Uncertainty of Radionuclide Calibrator Measurements of $^{99}$Tc$_{\text{m}}$

I.S. Hufton,
Department of Medical Physics,
Royal Liverpool University Hospital
NPL Intercomparison Exercise

- Traceability exercise
- Multi-centre trial funded by the D.T.I.
- Local Measurement of 4ml Tc-99m in a 10R Schott vial
  - 6 x Radionuclide calibrators @ RLUH
- NPL Tc-99m source measurement prior to shipping
Uncertainty of Measurement

- NPL requested an estimate of the *uncertainty* associated with each measurement
- 211 results reported
- 48 participating Centres
- 140 (66 %) supplied an estimate of the uncertainty associated with their measurement
- 71 (34 %) supplied no estimate
Type A or Type B uncertainties

- 41 (19%) quoted Type A only
- 91 (43%) quoted Type A & B
- 8 (4%) quoted Type B only

- Clearly a nationwide problem with the estimation of the uncertainties associated with radionuclide activity measurements
RLUH initial estimates

- Capintec ARC 120 (x2) = 7.6%
- Capintec 15R (x3) = 6.2%
- Veenstra VDC-505 (x1) = 6.2%

- Max variation from NPL: 5.5%
- Min variation from NPL: 0.2%
- Mean variation from NPL: 1.5%
- NPL “somewhat pessimistic”
Other Centres Uncertainties

- Range of values
  - Max 17% (Value: 3.8% over estimation)
  - Min 0.08% (Value: 1.3% over estimation)

- Variety of techniques used to estimate
  - Type A or B or both
  - Difficult to compare

- Discussed at the last RNCUF (Jan 2007)
Types of Uncertainty

- **Type A**
  - Determined statistically
  - Finite degrees of freedom
  - Normal (Gaussian) Distribution

- **Type B**
  - Non-statistically determined
  - Systematic
  - Infinite degrees of freedom
  - Non-normal distribution
Sources of Uncertainty (1)

- Traceability/accuracy
- Electronics: linearity inc. range changing
- Statistical: Repeatability
- High Activity: recombination effects
- Low Activity: near bg level, poor count stats
- Ionisation chamber thickness
- Backscatter from surroundings
- Source vessel material
Sources of Uncertainty (2)

- Geometric variation of source dimensions
- Positioning of source in chamber
- Source density
- Homogeneity: variations within the source
- Purity: inclusion of different radioisotopes
- Calibration factors derived by the manufacturer
Uncertainty Budget (1)

- Described in
  - Guide to the Expression of Uncertainty in Measurement, BIPM..., 1993
  - M3003: The Expression of Uncertainty and Confidence in Measurement, (UKAS), 2002
Uncertainty Budget (2)

- Spreadsheet table
- Type A uncertainties
  - linearity, repeatability, reproducibility,
- Type B uncertainties
  - calibration coeff., chamber wall, inherent accuracy, range changing, high activity, low activity, shielding, vessel thickness/material, volume geometry, sample density/homogeneity.
Calculations

- Standard Deviation
- Experimental std. Dev. of the mean
- Standard Uncertainty ($\pm 1$std. dev.)
- Confidence Level (typically 95%)
- Coverage Factor
- Degrees of freedom
- Expanded Uncertainty
Defining Uncertainty

- “The reported uncertainty is based on a standard uncertainty multiplied by a coverage factor or k=2 which provides a level of confidence of approximately 95%”

- Actually:
  - Coverage factor of k = 2.00 --> 95.45%
  - Coverage factor of k = 1.96 --> 95.00%
Summary

- Revised estimates of Uncertainty
  - Capintec ARC120 (x2) = 4.2%
  - Capintec CRC-15R (x3) = 2.4%
  - Veenstra VDC-505 (x1) = 3.3%

- Comparison Study
  - ARC120 all <1.0%
  - CRC-15R, 1 system 5.5%, others <1.0%
  - VDC-505, 4.0% (outside uncertainty margin)
References (1)


- NPL GPG93: *Protocol for Establishing and Maintaining the Calibration of Medical Radionuclide Calibrators and their Quality Control*, 2006


- (http://www.npl.co.uk/publications/good_practice/)
References (2)

- M3003: The Expression of Uncertainty and Confidence in Measurement, United Kingdom Accreditation Service (UKAS), 2002 – [www.ukas.com](http://www.ukas.com)

Acknowledgements

- Dr H.R. Stockdale
- Mr P. Maltby
- Mr J.S. Grime
<table>
<thead>
<tr>
<th>Category</th>
<th>CRC - 15R estimate</th>
<th>Value</th>
<th>Prob Dist</th>
<th>divisor</th>
<th>Ci</th>
<th>ui(x)</th>
<th>V or Veff</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calibration Factor</td>
<td>&gt; 2%</td>
<td>0.0200</td>
<td>rect</td>
<td>1.73</td>
<td>1</td>
<td>0.0115</td>
<td>inf</td>
</tr>
<tr>
<td>Wall Chamber</td>
<td>eff zero</td>
<td>0.0000</td>
<td>rect</td>
<td>1.73</td>
<td>1</td>
<td>0.0000</td>
<td>inf</td>
</tr>
<tr>
<td>Inherent acc’y</td>
<td>&lt; 2%</td>
<td>0.0020</td>
<td>rect</td>
<td>1.73</td>
<td>1</td>
<td>0.0012</td>
<td>inf</td>
</tr>
<tr>
<td>Linearity</td>
<td>&lt;0.2%</td>
<td>0.0020</td>
<td>Normal</td>
<td>1.00</td>
<td>1</td>
<td>0.0020</td>
<td>8</td>
</tr>
<tr>
<td>Range changing</td>
<td>unknown</td>
<td></td>
<td>rect</td>
<td>1.73</td>
<td>1</td>
<td>0.0000</td>
<td>inf</td>
</tr>
<tr>
<td>Statistical</td>
<td>0.05% Ba133 accp*</td>
<td>0.0005</td>
<td>Normal</td>
<td>1.00</td>
<td>1</td>
<td>0.0005</td>
<td>19</td>
</tr>
<tr>
<td>High Activity</td>
<td>eff zero</td>
<td>0.0000</td>
<td>rect</td>
<td>1.73</td>
<td>1</td>
<td>0.0000</td>
<td>inf</td>
</tr>
<tr>
<td>Low Activity/bg</td>
<td>eff zero</td>
<td>0.0000</td>
<td>rect</td>
<td>1.73</td>
<td>1</td>
<td>0.0000</td>
<td>inf</td>
</tr>
<tr>
<td>Shielding</td>
<td>eff zero</td>
<td>0.0000</td>
<td>rect</td>
<td>1.73</td>
<td>1</td>
<td>0.0000</td>
<td>inf</td>
</tr>
<tr>
<td>Container wall th</td>
<td>eff zero</td>
<td>0.0000</td>
<td>rect</td>
<td>1.73</td>
<td>1</td>
<td>0.0000</td>
<td>inf</td>
</tr>
<tr>
<td>Container type</td>
<td>eff zero</td>
<td>0.0000</td>
<td>rect</td>
<td>1.73</td>
<td>1</td>
<td>0.0000</td>
<td>inf</td>
</tr>
<tr>
<td>Volume</td>
<td>eff zero</td>
<td>0.0000</td>
<td>rect</td>
<td>1.73</td>
<td>1</td>
<td>0.0000</td>
<td>inf</td>
</tr>
<tr>
<td>Position</td>
<td>est 0.1%</td>
<td>0.0010</td>
<td>Normal</td>
<td>1.00</td>
<td>1</td>
<td>0.0010</td>
<td>49</td>
</tr>
<tr>
<td>Density</td>
<td>eff zero</td>
<td>0.0000</td>
<td>rect</td>
<td>1.73</td>
<td>1</td>
<td>0.0000</td>
<td>inf</td>
</tr>
<tr>
<td>Homogeneity</td>
<td>eff zero</td>
<td>0.0000</td>
<td>rect</td>
<td>1.73</td>
<td>1</td>
<td>0.0000</td>
<td>inf</td>
</tr>
<tr>
<td>Adsorption</td>
<td>eff zero</td>
<td>0.0000</td>
<td>rect</td>
<td>1.73</td>
<td>1</td>
<td>0.0000</td>
<td>inf</td>
</tr>
<tr>
<td>TOTAL</td>
<td>&gt; 6.2%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[
\text{Veff} = 9535.9306 \quad k = 2
\]

\[
\text{Uc} = 0.0117863 \quad 95\% \text{ UCl} = 2.35726 \% 
\]