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Fast Neutron Dose Mapping in a Linac Radiotherapy Facility

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ABSTRACT

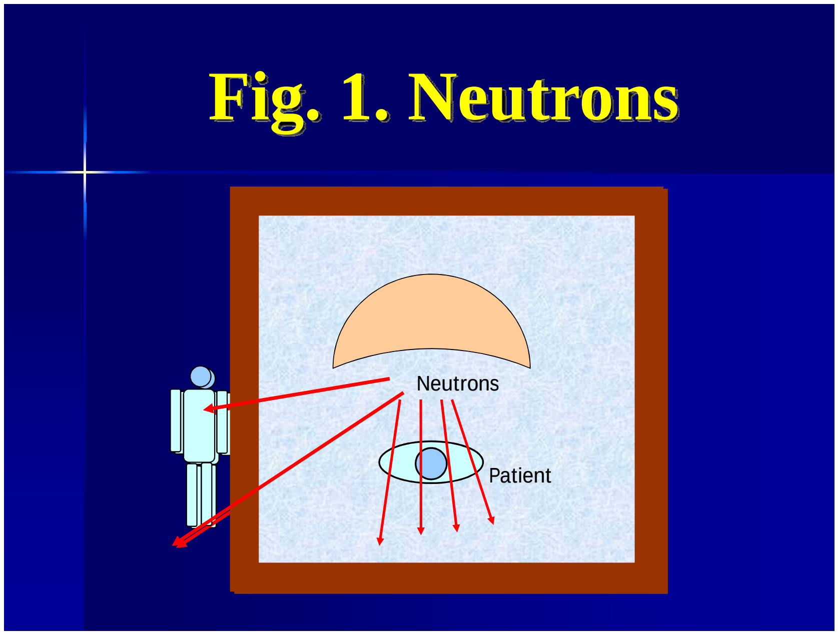
CR-39 plastic detectors were used for fast neutron dose mapping in the radiotherapy facility at King AbdulAziz University Hospital (KAUH). Detectors were calibrated using a ^{252}Cf neutron source and a neutron dosimeter. After exposure chemical etching was performed using 6N NaOH solution at 70 ^{0}C. Tracks were counted using an optical microscope and the number of tracks/cm^2 was converted to a neutron dose. 15 track detectors were distributed inside and outside the therapy room and were left for 32 days. The average neutron doses were 142.3 mSv on the accelerator head, 28.5 mSv on inside walls, 1.4 mSv beyond the beam shield, and 1 mSv in the control room.

INTRODUCTION

Conventional radiotherapy usually applies high-energy electrons or photons on tumors using linear accelerators (linacs). It can also be used for local disease control or symptomatic relief. Radiotherapy has also non-malignant applications, but these applications are limited by worries about induced cancers.

High-energy photons of energy greater than 8 MeV produce neutrons through photonuclear reactions such as, ^{180}W(γ,n)^{179}W, ^{182}W(γ,n)^{181}W, ^{184}W(γ,n)^{183}W, and ^{186}W(γ,n)^{185}W, that take place on a tungsten target. Other photonuclear reactions within materials other than the target material are also possible.

These include, (γ,p) reactions and (γ,α) reactions. It is also possible to have (n, fission) reactions, if the concrete shield contains residual uranium atoms [1]. Neutrons produced in the accelerator and in material in the treatment room can have wide range of energies, but most neutrons are fast [2]. Scattered neutrons as well as scattered photons can reach healthy organs in the body causing unwanted contaminant radiation and may cause cancer in these organs (Fig.1).



The problem becomes more severe if the scattered radiation reaches sensitive organs or fetuses in pregnant women. Fast neutrons cause more damage/unit flux than scattered γ-rays because their Radiation Weighting factor (Wg) is 20 compared to the γ-rays factor of one. Because of their low total cross-section, fast neutrons penetrate most materials like external shields and walls.

This penetration results in unwanted dose to working personnel and public. The dose depends on several parameters, such as x-ray beam size, type of surrounding material and therapy room geometry. From the radiation protection point of view it is important to assess unwanted doses delivered to the patient in order to prevent unwanted exposure [3]. In fact it has been reported that 10% of patients in the US suffer second malignancy. The main reasons for second malignancies are: continued lifestyle, genetic susceptibility, or they can be treatment-related [4]. Monitoring the treatment facility is also important in order to protect the medical staff and the public from unnecessary exposure to radiation.

Measurement of neutron dose is not a straight forward matter because of wide variations of their radiation-weighting factor. In order to measure the neutron dose accurately it is important to use a detector that has similar response to the Relative Biological Effectiveness (RBE) of neutrons. Fast neutrons of energy of higher than 1 MeV are the main contributors to the dose. These neutrons can produce a dose of 40 times that of slow neutrons of the same intensity [5].

Nuclear track detectors have been used by many researchers for detection of fast neutrons directly or for thermal neutrons with the application of a converter on the plastic detector [6, 7, 8]. Other applications include radon monitoring and neutron and nuclear physics research. Unlike heavy charged particles that produce tracks in the polymer through direct interaction, neutrons being neutral, produce tracks due to (n, p) recoil protons reaction [9, 10]. In this work poly allyl di-glycol carbonate polymer, generally known as CR-39 track detectors were used to estimate the fast neutron dose inside and outside the radiotherapy treatment facility at

KAUH, Jeddah, Saudi Arabia. These measurements may help in preventing unnecessary exposure through better shielding and/or time management.

MATERIAL AND METHODS

Detector Setup

The linear accelerator at KAUH is a Siemens ONCOR linear accelerator (Fig.2). It is a dual mode medical linear accelerator, capable of producing both clinically useful photon and electron beams.

Fig. 2. KAUH Linac

Fifteen (2cm×2cm) CR-39 detectors, manufactured by Track Analysis Systems Ltd., Bristol, UK, were placed in the radiotherapy facility for 32 days. Detectors were distributed to allow neutron dose mapping in the radiotherapy facility. Five detectors were mounted on the gantry itself. A detector was placed in the control room. The rest of the detectors were distributed in the treatment room. An adhesive tape was used to hold the detector on the walls and the gantry.

Etching and Track Counting

After exposure detectors were collected, placed in sealed polyethylene bags, transferred to a chemistry lab and etched using 6N Sodium Hydroxide solution at 70 ^{0}C for 6 hours using a temperature regulated water bath. Detectors were removed from the etching solution, washed in deionized water at 70^{0} C twice, wiped clean using isopropyl alcohol wipes and stored in a sealed bag for counting. Tracks were counted manually with an optical microscope using 40x objectives.

Dose Calibration

A neutron dosimeter type NM2 made by Nuclear Enterprises, USA (Fig. 3) was used. This detector has the closest similarity to neutron RBE. It consists mainly of thermal neutron detector surrounded by polyethylene moderator. Because of their heavy weight, the neutron dosimeter is not very suitable for dose monitoring in locations such as walls, doors, etc.,. Four CR-39 detectors were attached to the polyethylene cylindrical base of the dosimeter using an adhesive tape. The dosimeter and detectors were exposed to a Cf-252 neutron source for about 13 hours at a distance of one meter. The Californium neutron source produces fission neutrons that are mainly fast. After irradiation the detectors were removed from the dosimeter and etched using the procedure described above. Tracks were counted and number of tracks was translated to a dose by comparison to the dose registered by the neutron dosimeter. Calibration resulted in 1.2 tracks/mSv.

Fig. 3. NM2 Neutron Dosimeter

RESULTS AND DISCUSSION

Figure 4 shows detector numbers and the corresponding doses in the fifteen locations at the radiotherapy facility. Detectors 11, 12, 13, 14, and 15 on the accelerator head showed the highest dose of 142.3 mSv average dose. Detectors 1, 2, 6, 9, and 10 at the walls of the treatment room were approximately at equal distances from the center of gantry, accordingly doses were almost equal, and the average dose was 28.5 mSv. Detector 7 and 8 showed slightly lower doses as they were relatively at larger distances from the gantry. Detector 3 at the beginning of the corridor leading to the accelerator at a further distance was giving 10 mSv. Detector 5 shows a reduced dose of 1.4 mSv because of the greater distance and the presence of the shielding wall. Detector 4 placed in the control room, recorded a dose of 1 mSv. It is clear that the low doses given by detectors 4 and 5 are due to the shielding wall.

The dose in the control room of 1 mSv in 32 days will give an annual dose of about 12 mSv. The dose is more than 50 % of annual dose limit to workers of 20 mSv. It should be taken into consideration that workers may also be exposed to radiation from other sources.

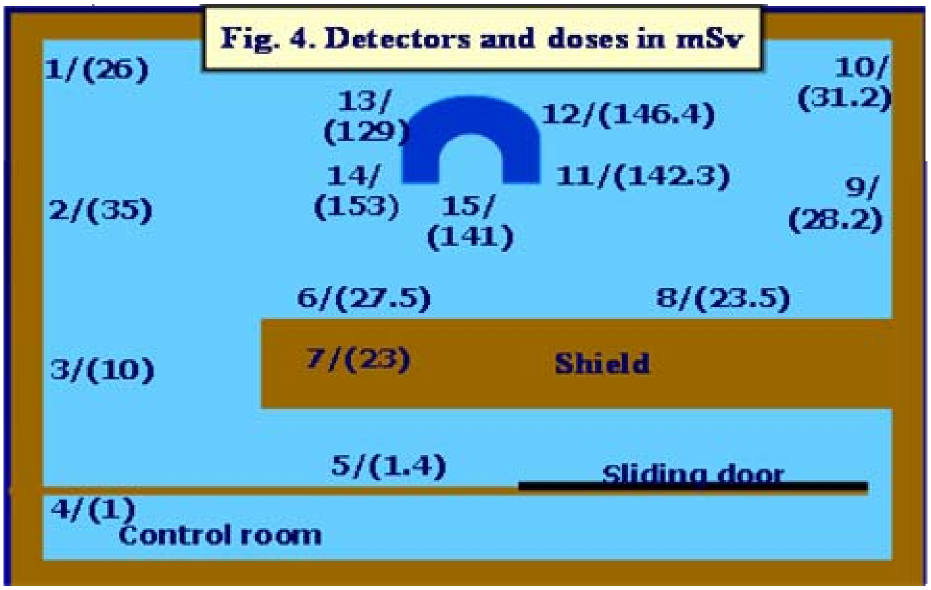


Fig. 4. Detectors and doses in mSv

The average dose near the accelerator head was 142.3 mSv in 32 days or about 4.5 mSv/day, suggesting that the dose to the patient is not very high. Actual assessment of dose to patients was not attempted in this work, but if few patients are treated daily, the dose will be of order of a mSv or a fraction of a mSv. This may not be high compared to gamma direct therapy dose. Because neutrons are going to be scattered in all directions, healthy tissues will receive unnecessary dose. Scattered neutrons dose can be reduced if proper patient shield is designed. Unlike scattered γ-rays within the patient body which nothing can be done to prevent them.

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