# PRESENT AND FUTURE OPERATION OF THE SEATTLE CLINICAL CYCLOTRON FACILITY

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The clinical cyclotron facility in Seattle continues its operation with traditional fast neutron therapy and production of PET isotopes. System availability remains high. Improvements to the extraction efficiency resulted in an increased beam intensity and a 3.5 kW beam is now routinely used for neutron production with the beryllium target in the therapy head. Neutron spectrum measurements have been performed using foil activation techniques. These measurements are part of the effort to enhance fast neutron therapy by boron neutron capture of moderated slow neutrons in the patient. Dosimetric measurements and animal experiments are being conducted for this modality. Improvements were made to the control system, power supplies and the neutron collimation system, where radiation damaged components had to be replaced. Plans for an external ion source for improved operation with different particle beams for production of experimental medical radionuclides are actively pursued.

## 1 Introduction

The clinical cyclotron facility at the University of Washington Medical Center became operational in 1984. The primary application for the Scanditronix MC50 accelerator is fast neutron therapy, where neutrons are produced in a beryllium target installed on a rotating isocentric gantry in a therapy room adjacent to the cyclotron vault. A fixed horizontal neutron beam is available in a second therapy room and a production station for PET radionuclides is located in the cyclotron vault. The traditional operating schedule continues, where therapy and radionuclide production take place from Tuesday through Friday, and maintenance is performed on Monday.

## 2 Fast Neutron Therapy

Fast neutron therapy has been shown to be highly effective for the treatment of salivary gland tumors, sarcomas of bone and soft tissues and for certain prostate cancers. For the relatively small group of cancers, where neutrons are superior to other types of therapy, this modality will continue to play an important role. The Seattle facility is fully integrated in a regular radiation therapy department and the neutron beam is available to the physicians in the same way as four standard medical electron linacs.

## 3 Boron Neutron Capture Enhancement of Fast Neutron Therapy

In addition to the cases, where conventional fast neutron therapy is advantageous, there are situations such as non-small cell lung cancer, melanomas and some brain tumors, where results are promising, but success is limited by normal tissue complications. A relatively small selective increase in the tumor dose might lead to a significant clinical improvement in these situations. The use of a boron neutron capture (BNC) boost, utilizing the moderated slow neutrons naturally present in the tissue during fast neutron therapy, may be beneficial for such patients. The availability of a suitable 10-B carrying drug is of course a prerequisite for the success of this modality.

Experimental work has started to explore the possibility of such a slow neutron boost. This work is done in collaboration with the Idaho National Engineering and Environmental Laboratory (INEEL), which has been involved in reactor based BNC therapy for some time. In a first set of experiments, the neutron spectrum of the Seattle fast neutron beam was measured using foil activation techniques [1]. The knowledge of this spectrum is essential for the use of Monte Carlo based treatment planning calculations. The spectral measurements were in reasonable agreement with a-priori neutron flux calculations for the Seattle target / collimation arrangement using cross section data extended to over 50 MeV.

The calculations were then used to investigate the possibility to produce an improved neutron beam with similar fast neutron dose distribution properties, but with an increased slow neutron component. The present neutron production target consists of a 10.5 mm beryllium layer, which slows the 50.5 MeV protons to about 25 MeV. The remaining energy is deposited in a copper beam stop. The theoretical investigation showed a marked increase in slow neutron flux, if the beam was stopped in tungsten instead of

copper. An experimental target was built with 5 mm beryllium and a tungsten stop. In this target the protons emerge from the beryllium at about 41 MeV. The neutron spectrum produced by this assembly was measured using the same foil activation technique [2] and agreed well with the calculation. The dose distribution as a function of depth in water was calculated and measured both for the fast neutron component as well as for the expected high LET (linear energy transfer) dose from the interaction of the slow neutrons with 10-B. Good agreement was again observed. The measurements were performed with an ion chamber for the fast neutrons and with sodium activation in soda-lime glass beads for the neutron capture component.

A comparison of the fast neutron distribution as a function of depth in water between the standard beam (in the isocentric gantry) and the experimental beam (in the fixed beam unit) is shown in figure 1. The fast neutron penetration (the depth, where the dose drops to 50 % of the maximum) for the two beams is very similar, however the experimental beam has only about 65% of the fast neutron intensity for the same proton current on target.

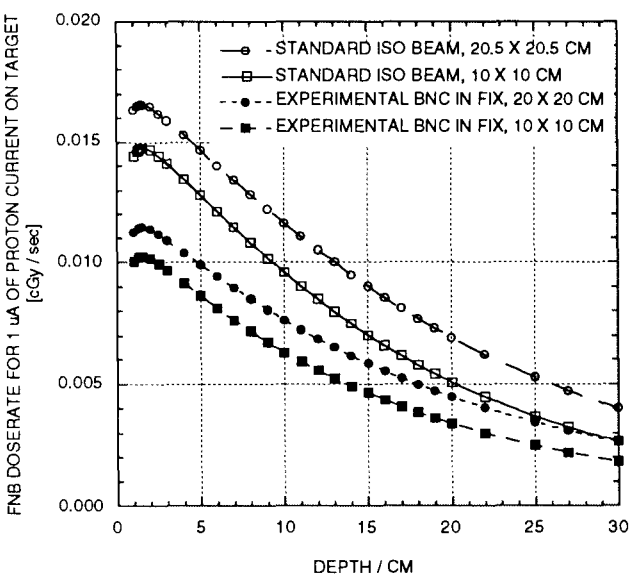


Figure 1: Fast Neutron Depth Dose Curve Comparison between the Standard and BNC Experimental Target

Fig. 2 shows the boron capture enhancement for the two beams. This is the relative increase in dose due to the presence of 1µg of 10-B per gram of tissue. It is expected, that a good boron carrying drug will eventually be found, which can selectively deposit 100 µg / g in a tumor. The peak dose enhancement with the experimental beam and for a 20 x 20 cm field would then reach the substantial dose increase of 20%. The enhancement is strongly field size dependent, because the neutrons are more effectively moderated in a larger irradiated volume.

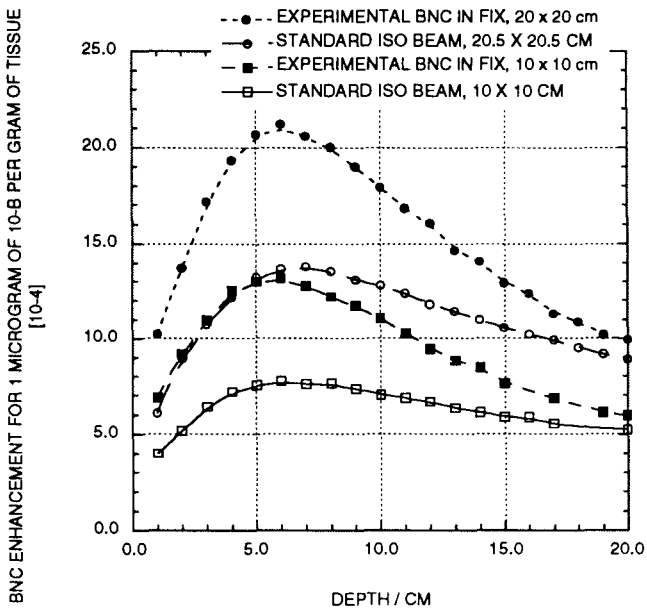


Figure 2: Comparison of Dose Enhancement from 10-B Neutron Capture Reactions between the Standard and BNC Experimental Target

The beam from the experimental target in the fixed beam unit is presently used to treat dogs with spontaneous non-small cell lung cancer, using B-10 enriched Disodium-decahydro-decaborate as the boron carrying drug [3].

## 4 Operational Statistics and Equipment Performance

The patient load during the past three years has somewhat decreased and about 100 patients were treated each year. This decrease is primarily caused by shrinking referrals and increased competition from other modalities. Since the beginning of operation roughly 1800 patients have been treated at the facility.

The reliability of the equipment continues to be high, over the past 18 months only one patient session had to be canceled for machine related reasons. During the past three years there were 4 events, where downtime was 4 hours or longer. These are the events, where typically patients cannot be re-called for another appointment the same day. The four events involved different subsystems each time: a mechanical failure in the neutron beam wedge mechanism of the gantry head, a defective RF driver amplifier, an air leak

in the ion source gas supply and a failure of a network computer, which prevented the transfer of patient data from the treatment planning system to the neutron therapy equipment.

So far there has never been a major scheduled down-time period for repairs or upgrades. It was always possible to perform major work over weekends, Saturday through Monday, with a few exceptions during the first few years, where Tuesday was also used.

## 5 Repairs and Equipment Improvements

The most involved repair during the past three years was the replacement of the leaf readout mechanism of the multi-leaf collimator installed on the isocentric gantry. This part contains a large number of rollers and guides made out of plastic and it had suffered severe radiation damage. All plastic parts were replaced with parts made of Vespel (polyimide) material.

After several failures of the water baffles on the two cyclotron diffusion pumps, where pin hole leaks into the vacuum developed from the water lines, it was finally realized, that the water flow through the baffle was too high, resulting in corroded tubing. The cooling circuits were re-arranged and the flow reduced. Flow reductions were also introduced in some other circuits to prevent similar failures.

The large banana plugs, which carry the 835 A main coil current to the top yoke of the cyclotron were replaced by a type with higher current capacity. The original plugs had to be cleaned regularly to prevent an unacceptable temperature rise of the contacts.

The fire protection system in the Power Supply Room was replaced. Instead of the original Halon system, a pre-action water sprinkler system in the ceiling and a CO-2 system below the computer floor was installed.

The upgrade of power supplies to units with improved characteristics and/or with the possibility of future digital control continues. In particular, the custom-built grid supplies for the two final tetrode amplifiers of the RF system were replaced by commercially available supplies.

A substantial improvement in beam performance was achieved by reducing the vertical dummy-dee gap in the cyclotron from the original 16 mm to 8 mm. This resulted in an improved extraction efficiency and lower septum temperature. Subsequently the beam intensity could be increased by 20 % resulting in shorter treatment times, which are more comfortable for the patients. For over a year we have now operated at a routine dose rate of 60 MU/min (1 MU (monitor unit) = 1 cGy at isocenter, at Dmax for a 10 x 10 cm field). Depending on flattening filter conditions, this requires a proton beam current on the beryllium target of 66 to 71 μA, or roughly 3.5 kW of beam power. There was one target failure since the intensity increase, however this target was already rather seasoned. A new target has now been running under these conditions for over 3000 therapy fields. It is hoped, that it will last at least for one year or 4000 to 5000 fields. The actual number of beam cycles of the target is substantially higher, because no statistics are kept of runs for experimental purposes, dosimetry measurements and calibrations.

## 6 Future Developments

A substantial effort has been put into the development of a new control system, with the goal to replace the aging computer and controller equipment and to make the system more user-friendly, more flexible and easier to maintain [4]. The first phase of this upgrade is nearing completion. It involves the replacement of the therapy portion of the system. In the original system both the accelerator / beam line control and the patient set-up are handled by a single PDP 11/23 computer. For the time being the PDP 11/23 will continue to control the proton beam part of the system. The therapy part will be replaced with a VME based system running the VxWorks operating system. The operator interface will be via X-window terminals and some panel mounted push-buttons connected to the existing programmable logic controller and the hardwired safety system.

At the same time some of the control system interface hardware is being modified. Additional safety features are under development, in particular with regards to the various mechanical motions of the therapy equipment.

Presently the new system is running for experimental beam delivery and is in the final stages of testing and fine tuning. Introduction into clinical service is expected later this year.

In recent years substantial interest has developed in the production of short lived alpha emitters, which can be attached to tumor seeking drugs. A prime candidate is 211-At with a half-life of 7.21 hours. This radionuclide is not

commercially available and because of its short half-life, it is preferably produced close to the point of use. 211-At is produced by bombarding a bismuth target with an alpha beam in the 30 MeV range. The alpha beam from the present internal cold cathode ion source in the Seattle cyclotron is limited to a few microamps, not sufficient for routine production of the desired quantities of 211-At. An upgrade to an external ion source with the capability to produce up to 50 μA of alpha beam from the cyclotron is presently being studied by a group at TRIUMF. The results of the preliminary design are reported elsewhere in these proceedings [5]. The testing and the final changeover to a new source must again be possible in the time frame of extended weekends, such that the routine therapy and PET operations can continue uninterrupted.

## 7 Conclusions

Operation of the clinical cyclotron facility continues with conventional neutron therapy and production of PET radionuclides. The development of methods to increase the efficacy of fast neutron therapy by using a boron neutron capture boost is progressing and the facility is well suited to make major contributions in this new area. The production of short lived alpha emitters for medical use is another interesting field, where the cyclotron will be a key element, and the necessary upgrade to deliver high intensity alpha beams is high on the priority list.

## References

[1] D.W.Nigg et al., to be published in *Proc. of the 8th Int. Symp. on Neutron Capture for Cancer, 13-18 Sep 98 in La Jolla, CA, USA.*

[2] D.W.Nigg et al., to be published in *Proc. of the 8th Int. Symp. on Neutron Capture for Cancer, 13-18 Sep 98 in La Jolla, CA, USA.*

[3] K.J.Stelzer et al., to be published in *Proc. of the 8th Int. Symp. on Neutron Capture for Cancer, 13-18 Sep 98 in La Jolla, CA, USA.*

[4] J.Jacky et al., *Proc. of the 10th International Conference of Z Users, Reading, UK, April 1997.* Lecture Notes in Computer Science 1212, 317-328, Springer 1997.

[5] B.F.Milton et al. in these proceedings.