EVALUATION OF TLD DOSE RESPONSE COMPARED TO MCNP-5 SIMULATION OF DIAGNOSTIC X RAY EQUIPMENT – RADIATION DIAGNOSTIC IMAGE

Rodrigo Sanchez Giarola[1], Tássio Antonio Cavalieri[1], Fábio de Paiva[1], Marco Antonio Rodrigues Fernandes[2], Paulo de Tarso Dalledone Siqueira[1], Vitor Vivolo[3], Hélio Yoriyaz[1]

[1] Centro de Engenharia Nuclear - Instituto de Pesquisas Energéticas e Nucleares – IPEN/CNEN (Avenida Professor Lineu Prestes 2242 – Cidade Universitária, ZIP Code: 05508-000, São Paulo, Brazil and chancez@hotmail.com)

[2] Departamento de Dermatologia e Radioterapia – Faculdade de Medicina de Botucatu – Universidade - Avenida Professor Montenegro s/n - Rubião Junior, ZIP Code 18601-970, Botucatu, Brazil)

[3] Gerência de Metrologia das Radiações - Instituto de Pesquisas Energéticas e Nucleares – IPEN/CNEN (Avenida Professor Lineu Prestes 2242 – Cidade Universitária, ZIP Code: 05508-000, São Paulo, Brazil)

Abstract

The thermo luminescent dosimeter (TLD) is used as a radiation dosimeter and can be used as environmental and staff personnel monitoring. The TLD measures ionizing radiation exposure by a process in which the amount of radiation collected by the dosimeter is converted in visible light when the crystal is heated. The amount of emitted light is proportional to the radiation exposure, and then the response of the TLD must be the related to the real dose. In this work it was used twenty four TLD-700 in order to obtain eight values of doses from a diagnostic X-ray equipment. The TLD-700 is a LiF TLD enriched with ^{7}Li isotope. One way to compare and study the response of TLD is by Monte Carlo method, which has been used as a computational tool to solve problems stochastically. This method can be applied to any geometry, even those where the boundary conditions are unknown, making the method particularly useful to solve problems *a priori*. In this work it was modeled the X-ray tube exactly as the one used to irradiate the TLD, after the simulation and the TLD irradiation the results of dose value from both were compared.

Keywords: TLD; MCNP-5; Monte Carlo method, Dosimetry.

1.- INTRODUCTION

The thermo luminescent dosimeter (TLD) is a radiation dosimeter that uses the principle of thermo luminescence. The TLD measures ionizing radiation exposure by quantifying the amount of visible light emitted when the crystal is heated. The TLD is an inorganic crystal or polycrystal doped with adequate amounts of activators. The activators create imperfections in the crystal lattice, so that, those imperfections results in electrons trap, which captures and hold the charge carriers and luminescence centers. When the ionizing radiation interacts with the electrons it deposits energy and allow the electrons to leave the valence layer and reach the conduction layer, then they are trapped.

After the irradiation the TLD is heated and the trapped electrons get back to valence layer, and during this process photons are emitted. Often the amount of light emitted is proportional to the absorbed dose that reaches the material. The thermo luminescence is a kind of phosphorescence with a long life time at ambient temperatures.

Due to the size, wide dynamic range and good repeatability the TLD is widely used in individual monitoring, in medical dosimetry procedures, environmental and industry dosimetry.

In this study the TLD was irradiated at the *Laboratório de Calibração de Instrumentos* (LCI-IPEN) and the previous thermal treatment, the reading and the simulation took place at *Centro de Engenharia Nuclear* (CEN-IPEN).

The Monte Carlo method is a statistical method of numerical simulation that can be applied to any problem described by probability density function by using a random number generator. This method can be applied to the transport of ionizing radiation and has become an important tool to calculate particle fluence, density of the particles and deposited energy. This tool also allows varying parameters by simulation, such as different compounds and setups in a cheap and faster way.

The main objective of this study is to establish a comparison between the calibrated ionization field of a certified laboratory, TLDs response and simulation process. Therefore the simulation data can provide interaction statistics and future studies for different configurations.

2.- MATERIALS AND METHODS

Firstly the TLDs were treated by a thermal process, remaining at a muffle for two hours at 400ºC and then one more hour at 100ºC, in order to untrap electrons and eliminate anterior residual information. The use of TLDs demands the following steps: thermal treatment, irradiation and reading. Twenty four Lithium Fluoride (LiF) type of TLD 700 were used in this work, they were previously calibrated for diagnostic energies.

Three TLDs were placed in an acrylic holder at 1 meter from the source and irradiated at a Pantak/Seifert System at diagnostic qualities, according to the Reference Quality Radiation (RQR 10) following the new recommendations of *International Electrotechnical Commission* (IEC) at the 61267 standard. The irradiation setting was adopted as 150 kV, 10 mA, 4.2 mmAl, 120 mGy/min of air kerma rate at a 12 cm field. Figure 1 shows a picture of the experimental design. [VIVOLO 2006].

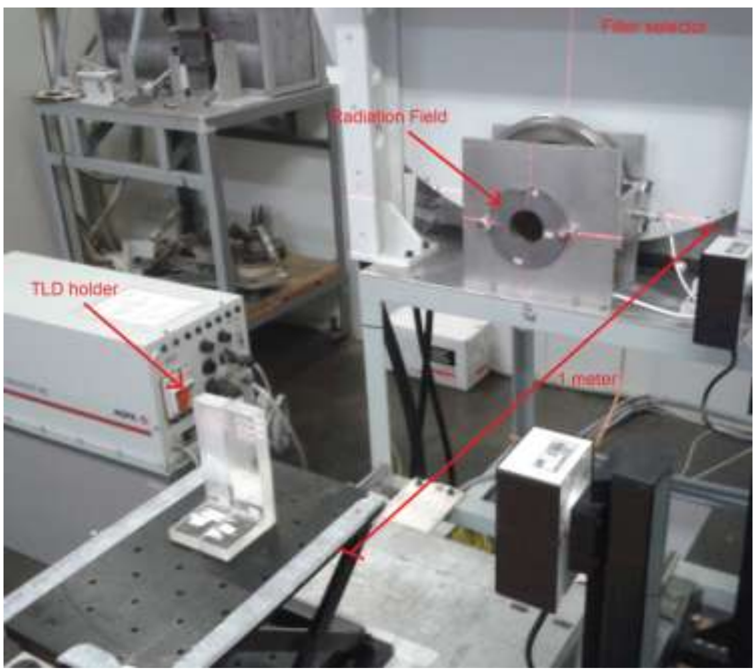


Figure 1.- Picture of the X ray system with the TLDs positioned at the field.

This irradiation protocol was repeated eight times using four different exposure times – 1, 2, 3 and 4 minutes in order to obtain different doses for the same irradiation rate - and the TLDs were grouped and named as shown in the Table 1.

Table 1.- Groups of TLDs.

Group	Quantity of TLDs	Exposure Time
C D	3 TLDs	1 minute
E F	3 TLDs	2 minutes
G H	3 TLDs	3 minutes
I J	3 TLDs	4 minutes

To ensure good accuracy, the simulation considered all of the fundamental elements and processes of a real X ray machine for diagnostic radiology. The geometry and components were modeled according to technical information available of the X ray machine. It was used an electron source, where the electrons were accelerated toward the anode, in order to have a similar process of the real X ray production. In this process part of the energy from the electron beam is converted into X rays, and these X rays are produced as characteristic radiation or *bremsstrahlung* radiation. [GIAROLA 2012]

The Monte Carlo Method is applied to some codes, in this work it was used the Monte Carlo N-Particle code (MCNP-5). The MCNP-5 is a general purpose code that can be used for neutrons, photons, electrons, or coupled neutrons/photons/electrons transport, including the capability to calculate eigenvalues for critical systems. This software application includes, but is not limited to, radiation protection and dosimetry, radiation shielding, radiography, medical physics, detector design and analysis. The code treats an arbitrary three-dimensional configuration of materials in geometric cells bounded by first and second degree surfaces and fourth-degree elliptical tori.

For photons, the code accounts for incoherent and coherent scattering, the possibility of fluorescent emission after photoelectric absorption, absorption in pair production with local emission of annihilation radiation, and *bremsstrahlung*. A continuous-slowing-down model is used for electron transport that includes positrons, k x-rays and *bremsstrahlung*.

The calculus of radiation interacting with matter is made firstly by determining the materials, density and the geometry used in the simulation. After selected the geometry it is described the source and all the outputs selected to be calculated. Finally it is selected the number of particle histories to run the simulation starts. [YORIYAZ 2011].

A $4x10^9$ number of particles histories were considered in the simulations and it was selected the MCNP tallies F4 (Track length estimate of cell flux) and F6 (Track length estimate of energy deposition). Figure 2 shows an image obtained by an extension of MCNP-5 called Vised 3-D [Visual Editor Consultants]. In the right side it is positioned the X ray tube, with the lead shell (pink part checked at right), glass shell (inside the pink volume, covering the yellow part), target (yellow sectioned cone) and inherent filters (blue parts added at the lead shell); in the left side the 3 TLDs are positioned.

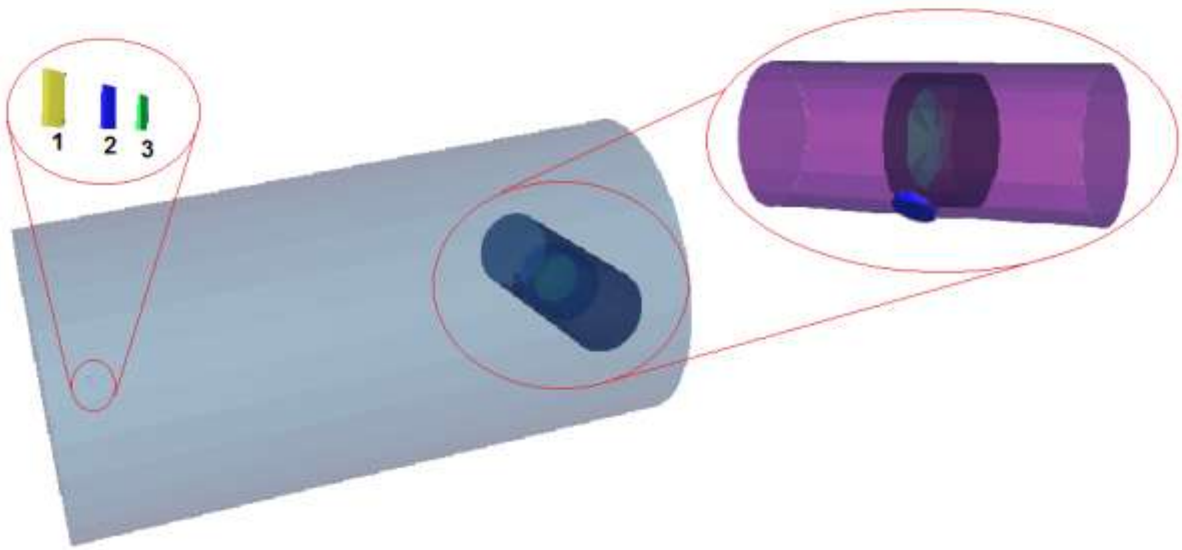


Figure 2.- MCNP5 Simulation set-up 3 TLDs positioned at the simulated irradiation field.

3.- RESULTS

The obtained dose from the TLD is measured taking the response of the TLD multiplied by a TLD calibration constant, as given by equation 1. This calibration constant was previously calculated. [CAVALIERI 2013].

$$D= \alpha \times R \qquad (1)$$

Where D=Dose, α= calibration constant and R=response.

After being irradiated, the TLDs were read and the field dose was calculated to the TLDs.

Two simulations were performed, in the first simulation it was calculated the dose in the TLD material (LiF) and in the second one the dose in the air occupied by the TLD volume. It was calculated the Tally F6, the results of TLDs response, calculated dose in LiF and calculated dose in air are shown in Table 2.

The error of TLDs and simulations are also presented in the table 2, inside the brackets. The error value is inconstant for all the range in the TLD and constant for simulations. It is worth mentioning that the calculus of error obtained by the MCNP-5 was 0,98% to the simulation of LiF material and 2,58% when the dose was calculated in the air volume of TLD, and the simulation process passed in all of the statistical tests.

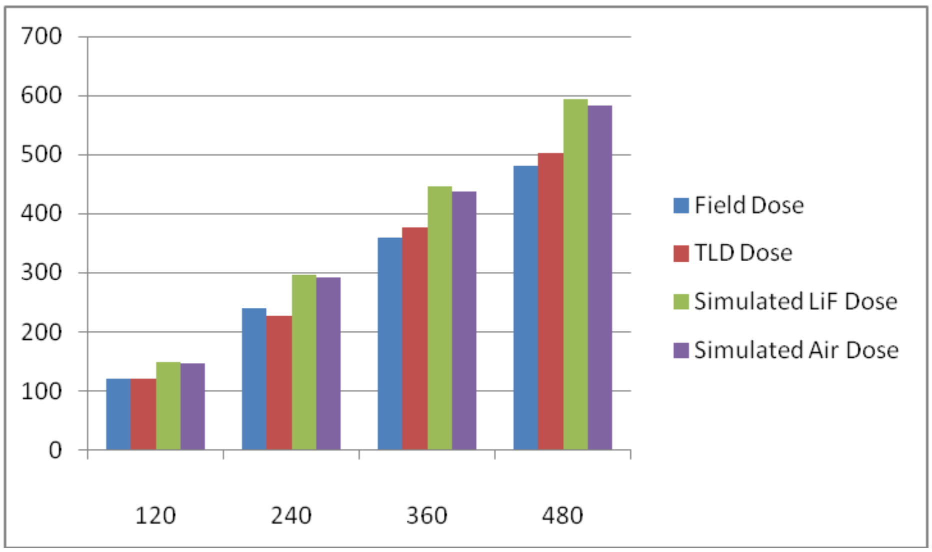
Table 2.- Comparison between Certified field, TLDs and simulation doses and the respective uncertainty measures.

Calibrated Field Dose	TLD response	Dose in Air (MCNP)	Dose in LiF (MCNP)
120 mGy	120,3 mGy(0,25%)	145,8 mGy(23,75%)	148,5 mGy(21,5%)
240 mGy	227,1 mGy(5,3%)	291,6 mGy(23,75%)	297 mGy(21,5%)
360 mGy	375,8 mGy(4,3%)	437,4 mGy(23,75%)	445,5 mGy(21,5%)
480 mGy	502,8 mGy(4,7%)	583,2 mGy(23,75%)	594 mGy(21,5%)

4.- DISCUSSION

In this work it was used a calibrated diagnostic X ray field at a certified laboratory. Besides, it was used calibrated TLDs for this energy range, making possible to assure the real dose of the irradiation field.

Therefore the simulation tool corroborates with the study of TLDs in diagnostic beam, as the TLDs also helps with the study of simulational parameters. The simulation took a high level of intricate data to guaranty the real process of X ray generation, as the process of X ray generation is performed by electrons interaction. This process took a high elapsed time in order to get low levels of uncertainty. The graph 1 shows the dose value obtained for each method.



Graph 1.-The comparison between field dose, TLD dose, Simulated LiF dose and simulated air dose, according to the field energies.

5.- CONCLUSIONS

The choice of using a calibrated field was important to compare the dose value obtained by the TLDs and by the MCNP. The TLD proved to be a proper tool for dose calculation in X ray diagnostic field, but the obtained dose cannot be monitored in real time, the given dose can only been counted after the reading process.

The validation of the simulation process (MCNP-5) allows future low costs changes in the apparatus configuration; this tool can also calculate different X ray parameters, interactions and enable future studies of diagnostic purpose.

In future studies it will be also used the Tally *F8, that calculates the energy deposition, not the kerma value. The use of Tally F6 in this work is valid and demonstrates accuracy, but the obtained dose value is overestimated.

Acknowledgments

The authors thank CAPES and CNEN for financial support.

REFERENCES

ALMEIDA JR., J. N.; SILVA, M.C.; TERINI, R.A.; HERDADE, S.B.; PEREIRA, M.A.G.. Estudo da calibração indireta de medidores clínicos do produto kerma-área. Revista Brasileira de Física Médica, 2011, V.4, Nº3 p.75-78. 2011.

ATTIX, FH. Introduction on radiological physics and radiation dosimetry. 2nd ed. New York, NY: John Wiley & Sons, 1986.

BRIESMEISTER, J.F.. "MCNP: A General Monte Carlo N-particle Transporte Code. Version 4C". LA-13709-M. Los Alamos Scientific Laboratory. Los Alamos. New México. 2000.

CAVALIERI, T.A.. "Emprego do MCNP no estudo dos TLDs 600 e 700 visando a implementação da caracterização do feixe de irradiação na instalação de BNCT do

IEA-R1" 2013. [Dissertação tese de Mestrado em Tecnologia Nuclear]– Instituto de Pesquisas Energéticas e Nucleares, USP, São Paulo.

FERNANDES, M.A.R.; GIAROLA, R. S.; FERNANDES, M.H.S., Silvestri, A.. "Inter-comparative analysis of the measures instruments of radiation time and dose in dental radiology beams". 18th International Conference on Medical Physics, 2011, Porto Alegre- RS. Brazilian Journal of Medical Physics. São Paulo-SP: Zeppelin Produção Editorial e Gráfica, 2011. V.5. p.134-134.

FERNANDES, M.A.R.; REIS, C.O.; GARCIA, P.L.; LIMA, M.A.F.; DALAQUA, F.L.D.. "Study of the variation of radiation dose in function of the radiological technicques used in x-ray diagnosis exams". Anais do International Nuclear Atlantic Conference (INAC 2011). Belo Horizonte-MG. 2011.

FERNANDES, M. A. R; YORIYAZ, H..; MAIO, M.F..; SANTOS, A.; FERNANDES, M.F.S.; FURUSE, C.F.; FURUSE, A.Y. " Determinação da Dose de Radiação Absorvida Utilizando o Método de Monte Carlo e Medidas dos Efeitos da Radiação Ionizante em Materiais Utilizados em Restaurações Dentárias" . Anais do IX Congresso da Sociedade Brasileira de Radioterapia e VII Jornada de Física Médica, Gramado - RS, setembro de 2007.

FRANCISCATTO, P.C.. "Caracterização das Qualidades de Radiação X seguindo as Recomendações da Norma IEC61267 no Laboratório de Calibração do IPEN". 2009. [Dissertação tese de Mestrado em Tecnologia Nuclear]– Instituto de Pesquisas Energéticas e Nucleares, USP, São Paulo.

GIAROLA, R.S.; FERNANDES, M.A.R; YORIYAZ, H. "Comparação do Valor de Dose entre Câmaras de Ionização com Volumes Sensíveis Diferentes". Anais do VIII Congresso de Física Aplicada à Medicina (CONFIAM), Botucatu – SP, setembro de 2012.

GIAROLA, R.S.; FERNANDES, M.A.R; YORIYAZ, H. " Comparison between the measured value of HVL from a X-ray machine and value of HVL from the Monte

Carlo N-Particle code". Anais do XXXVI Reunião de Trabalho sobre Física Nuclear no Brasil, Maresias- SP, Setembro de 2013.

GIAROLA, R.S.; FERNANDES, M.A.R; COELHO, T.S.; YORIYAZ, H. "Quantificação do Efeito Anódico em simulação por Método de Monte Carlo (MCNP-5) de um aparelho de raios-x em radiodiagnóstico". Anais do XVIII Congresso Brasileiro de Física Médica, São Pedro – SP, Agosto de 2013.

GIAROLA, R.S.; FERNANDES, M.A.R; COELHO, T.S.; STECHER, L.C.; CASTRO, V.A.; CAVALIERI, T.A.; ALCANTRA,R.R.; TARDELLI, T.C.; YORIYAZ, H. "Análise Comparativa do Número de Contagens Gerado por Anodos de Tungstênio e Molibdênio na Energia de 150kV Usando Código MCNP-5". Anais do VIII Congresso Internacional da Sociedade Brasileira de Biociências Nucleares, Recife – PE, Novembro de 2012.

GIAROLA, R. S.. "Estudo de parâmetros radiométricos e legislação sobre radioproteção em equipamentos de radiodiagnóstico". 2011. [Trabalho de Conclusão de Curso de Graduação] Curso (Bacharel) Física Médica) – Instituto de Biociências da UNESP de Botucatu.

JOHNS, H.E. & CUNNIGHAN, J.R.. "The Physics of Radiology". 4.ed. Springfield, Illinois, Charles C. Thomas Publisher. 1983.

KHAN, F.M. "The physics of radiation therapy". 2. Ed. Baltimore, MD. Willians, 1994.

OKUNO, E., YOSHIMURA, E.M.. "Física das Radiações". São Paulo: Oficina de Textos, 2010.

PODGORSAK, E.B. Technical Editor. " Radiation Oncology Physics: A Handbook for Teachers and Students' . Agência Internacional de Energia Atômica (IAEA). Vienna. 2005.

RAJAN, K. N. G. "Advanced medical radiation dosimetry". New Delhi: Prentice- Hall of India, 1992.

RIBEIRO, V.A.B.; GIAROLA, R.S.; FERNANDES, M.A.R.. Avaliação computacional do comportamento do feixe de radiação em equipamento de radioterapia intra-operatória- simulações com o Código MCNP-5C. VII Congresso de Física Aplicada à Medicina, 2011, Botucatu- SP: Departamento de Física e Biofísica- UNESP, 2011, 2011, v.1 p.23-28.

SO, A.J.H.; COSTA, P. R.; RIBEIRO, V.A.B.; FERNANDES, M.A.R.. Análise comparativa entre os espectros de raios-x de 140 kVp calculados pelo modelo de TBC e pelo método de Monte Carlo. VII Congresso de Física Aplicada à Medicina, 2011, Botucatu- SP: Departamento de Física e Biofísica- UNESP, 2011, 2011, v.1 p.23-28.

SCAFF, L.A.M. "Física da Radioterapia. A base analogical de uma era digital". Editora Projeto Saber. São Paulo – SP . 2010.

VISUAL EDITOR CONSULTANTS [online] MCNP VISED <http://www.mcnpvised.com/index.html> [Reviewed on December 2013].

VIVOLO, V. "Desenvolvimento de um Sistema de Referência para Determinação do Equivalente de Dose Pessoal e da Constância de Feixes de Radiação X." 2006. [Dissertação tese de Doutorado em Tecnologia Nuclear]– Instituto de Pesquisas Energéticas e Nucleares, USP, São Paulo.

XAVIER, A.M.; MORO, J. T.; HEILBRON, P. F.. "Princípios Básicos de Segurança e Proteção Radiológica". 3ª Ed. Universidade Federal do Rio Grande do Sul. Setembro 2006.

YORIYAZ, H. Método de Monte Carlo: princípios e aplicações em Física Médica. Revista Brasileira de Física Médica, 2009, V.3, Nº1 p.141-9. 2011.