CONTINUED OPERATION OF THE SEATTLE CLINICAL CYCLOTRON FACILITY

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ABSTRACT

The clinical cyclotron continues to be used for routine neutron therapy, and over 1100 patients have been treated over the past 7-3/4 years. Clinical results continue to be positive for certain tumor systems. PET isotopes are produced between patient runs.

System reliability has improved further and over the past 3 years less than 2% of the scheduled treatments had to be rescheduled for machine related reasons. Additional beams have been developed and used besides the routine 50.5 MeV proton beam. These include deuterons, $^3He^{++}$, and $^4He^{++}$ at several energies.

Slow neutrons are produced in a phantom or patient by moderation of the fast neutron beam. The potential use of these neutrons using Boron Neutron Capture (BNC) to enhance the present therapy beam is being explored. System improvements to allow more sophisticated treatment modes like conformal therapy are in progress.

1. INTRODUCTION

The clinical cyclotron facility at the University of Washington in Seattle is based on a Scanditronix built MC50 cyclotron with an isocentric neutron therapy gantry with leaf collimator. It has been in routine operation since 1984.[1] The original mission of the system was to conduct clinical trials comparing fast neutron therapy to other treatment modalities. This phase has been completed and at present no further trials have been funded. The clinical neutron therapy system continues to treat patients on a routine basis, concentrating on tumor systems which have shown promising results in the clinical trials.

Radionuclide production, primarily of short lived PET isotopes has been in operation since 1985 and the cyclotron use is expected to increase with the installation of a second PET scanner early next year.

The third use of the cyclotron beam is for experimental work to explore additional neutron therapy modalities, other radionuclide production schemes and some experiments by external users.

2. DAY TO DAY OPERATION

The original treatment schedule for fast neutron therapy has been changed from three treatments per week to four, with the same total treatment time of four weeks. Patients are now treated with 16 fractions instead of the original 12. This was done to reduce accute complications. As a result of this change the availability of the machine for other uses has been reduced. Mondays are now shared between experiments and maintenance. Tuesdays through Fridays are therapy days. Apart from major overhauls no weekend operations are scheduled, primarily for manpower reasons.

Radionuclide production continues as before with batch runs before the start of therapy and short runs between patients during the day on three to four days per week.

Apart from the increased demand because of the changed fractionation scheme, the beam use for therapy and radionuclide production has stayed fairly steady over the years. The number of patients treated continues to be determined by patient referral numbers and not by the availability of the system.

3. NEUTRON THERAPY

Neutron therapy has been proven to be superior to other treatment modalities in the case of salivary gland tumors.[2] Other tumors with positive results from clinical trials are locally advanced prostate cancer[3] and non-small cell lung carcinoma.[4] These tumors account presently for about 60% of the patient treatments performed with the neutron therapy unit (Table 1).

In order to keep normal tissue complication rates to a minimum, extensive shaping of the treatment fields to match the target volume is essential. The multi-leaf col-

Table 1. Treatment Sites Treated with Neutrons in 1991

Site	Patients Treated
Lung and Bronchus	31
Prostate Gland	28
Major Salivary Glands	20
Connective Tissue and Soft Tissue	7
Nasal Cavity and Sinus	6
Skin, Melanoma	6
Kidney	5
Brain	5
Leukemia	4
Nasopharynx	3
Others	18
Total	**133**

limator has proven to be very effective for this purpose. For the same reason multiple beam directions must be available, such as is possible with a rotating gantry.

4. OPERATIONAL STATISTICS

The operational statistics for the facility are summarized in Table 2. Rescheduled sessions are counted when they are rescheduled for a subsequent day. Minor delays during the day are not counted. Downtime is counted when the system is unavailable for technical reasons during the 10-hour operating days . The isotope production time reflects actual beam on target time for the production of radionuclides. Beamline switching time and tuning time is not counted.

Table 2 only shows the statistics for the standard operation with the 50.5 MeV proton beam for neutron therapy and PET radionuclide production. In addition, $^3He^{++}$ and $^4He^{++}$ beams have been developed at several energies for experimental production of radioisotopes. The internal PIG source is not very suited for this application and the beam intensity at the machine exit was limited to less than 5 μA with only 1 to 2 μA at the production station. If requests for Helium beams become more serious a new source will have to be acquired.

Also not shown are beam runs for quality assurance for the neutron therapy beam, for BNC experimental runs and some beam time for outside users.

5. EQUIPMENT PERFORMANCE

From Table 2 it can be seen that only very few patient sessions had to be rescheduled for equipment reasons during the past few years. This has been achieved by systematic improvements to the systems causing major interruptions and by building an extensive stock of spare parts.

The Anode Power Supply which used to cause major blocks of downtime has been improved with an upgrade kit from the manufacturer and has since run without problem.

The leaf collimator continues to operate reliably. The most major problem was a sticking leaf which was traced to a broken internal pin. It is not clear what caused the pin to break, one possibility is the original transport to Seattle. The collimator downtime reported is largely caused by bad cable connections. This is true also for failures in other systems such as the RF controls or power supply controls. We have started to replace or upgrade many of the connectors.

The new Beryllium target design reported at the last Cyclotron Conference[1] has worked well. The first prototype target lasted for 7100 therapy fields. It failed because of minute cracks in the copper beam stop which caused a vacuum leak from the cooling water. The leak developed slowly over a time period of about two weeks. The second target has now reached 8200 fields and is still in routine operation at 3kW of beam power.

A RTD thermometer probe was installed at the ion chamber location in the treatment head. It is used for the daily pressure/temperature correction of the dosimetry system. The daily variations of the built-in dosimetry system in comparison to an external standard is less than 0.5%.

6. TECHNOLOGISTS' EXPOSURE

Unlike standard radiation therapy with electrons and X-rays the technologists who set up the neutron patients are exposed to residual gamma radiation from the therapy equipment and the treatment room. In order to reduce the individual exposure, the technologists are rotated between neutron therapy and the other treatment machines in the department. The total dose for all technologists has been added each month and divided by the number of fields treated.

Year 6 (10/89 to 9/90): 5.1 ± 1.5 μSv per field
Year 7 (10/90 to 9/91): 3.9 ± 1.3 μSv per field

The variation shown is the standard deviation for the monthly exposure data. It is not known whether the difference between the two years is significant or not. The exposure per field is typically shared between two technologists.

This data can be compared to a similar study which was conducted for the first 18 months of operation.[5] At that time the technologists' exposure was 7.5 ± 1.9 μSv per field. The decreased exposure since then can be attributed to changes in working practices by the technologists and to more efficient set-up procedures as they became more familiar and confident with the equipment.

Comparisons with other similar facilities show that the Seattle exposures are somewhat lower, possibly because of the leaf collimator which requires no set-up time for blocking of irregular fields. Clatterbridge has reported 5.1 ± 1.8 μSv per field and technologist,[6] the NAC facility in South Africa 4.1 ± 1.5 μSv.[7]

7. PLANS FOR FUTURE IMPROVEMENTS

At present there are several projects in progress which will make the facility more reliable and easier to use:

1. Operation without the permanent presence of a cyclotron operator. After the start-up in the morning when the beam is tuned from the accelerator to the therapy target and a check of the proper operation of the dosimetry system is performed, the cyclotron operator so far was required to stay at the console to be able to respond to beam problems such as septum overtemperature, overcurrents on stray beam detectors because of magnet drifts and technical problems with the therapy equipment. As the stability of the system has improved, this permanent presence of the operator is no longer required and the person in charge of the machine can be on call somewhere else in the facility. We are at present experimenting with this new mode of operation.

2. Additional production station for ^{15}O. One of the major reasons for having an operator permanently stationed at the control console is his coordination function between neutron therapy and short ^{15}O runs between patients. The operator switches the beam line and coordinates the timing. Plans are being made to install a pop-up target in the beam line to the isocentric therapy unit. Such a system will allow a very rapid changeover from therapy to isotope production and back. As long as no therapy run is immediately ready or in progress, the group responsible for the PET isotope production will be free to insert their target at any time to produce ^{15}O.

3. Moving Floor Controls. A moving floor covers the 3m deep pit which allows the therapy gantry to rotate underneath the patient support assembly. The floor was delivered as part of the building and its automatic controls never worked. It has been run manually by the technologists. This is not very satisfactory and a new control system has been developed and is at present being installed.

4. Leaf Collimator Controller. The leaf collimator controller is at present the least reliable subsystem and work on a new controller has started.

5. Computer Control System. The PDP11/23 based control system is not very sophisticated and very difficult to maintain. Plans for a replacement system have progressed and are being reported separately.[8] A more elaborate control system is also needed for conformal therapy where the number of fields in a given treatment session is substantially increased and automatic remotely controlled patient set-up will be used.

Since the beginning of operation all major scheduled maintenance work has occurred over weekends, including Monday. On only two occasions has a therapy day been cancelled to gain an extra day for a scheduled modification. It is planned to continue with no scheduled downtime periods in order to minimize interruptions of the clinical operation.

8. BORON NEUTRON CAPTURE ENHANCEMENT OF FAST NEUTRON THERAPY

Thermal or epithermal neutrons can be used to deliver dose to cancerous tissue if a suitable substance with high neutron capture cross section can be selectively accumulated in the tumor.[9] 10-Boron is the most widely used target nucleus used so far. While the Seattle fast neutron beam has practically no intrinsic thermal component, some of the fast neutrons are moderated by the patient's tissue and a thermal energy component is added to the beam. Experimental investigations have shown that these slow neutrons can potentially be used to increase the dose to the tumor without affecting the surrounding tissue, if a suitable boron-10 carrier can be found.[10] During the past few years a series of experiments has been carried out to determine to what extent the fast neutron beam can be modified in order to enhance the BNC effect without losing the fast neutron beam characteristics. These experiments have taken advantage of the existing fixed beam room, which is not used for therapy. The fixed beam unit has a therapy head identical to the isocentric gantry, but has no leaf collimator. This arrangement allows to make modifications to the target and collimation system without interfering with the ongoing therapy. Further efforts to establish a basis for clinical applications of boron neutron capture are continuing.

9. CONCLUSION

The Clinical Cyclotron at the University of Washington Medical Center in Seattle has now been in successful operation for nearly eight years. It is used for routine fast neutron therapy and production of PET radionuclides. New medical applications, in particular boron neutron capture enhancement of fast neutron therapy may play a role in the future.

Table 2: OPERATING STATISTICS

YEAR	SCHEDULED TREATMENT SESSIONS	PERFORMED TREATMENT SESSIONS	RESCHEDULED SESSIONS PATIENT CAUSED	RESCHEDULED SESSIONS MACHINE CAUSED	DOWNTIME [HOURS]	FIELDS TREATED	PATIENTS STARTED	ISOTOPE PRODUCTION [HOURS]
OCT 84 SEP 85	1806	1430	27 (1.5%)	349 (19.3)		2954	142	0.0
OCT 85 SEP 86	1937	1623	83 (4.3%)	231 (11.9%)		3574	152	17.4
OCT 86 SEP 87	2235	1968	145 (6.5%)	122 (5.5%)		4016	160	68.6
OCT 87 SEP 88	1919	1630	173 (9.0%)	116 (6.0%)	143.0	3645	142	100.5
OCT 88 SEP 89	1812	1589	201 (11.1%)	22 (1.2%)	73.3	3455	157	69.8
OCT 89 SEP 90	1919	1575	273 (14.2%)	71 (3.7%)	87.3	3506	140	85.4
OCT 90 SEP 91	2239	1947	277 (12.4%)	15 (0.7%)	38.7	4360	133	62.6
OCT 91 JUN 92	1718	1569	129 (7.5%)	20 (1.2%)	28.2	3729	102	44.8
TOTAL	**15585 (100%)**	**13331 (85.5%)**	**1308 (8.4%)**	**946 (6.1%)**		**29239**	**1128**	**449.1**

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