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Kr-81m calibration factor for the npl ionisation chamber

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Abstract

A general method has been developed for the measurement of the activity concentration of ^{81m}Kr gas. Due to its short half-life, 13.1 s, this gas has to be eluted from a ^{81}Rb/^{81m}Kr generator. The ^{81}Rb parent has a half-life of about 4.6 h. The calibration was done in two steps: firstly, a γ-ray spectrometer was calibrated using ^{51}Cr and ^{139}Ce sources, nuclides with γ-ray energies bracketing that of ^{81m}Kr (190.5 keV). The measurement geometry was equivalent to that of the ^{81m}Kr measurement; the sources were inserted into two collimated PTFE tubes in front of the γ-ray detector. Secondly, a calibration factor for the NPL radionuclide calibrator was determined with a specially designed ionisation chamber insert. The ^{81m}Kr gas passed in front of the γ-ray detector in PTFE tubing before and after entering the ionisation chamber. The calibration factor for ^{81m}Kr in the radionuclide calibrator with this geometry was independent of the gas flow rate within determined limits. The analytical calculations of the activity determination, uncertainties and measurement criteria are discussed.

Keywords: Radionuclide calibrator; Ionisation chamber; Calibration factor; Gamma-spectrometry; ^{81m}Kr; Nuclear medicine

1. Introduction

The radionuclide ^{81m}Kr is frequently used in nuclear medicine for lung scintigraphy. ^{81m}Kr gas has a half-life of 13.10(3) s and is eluted by the user from a ^{81}Rb/^{81m}Kr generator. The cyclotron produced parent nuclide has a half-life of 4.576(5) h (ENSDF, 2005). Due to the short half-life of the gas, activity measurements are required in close proximity to the medical examination. This paper describes a means of performing accurate activity measurements by ionisation chamber, traceable to primary standards. The chain of measurements is illustrated in Fig. 1. A γ-ray spectrometer is calibrated using primary standards and then used to determine the activity concentration of the gas passing in a tube in front of the detector, before and after entering the ionisation chamber. An ion-chamber insert of PTFE tubing arranged in a coil (see Fig. 2) was specially designed for the purpose of having a measurement geometry that could be transferred between various chambers. The insert was designed for the NPL-CRC calibrator (Southern Scientific Ltd.), while calibration of other ionisation chambers would as well be possible. The calibration factor for ^{81m}Kr presented here is for the so-called NPL master chamber, situated at NPL. This chamber is the reference chamber for a large number of nuclides and links calibration figures for the ionisation chambers at hospitals to primary standards.

In previously published work (Waters et al., 1999), with a similar detector set-up, the ratio of the ionisation chamber and γ-ray spectrometry responses was investigated as a function of the flow rate and the length of the tubing. It was shown that the ratio between the ion-chamber and γ-ray spectrometer response was constant for a flow rate between 225 and 750 ml min^{-1}. The recommended value for the flow rate through this type of generator for clinical applications is 500 ml min^{-1}. Furthermore, the response ratio was found to be unaffected by the length of the tube (between the γ-ray detector and the ionisation chamber) as long as the gas transit time is kept short relative to the half-life of ^{81m}Kr.

2. Calibration of γ-ray spectrometer

A high-purity germanium (HPGe) detector was used to determine the activity concentration of the ^{81m}Kr gas. The

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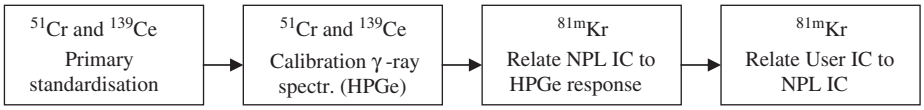

Fig. 1. The different steps of determining the calibration factor for ^{81m}Kr in an ionisation chamber.

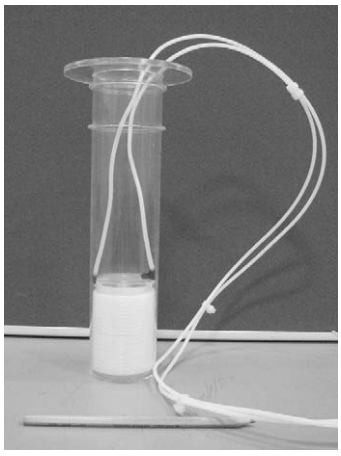

Fig. 2. The ionisation-chamber tube insert with sample holder.

HPGe detector was calibrated using ^{139}Ce and ^{51}Cr, which emit γ-rays with energies bracketing the ^{81m}Kr γ-ray (190.5 keV). The nuclear data (DDEP, 2005; ENSDF, 2005) and activity concentrations of the nuclides involved are summarised in Table 1. The ^{51}Cr solution was standardised by an absolute method and the result was submitted to the international reference system (SIR) (Rytz, 1983) held by the Bureau International des Poids et Mesures. The activity of the ^{139}Ce was determined by secondary standardisation using the NPL ionisation chamber, which is linked to the SIR. A nuclide with significantly longer half-life (1200 years), ^{166m}Ho, was used as a reference source for long-term stability checks of the HPGe detector system. A top view of the set-up of the γ-ray spectrometry measuring system is shown in Fig. 3. The ^{81m}Kr gas was passed two times in front of the calibrated γ-ray detector, before and after entering the ionisation chamber. The gas flowed through a thin PTFE tube (inner diameter of 1.59 mm) at a flow rate between 450 and 750 ml min^{-1}, and the photons were collimated using a lead collimator (11.83 ± 0.02 mm wide). The volume of the tube, seen by the γ-ray spectrometer, was determined by accurate weighing of the tube before and after it was filled with water.

For the calibration of the γ-ray detector, standardised sources of ^{139}Ce and ^{51}Cr were placed in tubes in the collimator position corresponding to the ^{81m}Kr measurements. A trial calibration, using solutions instead of solid sources failed as the calibration result had an unacceptably high uncertainty and was not reproducible for unknown reasons. Instead, measurements were performed with solid point sources positioned to the far left and right in the 12 mm collimator slit in order to determine any variation in the efficiency. The activity was deposited on thin VYNS foils, dried and rolled up to approximately a point-source geometry and inserted into the tube. Two tubes were used for each measurement, representing the in and out flow of the gas. In total, eight ^{51}Cr and nine ^{139}Ce solid sources on VYNS foils were used during the calibration process. The γ-ray spectrum was analysed with commercially available software (Genie2000, Canberra). The dead time of the system was corrected for by registering a calibrated 10 Hz pulser in the spectrum. The dead time ratio was always below 0.5%.

3. Calibration factor for the NPL ionisation chamber

The ^{81}Rb/^{81m}Kr generator was received from Imanet, the cyclotron unit at Hammersmith Hospital (London, UK) on three different occasions. The ^{81}Rb was produced by proton irradiation of enriched ^{82}Kr gas in a cyclotron target and subsequently absorbed onto a zirconium phosphate column to form the ^{81}Rb/^{81m}Kr generator. The generator was continuously eluted with room air using a small diaphragm pump. Approximately 15 measurements per day were performed during a measurement series. Before the calibration measurements, a quality check was performed with a ^{226}Ra reference source to ensure that the ionisation chamber was stable. The background was measured with the generator in place (behind lead shielding). The ionisation chamber current was measured with an electrometer routinely used for the NPL secondary standard ionisation chamber.

The generator was connected to the thin PTFE tubing (Fig. 4) that in one continuous length directed the gas past the collimated HPGe detector, into the coil insert in the NPL ionisation chamber and back past the HPGe detector again. The distances (in centimetres) between the system parts are shown in Fig. 4. Both the generator and the HPGe detector were shielded by lead to minimise the background and scattered radiation (not shown in the picture). A flow meter was used to register the flow rate (litres per minute) at both ends of the tubing during each measurement series. No difference in flow rate between the two positions was registered. At the end of the measurement set-up, the ^{81m}Kr gas was guided into a long loop of thick tubing for decay before exiting into the room. Before acquisition started, the flow rate was kept constant for at least 90 s to achieve an equilibrium state between the ^{81m}Kr and the ^{81}Rb activity in the generator.

The ion-chamber reading and the γ-ray spectrum were registered simultaneously during various measurement periods from 10 up to 40 min. Since the γ-spectrometer