STATUS REPORT OF THE CLINICAL CYCLOTRON FACILITY IN SEATTLE

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Abstract

The clinical cyclotron facility in Seattle continues to provide beams for neutron therapy and PET isotope production. Over 2000 patients have so far been treated using an isocentric gantry with multi-leaf collimator. Downtime remains below 2%. A new therapy control system has been in operation for nearly two years now and works efficiently and reliably. Developments to extend the therapeutic window for neutron therapy by adding a boron neutron capture dose component selectively to the tumor are continuing. Several beryllium-tungsten target combinations have been investigated with regard to neutron spectrum, dosimetry and radiobiology. The project of an external ion source to increase flexibility to accelerate other particle beams, in particular $^{4}He^{++}$ has been abandoned. The change-over to such a system would have created too serious an interruption in the therapy schedule. Instead, modifications to the existing internal cold cathode pig source are being investigated. Substantial progress has been made and the goal of 50 μA at an external target station appears achievable.

1 INTRODUCTION

The clinical cyclotron facility at the University of Washington Medical Center operates a Scanditronix MC50 cyclotron which is primarily used to produce a 50.5 MeV proton beam. This beam is transported to a treatment room with an isocentric gantry where neutrons are produced in a beryllium target and used for radiation therapy. The desired patient specific dose distribution is achieved with internal wedge filters and a 40-leaf collimator.

Alternatively the beam can be directed into a second treatment room with a simple horizontal fixed beam useful for technical developments and radiobiology experiments. An isotope production station is installed at the end of a short beamline in the cyclotron vault for routine production of short lived radionuclides for a PET scanner.

Recently a second short beamline stub in the vault has become available for the production of ^{211}At using a 29 MeV He^{++} beam.

2 FAST NEUTRON THERAPY

Fast neutron therapy continues to play an important role in the management of a few selected tumor sites, primarily for salivary gland tumors, as well as for some lung cancers, melanomas, sarcomas and for advanced prostate cancer. Salivary gland tumors presently represent over 65% of the cases treated at the Seattle facility. Fig. 1 illustrates the sites treated over the past ten years.

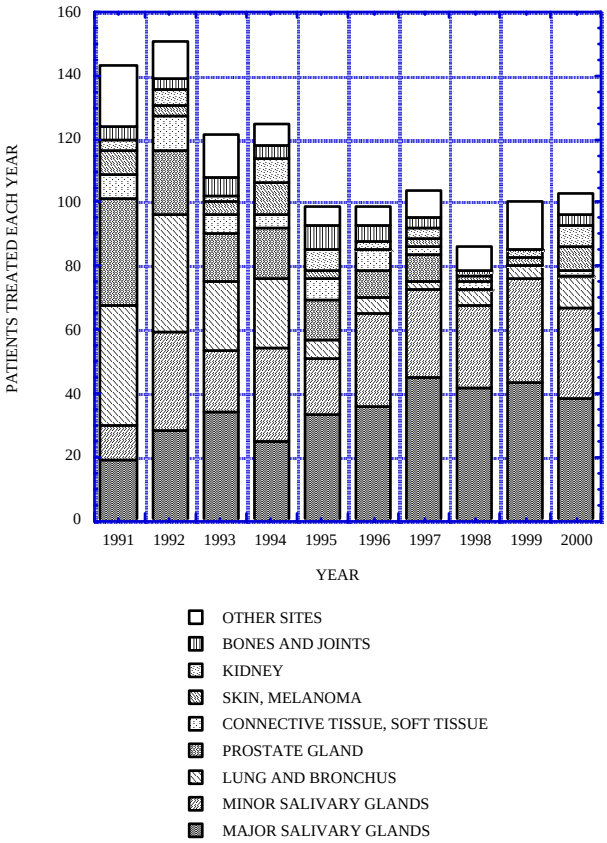

Figure 1: Treatment sites treated over the past ten years.

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3 BORON NEUTRON CAPTURE (BNC) ENHANCEMENT OF FAST NEUTRON THERAPY

If a drug containing 10-Boron can be developed which gets incorporated preferentially in the tumor but not in the surrounding tissue, thermal neutrons, which are present in the patient through moderation from higher energies, can get captured and the resulting helium and lithium recoil fragments will deposit additional high LET (lineal energy transfer) dose in the tumor. This has the potential to enlarge the narrow gap between tumor control probability and normal tissue complication rate.

Several modified neutron production target assemblies have been evaluated with the goal to increase the slow neutron component in the tissue without compromising the fast neutron dose distribution. An initial investigation [1], in collaboration with a team from the Idaho National Engineering and Environmental Laboratory (INEEL), showed that reducing the thickness of the beryllium and stopping the protons in a heavy backing such as tungsten would have this effect. Tungsten backed targets with 5.0 mm Be, 7.0 mm Be, 10.5 mm Be (our standard Beryllium thickness) were investigated using the fixed beam unit. All the targets produce similarly shaped fast neutron depth dose distributions, however they differ in the dose rate which can be produced by a given proton current on target. The 5.0 mm target achieves the highest boron capture boost but with a fast neutron dose rate of only 70% of the standard target.

If a decision is made to switch to one of the targets with increased slow neutron spectrum, it is of interest to know what change in relative biological effectiveness (RBE) is expected for the fast neutron therapy beam (without ^{10}B present). Three targets were investigated in a in vivo radiobiology experiment using intestinal crypt cell regeneration in mice as the assay. This system has been used extensively in other neutron therapy beams [2]. The three targets used were our standard target used in the isocentric unit (10.5 mm Be + 3.0 mm Cu), the target with 5.0 mm Be + 2.5 mm W and the target with 7.0 mm Be + 2.0 mm W in the fixed beam unit. The measured RBE for the three investigated targets was essentially equivalent. This means that to a first approximation the normal tissue tolerances which have been empirically established for our standard beam can be translated to the modified beam.

4 OPERATIONAL STATISTICS AND EQUIPMENT PERFOMANCE

The neutron therapy system continues to treat about 100 patients per year. The reliability remains high and less than 1% of the scheduled patient sessions had to be canceled because of equipment reasons. The therapy beam was available for over 98% of the time. The system has now been in operation for 16-1/2 years and has never been shut down for scheduled maintenance. However, the standard operating schedule requires beam only from Tuesday though Friday and the weekends, including Monday are available for major scheduled repairs and modifications.

5 THERAPY CONTROL SYSTEM

A new therapy control system was taken into operation about two years ago. It replaced the initial system delivered by Scanditronix running on a PDP11/23 computer. The new therapy control computer is a VME single board Motorola 68040 processor running the VxWorks real time operating system from Wind River Systems. It communicates with the original Scanditronix controllers for treatment motions, leaf collimator control and dose monitoring via RS-232 lines. Details of the development and the system are available at the UWMC Radiation Oncology Website .[1]

A private Ethernet network connects the therapy control computer to the two Modicon Quantum programmable logic controllers for digital I/O signals (primarily limit switches, push buttons and lamps) and some analog signals (barometric pressure and ion chamber temperature). Also on the network is the X-terminal for the user interface with the therapists and a Unix workstation which acts as file server and boot host for the therapy computer and the X-terminal. The workstation has two separate network cards, one for the private neutron therapy system network and one for the departmental network. Patient prescriptions are transferred from the departmental treatment planning computer system to the workstation. Access to the workstation is very restricted and no outside access to the private network is possible for security reasons.

It is planned to add more devices to this private network as the controls for the cyclotron and the beam lines are moved away from the PDP11/23, which is presently still in use for this part of the system.

A substantial effort went into the design of the user interface for the therapists. They have several screens to work with, such as for selecting patients, patient fields and set-up parameters. The screens display only a limited but carefully selected amount of information. Dedicated keys of the numerical key pad are used to switch between screens and to perform all standard therapy operations. The key pad has been fitted with customized keys for easy identification. In addition, the Function keys are used by the technical staff for operations such as calibration procedures or limited access to log files. Engineering staff can also inspect treatment records and event logs stored on disk by logging directly into the workstation.

[1] http://www.radonc.washington.edu/physics/cnts/

The therapy control system was developed using formal methods and some automated code checking. This contributed to a smooth transition and only few modifications to the code were necessary in the first two years of operation. While there were some programming errors, none was safety critical. Several fixes had to deal with situations not anticipated when the specifications were written, some created by the users and some by unexpected behavior of the controllers connected via RS-232 serial lines.

Together with the computer hardware and software several other control hardware changes were implemented at the same time. This included back-ups for several safety critical limit switches such as for the gamma shield glass stop at the exit of the collimator and a separate control station for selecting open collimator fields for X-ray verification films.

6 OTHER SYSTEM IMPROVEMENTS

The bracket supporting the beam scrapers in front if the focusing channels in the cyclotron exit path is now water cooled, allowing higher beam losses at this point.

The thermocouple system which monitors the septum temperature was modified to include a second thermocouple which measures the incoming cooling water temperature. By measuring the difference between the two points the system more accurately reflects the beam power lost in the septum. Several unwanted secondary thermocouple junctions could be eliminated making the system independent of ambient temperature changes.

The beam defining lamp system was modified to give better congruence between the projected light field and the neutron field. Together with a better calibration procedure for the multi-leaf collimator by using a mechanical jig, the accuracy of therapy beam delivery was improved.

Several seismic improvements to the equipment have been implemented and major modifications are scheduled later this year, in particular for the heaviest pieces: the cyclotron, isocentric gantry and the shielding doors. Fortunately the system suffered no damage during the 28-February-2001 earthquake.

7 PRODUCTION OF ALPHA PARTICLE BEAM

There is presently great clinical interest in ^{211}At which is an alpha emitter with 7.2 hours half-life. The hope is to find a carrier drug to transport the Astatine preferentially to the tumor where the alpha particles would deposit radiation dose within their short range of a few cell diameters. ^{211}At is produced by bombarding ^{209}Bi with 29 MeV alpha particles.

Initially it was planned to upgrade the cyclotron for alpha operation by adding an external ion source, which would have given optimal flexibility, also for the standard proton and deuteron beams [3]. However, the design study showed that major modifications to the yoke would have been required and this would have resulted in an extended interruption of the ongoing neutron therapy operation. It was therefore decided to investigate modifications to the existing internal cold cathode source to achieve the goal of 50 µA on an external target station. Guided by some advice from the TRIUMF accelerator division this goal has nearly been reached. Changes made include a new 3 kV power supply, reducing the first acceleration gap as far as feasible without excessive RF sparking, increasing the Dee voltage and enlarging the ion source window from 6.0 x 1.0 mm to 7.5 x 2.0 mm. Instead of the standard LaB_6 cathodes, HfC cathodes are used for longer service life. So far, 40 µA of He^{++} beam has been reached repeatedly on the first Faraday cup after the machine exit with a maximum observed current of 50 µA.

Routine production of ^{211}At with a preliminary target assembly at 15 µA has started on a monthly basis.

8 CONCLUSIONS

The cyclotron system continues to work well in a hospital environment and its flexible design lends itself to technical developments and modifications to adapt to changing clinical interest.

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