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Activity measurements of ^{192}Ir solid sources using a well-type ionization chamber

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Abstract

This work presents the preliminary activity measurements of ^{192}Ir solid sources, applied in industrial gammagraphy, produced by the Sealed Sources Laboratory in the Radiation Technology Center (CTR) at IPEN-CNEN/SP. The pellets' activity measurements were carried out with a well-type ionization chamber developed at CTR. The chamber current–voltage response was studied as a function of ^{192}Ir activities ranging from 27 GBq (0.75 Ci) to 4.1 TBq (110 Ci), under constant geometrical conditions. The results obtained have shown both the linearity of the ionization current and the absence of appreciable recombination or diffusion losses.

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1. Introduction

Ionization chambers serve in many standard laboratories as secondary standard measuring systems and are used to maintain the results of activity measurements from primary standardization [1,2]. Generally, such a chamber takes the cylindrical geometry, with a well in which a radiation source is placed and which is called a well-type or $4\pi\gamma$ ionization chamber. When operated in the saturated region, the ion current solely depends on the geometry of the source and the detector. Besides, it can remain stable over very long periods of time. A comprehensive review concerning activity measurements with ionization chambers can be found in Ref. [1] by Schrader.

This work presents the preliminary results related to activity determination of ^{192}Ir solid sources, applied in industrial gammagraphy, produced by the Sealed Sources Laboratory at IPEN-CNEN/SP, which is certified to deliver the sources to the national industry.

Ranging from 27 GBq (0.75 Ci) to 4.1 TBq (110 Ci), these sources are formed by adding up to 20 ^{192}Ir pellets (2.7-mm diameter and 0.15-mm thick), with activities from 296 GBq (8 Ci) up to 0.63 TBq (17 Ci) each, supplied by NORDION Inc.

The production of the sealed sources is very demanding. Therefore, the development of an acquisition system, remotely controlled by a PC, adds the required features to improve the established laboratory routine.

The pellet activities were measured by using a well-type ionization chamber manufactured for this purpose at Radiation Technology Center at IPEN-CNEN/SP. So as to verify the response and the reliability of the system, various measurements using standard radioactivity sources have been performed.

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In particular, the results regarding the determination of a quite accurate value for the half-life of a standard ^{99m}Tc source are described in Section 3.2.

Also, the correction factors for self-absorption of photons within the pellets and sample holders, which correspond to the fractional transmission of γ-rays from ^{192}Ir in each source, were taken into account by means of the PENELOPE simulation code [3].

To further check whether the code could be properly used in geometries currently employed in ionization chambers, calculations were performed with the parameters presented by Büerman et al. in Ref. [4], in which corrections for absorption and attenuation of photons inside a ^{192}Ir source utilized in brachytherapy have been discussed. The results obtained by PENELOPE are in good agreement with the correction factors showed in Ref. [4].

2. Experimental setup

The chamber (sketched in Fig. 1), at a volume of 2070 cm^3 and 15 inner collecting electrodes, 15 mm apart, was filled in with pure argon under a pressure of 0.1 MPa. The detector was connected to a Keithley model 617 Programmable Electrometer, fully computer-controlled by means of specially designed software written in C, which also provides complete statistical analysis of data and a user-friendly interface.

A high DC voltage power supply (Stanford, PS300) was applied to the ionization chamber and the voltage input was set manually.

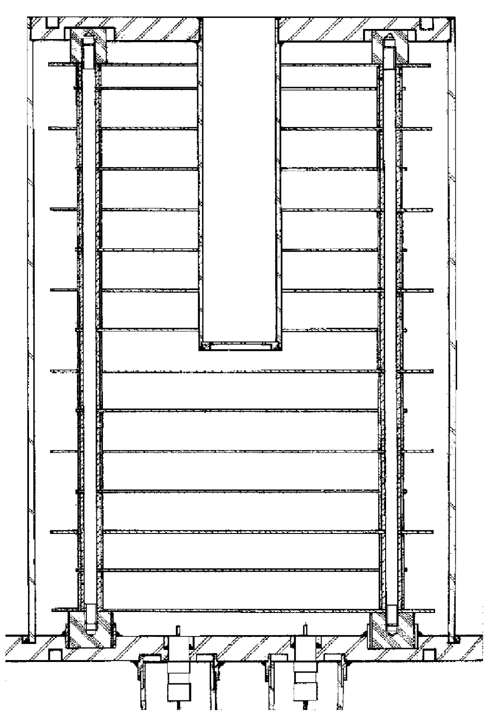

Fig. 1. Well-type ionization chamber used in this work.

3. Results

3.1. ^{192}Ir sealed sources

The chamber current–voltage response (Fig. 2) was studied as a function of ^{192}Ir activities from 27 GBq (0.75 Ci) up to 4.1 TBq (110 Ci), under constant geometrical conditions.

The determination of the saturation current plays an important role in ionization chamber calibration. Basically, two methods have been proposed in the literature [5–7]. The first one suggests that the saturation current should be determined by plotting the (I, V) data in the $(1/I, 1/V)$ mode (Fig. 3). The straight line obtained, extrapolated to $(1/V) = 0$, yields the saturation current (I_{sat}) for each activity. The other one considers the $(I, I/V^2)$ plot as being adequate to calculate the saturation current.

Making use of the values of I_{sat} as assigned before, preliminary calibration curves of the chamber (Fig. 4) were

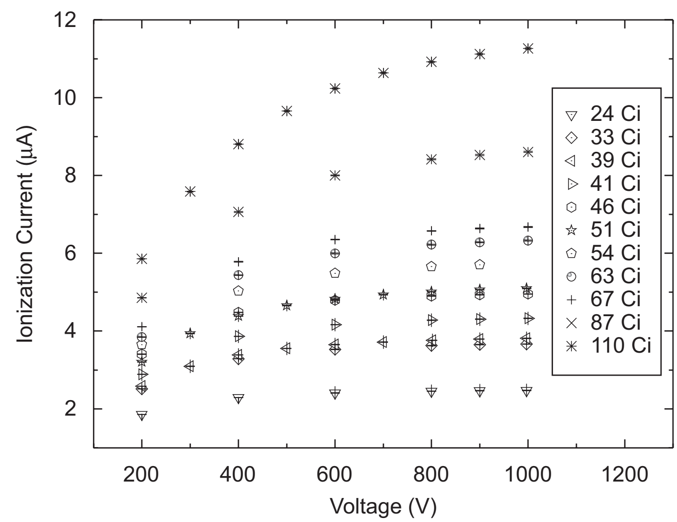

Fig. 2. Chamber current–voltage response for different source activities.

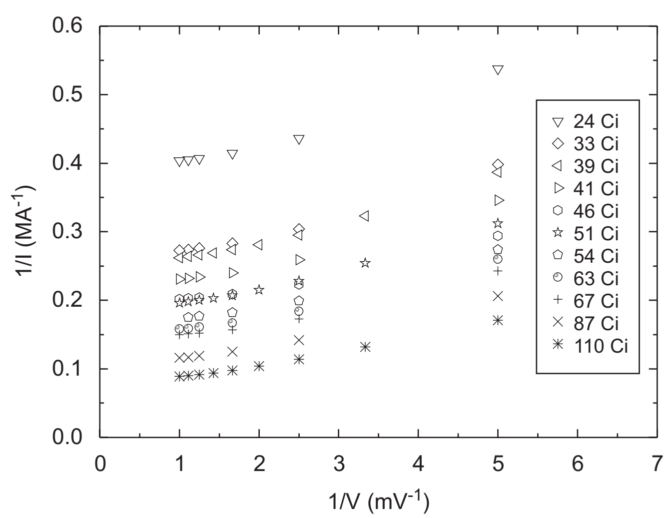

Fig. 3. Characteristic plot $(1/I, 1/V)$ for determining the I_{sat} current.

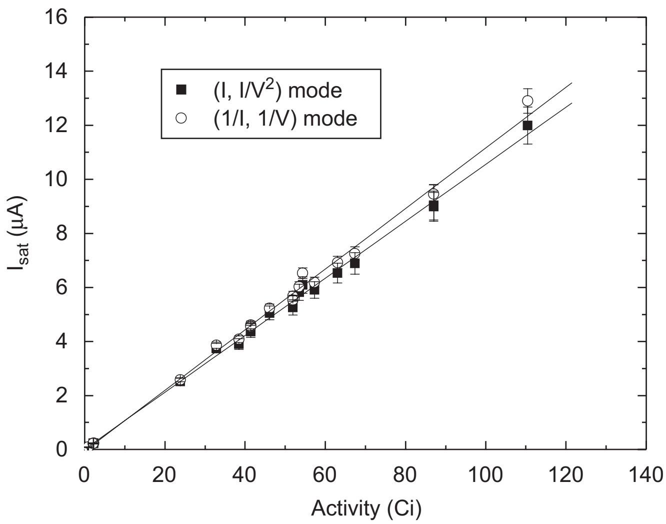

Fig. 4. Preliminary calibration curves of the chamber.

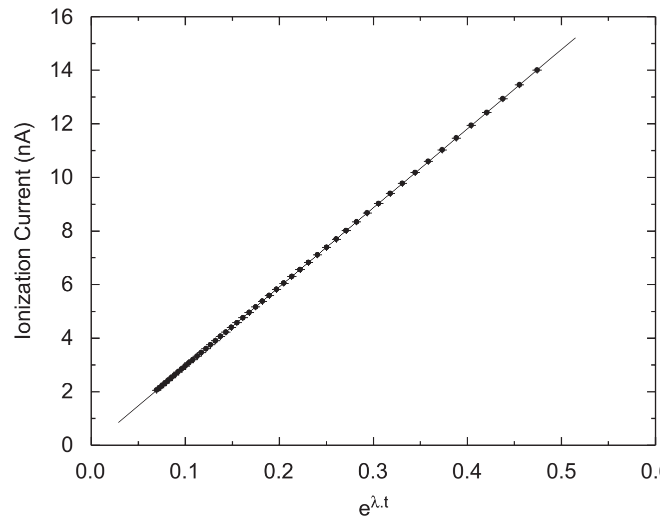

Fig. 5. Linear least-square fit of ^{99m}Tc data of ionization current as a function of $e^{\lambda t}$. The value of λ was taken from Ref. [8].

Table 1
Fractional transmission of γ-rays from ^{192}Ir for some sources studied in this work

Source activity (Ci)	No. of pellets	Fractional transmission
24	4	0.793
33	6	0.748
39	5	0.768
41	7	0.729
46	8	0.716
54	9	0.704
63	11	0.682
67	12	0.675
87	16	0.648
110	18	0.638

The associated statistical uncertainty is ~1%.

Table 2
Least-square fitting parameters from ^{99m}Tc decay

Parameter	Values
A	$0.2(16) \times 10^{-11}$
B	$2.95375(7) \times 10^{-8}$
χ^2	45.8
F	47
$P_f(\chi^2)$	47%
s_{res}	4.95×10^{-13}

A is the intercept, B is the slope, s_{res} is the S.D. of residuals and $P_f(\chi^2)$ is the probability of obtaining either χ^2 or a larger value given f degrees of freedom.

obtained. The results have shown both the linearity of the ionization current and the absence of appreciable recombination or diffusion losses for this activity range. In the range of activity studied, one can see that, as pointed out by Mustafa and Mahesh [7] (I, I/V^2), the plot offers an underestimated value of I_{sat}.

Due to the geometrical arrangement of the sources, a correction factor for self-absorption of photons in the pellets was applied in the calibration curve above. Table 1 shows the different combination of pellets used in the sources studied in this work, including the fractional transmission of γ-rays from ^{192}Ir through each one, which were calculated employing the PENELOPE simulation code.

3.2. ^{99m}Tc

The stability of the acquisition system for automatic current readings was checked by following the decay of a saline solution of ^{99m}Tc, initially at 37 GBq (1 Ci). The chamber was surrounded by a 5-cm lead shield to reduce background. The acquisition program was modified in

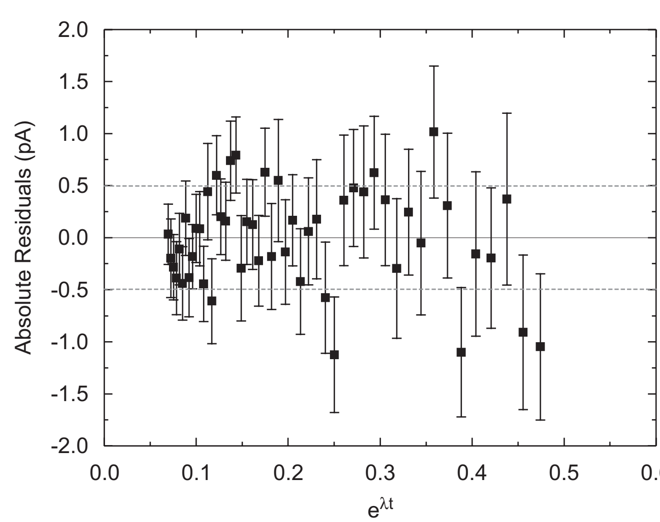

Fig. 6. Residuals of the experimental points and the fitted values. The confidence limits corresponding to a confidence level of 68% is represented by dashed lines.

order to allow automatic current readings every 20 min, over a 3-min time bin. The input voltage was kept constant at 600 V in all measurements. Fig. 5 displays the plot of the ionization current vs. $e^{\lambda t}$, which is proportional to the source activity.

A linear least-square fit was carried out and the parameters are shown in Table 2.

Fig. 6 exhibits the residuals of the experimental points comparatively with the fitted values. This plot shows no evidence of systematic effects. The confidence limit was obtained by calculating the standard deviation of residuals s_{res}, which is related to the linearity of the system. The average percentage residual was calculated, yielding the value 0.007%, which is a reasonable result.

A linear least-square fit of current vs. time in log-linear scale was performed in order to estimate the half-life for this radionuclide. The experimental half-life obtained was 6.007739(23) h, which agrees to within 0.01% with the value 6.0072(9) h [8] taken from the literature.

4. Conclusions

The preliminary tests have shown that the operation of the ionization chamber used is quite satisfactory. The values of I_{sat} evinced both the absence of appreciable recombination or diffusion losses and the linearity of the ionization current for activities as high as 4.1 TBq (110 Ci). Furthermore, the computational program developed for fully controlling the acquisition system exhibited a stable and reproducible behavior.

A spin-off of this work was to obtain the value of ^{99m}Tc half-life, 6.007739(23) h.

References

[1] H. Schrader, Monographie BIPM-4, 1997.

[2] G.F. Knoll, Radiation Detection and Measurement, third ed., Wiley, New York, 1999.

[3] J. Sempau, et al., Nucl. Instr. and Meth. B 132 (1997) 377.

[4] L. Büerman, H.-M. Kramer, H. Schrader, H.J. Selbach, Nucl. Instr. and Meth. A 339 (1994) 369.

[5] H.M. Weiss, Nucl. Instr. and Meth. 112 (1973) 291.

[6] M.T. Niatel, Phys. Med. Biol. 12 (1967) 555.

[7] S.M. Mustafa, K. Mahesh, Nucl. Instr. and Meth. A 150 (1978) 549.

[8] J.K. Tuli, G. Reed, B. Singh, Nucl. Data Sheets 93 (2001) 1.