
PTB
333-91
Fe-55
RADIO
Co-60

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# 1. PLACING OF ORDERS

## 1.1 General

The Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig and Berlin is the national institute for science and technology and the highest technical authority of the Federal Republic of Germany for the field of metrology and certain sectors of safety engineering.

The PTB comes under the auspices of the Federal Ministry of Economy and Labour. It meets the requirements for calibration and testing laboratories as defined in the EN ISO/IEC 17025.

It is the fundamental task of the PTB to realize and maintain the legal units in compliance with the International System of Units (SI) and to disseminate them, above all within the framework of legal and industrial metrology. The PTB thus is on top of the metrological hierarchy in Germany. Calibration certificates issued by it document that the object calibrated is traceable to national standards.

To ensure worldwide coherence of measures, the PTB cooperates with other national metrology institutes within EUROMET on the regional European level and on the international level within the framework of the Metre Convention. The aim is achieved by an intensive exchange of results of research work carried out and by comprehensive international comparison measurements.

Within the scope of the PTB's activities, the PTB's "Unit of Activity" Section is concerned with activity measurements and with the preparation of activity standards. The present catalogue describes the activity standards in their various forms available (solutions and solid sources).

## 1.2 Order

Orders may be placed in writing or by fax; they should comprise the following information:

- Name and address
- Customers Order number
- Address for deliveries
- Radionuclide and type of activity standard (e.g. solution, point source, area source)
- Desired specific activity (solutions) or desired activity (solid sources)
- Information about tolerable deviations from the activity ordered


Address: Physikalisch-Technische Bundesanstalt
Department 6.1
Bundesallee 100
D-38116 Braunschweig

Fax: +49 531 592-6305

Telephone: +49 531-592-6315 Mrs. M. Ehlers
+49 531-592-6110 Dr. K. Kossert
+49 531-592-6100 Dr. D. Arnold

e-mail addresses: Marion.Ehlers@ptb.de
Karsten.Kossert@ptb.de
Dirk.Arnold@ptd.de

## 1.3 Delivery

The standards ordered will usually be delivered within four weeks after receipt of the order. Otherwise, the customer will be informed about the date of delivery.

Usually, the standards ordered will be forwarded directly to the address stated, through a forwarding agency which has been granted the required transport licences. Deliveries abroad will in certain cases be sent by air freight. The resulting transport costs will be invoiced in addition; for budgetary reasons, the PTB is not in a position to integrate the transport costs into the total costs as is common practice in private firms. For the delivery of radioactive standard sources only the General Terms and Conditions of Business (AGB) of the PTB are exclusively valid.

## 1.4 Costs

The PTB calculates the costs to be paid in accordance with the "Regulations governing charges for services rendered by the PTB" in their version valid at the time in question (as published in the Bundesgesetzblatt, Teil I). For the delivery of certain activity standards, the PTB charges average fees which depend on the average time required for preparing the activity standard (including determination of the activity and quality assurance measures), and for order processing. The average fees applicable are published in the *PTB-Mitteilungen*. For orders from countries outside the European Community, additional fees will be charged for the additional work involved in the processing of the order.

The costs do not include forwarding charges. They are not subject to VAT (value-added tax) according to the present valid version of the Umsatzsteuergesetz (turnover tax law). Deduction of a discount is not permissible. Payments are to be made within 14 days after the date of the bill of costs.
The costs are subject to alteration.

## 1.5 Handling of radioactive material

Handling of radioactive material is governed by the German Radiation Protection Ordinance (Strahlenschutzverordnung, BGBl. I, 2001, p. 1714).

Radioactive material with activity values above the maximum permissible level may be delivered only if the receiver has a valid licence for handling these substances (sections 7 and 8 of the Ordinance). When radioactive material handling of which requires a licence, is purchased for the first time, the orderer is requested to enclose to the order a copy of the respective licence. Please inform the PTB in good time also about any changes of, and supplements to, the licence.

If several radionuclides or a radionuclide mixture of known composition are purchased at the same time, the maximum permissible level is to be determined as the sum of the nuclide fractions. The maximum permissible level is reached when the sum of the ratios of activity and maximum permissible level of the individual radionuclides reaches the value 1.

**Table 1:** Maximum permissible levels according to the German Radiation Protection Ordinance

| Nuclide | Maximum permissible level in kBq | Nuclide | Maximum permissible level in kBq | Nuclide | Maximum permissible level in kBq |
|---|---|---|---|---|---|
| H-3 | 1000000 | Sr-89 | 1000 | Ce-141 | 10000 |
| Be-7 | 10000 | Sr-90 | 10 | Ce-144 | 100 |
| C-14 | 10000 | Nb-93m | 10000 | Pm-147 | 10000 |
| Na-22 | 1000 | Mo-99 | 1000 | Eu-152 | 1000 |
| P-32 | 100 | Ru-103 | 1000 | Ir-192 | 10 |
| S-35 | 100000 | Ru-106 | 100 | Ta-182 | 10 |
| Cr-51 | 10000 | Cd-109 | 1000 | Hg-203 | 100 |
| Mn-54 | 1000 | Ag-110m | 1000 | Tl-204 | 10 |
| Fe-55 | 1000 | Sn-113 | 10000 | Bi-207 | 1000 |
| Co-56 | 100 | Te-123m | 10000 | Pb-210 | 10 |
| Co-57 | 1000 | Sb-124 | 1000 | Rn-222 | 100000 |
| Co-58 | 1000 | Sb-125 | 1000 | Ra-226 | 10 |
| Fe-59 | 1000 | I-125 | 1000 | Th-230 | 10 |
| Co-60 | 100 | I-131 | 1000 | Th-232 | 10 |
| Zn-65 | 1000 | Ba-133 | 1000 | Th-232sec | 1 |
| Se-75 | 1000 | Xe-133 | 10 | Th | 1,16* |
| Kr-85 | 10 | Cs-134 | 10 | Am-241 | 10 |
| Sr-85 | 1000 | Cs-137 | 10 | U | 10** |
| Y-88 | 1000 | Ce-139 | 1000 | | |

* This value corresponds to the total activity of the isotopes present in thorium activity standards of the PTB: Th-232sec and Th-230.

** This value corresponds to the total activity of the isotopes present in uranium activity standards of the PTB: U-238, U-234 and U-235.

# 2 TECHNICAL INFORMATION

## 2.1 Activity standards

This catalogue offers activity standards in the form of solutions and solid sources. For each activity standard, a calibration certificate is issued which states the specific activity (activity divided by mass of solution) and the solution mass or the activity and the assigned uncertainties valid at a defined reference time.

The activity standards are manily used for the calibration of measuring devices or as reference standards in relative measurements. The user may also prepare on his own special sources (e.g. filter sources) of defined activity from a solution. This is advisable in particular when uniformity of the dimensions and self-absorption of activity standard and sample to be measured are important.

Raw solutions of particular radionuclides which are important for calibrations (e.g. Be-7, Sr-85, Y-88, Ce-139) are no longer, or only occasionally, offered by producers. The dates of delivery for activity standards of such radionuclides are, therefore, undefined. In the tables of this catalogue, these radionuclides have been specially identified in the column "Availability".

Activity standards of radionuclides which are not stated in the tables of this catalogue may also be obtainable, however at irregular intervals. Deliveries in past years covered, for example, activity standards of the nuclides P-32, Co-56, Co-58, Fe-59, Se-75, Ru-106, Ag-110m, Sb-124, Ce-141, Ta-182, Ir-192 and Hg-203.

Please inform us if you are at long terms interested in certain radionuclides which are not always available.

For e-mail, telephone, fax, address, see section "Placing of order" above. As soon as activity standards of these nuclides are ready for delivery, you will be informed accordingly.

## 2.2 Calibrations and sources prepared to specification

In addition to delivering activity standards in the form of solutions and solid sources, PTB Section 6.11 also determines the activity of radioactive solutions and sources submitted by customers. Moreover, special activity standards may be prepared on request. The customer is, however, requested to inform the PTB by phone about the calibration problem before the order is placed.

Radioactive gases of the nuclides Kr-85 and Xe-133 filled in conventional ampoules may be handed in for calibration at any time; please inform PTB two weeks in advance.

It is also possible to obtain other kind of solutions and solid sources than those described in this catalogue from calibration laboratories of the German Calibration Service (Deutscher Kalibrierdienst, DKD) or to have activity determinations carried out there. DKD calibration laboratories are accredited laboratories of industry and of other institutions, whose personnel and equipment are capable of carrying out measurements of the required accuracy and whose measurement standards are traceable to the national standards held at PTB. Accreditation is granted by PTB after the metrological competence of the laboratory in question has been assessed. The calibration centres carry out the desired calibrations and issue a calibration certificate for the results obtained.

## 2.3 Methods of measurement applied in activity determinations

The measured values stated in the calibration certificates are based on activity determinations carried out by absolute methods, in most cases by the $4\pi\beta$-$\gamma$ coincidence method. The state of the art reached in metrology on the international level is guaranteed by the PTB's participating in international comparison measurements organised by the Bureau International des Poids et Mesures (BIPM), Sèvres, France. Various relative measurement devices, such as $4\pi$-ionization chambers, NaI and semiconductor spectrometers of high reproducibility and constancy with time are available, which have been calibrated against activity standards whose absolute values were measured. They allow the activity to be determined quickly at any time and without a considerable increase in measurement uncertainty.

## 2.4 Activity ranges

The activity ranges stated in the tables of this catalogue give a rough survey of the orders of magnitude of the activity values available. In the case of short-lived radionuclides, the reference time is the date at which the delivery begins. When activity standards of these radionuclides are ordered, the decrease in activity with time is to be taken into account. It is always recommended to indicate a desired range of activity upon placing of the order.

## 2.5 Uncertainties of measurement

The stated uncertainty of a standard covers the uncertainty components of the individual calibration caused by dilution, measuring technique, decay scheme, half-life and many other factors, and, in an appropriate way, the deviations found during international comparison measurements and internal calibrations carried out on different solutions and at different times.

The uncertainty stated in a calibration certificate is the expanded uncertainty of measurement obtained by multiplying the standard uncertainty by a coverage factor $k = 2$. Standard uncertainties are determined in accordance with the "Guide to the Expression of Uncertainty in Measurement" (ISO, 1995). Normally, the value of a measurand lies within the assigned range of values with a probability of 95 %.

## 2.6 Radionuclide data

The half-lives, energies and emission probabilities per decay stated in this catalogue have been taken from the following tables:

1. Schötzig, U. and Schrader, H.:
   Half-lives and photon emission probabilities of frequently used radionuclides. Report PTB-Ra-16/5, Braunschweig 2000

2. IAEA-TECDOC-619: X-Ray and Gamma-Ray Standards for Detector Calibration, Vienna 1991

## 3 ACTIVITY STANDARDS IN THE FORM OF SOLUTIONS

### 3.1 Solutions of individual nuclides

Activity standards in the form of solutions are delivered in sealed Jena glass ampoules. They are 15,2 mm in diameter, about 60 mm in height, and their wall thickness is 0,5 mm. They normally contain 2 mL of the respective solution.

The chemical composition of the solution is selected such that its stability is guaranteed at a minimum concentration of solid matter and acid. When dilutions are prepared, in particular in glass jars, the concentration of the inactive carrier stated in the calibration certificate should at least be maintained to avoid wall adsorption of the radionuclide.

On request, solutions of lower specific activity can be prepared by dilution of the solutions available. The customer will be charged with the production costs of the solution.

At irregular intervals, activity standards of other nuclides than those stated in the Table "Activity standards in the form of solutions" can be delivered in the form of solutions (cf. above: Activity standards).

The calibration certificate is accompanied by a data sheet stating the values of the radionuclide constants (photon energies and photon emission probabilities per decay and, where appropriate, maximum and mean beta-particle energies) recommended by the PTB.

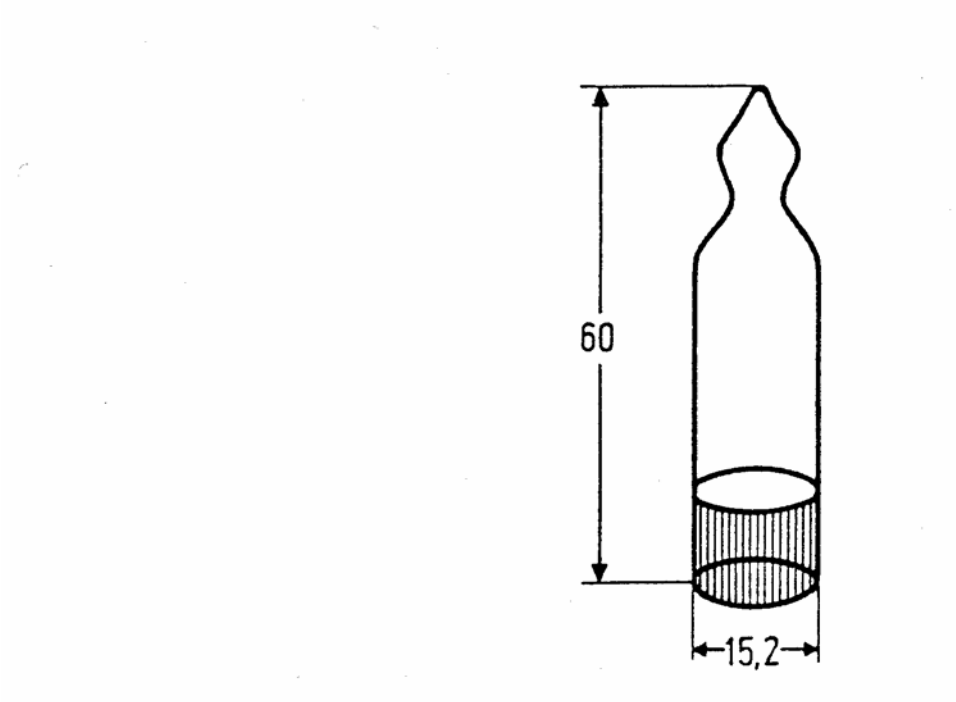



Figure 1**:** Ampoule dimensions (in millimetres)

**Table 2:** Activity standards in the form of solutions

| Nuclide | Half-life- | Chemical composition of the solution | Specific Activity in kBq/g | Uncertainty in % (3) | Availability |
|---|---|---|---|---|---|
| H-3 | 12,33 a | $H_2O$ | 5<br>50;500<br>5000;50000 | 1,7<br>1,4<br>1,4 | ex stock |
| Be-7 | 53,23 d | $BeCl_2$<br>HCl 0,1 mol/L | 200;2000 | 1,4 | (2) |
| C-14 | 5730 a | $Na_2CO_3$<br>NaOH 0,001 mol/L | 10;100<br>1000;10000 | 3,3<br>3,3 | ex stock |
| Na-22 | 950,5 d | NaCl<br>HCl 0,1 mol/L | 10<br>100;1000 | 1<br>0,7 | ex stock |
| Cr-51 | 27,71 d | $CrCl_3$<br>HCl 0,1 mol/L | 20<br>200;2000 | 1,4<br>1 | (1) |
| Mn-54 | 312,15 d | $MnCl_2$<br>HCl 0,1 mol/L | 10<br>100;1000 | 1<br>0,7 | ex stock |
| Fe-55 | 1005 d | $FeCl_3$<br>HCl 0,1 mol/L | 200;2000 | 2,5 | ex stock |
| Co-57 | 271,83 d | $CoCl_2$<br>HCl 0,1 mol/L | 20<br>200;2000 | 1,4<br>1 | ex stock |
| Co-60 | 1925,3 d | $CoCl_2$<br>HCl 0,1 mol/L | 4;40<br>400;4000 | 1<br>0,7 | ex stock |
| Zn-65 | 243,94 d | $ZnCl_2$<br>HCl 0,1 mol/L | 20<br>200;2000 | 1,4<br>1,4 | ex stock |
| Sr-85 | 64,85 d | $SrCl_2$<br>HCl 0,1 mol/L | 20<br>200;2000 | 1,4<br>1 | (2) |
| Y-88 | 106,63 d | $YCl_3$<br>HCl 0,1 mol/L | 10<br>100;1000 | 1,4<br>1 | (2) |

**Table 2:** Activity standards in the form of solutions

| Nuclide | Half-life | Chemical composition of the solution | Specific Activity in kBq/g | Uncertainty in % (3) | Availability |
|---|---|---|---|---|---|
| Sr-89 | 50,53 d | $SrCl_2$<br>HCl 0,1 mol/L | 2;20<br>200;2000 | 2<br>1,7 | (1) |
| Sr-90 | 28,81 a | $SrCl_2$+$YCl_3$<br>HCl 0,1 mol/L | 0,4;4<br>40;400;4000 | 1,7<br>1,4 | ex stock |
| Cd-109 | 462,1 d | $CdCl_2$<br>HCl 0,1 mol/L | 10;100<br>1000 | 1,7<br>1,7 | ex stock |
| Sb-125 | 1007,7 d | $SbCl_3$ and tartaric acid<br>HCl 2 mol/L | 10<br>100;1000 | 1,7<br>1,4 | ex stock |
| I-125 | 59,39 d | NaI and $Na_2S_2O_3$ with<br>0,1 % formalin | 10<br>100;1000 | 1,7<br>1,4 | (1) |
| I-129 | $1{,}57 \cdot 10^7$ a | NaI and $Na_2S_2O_3$ with<br>0,1 % formalin | 1 | 3,3 | ex stock |
| I-131 | 8,021 d | NaI and $Na_2S_2O_3$ with<br>0,1 % formalin | 4<br>1000 | 1<br>0,7 | March/<br>April |
| Ba-133 | 10,54 a | $BaCl_2$<br>HCl 0,1 mol/L | 0,4;4<br>40;400;1000 | 1,4<br>1 | ex stock |
| Cs-134 | 754,0 d | CsCl<br>HCl 0,1 mol/L | 10<br>100;1000 | 1<br>0,7 | ex stock |
| Cs-137 | 30,13 a | CsCl<br>HCl 0,1 mol/L | 0,4;4<br>40;400;4000 | 1,4<br>1 | ex stock |
| Ce-139 | 137,66 d | $CeCl_3$<br>HCl 1 mol/L | 10;100<br>1000 | 1<br>1 | (2) |
| Ce-144 | 284,7 d | $CeCl_3$<br>HCl 1 mol/L | 10;100<br>1000 | 1,4<br>1,4 | ex stock |

**Table 2:** Activity standards in the form of solutions

| Nuclide | Half-life | Chemical composition of the solution | Specific Activity in kBq/g | Uncertainty in % (3) | Availability |
|---|---|---|---|---|---|
| Pm-147 | 958,20 d | $NdCl_3$<br>HCl 0,5 mol/L | 40;400<br>4000 | 2<br>2 | ex stock |
| Eu-152 | 13,53 a | $EuCl_3$<br>HCl O,1 mol/L | 4<br>40;400;4000 | 2<br>1,4 | ex stock |
| Tl-204 | 1381 d | $Tl_2SO_4$<br>$HNO_3$ 0,1 mol/L | 6<br>60;600 | 1,7<br>1,4 | ex stock |
| Bi-207 | 31,55 a | $BiCl_3$<br>HCl 1 mol/L | 15 | 1,4 | ex stock |
| Pb-210 | 22,3 a | $Pb(NO_3)_2$ +$Bi(NO_3)_3$<br>$HNO_3$ 1,2 mol/L | 1,5<br>15;150;1500 | 1,7<br>1,4 | ex stock |
| Ra-226 | 1600 a | $BaCl_2$<br>HCl | 0,1; 1 | 1,4 | ex stock |
| Am-241 | 432,2 a | $La(NO_3)_3$<br>$HNO_3$ 0,1 mol/L | 1; 4<br>40;400;4000 | 1,4<br>1 | ex stock |

(1) The solutions are prepared and delivered yearly. The dates of delivery will be announced in good time. Please let us know about which deliveries you wish to be informed.

(2) Raw solutions of this radionuclide are offered only rarely by the producers. The dates of delivery for activity standards are, therefore, undefined.

(3) The uncertainty stated is the relative expanded uncertainty of measurement in percent obtained by multiplying the standard uncertainty by a coverage factor $k = 2$.

## 3.2 Mixed solutions

These solutions are intended to serve as calibration solutions for systems used to measure aqueous samples of low activity at short distances from the detector.

Available are plastic bottles (content: 100 mL) or glass ampoules (content: 2 mL) of identical total activity. The carrier concentration of the solution in plastic bottles is so high that a filling quantity of up to 1 L can be obtained when water which has been distilled twice is added after the solution has been filled into the measuring vessel. The ampoules are delivered together with a carrier solution. A data sheet states recommended values of half-lives, photon energies and photon emission probabilities per decay.

**Mixed solution 2 (ML 2)** is intended to serve as a reference solution for waste water measurements in nuclear power plants.

**Mixed solution 4 (ML 4)** allows germanium detectors to be quickly and accurately calibrated in the low-energy range between 40 keV and 130 keV. As no experience has so far been gained as regards the stability of this solution during further processing, the PTB's advice is not to mix this solution with other solutions.

**Mixed solution 5 (ML 5)** serves to quickly and accurately calibrate radiation detectors - in particular NaI(Tl) detectors - with respect to the efficiencies specific to the cesium isotopes contained in it. The activity values $A$ are set in such a way that, related to January 1,1996, the following is valid:

$A$(Cs-137)/$A$(Cs-134) = 6,8.

The relative expanded measurement uncertainty ($k$ = 2) of the individual activity values lie between 1,0 % and 1,7 % for all solutions.

Mixed solutions of other radionuclide compositions are available from commercial suppliers who have a calibration laboratory which has been accredited within the German Calibration Service (DKD). DKD-calibration certificates issued by accredited laboratories document that the object calibrated is traceable to national standards of the PTB. Please phone PTB in case of need.

**Table 3:** Composition of the mixed solutions

**MIXED SOLUTION 2**

| Nuclide | Half-life | Gamma radiation Energy in keV | Emission-probability in % | Activity in kBq |
|---|---|---|---|---|
| Co-60 | 1925,3 d | 1173,2<br>1332,5 | 99,857<br>99,983 | 10 |
| Cs-134 | 754,0 d | 569,3<br>604,7<br>795,9 | 15,39<br>97,63<br>85,4 | 10 |
| Cs-137 | 30,13 a | 661,7 | 85,1 | 10 |

**MIXED SOLUTION 4**

| Nuclide | Half-life | Gamma radiation Energy in keV | Emission-probability in % | Activity in kBq |
|---|---|---|---|---|
| Co-57 | 271,83 d | 122,1<br>136,5 | 85,60<br>10,68 | 4 |
| Cd-109 | 462,1 d | 88,0 | 3,63 | 20 |
| Pb-210 | 22,3 a | 46,54 | 4,24 | 20 |
| Am-241 | 432,2 a | 59,54 | 36,0 | 4 |

**MIXED SOLUTION 5**

Cs-134/Cs-137 MIXED SOLUTION (see page 17)

| Nuclide | Half-life | Gamma radiation | | Activity in kBq at 1.1.1996 |
|---|---|---|---|---|
| | | Energy in keV | Emission-probability in % | |
| Cs-134 | 754,0 d | 569,3<br>604,7<br>795,9 | 15,39<br>97,63<br>85,4 | 3 |
| Cs-137 | 30,13 a | 661,7 | 85,1 | 19 |

The statements for the emission probabilities per decay in table 3 are partly incomplete. Additionel photon radiations with low emission probabilities are listed in the report PTB-Ra-16/5.

# 4 ACTIVITY STANDARDS IN THE FORM OF SOLID SOURCES

## 4.1 Point sources of individual nuclides

Activity standards in the form of point sources are intended for the calibration of photon spectrometers. The radioactive substance is a very thin, compact-grained layer applied to a circular area about 5 mm in diameter, in the middle of the source between two polyethylene foils, each having a mass per unit area of (21,3 ± 1,8) mg·cm$^{-2}$. By heating under pressure, the two foils are welded together over the whole area so that they are leak-proofed. To facilitate handling, the foil 26 mm in diameter is mounted in a circular aluminium ring (outer diameter: 30 mm, height: 3 mm) from which it can easily be removed if and when required.

As the mechanical stress to which the sources are subject is low during the intended use, they are to be regarded as sealed radioactive sources in accordance with the German Radiation Protection Ordinance. It must, however, be ensured that the sources are not exposed to strong solvents and temperatures above 100 °C. Prior to their delivery, the sources are submitted to a wipe test to check their leak tightness and absence of contamination; they are released only if the activity of the wiped sample does not exceed 20 Bq. An emanation test is performed for Ra-226 sources.

The activity $A$ is stated in the calibration certificate accompanying the source. The emission rate $B$ for photons of a particular energy, which is often of interest, is determined from $A$ and from the emission probabilities $p$ stated in an information sheet according to $B = p \cdot A$.

The Table "Point sources of individual nuclides" only covers available sources or sources which can be obtained in regular time intervals. It is possible to prepare also solid sources from most of the nuclides stated in the Table "Activity standards in the form of solutions".

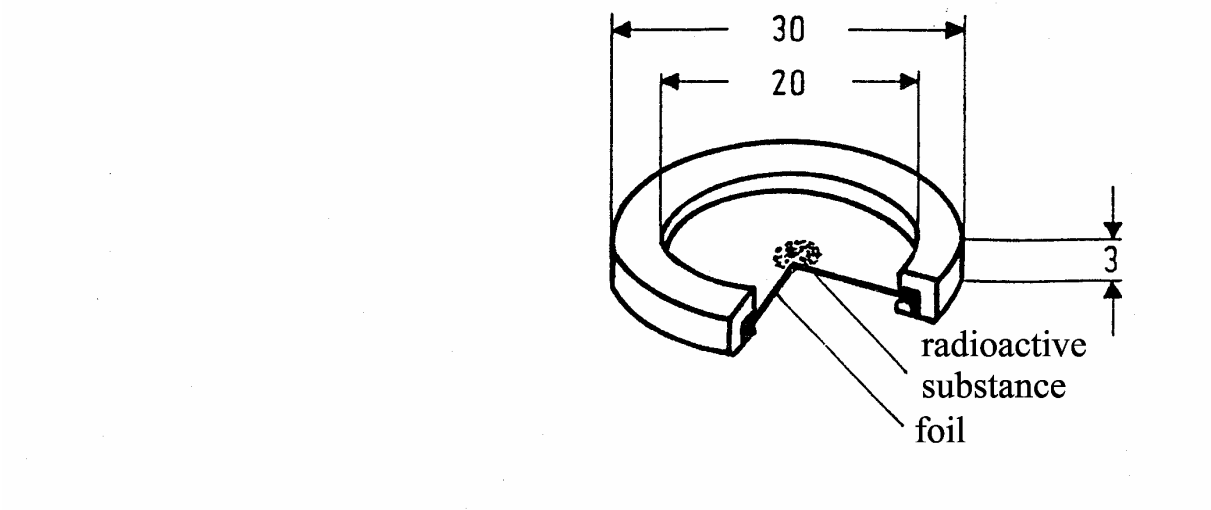



Figure 2: Dimensions of sources, in millimetres.

**Table 4:** Point sources of individual nuclides

| Nuclide | Half-life | Activity in kBq | Uncertainty in % (3) | Availability |
|---|---|---|---|---|
| Na-22 | 950,5 d | 4 to 400 | 0,7 | ex stock |
| Cr-51 | 27,71 d | 4 to 400 | 1 | (1) |
| Mn-54 | 312,15 d | 4 to 400 | 0,7 | ex stock |
| Co-57 | 271,83 d | 4 to 400 | 1 | ex stock |
| Co-60 | 1925,3 d | 4 to 400 | 0,7 | ex stock |
| Zn-65 | 243,94 d | 4 to 400 | 1 | ex stock |
| Sr-85 | 64,85 d | 4 to 200 | 1 | (1) |
| Y-88 | 106,63 d | 4 to 400 | 1 | (2) |
| Cd-109 | 462,1 d | 4 to 400 | 1,7 | ex stock |
| Ba-133 | 10,54 a | 4 to 400 | 1 | ex stock |
| Cs-134 | 754,0 d | 4 to 400 | 0,7 | ex stock |
| Cs-137 | 30,13 a | 1 to 400 | 1 | ex stock |
| Ce-139 | 137,66 d | 4 to 400 | 1 | (2) |
| Eu-152 | 13,53 a | 1 to 600 | 1,4 | ex stock |
| Ra-226 | 1600 a | 150 | 1,4 | ex stock |
| Am-241 | 432,2 a | 4 to 400 | 1 | ex stock |

(1) The sources are prepared and delivered once a year. The dates of delivery will be announced in good time. Please let us know on the enclosed printed form about which deliveries you wish to be informed.

(2) Raw solutions of this radionuclide are offered only rarely by the producers. The dates of delivery for activity standards are, therefore, undefined.

(3) The uncertainty stated is the relative expanded uncertainty of measurement in percent obtained by multiplying the standard uncertainty by a coverage factor $k = 2$.

## 4.2 Point sources with low-energy photon radiation

The sources described under "Point sources of individual nuclides" are only conditionally suitable as activity standards for photon radiation below 100 keV. In this energy range, increasing absorption and scattering effects occur in the relatively thick polyethylene foil. Whereas absorption can be determined rather well by calculation (approx. 1,7 % at 14 keV and 0,5 % at 30 keV), the scattering effects can hardly be quantified. Experiments with Si(Li) detectors have shown that scattering can give the deceptive impression of an up to 2,5 % higher detection probability in the total absorption line.

This is why sources enclosed in considerably thinner foils are prepared for more accurate measurements. In the case of these sources, the radioactive substance is enclosed between two polyester foils, each with a mass per unit area of $(2{,}20 \pm 0{,}07)\ mg \cdot cm^{-2}$. Both foils are welded together and pressed in an aluminium ring (outer diameter: 30 mm). For energies between 14 keV and 25 keV, absorption of the radiation by the foil is less than 0,3 %; for energies above 25 keV it is less than 0,1 %. Scattering effects are negligible.

These sources can be prepared from most of the solutions stated in the Table "Activity standards in the form of solutions". The following nuclides are recommended for the calibration of low-energy photon detectors.

| Nuclide | Energy in keV |
|---|---|
| Cr-51 | 4,95; 5,43 |
| Mn-54 | 5,41; 5,95 |
| Fe-55 | 5,90; 6,49 |
| Co-57 | 6,40; 7,06; 14,41 |
| Zn-65 | 8,04; 8,91 |
| Nb-93m | 16,58; 18,66 |
| Cd-109 | 22,10; 25,01; 88,03 |
| Ba-133 | 30,85; 35,14; 53,16; 79,62; 81,00 |
| Am-241 | 11,87; 13,93; 17,61; 21,00; 26,35; 59,54 |

The activity values cover a range between 40 kBq and 200 kBq.

In the case of sources of the nuclides Cr-51, Mn-54, Co-57 and Zn-65, self-absorption of K-x-rays can be observed in the layer containing the radioactivity contrary to absorption in the foil, it can only be estimated with low accuracy. The number of photons emitted per second vertical to the source at a solid angle of 1 steradian is, therefore, stated for these sources, in addition to the activity. For sources of the nuclide Fe-55, only this photon flux is indicated.

As the mechanical stress to which the sources are subject is low during the intended use, they are to be regarded as sealed radioactive sources in accordance with the German Radiation Protection Ordinance. It must, however, be ensured that the sources are not exposed to strong solvents and temperatures above 100 °C. Prior to their delivery, the sources are submitted to a wipe test to check their leak tightness and absence of contamination; they are released only if the activity of the wiped sample does not exceed 20 Bq.

Availability: on request.

### 4.3 Point sources from a mixture of various radionuclides

These sources are prepared on request.

### 4.4 Cylindrical sources

These sources are intended for the calibration of NaI(Tl) well-type crystal detectors. The radioactive substance is deposited at the lower end of an aluminium cylinder (outer diameter: 14 mm; height: 38 mm). Sources of the nuclides Co-60, Cs-137, Ra-226 and Am-241 with activities of approx. 1 kBq can be delivered. The relative expanded measurement uncertainty ($k$ = 2) of the activity is 2 %.

Availability: on request.

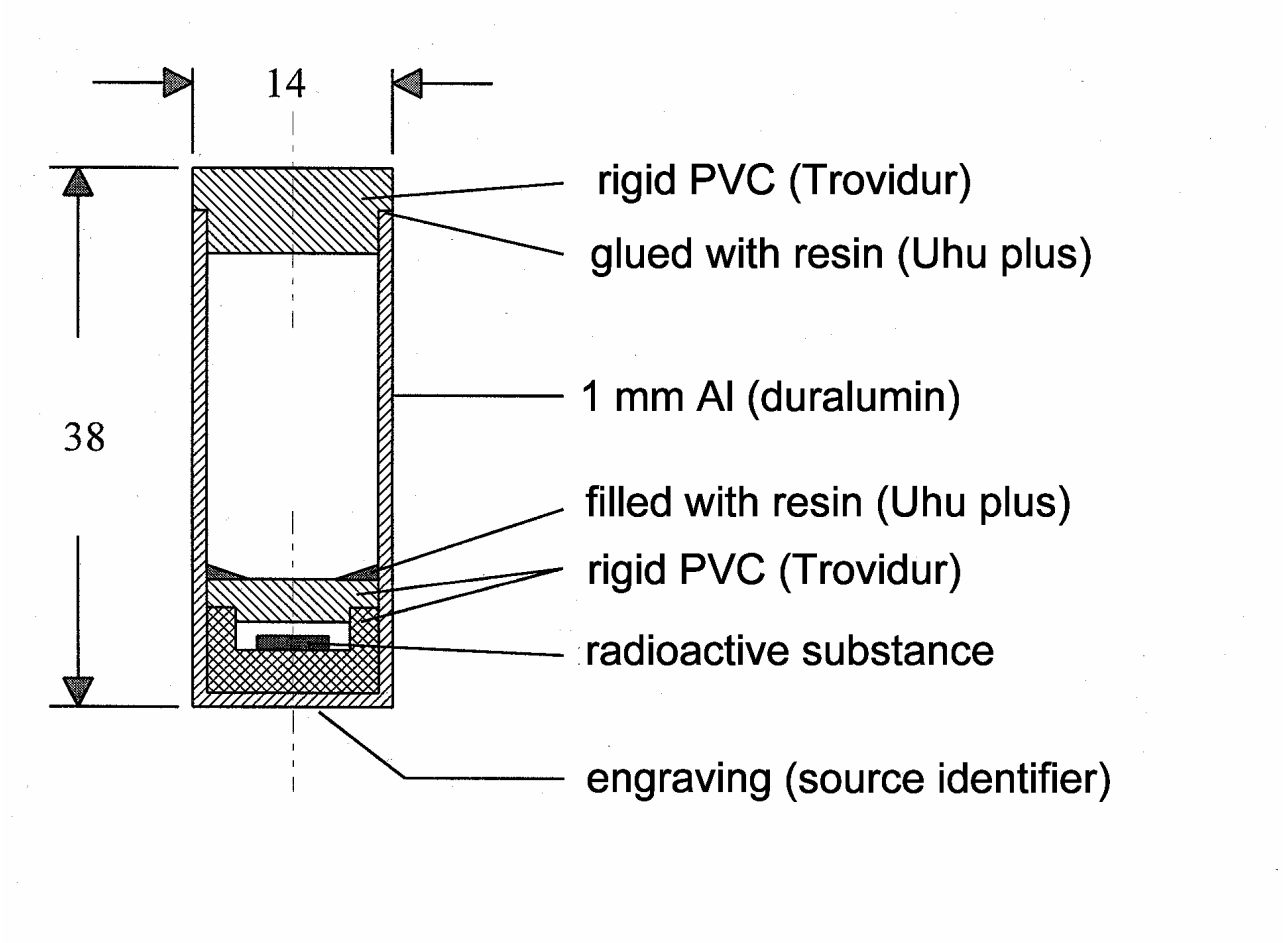



Figure 3: Construction and dimensions of a cylindrical source.

## 4.5 Point sources with Radium-226

The sources which are intended for the calibration of measuring devices with semiconductor detectors contain Ra-226 in equilibrium with its short-lived daughter products. The Ra-226 of a source is homogeneously distributed in a thin layer of precious metal roller-plated on a silver foil (thickness: 0,2 mm) and covered by a vacuum-evaporated AuPd layer 2 μm in thickness. The active layer is so thin that alpha-particles are still released.

A disc 2,5 mm in diameter with an activity of approx. 100 kBq of Ra-226 was cut from such a foil. The disc has been glued into an aluminium holder (outer diameter: 30 mm, thickness: 3 mm) and covered with an aluminium foil 50 μm in thickness to ensure additional sealing. Release of alpha-particles is prevented by this foil. The photon radiation is absorbed only slightly (0,16 % at $E$ = 0,2 MeV, 0,06 % at $E$ = 2 MeV). Radon release is below 4 Bq in 12 hours so that this source can be regarded as a sealed radioactive substance in accordance with the German Radiation Protection Ordinance.

When the source is used, the side showing the engraved label should be turned away from the detector, as the silver layer (0,2 mm in thickness) and the bottom of the aluminium holder considerably absorb gamma radiation in this direction.

The activity $A$ of the source is stated in the calibration certificate. The decay data of the source, which are important for its use (half-life $T_{1/2}$ and photon emission probabilities $p$), are stated on the enclosed data sheet. The emission rate $B$ for photons of a particular energy is obtained according to $B = p \cdot A$.

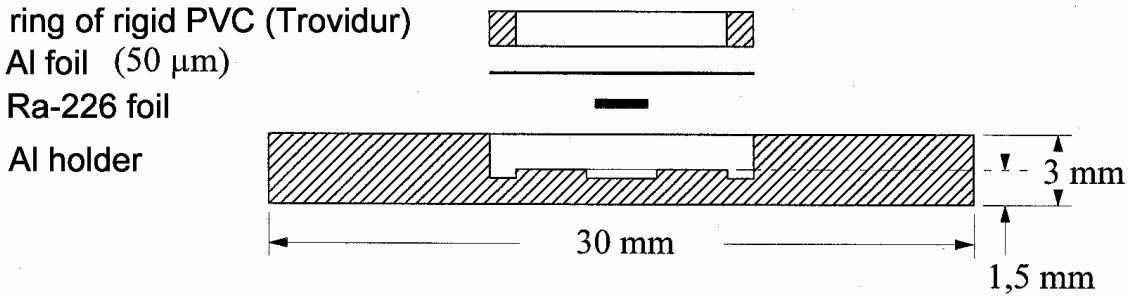



Figure 4: Sectional view of the sources with Ra-226

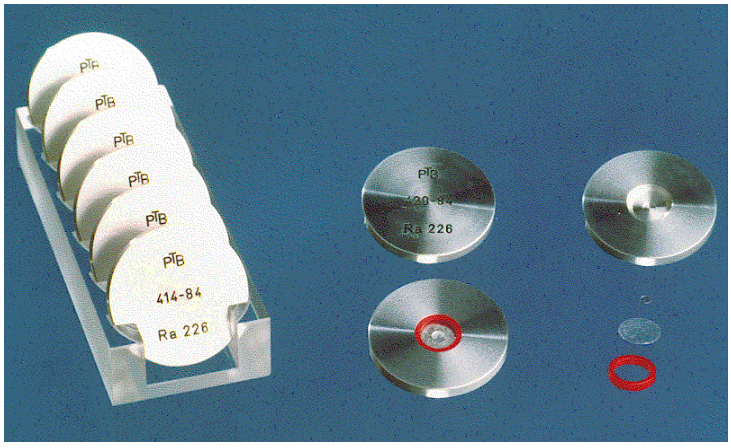



Figure 5: Ra-226 metall sources

## 4.6 Area sources

The determination of the activity of area sources (e.g. filter samples) at short distances from the detector requires calibration sources in which the activity is distributed as uniformly as possible over the area under study. In order to obtain a highly uniform activity distribution, area sources have been developed which are composed of point sources distributed in the form of regular patterns.

For the preparation of these sources, drops of similar mass are taken with a pipette from a calibrated solution and applied to the source backing (plastic foil) in one of the the patterns shown in Fig. 7, the masses of the individual drops vary by $\pm$ 5 % at the most. The activity of the source results from the specific activity of the solution used and the total mass of all drops, which is determined by weighing the pipette before and after application of the drops. The total mass ranges from 0,2 g to 2 g, depending on the size of the source. The uncertainty of the total activity is given by the uncertainty of the specific activity of the solution used, as the uncertainty of the drop masses is smaller by one order of magnitude. In the case of photon emitters, the radioactive residue of the dried-up solution is covered with a polyethylene foil with a density per unit area of (12,7 $\pm$ 0,4) mg·cm$^{-2}$; in the case of pure beta emitters, a polyester foil of (2,20 $\pm$ 0,07) mg·cm$^{-2}$ is applied. An adhesive layer on the rear allows the source to be fixed to a suitable support, if necessary, for example to a preparation dish.

On request, such sources are prepared from the mixed solutions and from all standard activity solutions stated in the Table "Activity standards in the form of solutions" - with the exception of H-3, C-14 and Ra-226.

Source sizes: 1 - 5 as indicated in Fig. 7, larger sources on request.

Availability: on request.

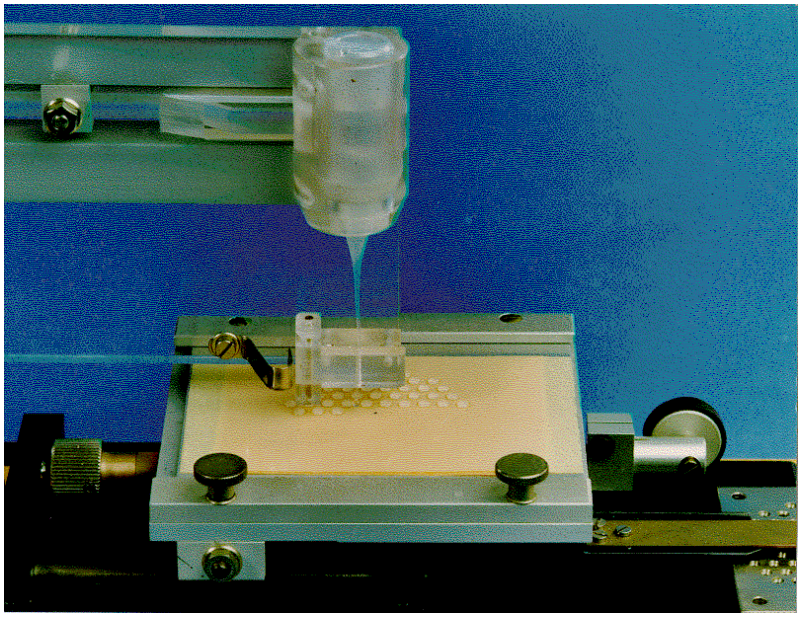
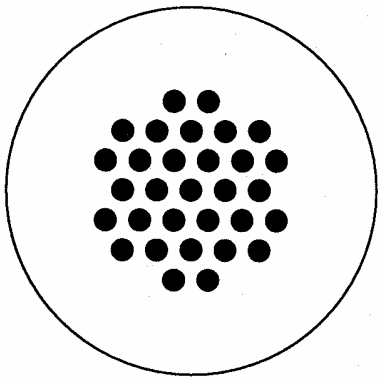
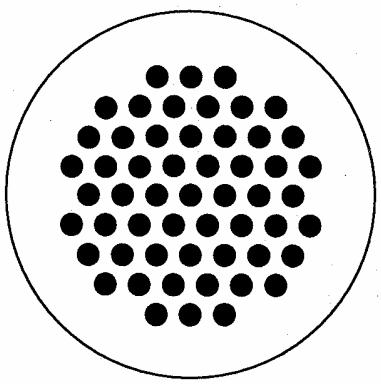


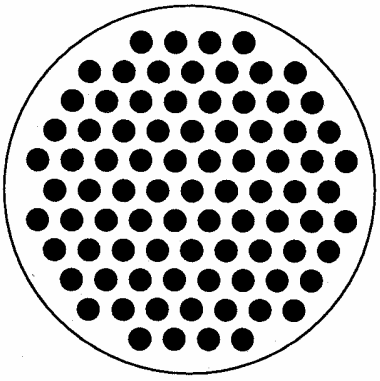
Figure 6: Device for the preparation of area sources



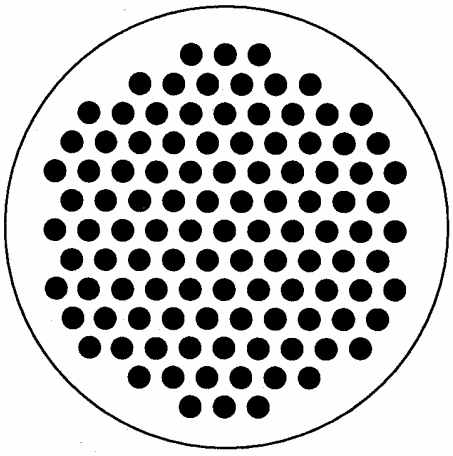
size 1
50 mm in diameter, 31 drops



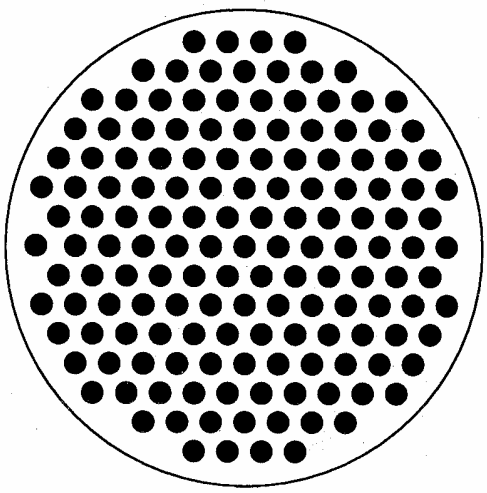
size 2
50 mm in diameter, 55 drops



size 3
50 mm in diameter, 85 drops



size 4
60 mm in diameter, 109 drops



size 5
65 mm in diameter, 151 drops

Figure 7: Drop patterns for area sources, not to scale

## 4.7 Alpha-particle sources

These sources serve to determine the detection probability of alpha-particle detectors in well defined geometries. The sources available are 5 mm, 10 mm and 25 mm in diameter and their activities range between 1 Bq and 5 kBq. The radioactive substance is electro-deposited on polished stainless steel discs 30 mm in diameter.

The radionuclide used is Am-241.

Alpha-emitting sources are not provided with a protective layer so that touching of the active area must be avoided. These sources are to be regarded as unsealed radioactive substances in view of the German Radiation Protection Ordinance.

The relative expanded measurement uncertainty ($k$ = 2) of the activity is 2 %.

Availability: on request.

# 5 THORIUM- AND URANIUM-ACTIVITY STANDARDS

## 5.1 Thorium-activity standard

### 5.1.1 Thorium-activity standards in the form of powder

The material used for the preparation of thorium-activity standards in the form of powder is pure thorium oxide ($ThO_2$) produced before 1950. The daughter products of Th-232 (Ra-228, Ac-228, Th-228,...) in the activity standards are, therefore, almost in radioactive equilibrium (within 1 %). In addition, the standards contain Th-230 of the uranium-radium series with a mass fraction in the order of $10^{-6}$. The activity fraction of Th-230 was determined by alpha-particle spectrometry. It amounts to $0{,}151 \pm 0{,}024$, related to the activity of Th-232.

Thorium-activity standards in the form of powders are made available as thorium oxide filled into tablet tubes (content: 10 g).

### 5.1.2 Thorium activity standards in the form of solution

The material used for the preparation of thorium-activity standards in the form of solutions is thorium nitrate dissolved in nitric acid. The thorium was separated in 1906. The daughter products of Th-232 (Ra-228, Ac-228, Th-228,...) in the activity standards are, therefore, almost in radioactive equilibrium. In addition, the standards contain Th-230 of the uranium-radium series with a mass fraction of the order of $10^{-6}$. The activity fraction of Th-230 was determined by alpha spectrometry. It amounts to $0{,}16 \pm 0{,}04$, related to the activity of Th-232.

The activity standards are delivered in the form of solutions filled into sealed glass ampoules (see 3.1) as $HNO_3$ solution (1 mol/L) with a thorium content of 0,2 mg or with 2 mg of thorium per gramme of solution.

## 5.2 Uranium-activity standards

The material used for the preparation of uranium-activity standards is pure triuranium octoxide ($U_3O_8$) in "natural isotopic composition". The isotopic fractions obtained by mass spectrometry are: 0,006 % of U-234, 0,713 % of U-235 and 99,28 % of U-238. From alpha-spectrometric measurements it can be concluded that U-234 and U-238 are in equilibrium with U-238 within 2 %.

The following standards are available:

a) Activity standards of triuranium octoxide, pulverised, filled into tablet tubes (content: 10 g);

b) Activity standards in the form of solutions, filled into sealed glass ampoules (see 3.1) as $HNO_3$ solution (1 mol/L) with a uranium content of 0,2 mg of uranium per gramme of solution;

c) Activity standards in the form of solutions, filled into sealed glass ampoules (see 3.1) as $HNO_3$ solution (1 mol/L) with a uranium content of 2 mg of uranium per gramme of solution.

Availability: ex stock.

## 6. Radon-in-gas activity standards

The source used for the preparation of radon-in-gas activity standards is solid radium sulphate in a special steel confinement, embedded in a filling facility made of special steel and evacuated before filling. This source allows Rn-222 with an activity $A$ of about 2,2 MBq to be produced. By evacuating the facility and subsequent cooling of a suitable filling vessel with liquid nitrogen, Rn-222 can be completely transferred from the source without use of a carrier gas. By adding a carrier gas ($N_2$) the pressure in the vessel can be increased up to ambient pressure.

Special steel cylinders with bellows-type valves (volume $V$ = 50 $cm^3$ or $V$ = 100 $cm^3$) or glass flasks of different volumes varying from $V$ = 40 $cm^3$ to $V$ = 140 $cm^3$ are preferably used as filling vessels. After consulting with the PTB, filling vessels may also be forwarded by the customer.

The activity of the radon gas is determined with the aid of a calibrated photon spectrometer by measuring the short-lived daughter products which are in radioactive equilibrium with Rn-222 after about 4 hours.

The relative expanded measurement uncertainty ($k$ = 2) assigned to the activity is 2 %.

Availability: on request.

## 7 NUCLIDE INDEX

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