CHARACTERIZATION OF THE CS30 CYCLOTRON AT KFSH&RC FOR RADIOTHERAPY APPLICATIONS

Belal Moftah, Faisal Alrumayan, Faisal Alzorkani, and Mamoun Shehadeh,
King Faisal Specialist Hospital and Research Centre, Riyadh, Kingdom of Saudi Arabia
Saad Aldelaijan, Saudi Food and Drug Authority, Riyadh, Saudi Arabia,
Slobodan Devic, Medical Physics Unit, McGill University, Montréal, Québec, Canada

Abstract

The 26.5 MeV beam of the CS30 Cyclotron at King Faisal Specialist Hospital and Research Centre (KFSH&RC) was characterized dosimetrically for the use in radiobiological experiments for pre-clinical and radiotherapy studies. Position of the beam's Bragg peak was measured with a stack of 100 pieces of HD-V2 model GAFCHROMIC®films (105 microns thick each). This film type was specifically designed for measurement of very high doses, ranging up to 1,000 Gy. The response of the film was calibrated in terms of dose to water by exposing calibration film pieces within a solid water phantom. Percentage depth dose (PDD) of the proton beam was measured using a calibrated parallel-plate chamber in water. The position of the Bragg peak was found to be at around 6 mm when 10 to 20 nA proton beam current was used. For beam profile measurements, pieces of GAFCHROMIC® EBT3 film were irradiated at 40, 70 and 100 cm from the primary collimator, where the Gaussian shaped beam profiles had values of 12, 26, 45 mm at FWHM, respectively. Proton beam characteristics in terms of the output and beam size appear to be acceptable for pre-clinical studies and radiotherapy applications.

INTRODUCTION

The use of protons in the field of radiation therapy has been growing in recent years due to the ability to localize their dose deposition with relatively low entrance and exit doses[1][2]. High cost of proton radiotherapy facilities is the limiting factor of spreading this modality. For radiopharmaceutical cyclotrons, another limitation is their low energy protons, which prevent them from treating deeply seated tumors. However, low energy radiopharmaceutical cyclotrons can still be utilized to treat superficial tumors as well as surgical beds [2].

The CS30 Cyclotron at KFSH&RC was built to produce positron emitters such as F-18 for positron emission tomography (PET) imaging. It is capable to accelerate four different particles at different energy levels. This facility has proton and neutron beam lines connected to experimental vaults and a gantry-based neutron treatment room. For this project, the cyclotron is used to accelerate proton beam up to 26.5 MeV for beam characterization and dose measurements on beamline 2. One unique goal of the current work is to adapt the CS30 cyclotron for intra-operative proton radiation therapy (IOpRT) technique.

MATERIALS AND METHODS

The CS30 Cyclotron at KFSHRC is a positive ion machine [3]. For beam characterization measurement, proton ions beam was used. Target stations are available on seven beamlines as well as on an internal target. For beam characterization measurements, beamline 2 was chosen due to its location in separate vault as shown in Fig. 1. This gives the flexibility to work on the beamline without interrupting the production of radiopharmaceuticals. Before beam current was sent externally to the target, the beamline was pumped down to 10^{-4} mbar using two means for vacuum pumps: the roughing pump and diffusion pump. The temperature of the water cooling system was ±10 °C.

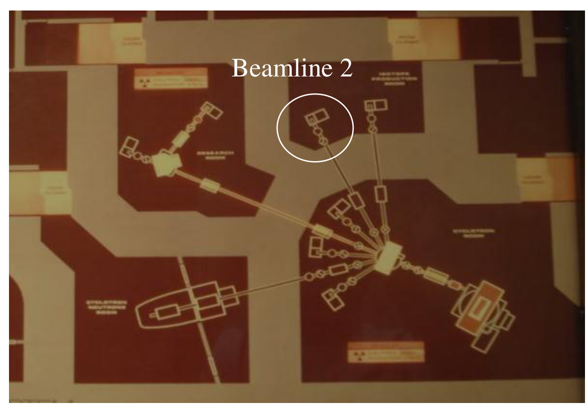

Figure 1: A general layout of the CS30 beamlines.

The CS30 cyclotron was used to deliver a beam current of 100 nA at 26.5 MeV for our measurements. Although the cold cathode internal ion source of the CS30 cyclotron, is quite reliable to deliver 100 μA internally and 20 μA externally, for these particular measurement, beam current needed is only 100 nA. Therefore, in order to have better control on the beam intensity and reach high stability level at such low current, few parameters were taken into consideration during the measurements.

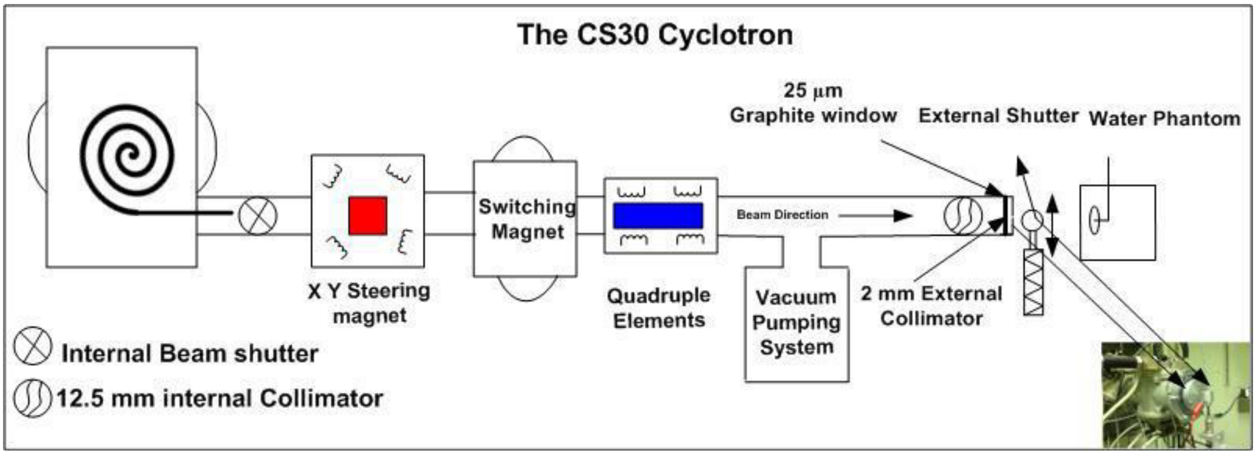

Figure 2: Beam controller components along the beamline 2.

Firstly, the intensity of the ion source current delivered in to the central region of the cyclotron is a function of the applied voltage across the cathodes of the ionsource. Therefore, the voltage of the ion source can be reduced to minimum level before it being accelerated and later delivered externally to the target. Usually 80% of delivered beam is lost during first acceleration and during extraction before finally being stabilized on the target. Secondly, it was crucial to find the optimum magnetic field suitable for the radiofrequency used for accelerating the beam and tune it to 100 nA delivered externally. Finally, the steering and quadruple magnets were used to, respectively, steer the magnet to the middle of the beam-line and focus the beam to the desired level. The control of the output of these two magnets is located in the cyclotron console and was adjusted before sending the beam to the target.

In addition to the internal components mentioned previously, two means of beam control were designed and fabricated in our machine shop; these are, respectively, a collimator with 2 mm aperture and a beam shutter. The purpose of the beam shutter is to improve the beam stability. The beam exits through a 25 µm Havar foil, which acts as elimination valve for the vacuum for the beamline. Figure 2 shows a simplified diagram of the main components used to stabilize the beam.

A primary collimator of aluminum was attached to the beam-line with a 2 mm aperture in order to unify the beam intensity over the radiation field. A GAFCHROMIC® EBT3 film pieces were irradiated while placed at a distance of 30 cm from the collimator.

In terms of coverage of the radiation field a beam profile was taken as at different distances (40, 70, and 100 cm) collimator to surface distance (CSD) where the GAFCHROMIC® HD-V2 film pieces were set. The cyclotron's beam current was set at 15 nA.

As a part of the characterization of the CS30 proton beam, various methods were used to measure the PDD and consequently the Bragg peak. The first method was to use the HD-V2 to allocate the Bragg peak by placing a stack of film pieces (100 pieces, 105 microns thick each [4]) orthogonal to the beam's path in a water equivalent material. The other method was to place a film piece of sandwiched between pieces of solid waterparallel to the beam's path with a tilt of 5 degrees. For this setup, the cyclotron's current was set at 100 nA, while the phantom was placed 70 cm for the primary collimator.

Moreover, an additional measurement of the Bragg peak was taken in a water phantom using a parallel-plate ionization chamber. The Phantom was set at 70 cm CSD, the chamber was centered to the beam center using an EBT3 film. The chamber was set at a depth of 1 mm. Dose Measurements of 1 mm step size were used for the first 4 mm and then a 0.5 mm step size was used for the rest measurements up to the 7^{th} mm The beam current was set to be 100 nA while the exposure time was 5 seconds for each measurement.

RESULTS AND DISCUSSION

The resulting profiles of the beam with the introduced aluminum collimator showed a circular symmetrical Gaussian fields. To assess beam divergence, beam profiles were measured at distances of 40, 70, and 100 cm from the primary collimator.The field-sizes at the full-width-half-maximum (FWHM) were found to be 12.0, 26.3, and 44.9 mm wide, respectively, as shown in Fig. 3.

The results of the Bragg peak measurements using the stack of films, the tilted film piece, and water phantom have shown some discrepancies. The locations of the Bragg peak were found at depths of 4.8, 6.0 and 6.5 mm as shown in Fig. 4.

ISBN 978-3-95450-128-1

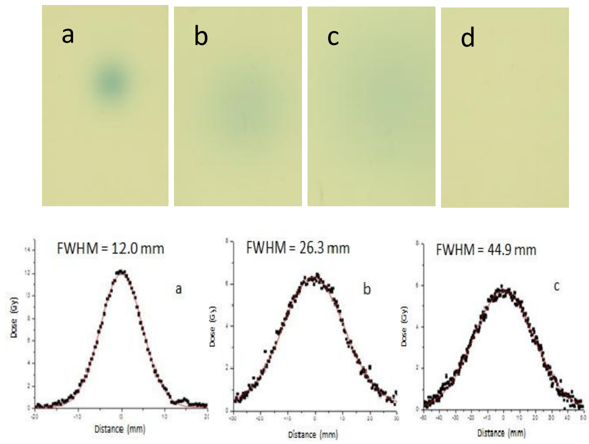

Figure 3: Scans and vertical profiles of the irradiated HD-V2 film pieces when placed at a) 40, b) 70 and c) 100 cm from the aperture d) background film.

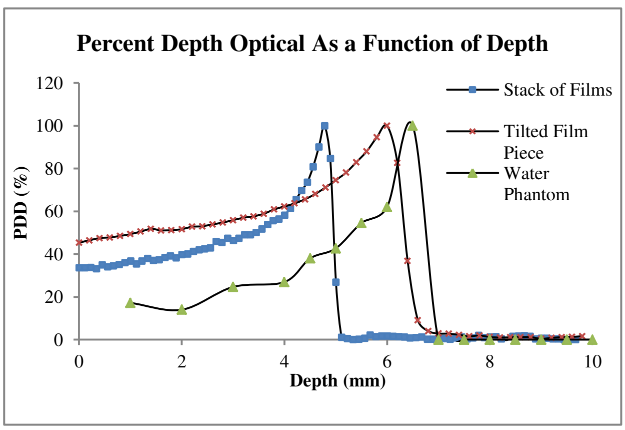

Figure 4: The PDDs of the two film measurements (stacked film pieces and tilted film piece) and the water phantom as a funtion of depth with CSD of 70 cm.

For the film measurements, the difference in depths of the Bragg peak is due to the heterogeneity of the film material the beam is passing through. Throughout the stack of film pieces, the beam is mostly penetrating through polyester (i.e. a density of 1.36 g/cm^3), which makes the bulk of the film material. However, for the tilted film piece method, the beam was irradiating the active layer of the film (i.e. water equivalent material). On the other hand, the difference between the tilted film measurement (6.0 mm) and the water phantom measurement (6.5 mm) is due to the difference in physical densities of the active film layer and the water. It should be noted that the actual Bragg peak is expected to be even higher since the water phantom measurement did not take into consideration the degradation of the proton beam due to the entrance window of the phantom (Mylar) as well as the in-between traversed air (CSD = 70 cm). These results agree with the theoretical calculations (7.06 mm) [5].

CONCLUSION AND FUTURE WORK

By using GAFCHROMIC® HD-V2 films, the beam was found to be symmetrical at 30 cm CSD after placing an aluminum collimator with a 2 mm aperture. The beam covers a larger area as the target is taken further away from the collimator; the field-sizes were found to be 12.0, 26.3, and 44.9 mm wide at distances of 30, 70, and 100 cm, respectively. Also, we were able to locate the Bragg peak by the film stack, a tilted piece of film, and water phantom. The Bragg peaks were at 4.8, 6.0, and 6.5 mm depths, respectively. The preliminary results of PDDs and beam profiles are acceptable for pre-clinical studies and radiotherapy applications.

The penetration power of the beam will be improved by changing the beamline window to a material of low atomic number such as Kapton. Also, the radiobiological effects of the proton beam irradiation will be examined using breast cancer cells. Finally, the beam will be broadened through passive scattering or active scanning techniques to cover larger targeted areas. In the latter technique the beam will be swept horizontally and vertically using steering magnets to cover as a large as possible area while ensuring homogeneous field.

ACKNOWLEDGMENT

This works was supported by King Abdul-Aziz City for Science and Technology (KACST) grant No. 11-BIO1428-20. This work was also supported in part by Natural Sciences and Engineering Research Council of Canada (NSERC) grant No. 386009. SD is a Senior Research Scientist supported by the Fonds de Recherche en Sante du Quebec (FRSQ).

REFERENCES

[1] Kim, Kye-Ryung, "Proton Beam Energy Measurement Using Semiconductor Detectors at the 45 MeV Test Beam Line of PEFP." Proceedings of PAC07 (2007): 4126-128.
[2] Cirrone, G.A.P., "A 62-MeV Proton Beam for the Treatment of Ocular Melanoma at Laboratori Nazionali Del Sud-INFN." IEEE Xplore. IEEE Transactions on Nuclear Science, June 2004. Web. 02 Sept. 2013.
[3] J. W. Stetson et al., "A status Report of the Cyclotron Facility at King Faisal Specialist Hospital and Research Centre" Proc.11th Int. Conf. on Cyclotron and their application, Tokyo,1987.
[4] "Gafchromic® Dosimetry Media, Type HD-V2." ASHLAND, n.d. Web. 2 Sept. 2013.
[5] "Stopping Power and Range Tables for Protons", US National Institute of Standards and Technology, http://physics.nist.gov/PhysRefData/Star/Text/PSTAR.html.