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A COMPACT AND MOBILE SYSTEM FOR BREAST IRRADIATION IN PRONE POSITION

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Abstract

The APAM (Accelerators of Particles for Medical Application) Laboratory in the ENEA-Frascati Research Center developed a prototype of a self-shielded device dedicated to the treatment of breast cancer with the patient in prone position. It consists of a rotating X-ray source, based on a compact 3 MeV electron accelerator, placed under the patient bed which is provided with a circular opening through which the breast hangs down and can be irradiated. The system has been designed to suitably screen the patient body from the underlying accelerator. This setup improves target coverage and gives a valuable advantage in sparing healthy tissues: prone position increases the separation of the target and critical organs and in addition minimizes target motion caused by breathing. The prototype has been developed in the framework of the TECHEA (TEChnology for HEAlth) Project aimed to the realization and validation of prototype systems for applications to health protection. The paper describes the apparatus and reports the results of the experimental characterization of the X-ray source done in collaboration with the Laboratory of Medical Physics and Expert Systems of Regina Elena Hospital.

INTRODUCTION

Breast radiation therapy (RT) after conservative surgery is now widely accepted as a standard of care for patients with early breast cancer. The conventional radiation course consists of 50 Gy in 25 daily fractions of 2 Gy on the whole breast usually followed by an additional boost dose to the tumour bed of 10 to 16 Gy in 5-8 daily fractions resulting in overall 6-7 week treatment. Generally, patients are treated in a breast board in the supine position with both arms extended overhead and supported by a dedicated arm rest. In most cases conformal three dimensional radiotherapy (3DRTC) is delivered by two or more opposed tangential photon fields. From the point of view of the side effect this type of technique involves the undesired irradiation of the lung and in some cases of the heart.

A technique to maximize the dose delivered on the target while minimizing the irradiation of healthy Organs at Risk (OARs) is to irradiate the breast cancer with the patient in prone position [1, 2]. In this framework, a prototype of a dedicated compact device for treatment of breast cancer in prone position has been built thanks to the TECHEA (TEChnology for HEAlth) [3] Project. The Project, launched by ENEA, aims to develop prototype systems to be applied in the field of health protection.

The paper reports a description of the system located in a bunker at APAM (Particle Accelerators and Medical Applications) Laboratory in the ENEA-Frascati Research Center and presents the results of the first experimental characterization measurements of the X-ray source led in collaboration with the Regina Elena Hospital. In the following the device will be named TECHEA-PBS (Prone Breast System).

TECHEA PBS

General Layout

The peculiarity of TECHEA-PBS system is the new design with respect to traditional clinical accelerators. All the machine components that generate the photon beam rotate around the breast while the patient is in prone position on a dedicated fixed treatment couch. The photon source consists of a small electron linear placed under a prone position table with a circular opening through which the breast hangs down. The conceptual scheme is shown in Fig. 1.

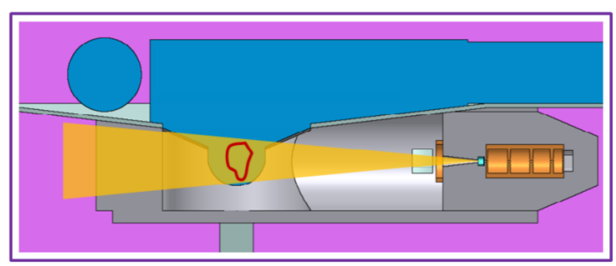

Figure 1: Conceptual layout of the Prone Breast Irradiation system.

The TECHEA-PBS prototype is shown in Fig. 2 and the main design characteristics are summarized in Table 1. Electrons accelerated to an energy of 3 MeV in a compact S-band linac hit a target composed of two layers, the first made of tungsten (400 µm thick) to produce the bremsstrahlung photon beam and the other made of copper (1.6 mm thick) to stop residual surviving electrons. The source is shielded in order to absorb the primary photon beam component and the secondary scattered radiation. The photon beam is collimated by a modular lead conical collimator having an aperture of 13 degrees consisting in a stack of blocks. An additional lead block is positioned behind the nominal irradiation position (isocenter) to shield the X-rays traversing the target.

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Figure 2: TECHEA-PBS prototype in the test bunker at ENEA-Frascati.

Table 1: Main Parameter of TECHEA-PBS

Parameter	**Value**
Rotation angle of the beam source	270°
Source-isocenter distance	60 cm
Treatment couch position	Fixed
Electron beam energy	3 MeV
Dose rate at isocenter	1.5 Gy/min
Maximum spot diameter	14 cm

The design value of 3 MeV for the electron energy was chosen to get a photon source equivalent to a ^{60}Co treatment unit and to reduce the stray radiation with respect to a typical 6MV unit. Differently from conventional medical accelerator or ^{60}Co units, that have a typical SSD (Source Surface Distance) of 100 cm and 80 cm respectively, the need of a compact machine resulted in a reduced SSD of 60 cm. However accurate Monte Carlo simulations [4] showed that 3MV PDD (Percentage Depth Dose) compared with ^{60}Co PDD at a SAD (Source Axis Distance) of 60 cm are very similar down to a depth of 10÷12 cm (average treatment volume thickness).

The rotation angle has been limited to 270° (instead of 360°) due to the limited available space in the test bunker. The system has been equipped with a cheap plexiglass table with a circular hole considered sufficient for the demonstrative aims of the prototype. In the final clinical device it will be replaced by a properly shaped carbon fiber couch.

The Accelerator

The accelerator is a compact pulsed linac operating in S-band powered by a 2MW peak power magnetron (EEV MG5125) driven by a solid state SCANDINOVA modulator M100 model. The beam is injected from a diode electron gun with a Perveance of about 0.3 µPerV provided with a dispenser cathode. The accelerated electrons exit through a 50 µm Titanium window and hit the e-X converter used also to measure the output current. The linac is completely embedded in the lead shielding. The main parameters of the linear accelerator are listed in Table 2.

Table 2: Main Parameter of TECHEA PBS Linac

Parameter	**Value**
Accelerating structure length	20.8 cm
RF frequency	2998 MHz
Number of accelerating cavities	4
Length of accelerating cavities	22,44,48,48 mm
Bore hole diameter	6 mm
Injection energy	12-15 keV
Output energy (max.)	3 MeV
Output pulse current	120 mA
Pulse duration	3.4 µsec
Repetition frequency	10-100 Hz

Figure 3 shows the linac without the external shielding followed by the converter and the bottom part of the beam shaping lead cone. The cooling channels for the converter (vertical-liquid cooling) and for the window (horizontal-air cooling) are visible.

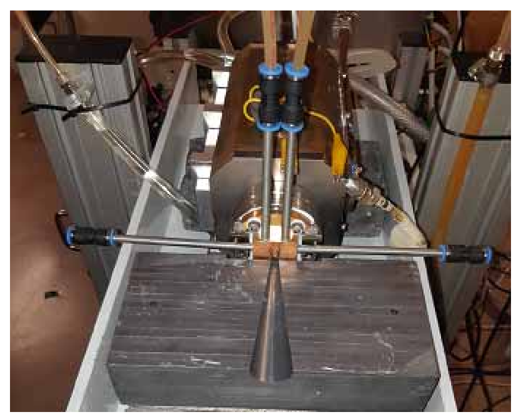

Figure 3: Front view of the linac (without external shielding) followed by the first part of the Pb collimator (open).

X-RAY EXPERIMENTAL CHARACTERIZATION

Dosimetry

Dosimetry is based on the use of Gafchromic film EBT3 type for the measure of the X-ray fields size and of two ionization chambers for measure and control of the dose both provided by PTW and compatible with the TANGO electrometer unit. The first one (Fig. 4a) is a transmission chamber (TM7862 model) with a 95 mm diameter sensitive area incorporated within the lead shielding to control the delivered dose during the irradiation and the second chamber is a Semiflex TM31010 model with a sensitive volume of 0.125 cm^3 (radius 2.75 mm) able to measure the dose at a point. The latter one, placed in the target position, is used as reference dosimeter (Fig. 4b) to measure of the absolute value of the dose and to calibrate the output of the transmission chamber.

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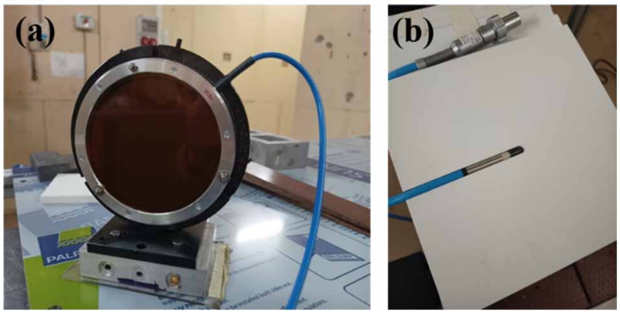

Figure 4: Ionization chambers employed on the system: (a) PTW TM7862 model and (b) PTW Semiflex TM31010 housed in the water phantom.

To perform a meaningful dose characterization of the X-rays, a solid water phantom (SWP) has been utilized. The phantom consists of over twenty 1 cm thick, 20 x 20 cm^2 solid water plates. These plates are made of a plastic material with a density of 1.035 g/cm^3. One of the plates is specifically slotted to accommodate the Semiflex ionization chamber, allowing the sensitive area of the device to lie on the water phantom axis (see Fig.4b).

X-ray Source Measurements

The X-rays characteristics were investigated with EBT3 films, and the Semiflex ionization chamber respectively for lateral distribution measurements and PDD curves acquisition.

The plot of Fig. 5 shows a comparison between the PDD curve of ^{60}Co with a computed 3MV PDD [5] and the measurements performed with the SEMIFLEX chamber in SWP. The measurements are in very good agreement with the expected curve.

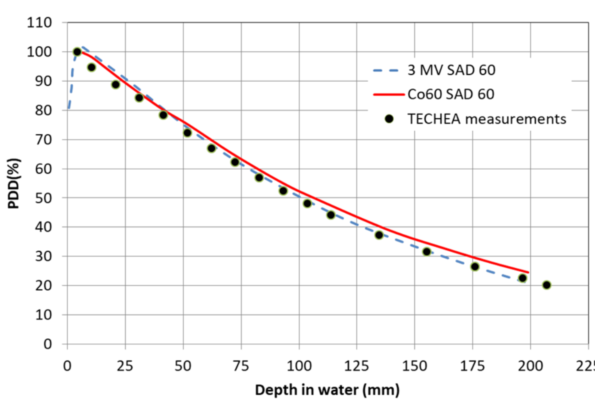

Figure 5: Measured Depth Dose curve at SAD of 60 cm.

The quality of the output radiation has been also evaluated by measuring the parameter TPR20/10 (Tissue Phantom Ratio) defined as the ratio between the dose at 20 and 10 cm with respect to a reference position [5]. The measured value, obtained keeping the Semiflex chamber at SAD=60 cm and placing before a proper number of SWP plates was 0.524, close to the typical value of a ^{60}Co unit.

Figure 6 shows the transverse photon beam profile as measured by an EBT3 film placed at SAD of 60 cm after a 2 mm thick solid water phantom plate.

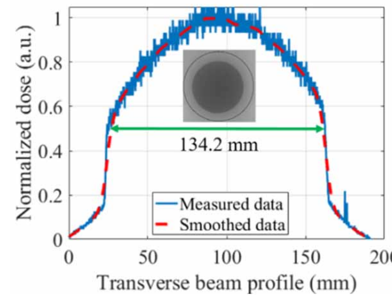

Figure 6: Measured transverse beam profile at SAD of 60 cm.

No flattening filter has been used to avoid increase of the stray dose and, consequently, of the shield weight. In the final device collimator jaws of different size to produce rectangular beams up to 10x10 cm^2 fields and a multileaf collimator to produce arbitrary shaped fields will be inserted.

To evaluate the effectiveness of the local shielding measurements have been performed with a portable LUDLUM chamber model 9DP at eight positions on a one meter radius of centred on the isocenter. During the measurement the accelerator was operated at the maximum dose rate of 1.5Gy/min, measured by the Semiflex chamber placed in the phantom at isocenter position. The results are shown in Fig. 7.

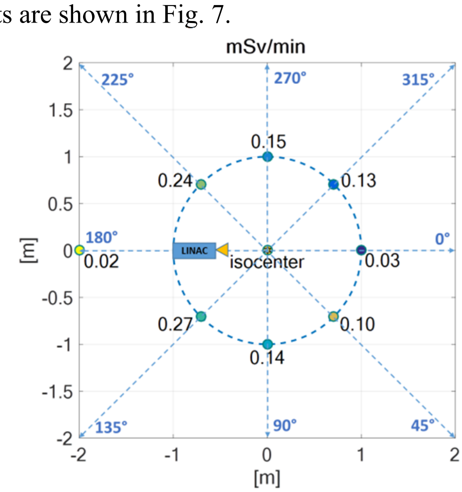

Figure 7: Environmental radiation measurements around the isocenter.

CONCLUSION

A prototype of an innovative compact and low stray radiation system to perform breast irradiation in prone position has been developed in the framework of the TECHEA Project. The preliminary experimental tests show that the apparatus is ready for an evolution toward an engineered clinical machine.

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