Development of a Calibration System for Dosimetry and Radioactivity of Beta-Emitting Sources

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ABSTRACT

This study aims to develop a calibration system for radioactivity of beta sources using a calibration constant which derived from comparing measurement and simulation. It is hard to measure the activity of beta emitter isotope due to self-absorption and scattering. So the activity involves high levels of uncertainty. The surface dose of Sr/Y-90 standard isotope was measured using extrapolation chamber and calculated using Monte Carlo. The activity (4.077 kBq) of source was measured by NIST measurement assurance program. And several correction factors were calculated Monte Carlo method. The measurement result was corrected by correction factors. The calibration constant was defined as the ratio of surface dose to activity. It was 4.5×10-8 and 6.52×10-8 for measurement and Monte Carlo, respectively. There was about 15.4% difference in the calibration constant determined by the two techniques. The depth uncertainty makes the difference because of high dose gradients. Some correction factors have error due to scattering by detector geometry. A test source will be produced by HANARO. The activity will be calculated using calibration constant. The activity will be performed cross-calibration with NIST. Finally, the system will provide accurate information of sources.

1. Introduction

Beta isotope is used widely in the various field of medical and industrial purpose. The activity measurement of isotope has become important because of quality assurance of source. The primary radiation measurement systems are gas-flow proportional counters or liquid scintillation counters.[1] But Self-absorption and scattering cause difficulty to measure beta-isotope radioactivity accurately. In general, a roughly approximate radioactivity is commonly calculated depending on target material composition, cross-section, and neutron flux which are determined upon operating parameters within nuclear reactor in order to provide user with activity information.[2] However, since those results involve high uncertainty, the user will use the beta isotope with incorrect activity.

We try to develop a Monte Carlo applied calibration system for radioactivity of beta sources using a calibration constant which derived from comparing measurement and simulation. The calibration constant was defined as the ratio of surface dose to activity. Therefore, we will simulate beta-isotope and detector to evaluate surface dose rate and several correction parameters using Monte Carlo tool. The extrapolation ion-chamber is used to measure the surface dose rate. The Sr/Y-90 standard isotope which was calibrated by NIST is used for this study.

Therefore, this will enable us to investigate potential of Monte Carlo-assisted calibration system for dosimetry and radioactivity of beta-isotope.

2. Materials And Method

2.1 Standard Source

A NIST traceable source was used to measure a surface dose rate and calculate calibration constant. The active material is uniformly distributed over the surface of Stainless Steel foil and sealed in an aluminum mounting ring under a 0.9 mg/cm^2 aluminized Mylar window for Sr-90. The Nature of source activity was evaporated Salts on Stainless Steel (0.254 mm thickness). And active diameter is 20 mm. The overall source diameter is 25.4 mm and 3.18 mm thick. Contained radioactivity is 4.077 kBq at reference date (1-Feb-12, 12:00 PST). The total uncertainty of source at the 99% confidence level is 3.1%. All measured dosimetry data were corrected for radioactive decay of Sr-90 between the measurement date and reference date

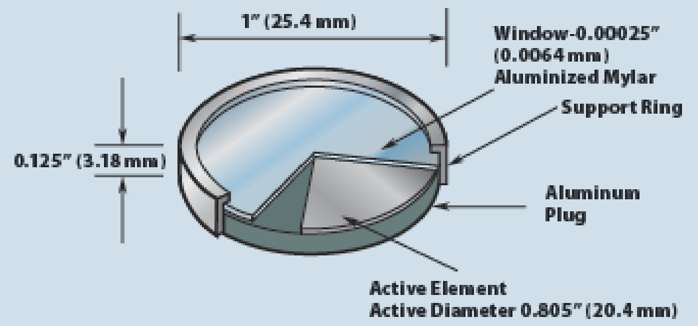

Fig 1. Schematic Diagram of Sr-90 Standard Source

2.2 Extrapolation chamber (EC)

The reference dose rate was determined using an extrapolation ionization chamber (Bohm extrapolation chamber, PTW, Germany). An extrapolation chamber (EC) can vary its ionization volume to a vanishingly small amount.[3] In the extrapolation chamber measurements, the spacing between the entrance foil and the collecting electrode (i.e., chamber air gap) was varied in the range of 3.0, 5.0, 7.0, and 9.0 mm. The range of 0.6 MeV electrons in air is approximately 200 cm, which is about 2000 times the maximum chamber air gap of 9 mm. The absorbed dose rate in water, Dw, was determined from the slope of the linear fitting (i.e., “extrapolation curve”), i.e., the change of the ionization chamber current (I) vs chamber [4] air gap thickness (t). All readings were normalized to a reference temperature, 20°C, and pressure, 101.325 kPa. The absorbed dose rate in water was given as below:[5]

$$\dot{D}_w = \frac{\left(\frac{W}{e}\right) S_{w,\mathrm{air}}}{\rho_0 a}\left(\frac{\Delta I}{\Delta t}\right)_{t\to 0} k_{\mathrm{back}} \qquad (1)$$

where (W/e) = the mean energy required to produce an ion pair in dry air divided by the elementary charge (33.83 ± 0.06 J/C), $S_{w,air}$ = the ratio of the mean mass-collision stopping power of water to that of air, ρ_0= the density of air (1.2047 kg/m^3) in the reference condition, a = the area of the collecting electrode (7.0685 cm^2), k_{back} = a correction factor, $(\Delta I{=}\Delta t)_{t\to 0}$ = the rate of change of current (I) with the distance (t), i.e., the extrapolation chamber electrode’s air gap.[6] The ionization currents were obtained in the Charge mode of the electrometer (UNIDOS, PTW, Germany) for each air gap and two voltage polarities (±300 V). And Measurement time is 100 seconds. Figure 2 shows the measurement setup for the Sr-90 standard source using the extrapolation chamber. A custom-made guide system housed both the extrapolation chamber and the applicator. The guide system allowed the applicator to be placed precisely at the specified distance from the detector (EC) and to align the applicator with the central axis of the chamber. Owing to this guide system, the measurements were repeated at five different SDDs (source-to-detector distance) of 1, 3, 5, 7, and 9 mm within 0.1 mm precision.

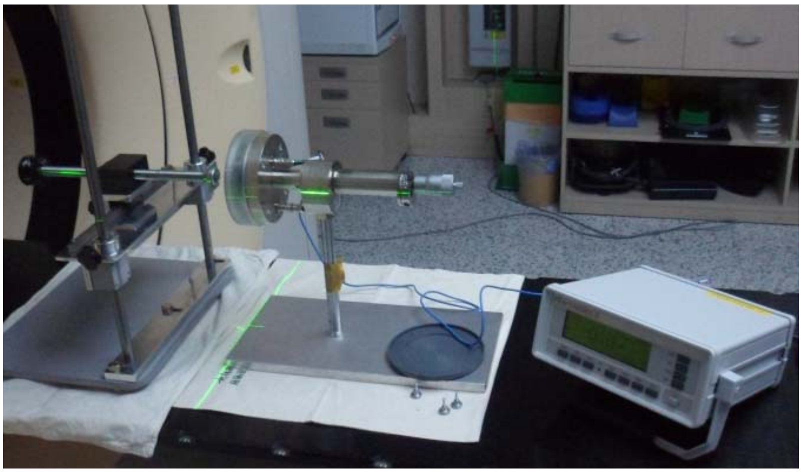

Fig 2. Measurement setup for Sr-90 standard source dosimetry using extrapolation chamber dosimetry with guide system

2.3 Monte Carlo simulations

Monte Carlo simulations were carried out using the MCNP5 code from the Los Alamos National Laboratory. The MCNP code employed an improved electron transport algorithm of ITS 3.0 (Integrated Tiger Series Version 3.0.[7,8] We assumed that the source activity was uniformly distributed in the entire volume of absorbent disk. Photons and electrons were tracked until they reached the cutoff energy of 1 keV. The MCNP5 simulations were carried out for the applicator placed on the top of a cylindrical water phantom that has a 2 cm radius and 1.5 cm height (Fig. 3). The pulse height tally (*F8) of MCNP was used for dose calculations in voxels (0.5 × 0.5 × 0.005 mm^3) shown in Fig. 3. The *F8 tally card describes energy distribution of pulses created in a detector. In order to reach statistical errors less than 1.5% for any voxels of interest in the simulation geometry, 8×10^7 histories were run in coupled electron=photon mode on a Linux cluster (2.67 GHz×24 CPUs) for approximate 12 h of computer time. The energy spectrum of beta particles emitted from the applicator was changed, since beta particles were moderated by metallic encapsulation. The change in the energy spectrum was calculated with the surface flux tally (F2) of MCNP5 using the tally energy card (En). The energy range of 0–2.21 MeV was separated into 22 bins with the same interval (0.1 MeV).[9] The energy spectrum was calculated at 0.25 mm depth in water from the surface of applicator. The extrapolation chamber detector efficiencies for various SDDs were determined by the Monte Carlo simulations using the Surface current tally (F1). The detector efficiency was defined as the ratio of particles emitted from the source to particles arrived at the detector. The cell of cylindrical type with a 30 mm diameter and 0.1 mm thickness was set at five different distances from the applicator in air.

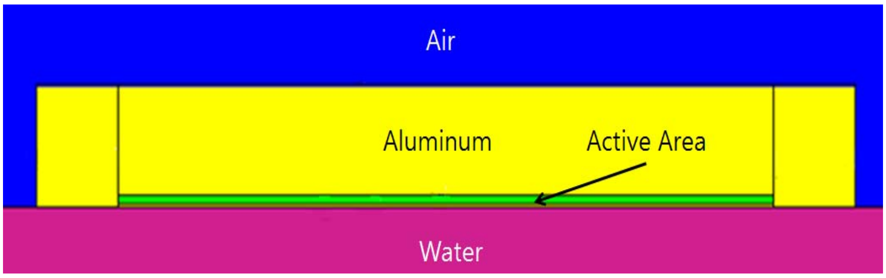

Fig 3. Schematic (cross-sectional) view of Sr-90 standard source for MCNP simulations.

3. RESULTS

The extrapolation curves of Fig. 4 were obtained by plotting the mean values of measured ionization currents as a function of the air-gap thickness between two chamber electrodes for various SDDs. The curves show a linear behavior for the air-gap thickness between 3.0 and 9.0 mm. All R-square values for this linear fitting were over 0.9. The current at the surface was obtained by extrapolating the curve to the air-gap thickness for various SDDs. By using this extrapolation curve, it was possible to determine the reference dose rate of the Sr/Y-90 Standard source. The rate of current change as the air-gap thickness approached zero was determined. The rate of current change was converted into the absorbed dose rate to water using Eq. (1). The average energy of betas at the outer surface of the applicator was determined to be 0.9346 ± 0.133 MeV. The stopping power ratio (Sw,air) was approximately 1.1256 ± 0.003 for the average energy. The detector efficiencies for seven SDDs were calculated to correct the reference dose rates (Table 1). These corrected reference dose rates for seven SSDs were averaged, yielding a reference dose rate of 6.09 × 10^{-5} cGy/s. And Calibration constant that dose rate was divided activity was calculated. It was 1.55 × 10^{-8} cGy/s·Bq for MC, 1.79 × 10^{-8} cGy/s·Bq for Monte Carlo Simulation.

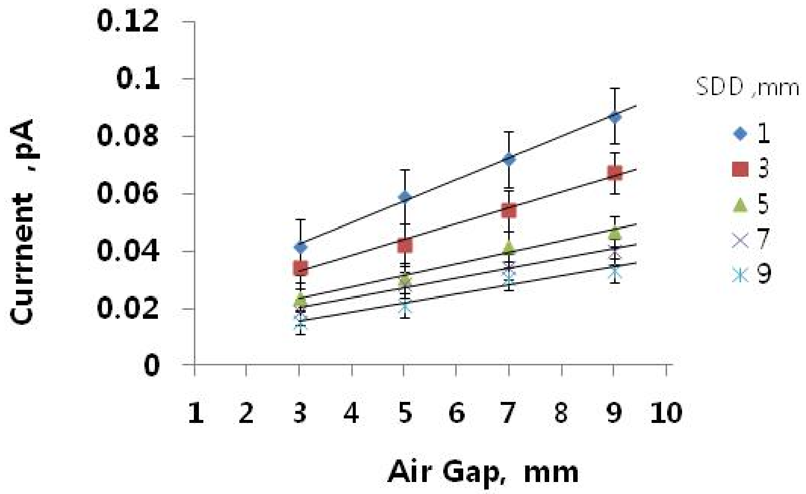

Fig 4 Extrapolation chamber current vs. air-gap thickness between two chamber electrodes for various SDDs.

SDD (mm)	Current (pA/mm)	Detector Efficiency	Corrected Reference Dose rate (cGy/s)
1	0.0089	0.55	6.81^{-05}
3	0.0067	0.50	6.05^{-05}
5	0.0062	0.43	6.24^{-05}
7	0.0045	0.37	5.71^{-05}
9	0.0041	0.32	5.61^{-05}
Mean			6.09^{-05}

Tab 1 : Measured currents and the reference dose rates corrected by the detector efficiencies for various SDDs

4. DISCUSSION

There was about 15.4% difference in the calibration constant determined by the two techniques. It is need to be considered the difference. Dose measurements for beta emitters are often very difficult for various reasons. One of them is an issue associated with high dose gradients near the beta source. The 0.5 mm depth was chosen to decrease depth uncertainty. But measurement is still subject to high depth uncertainty. The detector efficiency has some uncertainty. The detector efficiency was calculated without considering back scatter and side scatter by detector component. It may cause underestimate. To increase the accuracy, it is need to perform more detailed Monte Carlo simulation

We will verify the calibration system to using a test source. A test source will be produced by HANARO. The activity will be calculated using calibration constant. The activity will be performed cross-calibration with NIST. Finally, the system will provide accurate information of sources.

5. References

[1] MICHAEL S. PATTERSON and RONALD C. GREENE “Measurement of Low Energy Beta-Emitters in Aqueous Solution by Liquid Scintillation Counting of Emulsions” ANALYTICAL CHEMISTRY , VOL. 37, NO. 7(1965)

[2] U. C. MISHRA and R. KERALA VARMA “Low-level beta activity measurement of solid samples using plastic scintillator anticoincidence” Nuclear Instruments and Methods Volume 24, 473–476(1963)

[3] C. G. Soares, S. Vynckier, H. Jarvinen, W. G. Cross, P. Sipila, D. Fluhs, B. Schaeken, F. A. Mourtada, G. A. Bass, and T. T. Williams, “Dosimetry of beta-ray ophthalmic applicators: Comparison of different measurement methods,” Med. Phys. 28, 1373–1384 (2001).

[4] C. G. Soares, “Calibration of ophthalmic applicators at NIST: A revised approach,” Med. Phys. 18, 787–793 (1991).

[5] International Commission on Radiation Units and Measurements,“Dosimetry of beta rays and low-energy photons for brachytherapy with sealed sources,” ICRU Report 72 (ICRU, Bethesda, MD, 2004).

[6] A. T. Hakanen, P. M. Sipila, and A. Kosunen, “Calibration of a scintillation dosemeter for beta rays using an extrapolation ionization chamber,” Med. Phys. 31, 1123–1127 (2004).

[7] D. R. Schaart, J. T. Jansen, J. Zoetelief, and P. F. de Leege, “A comparison of MCNP4C electron transport with ITS 3.0 and experiment at incident energies between 100 keV and 20 MeV: Influence of voxel size, substeps and energy indexing algorithm,” Phys. Med. Biol. 47, 1459–1484 (2002).

[8] M. Gleckler, J. D. Valentine, and E. B. Silberstein, “Calculating lens dose and surface dose rates from 90Sr ophthalmic applicators using Monte Carlo modeling,” Med. Phys. 25, 29–36 (1998).

[9] D. E. Cullen, J. H. Hubbel, and L. Kissel, “EPDL97: The evaluated photon data library, ’97 version,” UCRL Report No. UCRL-50500, Vol. 6, Rev. 5 (1997).