# Impact of Beam Quality Q for $^{137}Cs$ on $N_K$ and $N_{D,W}$ for Different Types of Ionization Chambers

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**Abstract**

The calibration of different types of ionization chambers in radiotherapy level is done using different beam qualities i.e. γ-rays from $^{137}Cs$ and $^{60}Co$. The most common reference beam quality ($Q_o$) used for the calibration of ionization chambers in therapy level is $^{60}Co$ γ rays to calculate calibration coefficient factor either in air ($N_K$) or water ($N_{D,W}$). In this study we determine $N_K$ for two types of ionization chambers PTW-30013 and NE-2561 in beam quality (Q) of $^{137}Cs$. The reference values of $N_K$ for ionization chamber type M-32002 which determine in beam qualities Q and $Q_o$ were 24.8µGy/nC and 25.4 µGy/nC respectively. These values were used to determine the $N_K$ and $N_{D,W}$ for unknown chambers in beam quality Q. The beam quality correction factor $K_{QQ_o}$ in terms of air and absorbed dose to water for different ionization chambers used was 0.980±0.01, 0.983±0.009 and 1.0001±0.008, 1.0005±0.006 for TM-30013 and NPL 229 respectively.

**Keywords:** Absorbed dose to water, Air Kerma, Ionization chambers, Beam quality

## 1. Introduction

When a dosimeter is used in a beam of quality Q different from that used in its calibration, $Q_o$, the absorbed dose to water is given by

$$D_{w,Q} = M_Q\, N_{D,W_Q}\, K_{QQ_o}$$

Where, the factor $K_{QQ_o}$ corrects for the effects of the difference between the reference beam quality $Q_o$ and the actual beam quality Q, and the dosimeter reading $M_Q$ has been corrected to the reference values of influence quantities, other than beam quality, for which the calibration factor is valid. The beam quality correction factor

$K_{QQ_o}$ is defined as the ratio, at the qualities Q and $Q_o$ of the calibration factors in terms of air kerma or in terms of absorbed dose to water of the ionization chamber.

$$K_{Q,Q_o} = \frac{N_{K,Q}}{N_{K,Q,Q_o}} = \frac{N_{DW,Q}}{N_{DW,Q,Q_o}} \tag{1}$$

The most common reference beam quality $Q_o$ used for calibration of ionization chambers is $^{60}$Co γ-rays, in which case the symbol $K_Q$ is used for the beam quality correction factor. In some primary standard dosimetry laboratories (PSDLs) high-energy photon and electron beams are directly used for calibration purposes and the symbol $K_{QQ_o}$ is used in those cases. Where $N_{K,Q}$, $N_{K_{QQ_o}}$ are the calibration coefficients in terms of air kerma.

$N_{DW_Q}$ $N_{DW,QQ_o}$ are the calibration coefficients in terms of absorbed dose to water. Ideally, the beam quality correction factor should be measured directly for each chamber at the same quality as the user beam. However, this is not achievable in most standards laboratories. Such measurements can be performed only in laboratories having access to the appropriate beam qualities.

A calculated $N_{D,w,Q_o}$ can also be used to verify that the therapy beam calibrations based on the two formalisms, $N_{D,w}$ and $N_K$, yield approximately the same absorbed dose to water under reference conditions. When no experimental data are available, or when it is difficult to measure $k_{Q,Q_o}$ directly for realistic clinical beams; the correction factors can, in many cases, be calculated theoretically. By comparing eq. (1) with the $N_{D,air}$ formalism given above, $K_{Q,Q_o}$ can be written as eq. (2)

$$K_{Q,Q_o} = \frac{P_Q}{P_{Q_o}} \frac{S_{(W,air),Q}}{S_{(W,air),Q_o}} \tag{2}$$

including the following ratios, at beam qualities $Q$ and $Q_o$:

- Spencer–Attix water to air restricted stopping power ratios $S_{w,air}$;
- The perturbation factors $P_Q$ and $P_{Q_o}$ for departures from the ideal Bragg–Gray detector conditions.

The calculations of $K_{Q,Q_o}$ are based on exactly the same data used for calculations in air kerma based approach, but the parameters are used as ratios, which have reduced uncertainties compared with individual values. Most protocols provide a modified formalism for electron beams for use when a chamber is cross-calibrated (i.e. does not have a direct $N_{D,W}$, $^{60}$Co calibration coefficient). The details can be found in the IAEA TRS 398 (IAEA, 2000) and AAPM TG 51 protocols. (P. Andreo, 2005)

Hugo Palmans *et al* 1999 found that the beam quality correction factor ($K_{QQ}$) for three NE2571 chambers in the 5 MV and 10 MV photon beams are 0.995 ±0.005 and 0.979 ± 0.005, respectively. For the three chambers used, the maximum deviation of individual $K_{QQ}$ values is 0.2%. The Monte Carlo calculation of correction factors for primary standards of air-kerma were done by Rogers and Kawrakow 2003. Wojciech Bulski et al. found that calibration coefficients for ionization cylindrical chambers of the Farmer-type determined according to IAEA Report 398 are higher by about 1% than those determined according to the IAEA Report 277.

The IAEA code of practice provides the methodology necessary for the accurate determination of the absorbed dose to water from radiation beams used for radiotherapy. The formalism is based on the use of ionization chamber dosimeters which are calibrated in terms of air kerma. The ionometrically determined absorbed dose to water based on an air kerma calibration of the ionization chamber was compared with the absorbed dose derived from calorimetric measurements.

At standard laboratory the absorbed dose to air in $^{60}$Co beam is determined from the air kerma $(K_{air})_{air}$ using the following equation:

$$D_{air} = (K_{air})_{air}(1 - g)k_m k_{att} k_{cel}$$

Where;

(g) is the fraction of the total transferred energy expended in radiative interactions on the slowing down of secondary electrons in air; ($k_m$) is a correction factor for the non-air equivalence of the chamber wall and buildup cap; ($k_{att}$ ) is a correction factor for photon attenuation and scatter in the chamber wall; ($k_{cel}$ ) is a correction factor for the non-air equivalence of the central electrode.

The cavity air calibration coefficient $N_{D,air}$ is defined as:

$$N_{D,air} = D_{air}/M_Q$$

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where $M_Q$ is the chamber signal corrected for influence quantities.

The air kerma in air calibration coefficient $N_{K,Co}$ is defined as:

$$N_{K,Co} = (K_{air})_{air}/M_Q$$

The cavity air calibration coefficient can be determined from the air kerma in air calibration coefficient at the $^{60}$Co beam quality, using the relationship:

$$N_{D,air} = N_{K,Co}(1 - g)k_m k_{att} k_{cel}$$

The aim of this work is to measure and calculate calibration coefficient in terms of Air kerma ($N_K$) for different ionization chamber as of type PTW 30013 and NE-2561 chambers in different beam quality (Q) of $^{137}$Cs by using ionization chamber of type M-32002 calibrated at IAEA against $^{60}$Co ($Q_o$) and $^{137}$Cs (Q).

Also, calculate calibration coefficient in terms of absorbed dose to water ($N_{D,W}$) for all the pervious ion chambers. Find Beam quality correction factor ($K_{QQ_o}$) which is defined as the ratio, at the qualities Q ($^{137}$Cs) and $Q_o$ ($^{60}$Co) of the calibration factors in terms of air Kerma or in terms of absorbed dose to water of the ionization chamber.

## 2. Materials and methods

### *2.1 Gamma Irradiation Facility*

#### 2.1.1 Cesium-137 Source Description

Cesium-137 source used in this work was of type Gamma Beam-150B, manufactured by Atomic Energy of Canada Limited with activity of 500Ci, and dose rate 1.235 Gy/h at one meter from the source center. The calibration was performed by the substitution method using the NIS Reference Secondary Standard System. The half life time was 30.17 year. The unit consists of a source drawer moving vertically through the center of a cylindrical lead main shield. Source exposure time can be accurately controlled with the digital timer provided. A collimator of fixed filed sized is added to the source shield window resulting in a field size 10×10 cm$^2$ at source chamber distance SCD = 100 cm. Dimensions and angles are not to scale. The dose rate was 45.52 mGy/h at one meter from the source center as in fig. (1).

#### 2.1.2 Cobalt-60 Source Description

The $^{60}$Co therapeutic unit used in this work was Gammatron manufactured by Siemens, Germany. Head radionuclide capsulated $^{60}$Co standard source with 2.0 cm diameter type C-146 was manufactured by Theratronics, S. No.S-4275. The present activity is 750 Ci, and dose rate of 5.94 Gy/h at one meter from the center of the $^{60}$Co source, calibrated by the secondary standard dosimetry system of NIS (NPL system).

#### 2.1.3 Ionization chambers and electrometer

Three different types of ionization chambers of certain manufacturers were available and used in the study. These systems are: first system: spherical ionization Freiburg of type PTW M-32002 has (1000 cm$^3$), serial number 151. This chamber was calibrated by International Atomic Energy Agency (IAEA) by substitution method using IAEA reference standard chamber LS-01(#115) to calculate $N_K$ (µGy/nC) in reference beam $^{60}$Co ($Q_o$) and in different photon beam $^{137}$Cs (Q) fig. (2a). The $N_K$ factors were 24.8 and 25.4 for $^{60}$Co and $^{137}$Cs respectively. In this study, this system will be considered as secondary standard dosimetry system. Second system: ionization chamber of type PTW 30013 has (0.6 cm$^3$) and serial number 2016 used with electrometer PTW UNIDOS type UNIDOS 10001 and serial number 10522. The chamber was calibrated at the Bureau International des Poids et Mesures (BIPM) in the $^{60}$Co beam and $N_K$ = 49.63 Gy/µC, $N_{D,W}$ =54.42 ± 0.38 mGy/nC) fig. (2b). Third system: ionization chamber of type NE-2561 has (0.3 cm$^3$) and serial number 229 used with electrometer NPL electrometer of type NE-2560/200. The chamber was calibrated at the (BIPM) in the $^{60}$Co beam where $N_K$ = 94.84 mGy/nC and $N_{D,W}$ = 103.41 ± 0.31 mGy/nC fig. (2b).

Characteristics of the chambers (internal radii, the wall and build-up-cap materials) are given in table 1. As all chambers recommended in this document are open to the ambient air, the mass of air in the cavity volume is subject to atmospheric variations.

$$K_{TP} = \frac{(273.2 + T)P_O}{(273.2 + T_O)P} \tag{3}$$

The correction factor should be applied to convert the cavity air mass to the reference conditions, eq. (3). P and T are the cavity air pressure and temperature respectively at the time of the measurements, where $P_o$ and $T_o$ are the reference values (generally 101.3 kPa and 20° C). No corrections for humidity are needed if the calibration factor was referred to a relative humidity of 50% and is used in a relative humidity between 20% and 80%.

## 3. Results and discussions

As in the TRS of the IAEA-398 (2000) the radiation quantity can be measured in terms of exposure, air kerma, absorbed dose, dose equivalent, ambient dose equivalent and directional dose equivalent by using radiation measuring instruments calibrated at reference standard quality beam $Q_o$ for $^{60}$Co. In this work an attempt to determine the $N_k$ and $N_{D,W}$ factor for the ionization chamber using $^{137}$Cs source of beam quality (Q) using the information of $N_K$ and $N_{D,W}$ for another chamber calibrated against the two sources i.e different beam qualities.

### *3.1 Calibration coefficient in terms of Air ($N_k$)*

For all calibrated ion chambers, the calibration coefficients determined according to TRS 398 are higher than the corresponding coefficients determined according to TRS 277 (IAEA, 1997). This fact has also been noted by other authors (Bjerke H. and Hult A., 2004) and (Huq M. and Andreo P., 2004).

Temperature and pressure correction factors, equation (1), were taken into consideration during $N_k$ measurement for the two ion chambers TM-30013 & NPL 229 using $^{60}$Co. Then the ratio between measured and reference values were 0.985 and 0.999 respectively for $^{60}$Co as shown in table (2). Also $N_k$ for the two ion chambers TM-30013 & NPL 229 against $^{137}$Cs were calculated which can be used for the ion chamber calibration in air.

### *3.2 Calibration Coefficient in terms of absorbed dose to water ($N_{D,W}$)*

Temperature and pressure correction factors, equation (1), were taken into consideration during $N_k$ measurement for the two ion chambers TM-30013& NPL 229 using $^{60}$Co. Then the ratio between measured and reference values were 0.983 and 0.992 respectively for $^{60}$Co as shown in table (3). The ratio between measured and calculated values according to reference (Wojciech et. Al., 2008) was found to be 0.985 and 0.989. From this results we can calculate ($N_{D,W}$) according to the measured values against $^{137}$Cs which can be used for the Ion chamber calibration in water.

### 3.3 Beam quality correction factor ($K_{QQ_o}$)

Table (4) shows calculated $K_{Q,Q_o}$ in terms of air for ion chamber M-32002, as reference chamber, and was found 1.02419 and 0.98, 1.0001 for the other two ion chambers TM-30013 and NPL229 respectively. Results show that the ratio between all values is very close. Also, for calculated $K_{Q,Q_o}$ in terms of absorbed dose to water for ion chambers TM-30013 and NPL229, we found that the ratio values were 0.983 and 1.0005 respectively.

### *3.4 Total sources of uncertainty*

The IAEA TRS 398 dosimetry code of practice describes an extensive uncertainty analysis on the calculated values of the beam quality conversion factors $K_Q$ for photon and electron beams. For photon beams the estimated relative standard uncertainty for calculated beam quality conversion factors calibration of photon is 0.9 % for cylindrical chambers when based on a $^{60}$Co calibration technique (P. Andreo, 2005)

In this work errors were calculated due to the estimate of standard dose, errors due to $^{137}$Cs irradiation source used as different beam quality and errors due to $^{60}$Co irradiation source used as reference beam quality. The total combined uncertainty = ± 0.3 (ISO/IEC 2009).

## 4. Conclusion

Results of this study will allow our lab to use our dosimetry system in calibration in the terms of air ($N_k$) and absorbed dose to water ($N_{D,W}$) in beam quality $^{137}$Cs source (half life time 30 years) instead of $^{60}$Co (half life time 5.2 years), where activity of the source has impact on the dose measurement.

To achieve the values of calibration coefficient in terms of air ($N_k$) for chambers (PTW 30013 and NE 2561) are measured and calculated in beam quality $^{60}$Co and $^{137}$Cs according to TRS-398. Also the values of calibration coefficient in terms of absorbed dose to water ($N_{D,W}$) are measured and calculated for chambers (PTW 30013 & NE 2561) in beam quality $^{60}$Co and calculated in the beam quality $^{137}$Cs.

From the measured and calculated beam quality correction factors for $^{60}$Co and $^{137}$Cs, we find ($K_{QQ_o}$) were comparable with the certified reference values (BIPM). The combined uncertainty accompanied with those measurements was ± 0.53.

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Table 1. Characteristics of different ionization chambers

| **Ion Chamber type** | **Measuring volume $cm^3$** | **Wall Material** | **Build-up cap** |
|---|---|---|---|
| M-32002 | 1000 | POM | — |
| PTW 30013 | 0.6 | Graphite | PMMA |
| NE 2561 | 0.3 | Graphite | Derlin |

Table 2. Reference and measured values of $N_k$ calibration coefficients in terms of air kerma for different ionization chambers

| **Chamber Type** | **$N_k$ $^{137}$Cs (Q)** | **$N_k$ $^{60}$Co ($Q_o$)** |
|---|---|---|
| M-32002 | *(24.8 ±0.2 µGy/nC) | *(25.4±0.2 µGy/nC) |
| TM-30013 | –<br>50.29 ± 0.5 mGy/nC | *(49.63±0.09 Gy/µC)<br>48.90 ± 0.3 Gy/uC |
| NPL 229 | –<br>94.35 ± 0.5 mGy/nC | *(94.84±0.17 mGy/nC)<br>93.80 ± 0.3 mGy/nC |

* Reference $N_k$ (This value was taken from calibration certificate of BIPM, France in 2007-2012)

Table 3. Measured calibration coefficients values in terms of absorbed dose to water $N_{D,w}$ for the two sources $^{60}$Co and $^{137}$Cs

| **Chamber Type** | **$N_{D,w}$ $^{137}$Cs** | **$N_{D,w}$ $^{60}$Co** |
|---|---|---|
| TM-30013 | **(55.005 ± 0.3 mGy/nC) | *(54.42 ± 0.38 mGy/nC)<br>53.48 ± 0.3 mGy/nC<br>***(54.28 ± 0.31 mGy/nC) |
| NPL 229 | **(103.193±0.3 mGy/nC) | *(103.41 ± 0.31 mGy/nC)<br>102.59 ± 0.3 mGy/nC<br>***(103.729 ± 0.31 mGy/nC) |

* Reference $N_{D,w}$ (This value taken from calibration certificate of BIPM**,** France in 2007-2012)

** Calculated according to the measured values

*** Calculated according to reference values

Table 4. Beam quality correction factor ($K_{QQ_o}$) is defined as the ratio, at the qualities Q ($^{137}Cs$) and $Q_o$ ($^{60}Co$) of the calibration factors in terms of air Kerma or in terms of absorbed dose to water of the ionization chamber.

| Chamber Type | $K_{Q,Q_o} = N_{K,Q}/N_{K,Q,Qo}$ | $K_{Q,Q_o} = N_{DW,Q}/N_{DW,Q,Qo}$ |
|---|---|---|
| M-32002 | *(1.02419) | |
| TM-30013 | 0.9868<br>0.9723<br>Average = 0.980 ± 0.010 | 0.97236<br>0.989366<br>0.986878<br>Average = 0.983 ± 0.009 |
| NPL 229 | 0.99417<br>1.00593<br>Average = 1.0001 ± 0.008 | 0.99415<br>1.00210<br>1.00519<br>Average = 1.0005 ± 0.006 |

* Reference $N_k$ (This value was taken from calibration certificate of BIPM, France in 2007-2012)

Table 5. Different sources of uncertainty of the calibration coefficients in terms of air kerma ($N_k$) and the calibration coefficients in terms of absorbed dose to water ($N_{D,W}$)

| Source of uncertainty | Values |
|---|---|
| ***Errors due to the estimate standard dose*** | |
| $N_k$ calibration of SSDL | 0.2 |
| Long-term stability of secondary standard | 0.05 |
| Repeatability of secondary standard system | 0.05 |
| Position (the effective centre of the dosimeter) | 0.25 |
| Distance away from the source $^{137}Cs$ | 0.035 |
| Electrometer (Unidos) | 0.0001 |
| Temperature and pressure | 0.02 |
| ***Errors due to irradiation source $^{137}Cs$*** | |
| $^{137}Cs$ radionuclide source anisotropy | 0.2 |
| Effects of beam size | 0.025 |
| Room scatters correction | 0.3 |
| ***Errors due to irradiation source $^{60}Co$*** | |
| $^{60}Co$ radionuclide source anisotropy | 0.2 |
| Effects of beam size | 0.020 |
| Room scatters correction | 0.3 |

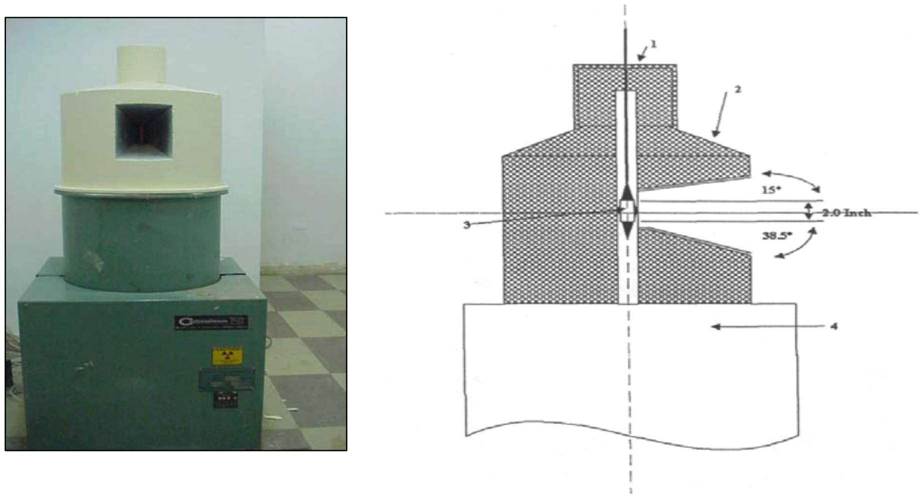


Figure 1. Cs-137 gamma beam source, (1) Top shielding, (2) Sky shield head, (3) source, (4) Drive enclosure. Dimensions and angles are not to scale


(2a)

(2b)

Figure 2. Ionization chambers with electrometer and extension cable. (2 a) type M32002 (2b) PTW 30013 and NE 2561 with electrometer and extension cable