PROCEEDINGS OF SCIENCE

Estimate of Photoneutrons Generated by 6-18 MV X-Ray Beams for Radiotherapy Techniques

R. Castillo[1]
Universidad Central de Venezuela
Caracas-Venezuela
E-mail: castillo.rita@gmail.com

J. Dávila
Radioterapia Oncológica GURVE, Centro Médico La Trinidad
Baruta, Caracas, Venezuela
E-mail: jdavila@radioterapia.com.ve

L. Sajo Bohus
Universidad Simón Bolívar, Valle de Sartenejas
Baruta, Caracas-Venezuela
E-mail: sajobohus@gmail.com

Photoneutron production was investigated on a Varian Clinac accelerator operating in the 6-18 MV range. Neutrons were measured at the surface and isocenter of a PMMA phantom. The prostate treatment plans were developed, and delivered to the PMMA phantom. Etched-track detectors with boronated converters and paraffin wax moderator were employed in this study. Tracks were counted using an optical microscope and the number of tracks/cm^2 were reported for each treatment approach. The relationship between tracks density per UM, distance from the treatment field, and depth in the phantom were studied.

X Latin American Symposium on Nuclear Physics and Applications (X LASNPA)
December 1-6 2013
Montevideo, Uruguay

[1] Speaker

PoS(X LASNPA) 067

1. Introduction

The use of Lineal Accelerators (LINACs) in Venezuela in clinical radiotherapy is producing an increasing demand for precise clinic-dosimetry. Bremsstrahlung X rays ≥ 10 MV may produce neutrons due to photonuclear giant nuclear dipole resonance (GR) reactions within different materials (e.g. W, Al) that constitute the accelerator head and infrastructural metals [1]. Neutrons have a wide range of energies, but most neutrons in radiotherapy energies are fast. Fast neutrons cause more damage/unit flux than scattered X rays, because their Radiation Weighting factor (Wg) is 20 compared to the X rays factor of 1 [2]. The relative biological effectiveness of a neutron varies according to its energy and there is a risk of tissue damage and secondary cancer in patients subjected to neutron exposure.

The beam-on time for intensity modulated radiation therapy (IMRT) and volumetric modulated arc therapy technique (VMAT) is increased significantly compared with conventional radiotherapy treatments (3D-CRT). Further, the presence of beam modulation devices may potentially affect neutron production [3]. Neutrons associated with high-energy IMRT have been found to make a substantial contribution to the total out-of- field dose equivalent; the neutron dose equivalent at 18-MV IMRT employ a variety of neutron dosimeters, including bubble detectors, foil activation and track etch detector [4,5]. In this work, poly allyl di-glycol carbonate polymer, generally known as CR-39™ track detectors with boronated converters and paraffin wax moderators were employed to estimate the neutron field gradient in the patient plane for a variety of prostate treatments focusing on IMRT. The isotope ^{10}B was employed due to its high thermal neutron capture cross section (3832 b), nuclear characteristics, being a non-radioactive element and readily available [6] and the paraffin wax was employed because of the high hydrogen content; paraffin is frequently used for neutron shielding [7].

2. Methods and materials

2.1 Photoneutron production in radiotherapy techniques

Three prostate treatment plans were developed and delivered to a Poly (methyl methacrylate) (PMMA) phantom: 18-MV 3D-CRT, 18-MV IMRT and 6-MV VMAT, employed a Varian Trilogy IX accelerator (Varian Medical Systems, Palo Alto, CA). 3D-CRT, IMRT and VMAT plans were delivered to the PMMA phantom according to: 6 fields, 5 fields and 2 fields respectively with 200 cGy prescribed to the isocenter. The treatment planning software, plan configurations, and accelerator model were used at GURVE Radiation Therapy Oncology Group. To determine the neutrons field and nuclear track, detectors (NDT) were distributed inside and outside the PMMA phantom: isocenter, anterior and left directions, and one nuclear track detector was placed at out- of-field photon (Fig. 1.).

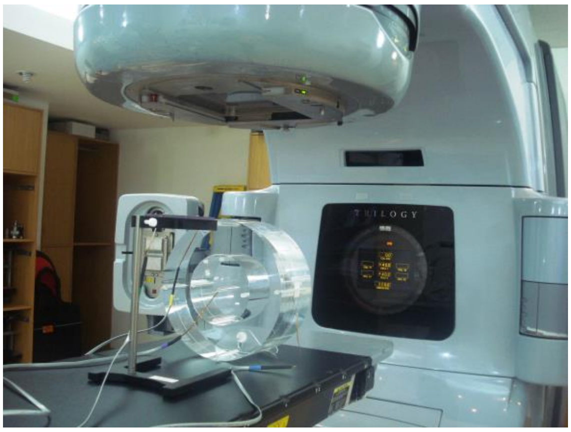


Figure 1: NDT positioned inside and outside the PMMA phantom for measuring fast neutron.

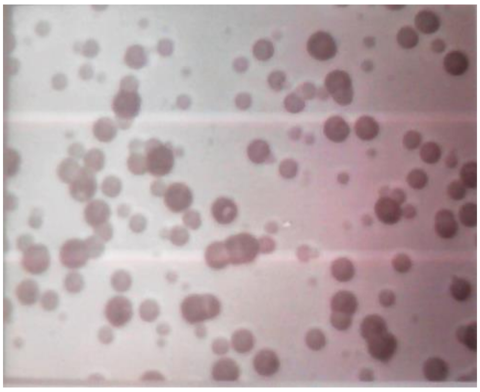
2.2 Neutron absorber material: paraffin wax and boric acid

Neutron shielding was studied in the patient plane for different prostate treatments: 18-MV 3D-CRT and 18-MV IMRT employed a neutron absorbed material: paraffin wax with 30 wt% commercially available boric acid (PWBA). The PWBA sample was positioned over the surface the PMMA phantom and NDT were distributed keeping the same measurement points. Prostate treatment plans were delivered, under the same irradiation parameters (Fig. 2).

Figure 2: Paraffin moderator with boric acid positioned over the surface the PMMA phantom.

2.3 Etching and track counting

After exposure, chemical etching was performed using 6N NaOH solution at 70 °C over 5 h. Tracks were visualized using an optical microscope, this, coupled to a CCD, can generate the digital image, which tracks density is determined. The program analysis of digitals images is the “MORFOL” developed in Budapest, Hungary [8] (Fig. 3).



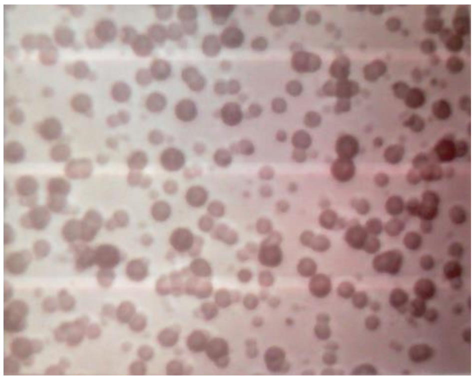


Figure 3: Images of etched tracks for: 3D-CRT (Left), IMRT (Right).

3. Results and discussion

The tracks densities per 200 cGy for each treatment technique in the patient plane are shown in the Table 1. As expected, in all cases the number of tracks inside the beam is greater than the numbers of tracks outside the beam.

Table 1: Tracks per 200 cGy for each treatment technique.

Measurement Points	Tracks/cm^2 3D-CRT 18 MV	Tracks/cm^2 IMRT 18 MV	Tracks/cm^2 VMAT 6 MV
Out of field	5,11 ± 0,03	11,41 ± 0,06	0,0
Anterior	6,90 ± 0,07	15,30 ± 0,14	0,0
Left	9,40 ± 0,10	16,76 ± 0,17	0,0
Isocenter	15,10 ± 0,14	35,84 ± 0,30	0,0

Neutron fluence depends greatly on treatment energy. As expected, no neutron contribution was detected at 6-MV VMAT treatment, however, energy photons of 5,75 MeV produce neutrons through photonuclear reactions in the isotope of ^{186}W [1].

For IMRT the number of tracks/cm^2 was 2 times higher at 3D-CRT, due to the monitor units (MU) used in IMRT is about 2 to 4 times higher than the total MU for conventional treatments. In addition multileaf collimator (MLC) leaves are opened and closed during IMRT, affecting the neutron production and scattering.

The tracks density per MU at the five locations to 3D-CRT and IMRT are presented in Table 2. For IMRT the number of tracks/cm^2 MU is of 5% comparable to 3D-CRT.

Table 2: Tracks per monitor unit (MU) for 18 MV 3D-CRT and IMRT.

Measurement Points	**Tracks/cm^2 MU x 10^{-2} 3D-CRT 18 MV**	**Tracks/cm^2 MU x 10^{-2} IMRT 18 MV**
Out of field	1,91 ± 0,01	1,71 ± 0,01
Anterior	2,58 ± 0,03	2,30 ± 0,02
Left	3,51 ± 0,03	2,51 ± 0,03
Isocenter	5,60 ± 0,05	5,36 ± 0,05

The relative importance of neutron absorber material: paraffin wax and boric acid to the five locations to 3D-CRT and IMRT are shown in the Table 3 and illustrated in Figure 4. Error bars are not shown on the figure because in most cases they are smaller than the markers in the legend.

Table 3: Tracks with PWBA for 18 MV 3D-CRT and IMRT.

Measurement Points	**Tracks/cm^2 3D-CRT 18 MV**	**Tracks/cm^2 MU IMRT 18 MV**
Anterior	2,02 ± 0,02	8,46 ± 0,03
Left	3,92 ± 0,04	10,35 ± 0,04
Isocenter	12,34 ± 0,05	20,96 ± 0,08

Paraffin wax and boric acid has a positive impact; in our case the PWBA-shielding capability is about 50 %.

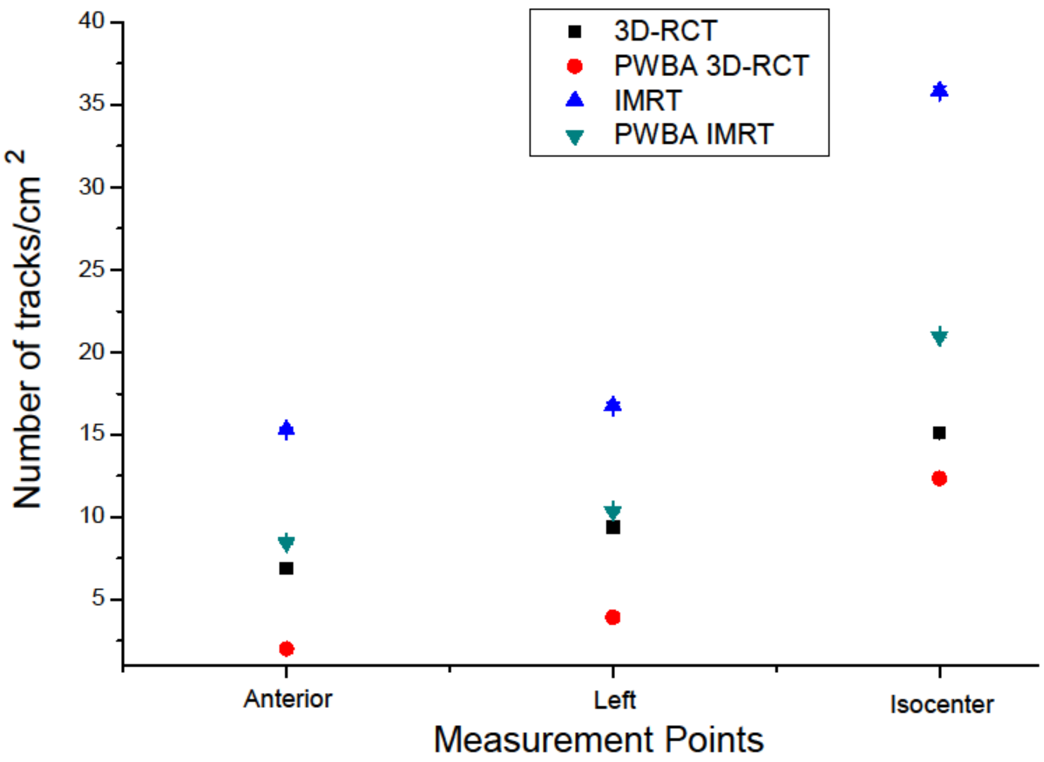


Figure 4: Numbers of tracks with o without PWBA at each measurement points.

4.Conclusion

The photoneutron production was investigated for a variety of radiation treatment techniques for prostate cancer, focusing on a comparison of IMRT, VMAT and a conventional therapy. Neutrons field and distributions in a PMMA phantom were measured using solid state track detectors. Neutrons contributed a significant portion at isocenter for IMRT and

conventional therapy. We observed that paraffin wax doped with boric acid introduce a 50% reduction of neutron intensity in the treated zone. Doses and neutron field influence can be reduced in radiation oncology employing a protecting device as given here. It is necessary to carefully determine the neutron dose, even though few neutrons are generated under normal conditions.

References

[1] National Council on Radiation Protection and Measurement. *Neutron Contamination from Medical Electron Accelerators*, NCRP Report N° 79, Nov 1984.

[2] D. Al-Othmany, S Abdul-Majid, M. Kadi. *Fast Neutron Dose Mapping in a Linac Radiotherapy Facility*, Tenth Radiation Physics & Protection Conference, Nov 2010, Egypt.

[3] N. Ipe, S. Roesler, S Jiang, C. Ma, *Neutron Measurements for Intensity Modulated*

[4] *Radiation Therapy*, Presented at Chicago 2000 World Congress on Medical Physics and Biomedical Engineering.

[5] S. Kry F, M. Salehpour, D. Followil , M. Stovall, D. Kuban, R. White, II Rosen, *Out-of-Field Photon and Neutron Dose Equivalents from Step-And-Shoot Intensity-Modulated Radiation Therapy*, Int. J. Radiat Oncol. Biol. Phys. 2005 Jul 15;62 (4):1204-16.

[6] T. Fujibuchi, S. Obara and H. Sato, *Estimate of Photonuclear Reaction in a Medical Linear Accelerator Using a Water-Equivalent Phantom*, Progress in Nuclear Science and Technology, 2011, Vol. 2, Pp.803-807.

[7] L. Sajo-Bohus, E. Greaves and J. Pálfalvi, *Boron Studies in Interdisciplinary Fields Employing Nuclear Track Detectors (NTDs),* Radioisotopes - Applications in Bio-Medical Science, Nirmal Singh (Ed.) 2011, ISBN: 978-953-307-748-2, InTech.

[8] B. Aygün and G. Budak, *A New Neutron Absorber material: Oil Loaded Paraffin wax. Nuclear Science and Technology*, 2012: 33-39 ISBN: 978-81-7895-546-9 Editor: Turgay Korkut.

[9] J. Palfalvi, *I.* Eordogh, K. Szasz, L. Sajo-Bohus. *New Generation Image Analyzer for Evaluating SSNTDs*, Radiat. Meas. 28, 849-852 (1997).