

Absorbed dose by a CMOS in radiotherapy

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Abstract

Absorbed dose by a CMOS circuit as part of a pacemaker, has been estimated using Monte Carlo calculations. For a cancer patient who is a pacemaker carrier, scattered radiation could damage pacemaker CMOS circuits affecting patient's health. Absorbed dose in CMOS circuit due to scattered photons is too small and therefore is not the cause of failures in pacemakers, but neutron calculations show an absorbed dose that could cause damage in CMOS due to neutron-hydrogen interactions.

Keywords: Absorbed dose, photons, neutrons, MCNP, linac, CMOS.

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1. Introduction

Approximately 50% of patients with cancer are treated with teletherapy using a linear accelerator "LINAC". To produce therapeutic beams of electrons or photons, these machines use intense and pulsed electromagnetic fields that together with ionizing radiation may affect the pacemaker function when a person carrying one of these devices has the need to undergo treatment to control some cancer type and since the pacemakers function as a "life support" their dysfunction carries a high risk to patients (Frizzell, 2009; Uiterwaal et al., 2006).

There are few published studies on cancer patients with pacemakers and available clinical practice guidelines are sometimes inconsistent, inexplicit and differ between radiation oncology centers (Ferrara et al., 2010; Solan et al., 2004). However, it is necessary to control device operation during and after radiation therapy sessions and monitor its correct performance within the patient (Boston Scientific Technical Services, 2008).

Actually, pacemakers use complementary metal oxide semiconductor, CMOS technology, because these devices have low voltage consumption, but on the other hand, have low resistance to radiation due to the phenomenon known as hole trapping (Marbach et al., 1994). Failures have been reported in pacemakers exposed to high dose rates applied instantly, explanations have been attributed to the transient interference induced by pulsed radiation; in some LINACs failure was observed during the beam on-off (Marbach et al., 1994; Hurkmans et al., 2005). The American Association of Physicists in Medicine, AAPM,

published in their report 34, recommendations for irradiation of patients with pacemakers; for AAPM, electromagnetic interference does not represent a hazard, due to technological improvements in new accelerators and pacemakers.

In general, for a safe pacemaker functioning with photon radiation, is recommended that the pacemaker should not be placed in the direct therapy beam, the dose rates is lower than 3 Gy/h and the total cumulative dose never exceed 5 Gy. Otherwise, neutron interactions can produce ionizing protons and secondary charged particles that could cause damage more than photons. (Koivunoro et al., 2011; Mouton et al., 2002).

Although radiation for people with pacemakers, generally are made in different areas of the location of these devices, pacemakers are exposed to doses generated by scattered or produced photons and neutrons in the radiotherapy room during treatment.

The aim of this work is to determine the dose due to photons and neutrons absorbed by the CMOS circuit in a pacemaker.

2. Materials and methods

Determination of absorbed dose due to scattered or produced photons and neutrons that reach to CMOS circuits was made with Monte Carlo methods using the MCNP 5 code (X-5 Monte Carlo Team, 2003). A generic radiotherapy room was used (Vega-Carillo and Baltazar-Raigosa, 2011), with a LINAC head and a phantom, to which was applied a

treatment for prostate cancer where was placed the isocenter, IC. LINAC's head was modeled as a 10 cm-radius tungsten sphere with a conic aperture to obtain a treatment field in IC of 10 x 10 cm²; phantom was modeled as a regular parallelepiped made of Frigerio's gel (ICRU, 1989) equivalent tissue. The CMOS circuit was simulated as a 2 Ø × 1 cm² polystyrene cylinder that was located 1 cm below top face of phantom, in a typical location of a pacemaker. In the model, only was simulated the CMOS like polystyrene and not the other pacemaker internal structures, since exact elemental composition and structures inside the pacemaker are company confidential information and thus not available from the manufacturer. In Fig. 1, is shown the patient and linac's head models.

In the center of head model was located for the case of photons, the source term of photons for a Varian 6 MV LINAC (Sheikh-Bagueri and Rogers, 2002) and for neutrons case, was located a point-like isotropic source term modeled with the Tosi et al. equation for the case of an 18 MV LINAC (Tosi et al., 1991). These source terms were chosen because in literature can be found that photons are considered negligible for accelerators with $E > 10$ MV and neutrons are considered important for linacs with $E > 6$ MV (Numark and Kase, 1985; Vega-Carillo and Baltazar-Raigosa, 2011), and it was desirable to have the characteristics under which both photons and neutrons, could affect the pacemaker.

In addition to calculating the spectra and absorbed doses of photons and neutrons in the CMOS, Monte Carlo calculations include two point-like detectors in each case to compare the photon and neutron fluence, one detector near the pacemaker but outside the phantom and the other at 100 cm from prostate.

3. Results and discussion

In Fig. 2, are shown the photon spectra obtained with Monte Carlo calculations in the CMOS and puntual detectors. Photon fluence present in CMOS is higher in comparison with the detectors near the phantom. In spectra calculated outside the phantom can be observed that both have approximately same shape, however, total fluence of photons is lower in detector located at 1 m from prostate than that located near the CMOS circuit. Also can be noticed that occurs in all three cases a considerably photons fall among 0.5 MeV, and from that value, the curve of fluence decreases with a slope more softened. Probably reasons for these results are the distance between IC and detector, because a smaller distance from isocenter there is a bigger fluence of photons, the other reason is the difference of density and elemental composition between CMOS, phantom and air. In Table 1 is shown the total photon fluence for each photon emitted by linac head, obtained in the CMOS cell and the point-like detectors located outside the phantom. With the photon spectrum reaching the CMOS the absorbed dose was calculated being $4.7623 \text{ E}(-17) \pm 3.33\% \text{ Gy}$ per photon emitted by the source term.

In Fig. 3, are shown the neutron spectra obtained with Monte Carlo calculations in the CMOS and puntual 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.

As in photon case, neutron spectra calculated outside the phantom have approximately the same shape, and the total neutron fluence is smaller in the detector at 1 m from prostate in comparison to the detector located near the pacemaker. Difference is also attributed to the distance with respect at isocenter that is the only zone exposed to neutron beam; equally, 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 (Vega-Carrillo et al., 2007; Vega-Carrillo et al., 2007). In Table 2 is shown the total neutron fluence for each photon emitted by linac head, obtained in the CMOS cell and the point-like detectors located outside the phantom. With the neutron spectrum reaching the CMOS the absorbed dose was calculated being $1.5222\text{E}(-17) \pm 8.10\%$ Gy per neutron emitted by the source term; the associated uncertainty to the absorbed dose in the CMOS is considered acceptable when less than 10% because it is a cell. Roughly the neutron intensity in a LINAC is $1\text{E}(12) \text{ s}^{-1}$, therefore the absorbed dose rate can be as large as $15.22 \mu\text{Gy/s}$ or 0.05 Gy/h .

Absorbed photon dose and absorbed neutron dose estimation is difficult due to the fact that the pacemaker structures that were not included in Monte Carlo simulation. Pacemakers include materials that emit, absorb or scatter neutrons and photons in a different manner than polystyrene. Anyway, 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 (Trocmé et al., 2008). Koivunoro et al., found

problems also related with epithermal neutrons and the produced nuclides (Koivunoro et al., 2011).

4. Conclusions

These results suggest that for a typical irradiation with linear accelerator, where the beam is not located in the pacemaker direction, scattered photons are not a problem for the pacemaker because absorbed dose due to these photons is not to be considered, however, the neutron spectrum that reach the CMOS contains a large contribution of thermal neutrons, the interaction of the scattered neutrons with the high hydrogen content material that covers the CMOS can produce (n,p) reactions damaging the CMOS circuits and putting the patient at risk from unexpected changes in the information contained in these semiconductors.

Acknowledgements

This work is part of the projects LINAC and MONITOR, partially supported by COZCYT. All of us, but LPG, VMHD and HRVC, are scholarship holder from CONACYT.

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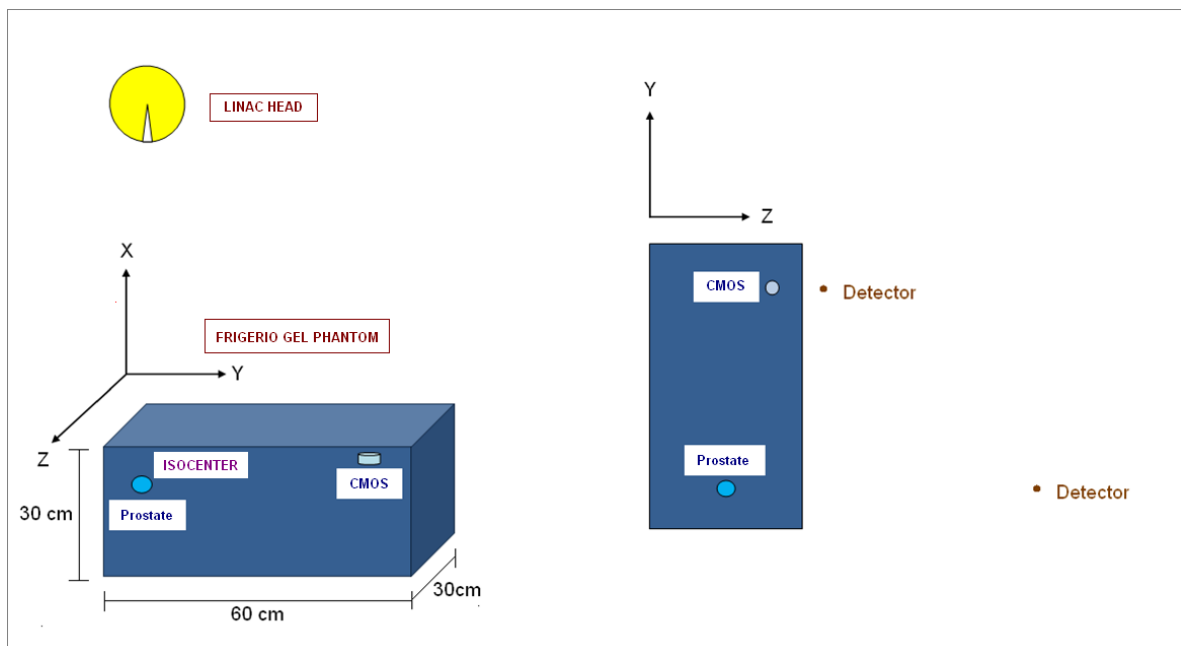


Fig. 1. Linac's head, CMOS and phantom models

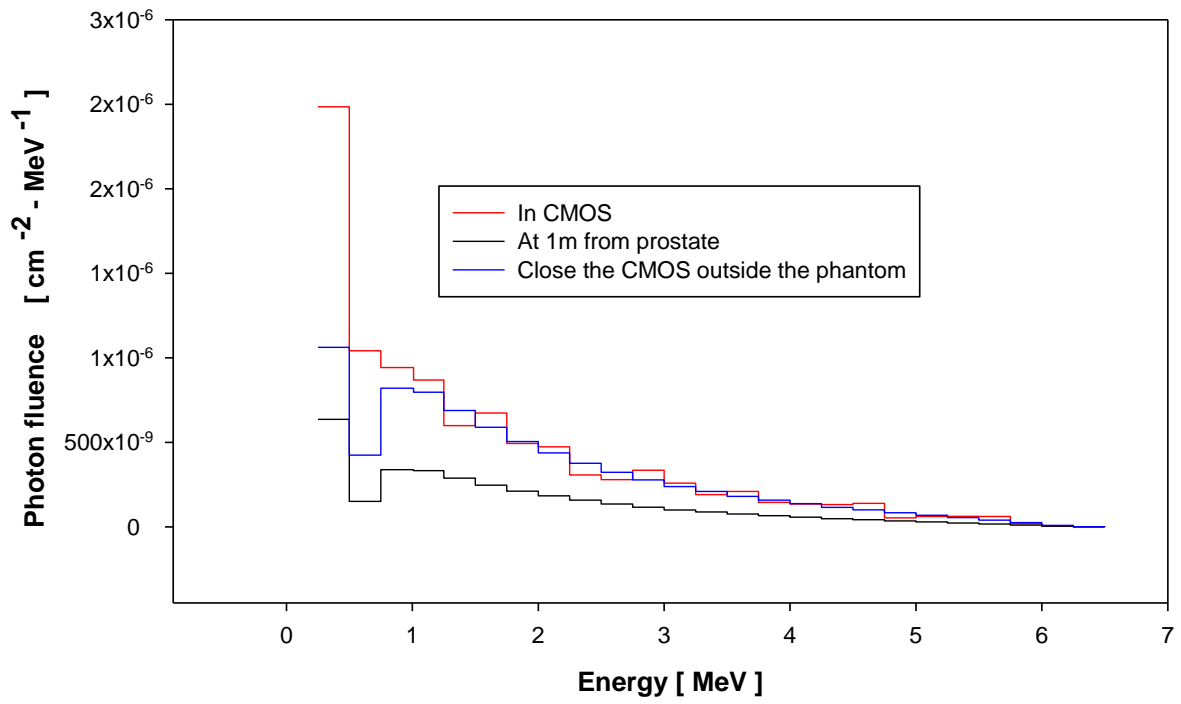


Fig. 2. Photon spectra in CMOS cell and puntual detectors.

Table 1 Total photon fluence in CMOS and detectors.

Site	Total fluence [photons/cm ²]
CMOS	9.9662 E(-6) ± 2.77%
At 1 m from prostate	3.3874 E(-6) ± 0.03%
Near the CMOS outside the phantom	7.7162 E(-6) ± 0.09%

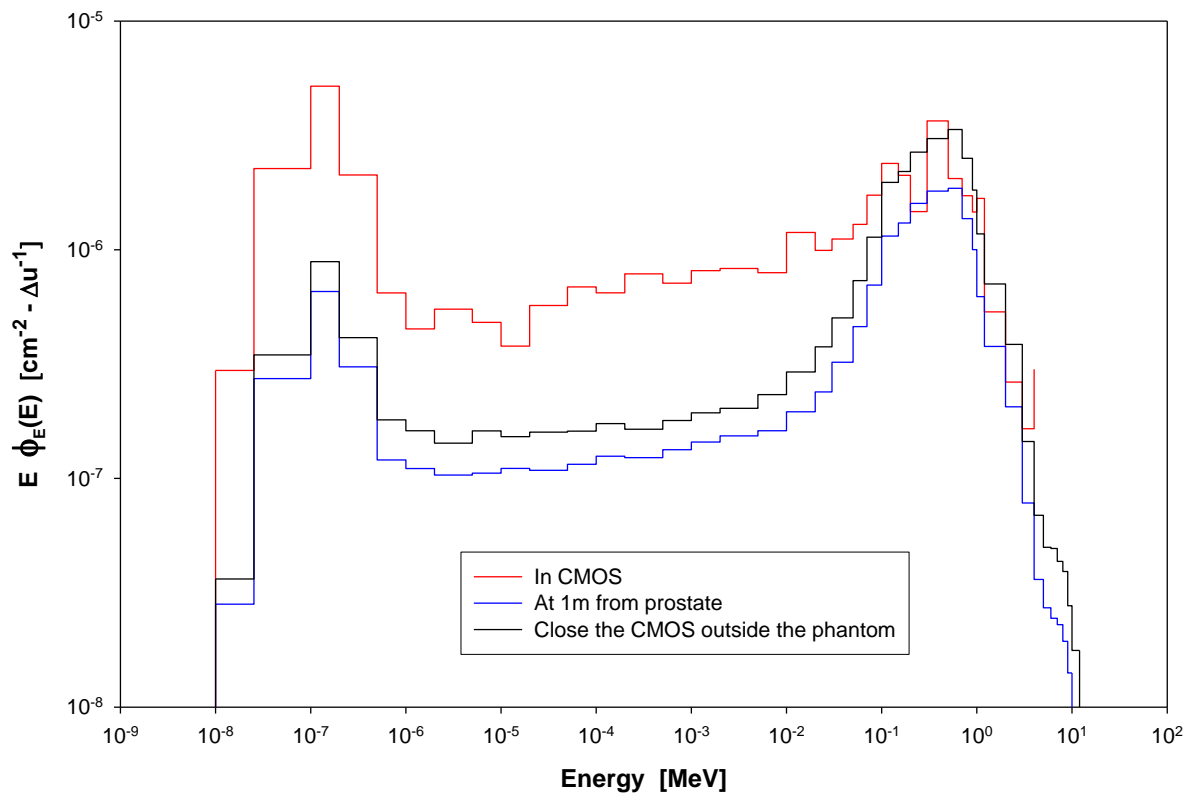


Fig. 3. Neutron spectra in CMOS cell and puntual detectors.

Table 2 Total neutron fluence in CMOS and detectors.

SITE	TOTAL FLUENCE [neutrons/cm ²]
In CMOS	2.7326 E(-5) ± 4.35%
At 1m from prostate	7.6912 E(-6) ± 0.04%
Close the CMOS outside of phantom	1.2296 E(-5) ± 0.30%