

**A.O.U. “OSPEDALI RIUNITI” di TRIESTE
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THE ACTIVITY CALIBRATOR

Dr. Maria Rosa Fornasier

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THE ACTIVITY CALIBRATOR: GENERAL FEATURES

DETECTOR USED AS ACTIVITY CALIBRATOR → should have the following characteristics:

- Sensitive to energies between 25 keV and 2 MeV
[^{99m}Tc (140.5 keV), ⁵⁷Co (122.1 ; 136.5 keV), ⁵⁸Co (810.8 keV), ²⁰¹Tl (135.3 ; 167.4 keV), ¹³¹I (284.3 ; 364.5 ; 637.0 keV), ¹²³I (159.0 keV), ⁶⁷Ga (300.2 keV), ¹¹¹I (171.3 ; 245.4 keV), ¹³³Xe (81.0 keV) ...]
- Linear response over a wide range of activity levels (10 kBq – 10 GBq)
- Stability
- Possibility to measure sample volumes like vials and syringes

GAS DETECTORS

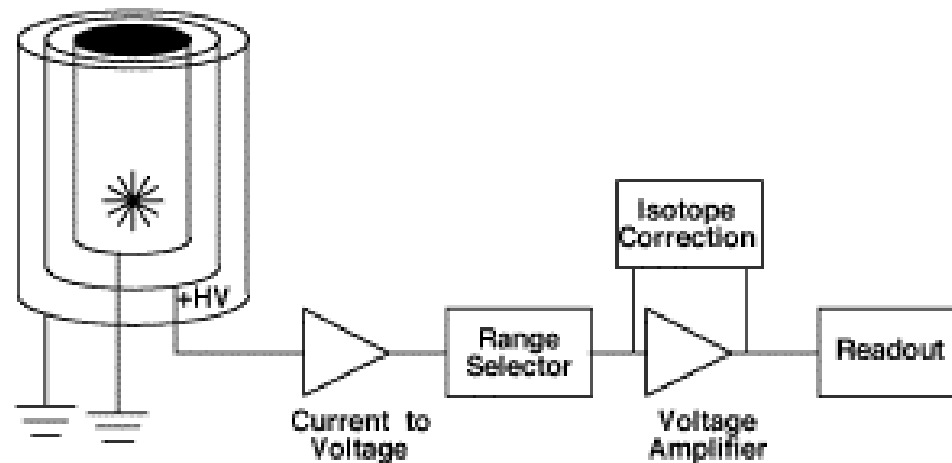
- a potential is applied across the collection electrodes → when the photon interacts in the gas, a large number of electron-ion pairs are formed and are collected by electrodes
- the current measured is dependent on the applied voltage → collecting voltage high enough to obtain saturation current, to prevent recombination of the electron - ion pairs (the probability for recombination increases with dose rate)
- the current measured is proportional to the energy deposited
- the ionization current is not linear with incident photon energy

DETECTOR DESIGN

- well geometry (the sample is almost completely surrounded by the sensitive volume of the chamber) → maximizes the geometric efficiency (near 4π geometry) and minimizes the effects of small variations in sample position and volume
- two co-axial cylindrical collection electrodes maintained at a voltage difference (typically: 150-350 V)
- walls in the well → thin to minimize absorption
- gas pressurized → to increase the linear attenuation coefficient which in turn increases sensitivity
- container sealed → to avoid temperature and pressure dependence
- gas with high Z (e.g. Ar, $Z = 18$) → to increase the number of ion pairs produced per interaction
- gas → inert to avoid corrosive effects
- ionization current is integrated by a ratemeter with a fixed time constant and converted to a voltage signal, which is amplified, processed and displayed, commonly in digital form in units of activity

- [fixed isotope corrections](#) for commonly used isotopes (push buttons)
- [holders](#) made of low-Z material → to ensure reproducibility of positioning for samples and reference sources

TYPICAL COMPONENTS OF AN ACTIVITY CALIBRATOR



CALIBRATION PROCEDURE

- measure the response of the chamber to all available calibrated standards of radionuclides emitting monoenergetic photon over the appropriate range of energy
- determine the efficiency of the chamber as a function of gamma-ray energy
- calculate the calibration factors for samples of photon-emitting radionuclides for which standards are not available (using the efficiency curve and the decay data)

R_A (response of the detector to a radioisotope A) def
=

detector output / activity of the radioisotope being measured

- It is convenient to express the response of the detector to a radioisotope A relative to that of a standard reference radioisotope (e.g. ^{60}Co , selected because its decay scheme is simple and it is one of the most commonly used radioisotope standard)

- the calibration factor $K_{R,\gamma}$ relative to that of the reference source is given by:

$$K_{R,\gamma} = P_{\gamma} A (R_R/R)$$

where

R = output for the calibrated source emitting a photon of energy E

P_{γ} = probability of emission per decay

A = activity of the calibrated source

R_R = output for the long-lived reference source

RECIPROCAL of the RELATIVE FACTOR $K_{R,\gamma}$ is EQUIVALENT to an EFFICIENCY \rightarrow

an EFFICIENCY CURVE can be established as a FUNCTION of ENERGY

- Activity of any other monoenergetic gamma-emitting nuclide \rightarrow can be determined using an interpolate value of $1/K$

$$A = (K_{R,\gamma} / P_\gamma) (R / R_R)$$

- Activity of a nuclide emitting n photons of different energies and of known probabilities per decay \rightarrow can be obtained by weighting the efficiency $1/K_{R,\gamma}$ for each photon of different energy by the appropriate probability per decay

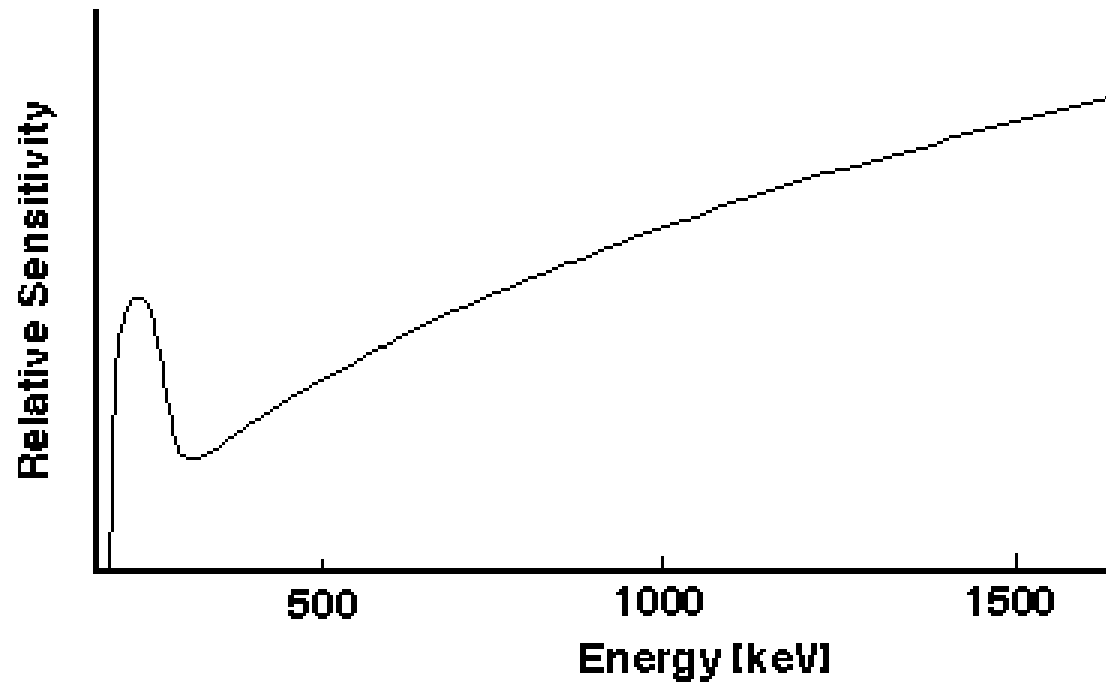
$$A = (R/R_R) \sum_i (K_{R,\gamma} / P_\gamma)_i$$

where the sum is carried out for all photons

- **RESPONSE OF THE INSTRUMENT DISPLAYED DIRECTLY IN TERMS OF ACTIVITY** →

GAIN SETTING : adjust the gain of the calibrator amplifier by dividing the amplifier output by some unique value for each radioisotope

EFFICIENCY OF A TYPICAL IONIZATION CHAMBER OF A CALIBRATOR AS A FUNCTION OF PHOTON ENERGY



COMMENTS

- sensitivity is normalized by chamber response to ^{60}Co radiations (SUZUKY et al.)
- energy range up to 1.9 MeV
- all photons with energies below about 13 eV are stopped before they reach the sensitive volume of the chamber (these photons don't contribute to the activity measurement)
- a significant fraction of photons with energies below 50 keV are stopped in the chamber walls; only few can enter the sensitive volume of the chamber and contribute to the activity measurement

- the peak in the low energy region of the sensitivity curve is due to
 - the rapid increase in photoelectric effect as photon energy decreases (Z^4/E^3)
 - the attenuation of low energy photons by the sample holder, the chamber liner and the chamber walls
 - the absorption of photons in the sample material and its container
- above a photon energy of 200 keV, the ionization in the chamber is mainly due to electrons resulting from Compton scattering of photons by the filling gas (Ar) and by the chamber walls (Al)

BETA-RAY CORRECTIONS

- for radioisotops with high-energy beta-ray emission, the contribution from beta emission may have to be included in the calculation of the response
- it is difficult to define a detector's sensitivity to beta rays because of the energy distribution of the emitted beta rays (ranging from 0 to the maximum transition energy) and because of the strong absorption of the radiation by the media (only bremsstrahlung is detectable by most calibrators due to the rather thick wall of the detector and the sample container)

EFFECTS OF AN EXTERNAL SHIELD

Advantage of the external shield:

- reduction of radiation exposure to the personnel handling the radioisotopes
- reduction of the background effects on the activity measurements
- prevention of efficiency changes caused by scattering material in the vicinity

The shielding around the dose calibrator should remain the same after the initial calibration

If a shield is placed around a calibrator:

- the sensitivity of the ionization chamber is enhanced due to backscattering of photons by the shielding
- at energies below 70 keV the backscatter is absorbed in the chamber walls
- the backscattering effects are more significant for photon energies between 70 and 250 keV than for other energy regions
- above about 250 keV the scattering of photons is mainly directed forward and at the low energy region

CALIBRATION GEOMETRY

- The calibration geometry will affect the reading of unknown samples:
 - calibration done with non-diluted point sources → the activity in a sample diluted in a volume will be underestimated (selfabsorption in the sample)
 - calibration done with diluted sources → the activity of a point source measured in the dose calibrator will be overestimated
- Generally the calibration sources have a similar geometry as the samples; the user should select a standardized procedure, volume and container for all radioactivity measurements

Typical calibration source geometry:

- 5 g radioactive solution (~ 5 ml)
- glass ampoules Ø 17 mm - height 40 mm
- wall thickness 0.6 mm

EFFECTS OF CONTAINER MATERIAL, SAMPLE VOLUME AND POSITION

- radioisotope measured in a different material or wall thickness than that of standards
→ possible errors for radioisotopes having a significant abundance of low-energy gamma and x-ray or high-energy beta-ray; often correction factors are supplied by the manufacturer (the radioisotopes more sensitive to source configuration and type of container are ^{125}I and ^{133}Xe ; for ^{125}I a correction factor of 2 is not unusual if the isotope is assayed in a glass vial)

- sample volume (effect due to position of the activity within the chamber well; for samples emitting low –energy gamma-rays , absorption in the sample and syringe is important)
- position within the chamber well (vertical displacements of the source → the source holders provided for use generally ensures that the correct vertical position is maintained; it is often easier to produce a horizontal displacement of the source)
- in radioactive solutions that tend to be instable, part of the radionuclide may be present in a gaseous phase (f.e. ^{133}Xe in saline) → reading depending on the partitioning between the gaseous and solution phases
- in radioactive solutions that tend to plate-out onto the walls of container → reading may be affected by change in geometry and internal absorption

EFFECTS OF IMPURITIES

A ionization chamber doesn't have intrinsic energy-discrimination capability

- the presence of radioisotope impurities affects the reading of the calibrator , particularly in measurements of short –lived radionuclides several half-lives akfter initial preparation(unless this effect is eliminated by photon filtration as with ^{99}Mo breakthrough in $^{99\text{m}}\text{Tc}$)
- determination of the photon energy with a photon – spectrometry system may be necessary

**PROCEDURE TO DETERMINE CALIBRATION FACTORS FOR
CLINICAL RADIONUCLIDES FOR WHICH
NO SETTING AND NO STANDARD IS AVAILABLE**

- preparation of standard samples of radionuclides (range of activities used clinically)
- determination of the activity of samples by a Ge detector (because of the difference in sensitivity between Ge detector and dose calibrator, dilution of the solution to be standardized is required for measurement with Ge counting system)
- once the specific activity of the solution is known, a volume of the solution representing a known activity can be measured (correction for radioactive decay over the time interval between standardization and measurement)

QUALITY CONTROL

- in order to assure that the activity calibrator is operating properly (correct assays of radiopharmaceuticals prior to administration to patients) it must be tested on a regular basis

PROTOCOLS

- ANSI N42.13 – 1986 : Calibration and Usage of “Dose Calibrators” Ionization Chambers for the Assay of Radionuclides, 1986
- IAEA – TECDOC - 602 : Quality Control of Nuclear Medicine Instruments, 1991
- National Council on Radiation Protection and Measurement : Quality Assurance for Diagnostic Imaging. NCRP Report No. 99, 1988

LIMITS OF ACCEPTABILITY						
	Background	Precision	Reproducibility (Stability)	Accuracy	Linearity	Geometry
ANSI	(d)	$\pm 5\%$ ⁽¹⁾	$\pm 10\%$ (d)	$\pm 10\%$ ⁽¹⁾	$\pm 5\%$ (q)	--
IAEA	$< 20\%$ ⁽²⁾ (d)	$\pm 5\%$ (q)	$\pm 5\%$ (d)	$\pm 10\%$ (q)	$\pm 10\%$ (q)	--
NCRP	(d)	$\pm 5\%$ (d)	$\pm 5\%$ (q)	$\pm 5\%$ (a)	$\pm 5\%$ (q)	$\pm 2\%$ ⁽³⁾

⁽¹⁾ for activity > 3.7 MBq

⁽²⁾ Increase in background $\geq 20\%$ \rightarrow further investigation

⁽³⁾ Variations $> 2\%$ \rightarrow apply correction factors

d \rightarrow DAILY; q \rightarrow QUARTERLY; y \rightarrow YEARLY

DAILY CHECKS

- Internal Test - test of circuitry
- CHECK OF BACKGROUND RESPONSE → to check the background response at the radionuclide settings to be used
 - the background reading should be manually or automatically subtracted from subsequently measured activities
 - significant increase in background → radioactive contamination of the instrument (remove the liner and repeat the measure) or increased environmental radiation from local sources

DAILY CHECKS

- CHECK OF REPRODUCIBILITY OF RESPONSE → to check the day-to-day reproducibility of performance of a calibrator in measurements of commonly used radionuclides
 - use a long lived reference source (^{137}Cs or ^{133}Ba or ^{226}Ra – a certified source may be used but knowledge of activity is not required)
 - measure apparent activity on all the settings of radionuclides to be used on that day
 - recorded the results and compare measured and expected values

QUARTERLY CHECKS

- LINEARITY OF RESPONSE AS A FUNCTION OF ACTIVITY → to reveal region and magnitude of non linearities due to saturation effects (ion-recombination); non-linearity near to zero activity (may indicate a wrong preset zero adjustment); discontinuities at change of range (systematic error in one of the ranges)

➤ DECAY METHOD

- prepare a source of a short-lived radionuclide (such as ^{99m}Tc); initial activity of the source → equal to or greater than the highest activity likely to be measured
- follow the activity of the source as a function of time; decay → to the lowest levels of activity that would normally be measured (or the activity range where the instrument is properly calibrated)
- apply decay correction to earlier measurements

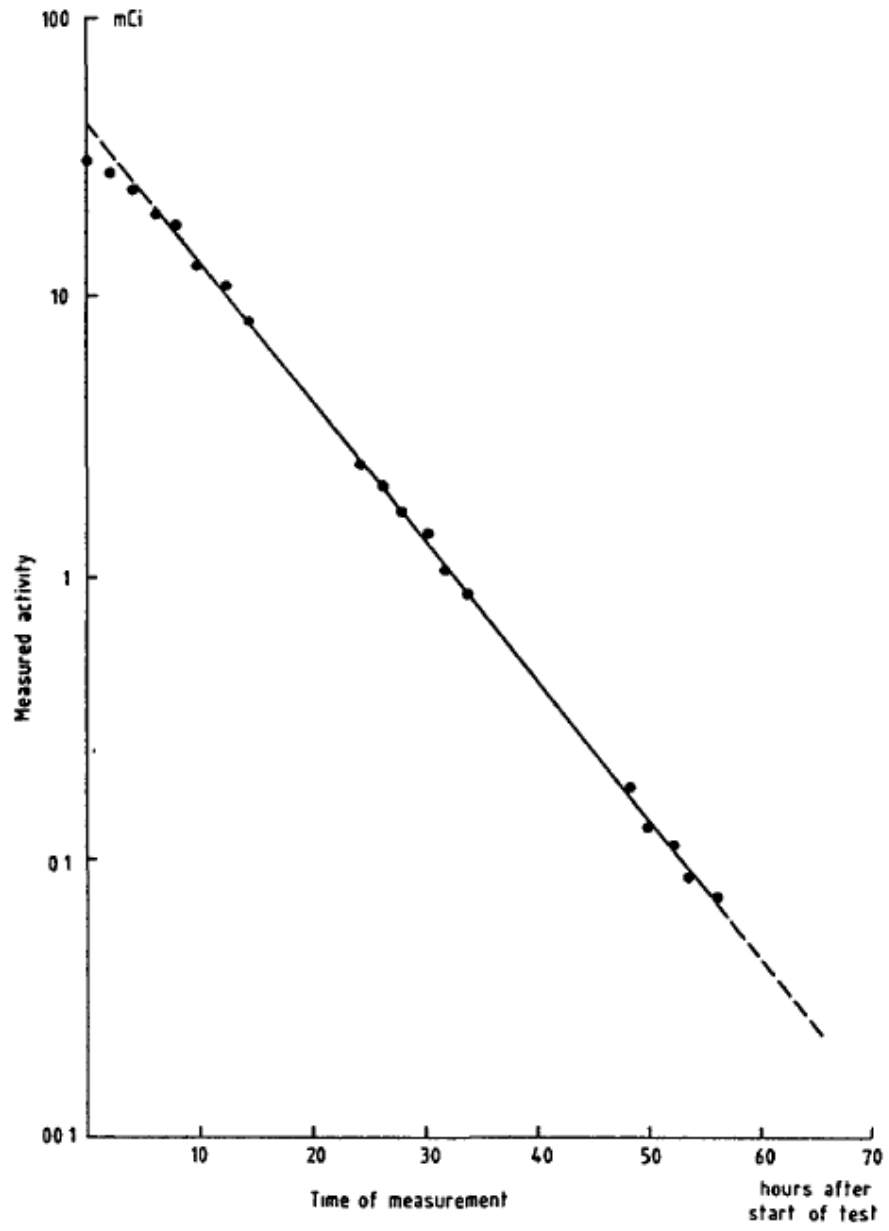
- determine the deviation of the decay – corrected measurements from the expected values (extrapolation from data points in the lower activity region, assumed to be correct)
- test material → free of long-lived radionuclidic impurities (^{99}Mo in $^{99\text{m}}\text{Tc}$; ^{113}Sn in $^{113\text{m}}\text{In}$) to prevent distortions of the half life curve (initially the activity of the contamination in the sample will be insignificant, but it causes an apparent levelling of the activity in the final part of the graph); impurities can be detected as residual activity

➤ PROPORTIONAL METHOD

- use identical sources with different radioactivity concentrations of the same radionuclide (moderate half-life, ^{131}I)
- if measurements are made over an interval of time short compared with the half lives of any photon emitting impurities, the method is insensitive to these impurities
- possible artefacts introduced by inaccurate preparation of radionuclide solutions

➤ SLEEVE METHOD

- insert calibrated lead shields into the calibrator well to produce an attenuation of photon flux to simulate the decay occurring from 0 through 50 hours (first elution from a new generator)
- this not a true measurement of linearity under identical geometrical conditions, can be used as supplementary consistency check



IAEA-TECDOC-602

- ACCURACY : initial accuracy is limited by the certified sources used by the factory for calibration (uncertainty $\pm 5\%$ or less); it may change with time as a result of changing pressure of the chamber gas and slow electrical drift
- use radionuclide standards spanning a wide range of energy (^{57}Co , ^{60}Co , ^{137}Cs , ^{133}Ba) and determine the present activity of the source for the proper calibration setting
- repeat the measurement to a total of 10 times
- calculate for each source the percentage difference between the mean measured activity, A_m , and the certified activity corrected for radioactive decay

$$[(A_m - C) / C] * 100$$

- PRECISION

- calculate for each source the percentage differences between the individual measured activities A_i and their mean A_m

$$[(A_i - A_m) / A_m] * 100$$

ANNUALY CHECKS

- GEOMETRY (SAMPLE VOLUME AND POSITION, CONTAINER)
 - VOLUME: gradually increase the volume of 1 ml Tc solution in a 10 ml syringe by adding known amounts of water (to 2, 3, 5 and 10 ml)
 - POSITION: vary the position of the syringe in two axes (vertical and horizontal displacement)
 - CONTAINER: test for various types of syringes (comparison between measured activity and real activity – real activity being the difference of the vial readings before and after filling the syringe)

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