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Secondary standard dosimetry laboratory at INFLPR

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National Institute for Laser, Plasma and Radiation Physics (INFLPR) has constructed a High Energy Secondary Standard Dosimetry Laboratory SSDL–STARDOOR – for to perform dosimetric calibrations according to SR EN ISO/IEC 17025:2005 standard. STARDOOR Lab has been accredited by the Romanian Accreditation Association – RENAR since 2011.01.10 to perform calibrations and measurements. It is outfitted with UNIDOS Secondary Standard Dosimeter from PTW (Freiburg Physikalisch-Technische Werksttaten) calibrated at the PTB - Braunschweig (German Federal Institute of Physics and Metrology). This paper presents some aspects related to the calibration, testing and characterization of dosimetric equipment and ionizing chambers in photon and electron fields following that in future they are to be extended to proton, neutron and ion fields as well.

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1. Introduction

In Romania the existence of a large number of ionizing radiation sources (i.e. 5045) located at economic agents in domains such as research and industry (1439), medicine (3449) and others (163) has led to the construction of a Secondary Standard Dosimetry Laboratory (SSDL) for high energies – STARDOOR Lab - on basis of a research project dated 2006-2008. The laboratory was evaluated as per SR EN ISO/IEC 17025:2005 for the function of a calibration laboratory and testing laboratory and on 2011.01.10 it was awarded the accreditation certification from RENAR (http://www.renar.ro/files/OEC/download/LE%20020%20C%20INCDFLPR%20LDSSEI.pdf?r=1354008761057 & http://www.renar.ro/files/OEC/download/LI%20906%20C%20INCDFLPR%20LDSSEI.pdf?r=1354008783451).

At the level of the year 2010, besides the radiotherapy centers outfitted with medical accelerators, cobalt therapy facilities, X-ray radiation installations for therapy and other types of sources for therapy and diagnosis, INFLPR 20 TW laser, which in the relativistic regime is equivalent to a 0.58 MeV ionizing radiation generator, was added. In the period to come the two 10 PW Apollon type lasers are to be finalized, in Extreme Light Infrastructure Nuclear Physics (ELI-NP) project, (http://www.nano-link.net/e-newsletter_NANOPROSPECT/supliment_e-news6/EL I-NP-WhiteBook.pdf). Since this laser is a high intensity radiation generator, STARDOOR Lab will participate in the testing on components and the system commissioning.

The 1 PW laser is operating in a relativistic regime, $1 < a_0 < 100$, a_0 being the amplitude of the laser field normalized vectorial potential and it is calculated with the expression $a_0 = |e|\ E / m_0\, \omega\, c = 4.8\ (\lambda / w_0) \sqrt{P}\ (TW)$]. In the above expression a_0 and m_0 represent the electron mass and charge, and E, ω, w_o and P represents the electric field, the frequency, the minimum radius of the spot and the power of the laser radiation beam.

In the ultra-relativistic regime ($10^2 < a_0 < 10^5$), the laser in interaction with a plasma target shall be a charged particle source of electrons, positrons, protons, and ions. The today generated radiation has the pulse duration in the range of picoseconds. Lasers of the PW power order have the radiation pulse duration in the range of femtoseconds. For detect the generated radiations it is necessary to have new radiation detectors for the range of femtoseconds and attoseconds. Certain calibration and testing methods will need to be modified for such very short duration radiations and in this respect STARDOOR importance will get greater and greater.

At present the main functions of STARDOOR Lab are the followings: calibration of dosimetric equipment for these Lab types, calibration of photon and electron beams, and testing of radiation beam characteristics.

In the next period the laboratory shall extend its measurement domains to the absorbed dose of neutrons, protons and ions generated by radio-frequency (RF) classical accelerators and in the future, to the expansion of the energy domain to GeVs and TeVs [1]. Absorbed dose values and their measurements are the main task of dosimetry. SSDL in INFLPR was constructed during 2006-2008 upon no. 225 / 2006 RENAR contract. The SSDL is a Lab which designated by the competent national authorities to undertake the task of providing the necessary link in the traceability of radiation dosimetry to national/international standards for users within that country.

A secondary standard dosimetry laboratory (SSDL) is equipped with secondary standards which are traceable to the primary standards of laboratories participating in the international measurement system (Primary Standard

Dosimetry Laboratories - PSDLs) and the Bureau International des Poids et Mesures (BIPM)) like in Fig. 1.

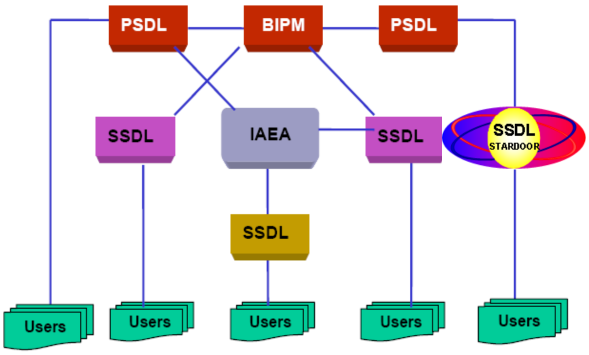


Fig. 1. Traceability chain in radiation dosimetry.

This paper presents the aspects related to the calibration and testing of ionizing chambers and dosimetric equipment in photon and electron fields.

2. STARDOOR Lab functions

SSDL-STARDOOR is offering calibration services for photon and electron beams, ionizing chambers and portable dosimetric instrumentation employed in various domains: education, research, industry, radiotherapy, radiation diagnostic, health physics / radiation protection and others.

In the SSDL – STARDOOR of INFLPR one can perform the following services: 1. calibration of the dosimetric devices for quantities: a) air kerma rate in photon and electron radiation field; b) air kerma in photon and electron radiation field; c) absorbed dose to water in photon radiation field; d) absorbed dose rate to water in photon radiation field; e) absorbed dose to water in electron radiation field; f) absorbed dose rate to water in electron radiation field; g) ambient dose equivalent in photon radiation field; h) ambient dose equivalent rate in photon radiation field; i) personal dose equivalent rate in photon radiation field [2] and j) the calibration of the dosimetric film [3] in air kerma; and 2. the measure of: a) air kerma rate in different media at one point in the irradiated phantom, for photon, electron and neutron radiations; b) air kerma in different medium at one point in the irradiated phantom, for photon, electron and neutron radiations; c) absorbed dose rate in different media (air, water, plexiglass) for electron radiation; d) absorbed dose in different media (air, water, plexiglass) for electron radiation [4]; e) absorbed dose rate in different media (air, water, plexiglass) for photon radiation; f) absorbed dose in different media (air, water, plexiglass) for photon radiation [5]; g) quality factor R_{50} (half-value depth in water) for electron beam in SSD geometry; h) mean energy, maximum energy and the most probable energy of the electron at the accelerator window, phantom surface and z depth, i) photon radiation beam quality in SSD (source - surface distance) and SCD (source - chamber distance) geometry, $TPR_{20,10}$ (tissue-phantom ratio in water at depths of 20 and 10 g/cm^{-2}) or *HVL* (half value layer); j) maximum energy of the photon in photon radiation beam at the accelerator window and k) absorbed dose distribution in 1D, 2D and 3D in air, film and water or plastic phantom - penumbra, homogeneity index and asymmetry index. All the procedures used in STARDOOR Lab. are applied in conformity with the international standards (Technical Reports Series – TRS-398 and TRS-277).

Having the devices and the working procedures described below, the SSDL – STARDOOR is capable to make inter-laboratory comparisons with any SSDL worldwide.

2.1. Reference samples and radiation sources

STARDOOR Lab is outfitted with high-tech devices: a) a UNIDOS Secondary Standard Dosimeter from PTW and ionization chambers calibrated at German Federal Institute of Physics and Metrology (PTB- Braunschweig), for calibrations and b) MULTIDATA EuroStandard Dosimetry System compounded by: EuroStandard 3D Realtime Dosimetry System, Universal Waterphantom, Transport / Storage Cart, Electrometer, Notebook, Printer, In-air Scanning Frame and Real Time Dosimetry (RTD) Software Version 5.2 to perform absorbed dose distribution in 1D, 2D and 3D measured in water, air and film dosimetry [6, 7].

The 3D dosimetric system is also allowing the determination of maximum bremsstrahlung energy, the mean energy for electron beam, pick and maximum energy of the electrons from the beam. The dosimetric system may be employed for the measurement, determination and dosimetric calibrations for photons in 5 keV (0.24 nm) – 50 MeV (24 fm) domain and electrons in 1 MeV - 50 MeV domain from the electromagnetic spectrum (EM) (Fig. 2).

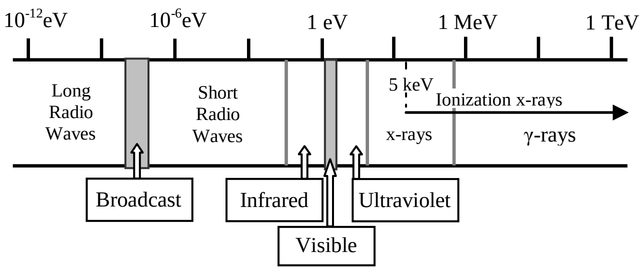


Fig. 2. Electromagnetic spectrum.

The laboratory has in it component a Kuhn chamber used for neutrons and STEP – PTW field dosimeter that allow for the calibration domain extension to neutron and protons. It is worth mentioning that STARDOOR Lab has also two calibration check devices sources: Sr – 90 of 20 MBq and Sr - 90 of 33 MBq, located in a special dedicated area within Lab, complying with National Commission for Nuclear Activity Regulations (CNCAN).

The calibration and measuring method used in STARDOOR Lab are standardized methods given by TRS-398 [8] and TRS-277 [9] international measuring standards.

Table 1. The parameters of the 7 MeV ALIN-10 linear accelerator.

Parameters	Values
Accelerated electron energy	6 MeV
Bremsstrahlung radiation energy	6 MeV
Electron mean current	10 μA
Macropulse duration	2.5 μs
Macropulse frequency	100 Hz
Micropulse duration	10 ps
Filling factor	$2 \cdot 10^{-5}$
Micropulse peak current	0.66 A
Micropulse frequency	3 GHz
Electrons fluency (1Gy/min)	$4.68 \cdot 10^{7}$ e^{-} / $cm^{2} \cdot s$
Photon power density (Pb)	6.5 μW/cm^2/R/min
Electical equivalence (1 Gy /min)	6.144 pA/ cm^2
Electron beam dose rate	2.00 Gy/min
Photon beam dose rate	1.00 Gy/min

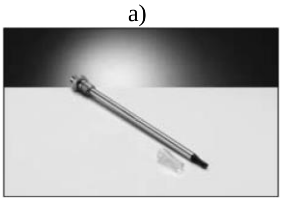
The linear accelerator ALIN-10 (7 MeV) is used for calibrating the ionization chambers in STARDOOR Lab, which have the parameters presented in the Table 1.

Besides the accelerators, SSDL STARDOOR is also employing two (2) isotopic sources – Cs-137 and Co-60 for calibration.

Herein below it is a presentation of some characteristics of the reference samples used, components of the secondary standard dosimeter UNIDOS and the principal type of ionization chamber form STARDOOR Lab.

The ionization chambers in Fig. 3 are vented cylindrical ionization chambers. The TN30010 type is a classical therapy chamber for absolute dosimetry in high energy photon (30 keV – 50 MeV), electron (10 – 45 MeV) and proton (50 – 270 MeV) beams [7] and the TN23332 type is a therapy chamber for absolute dosimetry in high-energy photon (70 keV – 50 MeV) and electron (10 – 45 MeV) beams.

a)



b)

Fig. 3. Ionization chambers: a) TN30010 type, b) TN23332 type.

The TN34045 type is a version of the famous classic Markus chamber for absolute dosimetry in high-energy electron (2 – 45 MeV) beams [7] and the TN34001 type is a waterproof chamber for absolute dosimetry in high-energy electron (2 – 45 MeV), photon (1 - 25 MeV) and proton (70 – 250 MeV) beams.

The ionization chamber TN23342 and TN23344 types are thin window plane parallel chambers used for dose measurements in superficial radiation therapy for X-ray (8 – 35 keV) beams.

The ionization chamber from TN31014 type is a ultra small-sized therapy chamber for dosimetry in high-energy photon (1 – 50 MeV) beams and the ionization chamber TN233612 type is a flat ionization chamber for precise dose measurements in the useful X - ray (35 – 75 keV) beam.

The ionization chamber TN32002 type is a spherical ionization chamber for radiation protection level and low level measurement (25 keV – 1.3 MeV) calibrated at PTB for ambient dose equivalent [10, 11]. The ionization chamber TN34035 type is a parallel plate ionization chamber for direct measurement of Hp(10) personal dose equivalent on a slab phantom for radiation quality between 15 – 140 keV [10, 12]. Above ionization chambers connected to secondary standard dosimeter UNIDOS are used for calibrations, using the method described below.

3. Calibration process

3.1. The Measurand Concept, Y

Calibration starts with defining the magnitude (quantity) that needs to be transmitted via the calibration process. Such a particular quantity that is to be determined is called ”measurand” and it is marked by „*Y*„. In our case ”measurand” is identified, for example, by the integral quantities: Kerma, Absorbed Dose, Dose Equivalent and their flow rates.

In many cases a measurand is not directly measured but it is determined from n other quantities $N, X_1, X_2, \ldots,$ X_n through a functional relation *f*, often called the measurement equation:

$$Y = f(X_1, X_2, \ldots, X_n). \tag{1}$$

Here $X_1, X_2, \ldots, X_n$ are the values ('actual' or 'true' values) of the inputs, and Y is the value ('actual' or 'true' value) of the measurand. An estimate of the measurand or output quantity Y, denoted by y, is obtained from measurement equation using input estimates $x_1, x_2, \ldots, x_n$ for the values of the n input quantities $X_1, X_2, \ldots, X_n$. Thus, the output estimate y, which is the result of the measurement, is given by:

$$y = f(x_1, x_2, \ldots, x_N). \tag{2}$$

This equation is the relationship between the estimates, $x_1, x_2, \ldots,$ x_n and the resulting estimate, y, of the Y measurand. By this equation the estimated y is calculated by means of the estimations of the input magnitudes and thus the first step of the process of calibrating in view of calibration is over. Next, the second step for the determination of the measurement uncertainties follows.

3.2 Uncertainty for measurand estimate, y

It is well know from the theory of normal distribution that the true value of the measurand lies in the following interval: $y - k\sigma/\sqrt{n} < Y < y + \sigma/\sqrt{n}$ or $Y - k\sigma/\sqrt{n} < y < Y + k\sigma/\sqrt{n}$ where $k\sigma/\sqrt{n}$ is random uncertainty, n is the number of the repeat observations, σ is the known standard deviation of the calibration process and the value of k is 1.96 for a 95 % confidence level (CL), 2.00 for a 95.44 % CL, 2.58 for a 99,02 % CL and 3.00 for a 99.80 % CL.

In our case, when the standard deviation of the calibration process is unknown, from the theory student t distribution, the true value of measurand is expected to lie within the following interval: $y - ts/\sqrt{n} < Y < y + ts/\sqrt{n}$ *or* $Y - ts/\sqrt{n} < y < Y + ts/\sqrt{n}$, where s is the standard deviation of the repeat observation calculated with equation $s^2 = \sum (x_i - x)^2 / (n - 1)$, and the multiplier factor t of the deviation standard is the Student factor whose value depends on the freedom degrees of the measurand estimate and coverage probability.

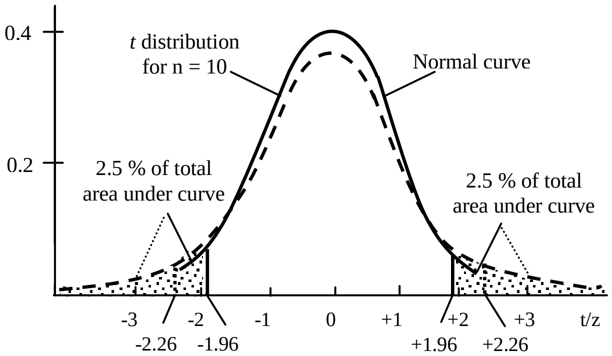


Fig. 4. Comparison between the normal curve and t distribution.

Fig. 4 illustrates the two distributions for $\upsilon = n - 1 = 9$ using the score $z = (\bar{x} - \mu)/\sigma$ for the normal standard distribution and the score $t = (\bar{x} - Y)/s_{\bar{x}}$ for Student distribution. Note that for $n \to \infty$, the two distributions are coincident. Practically it is considered that for $\upsilon \geq 50$ the two distributions are virtually equivalent.

By means of the Student probability density one may obtain the probability P_α for the Student factor t may take values in the interval $[-t_a , + t_a]$, or, which is equivalent, for the mathematical expectation Y of the random variable y, $E(y) = Y$, may lie within the interval $CI = [y \pm ts/\sqrt{n}]$ which is called confidence interval (*CI*) for the measurand.

So, the coverage interval for the measurand is that interval within which the true value of the measurand is located with high probability, usually 95 % or (less commonly) 99 % called confidence level.

Table 2. Model for error risk in hypothesis testing.

Truth Table	**H_0 is True**	**H_0 is False**
Test says: Retain H_0	Correct decision: Probability of retaining true H_0 is $1- \alpha$	Type II error: Probability (Risk) of retaining false H_0 is β
Test says: Reject H_0	Type I error: Probability(Risk) of rejecting H_0 is α	Correct decision: Probability (Risk) of rejecting false H_0 is $1- \beta$

In case of comparing the two measurements, the estimated standard error of the difference $Y_1 - Y_2$, at value t is $t_{1,2} = [(y_1 - y_2) - (Y_1 - Y_2)] / s_{\bar{y}_1 - \bar{y}_2}$, the confidence interval is $CI = [(y_1-y_2) \pm t\, s_{\bar{y}_1 - \bar{y}_2}]$ and with $s_{\bar{y}_1 - \bar{y}_2} = \{[((n_1-1)s_1^2+(n_2-1)s_2^2)/\upsilon_{eff}]][(n_1+n_2)/n_1n_2]\}^{1/2}$ and $\upsilon_{eff} = n_1 - n_2 - 2$. Null hypothesis H_0 is when $Y_1 = Y_2$. When comparing two measurements for the standard error of difference, Table 2 may be used as a model for the risk of errors in hypothesis testing. In statistics terminology, the result of rejecting a true H_0 is called „type I error„ and it is marked by α, and the result of accepting a false H_0 is re-called „type II error„ and it is marked by symbol β.

Test t demonstrates that $Y_1 = Y_2$ in null hypothesis when $t_{1,2} = [(y_1 - y_2)]/s_{\bar{y}_1 - \bar{y}_2} < t$. The t factor value is obtained from t Student distribution for various degrees of freedom and α represent the different criteria of significance.

3.3 Estimation of measurement uncertainties

In STARDOOR Lab the uncertainties are generally calculated as per the recommendations given in ISO (1993). In compliance with the recommendations, the uncertainties are of two categories: Type A - random uncertainties (non-determined errors, objective errors, “scalar” errors) and Type B - systematic errors (determined, subjective, “vectorial” errors).

Measurement errors may also be classified as follows:

- *Methodological errors* ε_m caused by unavoidable discrepancies between the actual quantity to be measured and its model used in the measurement;
- *Instrumental measurement errors* ε_i caused by imperfections of measuring instruments and
- *Personal errors* ε caused by the individual characteristics of the person performing the measurement. The general form for the absolute measurement error ε is $\varepsilon = \varepsilon_m + \varepsilon_i + \varepsilon_p$.

The steps of the measurement uncertainty component calculations for the estimate of measurand y, as per

STARDOOR Lab measurement procedure are the followings: 1. Type A evaluation of standard uncertainty, $u_A(x_i) = s(X_i)$; 2. Type B evaluation of standard uncertainty, $u_B(x_i)$, using a rectangular probability distribution; 3. Calculation of sensitivity coefficients, $c_i = (dY/dX)_0$; 4. Uncertainty budget: 4.1 Source of uncertainty, u(s); 4.2 Sensitivity coefficient, c_i; 4.3. Standard uncertainty, $u_i(x_i)$; 4.4. Combined uncertainty, $c_i.u_i\ (x_i)$; Factors: $[c_i.u_i\ (x_i)]^2$; 5. Combined standard uncertainty, $u_c(y) = \sqrt{\sum[c_i.u_i\ (x_i)]^2} = \sqrt{[\sum u_{A,i}^2 + \sum u_{B,j}^2]}$; 6. Effective degrees of freedom for measurand estimate after the Welch-Satterthwaite equation, $\nu_{eff}\ (y) = u_c^4(y)\ /\ \sum(u_i^4(y)/\nu_i)$, using $\nu = n - 1$ for uncertainties of Type A and $\nu = \infty$ for uncertainties of B type; 7. Expanded Uncertainty, $U = k{\cdot}u_c = 1.96\ u_c$, for $P_\alpha = 95\ \%$ and a normal standard distribution, when $\nu_{eff} \geq 50$; and $U = t{\cdot}u_c$ when $\nu_{eff} \leq 50$, where *t* Student factor depends on ν_{eff} and $P_\alpha = 0.95$; 8. Reporting the uncertainty and 9. Reporting Calibration Result is:

$$Y = y \pm U. \tag{3}$$

Note that the Type A and the Type B uncertainties are calculated at the same true level, P_α.

4. Representation of the dose distributions using RTD4

This chapter presents some dose distributions experimentally determined in a water phantom, and processed by means of RTD4. Version 5.2 allows the raise of such dose distributions and the calculation of their characteristics in compliance with TRS 398, TG-51 (protocol was written by Task Group 51), TRS 277. Using Universal Waterphantom and RTD4 software one may obtain the dose distributions in depth 1D, in various radiation fields. Such an example is presented in Fig. 5.

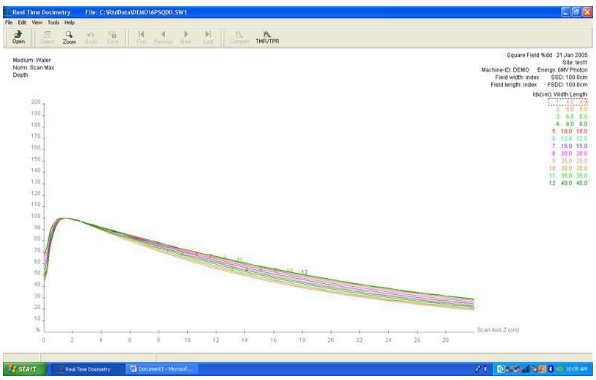


Fig. 5. 1D water depth dose distribution, in photon fields.

One example of isodose distribution in water, in photon field, is illustrated in Fig. 6.

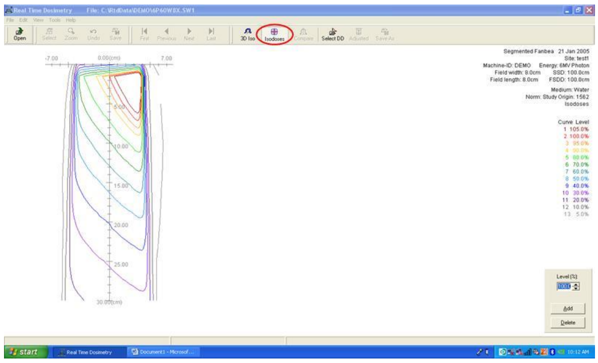


Fig. 6. Distribution of isodose in water, in photon field.

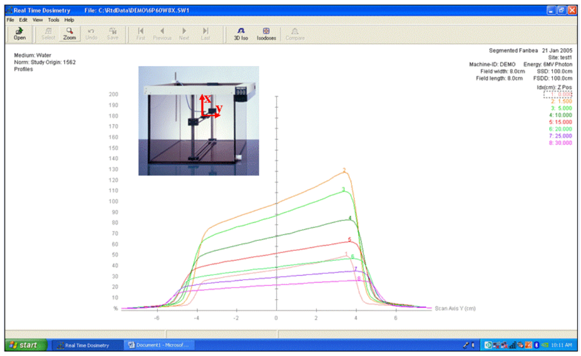


Fig. 7. The 2D distribution of the absorbed dose in water, in photon field.

Fig. 7 illustrates the 2D distribution of the dose experimentally raised in a water phantom, when photon irradiated.

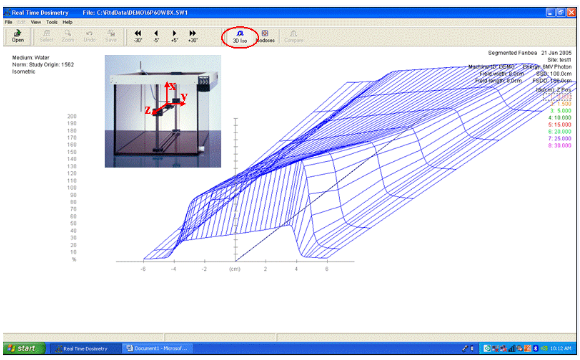
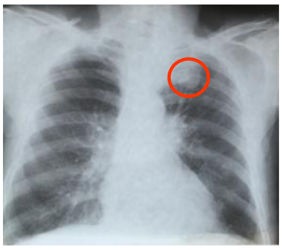
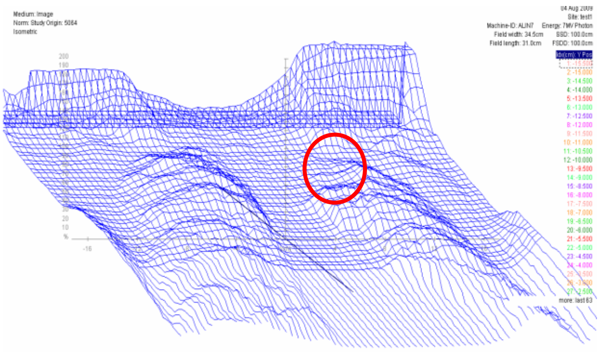


Fig. 8. 3D Distribution of water absorbed dose, in photon field.

An example of 3D distribution of water absorbed dose in photon field is presented in Fig. 8 [3].



a)



b)

c)

Fig. 9. 3D and isodose distributions for a pulmonary radiography: a) the investigated pulmonary radiography, b) 3D dose distribution, c) isodose distribution.

Using the film densitometer - MULTIDATA and RTD4 software, one can represent the 3D and isodose distributions (Fig. 9) for any medical radiography obtained in order to elaborate the treatment planning, beyond other medical practices [13, 14, 15]. The dose distributions obtained using the film densitometer, are equivalent with the blackening distributions recorded on the films.

5. Conclusions

Based on the above, the following conclusions may be drawn regarding STARDOOR Lab.

STARDOOR Lab was designed and constructed to calibrate the dosimetric equipment dedicated to: radiation dosimetry, radiation ratemeters, radiation exposure gauges and measurements of other parameters which characterize the radiation fields, in compliance with SR EN ISO/CEI 17025:2005.

STARDOOR Lab is outfitted with: a) a UNIDOS Secondary Standard Dosimeter from PTW and ionization chambers calibrated at PTB and b) MULTIDATA EuroStandard Dosimetry System compounded by: EuroStandard 3D Realtime Dosimetry System, c) in air scanning frame, d) Universal Water Phantom, and e) RTD Software version 5.2 to perform absorbed dose distribution in 1D, 2D and 3D measured in water, air and film dosimetry.

Within the Lab the above mentioned calibrations are performed, along with measurements. The conducted measurements are also dedicated to: dose, dose rate, kerma, kerma rate, 1D, 2D, 3D dose distributions in various conditions and radiation fields, as well as to the quality factors for the electron and photon radiations at various energies.

All the calibrations and measurements are conducted considering and meeting the work procedures in the Lab which were elaborated in compliance with the international accepted standards, namely: IAEA TRS 469 (2009), IAEA TECDOC 1585 (2008), IAEA TECDOC 1455 (2005), IAEA TRS 398 (2004), IAEA SRS 16 (2000), NIST Technical Note 1297 (1994), IAEA TRS 277 (1987), ISO 4037-3 (1999), ISO 4037-1 (1996) and ISO 4037-2 (1997).

The calibrations and measurements conducted in the Lab are dedicated to the dosimetric instruments in the radio-diagnosis centers and radiotherapy centers and STARDOOR being the only lab of this type in Romania.

The instruments employed in calibrations and measurements that can be developed by the laboratory personnel and for which the Lab was accredited by RENAR, are calibrated in PTB-Braunschweig (German Federal Institute of Physics and Metrology).

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