6th Conference on Nuclear and Particle Physics
17-21 Nov. 2007 Luxor, Egypt

ON THE ABSORBED DOSE DETERMINATION METHOD IN HIGH ENERGY PHOTON BEAMS

F. Scarlat, A. Scarisoreanu, M. Oane, E. Mitru, C. Avadanei[1)]

National Institute for Lasers, Plasma & Radiation Physics (NILPRP), Bucharest, Romania; [1)]National Institute of Physics and Nuclear Engineering Horia Hulubei – Vocational Training Center in the Nuclear Field, Bucharest, Romania

Abstract

The absorbed dose determination method in water, based on standards of air kerma or exposure in high energy photon beams generated by electron with energies in the range of 1 MeV to 50 MeV is presented herein. The method is based on IAEA-398, AAPM TG-51, DIN 6800–2, IAEA–381, IAEA–277 and NACP–80 recommendations. The dosimetry equipment is composed of UNIDOS T 10005 electrometer and different ionization chambers calibrated in air kerma method in a Co^{60} beam. Starting from the general formalism showed in IAEA–381, the determination of absorbed dose in water, under reference conditions in high energy photon beams, is given. This method was adopted for the secondary standard dosimetry laboratory (SSDL) in NILPRP-Bucharest.

Keywords**:** *absorbed dose, high energy photons beams, secondary standard dosimetry laboratory.*

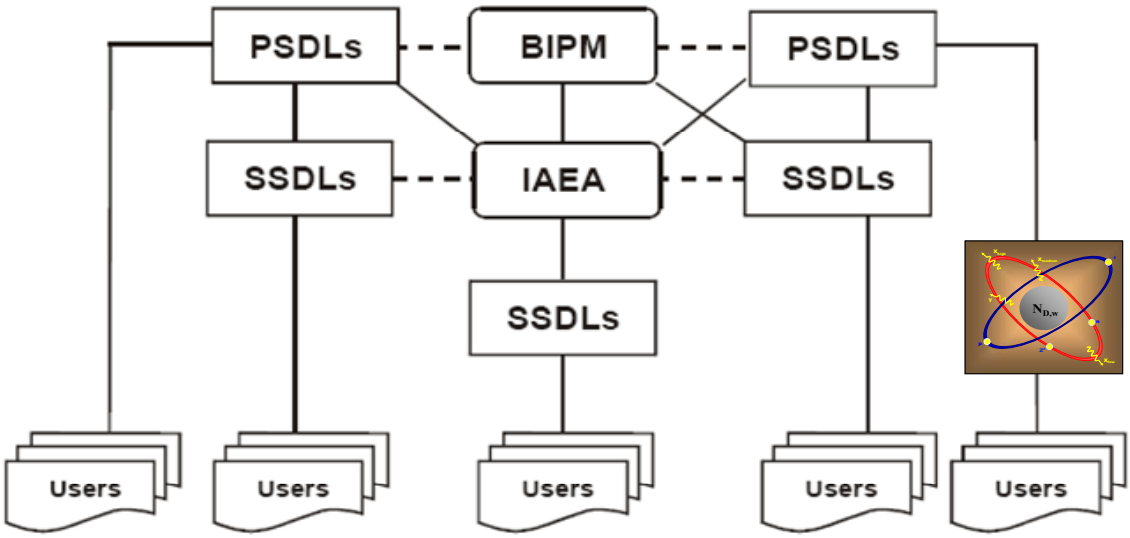
INTRODUCTION

Secondary standard dosimetry laboratory (SSDL) is a standard calibrated or standardizated at primary standard dosimetry. This is based on relative dosimetric methods and on associated dosimetric devices, calibrated or standardized by comparison. Dosimetry secondary standard is used for dosimetric values determination, based on a number of particles or on energy, for calibration or standardization of tertiary dosimetric devices - of work, of daily use, field or of laboratory. Main task of SSDL is transfer of dates obtained after calibration, from Primary Standard Dosimetry Laboratory (PSDL) to user. Beam quality and irradiation geometry at PSDL and SSDL, must be possible alike, for to avoid errors introduced in this transfer.

This work presents the absorbed dose to water determination methods for high-energy photon beams, methods used in SSDL - STARDOOR of NILPRP Bucharest. Ionization chamber calibration from users can be made directly in a PSDL or SSDL which satisfies the requirement of IAEA standards (International Atomic Energy Agency) and BIPM (Bureau

International des Poids et Mesures). Figure 1, presents SSDL – STARDOOR classification between PSDL and users. STARDOOR was endowed with proper devices in Project no. 225 / 10.08.2006 made between Renar and NILPRP. Renar is the national institution which will grant STARDOOR accreditation as SSDL.

From the methods used in IAEA-398, AATM TG-51 and DIN 68002 in this work are presented the methods from IAEA-398, which our laboratory adopted.



DOSIMETRY EQUIPMENT

The devices of STARDOOR, used for calibrations are: reference dosimeter UNIDOS, model T100005-50406 made in PTW; ionization chambers Farmer model TN30010 and Roos model TN34001 calibrated at PTW Freiburg and compatible with reference dosimeter UNIDOS, acrylic phantom model T2967 made of 33 plates with dimensions 30 x 30 cm of different width with a maximum tolerance of 0.1 mm and water phantom model 9750 made in Multidata Systems Germany.

.

Table 1. Measuring ranges for digital resolution of 0.2%.

Range	Current	Dose rate
Low	[500 fA … 100 pA]	[1.5 mGy/min … 0.3 Gy/min]
Medium	[50 pA … 10 nA]	[150 mGy/min … 30 Gy/min]
High	[5 nA … 1 µA]	[15 Gy/min … 3000 Gy/min]
Range	Integrated current	Integrated dose rate
Low	[5 pC … 6.5 µC]	[250 µGy … 325 Gy]
Medium	[500 pC … 650 µC]	[25 mGy … 30 kGy]
High	[50 nC … 65 nC]	[2.5 Gy … 3.25 MGy]

Reference dosimeter UNIDOS, could be used like secondary standard for calibrations. Measuring ranges for digital resolution of 0.2% are given in Table 1.

The Farmer is a wide spread ionization chamber for absolute dose measurement in high-energy photon beams (30 keV – 50 MeV), nominal sensitive volume of the chamber is 0.6 cm^3, wall material is PMMA, electrode material is Al with 1.1 mm diameter; the buildup cap is made of PMMA.

Table 2 presents the important parameters for reference dosimeter UNIDOS and for Farmer and Roos ionization chambers.

Table 2. Parameters of devices used for dosimetric measurements in high-energy photon beam

Equipment	Calibration factor of detector	Calibration factor of dosimeter	Uncertainty	Absorbed dose to water range
UNIDOS	-	k_{elec}=1,000±0.5%	0.2 %	-
Farmer ionization chamber	$N_{D,w}$=5.355x10^7Gy/C	k_{elec}=1,000±0.5 %	1.1 %	[5 10^2 …5,0] Gy
Roos ionization chamber	$N_{D,w}$=8.620x10^7Gy/C	k_{elec}=1,000±0.5 %	1.1 %	[5 10^2 …5,0] Gy

The Roos chamber is a plan-parallel chamber well suited for the measurement of high-energy (1 MeV – 25 MeV) photon depth dose curves up to 2.5 mm below the water surface, with nominal sensitive volume from 0.35 cm^3, wall material is PMMA cover with graphite and varnish.

Water phantom consist of a remote controlled probe positioning mechanism, mounted into a water tank designed to measure complete radiation field characteristics in any of three scanning planes. The tank is made from stress relieved acrylic with glued seams, each seam reinforced through casting and it has the dimensions: 59 cm width (X), 58 cm length (Y) and 49 cm height (Z). Scanning volume is: 48 cm on X axis, 48 cm on Y axis, 40 cm on Z axis and diagonal scan of 67 cm. Water phantom have like constitutive parts, amplification electrometer model 9755, witch is the dosimetry system for data acquisition and a pair ionization chamber. Electrometer is placed in room control with one calculator and it is connected with a cable with 25 de pins of water phantom and with two special cables by two ionization chambers calibrated. With „Real time Dosimetry Software" installed on computer, the probe could be moved slowly in desired place and could be made 1D, 2D and 3D measurement, transversal dose and depth determination.

BEAMS QUALITY SPECIFICATION

Beam in which was calibrated both ionization chamber, it was from a ^{60}Co source**,** with correction factor k_Q equal with 1.000 and uncertainty with 1.1 %.

High-energy photon beams (5 MeV), used in SSDL STARDOOR, are produced by linear accelerator ALID-7. For high-energy photos, quality beam is specified by tissue-phantom ratio, $TPR_{20,10}$ (Figure 2). $TPR_{20,10}$ represents absorbed dose ratios at depth 20 cm and 10 cm in a water phantom, measured at a constant source-detector distance of 100 cm and a field with dimensions of 10 cm x 10 cm at phantom surface [1]. $TPR_{20,10}$ could be obtained with relation (1):

$$TPR_{20,10}=1.2661\ PDD_{20,10}-0.0595 \quad (1)$$

where $PDD_{20,10}$ is the ratio of the percent depth-doses at 20 cm and 10 cm depths for a field size of 10 cm x 10 cm defined at the phantom surface with an SSD of 100 cm.

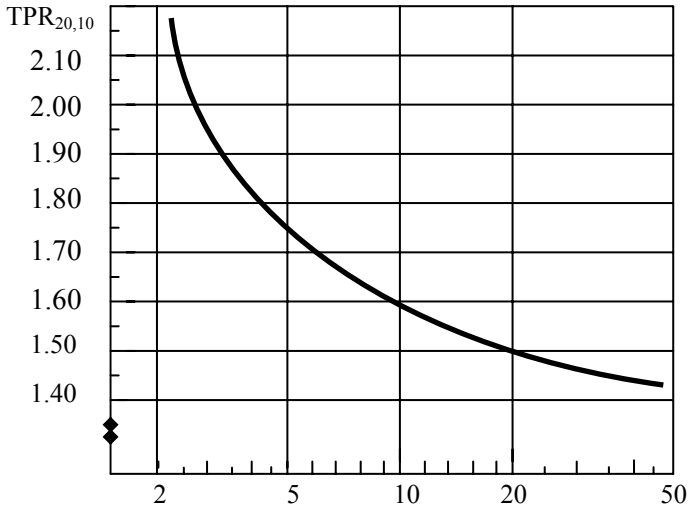


Figure 2. Accele h $TPR_{20,10.}$ [2]

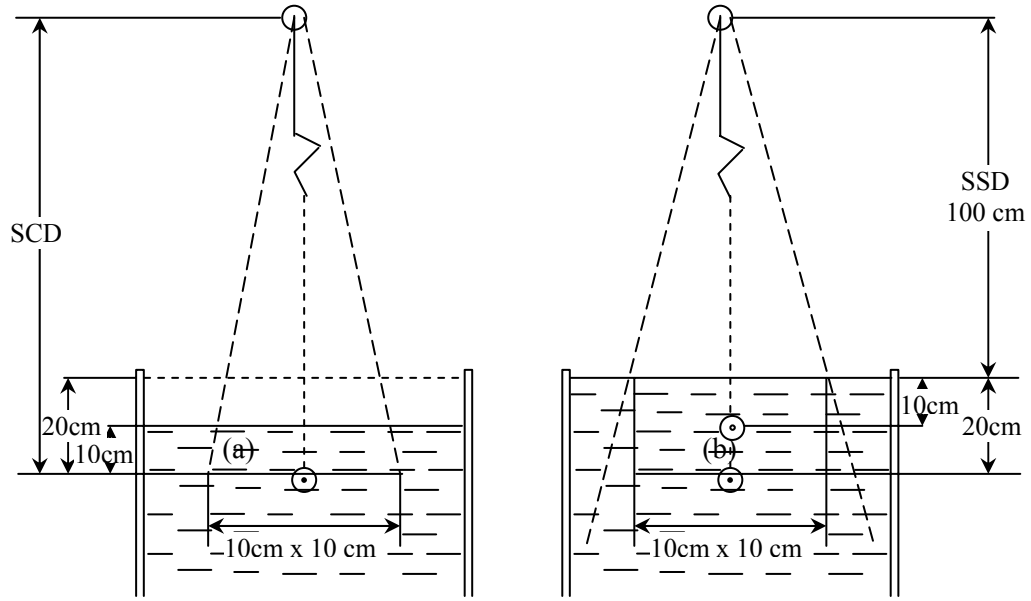


Figura 3. Methods used for quality beam determination to ALID-7, with vertical beam direction

This empirical equation (1) was obtained from a sample of almost 700 accelerators and has confirmed an earlier. Alternatively, $TPR_{20,10}$ can be estimated from a fit to the data for the percentage depth-dose at 10 cm depth, PDD(10), with relation (2):

$$TPR_{20,10}=-0,7898+0.0329PDD(10)-0.000166PDD(10) \quad (2)$$

Excepted energy of 50 MeV, uncertainty for equation (2) is 0.6 % for PDD (10) = 75 %. At PDD (10) = 91 %, uncertainty is 1 %. To determine quality beam could be realized two experimental models [3]. First method (Figure 3a) consists by kept constant source-chamber distance (SCD) and depth is changed by varying the amount of phantom material over the detector. In the second method, the source –surface distance (SSD) is kept constant and the detector is moved to different depths. D_{20}/D_{10} is measured. Both methods could be used in a vertical or horizontal beam (Figura 4).

Table 3. Reference conditions for the determination of photon beam quality $TPR_{20,10}$

Influence quantity	Reference value or reference characteristics
Phantom material	water
Chamber type	cylindrical or plane-parallel
Measurement depths	20 g cm^{-2} and 10 g cm^{-2}
Reference point of chamber	for cylindrical chambers, on the central axis at the centre of the cavity volume; for plane-parallel chambers, on the inner surface of the window at its centre
Position of reference point of chamber	for cylindrical and plane-parallel chambers, at the measurement depths
SCD	100 cm
Field size at SCD	10 cm x 10 cm

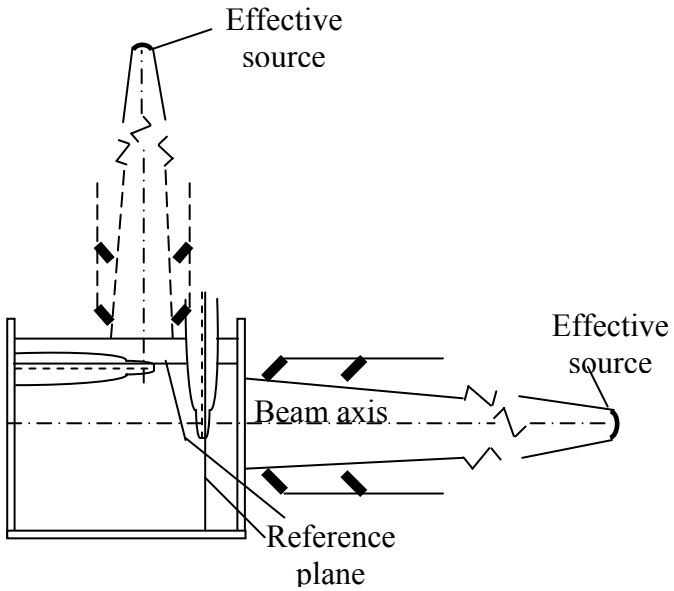


Figura 4. Ionization chamber use for determination absorbed dose to water at reference depth

CORRECTION FACTORS FOR BEAMS QUALITY USED BY SSDL

Correction factor of ^{60}Co beam in which was calibrated cylindrical chamber Farmer, k_{Qo}, is 1.000. Table 4 gives values of correction factor, k_Q, for cylindrical chamber up mentioned, varying $TPR_{20,10}$ of the beam used by SSDL.

Table 4. Calculated values of k_Q for high-energy photons beam as a function of beam quality $TPR_{20,10}$

$TPR_{20,10}$	0.50	0.53	0.56	0.59	0.62	0.65	0.68	0.70
k_{Qo}	1.004	1.003	1.001	0.999	0.997	0.994	0.990	0.988
$TPR_{20,10}$	0.72	0.74	0.76	0.78	0.80	0.82	0.84	-
k_{Qo}	0.985	0.981	0.976	0.969	0.962	0.955	0.943	-

CALIBRATION AT SECONDARY STANDARD LABORATORY

Absorbed dose to water, $D_{w,Qo}$, in reference point of a chamber, from a phantom irradiated with an reference quality beam Q_0 is given by relation:

$$D_{w,Qo} = M_{Qo} \cdot N_{D,w,Qo} \tag{3}$$

where $N_{D,w,Qo}$ is obtained at standard laboratory from standard quantity of absorbed dose to water in measurement point for quality beam of primary calibration Qo and M_{Qo} is reading indication for beam quality Qo. Is assumed that absorbed dose is determined at reference depth z_{ref} from phantom. In continuation is determine $D_{w,Q}$, absorbed dose for photon beam, in which is made the calibration of user ionization chamber:

$$D_{w,Q} = M_Q \cdot (N_{D,w,Q} / N_{D,w,Qo}) \cdot N_{D,w,Qo} \tag{4}$$

where M_Q is the reading for quality beam Q. It is known that

$$k_Q = N_{D,w,Q} / N_{D,w,Qo} \tag{5}$$

where k_Q is correction factor for differences between beam quality Qo and beam used by secondary standard Q and is taken from Table 4. Thus, from relation (4) and (5), we have:

$$D_{w,Q} = M_Q \, N_{D,w,Qo} \, k_Q \tag{6}$$

The other values for k_Q, which are not specified in Table 4, are induced by interpolation [4].

In M_Q value are included some correction factors given by different parameters: pressure, temperature, recombination and polarity effect. The correction factor for ionization chamber, represent difference between temperature and pressure specified in calibration certificate and temperature and pressure at which is used the ionization chamber, in different medium condition. This correction factor k_{TP} is calculated with relation:

$$k_{TP} = (273.2+T) \cdot P_0 / (273.2+T_0) \cdot P \tag{7}$$

were T is temperature in measuring volume in [ºC], P is air pressure at measuring point in [hPa], T_0 is reference temperature 20 ºC or 22 ºC and P_0 is reference air pressure 1013.25 hPa (mbar).

Polarization effect of ionization chamber must be verified, in special for plan- parallel chamber, it must be < 0.2 % and is determined by:

$$k_{pol} = ([M_+]+[M_-])/2M \tag{8}$$

where M is the reading for polarization effect of user, while $[M_+]$ and $[M_-]$ are the average related at M, for indication given by an external monitor.

Recombination effect is of no interest for continuous photon beam, but it is important for pulsed radiations.

ABSORBED DOSE DETERMINATION IN REFERENCE CONDITIONS

Reference conditions for absorbed dose to water are show in Table 5.

Table 5. Reference conditions for the determination of absorbed dose water in high-energy photon beams

Influence quantity	Reference value or reference characteristics
Phantom material	water
Chamber type	cylindrical
Measurement depth z_{ref}	for $TPR_{20,10} < 0.7$, 10 g cm^{-2} (or 5 g cm^{-2}) for $TPR_{20,10} \geq 0.7$, 10 g cm^{-2}
Reference point of chamber	on the central axis at the centre of the cavity volume
Position of reference point of chamber	at the measurement depth z_{ref}
SSD/SCD	100 cm
Field size	10 cm x 10 cm

Absorbed dose to water, D_w, in effective point of measuring is given by equation (6).

ABSORBED DOSE DETERMINATION IN NONREFERENCE CONDITIONS

For high-energy photon, the factor applied to readings give by measuring system, is assumed that are independent of depth, for a given quality beam. Appear some uncertainty only for big depth, but they could be neglected in practical dosimetry. So, relative ionization distribution could be used like relative absorbed dose distributions.

CALIBRATION OF THE IONIZATION CHAMBER

Although, for preference, the calibration of a ionization chamber should be carried out in a water phantom, it is must convenient to use a relatively compact solid phantom, so designed that it adequately reproduce the radiation qualities, witch would obtain in a full-sized water phantom. A Perspex comparison phantom has therefore been designed for use with the secondary ionization chamber. Being a solid phantom, it can be used with vertical and horizontal beams. Its basic dimensions are 200 mm x 200 mm x 120 mm, deep, and it is so arranged as to enable the ionization chamber of user and the secondary ionization chamber to be irradiated simultaneously with their axes 30 mm, apart, at depth of 50 mm, 70 mm or 100 mm. Calibration of the ionization chamber at a given incident radiation quality is carried out by setting up the phantom at the normal source distance using the entrance face which provides the chamber irradiation depth appropriated to the incident beam quality. Table 6 shows these calibration depths as a function of beam quality.

Table 6. Recommended values of the calibration depth in water

Fotoni	d / cm
150 kV – 10 MeV	5
11 MeV – 25 MeV	7
26 MeV – 50 MeV	10

To obtain the calibration factor for ionization chamber, for any particular incident radiation quality, a series of exposures is given to the two chambers simultaneously using a moderate

field size. The whole procedure is then repeated at least once. Then, for two series of readings ‚a' and ‚b', and mean instrument readings M_Q and M_{Qo} for each of the series, the true ratio, t' of the two instruments readings for identical exposures in the Perspex inter-comparison phantom may be taken as the arithmetic mean of $(M_{Qo}/M_Q)_a$ and $(M_{Qo}/M_Q)_b$. This true ratio is henceforth referred to as $(M_{Qo}/M_Q)_t$. For any chamber exposed in water phantom, we may write:

$$D_w = M\, N_{D,w}\, k_{Qo} \tag{9}$$

were D_w is the dose in rads in water at the position of the chamber centre is replaced by water, M is the instrument reading, $N_{D,w}$ is the calibration factor connecting the instrument reading with the corresponding exposure in roentgens and k_{Qo} is correction factor for quality beam. So, for two identical exposures (in a water phantom), we may write for the secondary standard and the ionization chamber:

$$D_w = (M_{Qo})_w\, N_{D,Qo}\, k_{Qo} = (M_Q)_w\, N_{D,\,Q}\, k_Q \tag{10}$$

Product $(N_{D,Q}\cdot k_Q)$ is the researched calibration factor, marked by N_Q, for the ionization chamber, changing one indication of the ionizing chamber M_Q into the dose equivalent.

$$K_Q = \left(N_Q \cdot k_Q\right) = \left(\frac{M_{Q_0}}{M_Q}\right)_{t,w} \cdot \left(N_{D,Q_0} \cdot k_{Q_0}\right) \tag{11}$$

where $\left(\frac{M_{Q_0}}{M_Q}\right)_{t,w}$ is the real ratio of the secondary standard indicated by the electrometer for the identical exposure in water. Suppose that:

$$\left(\frac{M_{Q_0}}{M_Q}\right)_{t,w} = \left(\frac{M_{Q_0}}{M_Q}\right)_{t,perspex} \tag{12}$$

than:

$$K_Q = \left(\frac{M_{Q_0}}{M_Q}\right)_{t,perspex} \cdot \left(N_{D,Q_0} \cdot k_Q\right) \tag{13}$$

$(M_{Qo}/M_Q)_{perspex}$ is derived from the inter-comparison in the Plexiglas phantom. The simultaneous irradiation of the ionization chamber and of the secondary standard chamber for to derive the initial chamber factor, is implying that the effects of various cross-scattering between the two chambers are negligible. Certainly, the secondary standard chamber will show no significant effect on the radiation and written will it have on the ionization chamber. Likewise, the ionizing chamber will not affect the significant indicators of the secondary standard chamber, only for the case when the ionization chamber has a thin metal framework. The relevance of such effects is easy to check if substituting any of the chambers with a piece of perspex. $N_{D,Qo}$ is the calibration factor for the secondary standard instrument. Using the Plexiglas phantom for comparison and the above mentioned method, the calibration factors N_{Qo} for the ionization chamber are obtained for each incident radiation of interest and such factors are those which will transform the indications showed by the electrometer in water phantom into the "rads-in-water" equivalent. Since the ionization chamber is provided with a

source for stability checking, it may also determine a reference indication, normalized as to the standard temperature and pressure.

CROSS-CALIBRATION OF THE IONIZATION CHAMBER IN FIELD

It's only the cylindrical ionization chambers whish are recommended for the reference dosimetry in high-energy photon beams. Plane-parallel chambers may be used only for the relative dosimetry. For high-energy photon beams, the reference point of the cylindrical chamber employed for calibration in standard labs and for measurement under reference conditions of the user's beam, will be considered on the chamber center-line, in the middle of the cavity volume. For plane-parallel chambers, the reference plane is considered to be on the inner surface of the entrance window, in the middle of the window. That location point needs to be positioned at the reference depth in the water phantom. If a ionization chamber is employed, the point needs to be cross-calibrated versus a reference chamber at the reference quality Q_0. The chambers are compared by alternate placing into the water phantom with their reference point in z_{ref}. The calibration factor in terms of absorbed dose as to water, for the ionization chamber, is given by the relation:

$$N_{D,w,Q_0}^{field} = \frac{M_{ref}}{M_{field}} N_{D,w,Q_0}^{ref} \tag{14}$$

where M_{ref} and M_{field} are the indications for the reference chamber and for the ionization chamber, corrected for the influence of pressure, temperature, polarity effect, recombination of ions and N_{D,w,Q_0}^{ref} is the calibration factor in terms of the absorbed dose as to water, for the reference chamber. It is recommended that the indications M_{ref} and M_{field} be the average between the ratios M_{ref}/M_{em} and M_{field}/M_{em} where the ratios are represented by the indications for the reference detector and the ionization chamber, related to the outer measurement device. It is advisory to locate the outer device inside the phantom, close to the reference depth but at a 3 – 4 cm distance for the chamber centre, along the important axis, in a transversal plane as to the beam. The ionization chamber with the calibration factor N_{D,w,Q_0}^{field} may be subsequently used to determine the absorbed dose as to water, in the user's beam.

DETERMINATION OF CALIBRATION FACTOR FOR PLANE-PARALLEL CHAMBERS

There are two methods to calibrate for plane-parallel ionization chamber. One method is given by the standard labs that are calibrating the instrument and the other method is given by the user who determining $N_{D,w,Q}$ by experimental comparisons with a reference ionization chamber which has a known calibration factor, N_{D,w,Q_o}. In practice second alternative is equivalent to the determination of the calibration factor in air, $N_{D,air}$, and it is based on the use of one ionization chamber made available by a dosimetric lab (PSDL or SSDL) and traceable at national and international standards. The reference beam used, Q_0, is usually a gamma radiation beam supplied by a ^{60}Co source. The formalism is based on the assumption that the voume of air in the sensitive area of the chamber cavity and the average energy required to generate a pair of ions, W_{air}, are identical in the user's beam of Q and in the calibration beam of Q_0 quality. So, $N_{D,air,Q}=N_{D,air,Q_o}=N_{D,air}$. The absorbed dose as to water, $D_{w,Q}$, in the user's beam of Q quality when the actual measurement point of the ionization chamber p_{eff} is positioned at the reference depth, is given by the relation:

$$D_{w,Q}(p_{eff})=M_Q N_{D,air}(s_{w,air})_Q\, p_Q \quad (15)$$

where M_Q is the indication of the system made-up of the ionization chamber and the electrometer, in the user's beam, corrected for the sensitive parameters; $N_{D,air}$ is the ionization chamber factor for the absorbed dose as to air; $(s_{w,air})$ is the ratio between the stopping power of the water and the air in the user's beam and p_Q is a total disturbance factor of the ionization chamber. Factor p_Q is the product of various disturbance factors for the ionization chamber of Q quality, namely p_{wall}, p_{cav} si p_{cel}. The first two factors are correcting the lack of equivalence among the materials phantom walls and the ionization chamber walls are made. Factor p_{cel} is correcting the effect of the chamber electrode during the measurement developed in the phantom. a.

CONCLUSION

The paper presents STARDOOR equipment used in the secondary standard dosimetry: ionization chambers and dosimeter (calibrated in a primary standard dosimetry lab) and the plastic and the water phantoms.

The paper alse specifies the quality of the beam that was employed in the primary standard dosimetry lab for calibration, the reference conditions for to determine $TPR_{20,10}$ of the photon beams and the quality of the beam the calibrations are made in the secondary standard dosimetry lab.

The formalism employed to calibrate the ionization chambers in the primary standard dosimetry lab is the paper along with the referencing conditions required for to conduct the calibrations.

The paper presents the methods employed by STARDOOR (Secondary Standard Dosimetry Lab) in the process of high-energy photon beams calibrations.

REFERENCES

[1] IAEA TRS 398, *"Absorbed Dose Determination in External Beam Radiotherapy: An International Code of Practice for Dosimetry based on Standards of Absorbed Dose to Water"*, Vienna (2004), ch 6, pp 61-71.

[2] NACP 80 – *"Procedures in External Radiation Therapy Dosimetry with Electron and Photon Beams with Maximum Energies Between 1 and 50 MeV"*; Acta Radiologica Oncology 19 (1980), pp 62.

[3] IAEA TRS 277, "*Absorbed Dose Determination in Photon and Electrons Beams: An International Code of Practice"*, Technical Report Series no. 277 (2nd ed in 1997), IAEA, Vienna (1997), ch 7, pp 52-54.

[4] IAEA TRS 381, "*The use of plane-parallel ionization chambers in high-energy electron and photon beams. An International Code of Practice for Dosimetry"*, Technical Report Series no. 381, IAEA, Vienna (1997), ch 4, pp 26.