Journal of Measurement Science & Applications, JMSA. Vol (4) Issue (2)

Protection Doses Standardization for metrological applications

R. H. Bakr*, S.H. Nagib, A.R. El-Sersy
Ionizing Radiation Metrology Lab, National Institute of Standards (NIS), Egypt
*Corresponding author: reham.hamdy@nis.sci.eg

Article Type: Research article
Received: 2024-09-10 **Accepted: 2024-10-03**

Abstract

This work accurately determined the radiation dose in radiation protection range using a PTW primary standard chamber model TN 32008. The characterization of the ion chamber used was performed at different radiation beam qualities. The performance of the chamber as a primary standard was studied in 137 Cs gamma source where the unit of absorbed dose in Gray was determined from its definition. Factors affecting the dose calculation such as operating voltage, saturation, and ion recombination were studied at the optimum conditions of the chamber usage. Moreover, the performance of the chamber as a primary standard dosemeter was extensively studied using the 60 Co gamma source and different X-ray beam qualities where the relation between its dose-to-collected charge (Gy/C) using the photon energy (keV) was determined. The detailed uncertainty budget was calculated for the used beam qualities. It was found that the chamber can be used in direct radiation dose determination as a primary standard chamber for wide photon energies from 42 keV (effective energy of 100 kV X-ray) to 1250 keV (60 Co) considering the relative stopping power of graphite to air correction and the relative attenuation of the precise beam quality to that of Cs-137 source. The uncertainty of the chamber Nk is 0.7% which shows an energy dependency.

Keywords: **Radiation Dosimetry, energy dependence, Protection doses, beam quality.**

1 Introduction

The calibration of radiation dosemeters in protection level should be performed using Cs-137 source. Ionizing Radiation Metrology Laboratory (IRML) used Cs-137 mainly for calibration and verification of radiation protection dosemeters in accordance with international protocols [1]. These dosemeters are calibrated in the operational quantities defined by ICRU [2] and these operational quantities are obtained from the knowledge of the air kerma [3] at a point in space, applying adequate conversion coefficients [4]. Until now the air kerma rate in IRML was obtained using a secondary standard dosemeter calibrated at BIPM each 5 years, an ionization chamber of model TN32008 which is a graphite spherical cavity ionization chamber constructed by PTW is recently used in IRML, for the gamma radiation of Cs-137. The graphite cavity chamber has been accepted as primary standard for gamma radiation. The advantage of the graphite cavity chamber is its small size, ease of measurement, and direct relation to the radiation quantity. The ion chamber used as a primary one should fulfil the Bragg cavity theory where charge equilibrium exists between the different media of the chamber (air and graphite). Since the chamber fulfills the Bragg-Gray theory relates dose to the medium, Dmed, to dose to the cavity filled by gas, Dgas, via the ratio of mass collision stopping powers between the medium and gas, $(\frac{S}{\rho})^{med}_{gas}$ [5].

$$\frac{D_{med}}{D_{gas}} = \left(\frac{S}{\rho}\right)^{med}_{gas} \qquad (1)$$

The chamber may be designed and constructed for a specific beam quality. The international procedures state that the dosemeter calibration in the standard laboratories should use Cs-137 beam quality [14], the chamber model PTW TN 32008 was constructed for such purpose.

The air kerma (k.) can be calculated with the aid of the induced charge in the primary chamber for a certain beam quality using the following equation [6]:

$$\dot{K} = \frac{I}{\rho_a V}\frac{W}{e}\frac{1}{1-\bar{g}}\left(\frac{\bar{\mu}_{en}}{p}\right)_{a,c}\bar{S}_{c,a}\prod k_i \qquad (2)$$

Where I is the induced current in nA, ρa is the density of air within the chamber cavity volume V, W/e is the energy required to produce one ion pair in air (eV), g is Bremsstrahlung ratio of a specific beam quality, µ/p is relative stopping power and k is the correction factors. The air density within the chamber is obtained from literature and corrected to that of the standard ambient conditions.

This work aims to study the performance of the primary ion chamber TN 32008 for the absolute gamma dose of Cs-137 and Co-60 sources. Moreover, check the use of the chamber in primary dosimetry of other X-ray beam qualities. The detailed uncertainty budget of the determined dose was also studied for the used radiation beam qualities.

2 Experimental work

2.1 dosimetry system

In this work a dosimetry system composed of PTW spherical primary ion chamber Model TN32008 used for dosimetry and electrometer model PTW Unidos T10021 used for charge collection. In addition to a chamber model NE 2561 which is traceable to the SI units through BIPM was also used with the above electrometer.

2.2 Radiation sources

Theratronic T780 E with a Cobalt-60 (60Co) source with an original activity of 292.3 TBq in June 1997 made by Kanata (Ontario, Canada) was used. The present activity of the Cobalt source is 6.3 TBq[7]. Cesium-137 (137Cs) source manufactured by Atomic Energy of Canada Ltd in April 1970 of model GB150 serial No. 37 and original activity of 370 TBq was used.

The X-ray machine used in this study is of model MCN-323 metal-ceramic Philips double pole. The high voltage (HV) and tube current were adjusted in the range 15–180 kV and 0–22.5 mA, respectively. The X-ray tube was made to satisfy and follow up TRS No.469 [8] of the International Atomic Energy Agency (IAEA).

3 Results and discussion

3.1 Ion Chamber Characterization

One of the important factors for ion chamber use is the determination of its optimum polarizing voltage. Different polarizing voltage was used for detecting the optimum voltage. The chamber is supported at reference condition 100 cm and field size 10X10 cm2 using the Co-60 and Cs-137 gamma sources. The optimum polarizing voltage from this experiment was 400 V. Set of correction factors used with the primary chamber such as attenuation, polarity and ion recombination were determined as the method proposed in the Technical Reports Series TRS 398 of IAEA and illustrated in table 1.

Table 1: *Correction factors of the ion chamber for both Co-60 and Cs-137 beam qualities.*

Correction factor	Cs-137	Co-60
Attenuation	1.040 ± 0.007	1.018 ± 0.132
Polarity Kp	1.001 ± 0.001	0.999 ± 0.001
Ion recombination Ks	0.004	1.005± 0.001

3.2 Radiation dosimetry using the primary ion chamber

Since the used chamber is a primary one which is designed to radiation protection level using Cs-137 source as stated by the international protocols. This work verifies the performance of this chamber to absolute dosimetry of Cs-137 and Co-60 sources. The air kerma rate (Kref) for gamma using a primary ion chamber can be given as eq.2.

From collected charge and chamber parameters, the output doses for both Co-60 and Cs -137 sources were calculated using Eq.2 as absolute dosimetry [9]. Table (2) shows the data of the dose as measured by the transfer chamber with the calculated using eq2.

Table 2: *Comparison between doses calculated by primary and secondary ion chamber.*

Chamber type	Cs-137 source	Co-60 source
Absolute dose mGy/h	179.46	202.91
Transferee chamber dose mGy/h	179.825	202.107
Factor	0.997	1.001

From the above table, the dose obtained by the primary chamber is in good agreement with that obtained by the secondary BIPM traceable chamber which concluded the use of the primary ion chamber directly for absolute radiation dosimetry for both Co-60 and Cs-137 gamma source in radiation protection range.

3.3 Check the use of the primary ion chamber for X-ray dosimetry

Before using the chamber for X-ray dosimetry, the photon energies of the used X ray beam qualities should be specified i.e. the mean X-ray energy in keV corresponding to the applied voltage in kV should be specified. In this study, the Half Value Layer (HVL) in a standard reference Cu and Al filter was used for this purpose according to the method proposed by El-Sersy et al [10]. Table (3) shows the tube applied voltage to the corresponding mean energy and corresponding HVL.

Table 3: *energies of the used X-ray beam quality and their corresponding energies.*

Applied Volte (kV)	25	50	100	135	180
HVL	0.51 Al	2.34 Al	0.17 Cu	0.49 Cu	0.97 Cu
X-ray energy (keV)	18	29.5	42	60	82

The X-ray output dose was measured by a BIPM traceable secondary ion chamber at distance of 120 cm. The primary ion chamber output dose was calculated using equation (2) [11,12], the data of X-ray doses as measured by secondary and primary ion chambers is shown in Figure 1.

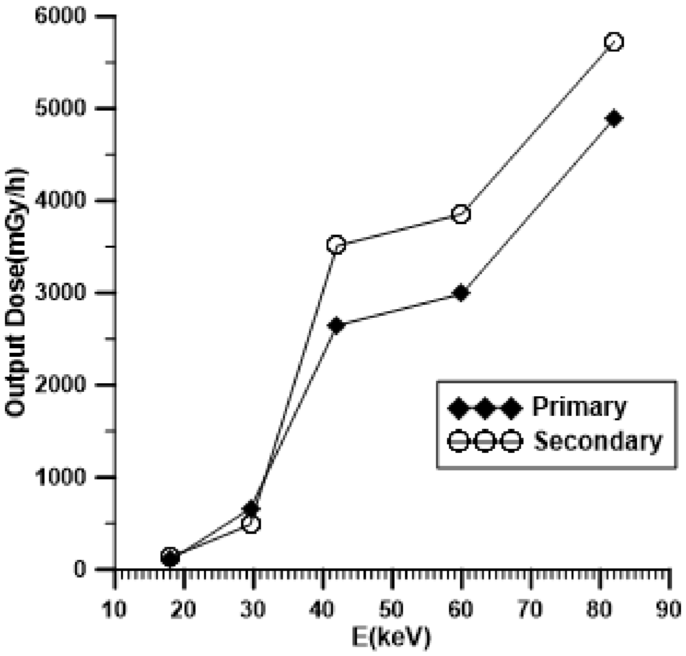

Figure 1: shows the output dose as measured by primary and secondary chambers.

From the above figure, it is noticed that the dose measured by the secondary ion chamber is relatively higher than that measured by the primary one which may be attributed to the use of the primary chamber in different X-ray beam qualities, while the chamber was designed for Cs-137 dosimetry. Moreover, the dose measured by the secondary chamber was performed using a finite calibration factor obtained from the BIPM while that obtained from the primary chamber was performed using Eq.2 which needs some corrections due to its use for beams other than Cs-137.

As known the energy of Cs-137 source is much higher than that of X-ray (see Table 3) and then attenuation coefficient should be considered for each used X-ray beam quality. The relative attenuation coefficient of a precise X-ray beam quality in used ion chamber construction materials (graphite and air) was calculated using the relative stopping power of graphite to air and air to graphite at different energies by the Win-Xcom [16] software and represented in Fig. 2.

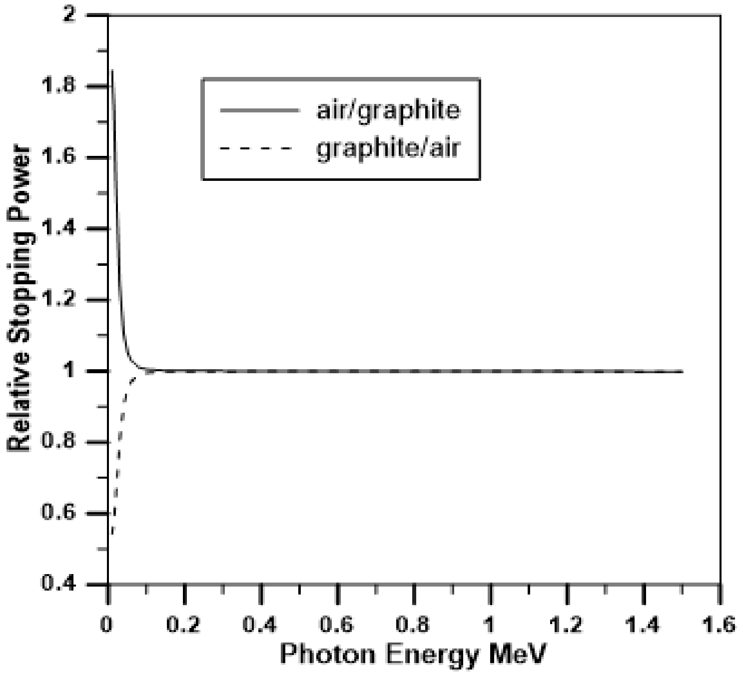

Figure 2: Relative stopping power of air to graphite and graphite to air with different photon energies.

The data of the above figure shows ratio of the stopping power is equal one above about 50 keV and strong energy dependency up to 50 keV. Since the chamber wall is made of graphite, one can calculate the penetrated dose in relative to the incident dose at a certain X-ray energy from the relation:

$$D_{\text{penetrated}} = D_{\text{incident}}\, e^{-\mu x} \qquad (3)$$

Where Dpentrated is the dose within the cavity chamber calculated using eq.2, Dincident is the photon dose incident on the chamber surface and x is wall graphite thickness. As mentioned above the chamber is designed to measure the dose from Cs-137 gamma source source i.e. the attenuation factor is equal to one for Cs-137 photon energy. To use the chamber for dosimetry of any other beam quality, it is suggested that the dose should corrected to the relative attenuation of Cs-137 photon energy to the precise beam quality. Figure 3 shows the relative attenuation correction factor, as calculated by eq. 3, for Cs137 to another beam quality with different energies up to 2000 keV. The figure shows the strong energy dependence of this factor between 20 to 50 keV and then becomes unity to reflect the use of the chamber for X-ray dosimetry above 50 keV. which may attribute the attenuation factor at any X-ray beam with energy more than 50 keV relative to its value in Cs-137 is equal to one.

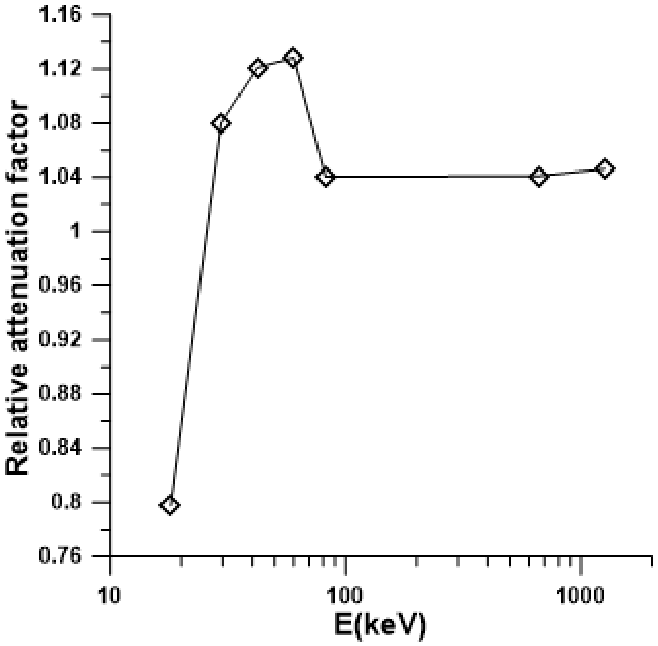

Figure 3: The relative attenuation factor for any photon relative to Cs-137 .

Using the calculations mentioned above and from dose measured by the primary chamber, the Dose-collective charge factor (Nk) of primary chamber is calculated and presented in Table 4.

Table 4: *Dose-collective charge factor (Nk) of the primary chamber.*

Photon energy (keV)	18	29.5	42	60	82	662	1250
Nk	1.275	1.351	1.327	1.290	1.171	1.04	1.018

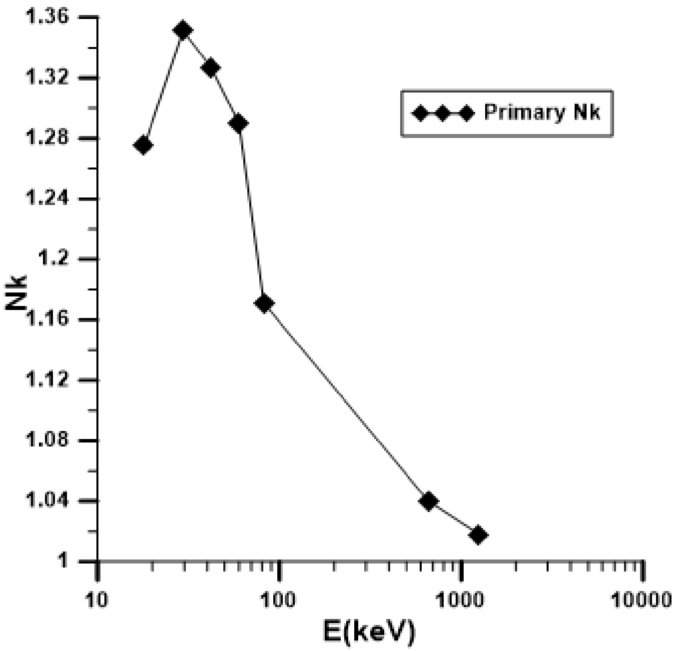

Figure 4: Nk with and without the correction.

3.4 Performance and validation of the use the primary chamber in dosimetry of different radiation

After applying the suggested correction factor of the primary standard chamber, a comparison between the dose calculated by the primary and BIPM traceable secondary ion chamber is represented in Figure 5. The figure shows a good agreement between doses measured by the primary and the secondary one.

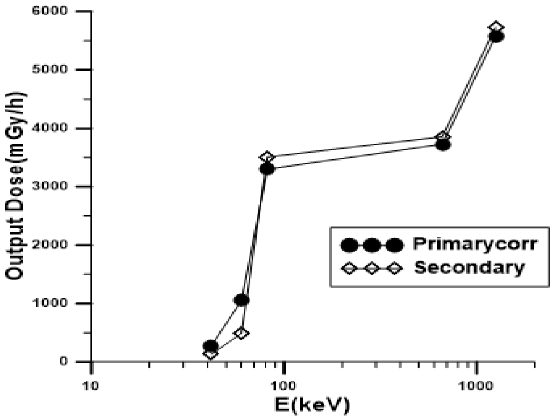

Figure 5: A comparison between doses measured by primary and secondary ion chamber.

To assure the agreement between doses measured by primary and secondary ion chamber, a ratio between them was calculated and represented in figure 6 where a value of one is obtained with a wide range of doses from 18 to 1250 keV [13].

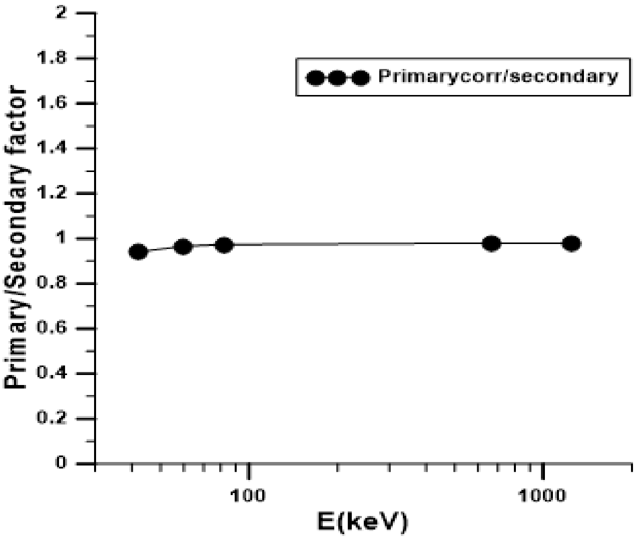

Figure 6: primary and secondary ion chamber ratio.

The secondary Standard Dosemeter Laboratory (SSDL) should promote its capabilities by owning a primary tool for the dosimetry of each activity. In this work, IRML has a primary chamber for protection level that is designed for using in Cs137 and Co60 gamma radiation sources. In this study the chamber is extensively used for wide range of photon energies by considering some of correction factors such as the attenuation of a precise beam through the chamber wall in relative to that of Cs137. Using such a correction factor, chamber can be used in absolute dosimetry for a wide range of photon energies with reasonable accuracy. This work is important to maximize the use of SSDL tools in dosimetry applications.

3.5. Uncertainty of dose determination of the primary ion chamber

Table 5 : *Uncertainty budget for dose: for both Cs-137 and Co-60 as the following budget.*

Source	0.6 PTW 30013 (%)		Primary (%)	
	Type A	Type B	Type A	Type B
Readability	0.10	-	0.10	-
Temperature	0.1000	0.1000	0.1	0.1
Resolution	-	0.1	-	0.1
Pressure	0.1000	0.1000	0.1	0.1
Humidity		0.1000		0.1
current measurement	0.3000	0.1000	0.1	0.0.1
Calibration factor	-	0.10	-	-
Reference conditions	0.30	0.2	0.2000	0.200
Combined Uncert.	0.46	0.24	0.28	0.3
Total uc	0.52		0.41	

Table 6 : *The uncertainty budget in X-ray dosimetry as the following budget.*

Source	**0.6 PTW 30013 (%)**		**Primary (%)**	
	Type A	**Type B**	**Type A**	**Type B**
Readability	0.20	-	0.2	-
Temperature	0.1000	0.1000	0.1	0.1
Resolution	-	0.1	-	0.1
Pressure	0.1000	0.1000	0.1	0.1
Humidity		0.1000		0.1
current measurement	0.3000	0.1000	0.1	0.0.1
Calibration factor	-	0.15	-	-
Reference conditions	0.30	0.2	0.2000	0.200
Combined Uncert.	0.49	0.34	0.33	0.3
Total uc	0.59		0.45	

4 Conclusion

The PTW primary ion chamber is used as a tool for absolute dosimetry in Co-60, and Cs-137 in protection level and shows a high performance for such purpose. The assumption considered in this study is to use a PTW primary ion chamber in absolute dosimetry for different photon energies which shows a high performance considering the relative attenuation coefficient to that of a precise beam quality. Using the relative attenuation coefficient correction factor, the ion chamber can be used in a wide range of energy independent; hence the chamber can be used in absolute dosimetry in different photon energies from 100 kV X-ray to 1250 keV with a reasonable uncertainty.

5.Declarations

5.1 Study Limitations

, None.

5.2 Funding source

None.

5.2 Competing Interests

The authors have no financial or proprietary interests in any material discussed in this article.

5.3 Ethical Approval

Not Required

References

[1] Hassan, M.A., Esmat, E., El-Sersy, A.R., "Development of 137Cs irradiation facility for metrological application", International Journal of Metrology and Quality EngineeringThis link is disabled., 8, 20, 2017.

[2] ICRU Report 95: Operational quantities for External Radiation Exposure, vol.20 no.1, 2020.

[3] Pongphanot Rindhatayathon, Apichart Siriwitpreecha, Vithit Pungkun, "Establishing of primary standard for Cs-137 air-kerma of OAP, Thailand", Applied Radiation and Isotopes 170, 109586, 2021

[4] M.M. Szymko, L. Michalik, A.B. Knyziak, A.W. Wójtowicz, "Development and characterization of air kerma cavity standard", Measurement 136, 647-657, 2019

[5] Hamed Imani-Shirvanehdeh, Abdollah Khorshidi, Jamshid Soltani-Nabipour, Anita Alipour3, Kourosh Arbabi, "Design and Construction of a Cylindrical Ionization Chamber for Reference Dosimetry in Radiation Protection" Iran J Sci Technol Trans Sci 45:1837–1841, 2021

[6] Pongphanot Rindhatayathon and Apichart Siriwitpreecha, "Calculation for Graphite Cavity Ion Chamber Response to Cs-137 Gamma Ray using EGSnrc Monte Carlo Code", Proceedings of RSU International Research Conference (2020), 694-700, 2020.

[7] M.A. Fadel, R.H. Bakr, A.R. El-Sersy, "An in-vivo study on the energy dependence of X-ray biological effectiveness", International Journal of Radiation Research, Volume 17, No 1, 111-118, January 2019

[8] TECHNICAL REPORTS SERIES No. 469: calibration of reference dosemeters for external beam radiotherapy, international atomic energy agency, 2009

[9] Bakr, R.H., Nagib, S.H., El-Sersy, A.R., "Characterization of ion chambers set for different metrological applications", Radiation Physics and Chemistry, 201, 110399, 2022.

[10] A. R. El-Sersy, N.R.Khalel, N.E.Khaled, S.A.Eman, H.M.Eissa, "Characterization study on NIS X-ray beam qualities and its applications" Measurement, Volume 45, Issue 5, Pages 1301-1307,2012.

[11] A. Solimanian and M. Ghafoori, "Standard calibration of ionization chambers used in radiation therapy dosimetry and evaluation of uncertainties" Iran. J. Radiat. Res., 8 (3): 195-19, 2010

[12] N F Silva, M Xavier, V Vivolo and L V E Caldas, "Characterization of a free air ionization chamber for low energy X-rays", 8th Brazilian Congress on Metrology (Metrologia 2015), Journal of Physics: Conference Series 733, 012090,2016.

[13] Ronaldo Minniti and Ladislav Czap, "Comparison of the air kerma standards for 137Cs and 60Co gamma-ray beams between the IAEA and the NIST", Metrologia 48 Tech. Supp. 06005, 201.

[14] Safety reports series no. 16, "calibration of radiation protection monitoring instruments" international atomic energy agency, vienna, 2000.

[15] International atomic energy agency, Absorbed Dose Determination in External Beam Radiotherapy, Technical Reports Series No. 398 (Rev. 1), IAEA, Vienna (2024)

[16] https://physics.nist.gov/PhysRefData/Xcom/html/xcom1.html