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A portable precision ionization chamber: The transfer ionization reference chamber

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HIGHLIGHTS

- We designed a portable ionization chamber for short half-lives nuclides activity measurement on site.
- A precise estimation of the uncertainties was made allowing an accuracy less than 1%.
- The chamber is calibrated using standardized reference samples.
- External background is monitored using a probe in coincidence.
- The chamber is validated with measurements of F-18 in production site and in a nuclear medicine department.

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ABSTRACT

A portable instrument was developed at the Institute of Radiation Physics (IRA) for on-site radionuclides measurements. It will enable the measurement of short-lived radionuclides in nuclear medicine departments or isotope production centres. The system involves an ionization chamber read directly by an electrometer and it was optimized to ensure a good reproducibility through the selection of an appropriate vial, filling volume and source position in the well chamber, as well as monitoring the external background and performing a detailed uncertainty estimation. The calibration factors were determined using solutions whose activity concentration is traceable to the international reference system using the IRA reference chamber. Currently the transfer ionization chamber is calibrated for F-18, C-11, O-15, N-13, I-131 and Tc-99m. The final instrument is able to measure isotope activities with a relative standard uncertainty not larger than 1%.

1. Introduction

In the field of nuclear medicine, radioactivity is used to diagnose or treat diseases. Patients' exposures are primarily controlled by the administered activity. Typically, radionuclide calibrators are the instrument routinely used for measuring radiopharmaceutical activity. They are sold commercially worldwide and can be found in most nuclear medicine departments throughout the world. The quality assurance as well as the calibration of these instruments requires the use of sources whose activity is traceable to international standards (Ordonnance, 2012).

In Switzerland, the activity unit is maintained by the "chambre d'ionisation de reference" (CIR) (Gostely, 1991) at the Institute of Radiation Physics which is the designated institute (DI) of the Swiss Institute of Metrology (METAS) for the unit of activity (Bq).

The CIR was calibrated for over 20 radionuclides with activities traceable to the international reference system (SIR) (Ratel, 2007) at BIPM. Additionally, precision radionuclide calibrators, with calibration factors obtained from solutions with activities determined by the CIR, are operated at IRA for routine work. The relative standard uncertainties of CIR activities are lower than 0.5% while those of the precision calibrators are about 1%. For radionuclide calibrator at the user level, the legal tolerance for gamma emitters is +/−10% (METAS, 2006; Caffari et al., 2010). The CIR is over 30 years old and needs to be replaced. As part of a wider project to design a new reference chamber (CIR II) and to broaden our secondary measurement capabilities, a project to develop a portable precision ionization chamber was started in 2012, in order to measure short-lived radionuclides in hospitals or radioisotope production centres: the Transfer Ionization Chamber (T-CIR).

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The TCIR will typically offer new services to nuclear medicine departments and cyclotron facilities. Reference measurements on site and short-lived radionuclide traceability will be possible. Furthermore, automated dispensers, which have not been characterized metrologically so far, will greatly benefit from such services.

This project will support radionuclide metrology in Switzerland and improve the traceability of short-lived radionuclides.

2. Instruments and methods

The choice of material was informed by the expertise acquired in operating the ionization chambers for 30 years in addition to meeting the requirement of mobility, robustness, compactness and ease of operation expected for a portable chamber. The initial idea was to have a measurement system directly reading the ionization chamber output current using an electrometer with the latter controlled by a computer using LabView acquisition software.

2.1. Ionization chamber

The ionization chamber is a sealed well type 4πγ Centronic IG12 (Centronic LTD, Croydon, United Kingdom), filled with argon at a pressure of 2 MPa. The well diameter is 50.7 mm which is broad enough for the insertion of vials used in nuclear medicine. The chamber operates at a positive DC voltage of 1000 V provided by a Matsusada HSX-3R5 LRs power supply (Matsusada Precision Inc., Japan).

The ionization current is read by a Keithley 6517B digital electrometer (Keithley Instruments Inc., Cleveland, USA) and the measurement method consists of loading the internal capacitor of the electrometer during a given time, typically 100 s. The clock of the PC is used to calculate this time. We checked that it is stable at 10^{-5} and we have neglected the uncertainty on the acquisition time.

The electrometer was calibrated at the DC and Low Frequency Laboratory of METAS (METAS, 2016) and the measured uncertainty on the capacitor charge is 0.02%. A LabView program sets automatically the charge capacitor. The capacitor is chosen at the beginning, according to the current of the measured source, in order to keep the same capacitor during the whole measurement. It finally calculates the currents average and the standard deviation over the several measurements performed. However, several corrections must be made to the raw current; the background current must be subtracted, the decay of the isotope must be corrected and the correction for the charge saturation in the gas chamber must also be applied.

The saturation correction (Schrader, 1997) was estimated by varying the voltage in the chamber in steps of 50 V from 200 V until the maximum voltage of 2000 V. The ionization current produced in the chamber was measure at each step. Fig. 1 shows the measurements obtained for a given activity of a Tc-99m source. For our standard operating voltage of 1000 V, the measurement current is 2592.8 pA whereas the real current, which corresponds to the intercept of the line fitting the high voltage points, is 2617.5 pA. By repeating these measurements for different activities, the saturation correction curve is derived for various activity regimes. This was done with two Tc-99m sources of 1 and 1.5 GBq respectively. The short half-life of Tc-99m (~ 6 h) enables an automated acquisition of the saturation current in various activity regimes.

Moreover, three vials of Co-57, Co-60 and Cs-137 were measured to probe whether the saturation correction is γ-energy dependent as well as to cross-check the validity of the curve. A further high activity Cs-137 source of 2 GBq was used to get a saturation correction data point at high current (25298 pA). The obtained saturation curve shown in Fig. 2, is validated for different isotopes and activity regimes. The relative deviation between the fitted function and the measured points is always below 0.1%. This difference entails a 0.05% relative uncertainty on the saturation correction which will have to be added to the final uncertainty.

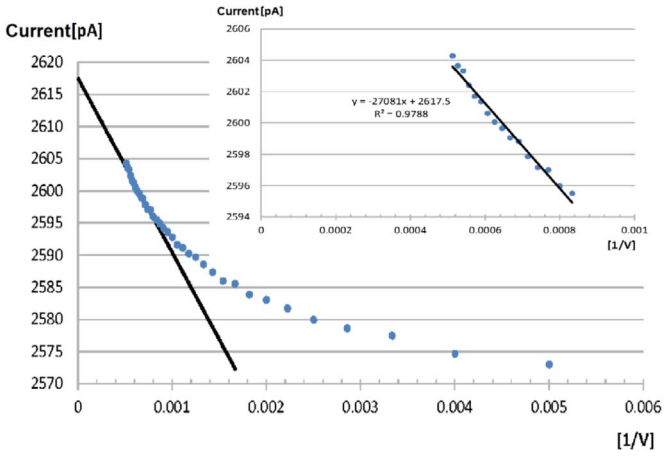

Fig. 1. Saturation for Tc-99m for a current of 2592.8 pA (measured with the nominal high voltage of 1000 V). The x-axis corresponds to the inverse of the voltage for steps of 50 V and the y-axis gives the value of the measured current (blue dot). The line (in black) corresponds to the linear fit on the last points to obtain the value of the saturation current corresponding to the intercept of the line. The figure in the upper right is a zoom showing in more details the linear fit. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

2.2. Geometry and vial

To ensure the reproducibility of the measurement, it was decided to use only one type of vial with a fixed filling volume i.e. a 10 ml penicillin glass vial filled at 5 g. Only vials with a thickness as regular as possible must be used for the measurement. A dedicated method was developed at IRA to select the vials by measuring the thickness of their walls (Juget et al., 2017).

The positioning of the vial in the well is fixed to have the maximum current measured for Co-60. A dedicated holder was built to move the vial vertically in the well and find the optimal position for the largest signal. Once this position was determined, the holder was then rigidified to keep vials always at the same position.

A standard measurement consists of measuring vials filled with 5 g, a different level of filling will require correction. The method to evaluate the mass correction consists of measuring the current produced by a vial filled with 3 g of Tc-99m with about 1 GBq of activity. Once this is done, 0.5 g of the carrier solution is added and the current is measured again. This operation is repeated until the vial is filled up to 7 g. Fig. 3 displays the resulting variation of the current with vial filled mass. One notes that the ionization current of 7 g is 0.25% lower than the one measured with the standard mass of 5 g. The difference is less than 0.1% for vials filled with a mass ranging between 4.5 and 5.5 g.

To check whether this filling correction varies with the energy of gamma and hence valid for other isotopes, the same procedure is repeated with a vial containing 30 MBq of Cs-137.

Fig. 4 shows the results obtained after applying the correction previously calculated with Tc-99m. It restores the values around the reference value of the filling at 5 g. Therefore a unique correction curve can be used in case of a measurement of a vial not filled at the reference value of 5 g. This correction entails a 0.05% relative uncertainty which will have to be added to the final uncertainty. This uncertainty is taken as the average of the difference between the value at 5 g and the corrected values for the other filling level. But usually we will measured vials filled with 5 g and therefore not apply this correction.

2.3. External background monitoring

The TCIR is planned for measuring samples on-site and hence could be placed in an environment where the external background can interfere with the measurement. As the TCIR is a movable instrument it is not possible to add a heavy shielding which would impede transport.