The influence of an extrapolation chamber over the low energy X-ray beam radiation field

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Abstract

The extrapolation chambers are detectors whose sensitive volume can be modified by changing the distance between the electrodes and has been widely used for beta particles primary measurement system. In this work, was performed a PTW 23392 extrapolation chamber Monte Carlo simulation, by mean the MCNPX code. Although the sensitive volume of an extrapolation chamber can be reduced to very small size, their packaging is large enough to modify the radiation field and change the absorbed dose measurements values. Experiments were performed to calculate correction factors for this purpose. The validation of the Monte Carlo model was done by comparing the spectra obtained with a CdTe detector according to the ISO 4037 criteria. Agreements smaller than 5% for half value layers, 10% for spectral resolution and 1% for mean energy, were found. It was verified that the correction factors are dependent of the X-ray beam quality.

Keywords: Extrapolation chamber; Monte Carlo simulation; CdTe spectrometry; low energy

1. - INTRODUCTION

According to the principles of radiation protection, practices involving ionizing radiation should be planned and executed so that the values of individual doses, the number of people exposed and the likelihood of accidental exposures are as low as reasonably achievable.[1] To this end, it is necessary that in the course of radiation dosimetry, reliable dosimeters must be used. The International Organization for Standardization (ISO), in order to promote the standardization and international metrology consistency established sets of X-ray beams of reference, filtered and fluorescence for calibration and dosimeters tests, whose implementation in metrology laboratories must meet specific technical requirements.[2] National laboratories, including the Nuclear Technology Development Center / Dosimeters Calibration Laboratory (LCD / CDTN) implanted reference beams of filtered X-rays ISO 4037. By the other hand, the lack of traceable detectors prevented the attainment of some implanted beams dosimetry.

However, cavitary chambers can be made of air equivalent material and, with proper choice of its walls thickness could be used for primary measurements; provided that it is possible the application of Bragg-Gray principle. [3] One conditions of the Bragg-Gray principle is that the detector presence does not affect the electron fluency. Although the sensitive volume of an extrapolation chamber can be reduced to very small size, their packaging is large enough to modify the radiation field and change the absorbed dose measurements values and so, it is no possible the applying of Bragg-Gray principle without corrections factors.

In this paper the LCD / CDTN irradiation system consisting of the X-ray equipment model ISOVOLT HS 320, manufactured by Pantak Seifert,[4] and the extrapolation chamber PTW 23392[5] were simulated, by the Monte Carlo method, using the MCNPX code [3]. An extrapolation chamber is a cavitary-chamber whose sensitive volume can be adjusted by the electrodes distance adjusts.[7]

Were introduced in the simulation environment the additional filtration for ISO L low energy X-ray quality. A second simulation was performed in the same environment but without the extrapolation chamber. The validation of the Monte Carlo model was done by comparing the spectra obtained with a CdTe detector according to the ISO 4037 criteria.[2]

The aim of this paper is to evaluate the influence of the presence of a PTW 23392 extrapolation chamber on low energy radiation fields and calculate correction factors.

2.- MATERIALS AND METHODS

2.1 The Simulation of the Irradiation Room

In this study, to simulate the irradiation room of dosimeters calibration laboratory (LCD/CDTN) was used the MCNPX code that is able to simulate the spread of both, photons and electrons, in the energy range of interest. The MCNPX is a tool in large use for dose calculation and shielding. Has been constantly updated and has a huge user community.

The constant flow of e-mail between users led good documentation. The MCNPX code instructions, through command lines, divided three main parts: surface card, cells card, and material card. On the surface card are defined the geometry of the cells, in turn, will be filled by the materials defined in material card. The command *tally* refers to the quantity is being studied and should be positioned in the cell of interest. The radiation source may be defined in various ways, depending on the problem.

The geometry of this specific system was described by cells, which are defined by surfaces filled with materials whose data is available. In this paper, the geometry of the simulation project was built by macrobodies, especially the right circular cylinder (RCC), to the PTW 23392 extrapolation chamber and rectangular parallelepiped (RPP) to the X-ray tube shielding box and to the characterization filters. The geometry contemplated only the relevant objects of irradiation room, mainly the PTW 23392 extrapolation chamber, in accordance with the chamber instruction manual [5] and additional information [8].

Figure 1 shows the PTW 23392 extrapolation chamber cross section view.

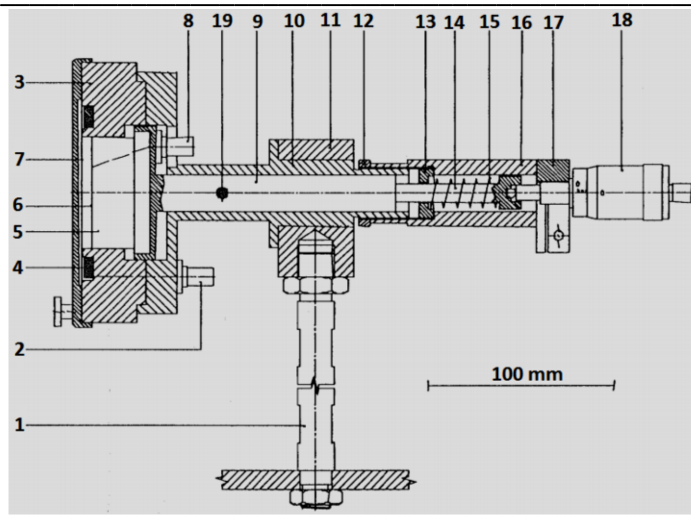

Figure 1 PTW 23392 extrapolation chamber cross-section; 1 support ; 2 bias terminal ; 3 encapsulation ; 4 tension ring ; 5 acrylic block ; 6 graphitized surface; 7 entry sheet; 8 terminal collector ; 9 sliding rod ; 10 central guide ; 11 adjuster ; 12 nut ; 13 screw ring ; 14 pin , 15 Spring ; 16 Tube; 17 bracket , 18 micrometer ; 19 piston clamping screw. (Source : PTW 2002)

A simplified front of PTW 23392 extrapolation chamber was used for modeling; figure 2 shows a PTW 23392 not scaled diagram view.

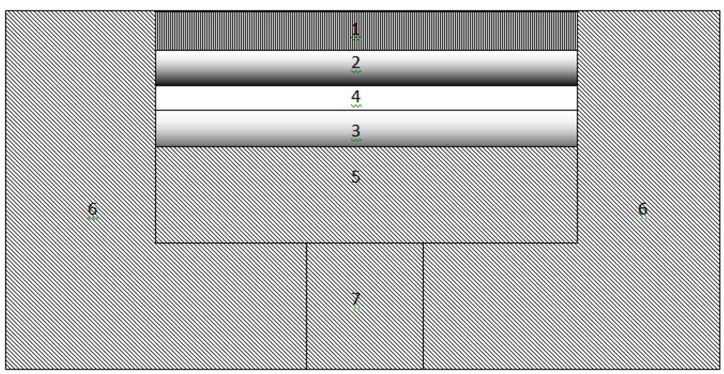

Figure 2 Relevant parts of the extrapolation chambers: 1- Polyethylene terephthalate (entrance foil) 2- Graphite Coated surface 3- Graphite coated surface 4– Extrapolation chamber sensitive volume 5- Rear electrode 6- Polymethylmethacrylate (acrylic) encapsulation. 7- Stem sliding adjustment

Were included in the simulating environment the X-ray shield box and the additional filters for the reproduction of the low energy ISO X-ray beams, series L, both built by rectangular parallelepipeds (RPP).[9] The X-ray beams pulse height spectra of the LCD / CDTN irradiation system up to 30 kV was measured by mean the CdTe spectrometry system, without any additional filtration. These normalized spectra were used to provide the energy histogram to define the source specifications (SDEF). It was chosen a point isotropic source with a histogram of energy, but collimated into the cone of direction, where particles are confined to a directional cone, whose angle was calculated to fit exactly the diameter of the irradiation system shutter.

In low-energy radiation systems, the interaction of photons with the layer of atmospheric air between source and detector is relevant, and so therefore it is necessary to carefully examine the atmospheric air composition that may change with climatic conditions. In this study it was considered dry air as a gas mixture that compiles the ratio showed at table 1[10]

Table 1 Atmospheric Dry Air Composition

Nitrogen	Oxygen	Argon	Carbon
78.4437 %,	21.0750%,	0. 4671%	0.0151%

By the other hand, the amount of water vapor in the atmospheric air depends on the climatic parameters: temperature, atmospheric pressure and relative humidity and was determined based on the LCD climate conditions, measured during the experimental performance, which they were: temperature 21.3ºC atmospheric pressure 91.92kPa and relative humidity 72.7%. It was determined the saturation pressure for the above temperature, by Tetens formula. The definition of the climate conditions on the LCD / CDTN, allowed to calculate the water vapor fraction in the atmospheric air and hence the fraction of each of the main elements of the mixture.

To evaluate the influence of the presence of an extrapolation chamber on a radiation field would be necessary to carry out dosimetric quantities measures, with the ionization chamber and in her absence. The ratio of results would be used as correction factor. Of course this is not a feasible experiment, except by means of computer simulation. In this simulation project it was choosen the Tally +f6 that matches to deposition energy by mass unit. Results for N and L low energy series, in both cases, were compared.

2.2 The Spectra Measurements

The simulating project of the irradiation system was constructed from the probabilities of each energy, consists of X-rays beams, specific for each tube voltage value. These probabilities were experimentally obtained by normalizing the measured spectra. In this study, the spectrum measurements were carried out at the shortest distance possible- 25 cm, between the focus and detector - in order to avoid, or reduce, the influence of air layer, whose relevance is greater at low energy. Distance limitations are mainly due the low counts rates allowed by Amptek spectrometric system.[11] The spectra, obtained in tabular form, were normalized and used in the source specification (SDEF) and presented in graphical form for purposes of comparison results.

2.3 The Validation of MCNPX Project

There are no, universally established, criteria for validation of computer simulations. In this study were used the ISO 4037 criteria for characteristics x-ray beam implanting. The ISO 4037-1, *X and gamma reference radiation for calibrating dosemeters and doserate meters and for Determining Their response as a function of photon,* determines that an X-ray beam of reference, ISO 4037, can be considered implanted in an irradiation system, since measured characterization parameters, agrees within limits of the specific ISO values, for each quality. The defined parameters are: half-value layers, spectral resolution and mean energy.[2] In this work the measured spectra and the simulation spectra respectively, were used to calculate the parameters mean energy and spectral resolution. By the other hand, the half-value layer in both case, were determined through the use of absorbers for various thicknesses. Results were compared.

3.-RESULTS AND DISCUSSIONS

Table 2 shows the distribution of components of atmospheric air within the aforementioned parameters.

Table 2 Composition of Atmospheric Air in Average Climatic Conditions

Element	Nitrogen	Oxygen	Argon	Hydrogen	Carbon
(%)	75.799	20.716	0.451	1,132	0,0144

The proportions shows in table 2 were used in the material card description. Were observed a reduction, in terms of density, comparing with dry air, by the introduction of water vapor. In fact, the other climatic parameters, atmospheric pressure and temperature are not relevant in this case, since, in the laboratories, the percentage variations in, Kelvin temperature and atmospheric pressure, are minimal, however the relative humidity can change dramatically.

Moreover the results showed that even for a large variation, in relative humidity, the composition of atmospheric air remained essentially the same and produced no significant changes in terms of the photon interaction, but it is necessary to study their contribution as a source of uncertainty.

The measurements of low-energy X-ray spectra, without additional filtration, served primarily to provide the histograms of the sources description. On the other hand, measures of the filtered beams L10, L20 and L30 spectra, with the detector positioned at the standard distance, allowed model validation, giving the results of correction factors improved reliability.

Figures 3, 4, 5, 6 and 7 shows the normalized spectra of the aforementioned reference radiation.

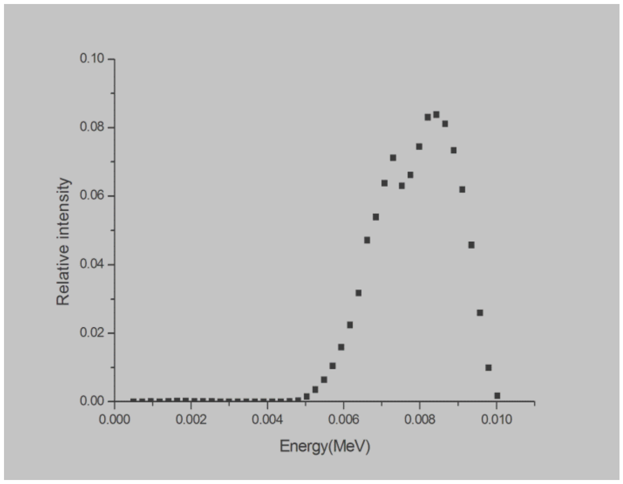

Figure 3 Measured and normalized spectrum of 10 kV beam with7mm Be filtration

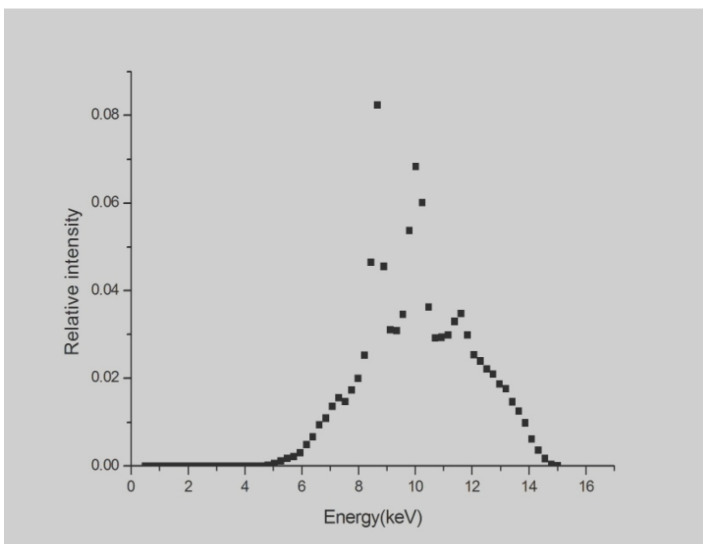

Figure 4 *Measured and normalized spectrum of 15 kV beam with7mm Be filtration*

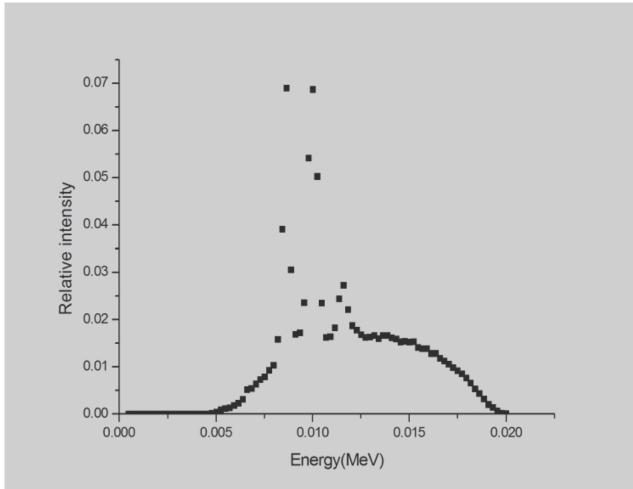

Figure 5 Measured and normalized spectrum of 20 kV beam with7mm Be filtration

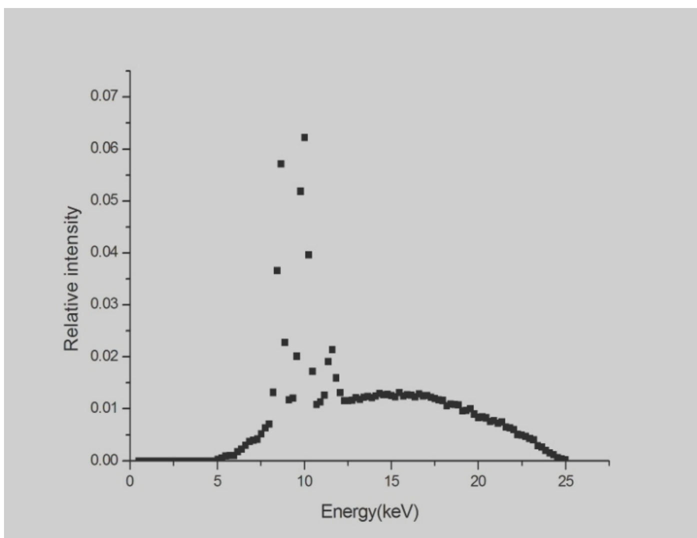

Figure 6 Measured and normalized spectrum of 25 kV beam with7mm Be filtration

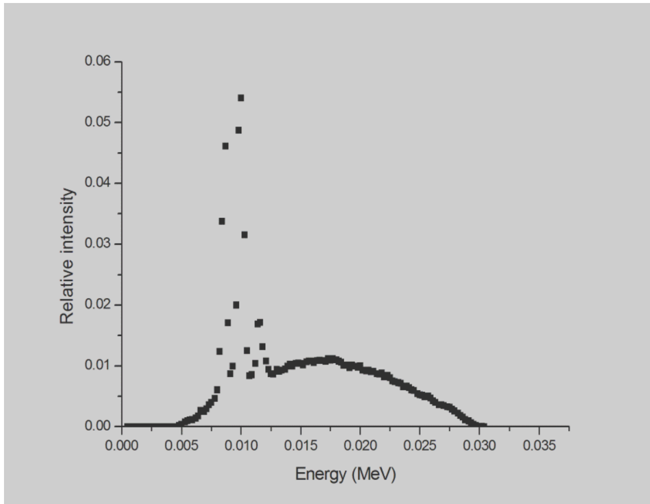

Figure 7 Measured and normalized spectrum of 30 kV beam with7mm Be filtration

Figures 8 and 9 show the simulated and the measured spectra of the ISO L30 X- ray beam.

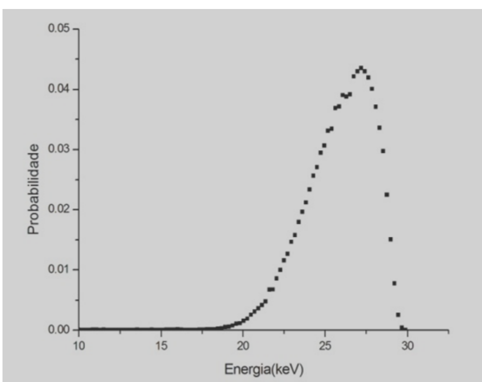

Figure 8 L 30 measured spectra

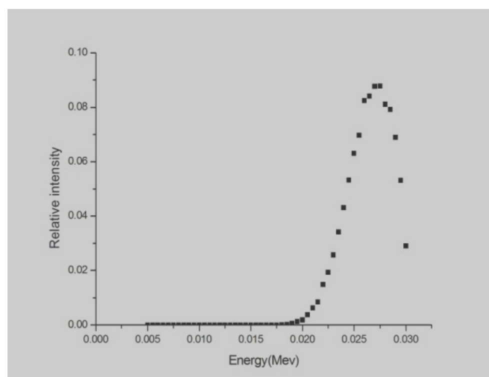

Figure 9 L 30 MCNPX simulated spectra

Table 5 shows the characterization parameters: half-value layer, spectral resolution and mean energy, obtained by analysis of measure and simulated spectra and through complementary experiment.

Table 3 comparing values of the measured L 30 ISO characterization parameters and obtained by simulation MCNPX

ISO Quality	half- Value layer(mmAl)		mean energy (keV)		spectral resolution	
	Experimental	MCNPX	Experimental	MCNPX	Experimental	MCNPX
L 30	1.45	1.51	26.42	26.31	24.03	21.71

Compared to the values of the parameters of the implementation procedure, here was an increase in half value layer of 4.1% a reduction in mean energy 0.5% and a9.6% reduction of the spectral resolution This limits fall within the deployment criteria of ISO 4037 reference X-ray beam.

The correction factors for the presence effect of the extrapolation chamber, over the radiation fields, were calculated comparing the absorbed dose values, observed in the cell that corresponds to the extrapolation chamber sensitive volume, in both cases, ie, with the extrapolation chamber and in it absence.

Table 4 correction factors of the presence of extrapolation chamber of the radiation field at low energies obtained by MCNP simulation

	Dose (Mev/g.N)							
	L 10	L 20	L 30	N10	N15	N20	N25	N30
Absence	9.993E-06	5.806 E-06	4.237 E-07	6.22E-05	5.59E-05	5.03E-05	1.93E-05	8.01E-06
Presence	9.792E-06	5.312 E-06	3.317E-07	5.95E-05	5.02E-05	4.41E-05	1.85E-05	7.32E-06
Correction factor	1.022	1.094	1.277	1.044	1.115	1.140	1.046	1.093

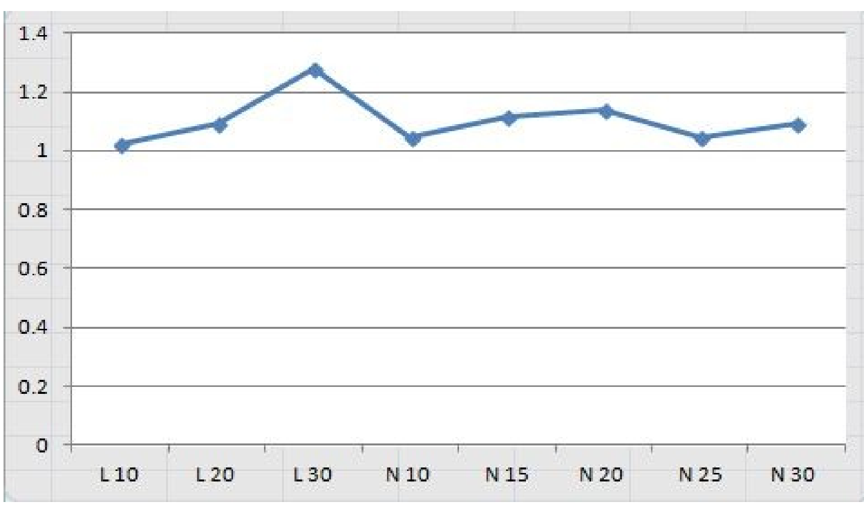

Figure 10 correction factors of the presence of extrapolation chamber of the radiation field at low energies obtained by MCNP simulation

4.-CONCLUSIONS

The results obtained in the validation procedures indicated that the model was designed properly and they were consistent with experimental results. By the other hand, the focus of the issue is to obtain a single correction factor that could calculate all the modifying action of the extrapolation chamber over the radiation field. The clear dependence of the correction factors, with the radiation quality, indicates that the correction factors are to be calculated individually for each reference X-ray beam, implanted on the irradiation system.

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