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ON THE ABSORBED DOSE DETERMINATION METHOD IN HIGH ENERGY ELECTRONS BEAMS

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Abstract

The absorbed dose determination method in water for electron beams with energies in the range from 1 MeV to 50 MeV is presented herein. The dosimetry equipment for measurements is composed of an UNIDOS–PTW electrometer and different ionization chambers calibrated in air kerma in a Co^{60} beam. Starting from the code of practice for high energy electron beams, this paper describes the method adopted by the secondary standard dosimetry laboratory (SSDL) in NILPRP - Bucharest.

Keywords: *absorbed dose in water, high energy electrons beams, secondary standard dosimetry laboratory*

INTRODUCTION

It is generally agreed that physical measurements must be traceable to primary standards. Such standards are developed and maintained at national and standardizing laboratories and the International Office of Weights and Measures. The lack of calibration facilities in some countries made IAEA to consider some assistance in the establishment of Secondary Standard Dosimetry Laboratories (SSDLs).

The main task of SSDLs is: to transfer the calibration from the Primary Standard Dosimetry Laboratorys (PSDLs) to the user. The beam qualities and the irradiation geometries at the PSDLs and at the SSDLs need to be as similar as possible in order not to introduce errors in the transfer and to advise and help the users to calculate the chamber factors to be used in the Bragg-Gray equation in order to determine the absorbed dose at the user's beam. The derived factor to be used for this purpose is the absorbed dose to air chamber factor [2].

The SSDLs-NILPRP aims are: to perform dosimetry calibrations in electron beams and to calibrate tertiary devices in high energy electron beams, to increase the quality of ionizing radiation services, the quality parameters of high energy electron beam, exposure distributions, in air kerma, absorbed dose to air and absorbed dose to water in 1D, 2D & 3D in a water phantom.

The present paper provides a methodology for the determination of the absorbed dose to water in the high energy electron beams used by Secondary Standard Laboratory Dosimetry from NILPRP – Bucharest, ROMANIA. The ranges of radiation qualities covered in this work are electrons in the 1 MeV – 50 MeV range energy.

The high energy electron beam calibration procedures are validated, standardized and accepted by AIEA, ICRU, DIN 6800, 6809 – Germany, SCARAD – USA, HPA - G B, and NACP- countries from Northern Europe. From the accepted standards, our laboratory adopted the methods from IAEA 398.

Our "STARDOOR" laboratory starts to be certified as SSDLs by Romanian Accreditation Association - RENAR. The next step following integration to be it's in IAEA PSDLs – SSDLs system.

DOSIMETRIC EQUIPMENT

National Institute for Lasers Plasma and Radiation Physics – NILPRP, the contractor in the project between RENAR and NILPRP, has acquired the following dosimetric equipment necessary for such calibrations: a Universal Dosimeter UNIDOS from PTW including ionization chambers gauged to PSDLs PTW – Freiburg Germany; from USA – an Eurostandard 3D Multi-data Real-Time Dosimetry by computer System with software date processor and color printing equipment including 2-D Scanning Frame with USB, 9755 Dual Channel Electrometer Amplifier, 9750 Water phantom and 9721 Film Densitometer. The last one is a high accuracy Dosimetry System peripheral device for the measurement of relative density/dose information.

UNIDOS-PTW – Universal Dosimeter - T 10005 with Interface RS232

It is a reference class I equipment for use as a Secondary Standard according to IPEM specifications for calibration purposes. It is a therapy dosimeter according to IEC 60731 including an UNIDOS Electrometer type T10005-50406 manufactured by PTW – Freiburg.

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]

Measuring modes: measurement of current and charge in electrical units (A,C) and measurement of radiological quantities as exposure J_S in R, photon equivalent dose Hx in Sv, air kerma K_a and absorbed dose to water D_w in Gy.

UNIDOS can store up to 30 ionization chambers or detectors in the chamber library.
Table 1 shows the measuring ranges for a digital resolution of 0.2%.

MULTIDATA Electrometer

The Dual Channel Electrometer Amplifier Model 9755 consists of two identical, hardened radiations, electrometer amplifier circuits. The amplifiers have exceptionally high input impedance 10^{14} Ω; 0.02 pico-ampere leakage. It has a standard connection with water phantom and a computer interface is designed as an integral part of a water phantom based data acquisition system for dosimetry. The unit is normally placed outside the treatment room, next to the control (computer) unit and interconnected to the water phantom and ion-chambers. Dynamic range selected by sensor type Solid State (Diode): 1 x 10^{-8} Amp. for 10V full scale output.

UNIDOS Ionization Chambers

The cylindrical ionization chamber Farmer, and the plane-parallel chamber Markus, associated to the UNIDOS dosimeter, are used in an absolute dosimetry for absorbed dose to water determination in high electron beam, in the energy range between 5MeV- 50 MeV. Ross is a plane-parallel chamber used for a relative dosimetry in the energy range between 1MeV- 10 MeV.

Table 2 shows the UNIDOS ionization chamber's important parameters for a 10 x 10 cm field size with a Correction factor k_Q = 1.000 and at SSD = 80cm

Table 2. The ionization chamber's parameters used for the determination of the absorbed dose in the water in high electron beam

Chamber type	**Absorbed dose to water range (D_w)**	**Detector calibration factor ($N_{D,w}$) [Gy/C]**	**Electrometer calibration factor (k_{elec})**	**Uncert-ainty**	**Polarity effect**
Farmer TN 30010	$[5\cdot10^{-2}$ …5,0] [Gy]	$5.355\cdot10^{7}$	1.000±0.5%	1.1%	≤ 0.2 %
Markus TN 34045	$[5\cdot10^{-2}$ …5,0] [Gy]	$1.404\cdot10^{9}$	1.000±0.5%	1.1%	≤ 0.5 %
Ross TN 34001	$[5\cdot10^{-2}$ …5,0] [Gy]	$8.620\cdot10^{7}$	1.000±0.5%	1.1%	≤ 0.2 %

MULTIDATA Ionization chambers

The ionization chambers model 9732-2, are designed for use with the 9754 Electrometer and dose-meters as part of a water dosimetry system or in connection with an absolute therapy dose-meters according to IEC 6073 1, commonly used for relative measurements in water and other phantoms for the analysis of radiation fields of linear accelerators and Cobalt treatment machines.

MULTIDATA Water Phantom

The Water phantom model 9750 consists of a remote control, precision probe positioning mechanism, mounted into a water tank and designed to measure complete radiation field characteristics in any of three scanning planes. The probe carriage is supported on both sides

and remains submerged when the detector is at or above the water surface. The probe holder(s) are indexed for rotation at 45 degree intervals and shaped to minimize water ripple. The tank is made of stress relieved acrylic (lucite) with glued seams; each seam reinforced through casing. The left, front and right side walls are only 10mm thick, providing a horizontal 'window' access from three sides. The scanning mechanism's design is extremely efficient in using all the water volume available and provides excellent water surface access, assuring easy positioning of even the largest Electron Cone.

The water phantom is fully compatible with Multidata's Real-Time Dosimetry System equipment as well as with most other minicomputer analog acquisition and parallel output sub-systems.

3D MULTIDATA Real-Time Dosimetry System

Using 3D Multi-data Real-Time Dosimetry System with Markus ionization chamber calibrated by PSDL PTW – Freiburg and RTD-4 multi-data software including Acquisition Plan; Analysis & Modification; Scan Device Calibration and Imaging Acquisition Guide, all control and positioning signals are transmitted from the water phantom to the dosimetry interface by a single, flat, armored cable. This complex computer program make possible the automatically scanning of 3 D device, measuring the absorbed dose to water and at the same time to register the numerical parameters obtained, show the study as a collection of isodose curves, display it on the monitor and print them in 1 D, 2 D, or 3 D. The dosimetry system is shown in Figure 1.

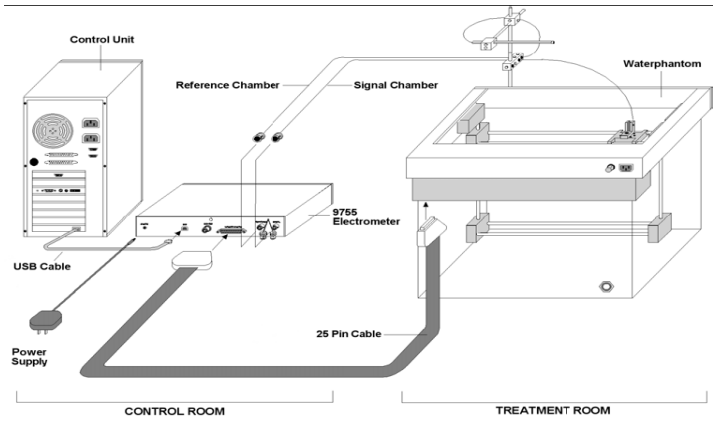

Figure 1. The water phantom in Multi-data system dosimetry

BEAM QUALITY SPECIFIATION

Reference dosimetry (beam calibration) and relative dosimetry in clinical electron beams with energies in the range from 1 MeV to 50 MeV is based upon a calibration factor in terms of absorbed dose to water $N_{D,w,Qo}$ for a dosimeter in a reference beam of quality *Qo*.
This reference quality may be either ^{60}Co gamma radiation or an electron beam quality. In the latter case the dosimeter may be calibrated either directly in a standard laboratory or by cross-calibration in a clinical electron beam [1]. With standards of absorbed dose, the most significant change from current practice is the use of a new reference depth. For simplicity, beam qualities and all factors dependent on beam quality are expressed in terms of the half-value depth R_{50} (Figure 2) rather than beam energy.

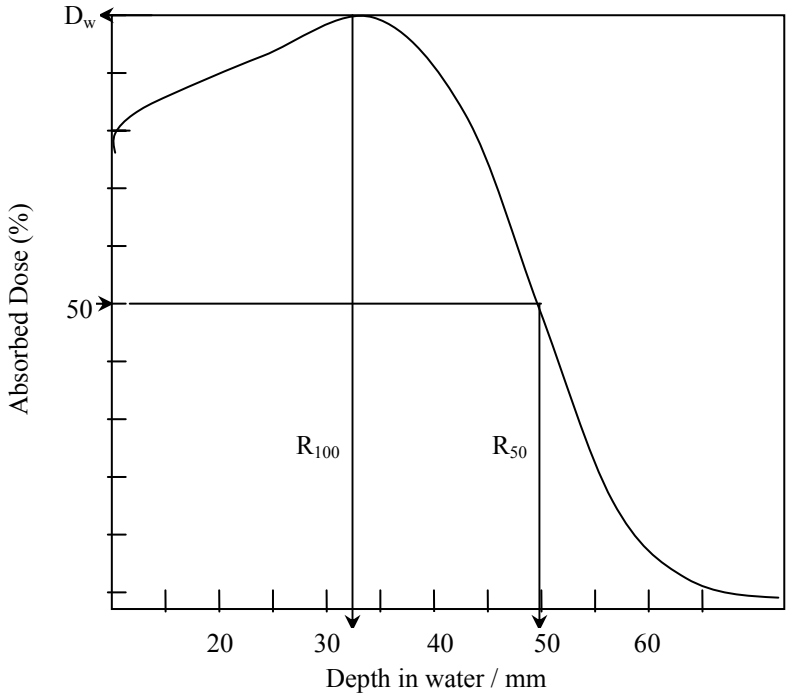

Figure 2. Depth in water by absorbed dose [4].

For electron beams the beam quality index is the half-value depth in water R_{50}. This is the depth in water (in g cm^{-2}) at which the absorbed dose is 50% of its value at the absorbed-dose maximum, measured with a constant SSD of 100 cm and a field size at the phantom surface of at least 10 cm x 10 cm for $R_{50} \leq 7$ g cm^{-2} and at least 20 cm x 20 cm for $R_{50} > 7$ g cm^{-2}. As noted in TRS-381, some accelerators at high electron energies have an intrinsic poor homogeneity at large field sizes which may improve at smaller field sizes as a result of electrons scattered from the collimator (or applicator, cones, etc). In such cases a field size smaller than 20 cm x 20 cm may be used provided that R_{50} does not change by more than about 0.1 g cm^{-2} from the value measured for a 20 cm x 20 cm field. The choice of R_{50} as the beam quality index is a change from the current practice of specifying beam quality in terms of the mean energy at the phantom surface E_o. As E_o is normally derived from R_{50} this change in beam quality index is merely a simplification which avoids the need for a conversion to energy. The reference conditions for the determination of R_{50} are given in Table 3.
For all beam qualities, the preferred choice of detector for the measurement of R_{50} is a plane-parallel chamber. For beam qualities $R_{50} \geq 4$ g cm^{-2} a cylindrical chamber may be used, with the reference point positioned 0.5 r_{cyl} deeper than the point of interest in the phantom. A water phantom is the preferred choice. In a vertical beam the direction of scan should be towards the surface to reduce the effect of meniscus formation. For beam qualities $R_{50} < 4$ g cm^{-2} a plastic phantom may be used. Ion recombination and polarity corrections are required at all depths. These may be derived from a reduced set of representative measurements, for example near the surface, the ionization maximum and the depths corresponding to 90% and 50% of the ionization maximum. For measurements made over a short period of time, air temperature and pressure corrections need not be made.

Table 3. Reference conditions for the determination of electron beam quality (R_{50})

Influence quantity	Reference value or reference characteristics
Phantom material	for $R_{50} \geq 4$ g cm^{-2}, water. For $R_{50} < 4$ g cm^{-2}, water or plastic
Chamber type	for $R_{50} \geq 4$ g cm^{-2}, plane-parallel or cylindrical. For $R_{50} < 4$ g cm^{-2}, plane parallel
Reference point of chamber	for plane-parallel chambers, on the inner surface of the window at its centre. for cylindrical chambers, on the central axis at the centre of the cavity volume
Position of reference point of Chamber	for plane-parallel chambers, at the point of interest For cylindrical chambers, 0.5 r_{cyl} deeper than the point of interest
SSD	100 cm
Field size at phantom surface	for $R_{50} \leq 7$ g cm^{-2}, at least 10 cm x 10 cm For $R_{50} > 7$ g cm^{-2}, at least 20 cm x 20 cm

When using an ionization chamber, the measured quantity is the half-value of the depth-ionization distribution in water, $R_{50,ion}$. This is the depth in water (in g cm^{-2}) at which the ionization current is 50% of its maximum value. The half-value of the depth-dose distribution in water R_{50} is obtained using

$$R_{50} = 1.029\, R_{50,ion} - 0.06 \text{ g cm}^{-2} \quad (R_{50,ion} \leq 10 \text{ g cm}^{-2}) \tag{1}$$

$$R_{50} = 1.059\, R_{50,ion} - 0.37 \text{ g cm}^{-2} \quad (R_{50,ion} > 10 \text{ g cm}^{-2}) \tag{2}$$

As an alternative to the use of an ionization chamber, other detectors (for example diode, diamond, etc.) may be used to determine R_{50}. In this case the user must verify that the detector is suitable for depth-dose measurements by test comparisons with an ionization chamber at a set of representative beam qualities.

DETERMINATION OF ABSORBED DOSE TO WATER IN REFERENCE CONDITION

The reference conditions for the determination of absorbed dose to water in electron beams are given in Table 4. Because the precise choice of field size is not critical, a convenient choice for the reference field size is that which is used for the normalization of output factors, subject to the constraint that it should not be less than 10 cm x 10 cm at the phantom surface. The reference depth z_{ref} is given by

$$z_{ref} = 0.6\, R_{50} - 0.1 \text{ g cm}^{-2} \quad (R_{50} \text{ in g cm}^{-2}) \tag{3}$$

This depth is close to the depth of the absorbed-dose maximum z_{max} at beam qualities $R_{50} <$ 4 g cm^{-2}, but at higher beam qualities is deeper than z_{max}. It is recognized that this choice of reference depth may be less convenient, since for a given accelerator no two reference beams

will have the same reference depth. However, the new depth has been shown to significantly reduce machine-to-machine variations in chamber calibration factors and the accuracy gained justifies its use, particularly for plane-parallel chamber types. It should be noted that by recommending that reference, dosimetry at higher energies may be conducted at a depth beyond z_{max}, and the uncertainty arising from cavity perturbation effects for cylindrical chambers may be larger. In the worst case, around R_{50} = 5 g cm^{-2} the increased uncertainty is approximately 0.3%.

The absorbed dose to water at the reference depth z_{ref} in water, in an electron beam of quality Q and in the absence of the chamber, is given by

$$D_{W,Q} = M_Q N_{D,W,Q} k_{Q,Qo} = M_Q N_{D,W,Qo} k_{Q,Qo} \cdot (N_{D,W,Q} / N_{D,W,Qo}) \qquad (4)$$

where

$$k_{Q,Qo} = N_{D,W,Q} / N_{D,W,Qo} = k_Q \qquad (5)$$

when Q_o *is* ^{60}Co.

M_Q is the reading of the dosimeter corrected for the influence quantities temperature and pressure, electrometer calibration, polarity effect and ion recombination. The chamber should be positioned in accordance with the reference conditions, $N_{D,w,Qo}$ is the calibration factor in terms of absorbed dose to water for the dosimeter at the reference quality Qo and $k_{Q,Qo}$ is a chamber-specific factor which corrects for differences between the reference beam quality Qo and the actual beam quality Q.

Clinical normalization most often takes place at the depth of the dose maximum z_{max}, and it does not always coincide with z_{ref}. To determine the absorbed dose at z_{max} the user should use for a given beam the measured central-axis depth-dose distribution to convert the absorbed dose at z_{ref} to that at z_{max}.

Table 4. Reference conditions for the determination of absorbed dose to water in electron beams

Influence quantity	Reference value or reference characteristic
Phantom material	for $R_{50} \geq$ 4 g cm^{-2}, water. For R_{50} < 4 g cm^{-2}, water or plastic
Chamber type	for $R_{50} \geq$ 4 g cm^{-2}, plane-parallel or cylindrical. For R_{50} < 4 g cm^{-2}, plane parallel
Measurement depth z_{ref}	0.6 R_{50} – 0.1 g cm^{-2}
Reference point of chamber	for plane-parallel chambers, on the inner surface of the window at its centre For cylindrical chambers, on the central axis at the centre of the cavity volume
Position of reference point of chamber	for plane-parallel chambers, at z_{ref}. For cylindrical chambers, 0.5 r_{cyl} deeper than z_{ref}
SSD	100 cm
Field size at phantom surface	10 cm x 10 cm or that used for normalization of output factors, whichever is larger

VALUES FOR $k_{Q,Qo}$

UNIDOS's ionization chambers are calibrated in ^{60}Co gamma radiation so, $k_{Q,Qo}=k_Q$. For ionization chambers calibrated at various electron beam energies or several beam quality index R_{50}, that means $k_Q=k_{Q,Qo}(R_{50})$. Typical k_Q values for ionization chambers from STARDOOR are given in Table 5.

Table 5. Value of k_Q for ionization chamber: Farmer, Markus and Roos

Electron Beam Quality R_{50} [g/cm^2]	Ionization Chamber Farmer	Ionization Chamber Markus	Ionization Chamber Roos
1. 0	-	0.966	0.965
1.4	-	0.956	0.955
2.0	-	0.945	0.944
2.5	-	0.938	0.937
3.0	-	0.932	0.931
3.5	-	0.926	0.925
4.0	0.911	0.921	0.920
4.5	0.909	0.917	0.916
5.0	0.907	0.912	0.912
5.5	0.905	0.909	0.908
6.0	0.904	0.905	0.904
7.0	0.901	0.899	0.898
8.0	0.898	0.893	0.892
10.0	0.893	0.883	0.882
13.0	0.885	0.871	0.870
16.0	0.877	0.861	0.860
20.0	0.868	0.849	0.848

IONIZATION CHAMBER CALIBRATION

The highest-energy electron beam available should be used; $R_{50} > 7$ g cm^{-2} is recommended. The reference chamber and the chamber to be calibrated are compared by alternately positioning each at the reference depth z_{ref} in water in accordance with the reference conditions for each, Table 4. The calibration factor in terms of absorbed dose to water for the chamber under calibration, at the cross-calibration quality Q_{cross}, is given by:

$$N^{x}_{D,w,Q_{cross}} = \frac{M^{ref}_{Q_{cross}}}{M^{x}_{Q_{cross}}} N^{ref}_{D,w,Q_0} k^{ref}_{Q_{cross},Q_0} \qquad (6)$$

where M_{ref} and M_{Qcross} are the dosimeter readings for the reference chamber and the chamber under calibration, respectively, corrected for the influence quantities temperature and pressure, electrometer calibration, polarity effect and ion recombination. N^{ref}_{D,w,Q_0} , is the calibration factor in terms of absorbed dose to water for the reference chamber at quality *Qo* and $k^{ref}_{Q_{cross},Q_0}$ is the beam quality correction factor for the reference chamber. In practice, to minimize the effect of any variation in the accelerator output, the readings $M^{ref}_{Q_{cross}}$ and $M^{x}_{Q_{cross}}$ should be the averages $\overline{M^{ref}_{Q_{cross}} / M^{em}_{Q_{cross}}}$ and $\overline{M^{x}_{Q_{cross}} / M^{em}_{Q_{cross}}}$, respectively, measured

relative to an external monitor. The external monitor should ideally be positioned inside the phantom at the reference depth z_{ref} but displaced laterally a distance of 3 cm or 4 cm from the chamber centre. Normally, the calibration quality Q_o for the reference chamber will be ^{60}Co and the value for $k^{ref}_{Q_{criss},Q_0}$, is derived from Table (5). In the event that *Qo* is a high-energy electron beam, the value for $k^{ref}_{Q_{criss},Q_0}$, must be derived.

$$k^{ref}_{Q_{cross},Q_0} = \frac{k^{ref}_{Q_{cross},Q_{\text{int}}}}{k^{ref}_{Q_o,Q_{\text{int}}}} \tag{7}$$

where $k^{ref}_{Q_{cross},Q_{\text{int}}}$ and $k^{ref}_{Q_o,Q_{\text{int}}}$ are taken from tables.

The cross-calibrated chamber with calibration factor $N^{x}_{D,w,Q_{cross}}$ may be subsequently used for the determination of absorbed dose in a user beam of quality Q;

$$D_{w,Q} = M^{x}_{Q} N^{x}_{D,w,Q_{cross}} k^{x}_{Q,Q_{cross}} \tag{8}$$

The values for $k_{Q,Q_{cross}}$ are derived and is obtained

$$k^{x}_{Q,Q_{crioss}} = \frac{k^{x}_{Q,Q_{\text{int}}}}{k^{x}_{Q_{cross},Q_{\text{int}}}} \tag{9}$$

where $k^{x}_{Q,Q_{\text{int}}}$ and $k^{x}_{Q_{cross},Q_{\text{int}}}$ are taken from tables. Note that the above may also be used for chambers calibrated at a standards laboratory at a single electron beam quality Q_{cross}.

DETERMINATION OF ABSORBED DOSE TO WATER IN NON-REFERENCE CONDITION

If an ionization chamber is used, the measured depth ionization distribution must be converted to a depth-dose distribution. For a beam of quality R_{50}, this is achieved by multiplying the ionization current or charge at each measurement depth z by the stopping-power ratio $s_{w,air}$ at that depth. Values for $s_{w,air}$ are given in Table 6 as a function of R_{50} and the relative depth z / R_{50}. Linear interpolation between table entries is sufficient.

For a given electron beam, the output factors should be measured at z_{max} for the non-reference field sizes. The output factors may be determined as the absorbed dose at z_{max} for a given set of non-reference conditions relative to the absorbed dose at z_{ref} (or z_{max}) under the appropriate reference conditions. Users should be aware of the variation of the maximum dose depth, z_{max}, particularly for small field sizes and high energies. For detectors such as diodes, diamonds, etc. the output factor will be adequately approximated by the detector reading under the non-reference conditions relative to that under reference conditions. If an ionization chamber is used, the measured ratio of corrected ionization currents or charges should be corrected for the variation in $s_{w,air}$ with depth, using Table 6.

Table 6. Spencer-Attix stopping-power ratios (Δ=10 keV) water to air ($s_{w,air}$) for electron beams, as a function of beam quality R_{50} and relative depth z/R_{50} in water [3]

Beam quality R_{50} (g cm^{-2})											
	1.0	2.0	3.0	4.0	5.0	6.0	7.0	10.0	13.0	16.0	20.0
z_{ref}(gcm^2)	0.5	1.1	1.7	2.3	2.9	3.5	4.1	5.9	7.7	9.5	11.9
$s_{w,air}(z_{ref})$	1.102	1.078	1.064	1.053	1.044	1.036	1.029	1.010	0.995	0.983	0.970
Relativ depth in water z/R_{50}											
0.02	1.076	1.042	1.020	1.004	0.991	0.980	0.971	0.950	0.935	0.924	0.914
0.05	1.078	1.044	1.022	1.006	0.994	0.983	0.974	0.952	0.937	0.926	0.916
0.10	1.080	1.047	1.026	1.010	0.998	0.987	0.978	0.957	0.942	0.931	0.920
0.15	1.083	1.050	1.030	1.014	1.002	0.992	0.983	0.961	0.946	0.935	0.924
0.20	1.088	1.053	1.034	1.019	1.006	0.996	0.987	0.966	0.951	0.940	0.929
0.25	1.091	1.057	1.037	1.023	1.011	1.001	0.992	0.971	0.956	0.945	0.933
0.30	1.093	1.060	1.041	1.027	1.016	1.006	0.997	0.976	0.961	0.950	0.938
0.35	1.096	1.064	1.045	1.032	1.020	1.011	1.002	0.982	0.966	0.955	0.943
0.40	1.099	1.067	1.049	1.036	1.025	1.016	1.007	0.987	0.972	0.960	0.948
0.45	1.102	1.071	1.054	1.041	1.030	1.021	1.013	0.993	0.978	0.966	0.953
0.50	1.105	1.075	1.058	1.046	1.035	1.027	1.019	0.999	0.984	0.971	0.959
0.55	1.108	1.078	1.062	1.051	1.041	1.032	1.025	1.005	0.990	0.977	0.964
0.60	1.111	1.082	1.067	1.056	1.046	1.038	1.031	1.012	0.996	0.984	0.970
0.65	1.114	1.086	1.072	1.061	1.052	1.044	1.037	1.018	1.003	0.990	0.976
0.70	1.117	1.090	1.076	1.066	1.058	1.050	1.043	1.025	1.010	0.997	0.983
0.75	1.120	1.094	1.081	1.072	1.064	1.057	1.050	1.033	1.017	1.004	0.989
0.80	1.123	1.098	1.086	1.077	1.070	1.063	1.057	1.040	1.025	1.012	0.996
0.85	1.126	1.102	1.091	1.083	1.076	1.070	1.064	1.048	1.033	1.019	1.004
0.90	1.129	1.107	1.096	1.089	1.083	1.077	1.072	1.056	1.041	1.028	1.011
0.95	1.132	1.111	1.102	1.095	1.090	1.085	1.080	1.065	1.050	1.036	1.019
1.00	1.136	1.115	1.107	1.101	1.097	1.092	1.088	1.074	1.059	1.045	1.028
1.05	1.136	1.120	1.113	1.108	1.104	1.100	1.096	1.083	1.069	1.055	1.037
1.10	1.139	1.125	1.118	1.115	1.112	1.109	1.105	1.093	1.079	1.065	1.046
1.15	1.142	1.129	1.124	1.122	1.119	1.117	1.114	1.104	1.090	1.075	1.056
1.20	1.146	1.134	1.130	1.129	1.128	1.126	1.124	1.115	1.101	1.086	1.066

CONCLUSIONS

The paper presents the methods employed by the SSDL STARDOOR for to conduct calibrations in high energy photon beams. STARDOOR equipment used to develop the secondary standard dosimetry is also presented herein.

The paper presents the beam quality that was employed in the primary standard dosimetry lab for calibration, the reference conditions for to determine R_{50} of the electron 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 are also presented in the paper along with the reference conditions required for to conduct the calibrations.

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