DOSE PROFILE OF A DENTAL FACILITIES

Diogo da Silva Borges ^{1a}, Deise Diana Lava ^{1b}, Maria de Lourdes Moreira ^{1c}, Antonio Cesar Ferreira Guimarães ^{1d} and Lucinda Fernandes da Silva^{1e}

¹ Instituto de Engenharia Nuclear (IEN / CNEN - RJ) Rua Hélio de Almeida 75 21941-906 Rio de Janeiro, RJ - Brasil - Caixa-Postal:68550 ^a diogosb@outlook.com, ^b deise_dy@hotmail.com , ^c malu@ien.gov.br, ^d tony@ien.gov.br, ^e lucinda@ien.gov.br

ABSTRACT

The determination of the dose profile is important to classify the level of danger which the individuals are exposed (considering their positioning) in dental facilities. From this, this paper aims to present a methodology capable of mapping the dose within dental rooms in three dimensions. The methodology used for dose mapping in conjunction with techniques for calculating shielding for dental facilities, provided by the National Council on Radiation Protection & Measurements (NCRP), form a complete system able to generate meaningful data on the safety of occupationally Exposed Individuals (IOEs) and of the public. As the dose is strongly dependent on the distance, the estimated value of the initial dose was made in the isocenter of the source. This value was adopted because the model of dose calculus tends to infinity when it is desired to analyze points very close of the source. The model of room to be presented, as a case of illustration of the methodology, was arbitrarily constructed to generate better understanding of the problem. Its inclusion in the calculus was made through discretizations performed with the aid of high-performance computers. This discretizations allowed the obtain of dose values for an infinitesimal distance after the start point.

1. INTRODUCTION

The radiography is an essential component for the dental diagnosis. The use of ionizing radiation can cause biological damage in the long or short term [7], however it is not clear what the minimum of the dose value, present in dental radiographs, capable to cause damages to the health IOEs or of the patients. Thus, the use of radiation is justified by the need to offer more benefits than risks and is guaranteed by the following conditions:

- The dental radiographic examination is indicated by means of justifications;
- The techniques are optimized so that they may ensure high quality diagnostic imaging;
- The principles identified by the NRCP-145 Report are followed to minimize the exposure of patients, ions and the public to ionizing radiation. The Radiological Protection in Dentistry Report (NCRP-145), establishes calculations and standards to be adopted in order to ensure safety to those who might to be exposed to ionizing radiations in dental facilities, according to the dose limits set. In the standard CNEN-NN-3.01 is possible search the values of these limits [2].

The radiation protection appears as a key factor security that focuses on concern for the interaction of the ionizing radiations with matter. The two biggest concerns are attributed to the deterministic effects and stochastic, since they can cause health problems in the short or long term from those that have contact direct and indirect with radiations.

The deterministic effects are characterized how problems caused in exposed individuals, in a short period of time, to a high level of ionizing radiation. The cataracts and the sudden fall of hair are diseases caused by this effect, for example. The severity of deterministic effect is highly dependent on the level of radiation used, a factor that determines a threshold dose below which clinically is not possible to observe effects in a short-term of time [3].

In turn, the stochastic effects are evident damages after a long period of time starting from the interaction of radiation with biological matter. This effect creates a problem that is being studied thoroughly due to the need to examine the benefit of using radiation, since inevitably it will lead an individual to exhibit some disease throughout his life, like cancer for example [4].

Due the necessity to ensure the safety of those involved in dental radiography operations, this paper proposes the construction of a methodology able to map the distribution of dose behavior in air volume of a dental room. Such methodology is able to quickly pinpoint places of greater and lesser danger to the IOEs

2. METHODOLOGIES

2.1. Shielding for X-Rays and Gamma

The principal equation used to perform the calculation of the barrier thickness for X-Rays and Gamma is shown in the equation (1).

$$X(B,m,V_t) = \frac{1}{\alpha(m,V_t) \gamma(m,V_t)} ln \left[\frac{B^{-\gamma(m,V_t)} + \frac{\beta(m,V_t)}{\alpha(m,V_t)}}{1 + \frac{\beta(m,V_t)}{\alpha(m,V_t)}} \right]$$
(1)

This equation provides the thickness of a material for constructing barriers against ionizing radiations based on values of α , $\beta \in \gamma$, which are the transmission parameters (B) of a material (m) like the wood, lead, steel, plate glass, gypsum, concrete and lead acrylic, for each operation potential (V_t) commonly used (50 kVp, 60 kVp, 70 kVp, 80 kVp, 90 kVp and 100 kVp) for generating beams (continuous or single-phase pulse) of X-rays.

2.1.1. Primary Beam

The primary beam is defined with the amount of the X-ray that emerges from the machine tube through and strikes a sample [5]. The beam type (primary or secondary) can impact the

value of transmission for a given material. For the transmission by the primary barrier (B_p) is adopted the relation given by equation (2).

$$B_{p}(x,m,V_{t}) = \frac{P d_{p}^{2}}{K_{w}(V_{t}) W(V_{t}) A_{pt}(V_{t}) U T}$$
(2)

Where:

- P is the limiting factor of dose;
- d_p is the distance between the source and the primary barrier;
- $W(V_t)$ is the level of use of the source of X-ray by volume of examination;
- $A_{pt}(V_t)$ is the transmission factor of the primary beam through a patient;
- U represents the fraction of the time of X-ray emission in the direction of a specific barrier;
- T is the probability of exist a person in a protected area during the time of operation of an X-ray machine.
- K_w(V_t) represents the amount of air Kerma per workload (W) of the primary beam (continuous pulse (equation (3)) and wave single-phase (equation (4))) at one meter from source of X-rays for a potential (V_t), such that:

$$K_w(V_t) = 1.222 - (0.05664)V_t + (0.001227)V_t^2 - (0.000003136)V_t^3$$
(3)

$$K_w(V_t) = -0.37 - (0.00258)V_t + (0.000537)V_t^2 - (0.00000102)V_t^3$$
(4)

2.1.2. Secondary Beam

The secondary radiation is an inevitable consequence due to the interaction of the primary beam with any object or person [6]. The equation (1) can be used for calculating barrier due to radiation scattering and leakage radiation (secondary beam). The adaptation of this equation is given through of replacing the parameter that represents the amount of air-Kerma due the primary beam $(K_w(V_t))$ by the amount of scattering air-Kerma $(K_s(x,m,\theta))$ and leakage air-Kerma $(K_L(V_t))$.

The intensity of scattered radiation due to the interaction of the primary beam of X-rays is dependent on an angle (θ), of the source location and the number and energy of photons incident to a patient. It is assumed that the number of photons from the primary beam incident on the patient varies linearly with the area of the X-ray beam [7], so by fixing the intensity of the beam (kVp), the milliampere-seconds and of the collimating, the scattered radiation intensity become independent of the distance between the source and the patient. It can be shown that the total amount of scattering air-Kerma ($K_s(x,m,\theta)$, in a protected area due to scattered radiation from a single source of operating potential (V_t), is given by equation (5).

$$K_{s}(x,m,\theta) = \frac{a_{1(\theta,V_{t})} \ 10^{-6} \ K_{w}(V_{t}) \ (1-U) \ W(V_{t})}{d_{s}^{2}} \ B_{p}(x,m,V_{t}) \ \frac{F}{d_{F}^{2}}$$
(5)

Such that:

- d_{g} is the distance (in meters) from the patient to the point of calculation;
- •
- F is the size of the primary field (in units of cm²);
- $\mathbf{d}_{\mathbf{F}}$ is the distance (in meters) from the source to the point of calculation.
- a_{1(0,Vt}) is the fraction of dispersion in scale per unit area of the beam (in units of cm⁻²) from the one meter from the source of scattered radiation. Its value is given by equation (6).

$$a_{1(\theta,V_t)} = ((0.0160) (V_t - 125)) + 8.434 - (0.1105)\theta + (0.0009828)\theta^2$$
(6)
- (0.000001741)\theta^3

The NCRP-145 report shows that the rate of Kerma in air, according to the US standard (100 mR.h 1m-1), from a leak in a spot protected by a barrier of thickness (x) and a material (m) for any one tube operated at a potential (V_t) is given by equation (7) [7].

$$K_{L}(x,m) = (0.0146) \cdot \frac{V_{t}^{2} B_{p}(x_{H},V_{t}) (1-U) W(V_{t})}{V_{t,max}^{2} B_{p}(x_{H},V_{t}) I_{max} d_{l}^{2}} e^{\left[\frac{-0.693X}{X_{1/2}(m,V_{t,max})}\right]}$$
(7)

Where:

- $B_p(x_H, V_t)$ is the transmission factor of the barrier by the thickness x_H ;
- I_{max} is maximum current image or movie. For continuous operation with tubes unclassified, this factor becomes the average current in one hour of operation when the X-ray tube is working in its maximum cycle work;
- The international standard requires that the constant **0.0146** mGy.min⁻¹ is modified to 0.00417 mGy.min⁻¹ or 0.25 mGy/h [7];
- $X_{1/2}(m, V_{t,max})$ is the value of half-value layer, such that: $X_{1/2} = 0.693/\alpha$ (m, V_t) [7].

2.2. Technique for Determination of Dose Profile

In practice, the determination of dose at a posterior point near of the source beam (after the isocenter of the source) can be made by the exponential decay law (equation (8)).

$$D = (D_0/d^2) e^{-\mu x}$$
(8)

Where:

- **µ** is the attenuation coefficient of a material;
- **x** is the value of the attenuating material thickness;
- d is the distance between the isocenter of a source and an area of interest;
- **D**₀ represents the initial dose in Gray (Gy) and can be calculated by equation (9).

$$\boldsymbol{D}_0 = \boldsymbol{P} \, \boldsymbol{d}_p^2 / \boldsymbol{B} \tag{9}$$

The numeric value of $\mathbf{d}_{\mathbf{p}}$ in the equation (9) is equal to the difference between the measured distance from the isocenter to the protected area and the thickness of the barrier. Whereas the absence of attenuating materials, the initial dose is given by equation (10).

$$\boldsymbol{D} = \boldsymbol{D}_0 / \boldsymbol{d}_p^2 \tag{10}$$

X Congreso Regional Latinoamericano IRPA de Protección y Seguridad Radiológica, 2015

For a construction project of dental rooms, excluding attenuators materials present, the equation (8) has a strong dependence on the distance. His behavior has similar to other known quantities such as activity (A), beam intensity (I) and exposure (X) patterns. The Fig. 1 shows a graph based on the equation for determining the dose in the air.



Figure 1. Dose dependence with distance.

With the value of the initial is possible to perform a point-to-point integration of the room to obtain the dose in regions of interest. The amount of points to be analyzed is directly related to the degree of quality of the results, such that for a high number of point the dose profile tends to present values with small margins of error.

The proposed method consists of performing integrations in three dimensions to determine the dose profile of the dental room. Assuming a model where the source presents dependence only with the distance, the only problem to be solved is the choice of methods able to reference points in the room volume to be studied. To determine the placement of points the use of the Cartesian plane in three dimensions (Fig. 2) is required is necessary.



Figure 2. Reference Point in a Three-Dimensional System.

The three-dimensional model allows a simple way to determine the distance between the origin and any point in space. The determination of the distance in this model is given by equation (11).

$$d = \sqrt{x^2 + y^2 + z^2}$$
(11)

Where x, y and z represent points in the space of interest for a problem analysis. With the determining the location of the initial dose in the air, the equation (10) can be adapted to the three-dimensional system (equation (12)).

$$D = D_0 / (x^2 + y^2 + z^2)$$
(12)

The equation (12) provides the solution for the dose mapping profile on the volume of the dental room. Its application is efficient when there is the possibility of using computers for the processing. Because of the need to use many points, this equation becomes infeasible for manual application and without the use of equipment.

X Congreso Regional Latinoamericano IRPA de Protección y Seguridad Radiológica, 2015

3. METHODOLOGY APPLICATION

The methodology application is performed on simulated dental facility in Fig. 3. Its creation was arbitrary, however it is considered regions commonly found in traditional dental rooms. Furthermore, the method comprises the use of monophasic beams and continuous pulse. Importantly, the methodology discarded attenuators materials between the source and the barriers.



1 - Parking, 2 - Reception, 3 - Bathroom, 4 - Deposit, 5 - Parking, 6 - Waiting Room, 7 - Room Service, 8 - Walk, 9 - Boulevard.

Figure 3. Model of Dental Installation.

The Tab.1 presents detailed data for design of the dental facility in order to consider all possible variables (excluding attenuators materials and the presence of people). The value of the workload was overestimated for a better view of the dose profile. It is noteworthy that the initial values for the simulated installation are totally arbitrary.

PLACE	USE FACTOR	OCCUPATIONAL FACTOR	DISTANCE (m)	AREA
WALL A	0.025	1.000	4.000	FREE
WALL B	0.400	0.050	1.410	CONTROLLED
WALL C	0.400	0.025	1.000	FREE
WALL D	0.000	1.000	0.500	FREE
FLOOR	0.000	0.000	1.000	FREE
CEILING	0.000	0.000	2.000	FREE

Table 1. Data for the Project of the Dental Installation.

Addition to the data shown in Tab.1 was considered a correction of the primary beam air-Kerma due to interaction of radiation leakage in 5.51%. The workload was estimated at 266.7 mA.min/Week for a beam of 50 kVp. The methodology is directed to the continuous pulse beam, seeing that this has greater contribution to the dose value in the volume of dental room. To calculate the transmission of primary and secondary barriers as well as the determination of the dose previous them was used as base the concrete.

3.1. Results Analysis and Discussions

The data calculated for phase wave and continuous pulse for some materials, which may be used in shielding, are arranged in Tab. 2.

BARRIES	WAVE SINGLE	CONTINUOUS PULSE			
	THICKNESS (mm)				
WALL A					
LEAD	0.033	0.051			
STELL	0.179	0.288			
PLATE GLASS	4.429	7.019			
GYPSUM	9.645	15.856			
WOOD	85.725	133.058			
CONCRETE	^a	6.620			
WALL B					
LEAD	0.030	0.02			
STELL	0.100	0.100			
PLATE GLASS	0.190	0.190			
GYPSUM	0.430	0.470			
CONCRETE	0.180	0.200			
WALL C					
LEAD	0.280	0.200			
STELL	1.050	0.970			
PLATE GLASS	1.970	1.820			
GYPSUM	4.460	4.550			
CONCRETE	1.900	1.950			

Table 2. Thickness of Barriers to Wave Single and Continuous Pulse.

^a Unavailable data for use of this material.

The NCRP-145 Report determines that an interaction between the radiation and the ceiling and the floor is very low or zero, so it is not necessary to shield these structures, as well as the wall which lies behind the machine. According to this report, a machine of dental X-rays are able to shield the primary beam deviation angles of 180° [7].

The dose profile is constructed with based on the results obtained for the continuous beam pulse. For the case analysis, it was considered which the principal beam has an aperture angle

enough so that you can view the dose of behavior "blades" of different heights. Using the equation (1) and equation (9) for the distance of one meter is possible to adopt the value of the thickness of one of the materials shown in Tab.2 and determine the value for transmission of primary and secondary barriers and therefore the previous dose them (equation (12)). For the determination of the dose profile was not considered materials attenuators among the source and the barriers and the Compton scattering effect.

$$B(x,m,V_t) = \left\{ \mathbf{1} + \left[\frac{\beta(m,V_t)}{\alpha(m,V_t)} \right] e^{\alpha(m,V_t) \cdot x} - \frac{\beta(m,V_t)}{\alpha(m,V_t)} \right\}^{-\gamma(m,V_t)}$$
(12)

Through the application of these adjustments, it was created a table (Tab.3) with the values of transmission and the dose previous the primary and secondary barriers.

PLACE	TRANSMISSION	DOSE (mGy/Week)
Wall A	1.722E-02	1.160E+00
Wall B	1.398E-01	7.150E-01
Wall C	3.525E-05	5.673E+02

 Table 3. Dose values and Transmission.

With the values of transmission determined, as well as of the dose, the methodology for the mapping of the dose profile of the room can be applied. Integrating the volume of the room and applying equation (9) and equation (10) it is possible to determine blades with the behavior of the dose for different heights. The Fig. 4 comprises the result of the technique application for the primary beam.



Figure 4. Dose Profile (Primary Beam).

In the determination of the radiation of scattering was considered the possibility that each point of the primary barrier has the same probability of reflection of the primary beam, that is, each point of barrier can spread radiation everywhere, moreover, it was considered also the radiation that passes through the barrier. For the determinate the beam formed by spread of radiation by primary barrier, it was made an integration with intervals of 0.01 m in all Wall D. Due to the large amount of data generated by the integration, the analysis considered an area of 0.1 m² aligned with the source. Another reason for the other points have not been considered it is due also by the low participation in the dose of the environment. After the determining of the dose profile of the primary beam and application of the assumed conditions, it was built a graph (Fig. 5) shows the dose profile for the beam formed by scattered radiation.



Figure 5. Dose Profile (Scattering).

Another analysis made by the methodology it is the consideration of the radiation leak in the creation of the dose profile of the dental room. The initial value used was the maximum allowed (0.876 mGy/h) according to US standards [7]. According to this value, the dose profile due to leakage of radiation is shown in the Fig. 6.



Figure 6. Dose Profile (Leakage).

The methodology application generated in average eight thousand points (x, y, z, dose) for each type of the radiation beam (primary beam, leakage and scattering). The points were obtained with an algorithm written in the computational language C ++. Its goal was to perform the integration responsible for generating the viewing the volume of the room. Inside the room has not considered the interaction of radiation with other materials or the effect of Compton scattering.

The graphic used was of type 3D scatter with color mapping associated with the dose of the room in gray scale.

4. CONCLUSIONS

For the methodology application it was necessary to the use of computers for the processing and generation of the volume of the dental room. The obtained data were as expected and they can contribute to the increasing the security level of dental facilities. The determination of the dose profile, besides generating significant data about the level of danger at every point of the room, can be used to determine the basis of a project. Analyzing the regions where the dose has more or less intensity it is possible to use the fundamental principles of the radiation protection (time, distance and shielding) more flexibly, impacting directly in the increased security and possible decreases in spending for construction of a dental facility.

The dose profile due to scattering of radiation, made by the primary barrier, required a little more abstraction and calculations. For the formation of the dose profile due to scattered radiation, it was considered barrier points spaced in an interval of 0.01 m and limited by a 0.1 m² area, where the center is aligned with the source. Each point was considered as a point source with initial value determined with base in the radiation which hits and passes through the primary barrier.

The applied methodology was developed with based on the principles of the radiation protection and modeled with the aid of mathematical tools. Its application can to reveal relevant data about the volume of a dental room, in addition, with small increases in the methodology it is possible realize analysis in regions surrounding the room, which would be helpful to estimate the thickness of barriers in facilities whose internal volume can be influenced by many sources, even by the radiation background. The application was deemed successful and may contribute to the increased of safety of the dental facilities.

5. REFERENCES

- 1. HOESCHEN, C.; SÖREN, M. Radiation Protection in Nuclear Medicine, Heidelberg, Springer (2013).
- COMISSÃO NACIONAL DE ENERGIA NUCLEAR. CNEN-NN-3.01:2011 Diretrizes Básicas de Proteção Radiológica. Comissão Nacional de Energia Nuclear. [S.I.], p. 22. (2011).
- 3. MCPARLAND, J. Nuclear Medicine Radiation Dosimetry, New York, Springer, 2010.
- 4. TURNER, J. E. *Atoms, Radiation, and Radiation Protection.* 3^a. ed. ,Weinheim, Wiley (2008).
- SHAPIRO, J. Radiation Protection: A Guide for Scientists, Redulators and Physicians. 4^a. ed. Massachusetts, Harvard University Press (2002).
- TAUHATA, L. et al. *Radioproteção e Dosimetria: Fundamentos*. 5^a. ed. Rio de Janeiro, CNEN (2013).

X Congreso Regional Latinoamericano IRPA de Protección y Seguridad Radiológica, 2015