**Determination of the Efficiency of Commercially Available Dose Calibrators for β-Emitters**

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**Objectives:** The goals of this investigation are to determine whether commercially available dose calibrators can be used to measure the activity of β-emitting radionuclides used in pain palliation and to establish whether manufacturer-supplied calibration factors are appropriate for this purpose.

**Methods:** Six types of commercially available dose calibrators were studied. Dose calibrator response was controlled for 5 γ-emitters used for calibration or typically encountered in routine use. For the 4 most commonly used β-emitters (32P, 90Sr, 90Y, and 169Er) dose calibrator efficiency was determined in the syringe geometry used for clinical applications. Efficiency of the calibrators was also measured for 153Sm and 186Re, 2 β-emitters with significant γ-contributions. Source activities were traceable to national standards.

**Results:** All calibrators measured γ-emitters with a precision of ±10%, in compliance with Swiss regulatory requirements. For β-emitters, dose calibrator intrinsic efficiency depends strongly on the maximal energy of the β-spectrum and is notably low for 169Er. Manufacturer-supplied calibration factors give accurate results for β-emitters with maximal β-energy in the middle-energy range (1 MeV) but are not appropriate for use with low-energy (169Er) or high-energy (90Y) β-emitters. β-emitters with significant γ-contributions behave like γ-emitters.

**Conclusion:** Commercially available dose calibrators have an intrinsic efficiency that is sufficient for the measurement of β-emitters, including β-emitters with a low maximum β-energy. Manufacturer-supplied calibration factors are reliable for γ-emitters and β-emitters in the middle-energy range. For low- and high-energy β-emitters, the use of manufacturer-supplied calibration factors introduces significant measurement inaccuracy.

**Key Words:** dose calibration; β-emitters; radiation therapy; palliation


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The analgesic radiation therapy of bone metastasis calls for β-emitting radionuclides able to concentrate at the site of bone repair and deliver a dose sufficient for pain palliation for a period of time (1). Dosimetry of these radionuclides is difficult because of the complex geometry of bone marrow and the variability of uptake. The aim of this palliative therapy is not to deliver the highest possible dose to the tumor but to obtain a reduction in bone pain. The principal limiting factor for therapy is the depression of bone marrow activity. Doses delivered are much lower than those in conventional radiation therapy, and standardized activities based on clinical experience are used.

Before treatment, the activity to be delivered to the patient must be checked. This measurement is performed in a dose calibrator with the radionuclide in either the manufacturer’s glass vial or, preferably, in the syringe to be used for injection. Dose calibrator sensitivity has been studied extensively (2,3). Commercially available calibrators are supplied with calibration factors for commonly used γ-emitting radionuclides. However, some problems have been reported in the accuracy of these factors, and Zimmerman and Cessna (4) reported errors of about 10% for positron emitters. In addition, the presence of low-energy x- or γ-ray components can introduce a high dependence of dose calibrator sensitivity on measurement geometry because of the high attenuation between the source and the sensitive volume. The use of a copper filter to absorb low-energy radiation and stabilize calibrator response has been proposed (5).

Radiopharmaceuticals used for bone palliation are delivered to hospitals in glass vials, and dose calibrator ionization chambers are usually calibrated for measurement in these vials. However, the activity check is best performed in the syringe that will be used for injection. The difference in calibration factor for glass vial and syringe measurements should not be significant for γ-emitters, although differences on the order of 10% for 67Ga and 201Tl have been reported for a Capintec (Capintec, Inc., Pittsburgh, PA) CRC-35 calibrator (6).

For β-emitters, dose calibrator activity measurement is mainly based on indirect detection. β-Radiation is absorbed in the radioactive solution itself or in the walls of the recipient vial or syringe, producing bremsstrahlung radia-
tion that is measured by the ionization chamber. Because of this mechanism, sensitivity to β-emitters is much less than sensitivity to γ-emitters, since the energy fraction converted to bremsstrahlung is small and attenuation of the low-energy bremsstrahlung is significant. In addition, the amount of the bremsstrahlung produced depends strongly on the atomic number of the material from which it originates.

Problems with the sensitivity of ionization chambers to β-radiation were first discussed in connection with the determination of correction factors for calibrator response to γ-emitters with a nonnegligible β-component (2,3). The response of commercially available ionization chambers to β-emitters has been studied for different nuclides: ⁸⁹Sr (7), ¹⁸⁶Re (8), and ¹⁸⁶Re and ¹⁸⁸Re (9). Each of these authors reported variability of response with measurement geometry and stated the necessity of dispensing with calibration factors that are specific to the measurement geometry used in routine practice. For ⁹⁰Y, an error of 50% in the calibration factor of a commercially available detector has been reported (10).

Most commercially available ionization chambers are provided with calibration factors for commonly used β-emitters, but the specific conditions of these calibrations (geometry, recipient type) often are not specified and usually correspond to a measurement in vial geometry. Assuming that ionization chamber response is approximately constant for β-emitters in the middle-energy range (0.7–1.3 MeV), the problem remains that chamber response may differ significantly for low-energy β-emitters because of wall attenuation and for high-energy β-emitters (>2 MeV) in which β-radiation contributes directly to ionization in the chamber’s sensitive volume.

The aim of the present work is to investigate the intrinsic efficiency (electrical signal per unit activity) of different commercially available calibrators for β-emitters most commonly used in bone palliation therapy. The appropriateness of the measurements performed to control the activity delivered to patients is considered, and the possible need for a calibration methodology for routine use is discussed.

IONIZATION CHAMBER SENSITIVITY

For measurements with a dose calibrator, the radioactive source to be measured is placed in a well surrounded by a gas volume to which a charge collection voltage is applied. The resultant measured current is directly proportional to the source activity. Stability and robustness of the system are high because of the almost 4π measurement geometry. The system operates in current mode (i.e., not based on the counting of each event), and, as a result, the sensitivity of the system is relatively low. For γ-emitters, sensitivity is of the order of 10 pA/MBq, which corresponds to a mean energy deposition of about 1 keV per disintegration. For β-emitters, the energy fraction converted to bremsstrahlung

![Figure 1](https://example.com/f1.png)

**FIGURE 1.** Positioning of glass vial and syringe in dose calibrator. (A) Glass vial geometry. (B) Syringe geometry.

### TABLE 1

Calibrators Used

<table>
<thead>
<tr>
<th>Activimeter type</th>
<th>VEENSTRA VDC-405</th>
<th>Atomlab 100</th>
<th>Capintec CRC</th>
<th>Isomed 1000</th>
<th>Centronic* IG12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas Pressure</td>
<td>Argon</td>
<td>Argon</td>
<td>Argon</td>
<td>Xenon/argon</td>
<td>Argon</td>
</tr>
<tr>
<td>(bars)</td>
<td>12</td>
<td>5</td>
<td>12</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>Well dimensions</td>
<td>69 × 260</td>
<td>64 × 260</td>
<td>61 × 254</td>
<td>47.5 × 220</td>
<td>50 × 315</td>
</tr>
<tr>
<td>(mm)</td>
<td>3</td>
<td>6.4</td>
<td>12.7</td>
<td>4</td>
<td>50</td>
</tr>
<tr>
<td>Shielding (mm)</td>
<td>6.4</td>
<td>3</td>
<td>12.7</td>
<td>4</td>
<td>50</td>
</tr>
</tbody>
</table>

*The electronic measurement circuit was developed in our institute.
is of the order of about 2% in low-Z material and 5% in glass for a maximal β-energy of about 1 MeV. Energy deposition in the sensitive volume is much smaller than that for γ-emitters, being on the order of 10 eV per disintegration.

According to Schrader (11), the sensitivity of an ionization chamber to a nuclide is expressed by the following formula:

$$\varepsilon = \sum_j p_{\beta j} \varepsilon_{\beta j}(E_{\beta j}) + \sum_i p_i(E_{\gamma i}) \varepsilon_{\gamma i}(E_{\gamma i}),$$

where $p_{\beta j}$ is the emission probability and $\varepsilon_{\beta j}$ the sensitivity of the chamber for a β-particle of maximal energy $E_{\beta j}$. $p_i$ is the emission probability, and $\varepsilon_{\gamma i}$ is the sensitivity of the chamber to a photon of energy $E_{\gamma i}$.

A sophisticated method has been developed to determine experimentally the relation $\varepsilon_{i}(E)$ for about 30 different nuclides, using initially pure monoenergetic γ-emitters and subsequently applying correction factors for multi-γ-emitters and β-contributors. In the case of β-emitters, the β-efficiency has been calculated using some pure β-emitters (3).

For commercially available calibrators, efficiency is determined by the manufacturer using calibrated radioactive solutions. Specific calibration factors are derived for use with different nuclides based on these measurements.

**MATERIALS AND METHODS**

**Dose Calibrators**

The main characteristics of the calibrators used in this study are given in Table 1.

For the VEENSTRA (VEENSTRA Instrumenten BV, Joure, The Netherlands) and Isomed (MED Nuklear-Medizintechnik, Dresden, Germany) calibrators, measurements were made using 3 different calibrators of the same model. There was excellent reproducibility from one calibrator to another for all nuclides, with maximum difference <1%. This confirms the precise manufacturing of the chamber and the appropriateness of defining generic calibration factors applicable to all chambers of the same type.

For measuring β-emitters, an instrument based on a sodium iodide crystal (Capintec β) was also used.

**Measurement Geometry**

Different measurement geometries were used for γ- and β-emitters. For γ-emitters, where detection efficiency is not critically influenced by measurement geometry, commercial glass vials (CIS Bio International, Gif-sur-Yvette, France; and Amersham Health, Little Chalfont, Buckinghamshire, U.K.) were placed in a low position in the calibrator well (Fig. 1A). For β-emitters, a polypropylene tube was used to simulate a 2-mL syringe and was positioned in the well in the same position as for a syringe measurement (Fig. 1B). Table 2 compares the characteristics of the tube and the syringe.

Calibrator response was compared for syringe and plastic tube measurements using $^{32}$P and $^{169}$Er. The observed differences were on the order of 1% for all calibrators.

**Radionuclides**

In Switzerland, 5 γ-emitters are used to verify the response of systems used in nuclear medicine laboratories: $^{57}$Co, $^{60}$Co, $^{137}$Cs, $^{99m}$Tc, and $^{131}$I. Calibrator response was checked initially for these radionuclides using glass vial geometry and calibration factors supplied by the manufacturer.

Next, efficiency was measured using syringe geometry for 4 β-emitters with little or no γ-component: $^{32}$P, $^{169}$Er, $^{99m}$Tc, and $^{89}$Sr.

Finally, $^{153}$Sm and $^{186}$Re, 2 nuclides with nonnegligible components, were measured using syringe geometry.

**Radioactive Solutions**

Radioactive solutions in ionic form were used so that solutions could be transferred with sufficient accuracy.

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**TABLE 2**

Plastic Tube and Syringe Characteristics

<table>
<thead>
<tr>
<th>Container</th>
<th>Material</th>
<th>Maximal Volume (mL)</th>
<th>Volume used (mL)</th>
<th>External Diameter (mm)</th>
<th>Wall Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Syringe</td>
<td>Polypropylene</td>
<td>2</td>
<td>2</td>
<td>10.65</td>
<td>0.85</td>
</tr>
<tr>
<td>Plastic tube</td>
<td>Polypropylene</td>
<td>3.5</td>
<td>2</td>
<td>11.50</td>
<td>0.90</td>
</tr>
</tbody>
</table>

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**TABLE 3**

Efficiency of Calibrators for $^{137}$Cs

<table>
<thead>
<tr>
<th>VEENSTRA</th>
<th>Atomlab</th>
<th>Isomed</th>
<th>Capintec</th>
<th>Centronic</th>
</tr>
</thead>
<tbody>
<tr>
<td>VDC-405</td>
<td>100</td>
<td>1000/2000</td>
<td>CRC</td>
<td>IG12</td>
</tr>
<tr>
<td>R($^{137}$Cs)</td>
<td>0.93</td>
<td>0.95</td>
<td>0.99</td>
<td>0.98</td>
</tr>
</tbody>
</table>

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**TABLE 4**

Dose Calibrator Efficiency for γ-Emitting (R$_n$)

<table>
<thead>
<tr>
<th>Γ-Emitter</th>
<th>VEENSTRA</th>
<th>Atomlab</th>
<th>Isomed</th>
<th>Capintec</th>
<th>Centronic</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{57}$Co</td>
<td>1.01</td>
<td>1.03</td>
<td>1.08</td>
<td>0.99</td>
<td>0.96</td>
</tr>
<tr>
<td>$^{60}$Co</td>
<td>1.03</td>
<td>1.02</td>
<td>0.99</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>$^{99m}$Tc</td>
<td>1.02</td>
<td>0.94</td>
<td>0.97</td>
<td>0.85</td>
<td>1.00</td>
</tr>
<tr>
<td>$^{131}$I</td>
<td>1.06</td>
<td>0.99</td>
<td>1.02</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>
Manufacturer-specified activities were checked using measurements from the national metrology laboratory. For γ-emitters, γ-spectroscopy was used. For β-emitters, liquid scintillation counting was used. Radionuclide purity was checked to make sure that no correction factor was necessary. The uncertainty in the absolute activity of the sources was 2% (1σ) for γ-emitters and 2% (1σ) for β-emitters.

**Measuring Procedure**

Measurement conditions for the study calibrations were carefully controlled by following a rigorous measurement protocol. For each instrument, measurement characteristics, including stability, linearity, and background subtraction, were checked. For background subtraction, in particular, careful attention was necessary because for the 169Er measurements the background signal corresponds to a significant fraction of the measuring signal. For all of the measurements, validation tests were used to confirm the consistency of the results.

**RESULTS**

**Efficiency for 137Cs and Normalization**

To ensure that measurements were independent of calibrator sensitivity adjustment, results were all normalized using the 137Cs response. Table 3 gives the results of 137Cs measurements, where R is the ratio of the activity indicated by the instrument using the 137Cs calibration factor (cesium scale) to the absolute activity of the solution. The results have been normalized by dividing the measured values by R to give efficiencies that are independent of the temporary current intensity amplification setting.

**Efficiency for γ-Emitters**

Detection efficiency for γ-emitters was measured in glass vial geometry using the manufacturer’s calibration factors. Results normalized (Rn) to 137Cs are given in Table 4.

The uncertainty for Rn is about 5% (1σ), resulting in normalized efficiencies that are all approximately unity. It follows that the manufacturer-supplied calibration factors are accurate.

**Intrinsic Efficiency for β-Emitters**

To determine the intrinsic efficiency of the calibrators for β-emitters, measurements were first performed using the manufacturer’s 32P calibration factor (phosphor scale). Table 5 shows the results normalized to 137Cs measurements.

**Check of Calibration Factors**

Measurements were made to check the accuracy of the calibration factors supplied by the manufacturer. Results normalized to 137Cs measurements are given in Table 6. For each nuclide, the corresponding scale on the calibrator was used.

To determine the effect of measurement conditions on response, β-emitting solutions were measured in both syringe and glass vial geometries. Table 7 presents the ratio of the glass vial measurement to the syringe measurement for each nuclide/calibrator combination.

**Dose Calibrator Efficiency for β-Emitters with a γ-Component**

The intrinsic efficiency of dose calibrators for β-emitters with a γ-component (153Sm and 186Re) was measured in syringe geometry using the 32P calibration factor (Table 8). Calibrator efficiency using the manufacturer’s calibration factor for each nuclide is given in Table 9.

**DISCUSSION**

**Efficiency for γ-Emitters**

For the efficiency for 137Cs (Table 3), the calibration factors fulfill the accuracy requirement under Swiss law for nuclear medicine calibrators of ±10%. The results for other

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**TABLE 5**

<table>
<thead>
<tr>
<th>β-Emitter</th>
<th>Veenstra VDC-405</th>
<th>Atomlab 100</th>
<th>Isomed 1000/2000</th>
<th>Capintec CRC</th>
<th>Centronic IG12</th>
<th>Capintec CRC</th>
<th>β</th>
</tr>
</thead>
<tbody>
<tr>
<td>32P</td>
<td>0.97</td>
<td>1.05</td>
<td>1.07</td>
<td>1.06</td>
<td>0.97</td>
<td>0.96</td>
<td></td>
</tr>
<tr>
<td>89 Sr</td>
<td>0.83</td>
<td>0.90</td>
<td>0.89</td>
<td>0.91</td>
<td>0.91</td>
<td>0.85</td>
<td></td>
</tr>
<tr>
<td>90 Y</td>
<td>1.59</td>
<td>1.73</td>
<td>2.80</td>
<td>1.71</td>
<td>2.01</td>
<td>1.47</td>
<td></td>
</tr>
<tr>
<td>169 Er</td>
<td>0.068</td>
<td>0.078</td>
<td>0.081</td>
<td>0.078</td>
<td>0.024</td>
<td>0.041</td>
<td></td>
</tr>
</tbody>
</table>

*No specific factor available.*
nuclides have been normalized to this response so that they are independent of the temporary setting of the calibrator. Dose calibrator efficiencies for $\gamma$-emitters using the manufacturer’s calibration factors are satisfactory (Table 4). The uncertainty of these results is about 5% (1 $\sigma$). However, it is worth noting that the manufacturer’s calibration conditions are unknown (e.g., vial type) and that a difference between these conditions and the current measurement geometry could cause a difference of some percentages in $\text{Rn}$, which is acceptable.

### Efficiency for $\beta$-Emitters

For $\beta$-emitters, important differences in intrinsic efficiency are related to the maximum energy of the $\beta$-spectrum (Table 5).

For $^{32}\text{P}$ ($E_{\text{max}} = 1.7 \text{ MeV}$), results are excellent for all calibrators, with the difference between calibrators $<10\%$, indicating that this nuclide could be used as a reference for ionization chamber calibration for $\beta$-emitters.

For $^{89}\text{Sr}$ ($E_{\text{max}} = 1.5 \text{ MeV}$), all commercially available calibrators show efficiency reduced by 16%–20%. For the Centronic and Capintec $\beta$ instruments, reductions are 7% and 13%, respectively. The small difference in intrinsic sensitivity for $^{32}\text{P}$ and $^{89}\text{Sr}$ is expected because of the small difference in maximum $\beta$-energy for the 2 nuclides.

For $^{90}\text{Y}$ ($E_{\text{max}} = 2.3 \text{ MeV}$), a significant increase in intrinsic efficiency is observed for all calibrators. The enhancement factor of the response is considerably different for different calibrators and varies between 1.5 and 2.8. It is possible that a fraction of the $\beta$-particles reaches the sensitive volume of the ionization chamber and that the size of this fraction is strongly related to chamber construction.

Efficiency for $^{169}\text{Er}$ ($E_{\text{max}} = 0.35 \text{ MeV}$) is very low. For the 4 commercially available calibrators, response compared with $^{32}\text{P}$ is reduced by a factor of about 12. For the Centronic and Capintec $\beta$ systems the reduction is even more significant.

To summarize, all systems have a good calibration for $^{32}\text{P}$ and a reduction in efficiency for $^{90}\text{Sr}$ of $<20\%$. For high-energy $\beta$-emitters ($^{90}\text{Y}$), there is a strong divergence in intrinsic efficiency for different calibrators. For low-energy $\beta$-emitters ($^{169}\text{Er}$), intrinsic efficiency is greatly reduced, but commercially available calibrators show approximately the same response reduction.

The results obtained using the calibration factors supplied by the manufacturers (Table 6) show that these factors do not adequately correct the intrinsic efficiencies.

For $^{89}\text{Sr}$, the results for all calibrators are satisfactory, with the exception of the Isomed instrument. In this case, the calibration factor adjusts the measurement in the wrong direction in relation to $^{32}\text{P}$. For this instrument, better results would be obtained using the $^{32}\text{P}$ factor.

For $^{90}\text{Y}$, the sensitivity factors for the VEENSTRA and Atomlab (BIODEX Medical Systems, Inc., New York, NY) are too small compared with the factor for $^{32}\text{P}$, and the sensitivity factor for the Isomed is too high.

For $^{169}\text{Er}$, the most critical nuclide, calibration factors are not available for the Atomlab and Capintec CRC calibrators. For the VEENSTRA and Isomed calibrators, activity is underestimated by factors of 3 and 1.5, respectively.

The difference in response between the calibrators is significant and possibly can be attributed to differences in measurement conditions.

The ratios of the glass vial measurement to the syringe measurement (Table 7), with the exceptions of $^{169}\text{Er}$ and the Isomed yttrium measurement are between 0.9 and 1.1. For the Isomed, one could suspect that the reduced efficiency for yttrium in vial geometry is related to the reduced fraction of $\beta$-particles reaching the chamber sensitive volume. This result and the strong overestimation in syringe geometry

### TABLE 7
Ratio of Glass Vial Measurements to Syringe Measurements

<table>
<thead>
<tr>
<th>Emitter</th>
<th>VEENSTRA</th>
<th>Atomlab 100</th>
<th>Isomed 1000/2000</th>
<th>Capintec CRC</th>
<th>Centronic IG12</th>
<th>Capintec β</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{32}\text{P}$</td>
<td>0.97</td>
<td>0.92</td>
<td>1.01</td>
<td>0.92</td>
<td>1.02</td>
<td>1.28</td>
</tr>
<tr>
<td>$^{89}\text{Sr}$</td>
<td>0.94</td>
<td>0.89</td>
<td>0.98</td>
<td>0.89</td>
<td>1.01</td>
<td>1.03</td>
</tr>
<tr>
<td>$^{90}\text{Y}$</td>
<td>1.08</td>
<td>1.02</td>
<td>0.65</td>
<td>1.02</td>
<td>1.07</td>
<td>1.24</td>
</tr>
<tr>
<td>$^{169}\text{Er}$</td>
<td>0.77</td>
<td>0.73</td>
<td>0.86</td>
<td>0.69</td>
<td>0.96</td>
<td>0.96</td>
</tr>
</tbody>
</table>

*No specific factor available.

### TABLE 8
Intrinsic Efficiency of Dose Calibrators for $\beta$-Emitters with a $\gamma$-Component

<table>
<thead>
<tr>
<th>$\beta$-Emitter</th>
<th>VEENSTRA VDC-405</th>
<th>Atomlab 100</th>
<th>Isomed 1000/2000</th>
<th>Capintec CRC</th>
<th>Centronic IG12</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{153}\text{Sm}$</td>
<td>41.5</td>
<td>42.9</td>
<td>47.7</td>
<td>43.0</td>
<td>*</td>
</tr>
<tr>
<td>$^{186}\text{Re}$</td>
<td>6.30</td>
<td>5.93</td>
<td>7.57</td>
<td>6.14</td>
<td>7.27</td>
</tr>
</tbody>
</table>

*No specific factor available.

### TABLE 9
Efficiency of Dose Calibrators for $\beta$-Emitters with a $\gamma$-Contribution

<table>
<thead>
<tr>
<th>$\beta$-Emitter</th>
<th>VEENSTRA VDC-405</th>
<th>Atomlab 100</th>
<th>Isomed 1000/2000</th>
<th>Capintec CRC</th>
<th>Centronic IG12</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{153}\text{Sm}$</td>
<td>*</td>
<td>1.24</td>
<td>1.09</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>$^{186}\text{Re}$</td>
<td>1.00</td>
<td>1.00</td>
<td>0.98</td>
<td>0.96</td>
<td>1.22</td>
</tr>
</tbody>
</table>

*No specific factor available.
could be explained by a manufacturer calibration in vial geometry. However, for \(^{160}\text{Er}\) the reduction in efficiency in changing from syringe to glass vial geometry is <20\%, so this effect alone cannot explain the change in response by a factor of 3.

**Efficiency for \(\beta\)-Emitters with a \(\gamma\)-Component**

For both \(^{153}\text{Sm}\) and \(^{186}\text{Re}\), the intrinsic efficiency is high compared with \(^{32}\text{P}\) (Table 8). The relative efficiency between \(^{153}\text{Sm}\) and \(^{186}\text{Re}\) is proportional to the \(\gamma\)-emission probability of each nuclide, suggesting that efficiency is determined by the \(\gamma\)-contribution. Efficiency is approximately the same for all of the calibrators.

The efficiency obtained using the calibration factors supplied by the manufacturers (Table 9) is in most cases between 0.9 and 1.1.

The syringe geometry used for these measurements may differ from the manufacturers’ calibration geometry, but this should not be significant because it is the \(\gamma\)-component that mainly determines response.

**CONCLUSION**

This work confirms that commercially available dose calibrators are well calibrated for \(\gamma\)-emitting radionuclides (accuracy better than 10\%). The calibrators are also generally well calibrated for \(\beta\)-emitting nuclides with a nonnegligible \(\gamma\)-component used for bone palliation (\(^{153}\text{Sm}\) and \(^{186}\text{Re}\)).

Intrinsic efficiency measurements show that although sensitivity to \(\beta\)-radiation is low, it is possible to measure \(\beta\)-activity using these instruments. A calibration factor specific to the measurement conditions should be used.

Manufacturer-supplied calibration factors are unsatisfactory for high-energy \(\beta\)-emitters (\(^{90}\text{Y}\)) and low-energy \(\beta\)-emitters (\(^{160}\text{Er}\)). For these nuclides, differences in efficiency observed cannot be attributed to differences in measurement conditions. This is a problem recognized by dose calibrator manufacturers, and new calibration techniques are under investigation.

Our results also show that calibration factors can correctly be applied to all calibrators of the same type. Dose calibrators used in nuclear medicine laboratories could be calibrated by the manufacturers for all \(\beta\)-emitters clinically used and be regularly verified using only 1 \(\beta\)-emitter (e.g., \(^{32}\text{P}\)).

It is recommended that users contact the supplier of their calibrator to verify the validity of the calibration factors for \(\beta\)-emitters, in preference to adjusting these factors themselves.

Further investigations using Monte Carlo calculations are in progress to better quantify the effect of measurement conditions on dose calibrator efficiency.

**ACKNOWLEDGMENTS**

The authors thank the companies Uehlinger Piffner AG (Schöftland, Switzerland) and Goetele (Frauenfeld, Switzerland) for kindly making available the activimeters and the task group established by the Swiss Federal Office for Metrology and Accreditation and the Federal Office for Public Health for discussions and support.

**REFERENCES**