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A Model for the Characterization and Selection of Beeswaxes for use as base Substitute Tissue in Photon Teletherapy

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***Abstract*—**This paper presents a model for the characterization and selection of beeswaxes for use as base substitute tissue for the manufacture of objects suitable for external radiotherapy using megavoltage photon beams. The model of characterization was divided into three distinct stages: 1) verification of aspects related to the origin of the beeswax, the bee species, the flora in the vicinity of the beehives and procedures to detect adulterations; 2) evaluation of physical and chemical properties; and 3) evaluation of beam attenuation capacity. The chemical composition of the beeswax evaluated in this study was similar to other simulators commonly used in radiotherapy. The behavior of the mass attenuation coefficient in the radiotherapy energy range was comparable to other simulators. The proposed model is efficient and enables convenient assessment of the use of any particular beeswax as a base substitute tissue for radiotherapy.

***Keywords*—**Beeswaxes, characterization, model, radiotherapy

I. Introduction

RADIOTHERAPY is a very effective tool in cancer treatment, and relies on advanced equipment and computerized treatment planning systems (TPS). Computerized TPS accurately simulate the projection of the radiation field, enabling deliverance of sufficient radiation to a tumor, while sparing critical organs and minimizing the radiation dose to healthy tissues. However, the relationship between the dose delivered by the device and that received by the patient can not be easily determined [1]. To address this issue, methods to reproduce actual clinical treatments, by substituting the patient with an experimental device that has physicochemical properties which are similar to human tissue, must be developed. Unfortunately, the equipment and accessories currently available for this purpose have differing degrees of complexity and, although no similar domestically produced equipment is available, all are highly taxed by the Brazilian government, which has no specific tax legislation for importing such equipment [2]. Then, experimentation with alternative products which can be used with this equipment is very important. In particular, the production of low-cost simulators and bolus will give to small radiotherapy centers the ability to investigate and develop new treatment techniques and improve quality control. In radiotherapy, materials that simulate human tissues are commonly called simulators or substitute tissues. However, according to White [3], there is no simple chemical substance capable of mimicking the atomic composition of human tissues. Although the desired composition can usually be obtained in aqueous mixtures or gels, these mixtures are inconvenient, because of their toxicity and lack of availability. To create alternative tissue substitutes, an appropriate base material must be chosen, which has scattering and attenuation properties that are similar to the tissue to be simulated [4]. In a second stage, additional substances are added to correct any deficiencies in the base material [5]. The official document that regulates the procedures for tissue substitute characterization is the REPORT 44 of the International Commission on Radiation Units and Measurements (ICRU) [6]. This document discusses the coefficients that must be obtained and the quantities that should be considered during the characterization process. REPORT 44 recommends that in the process of evaluation and characterization of a simulator material the following criteria should be evaluated:

1) (Composition/purity) The elemental composition of the material must be known to the degree of accuracy required for the desired application; contaminants should be avoided, especially those whose atomic number is greater than 20 (Z> 20).
2) (Homogeneity) Inhomogeneities, due to poor component dispersion and porosity must not introduce uncertainties greater than 1% in transmission, or in the estimation of radiation doses.
3) (Stability) The base material should be inert and should not degrade upon repeated exposure to radiation.
4) (Shape) Substitute tissues should be pliable, and capable of being molded into the desired shape.

This paper proposes a model for the characterization of beeswax, according to the above criteria, for use as a substitute base tissue, to enable their use in the manufacture of objects suitable for radiotherapy with megavoltage photons beams.

A. Beeswaxes

Beeswax is a physiological product produced by bees in their beehive. To produce beeswax, bees swallow and digest honey, converting the food into fat; 24 hours after honey ingestion the bees are capable of producing beeswax [7]. Four pairs of wax glands are located in the ventral abdomen of bees and are projected side-by-side in the last abdominal segments. The wax is expelled from these glands in liquid form, and solidifies only when in contact with the environmental temperature. The bees produce wax for the construction of honeycombs and operculation, the process by which bees close the alveoli (the brood and honey) with a thin layer of wax. Operculum beeswax is of better quality with fewer

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impurities [7]. Beeswax has already been used as bolus with satisfactory results [8] [9]. In addition to being a natural product, the market value of a kilogram of beeswax is much less than that of other types of materials used for this purpose, such as acrylic and polyethylene [10]. These features make the beeswax a great alternative material to replace the usual soft tissue substitutes. However, it is common practice to stochastically modify their original composition [10]. In addition, other important factors [11], such as the environmental conditions present during beeswax production, the geographic location of the beehive, and the bee species which produced the wax, can alter the composition of the resulting beeswax base substitute tissue. Because even small changes in the chemical structure of the wax can promote undesirable uncertainties in radiotherapy measurements, a convenient and reliable method for the assessment of beeswax material as a base tissue substitute is needed. Thus, in the present study, we propose a method to characterize beeswaxes for use as base substitute tissue for the manufacture of objects suitable for external radiotherapy.

B. Model Characterization Structure

Beeswax characterization was divided into three distinct stages: 1) study of aspects related to the origin of the beeswax; 2) assessment of physical and chemical properties; and 3) evaluation of beam attenuation capacity. During first stage (preliminary characterization stage), some chemical properties were assessed to verify the absence of adulterating agents. In the second stage, physical and chemical properties were evaluated, such as moldability, and the percentage of constituent elements. Finally, in the third stage, practical linear and mass attenuation coefficients were determined. Results from these three stages were related to the origin of the beeswax, the bee species which produced the beeswax, the flora in the vicinity of the beehive, and the extraction form.

II. Materials and Methods

A. Preliminary Characterization

The choice of beeswaxes used in the present study was based on a published characterization of honey bee flora from the semi-arid Brazilian state of Paraiba, performed by Silva and Aquino [12]. Official methods for analysis of fats and oils adopted by Brazil, the United States, the United Kingdom and Spain were used, with minor modifications, to determine the purity of the beeswax for these experiments [13]-[20]. The following values were obtained: density, saponification, acid, esters, iodine absorption, peroxide, ash content, and melting point. Obtained results were then compared with parameters described in the literature for pure unadulterated beeswax [10] [21].

B. Physical and Chemical Characteristics

a.(Shape) The physical properties of the beeswax were evaluated as a function of environmental temperature, using a temperature-controlled oven. Evaluations were performed by palpation and observation.

b.(Degradation by Repeated Irradiations) To evaluate the degree of degradation associated with repeated irradiations, beeswax cubes (4 cm on edge) were irradiated with a dose of 50,000 Gy using a Gammacell 220 MDS Nordion model 220E GC No 65 R (ASSY), with a ^{60}Co source.

c.(Density) The density of the wax was measured by the pycnometer method. At room temperature, the mass of the empty pycnometer, m_1, was measured using a digital scale. Then, the mass of the pycnometer filled with distilled water, m_2, was measured. Finally, pieces of wax were introduced into the water filled pycnometer, and the mass, m_3, was determined. The relative density was then calculated by the expression,

$$\rho_{w,b} = \frac{m_{water}}{m_{beeswax}}. \quad (1)$$

Where:

$$m_{water} = m_2 - m_1, \quad (2)$$

$$m_{beeswax} = m_2 - m_3. \quad (3)$$

The density of distilled water is $\rho_{water} \cong 1g/cm^3$. Therefore, the absolute density of beeswax in g/cm^3 can be calculated by,

$$\rho = \frac{\rho_b}{\rho_w}. \quad (4)$$

d.(Composition) The chemical compositions of the beeswaxes used in this work were characterized using three techniques: CHN elemental analysis; energy dispersive microanalysis (using a scanning electron microscope**);** and atomic emission spectroscopy (by inductively coupled plasma)**.**

C. Beam Attenuation Capacity

a.(Practical Linear Attenuation Coefficient) REPORT 44 asserts that tissue substitutes will attenuate X-rays similarly to human tissues, only if the variation of the total attenuation coefficient as a function of incident photon energy is identical to the tissue being simulated [6]. To obtain linear attenuation coefficients, beeswax blocks (25x25 cm^2, with various thicknesses) were prepared and greased with graphite, which were then irradiated in a SIEMENS linear accelerator (PRIMUS Mid Energy model with a 6 MV beam energy). Measurements were conducted using a PTW 31011 ionization chamber connected to a PTW UNIDOS E electrometer as illustrated in Fig. 1.

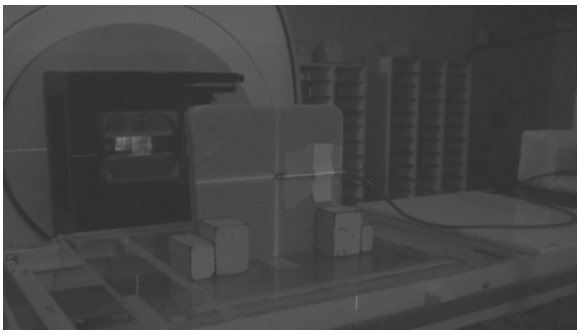

Fig. 1 Illustration of the correct positioning of a board on the treatment table of the accelerator aligned with the ionization chamber

To obtain the practical linear attenuation coefficient, the approximation method was used [22]. Beeswax blocks were placed at a distance of 100 cm from the head of the machine, in order to attenuate the beam. The blocks were placed separately in random configurations. Many measurements were made with different field sizes.The electrometer readings were introduced as I and I_0 in the equation,

$$I = I_0 . e^{-\mu x}. \quad (5)$$

Because the thickness of the plates is known (obtained using a micrometer), it is possible to determine the total linear attenuation coefficients for various field sizes on the surface of the blocks. Field sizes of 12x12, 10x10, 6x6, 5x5, 4x4 and 3x3 cm^2 were tested. From the 3x3 cm^2 field, an approximation of a Gaussian function was used to estimate the linear attenuation coefficient for a 0x0 cm^2 field, by referring to the thin beam with the same half-value layer as the 6 MV beam. Measurements with field less than 3x3 cm^2 were not performed, due to the size of the cavity of the ionization chamber used.

b.(Practical Mass Attenuation Coefficient) The value obtained for the linear attenuation coefficient μ is related to the density of the beeswax used in the attenuation process using the equation,

$$\left(\mu/\rho\right)_c = \sum i w_i \left(\mu/\rho\right)_i. \quad (6)$$

Where, $(\mu/\rho)_c$ is the mass attenuation coefficient for the compound, $(\mu/\rho)_i$ is the mass attenuation coefficient for each individual element and w_i, is the fractional weight of the elements in the compound. The value obtained from that operation was compared with values obtained by Hubbell and Seltzer [23], in order to determine the effective energy of the 6 MV polienergetic beam, and consequently, the practical simulation power of the beeswax. These data relate the mass attenuation coefficients for different elements and compounds with the effective energy of the incident photon beam on the material.

c.(Theoretical Mass Attenuation Coefficient) After obtaining the percentage of the chemical elements present in the beeswaxes, the program Xcom [24] enables comparisons of the behavior of the mass attenuation coefficient with respect to other simulators and body tissues.

III. Results and Discussion

A. Preliminary Characterization

Bees commonly found in Brazil are a hybrid of European honeybees: Apis *mellifera mellifera, Apis mellifera ligustica, Apis mellifera caucasica and Apis mellifera carniça* with the African bee *Apis mellifera scutellata* [10]. In this work, beeswax obtained from bees similar to *Apis mellifera scutellata* was evaluated.

We collected three quantities of beeswax during the off-season of honey production in 2010. The first extraction (extraction A) was conducted in February from old combs, during flowering (October - December 2009) of *zizipos joazeiro*. The second extraction (extraction B) was conducted in March from the operculum, during flowering (January – February 2010) of *croton sonderianus*. The third extraction (extraction C) was conducted in July 2010 (also from operculum), during flowering (March - May) of *prosopis juliflora* [12]. Hereafter, beeswaxes obtained by these extractions will be referred to as beeswax A, B and C, respectively. For all samples, extraction was performed by melting and filtering through filtration screens. Contaminating agents were not detected. Table I below shows the values measured for our experimental beeswax samples and parameters for pure beeswax.

TABLE I
Values Measured for Beeswaxes Samples And Parameters for Pure Beeswax

Method	Beeswax			Parameter
	A	B	C	
Density (g/mL)	0.94	0.923	0.923	0.92 - 0.947
Saponification (mg KOH/g)	89.8	84.5	84.7	83 – 103
Acidity (mg KOH/g)	23.2	18.3	18.3	17 - 24
Esters (mg KOH/g)	81.6	74.9	74	66 – 82
Melting Point (ºC)	65.9	65.2	65	61 – 66
Iodine Absorption (g I/100g)	9.2	8.2	8.3	7.6 – 10.6
Peroxide (meq O/kg)	0.01	0.00	0.00	---
Ash Content (%)	0.035	0.032	0.036	0.000 – 0.055

B. Physical and Chemical Characteristics

a. (Shape) The document, TEC DOC1151 [25], recommends that each institution have the means to ensure that the quality of radiotherapy services offered remain within internationally accepted limits, and the ability to correct deviations that may lead to treatment errors.

The quality of a photon beam depends on its power of penetration [26] [27]. As outlined in TEC DOC1151 [25], certain tests must be performed monthly to ensure beam quality constancy for the percentage depth dose (PDD 20.10) or tissue phantom ratio (TPR 20.10), and daily to ensure the constancy of the reference dose. All of these measures help monitor and improve the dose of radiation delivered to the patient, but to be performed, require specific accessories, such

as simulators [28].For this purpose, specialized companies manufacture blocks of solid water with suitable holes for accommodation of dosimeters. The beeswaxes tested in this work were solid at room temperature and not flexible, which is advantageous for forming the necessary blocks. Waxes from the operculum (types B and C) were found to be more pliable, a characteristic that also facilitated the removal of blocks from the form. In addition, Type A beeswax (from old combs) was stickier than Types B and C, which caused difficulties in handling.For use as a bolus, the solidity displayed by beeswax types A, B and C at room temperature was an obstacle, because for this purpose greater flexibility is required, enabling creation of custom molds of the surface and patients contours. However, at temperatures above 39°C, the beeswax samples displayed greater capacity for plastic deformation. Although healthy skin supports the application of wax at this temperature, the skin of patients undergoing treatment is already very sensitive, preventing their application as a bolus.

b.(Degradation due to Repeated Irradiation) Type A, B and C beeswaxes did not display any changes after irradiation with 50,000 Gy. This dose corresponds to at least 25,000 radiotherapy sessions, supporting the feasibility of using beeswax as a base tissue substitute.

c.(Density) The density values obtained are shown in Table I. Density values for beeswaxes A, B and C are close to the density value of water 1 g/cm^3, which is the reference material normally used in dosimetric simulations with megavoltage beams in radiotherapy.

d.(Chemical Composition) Table II shows results from chemical composition analyses obtained for each type of beeswax versus other materials used as base tissue substitutes.

TABLE II
CHEMICAL COMPOSITION (PERCENTAGES) OBTAINED FOR EACH TYPE OF BEESWAX COMPARED TO OTHER MATERIALS USED AS SIMULATORS

Elements	Z	Beeswaxes			Other simulators			
		A	B	C	Parafinn	Water	Mix D	Temex
H	1	12.9	12.3	12.1	14.9	11.2	13.4	9.6
C	6	80.7	80.0	80.0	85.1	-	77.7	87
N	7	1.38	1.36	1.32	-	-	-	0.06
O	8	2	1.99	1.98	-	88.8	3.5	0.47
Na	11	< 3	< 3	< 3	-	-	-	-
Mg	12	-	-	-	-	-	3.8	-
Si	14	< 3	< 3	< 3	-	-	-	-
S	16	< 1	< 1	< 1	-	-	-	1.53
Ca	20	< 3	< 3	< 3	-	-	-	-
Ti	22	-	-	-	-	-	1.44	0.33
Fe	26	< 1	< 1	< 1	-	-	-	-
Zn	30	< 1	< 1	< 1	-	-	-	0.45

Carbon, hydrogen, oxygen and nitrogen were found to be in higher concentrations in beeswax versus the other substitute materials. Substitute materials that most resemble beeswax in terms of chemical composition are Mix D wax, paraffin and Temex, based on the quantities of carbon and hydrogen, respectively. The low amount of oxygen in the beeswax samples does not preclude the use of beeswaxes as a tissue substitute, because various substitutes, such as Temex and Mix D wax, also have low concentrations of this element. The presence of zinc, calcium and iron in the beeswax formulation can compensate for the oxygen deficiency; similarly, titanium and zinc compensates for oxygen deficiency in Temex and Mix D wax.

C. Beam Attenuation Capacity

a.(Linear and Mass Attenuation Coefficient) Fig. 2 shows a graph of the average values of linear attenuation coefficient versus field size obtained from the apparatus shown in Figure 1 for beeswax type B. From the 3x3 cm^2 field, an approximation of a Gaussian function was used to estimate the linear attenuation coefficient for a 0x0 cm^2 field.

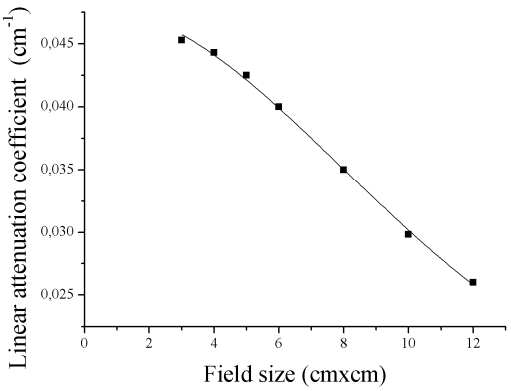

Fig. 2 Linear attenuation coefficient versus field size

Fig. 3 shows the variation of energy with the effective mass attenuation coefficient obtained from the Hubbell and Seltzer data [23] for beeswax type B.

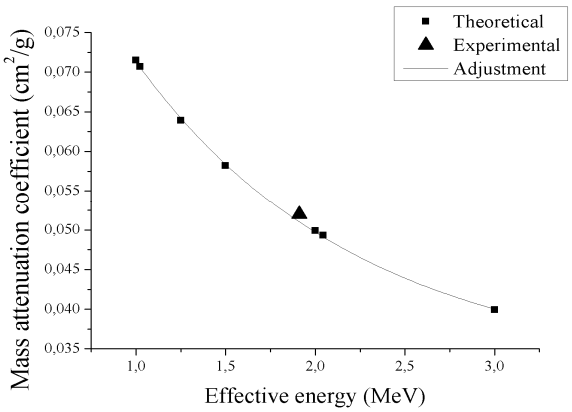

Fig. 3 Mass attenuation coefficient versus field size for type B beeswax

The triangle point in Fig. 3 corresponds to the mass attenuation coefficient value obtained during the experiment. The values of attenuation coefficient and effective energy for the other beeswaxes are presented in Table III below.

TABLE III
ATTENUATION COEFFICIENTS AND EFFECTIVE ENERGY

Beeswax	Linear attenuation coefficient μ	Mass attenuation coefficient μ/ρ	Effective energy 6 MV E_{eff}
Type	cm^{-1}	cm^2/g	*MeV*
A	0.0489 ± 0.0010	0.0520 ± 0.0003	1.93 ± 0.02
B	0.0479 ± 0.0054	0.0520 ± 0.0005	1.94 ± 0.03
C	0.0471 ± 0.0031	0.0510 ± 0.0002	1.89 ± 0.03

The values shown in Table III are in accordance with those obtained by Robinson and Scrimger [22] for the monoenergetic approximation of a polienergetic 6 MV beam, demonstrating that the beeswax analyzed attenuates the beam properly and does not require significant chemical corrections to be employed as base substitute tissue.

B.(Behavior of the theoretical mass attenuation coefficient) Fig. 4 and Fig. 5 show variations in the mass attenuation coefficients of beeswax type B with respect to other simulators and main body tissues.

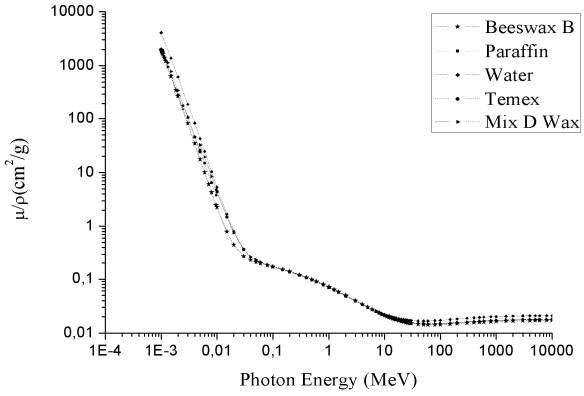

Fig. 4 Comparison of the behavior of the mass attenuation coefficients (obtained using the program Xcom) of beeswax B with other simulators

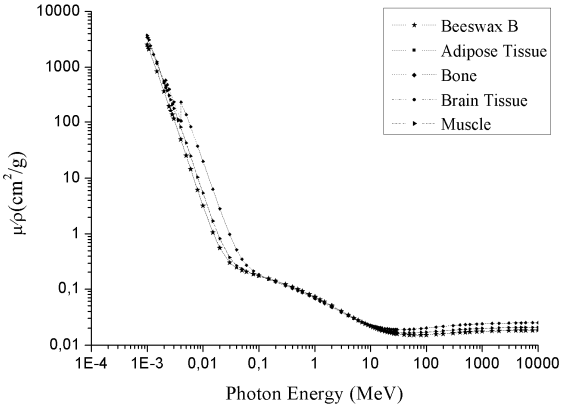

Fig. 5 Comparison of the behavior of the mass attenuation coefficient (obtained using the program Xcom) of beeswax B with main body tissues

In the therapeutic energy range (i.e. energies above 1 MeV), all materials described in the graphs above show similar behaviors. Type A and C beeswax also behaved similarly (not shown).

IV. CONCLUSION

The analysis model proposed in this work is efficient and confirms that beeswaxes represents an excellent option for a base tissue substitute in external radiotherapy with megavoltage photon beams. The model presented here is convenient, and show than beeswaxes can dramatically reduce the costs of products related to this type of application. The major advantage of beeswax is its intrinsic attenuation properties, which do not require significant chemical correction.

REFERENCES

[1] E.B. Podgorsak, *Radiation Oncology Physics: A Handbook for Teachers and Students*, IAEA,1957.
[2] Brazilian Radiotherapy Society. [on line] http://www.sbradioterapia.com.br.
[3] D.R. White, *Tissue substitutes in experimental radiation physics*. Medical Physics, pp. 467-479, 1978.
[4] D.R. White, *The formulation of tissue substitute materials using basic interaction data***.** Physics in medicine and biology, pp. 22-25, 1975.
[5] D.R. White, C. Constatinou, C: *Anthropomorphic phantom materials. The Progress in Medical Radiation Physics.* Medical Radiation Physics, pp. 133-193, 1982.
[6] International Commission On Radiation Units And Measurements, *Tissue Substitutes in Radiation Dosimetry and Measurement*. Report.44, 1989.
[7] R. Zovaro, *Ceras de abelhas: Produção e beneficiamento*. Vol.1, AEP, 2007.
[8] D. Scheidegger, *Bólus e filtros em cunha feitos com cera de abelha para utilização em radioterapia com ^{60}Co*. Publicações, CEFET, 2003.
[9] M. Tobler, *Design and production of wax compensators for electron treatments of the chest wall*. Medical dosimetry. pp. 199-206, 2006.
[10] Embrapa Meio-Norte. [on line] http://www.embrapa.mn.gov.br.
[11] J.L. Bernal, *Physico-chemical parameters for the characterization of pure beeswax and detection of adulterations*. European Journal of lipid science and technology, pp. 158-166, 2005.
[12] A.R. Silva, *Characterization of the honey bee flora in the semi-arid of Brazilian state of Paraiba*. Arquivos de Zootecnia, pp. 2-4, 2000.
[13] Ministério da Agricultura, Pecuária e Abastecimento. *Regulamentos técnicos de identidade e qualidade de produtos apícolas*. Instrução normativa n°3, Sistema de consulta a legislação – SISLEG, 2001.

[14] United States Pharmacopoeial Convention, National Publishing, 2000.
[15] British Prarmacopoeia Commission Secretariat, HMSO, 1993.
[16] Real Farmacopea Española, Ministerio de Sanidad y Consumo, 1997.
[17] R.N. Rangel, *Práticas de físico-química*. Blucher, 2006.
[18] L. Casares, *Tratado de Analisis Químico*. Toledo, 1997.
[19] E. Moretto. *Óleos e gorduras vegetais*: *Processamento e análises*. Ed.UFSC, 1989.
[20] Farmacopeia Brasileira, Ministério da Saúde, Atheneu, 1988.
[21] J. Serra, *Características físico-químicas de la cera de abejas producida en España*. Alimentación, equipos y tecnologia, pp. 213-216, 1989.
[22] D.M. Robinson, J.W. Scrimger, *Monoenergetic approximation of a polyenergetic beam: a theorical approach*. The British Journal of Radiology, pp. 452-454, 1990.
[23] J.H. Hubbel, S.M. Seltzer, *Tables of X-Ray Mass Attenuation Coefficients and Mass Energy-Absorption Coefficients 1 keV to 20 MeV for Elements Z=1 to 92 and 48 Additional Substances of Dosimetric Interest*. NISTIR 5632, 1995.
[24] M. J. Berger, J.H. Hubbell, S. M. Seltzer, J. S. Coursey, and D. S. Zucker, *XCOM: Photon Cross Section Database (Version 1.2)*. Gaithersburg, MD: National Institute of Standards and Technology, 1999.
[25] IAEA - TECDOC 1151 - *Aspectos Físicos de La Garantía de Calidad en Radioterapia: Protocolo de Control de Calidad*. IAEA, 2000.
[26] E.J. Turner, *Atoms, radiation, and radiation protection*. Willey, 2007.
[27] F. Khan. *The physics of radiation therapy*. Williams and Wilkins, 1994.
[28] AIEA, *Absorbed dose determination in external beam radiotherapy: An international code of practice for dosimetry based on standards of absorbed dose to water*. Technical Report Series – 398, 2000.