	0.0001
BD LS blue	0.9047	0.0045	-	0.8946	0.0008	-	0.8694	0.0001	-	0.8716	0.0001	-
BD LL green	0.8806	0.0088	0.0012	0.8760	0.0016	0.0002	0.8575	0.0003	0.0001	0.8615	0.0002	0.0001
BD LL blue	0.9037	0.0056	-	0.8871	0.0004	-	0.8742	0.0002	-	0.8734	0.0001	-
Sherwood LS green	-	-	-	0.8862	0.0028	-	0.8683	0.0004	-	0.8432	0.0001	-
Sherwood LS blue	-	-	-	0.8971	0.0011	-	0.8804	0.0004	-	0.8770	0.0001	-
Sherwood LL green	-	-	-	0.8888	0.0011	-	0.8573	0.0005	-	0.8625	0.0002	-
Sherwood LL blue	-	-	-	0.8905	0.0006	-	0.9004	0.0004	-	0.8828	0.0001	-
B Inkjekt LS green	-	-	-	0.8824	0.0008	-	0.8764	0.0006	-	0.8675	0.0002	-
B Inkjekt LS blue	-	-	-	0.9036	0.0019	-	0.8961	0.0004	-	0.8862	0.0002	-
B Inkjekt LL green	-	-	-	0.8867	0.0011	-	0.8731	0.0005	-	0.8742	0.0002	-

^{201}Tl	1 ml syringe			3 ml syringe			5 ml syringe			10 ml syringe		
Syringe type	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**
B Inkjekt LL blue	-	-	-	0.8883	0.0006	-	0.9027	0.0006	-	0.8914	0.0002	-
B Omnifix LS green	-	-	-	0.9000	0.0031	-	-	-	-	0.8515	0.0001	-
B Omnifix LS blue	-	-	-	0.8923	0.0006	-	-	-	-	0.8935	0.0002	-
B Omnifix LL green	-	-	-	-	-	-	0.8859	0.0008	-	0.8504	0.0002	-
B Omnifix LL blue	-	-	-	-	-	-	0.8987	0.0006	-	0.8704	0.0002	-
Terumo LS green	-	-	-	0.8879	0.0023	-	-	-	-	0.8640	0.0002	-
Terumo LS blue	-	-	-	0.9054	0.0030	-	-	-	-	0.8844	0.0002	-
Terumo LL green	-	-	-	-	-	-	-	-	-	0.8756	0.0002	-
Terumo LL blue	-	-	-	-	-	-	-	-	-	0.8826	0.0001	-

BD – Becton Dickinson
B Inkjekt – Braun inkjekt
B omnifix – Braun omnifix
LS - Luer slip
LL – Luer lok
Green- green microlance 3 needle
Blue- blue microlance 3 needle

Table 10 - Calibration Figures and Volume Correction factors for Solution sources.
NPL Secondary Standard Ionisation Chamber (NPL-CRC)
Becton Dickinson Luer slip syringes - Green needle

Container (nominal volume)	**1 ml Luer lok BD syringe (1 ml)**			**3 ml Luer lok BD syringe (2 ml)**			**5 ml Luer lok BD syringe (5 ml)**			**10 ml Luer lok BD syringe (10 ml)**		
Nuclide	**Calibration figure ($pA\ MBq^{-1}$)**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure ($pA\ MBq^{-1}$)**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure ($pA\ MBq^{-1}$)**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure ($pA\ MBq^{-1}$)**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**
^{67}Ga	1.5935	0.0047	-0.006	1.5240	0.0013	0.0002	1.4795	0.0005	0.0001	1.4775	0.0002	0.0001
^{99m}Tc	1.5466	0.0006	0.0001	1.2337	0.0015	0.0001	1.2166	0.0002	0.0001	1.1722	0.0004	0.0001
^{111}In	4.2629	0.0039	-0.0007	4.1139	0.0002	-0.0001	4.0845	0.0001	-0.0001	4.0746	0.0001	0.0001
^{123}I	1.8384	0.0161	0.0024	1.8132	0.0016	-0.0001	1.7393	0.0001	0.0005	1.7486	0.0003	0.0001
^{125}I	0.6387	0.0103	0.0058	0.6022	0.0013	0.0003	0.5536	0.0011	0.0001	0.5476	0.0012	0.0001
^{131}I	3.9974	0.0011	0.0001	3.9483	0.0004	0.0001	3.9508	0.0001	0.0001	3.8108	0.0004	0.0001
^{201}Tl	0.8868	0.0091	0.0033	0.8795	0.0012	0.0002	0.8564	0.0002	0.0001	0.8566	0.0002	0.0001

Table 11 - Calibration Figures and Volume Correction factors for Solution sources.
NPL Secondary Standard Ionisation Chamber (NPL-CRC)
Becton Dickinson Luer slip syringes - Blue needle

Container (nominal volume)	**1 ml Luer lok BD syringe (1 ml)**			**3 ml Luer lok BD syringe (2 ml)**			**5 ml Luer lok BD syringe (5 ml)**			**10 ml Luer lok BD syringe (10 ml)**		
Nuclide	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**
^{67}Ga	1.5609	0.0774	-	1.5519	0.0007	-	1.5380	0.0002	-	1.5116	0.0001	-
^{99m}Tc	1.5420	0.0003	-	1.2308	0.0005	-	1.2074	0.0002	-	1.1963	0.0002	-
^{111}In	4.2793	0.0035	-	4.2311	0.0003	-	4.1492	0.0001	-	-	-	-
^{123}I	1.7550	0.0162	-	1.8310	0.0009	-	1.7766	0.0002	-	1.7593	0.0001	-
^{125}I	0.6370	-0.0555	-	0.6124	0.001	-	0.5814	0.0003	-	0.5569	0.0005	-
^{131}I	4.0504	0.0009	-	4.0012	0.0003	-	4.0254	0.0002	-	3.9545	0.0003	-
^{201}Tl	0.9047	0.0045	-	0.8946	0.0008	-	0.8694	0.0001	-	0.8716	0.0001	-

Table 12 - Calibration Figures and Volume Correction factors for Solution sources.
NPL Secondary Standard Ionisation Chamber (NPL-CRC)
Becton Dickinson Luer lok syringes - Green needle

Container (nominal volume)	1 ml Luer lok BD syringe (1 ml)			3 ml Luer lok BD syringe (2 ml)			5 ml Luer lok BD syringe (5 ml)			10 ml Luer lok BD syringe (10 ml)		
Nuclide	**Calibration figure ($pA\ MBq^{-1}$)**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure ($pA\ MBq^{-1}$)**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure ($pA\ MBq^{-1}$)**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure ($pA\ MBq^{-1}$)**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**
^{67}Ga	1.5498	0.0172	-0.0081	1.5054	0.0016	0.0003	1.5119	0.0002	0.0001	1.4844	0.0001	0.0001
^{99m}Tc	1.5511	0.0018	0.0012	1.5463	0.0001	0.0001	1.2140	0.002	-	1.1783	0.0004	0.0001
^{111}In	4.2237	0.0101	0.0027	4.1034	0.0009	0.0001	4.0693	0.0002	0.0001	4.0841	0.0001	0.0001
^{123}I	1.7438	0.2009	0.159	1.8040	0.001	-0.0003	1.7378	0.0004	0.0001	1.7556	0.0002	0.0001
^{125}I	0.6138	0.0124	0.007	0.5379	0.0057	0.0013	0.5637	0.0006	0.0001	0.4035	0.505	0.0069
^{131}I	3.9369	0.0028	0.0011	3.8632	0.0014	0.0004	3.9103	0.0003	0.0001	3.8793	0.0001	0.0001
^{201}Tl	0.8806	0.0088	0.0012	0.8760	0.0016	0.0002	0.8575	0.0003	0.0001	0.8615	0.0002	0.0001

Table 13 - Calibration Figures and Volume Correction factors for Solution sources.
NPL Secondary Standard Ionisation Chamber (NPL-CRC)
Becton Dickinson Luer lok syringes - Blue needle

Container (nominal volume)	1 ml Luer lok BD syringe (1 ml)			3 ml Luer lok BD syringe (2 ml)			5 ml Luer lok BD syringe (5 ml)			10 ml Luer lok BD syringe (10 ml)		
Nuclide	**Calibration figure ($pA\ MBq^{-1}$)**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure ($pA\ MBq^{-1}$)**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure ($pA\ MBq^{-1}$)**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure ($pA\ MBq^{-1}$)**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**
^{67}Ga	1.5077	0.0055	-	1.5481	0.0007	-	1.5438	0.0004	-	1.5138	0.0001	-
^{99m}Tc	1.5774	0.0004	-	1.5734	0.0001	-	1.2357	0.0014	0.0001	1.1944	0.0001	-
^{111}In	4.3380	0.0062	-	4.2117	0.0004	-	4.1501	0.0001	-	4.1338	0.0001	
^{123}I	1.8734	0.0158	-	1.8308	0.0012	-	1.7660	0.0003	-	1.7832	0.0001	-
^{125}I	0.6222	0.0026	-	0.5460	0.0019	-	0.5618	0.0003	-	0.4081	0.0001	-
^{131}I	4.0032	0.0009	-	4.0081	0.0007	-	3.9863	0.0002	-	3.9415	0.0001	-
^{201}Tl	0.9037	0.0056	-	0.8871	0.0004	-	0.8742	0.0002	-	0.8734	0.0001	-

Table 14 - Calibration Figures and Volume Correction factors for Solution sources.
NPL Secondary Standard Ionisation Chamber (NPL-CRC)
Sherwood Luer slip syringes - Green needle

Container (nominal volume)	**1 ml Luer lok BD syringe (1 ml)**			**3 ml Luer lok BD syringe (2 ml)**			**5 ml Luer lok BD syringe (5 ml)**			**10 ml Luer lok BD syringe (10 ml)**		
Nuclide	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**
^{67}**Ga**	1.5233	0.0043	-	1.5259	0.001	-	1.4784	0.0003	-	1.5016	0.0001	-
^{99m}**Tc**	1.5529	0.0002	-	1.2247	0.0006	-	1.1824	0.0003	-	1.1853	0.0002	-
^{111}**In**	4.2588	0.0041	-	4.1699	0.0003	-	4.0479	0.0001	-	4.0558	0.0001	-
^{123}**I**	1.8482	0.0203	-	1.8130	0.0022	-	1.7773	0.0005	-	1.7435	0.0002	-
^{125}**I**	0.6231	0.0052	-	0.6679	0.0017	-	0.5511	0.0006	-	0.5377	0.0006	-
^{131}**I**	3.9860	0.0009	-	3.9478	0.0002	-	3.9536	0.0002	-	3.8410	0.0002	-
^{201}**Tl**	-	-	-	0.8862	0.0028	-	0.8683	0.0004	-	0.8432	0.0001	-

Table 15 - Calibration Figures and Volume Correction factors for Solution sources.
NPL Secondary Standard Ionisation Chamber (NPL-CRC)
Sherwood Luer slip syringes - Blue needle

Container (nominal volume)	**1 ml Luer lok BD syringe (1 ml)**			**3 ml Luer lok BD syringe (2 ml)**			**5 ml Luer lok BD syringe (5 ml)**			**10 ml Luer lok BD syringe (10 ml)**		
Nuclide	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**
^{67}Ga	1.5568	0.0668	-	1.5469	0.0006	-	1.5415	0.0003	-	1.5121	0.0001	-
^{99m}Tc	1.5771	0.0001	-	1.2449	0.0006	-	1.2089	0.0001	-	1.2050	0.0002	-
^{111}In	4.3000	0.0039	-	4.1274	0.0002	-	-	-	-	4.1079	0.0001	-
^{123}I	1.9077	0.0191	-	1.8541	0.0014	-	1.8031	0.0004	-	1.7712	0.0002	-
^{125}I	0.6348	0.0036	-	0.6732	0.0009	-	0.5659	0.0004	-	0.5419	0.0002	-
^{131}I	4.0384	0.001	-	4.0041	0.0002	-	4.0134	0.0001	-	3.9081	0.0001	-
^{201}Tl	-	-	-	0.8971	0.0011	-	0.8804	0.0004	-	0.8770	0.0001	-

Table 16 - Calibration Figures and Volume Correction factors for Solution sources.
NPL Secondary Standard Ionisation Chamber (NPL-CRC)
Sherwood Luer lok syringes - Green needle

Container (nominal volume)	1 ml Luer lok BD syringe (1 ml)			3 ml Luer lok BD syringe (2 ml)			5 ml Luer lok BD syringe (5 ml)			10 ml Luer lok BD syringe (10 ml)		
Nuclide	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)
^{67}Ga	-	-	-	1.5264	0.0009	-	1.4847	0.0003	-	1.4849	0.0001	-
^{99m}Tc	-	-	-	1.5559	0.0001	-	1.2245	0.0004	-	1.1864	0.0002	-
^{111}In	-	-	-	4.0708	0.0005	-	4.0670	0.0001	-	4.0638	0.0001	-
^{123}I	-	-	-	1.8514	0.0024	-	1.7830	0.0004	-	1.7703	0.0001	-
^{125}I	-	-	-	0.5769	0.0028	-	0.5514	0.0004	-	0.3912	0.0039	-
^{131}I	-	-	-	3.9854	0.0011	-	3.9169	0.0001	-	3.8987	0.0001	-
^{201}Tl	-	-	-	0.8888	0.0011	-	0.8573	0.0005	-	0.8625	0.0002	-

Table 17 - Calibration Figures and Volume Correction factors for Solution sources.
NPL Secondary Standard Ionisation Chamber (NPL-CRC)
Sherwood Luer lok syringes - Blue needle

Container (nominal volume)	1 ml Luer lok BD syringe (1 ml)			3 ml Luer lok BD syringe (2 ml)			5 ml Luer lok BD syringe (5 ml)			10 ml Luer lok BD syringe (10 ml)		
Nuclide	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**
^{67}Ga	-	-	-	1.5459	0.0007	-	1.5497	0.0003	-	1.5176	0.0001	-
^{99m}Tc	-	-	-	1.5721	0.0001	-	1.2472	0.0004	-	1.2100	0.0001	-
^{111}In	-	-	-	4.1960	0.0005	-	4.1186	0.0001	-	4.1082	0.0001	-
^{123}I	-	-	-	1.8822	0.0022	-	1.8198	0.0004	-	1.7634	0.0001	-
^{125}I	-	-	-	0.5873	0.0012	-	0.5607	0.0003	-	0.3868	0.0001	-
^{131}I	-	-	-	4.0253	0.0006	-	3.9870	0.0001	-	3.9305	0.0001	-
^{201}Tl	-	-	-	0.8905	0.0006	-	0.9004	0.0004	-	0.8828	0.0001	-

Table 18 - Calibration Figures and Volume Correction factors for Solution sources.
NPL Secondary Standard Ionisation Chamber (NPL-CRC)
Braun inkjekt Luer slip syringes - Green needle

Container (nominal volume)	1 ml Luer lok BD syringe (1 ml)			3 ml Luer lok BD syringe (2 ml)			5 ml Luer lok BD syringe (5 ml)			10 ml Luer lok BD syringe (10 ml)		
Nuclide	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**
^{67}Ga	1.5217	0.0042	-	1.5322	0.0005	-	1.4801	0.0002	-	1.5134	0.0001	-
^{99m}Tc	1.5640	0.0016	-	1.2192	0.0005	-	1.2400	0.0002	-	1.1821	0.0002	-
^{111}In	4.2941	0.0014	-	4.1646	0.0001	-	4.1094	0.0001	-	4.0556	0.0001	-
^{123}I	1.8312	0.0196	-	1.7760	0.0017	-	1.7514	0.0006	-	1.7176	0.0002	-
^{125}I	0.6358	0.0095	-	0.5992	0.0028	-	0.5934	0.002	-	0.5678	0.0006	-
^{131}I	3.9672	0.0006	-	1.878	0.0004	-	3.9838	0.0002	-	3.8517	0.0002	-
^{201}Tl	-	-	-	0.8824	0.0008	-	0.8764	0.0006	-	0.8675	0.0002	-

Table 19 - Calibration Figures and Volume Correction factors for Solution sources.
NPL Secondary Standard Ionisation Chamber (NPL-CRC)
Braun inkjekt Luer slip syringes - Blue needle

Container (nominal volume)	1 ml Luer lok BD syringe (1 ml)			3 ml Luer lok BD syringe (2 ml)			5 ml Luer lok BD syringe (5 ml)			10 ml Luer lok BD syringe (10 ml)		
Nuclide	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)
^{67}Ga	1.5510	0.0053	-	1.5492	0.0006	-	1.5594	0.0003	-	1.5429	0.0001	-
^{99m}Tc	1.5830	0.0004	-	1.2328	0.0003	-	1.2136	0.0003	-	1.2495	0.0003	-
^{111}In	4.3480	0.0008	-	4.1872	0.0001	-	4.1833	0.0001	-	4.1360	0.0001	-
^{123}I	1.8643	0.0125	-	1.7902	0.0013	-	1.7839	0.0005	-	1.7655	0.0002	-
^{125}I	0.6423	0.0067	-	0.6088	0.0022	-	0.5976	0.0019	-	0.5778	0.0005	-
^{131}I	4.0711	0.0004	-	-	-	-	4.1206	0.0003	-	4.0381	0.0003	-
^{201}Tl	-	-	-	0.9036	0.0019	-	0.8961	0.0004	-	0.8862	0.0002	-

Table 20 - Calibration Figures and Volume Correction factors for Solution sources.
NPL Secondary Standard Ionisation Chamber (NPL-CRC)
Braun inkjekt Luer lok syringes - Green needle

Container (nominal volume)	1 ml Luer lok BD syringe (1 ml)			3 ml Luer lok BD syringe (2 ml)			5 ml Luer lok BD syringe (5 ml)			10 ml Luer lok BD syringe (10 ml)		
Nuclide	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**
^{67}Ga	-	-	-	1.5280	0.001	-	1.5154	0.0004	-	1.5167	0.0001	-
^{99m}Tc	-	-	-	1.5517	0.0001	-	1.2523	0.0007	-	1.1920	0.0002	-
^{111}In	-	-	-	4.1458	0.0001	-	4.0976	0.0001	-	4.0676	0.0001	-
^{123}I	-	-	-	1.7718	0.002	-	1.7468	0.0007	-	1.7295	0.0002	-
^{125}I	-	-	-	0.6014	0.0034	-	0.5946	0.0015	-	0.4321	0.0058	-
^{131}I	-	-	-	3.9987	0.0007	-	3.9124	0.0001	-	3.9022	0.0001	-
^{201}Tl	-	-	-	0.8867	0.0011	-	0.8731	0.0005	-	0.8742	0.0002	-

Table 21 - Calibration Figures and Volume Correction factors for Solution sources.
NPL Secondary Standard Ionisation Chamber (NPL-CRC)
Braun inkjekt Luer lok syringes - Blue needle

Container (nominal volume)	1 ml Luer lok BD syringe (1 ml)			3 ml Luer lok BD syringe (2 ml)			5 ml Luer lok BD syringe (5 ml)			10 ml Luer lok BD syringe (10 ml)		
Nuclide	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**
^{67}Ga	-	-	-	1.5405	0.0012	-	1.5466	0.0003	-	1.5204	0.0001	-
^{99m}Tc	-	-	-	1.5800	0.0001	-	1.2512	0.0003	-	1.2149	0.0001	-
^{111}In	-	-	-	4.2141	0.0001	-	4.1811	0.0001	-	4.1426	0.0001	-
^{123}I	-	-	-	1.7938	0.0016	-	1.7747	0.0004	-	1.7659	0.0001	-
^{125}I	-	-	-	0.6106	0.002	-	0.5926	0.0009	-	0.5760	0.0031	-
^{131}I	-	-	-	3.9968	0.0048	-	-	-	-	3.9777	0.0001	-
^{201}Tl	-	-	-	0.8883	0.0006	-	0.9027	0.0006	-	0.8914	0.0002	-

Table 22 - Calibration Figures and Volume Correction factors for Solution sources.
NPL Secondary Standard Ionisation Chamber (NPL-CRC)
Braun omnifix Luer slip syringes - Green needle

Container (nominal volume)	1 ml Luer lok BD syringe (1 ml)			3 ml Luer lok BD syringe (2 ml)			5 ml Luer lok BD syringe (5 ml)			10 ml Luer lok BD syringe (10 ml)		
Nuclide	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)
^{67}Ga	-	-	-	1.5198	0.0007	-	-	-	-	1.5113	0.0001	-
^{99m}Tc	-	-	-	1.2217	0.0006	-	-	-	-	1.2214	0.0003	-
^{111}In	-	-	-	4.0689	0.0004	-	-	-	-	4.0750	0.0001	-
^{123}I	-	-	-	1.8342	0.0015	-	-	-	-	1.7383	0.0002	-
^{125}I	-	-	-	0.6571	0.0008	-	-	-	-	0.5584	0.0005	-
^{131}I	-	-	-	3.9380	0.0002	-	-	-	-	3.8440	0.0002	-
^{201}Tl	-	-	-	0.9000	0.0031	-	-	-	-	0.8515	0.0001	-

Table 23 - Calibration Figures and Volume Correction factors for Solution sources.
NPL Secondary Standard Ionisation Chamber (NPL-CRC)
Braun omnifix Luer slip syringes - Blue needle

Container (nominal volume)	**1 ml Luer lok BD syringe (1 ml)**			**3 ml Luer lok BD syringe (2 ml)**			**5 ml Luer lok BD syringe (5 ml)**			**10 ml Luer lok BD syringe (10 ml)**		
Nuclide	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**
^{67}Ga	-	-	-	1.5557	0.0009	-	-	-	-	1.5414	0.0001	-
^{99m}Tc	-	-	-	1.2391	0.0005	-	-	-	-	1.2158	0.0002	-
^{111}In	-	-	-	4.2199	0.0004	-	-	-	-	4.1175	0.0001	-
^{123}I	-	-	-	1.8661	0.0017	-	-	-	-	1.7813	0.0002	-
^{125}I	-	-	-	0.6659	0.0007	-	-	-	-	0.5575	0.0004	-
^{131}I	-	-	-	4.0334	0.0002	-	-	-	-	3.9339	0.0001	-
^{201}Tl	-	-	-	0.8923	0.0006	-	-	-	-	0.8935	0.0002	-

Table 24 - Calibration Figures and Volume Correction factors for Solution sources.
NPL Secondary Standard Ionisation Chamber (NPL-CRC)
Braun omnifix Luer lok syringes - Green needle

Container (nominal volume)	1 ml Luer lok BD syringe (1 ml)			3 ml Luer lok BD syringe (2 ml)			5 ml Luer lok BD syringe (5 ml)			10 ml Luer lok BD syringe (10 ml)		
Nuclide	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)
^{67}Ga	-	-	-	-	-	-	1.5225	0.0004	-	1.4947	0.0001	-
^{99m}Tc	-	-	-	-	-	-	1.2284	0.0004	-	1.1887	0.0002	-
^{111}In	-	-	-	-	-	-	4.0655	0.0001	-	4.0742	0.0001	-
^{123}I	-	-	-	-	-	-	1.8136	0.0007	-	1.7564	0.0002	-
^{125}I	-	-	-	-	-	-	0.5645	0.0007	-	0.5408	0.0021	-
^{131}I	-	-	-	-	-	-	3.9152	0.0002	-	3.8790	0.0001	-
^{201}Tl	-	-	-	-	-	-	0.8859	0.0008	-	0.8504	0.0002	-

Table 25 - Calibration Figures and Volume Correction factors for Solution sources.
NPL Secondary Standard Ionisation Chamber (NPL-CRC)
Braun omnifix Luer lok syringes - Blue needle

Container (nominal volume)	1 ml Luer lok BD syringe (1 ml)			3 ml Luer lok BD syringe (2 ml)			5 ml Luer lok BD syringe (5 ml)			10 ml Luer lok BD syringe (10 ml)		
Nuclide	**Calibration figure ($pA\ MBq^{-1}$)**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure ($pA\ MBq^{-1}$)**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure ($pA\ MBq^{-1}$)**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure ($pA\ MBq^{-1}$)**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**
^{67}Ga	-	-	-	-	-	-	1.5486	0.0002	-	1.5445	0.0001	-
^{99m}Tc	-	-	-	-	-	-	1.2529	0.0004	-	1.1742	0.0001	-
^{111}In	-	-	-	-	-	-	4.1298	0.0001	-	4.1238	0.0001	-
^{123}I	-	-	-	-	-	-	1.8307	0.0004	-	1.7879	0.0002	-
^{125}I	-	-	-	-	-	-	0.5754	0.0005	-	0.5638	0.0014	-
^{131}I	-	-	-	-	-	-	3.9800	0.0001	-	3.9663	0.0001	-
^{201}Tl	-	-	-	-	-	-	0.8987	0.0006	-	0.8704	0.0002	-

Table 26 - Calibration Figures and Volume Correction factors for Solution sources.
NPL Secondary Standard Ionisation Chamber (NPL-CRC)
Terumo Luer slip syringes - Green needle

Container (nominal volume)	1 ml Luer lok BD syringe (1 ml)			3 ml Luer lok BD syringe (2 ml)			5 ml Luer lok BD syringe (5 ml)			10 ml Luer lok BD syringe (10 ml)		
Nuclide	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)	Calibration figure (pA MBq^{-1})	Volume Correction factor (a_1)	Volume Correction factor (a_2)
^{67}Ga	1.5718	0.0046	-	1.5724	0.0002	-	-	-	-	1.5470	0.0001	-
^{99m}Tc	1.5620	0.0005	-	1.2122	0.0007	-	-	-	-	1.1991	0.0002	-
^{111}In	4.1778	0.0014	-	4.1094	0.0001	-	-	-	-	4.0538	0.0001	-
^{123}I	1.8401	0.019	-	1.8087	0.0002	-	-	-	-	1.7322	0.0001	-
^{125}I	0.6307	0.0065	-	0.6005	0.0008	-	-	-	-	0.5622	0.0006	-
^{131}I	3.9702	0.0012	-	3.7564	0.0003	-	-	-	-	3.9128	0.0001	-
^{201}Tl	-	-	-	0.8879	0.0023	-	-	-	-	0.8640	0.0002	-

Table 27 - Calibration Figures and Volume Correction factors for Solution sources.
NPL Secondary Standard Ionisation Chamber (NPL-CRC)
Terumo Luer slip syringes - Blue needle

Container (nominal volume)	**1 ml Luer lok BD syringe (1 ml)**			**3 ml Luer lok BD syringe (2 ml)**			**5 ml Luer lok BD syringe (5 ml)**			**10 ml Luer lok BD syringe (10 ml)**		
Nuclide	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**
^{67}Ga	1.6093	0.0065	-	1.6075	0.001	-	-	-	-	1.5719	0.0001	-
^{99m}Tc	1.5864	0.0004	-	1.2392	0.0005	-	-	-	-	1.2168	0.0002	-
^{111}In	4.1703	0.0016	-	4.1851	0.0001	-	-	-	-	4.1216	0.0001	-
^{123}I	1.8557	0.0135	-	1.8414	0.0001	-	-	-	-	1.7669	0.0001	-
^{125}I	0.6380	0.0056	-	0.6121	0.0007	-	-	-	-	0.5743	0.0005	-
^{131}I	4.0275	0.0007	-	4.0006	0.0003	-	-	-	-	3.9702	0.005	-
^{201}Tl	-	-	-	0.9054	0.0030	-	-	-	-	0.8844	0.0002	-

Table 28 - Calibration Figures and Volume Correction factors for Solution sources.
NPL Secondary Standard Ionisation Chamber (NPL-CRC)
Terumo Luer lok syringes - Green needle

Container (nominal volume)	1 ml Luer lok BD syringe (1 ml)			3 ml Luer lok BD syringe (2 ml)			5 ml Luer lok BD syringe (5 ml)			10 ml Luer lok BD syringe (10 ml)		
Nuclide	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**
^{67}Ga	-	-	-	-	-	-	-	-	-	1.5381	0.0001	-
^{99m}Tc	-	-	-	-	-	-	-	-	-	1.1855	0.0001	-
^{111}In		-	-	-	-	-	-	-	-	4.0748	0.0001	-
^{123}I	-	-	-	-	-	-	-	-	-	1.7394	0.0001	-
^{125}I	-	-	-	-	-	-	-	-	-	0.5958	0.0186	-
^{131}I	-	-	-	-	-	-	-	-	-	3.9396	0.0001	-
^{201}Tl	-	-	-	-	-	-	-	-	-	0.8756	0.0002	-

Table 29 - Calibration Figures and Volume Correction factors for Solution sources.
NPL Secondary Standard Ionisation Chamber (NPL-CRC)
Terumo Luer lok syringes - Blue needle

Container (nominal volume)	**1 ml Luer lok BD syringe (1 ml)**			**3 ml Luer lok BD syringe (2 ml)**			**5 ml Luer lok BD syringe (5 ml)**			**10 ml Luer lok BD syringe (10 ml)**		
Nuclide	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**	**Calibration figure (pA MBq^{-1})**	**Volume Correction factor (a_1)**	**Volume Correction factor (a_2)**
^{67}Ga	-	-	-	-	-	-	-	-	-	1.5592	0.0001	-
^{99m}Tc	-	-	-	-	-	-	-	-	-	1.2600	0.0003	-
^{111}In	-	-	-	-	-	-	-	-	-	4.1239	0.0001	-
^{123}I	-	-	-	-	-	-	-	-	-	1.7560	0.0001	-
^{125}I	-	-	-	-	-	-	-	-	-	0.5911	0.0143	-
^{131}I	-	-	-	-	-	-	-	-	-	3.9756	0.0001	-
^{201}Tl	-	-	-	-	-	-	-	-	-	0.8826	0.0001	

Figure 1 – NPL Secondary Standard Radionuclide Calibrator

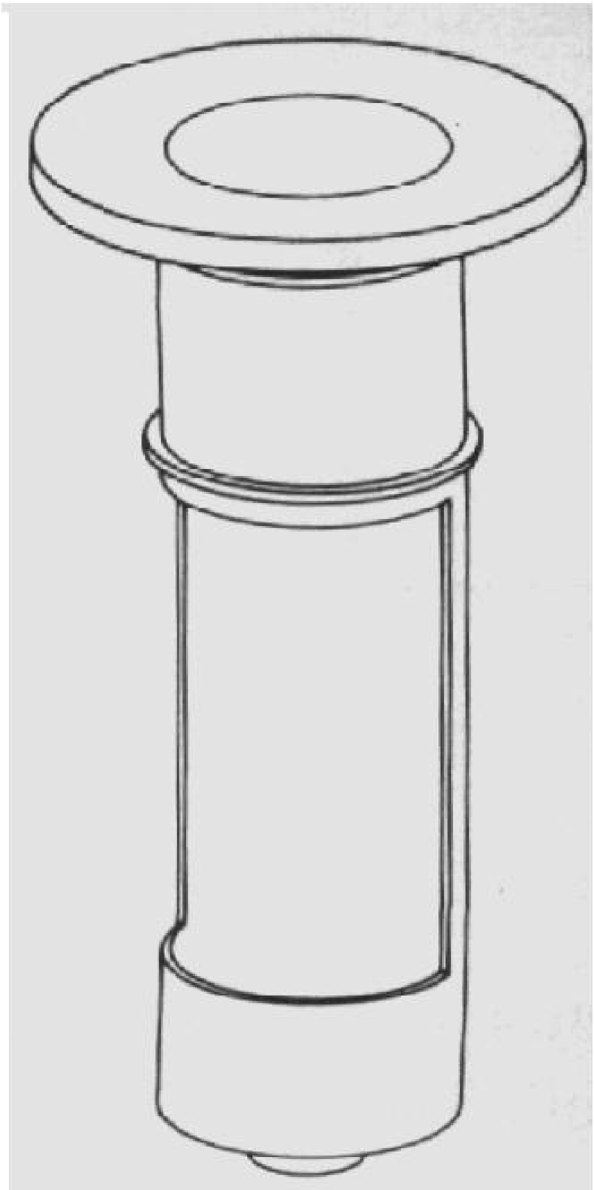

Figure 2 – Perspex holder for NPL Secondary Standard Radionuclide Calibrator

Figure 3 – I-125 Activity measured in syringe using vial calibration factors compared to true activity

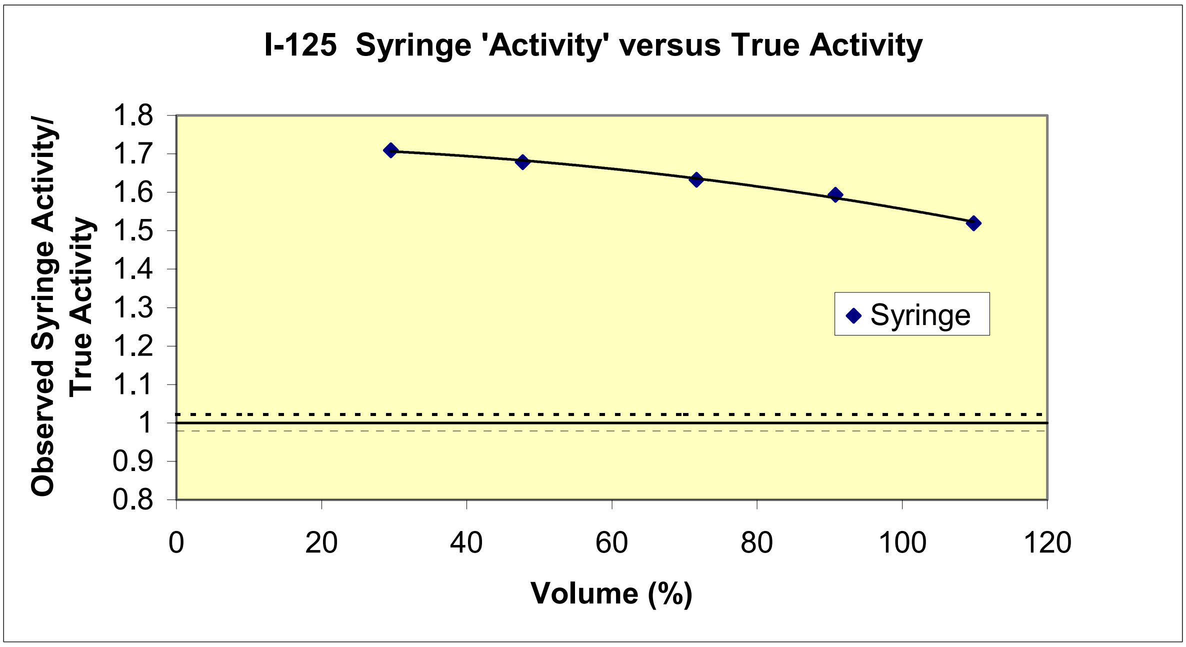

Figure 4 – I-131 Activity measured in syringe using vial calibration factors compared to true activity

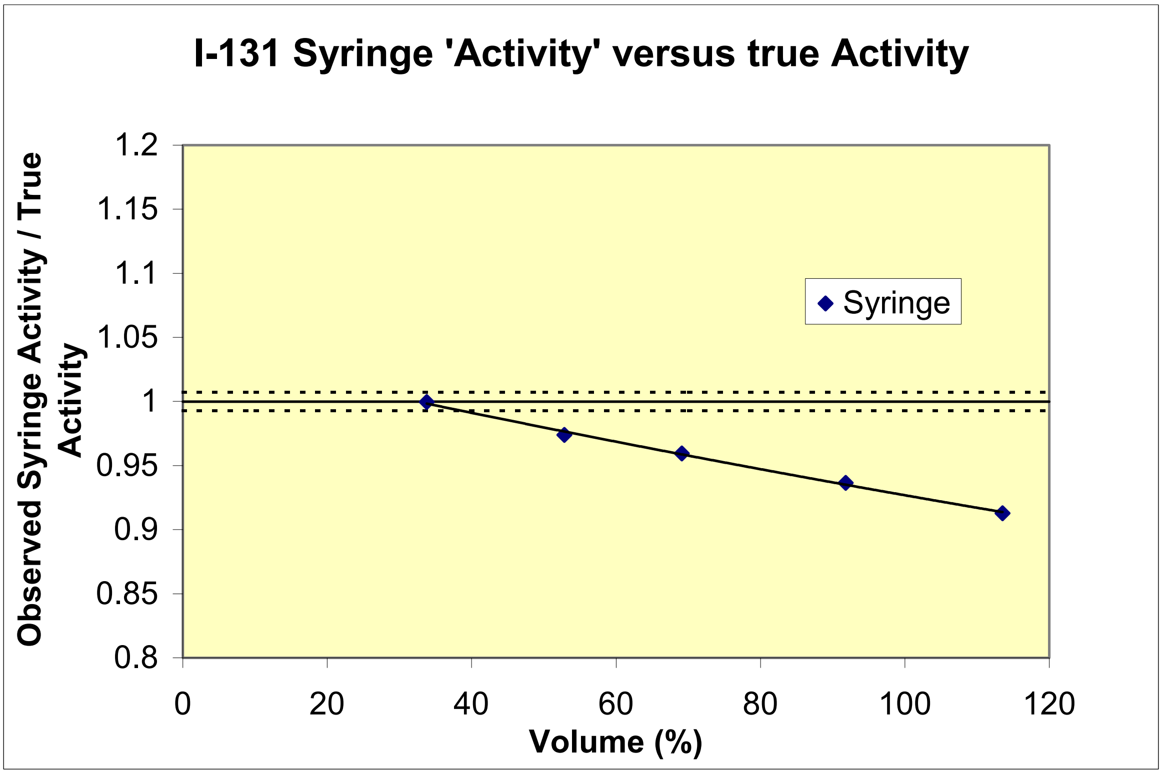

Figure 5 – ^{123}I syringe results from 1996 Comparison.

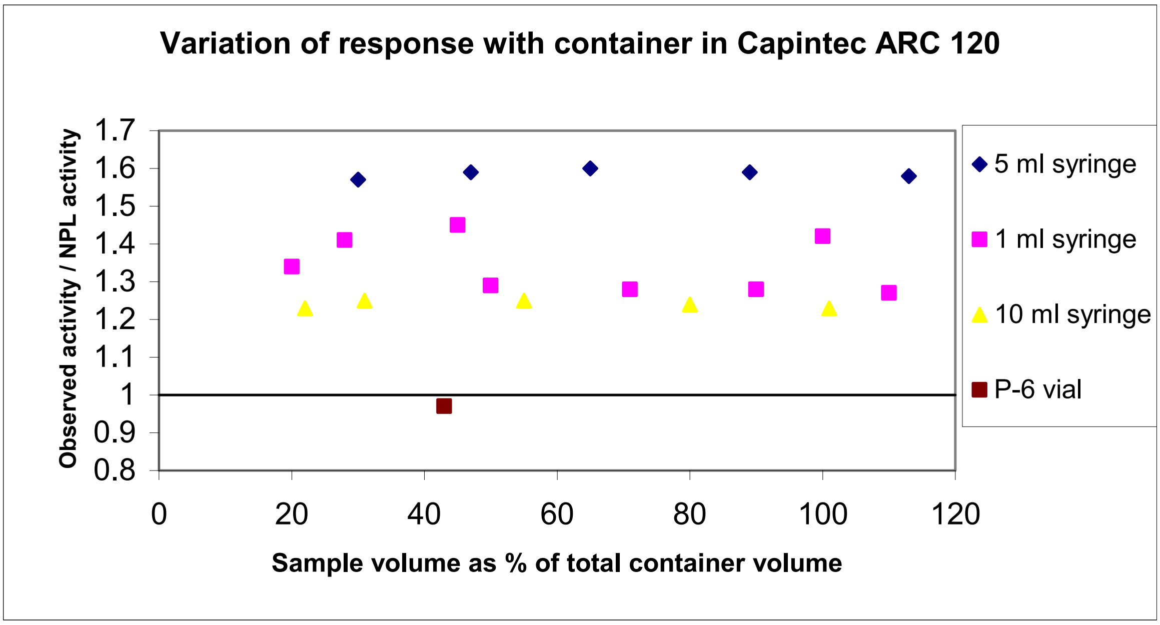

Figure 6 – ^{111}In syringe results from 1997 Comparison.

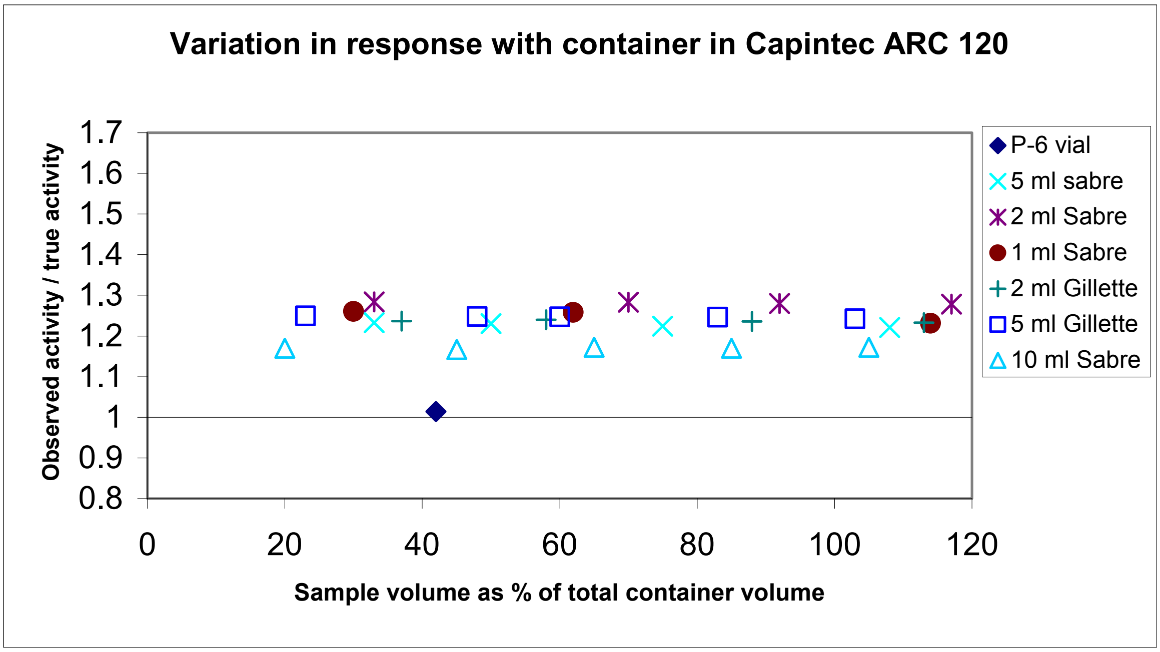

Figure 7 – Comparative Measurements for ^{111}In in syringes and vials for ARC 120

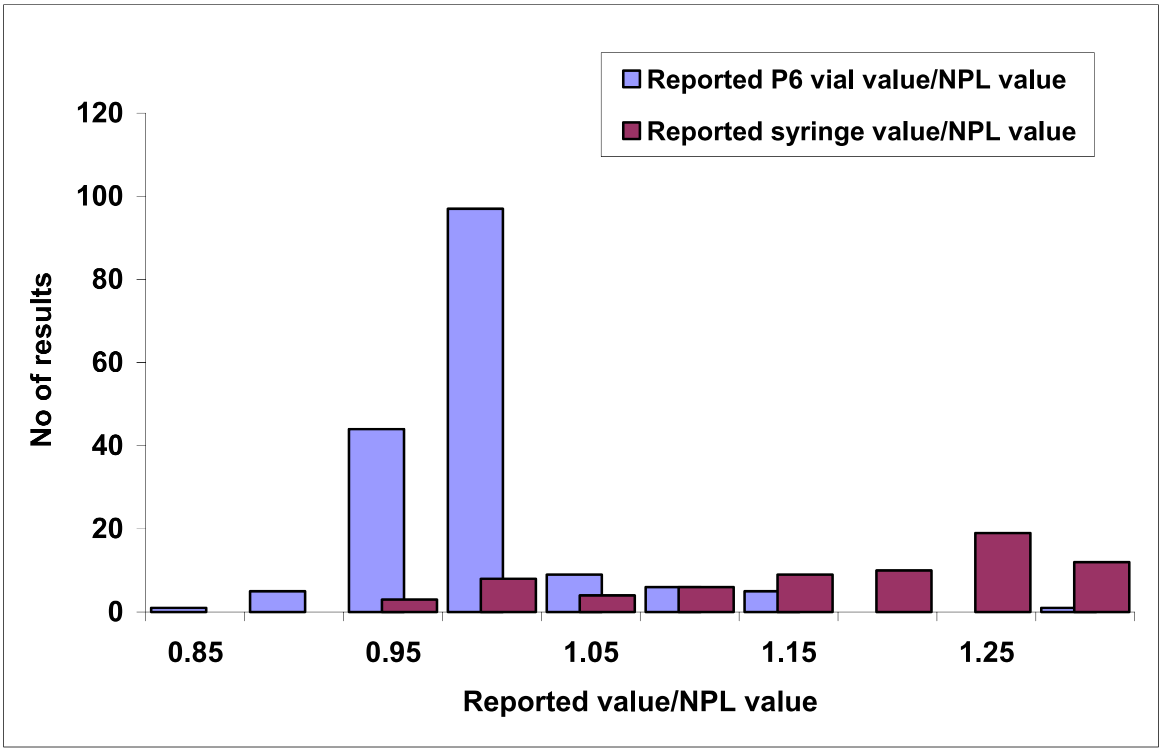

Figure 8 – Comparative Measurements for ^{123}I in syringes and vials for ARC 120

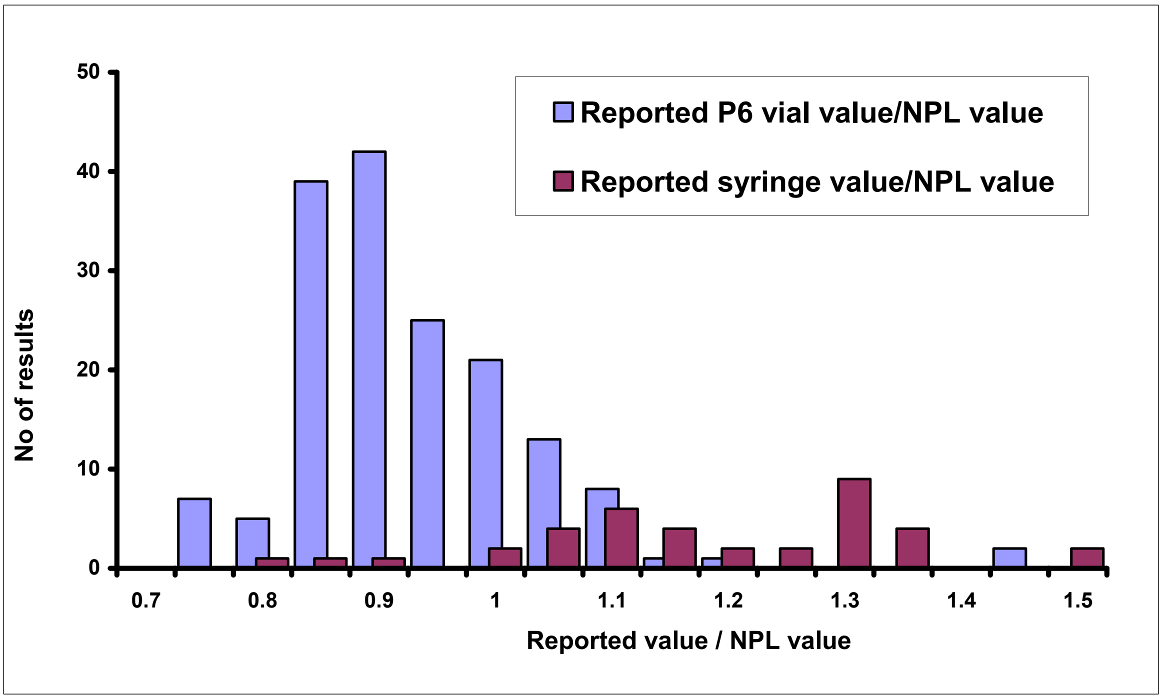

Figure 9 – Illustration showing the different types of needles.

Figure 10 – Range of syringes in common use.

APPENDIX 1

QUESTIONNAIRE.

Name:
Hospital:

The following questions refer to radionuclides contained in a syringe and placed into a radionuclide calibrator, for an activity measurement.
Please answer the following questions in as much detail as possible.

1. Which nuclides do you normally measure in a syringe?

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2. Which types of syringes do you use for the radionuclides? What are the sizes normally used? (e.g. 2ml, 10ml etc)

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3. What type and length of needle do you use?

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4. What volumes of the radionuclide are normally placed in the syringes?

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5. Which manufacturer do you use? Do you normally use the same manufacturer?

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6. Do you have any control of the type of syringes that you stock? (Can you guarantee that the syringes will always be of the same type and from the same manufacturer)

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P.T.O

7. When you place the syringe in the calibrator are there any problems that arise? (e.g. is the needle attached/ or replaced by a stopper etc)

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8. Any other comments.

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Many thanks for your co-operation.

Please return this to: Dagmara Modna, National Physical Laboratory, Queens Road, Teddington, Middlesex, TW11 0LW

Tel: 020 8943 6085

Fax: 020 8943 6161

E-mail: dagmara.modna@npl.co.uk

P.T.O

APPENDIX 2

Chemistry of solutions and carriers.

Gallium-67

Stock solution - Gallium Citrate

Carrier -100 μg / g of Ga in water / citric acid

Technetium-99m

Stock solution – Amertec II Tc-99m Sterile Generator

Carrier – 1 mg of formaldehyde/g of solution in 0.01 M NH_4OH

Indium-111

Stock solution – Indium Chloride

Carrier – 72.5 μg/g In in 0.05 M HCl

Iodine (^{123}I, ^{125}I, ^{131}I)

Stock solution – Sodium Iodide

Carrier – 6 mg/g $Na_2S_2O_3$ + 6 mg/g NaI in 1 M NaOH

Thallium-201

Stock solution – Thallous Chloride

Carrier – 58 μg/g of Tl in 0.01 M HCl