Neutron absorbed dose in a pacemaker CMOS

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The neutron spectrum and the absorbed dose in a Complementary Metal Oxide Semiconductor, has been estimated using Monte Carlo methods. Eventually a person with a pacemaker becomes an oncology patient that must be treated in a linear accelerator. Pacemaker has integrated circuits as CMOS that are sensitive to intense and pulsed radiation fields. Above 7 MV therapeutic beam is contaminated with photoneutrons that could damage the CMOS. Here, the neutron spectrum and the absorbed dose in a CMOS cell was calculated, also the spectra were calculated in two point-like detectors in the room. Neutron spectrum in the CMOS cell shows a small peak between 0.1 to 1 MeV and a larger peak in the thermal region, joined by epithermal neutrons, same features were observed in the point-like detectors. The absorbed dose in the CMOS was 1.522×10^{-17} Gy per neutron emitted by the source.

Keywords: Pacemaker; CMOS; radiotherapy; neutrons; Monte Carlo.

El espectro y la dosis absorbida, debida a neutrones, por un Semiconductor de Óxido Metálico Complementario ha sido estimada utilizando métodos Monte Carlo. Eventualmente, una persona con marcapasos se convierte en un paciente oncológico que debe ser tratado en un acelerador lineal. El marcapasos contiene circuitos integrados como los CMOS que son sensibles a los campos de radiación intensos y pulsados. El haz terapéutico de un LINAC operando a voltajes mayores a 7 MV está contaminado con fotoneutrones que pueden dañar el CMOS. En este trabajo se estimó el espectro de neutrones y la dosis absorbida por un CMOS; además, se calcularon los espectros de neutrones en dos detectores puntuales ubicados dentro de la sala. El espectro de neutrones en el CMOS tiene un pico entre 0.1 y 1 MeV y otro en la región de los térmicos, conectados mediante neutrones epitérmicos. Estas mismas características se observan en los otros detectores. La dosis absorbida por el CMOS es 1.522×10^{-17} Gy por cada neutrón emitido por el término fuente.

Descriptores: Marcapasos, CMOS, radioterapia, neutrones, Monte Carlo

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1. Introduction

Pacemakers are one of the most important innovations of the past century, since their development in the 50's and are becoming common in the general population. Basically, a pacemaker has the capacity to sense heart function and augment it as needed, it works by delivering a very short (< 1.0 ms), low voltage (< 3.0 V) electrical current via an insulated pacing lead to the heart muscle at a preprogrammed rate (with a random access memory above than 512 MB) [1-3].

Electromagnetic interference, EMI, and ionizing radiation can influence the pacemaker function, therefore, in patients with pacemaker EMI and radiation can affect the pacemaker operation when patient requires radiotherapy treatment [4-6]. The frequency of patients with pacemakers that need radiation therapy is increasing and is far from rare [3,7].

Few papers about oncology patients with pacemakers have been published and the available clinical practice guidelines for such patients are occasionally inconsistent, inexplicit and differ between radiation oncology centers [3-9]. However, monitoring the device operation during and after radiation treatment sessions and a close survey of patient performance are required in patient management [10].

Since early 70' up to actual cardiac pacemakers use complimentary-metal-oxide silicon, CMOS, devices [6] because have low power consumption, however have reduced radiation resistance, 100 to 1000 Grays, due to a phenomenon known as hole trapping [6,9].

The American Association of Physicists in Medicine report task group 34 published recommendations for irradiation of pacemaker patients [6]. It was reported failures in CMOS in different studies where high instantaneous dose rates were applied. In general is recognized that a transient interference from pulsed radiation beams, as those from linear accelerators could affect the pacemaker, however there is a need of further studies when the pacemaker is kept inside the machine collimated edge of the beam. Also the report put in discussion an inhibition of the pacemaker during turn on/off of certain linear accelerators, but without dangerous consequences for the patient [5,6]. Inhibition occurs when the pacemaker fails to produce a pulse or when are changed the characteristics of that pulse (pulse form, repetition frequency, and amplitude).

The AAPM consider that EMI is not dangerous due to the improvements made in the new linacs and pacemakers [3]; however, the radiation dose to patients has not been reduced and consequential damages are still a concern. The studies mentioned in the AAPM report include older pacemaker types, based on old bipolar semiconductor devices and the first generation of CMOS, but modern pacemakers use new CMOS circuits that are different in their sensitivity to radiation and the type of malfunction observed [5].

Despite the scientific and technological advances and the research to treat cancer, radiotherapy with LINACs are the technique most frequently used worldwide [11]. Besides the therapeutic radiation the patient is exposed to a neutron field that is produced in LINACs working above 8 MeV in Bremsstrahlung mode. Photoneutrons are originated in (γ, n) nuclear reactions occurring in materials in the LINAC's head, patient body and bunker's walls that have the Giant Dipole Resonance in their cross sections [12, 13]. It has been reported that neutron dose received by the radiotherapy patient treated with a LINAC is not negligible [14,15].

Since realized studies to identify the malfunction of commercial pacemaker only took into account the absorbed dose produced by photons in radiotherapy rooms and was not considered the effect produced by neutron LINACs the aim of this study is to calculate the neutron spectrum in one CMOS of a pacemaker during a radiotherapy treatment with a 18 MV LINAC.

2. Materials and methods

Neutron adsorbed dose estimation was made using Monte Carlo method using the MCNP 5 code [16]. A generic radiotherapy room was used [17], here the wall thickness were smaller than those in actual bunkers, but the wall that separates the linac's hall to the maze. It was assumed the case of a prostate treatment; a 10×10 cm^2 irradiation area was modeled. The linac head was modeled as a 10 cm-radius tungsten sphere with a conic aperture. In the center of head model was located a point-like isotropic source term modeled with the Tosi *et al*., equation [18]. Patient body was modeled as a regular parallepiped phantom made of Frigerio's gel equivalent tissue [19]. In Figure 1 is shown the patient and linac's head models. The CMOS circuit was simulated as a 2 Ø $\times$ 1 cm^2 polystyrene cylinder.

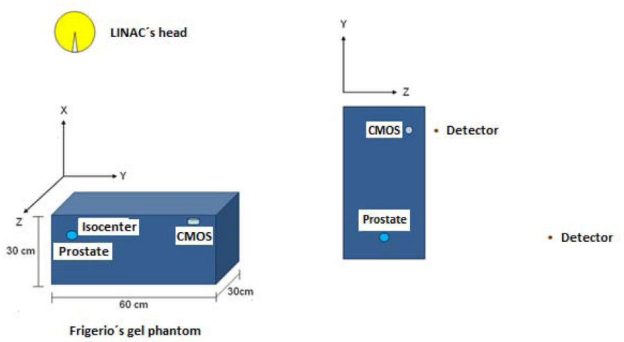

FIGURE 1. Linac's head, CMOS and phantom models.

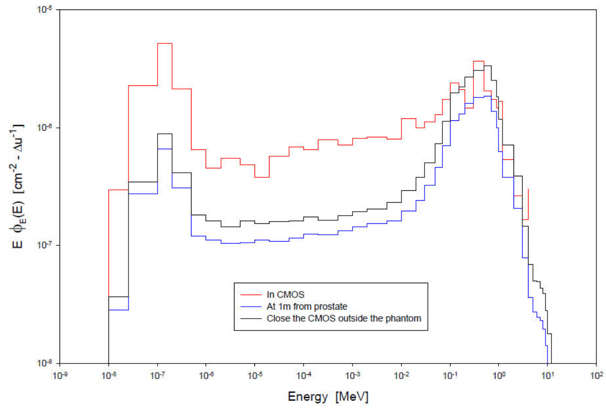

FIGURE 2. Neutron spectra in the CMOS cell the external detectors.

In the Monte Carlo calculations beside the neutron spectrum and dose in the pacemaker, two point-like detectors were included, on near the pacemaker and another a 100 cm from the prostate.

3. Results and discussion

In Figure 2 are shown the neutron spectra in the CMOS and in the external detectors.

Neutron spectrum in the CMOS has a peak between 0.1 to 1 MeV, which is the maximum peak in the Tosi et al. equation shifted to lower energies. It also contains a large contribution of thermal neutrons. These features are produced by the neutron moderation in the phantom materials.

In the neutron spectra calculated outside the phantom can be noticed that both have approximately the same shape, however the total neutron fluence is smaller in the detector a 1 m from prostate in comparison to detector locate near the pacemaker. This difference is attributed to the distance with respect the isocentre that is the only zone exposed to neutron beam.

Neutrons are scattered out the phantom, reaching both detectors, those neutrons loose energy becoming epithermal and thermal, this last group is increased by those neutrons that are scattered into the room by the linac walls, phenomenon known as room-return [20,21].

In table I is shown the total neutron fluence in the CMOS cell and the point-like detectors located outside the phantom.

TABLE I. Total neutron fluence in CMOS and detectors

Site	Total fluence per neutron emitted by the LINAC's head [n/cm^2]
In CMOS	$2.7326 \times 10^{-5} \pm 4.35\%$
At 1m from prostate	$7.6912 \times 10^{-6} \pm 0.04\%$
Close the CMOS outside of phantom	$12296 \times 10^{-5} \pm 0.30\%$

The largest fluence is in the CMOS, the neutron fluence in the detector near the CMOS receive more neutrons than the detector located a 1 m from the prostate this is due to the distance, however in the three locations the spectra have the same shape. Considering that the photon scattering in an 18 MV LINAC is not important then the pacemaker could fail probable due to the (n, p) reactions occurring in the rich-H material that covers the CMOS circuits. Also the presence of thermal neutrons could induce activation in the CMOS' materials.

This can be explained due to the distance from CMOS cell to isocenter is smaller than distance from detectors to isocenter, or due to the size of CMOS cell because this cell has an area and the detectors are only points. Other explanation of the major flux in CMOS can be the influence of CMOS, phantom or air materials.

With the neutron spectrum reaching the CMOS the absorbed dose was calculated being $1.5222\times10^{-17}\pm$ 8.10% Gy per neutron emitted by the source term. Roughly the neutron intensity in a LINAC is 1E(12) s^{-1}, therefore the absorbed dose rate can be as large as 15.22 μGy/s.

4. Conclusions

The neutron spectrum in the model of one pacemaker CMOS has been calculated using Monte Carlo methods. The spectrum was also estimated in two locations around the patient phantom.

The neutron spectrum that reach the CMOS shows a peak between 0.1 to 1 MeV, this neutrons can produce (n, p) reactions in the H-rich material that covers the CMOS sensitive materials damaging the circuitry.

Neutron absorbed dose by the CMOS is 1.5222×10^{-17} Gy per neutron emitted by the source term.

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