ROUTINE OPERATION OF THE SEATTLE CLINICAL CYCLOTRON FACILITY

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ABSTRACT

The Clinical Neutron Therapy System (CNTS) at the University Medical Center in Seattle has been in use for patient treatments for 4-1/2 years. In addition, radionuclides have been produced for 3-1/2 years in conjunction with a PET facility which has been in routine use for 1-1/2 years.

During the first three years, downtime was largely related to the prototype nature of the facility and the inexperience of the staff. This initial phase is now over and the operation has become routine. Weak components in the system were identified and improvements have been made to all problem areas or are planned for the near future. The reliability of the system has increased substantially. The number of therapy sessions which had to be rescheduled for machine related reasons has dropped from around 20% to less than 5%.

Improved techniques to verify the congruence of the treatment beam with the target volume have been developed. Other modifications are aimed at a more sophisticated use of the equipment. A massive upgrade of the control system software and hardware is required.

1 INTRODUCTION

Cancer therapy with fast neutrons continues to exhibit favorable results for several selected disease sites. In particular, patients with inoperable/recurrent salivary gland tumors are no longer being treated under formal protocol studies since fast neutron therapy seems to be the "treatment of choice" for this tumor system[1,2]. Positive results continue to hold for prostate gland tumors[3]. There are preliminary results indicating an advantage of neutron therapy in the case of non-small lung cell carcinoma[4]. Potential benefits are seen for some inoperable sarcomas[5].

The clinical cyclotron at the University of Washington Medical Center was among the first systems specifically built for neutron therapy in a hospital environment. Patient treatments started in October 1984.

A description of the facility, of the equipment installation and of the initial operation is given in earlier cyclotron conference proceedings [6,7].

Production of radioisotopes[8] for the PET scanner located in the Nuclear Medicine Department of the Medical Center is now routinely done before and between therapy operation.

2 DAY TO DAY OPERATION

The initial schedule of three ten-hour neutron therapy days on Tuesday, Wednesday and Thursday, experimental work on Friday and maintenance on Monday is still in effect and has worked well. Friday is also used for treatment of AVM's (arterio-venous malformation) of the brain. On Tuesday and Thursday a 30 minute isotope run is scheduled before the begin of therapy. It is primarily used for batch production of 11-C or 18-F. Production of 15-O is done in short (3min) runs between treatments. This is possible because the isotope station is built for operation with the 50.5 MeV proton beam used for neutron therapy. Switching between therapy and isotope station can easily be done in two minutes or less.

There is a cyclotron operator present at the control console at all times during the operation of the system. Originally his main task was to restart the RF system and check the beam quality prior to each therapy run. This step has been eliminated and the cyclotron is now started automatically by the therapy technologists. The operator is therefore available for other tasks, such as minor repairs. He still must be present to recover the system from unscheduled shut-downs, caused for example by excessive losses on protective beam pick-ups along the beamline. The operator also coordinates the beam use between therapy and isotope production and is responsible for the line switching.

So far the interwoven use of the cyclotron by two users has not created any major problems. Minor delays can result from this operation and a good relationship between the two user groups is essential for the smooth operation.

3 THERAPY OPERATIONS

The standard treatment procedure with 12 treatment sessions spread over 4 weeks has remained unchanged. The average number of treatment fields per session has remained constant at 2.0 to 2.2. With a typical time of 15 minutes per treatment field the capacity of the facility for a ten-hour day is 40 fields. Taking into account some down-time and time lost because of patient related problems, this translates into about 200 available treatment sessions per month.

Table 1 shows the treatment statistics for the first 4-1/2 years of operation.The table shows the number of treatment sessions scheduled and the number of treatments actually performed to that schedule. If a treatment was not carried out, that is had to be rescheduled, a distinction is made between patient related causes (sickness, no-shows) and equipment malfunctions. Note that these statistics do not reflect minor delays during a treatment day, a session is counted as rescheduled if it had to be performed on a subsequent day.

Table 1: OPERATIONAL STATISTICS FOR THE SEATTLE CLINICAL NEUTRON THERAPY FACILITY

YEAR	PATIENT SESSIONS SCHEDULED	PATIENT SESSIONS PERFORMED	FIELDS PERFORMED	SESSIONS PATIENT RELATED	RESCHEDULED MACHINE RELATED	NUMBER OF PATIENTS STARTED
OCT 84-SEP 85	1806	1430	2954	27 (1.5%)	349 (19.3%)	142
OCT 85-SEP 86	1937	1623	3574	8 (4.3%)	231 (11.9%)	152
OCT 86-SEP 87	2235	1968	4016	145 (6.5%)	122 (5.5%)	160
OCT 87-SEP 88	1919	1630	3645	173 (9.0%)	116 (6.0%)	142
OCT 88-APR 89	920	795	1749	104 (11.3%)	21 (2.3%)	81

An average therapy run takes 3 to 5 minutes of beam time. The unused time is available for other uses. Typically 3 min isotope production runs are fitted between successive patients. The set-up time for the second and third field of the same patient can be very short and may be too short to switch to isotope production.

Over the past few years the treatment fields have become more complex as the possibilities of the leaf collimator system are being utilized to greater extent. It is important to verify the position of the neutron beam with respect to the patient's anatomy. Neutrograms do not show sufficient anatomical details to be useful for this purpose. The treatment head is equiped with an X-ray tube which can be inserted on the beamline axis, 122 mm downstream from the Beryllium target. For most applications X-ray images showing the outline of the treatment field within the patient are sufficient. Because of the geometric difference in origin of the neutrons and X-rays they are not always collimated by the same edges of the collimator leaves, and large discrepancies between the two beams are possible. In particular this is true for fields with a mid-line block or similar arrangement. In these cases the best results can be achieved by superimposing, on the same film, a neutrogram showing the outline of the treatment field on an X-ray exposure showing the anatomy.

Over the past 2-1/2 years 18 patients were treated for an AVM (arterio-venous malformation) of the brain. This treatment is performed in a single session with typically 9 small precision fields. As the total facility use time is in the order of 4 hours, these procedures are scheduled on a case by case basis on Fridays.

4 PERFORMANCE

From Table 1 it can be seen that down-time for equipment related reasons has decreased substantially since the beginning of operation.

The Seattle facility was the first neutron therapy system produced by the manufacturer. Most of the major components were the first of their kind built by Scanditronix. These included the 50 MeV cyclotron, the therapy gantry, the leaf collimator and the computer control system. Many of the problems encountered during the first three years had to do with the fact that the system is a prototype. In addition the location in a radiation therapy department of a hospital complicated servicing of the equipment as all the support facilities had to be built up from zero. Fortunately the location on a University campus brought easy access to several machine shops and other facilities. The on-site staff is primarily responsible for the operation of the facility, for routine maintenance, for trouble- shooting, for making repairs and for development of modifications. A radiation therapy department does not usually have the manpower to deal with major repairs and modifications, and we are relying on outside support for these occasions.

Some of the early down time was aggravated by the fact that the staff was inexperienced and repairs took longer. Also the stock of spare parts was systematically built up as experience with the system grew.

The leaf collimator has had very few failures, primarily caused by the leaf drive motors which were not geared properly. As they fail they are being replaced with the proper type and none of the replacements has failed so far. Including experimental runs the collimator has been used to set up 25,000 to 30,000 fields with only minor problems.

5 SYSTEM IMPROVEMENTS

5.1 Extraction System

During the initial operation several major failures in the extraction system caused down time and resulted in relatively high personnel exposure. At several occasions the septum was damaged and had to be replaced. The septum temperature monitor, which uses a thermocouple sensor, initially did not work properly. After this problem was solved no more damage to the septum was observed.

The graphite beam pick-ups along the extraction path turned out to be too thin for the full energy beam, resulting in incorrect readouts and heating of the support structure behind the pick-ups. This was corrected.

5.2 Anode Power Supply

The high voltage rectifier set in the anode supply has a limited life time and shorts out every two years or so. A different set of rectifiers is on order.

On two occasions problems developed involving the series power tube. Repair was slow because a replacement was not immediately available and because several components in the vicinity of the tube were damaged as well. On the last occasion down time was over a week, the longest interruption in the treatment schedule since the beginning of operation.

5.3 Beryllium target

While the original targets from the manufacturer could be operated to the full specified intensity (0.5 Gy/min at isocenter, requiring 60 μA of target current) it was not possible to maintain this operation on a day to day basis as the targets developed cracks in the housing, creating leaks from the cooling circuit into the vacuum.

A redesigned target system has now been in operation at full power for about 1-1/2 years. It has run for over 5000 treatment fields, not counting experimental runs, and no degradation in performance has been observed. For test purposes the intensity was increased to 70 μA with no immediately apparent problem. Routine operation above 60 μA on target is limited by the extraction efficiency of the cyclotron. Acceptable septum temperatures at over 60 μA target current (65 μA extracted) can only be maintained with constant operator attention.

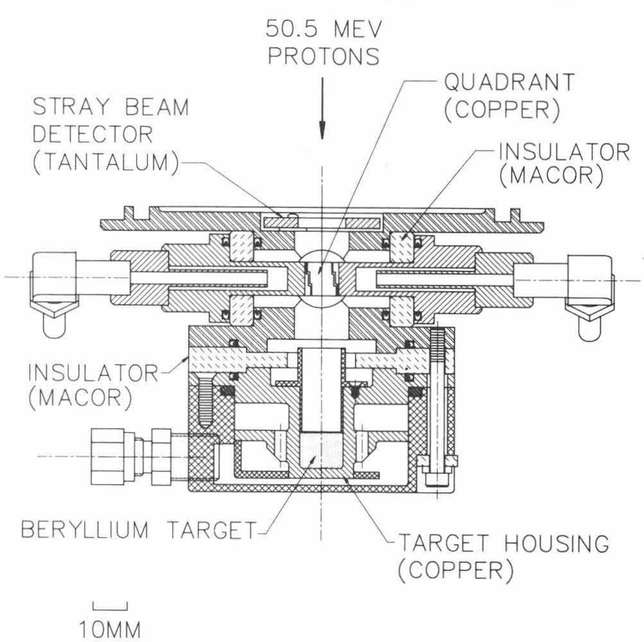
The electron suppression electrode provided with the original target did not work as intended and was replaced by a chimney shaped structure which reduces the solid angle for electrons trying to escape the target.

The ratio between integrated neutron dose and collected target charge is constant within 1%, the accuracy is limited by the target current monitoring which can exhibit offset currents.

On several occasions targets were destroyed because of the lack of a protection electrode at the target entry. A small deviation of the gantry magnet setting can steer the beam onto the entry flange and the heat destroys the quadrant vacuum seals. To prevent this, a ring shaped pick-up was added in front of the quadrant system. If beam is detected on this ring, the cyclotron is turned off.

The new target design is shown in Fig.1.

Fig.1 Neutron Production Target for Therapy



The 50.5 MeV proton beam loses half its energy in the 10.5 mm long cylindrical Beryllium target and is stopped in the copper backing. The cooling water passes at the back of the copper stop, then enters 12 holes in the target housing, cooling the target on all sides before being collected on the beam entry side.

5.4 Neutron Therapy Head

The therapy head contains the target, dose monitoring system, the X-ray tube for port films, the beam defining lamp system, the flattening filter system and an internal wedge system to produce asymmetric dose distributions. Three wedges can be selected and oriented in the four principal directions. The head also contains the bearing for the rotation of the leaf collimator.

In order to power the various mechanical drives and to be able to read position signals, two cable take-up systems connect fixed portions of the head to rotating parts. During the first years we experienced breaks in the take-up wires of the wedge rotation system. The system was modified to reduce the tension on the wires and it has worked well since.

Another major failure occurred within the collimator rotation bearing. The plastic spacers which separate the balls of the wire-race bearing disintegrated from radiation damage and the collimator could not be rotated any longer. The plastic spacers were replaced by a continuous strip of brass with holes for the bearing balls. The same modification was done to the wedge rotation bearing.

The availability of a two-ton hoist on a rail in the treatment room turned out to be very advantageous for these head repairs. All repair work was done in 4-day periods from Friday to Monday, and no interruption of the therapy schedule was caused by these failures.

5.5 Leaf Collimator Controller

This Z-80 microprocessor based unit is at the moment the limiting factor for a more efficient use of the collimator. The internal control sequence for achieving a new collimator setting is very cumbersome and it can take over a minute to achieve a new configuration. The processor also responds unfavorably to minor mechanical or electrical problems, such as positioning errors when two opposing leaves are closed against each other.

A new system is under development using a MicroVAX II computer. The goal is to achieve any new setting within less than 15 seconds. The new system will also allow more complex uses envisioned for the future, for instance for conformation therapy.

5.6 Beam Stability

The beam from the cyclotron exhibits slow drifts in its tuning properties. In order to keep the system within acceptable limits with regard to septum temperature and beam losses along the beam line frequent operator intervention was necessary. The fact that the cyclotron is turned off over night contributes also to the drifts.

A systematic search for the cause of these drifts has been started and is continuing. Several parameters were found to be changing because of temperature drifts of buffer amplifiers. We have started to modify these circuits. While there is still more work to be done, it is now possible to run the cyclotron for several hours without operator intervention. The control system was changed to take advantage of this.

The RF system is now started automatically when the Radiation Technologists press their "start" button. While the beam plug in the wall between the cyclotron vault and the therapy room is opened and radiation shutters in the head and on the collimator are removed, the RF system is tuned and ramped to full dee-voltage. The beam is temporarily stopped on a Faraday cup which is opened as soon as the beam path to the target is clear. This automatic operation works well and frees up the operator for other tasks.

An improved stability of the beam will let us increase the beam intensity as crucial parameters like the septum temperature will stay longer within acceptable limits.

5.7 Ion Source

An investigation was completed to determine the best slit configuration of the internal PIG source. The original slit is 10 x 1 mm. It was found that for similar arc conditions the slit could be shortened to 5 or 6 mm with no change in beam intensity. As the gas flow can be reduced with the shorter slit and the local vacuum at the machine center improves, it was decided to switch to shorter slits. At present we are running with a 5 x 1.5 mm slit with good results.

A total of 11 slit configurations were tested and within the accuracy of the experiment no change in external beam characteristics or in septum temperature was observed.

5.8 Future Projects

Among others, the following improvements are planned for the near future:

- Improve the beam defining light system to provide a sharper definition of the field edge.
- Addition of a "no filter" position to the flattening filter system to increase the dose rate in cases where beam flattening is not needed.
- Improve the moving floor system which covers the gantry pit. Provide collision protection and automatic tracking.
- Replace the control system hardware and software to make the system faster, easier to operate and easier to maintain and adapt to new applications.

6 FACTORY SUPPORT

As there are only a limited number of neutron therapy systems in operation, the manufacturer cannot be expected to provide an extensive support service. While information from the factory is readily available, access to spare parts can be very time consuming and delivery times of 6 months are routine. A local stock of spare parts is therefore essential. Another problem is the software support of the control system, in particular with regard to the peripheral microprocessors.

Apart from one service call at the end of the one-year warranty period all service work was performed by on-site staff, supported by on-campus workshops and services. On several occasions crucial information from the manufacturer, received over the phone or in FAX messages, helped keeping downtime to a minimum.

7 CONCLUSIONS

The Seattle Neutron Therapy System has now been in routine operation for 4-1/2 years. It has turned into a reliable instrument for cancer therapy and isotope production. The basic system design is intrinsically sound. In order to fully achieve the specified performance, a substantial amount of work had to be accomplished by on-site staff. Future efforts are aimed at further increasing the reliability and to make the system easier to use, in particular as more sophisticated treatment procedures are being introduced.

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