THE MIDWEST INSTITUTE FOR NEUTRON THERAPY (MINT)

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ABSTRACT

A description of the planned facility for neutron therapy and nuclear medicine is presented. This facility would have a 20 to 70 MeV proton accelerator, with an external beam current of 200 μA. Simultaneous operations for nuclear medicine and therapy may take place by beam extraction at two different energies, through separate ports, to target and treatment rooms. Well shielded localized areas for planned beam losses are anticipated. At least two neutron beams of different penetrations will be available for optimizing patient treatment. A low intensity 70 MeV proton beam may also be extracted for eye melanoma treatments. Computer controls will be derived from those now in use at Fermilab. Plans to maximize system reliability, to minimize costs and to reduce exposure to personnel will also be discussed.

INTRODUCTION

The Midwest Institute for Neutron Therapy (MINT) was conceived some five years ago. Then, as time passed, and emphasis shifted from neutron therapy to the nuclear medicine, the MINT became the MI^{3}NT (Midwest Institute for Imaging, Instrumentation and Neutron Therapy). However, some of the principles remained unchanged. These are:

(1) High reliability of operations;

(2) Flexible neutron therapy facility;

(3) Highly flexible proton beam distribution; and

(4) Operations at minimum cost.

Before addressing these four items, a review of the MI^{3}NT system components is in order.

ACCELERATOR

Two types of accelerators have been under consideration. One is an H$^-$ FFAG, also known as AVF, cyclotron, and the other one a linac with an RFQ input stage (Ha81). What is sought in these accelerators is high extraction efficiency, simple and reliable operation, and fast change of proton beam current and energy. Experience at Fermilab indicates that a linac, if properly

aligned, is nearly lossless, requires only very minimal human supervision and is very reliable (beam has been available over 95% of the scheduled time). Use of a multitank architecture in a linac would allow fast changing of discrete beam energies. An H⁻ cyclotron may have an extraction efficiency of 98% if suitable care is taken with the RF and magnetic field to control orbit phase stability (He82). The only real advantage of a linac is the possibility of very high average beam currents. On the other hand, the continuous beam characteristics of a cyclotron make the average and peak powers dissipated in the target the same. This may be important with regard to the reliability and efficiency of certain targets.

The actual accelerator specifications would vary with the type chosen. However, the general requirements would include:

Energy range: approximately 20 MeV to 70 MeV;

External beam current: $\geq$200 µA;

Duty cycle: cyclotron = continuous,

                               linac = 20% to 50% at 60 to 180 Hz;

Number of simultaneous or nearly simultaneous external beams of equal or unequal energy: 2;

Current splitting between the two external beams: arbitrary, but subject to sum of currents $\leq$200 µA.

The above energy range was chosen based on the following considerations:

(a) The maximum energy, about 70 MeV, is needed to permit uninterrupted neutron therapy research with a high penetration beam (16 cm depth for half maximum dose in tissue for a 10x10 cm^2 beam at SAD = 170 cm). Therapy at Fermilab is presently being done with a p(66)Be(49) neutron beam (Ro81). The MI^3NT, might be using a p(70)Be(45) beam. This proton energy would also permit the production of very pure ^{123}I via the $^{127}I(p,5n)$ ^{123}Xe reaction. (b) The intermediate energy, about 35 MeV, could generate a low penetration p(35)Be neutron therapy beam comparable to ^{60}Co gamma rays. This beam would be used mostly for head and neck irradiations as well as some brain tumors.

(c) The low energy, about 20 MeV, would be used for the production of short lived positron emitters such as ^{11}C, ^{13}N, ^{15}O and ^{18}F.

SWITCHYARD

All magnets would be under computer control (see below). Beam lines would direct the proton beams simultaneously (or almost so) to the appropriate treatment and target rooms. A well shielded beam dump would be provided for beam studies. Beam halos would be removed by graphite collimators inside steel shields surrounded by lead. This would allow minimal remanent exposure rates in the accelerator-switchyard vault after beam turn-off.

These small apperture slits, coupled with rather large beam pipes (10-15 cm diameter), would effectively constitute low pass filters, affording protection to the accelerator proper through use of fast acting valves in case of catastrophic target failures.

CENTRAL CONTROL COMPUTERS

All accelerator controls would be adjusted and all variables would be monitored via a central control computer (CCC).

To provide independent control of the proton beams to be used for nuclear medicine (NM) and neutron therapy, two control computers are planned. A CCC such as a PDP-11/23 would be used to control all hardware, communicate with the NM computer and the local controls at the treatment rooms, as well as keep records of all operations including patient treatments.

TARGETS AND TARGET ROOMS

Targets and target handling systems will be specialized and, in general, duplicated in each target room. Thus, if a target system fails, a similar one would be available in another target room. Although two target rooms have been under consideration so far, there may be advantages in having more target rooms and fewer target systems in each.

Each target system would be individually shielded. This shielding would be designed to simplify maintenance, repairs, and replacement with as low as possible dose to personnel.

Targets will be transferred from the irradiation system to the chemistry cells via suitable tubing or pneumatic "rabbits".

The chemistry cells would be specialized. Thus, it will be relatively simple to program a second computer to control target systems, target transport, chemical operations and quality control. This computer would request beam from the CCC specifying proton beam energy and current, target room, target system, and times to start and terminate the target irradiation. Thus, radiopharmaceuticals would automatically be ready for use at the desired time.

Standard radiation safety features would be built into the facility to control spills, store and ship radionuclides and, in general, comply with the letter and spirit of state and federal rules and regulations.

NEUTRON THERAPY

Two neutron beams, p(70)Be(45) and p($\simeq$35)Be, would be provided, with the targets mounted on an isocentric gantry. The usual components of modern X-ray therapy systems would be included: gantry rotation over $\pm190^{o}$, continuously adjustable and rotatable collimators, field lights, laser beams coaxial with the neutron beams, built-in verification x-ray tubes, twin transmission ionization chambers and treatment couches with the usual degrees of freedom. In addition, the neutron beams would be modified through the use of hydrogenous hardening filters and non-hydrogenous flattening filters and wedges (Ro82, Te82).

All adjustable parameters would be under computer control and monitoring. The patients would be positioned with the center of the target volume at the isocenter using appropriate laser-light planes. From then on, the CCC would take over and the radiation therapy technologists (RTTs), would be verifiers of proper operation of the treatment set-up rather than workers adjusting all kind of variables. The data for the patient set-up would reside both in the patients' individual floppy disks and in the CCC hard disk memories.

The neutron source shielding in the gantry would be designed keeping two different criteria in mind:

(1) minimum dose absorbed by the patient outside the nominal neutron beam during treatment, and

(2) minimum remanent exposure rate after end of treatment.

The shielding specifications would therefore include:

(1) Maximum total dose rate to soft-tissue at isoplane (plane perpendicular to central axis through the I/C) and at 10 cm or more from beam axis shall be 1% or less of the total dose rate at the I/C for a field size of $10x10cm^2$ (Am80);

(2) Maximum total dose rate to soft-tissue at any point 30 cm from the gantry shield in the hemisphere away from the patient shall not exceed 1% of the total dose rate to soft-tissue at the I/C;

(3) The combination of shielding design, beam losses, and shielding materials in the gantry shall be such that, after one year of standard operation, at the end of a typical treatment day, one minute after the last irradiation, measurements made at 30 cm away from the surface of the gantry with the collimators closed shall register exposure rates of less than 1 mR/hr. Standard operation for the above specification consists of five treatment days a week for fifty two weeks a year utilizing a 70 MeV, 100 µA proton beam on a thick Be target. A typical treatment day consists of six four-minute beam periods per hour for ten consecutive hours.

(4) To minimize dose to personnel working near the isocenter during patient set-up, the collimator jaws shall automatically close whenever access to the treatment room is made. This precaution will shield the RTTs from most of the remanent radioactivity from the target area and the collimators themselves.

PROTON THERAPY

Proton energies of 70 MeV are suitable for direct treatment of eye melanomas and other shallow tumors (Ve82). Since eye melanoma and shallow tumors not suitable for electron beam therapy would be rather uncommon, it has been planned to arrange one therapy room for dual service permitting use of a neutron or a proton beam.

Now, it is possible to consider items 1 through 4 mentioned in the introduction.

RELIABILITY

This is achieved in four ways: (1) by conservative design and under-rating of components; (2) by standardization of parts, modularity, and stocking of appropriate spares; (3) by controlling beam losses, making it relatively easy and safe to work around the beam areas of the facility; and (4) by having suitable diagnostic

capabilities in the CCC.

FLEXIBLE NEUTRON THERAPY FACILITY

This has already been discussed in such areas as variable penetration neutron beams, computer control and monitoring of nearly all variables and allowing the RTTs time to think about the procedures underway by freeing them from mechanical tasks. Dynamic treatment planning would also be easy to implement.

HIGHLY FLEXIBLE PROTON BEAM DISTRIBUTION

This flexibility has two reasons. The first one is psychological: in order to gain the broadest support from the medical community, both main users, nuclear medicine and radiation therapy, should be on an equal standing. The second reason is financial: the accelerator must be productive the largest possible fraction of the time. Thus, its beam should be available not only to produce neutron beams for therapy and radiopharmaceuticals for "in-house" use, but also to produce radiopharmaceuticals suitable for sale to medical and industrial users.

OPERATIONS AT MINIMUM COST

Examining the operational costs of any research oriented facility, manpower costs are most often seen as a major, if not the single largest, item in the budget. Therefore, state-of-the-art control computers with good diagnostics and fast record keeping capabilities are extremely useful to detect (and correct!) components approaching failure and also to reconstruct the sequence of events leading to such failures. Trouble-shooting and start-up become much more easy, too.

Another cost saving capability of a properly programmed control computer is that no operator is needed when irradiating targets for production of radionuclides overnight or on week-ends. "Autopilot" software may keep an accelerator operating safely for many days (He82). On the other hand, should the CCC be unable to handle an unusual combination of parameter values, it can dial the operator on duty at his/her home and asks for help. Suitable CRT terminals and modems are no longer costly.

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REFERENCES

Am80. American Association of Physicists in Medicine, Report #7, 1980, "Protocol for Neutron Dosimetry", New York: American Institute of Physics.

Ha81. Hansborough, L. D., 1981, "PIGMI: A Design Report for a Pion Generator for Medical Irradiations," Los Alamos National Laboratory, LA-8880.

He82. Hendry, G., 1982, The Cyclotron Corporation, Berkeley, CA, private communication.

Ro81. Rosenberg, I., Awschalom, M., 1981, "Characterization of a p(66)Be(49) Neutron Therapy Beam: I. Central Axis Depth Dose and Off-axis Ratios", Med. Phys. 8, 99-104.

Ro82. Rosenberg, I., Awschalom, M., Ten Haken, R. K., 1982, "The Effects of Hydrogenous and Nonhydrogenous Filters on the Quality of a p(66)Be(49) Neutron Beam", Med. Phys. $\underline{9}$, 199-203.

Te82. Ten Haken, R. K., Awschalom, M., Rosenberg, I., 1982, "The Use of Nonhydrogeneous Wedges for Therapeutic Neutron Beam Shaping,", Med. Phys. $\underline{9}$, 204-207.

Ve82. Verhey, L. J., Munzenrider, J. E., 1982, "Proton Beam Therapy," Ann. Rev. Biophys. Bioeng. $\underline{11}$, 331.