EXTRACORPOREAL IRRADIATION IN BONE TUMOURS THERAPY AT THE GHENT LOW ENERGY HIGH POWER ELECTRON LINAC

W. Mondelaers, K. Van Laere, P. Berkvens*, and D. Uyttendaele**
Nuclear Physics Laboratory,
Proeftuinstraat 86
9000 Gent, Belgium

Abstract

At Ghent State University a new promising accelerator based treatment in bone tumours therapy is applied: extracorporeal irradiation of the bone affected by cancer, carried out at a 15 MeV 2% duty factor electron linac. The high dose high uniformity irradiation set-up, associated control equipment, irradiation procedure and some results are presented.

Introduction

The treatment of primary bone tumours has changed dramatically since the early 1970s. Chemotherapy came into use and radical ablative surgery was abandoned in favour of limb salvation techniques. Nowadays applied procedures, consist of a resection of the tumour and a reconstruction with a prosthesis, an allograft or a bridging technique. Several disadvantages are inherent to these treatments: loosening or breakage of a massive prosthesis, rejection of a graft or the necessity to organise a bone bank.

At Ghent State University a new alternative treatment is developed: en bloc resection of the bone affected by cancer, extracorporeal irradiation and reimplantation of the irradiated bone. The surgical operation is carried out at the Department of Physiotherapy and Orthopedy at the University Hospital.

The extracted bone needs a total homogeneous dose of 300 Gy, lethal for every human cell and tissue. Therefore, an extracorporeal irradiation is needed.

Conventional radiotherapy linear electron accelerators are not well suited for such a kind of bremsstrahlung irradiation, due to their rather low dose rates and accordingly long irradiation times. The low energy high intensity linear electron accelerator of the Nuclear Physics Laboratory, nearby the University Hospital, offered an excellent opportunity to develop this new treatment technique.

The purpose of this paper is to present this new radiotherapeutical technique, with emphasis on the accelerator related problems. The medical aspects are described in detail elsewhere [1].

Irradiation facility

The Ghent low energy 2% duty factor electron linac, mainly dedicated to fundamental nuclear physics research, began regularly scheduled operation in March 1986. Machine performance and operational experience are presented during this Conference [2]. The accelerator characteristics relevant to this application are given in Table 1.

This two section linac has 5 electron beam transport channels that are provided with appropriate high beam power handling and monitoring equipment. We developed and installed a high dose photon irradiation facility at the end of the direct beam line in order to fulfill the following therapeutical requirements: delivery of a dose of 300 Gy, uniform within 10%, over a surface of 25x10 cm^2, within a time interval of less than 10 min, using a photon beam with $E_{max,\gamma} \leq 10$ MeV.

Beam energy range :	1.75 - 15 MeV
Duty factor :	2%
Beam pulselength :	variable between 2 and 10 μsec
Beam pulse repetition rate :	variable between 0.1 and 5000 Hz
Peak beam current :	100 mA
Max. average beam current :	2 mA
Max. average beam power :	20 kW
Accelerated current in 1% energy bin :	up to 80% of I_{max}
Beam emittance :	2.7 π mm mrad

Table 1 : Relevant accelerator characteristics

To reach the required high photon dose rate an electron beam intensity of more than 1 mA is needed. The electrons are stopped in a radiation cooled graphite beam stop, in vacuum mounted. This cylindrical beam stop, with reentrant conical core hole, specially designed to allow for the dissipation of a 1 mm diameter 20 kW electron beam, is used as bremsstrahlung target for the production of the photon beam.

Both electron and produced photon beam have a high directivity, giving a sharply peaked absorbed dose distribution in planes perpendicular to the central beam axis. In general, there are two possible solutions to reach the required dose uniformity: scanning of the electron beam or flattening of the photon beam. We have chosen the second alternative because of its relative simplicity and reliability.

As shown in figure 1, a Pb-flattening filter is fixed to the endplane of the beam stop, to compensate for the off-axis reduction in photon dose. Figure 2 shows isodose charts measured in an irradiation phantom, irradiated with a photon beam with $E_{max,\gamma} \leq$ 10 MeV. The effect of the flattening filter is obvious. The filter substantially reduces the straight ahead photon beam, but the dose rates available from the high intensity of this high power linac are sufficient, to allow this loss of dose rate. At 25 cm from the target we obtain a dose rate of 1 Gy/sec, with a homogeneity of better than 10%, over a lateral distance of 25 cm. A possible reduction of irradiation time from 5 to 1 min, by using an optimised water-cooled bremsstrahlung target and scanning techniques, would be insignificant in view of the total surgical operation time (6 hours).

As a first approximation to the design of the filter, we used the measured unflattened dose profile and photon attenuation coefficients to calculate its shape. Because of the spectrum width of the photon beam, photon absorption and scattering in the phantom, this filter cannot be computed very accurately and the final shape had to be determined experimentally by successive approximations.

* Now at ESRF, Grenoble
** University Hospital, Ghent State University

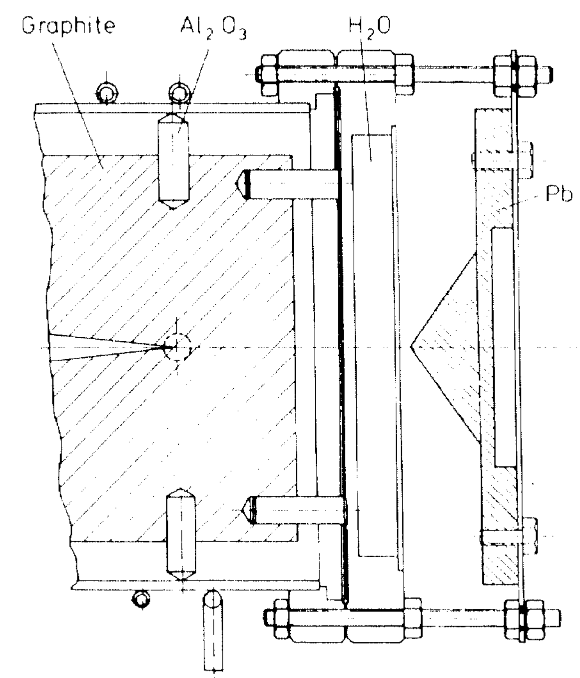

Fig.1. Schematic view of beam stop with Pb-flattening filter

Dose uniformity and symmetry are very sensitive to the beam position and normal incidence on the target, and consequently to the alignment of photon beam axis and filter axis. Carefull electron beam monitoring and control of radiation field intensity and uniformity are prerequisite.

Dose monitoring and irradiation procedure

We have developed a motor-driven scanning system for a .6 cm^3 NE2571 air ionisation chamber, covering a square of 24x24 cm^2 in front of the irradiation phantom. With this scanning system, absorbed dose homogeneity over the whole cross-section of the radiation field is optimised on-line. An unacceptable degree of dose asymmetry or inhomogeneity is corrected by changing the position or angle of incidence of the electron beam.

If the field uniformity is within acceptable limits, accurate absorbed doses at the desired central irradiation plane inside the phantom, are measured, for calibration purposes, using ferrous sulphate (Fricke) dosimeters. Absolute dose profiles can easily be determined by irradiating different Fricke dosimeters at the same time. The irradiation phantom consists of a 50x30x30 cm^3 Perspex box filled with a homogeneous rice medium. We have chosen rice because of its tissue-equivalence and its practical handling.

The surgical operation is carried out at the University Hospital. A wide resection, but limited by anatomical and functional restrictions, is prefered. While the patient remains anaesthetised in the operating-room, the excised specimen including the tumour-bearing bone and its surrounding tissues is transported to the Nuclear Physics Laboratory. The specimen, positioned inside the irradiation phantom, is given routinely a total dose of 300 Gy. Fricke dosimeters are placed at strategic locations to check

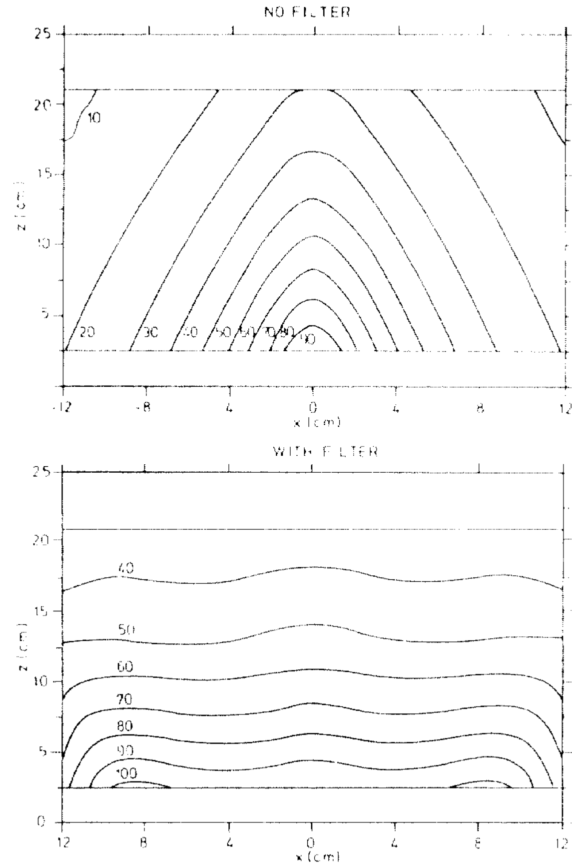

Fig.2. Isodose charts measured in the irradiation phantom
(x : distance from center   z : depth in phantom)

absorbed dose. Halfway the exposure time the specimen is turned, to account for depth dose attenuation. Transport and irradiation procedure take less than 30 minutes. Before reimplantation, soft tissues and the bulk of the tumour are removed, but part of the tumour is always left in place, so that some dead tumour cells are available to help stimulate the patients immunological system. Postoperative revalidation depends on size and anatomical location of the graft, but takes at least six months.

Results

50 patients have been treated up to now. A detailed medical analysis of the first 17 cases treated in this way [1], after a follow-up of several years, indicates a possible survival rate similar to the prosthetic replacement method, proving that extracorporeal irradiation technique may provide a rewarding alternative to the more radical treatments of primary bone tumours.

References

[1] D. Uyttendaele, A. Deschryver, H. Claessens, H. Roels, P Berkvens, W. Mondelaers, Journal of Bone and Joint Surgery, 70B (1988) 348.

[2] W. Mondelaers, "Operational experience with the low energy 2% duty factor Ghent electron linac", these proceedings.