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# Proton Linac for Hospital-Based Fast Neutron Therapy and Radioisotope Production*

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## Abstract

Recent developments in linac technology have led to the design of a hospital-based proton linac for fast neutron therapy. The 180 microamp average current allows beam to be diverted for radioisotope production during treatments while maintaining an acceptable dose rate. During dedicated operation, dose rates greater than 280 neutron rads per minute are achievable at depth, DMAX = 1.6 cm with source to axis distance, SAD = 190 cm. Maximum machine energy is 70 MeV and several intermediate energies are available for optimizing production of isotopes for Positron Emission Tomagraphy and other medical applications. The linac can be used to produce a horizontal beam for a treatment room having a special chair designed for isocentric patient positioning or a gantry can be added to the downstream end of the linac for conventional patient positioning. The 70 MeV protons can also be used for proton therapy for ocular melanomas.

## Introduction

For over a decade the National Cancer Institute has conducted clinical trials to determine the efficacy of neutrons in the treatment of malignant tumors. Results established neutron therapy as the treatment of choice for certain tumors known to be resistant to conventional radiation therapy[2][3][4][5]. In addition, follow-up studies have shown that the severity of late side effects decreases significantly as the energy of the neutron beam increases.[6] The highest energy neutron therapy beam in the United States is generated by a proton linac constructed for high energy physics research at Fermi National Accelerator Laboratory (Fermilab). Until now, the large size of the Cockcroft-Walton pre-injector and the ~60 meter length of the linac, as well as the power and maintenance costs, have prohibited duplicating this facility in a hospital setting. However, recent advances in linac technology are making it possible for hospitals to use a proton linac as a neutron source.[1]

Improvements in proton source designs and radio-frequency (rf) systems have dramatically reduced the physical size of a 70 MeV proton linac. A modern 70 MeV linac consists of one or more cylindrical tanks about 46 cm in diameter and has a total length about 20 meters. The Cockroft-Walton injector is replaced by a system consisting of a duoplasmatron source, low energy beam transport module (LEBT) and a radio-frequency quadrupole (RFQ) linac.

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|---|---|
| Beam Energies | 19, 36, 53 & 70 MeV |
| Peak Beam Current | 50 milliamperes |
| Average Beam Current | 180 microamperes |
| Pulse Length | 60 microseconds |
| Pulse Repetition Rate | 60 Hz |
| Operating Frequency | 425 MHz |
| Peak Power | 8.8 MW |
| Duty Factor | 0.36% |
| Total Power | 200 kW |
| RFQ Output Energy | 2 MeV |
| Ion Source Energy | 20 keV |
| Accelerator Overall Length | 24 meter |
| Linac Tank Diameter | 46 cm |
| Linac Mass | 260 kg/meter |

Table 1: Parameters of a Medical Proton Linac.

These components bring the total length of the neutron generator to about 24 meters. As has been suggested by the proposers of the PIGMI project[7], such a machine could be located in a tunnel under an existing parking lot at a typical hospital. The structure housing the machine would resemble a typical hospital corridor in both length and cross sectional area. Power requirements are about 200 kW, which compares favorably with the 600 kW required to run a 70 MeV cyclotron for fast neutron therapy[8]. Radiation levels are minimal along the length of the linac and adequate shielding can be achieved using ordinary cinder block construction. (Of course, the target area and treatment rooms would require shielding comparable to that used for conventional photon therapy.) Most components of the machine are commercially available and are used in other, nonmedical applications so that the first hospital to build the proton linac described here would not be dealing with the problems of repairing and maintaining one-of-a-kind equipment. Thus, it is now realistic to consider more widespread clinical use of a medical proton linac for generating neutrons and radioisotopes.

## Machine Parameters

We report here the results of a design study which combined sophisticated accelerator computer codes with practical operating experience from existing machines to demonstrate that construction of a dedicated medical proton linac is technically feasible. Table 1 summarizes the operating parameters and Figure 1 shows an artist's conception of the machine we have designed. The linac itself is of the conventional drift tube type (DTL). Beam is injected into the DTL from an RFQ, which is a special type of linear accelerator able to efficiently accelerate proton beams from very low energies. Our design for the RFQ has evolved over many years and a number of these RFQ's are in use commercially. An RFQ of similar design is in use as an injector for a medical proton synchrotron.[9] There are several possible designs for the LEBT, some of which are already in use in existing systems and others which are yet to be tested.[10][11] [12] The controls system would be the same as the recently upgraded controls system in use at Fermilab's Neutron Therapy Facility.[13]

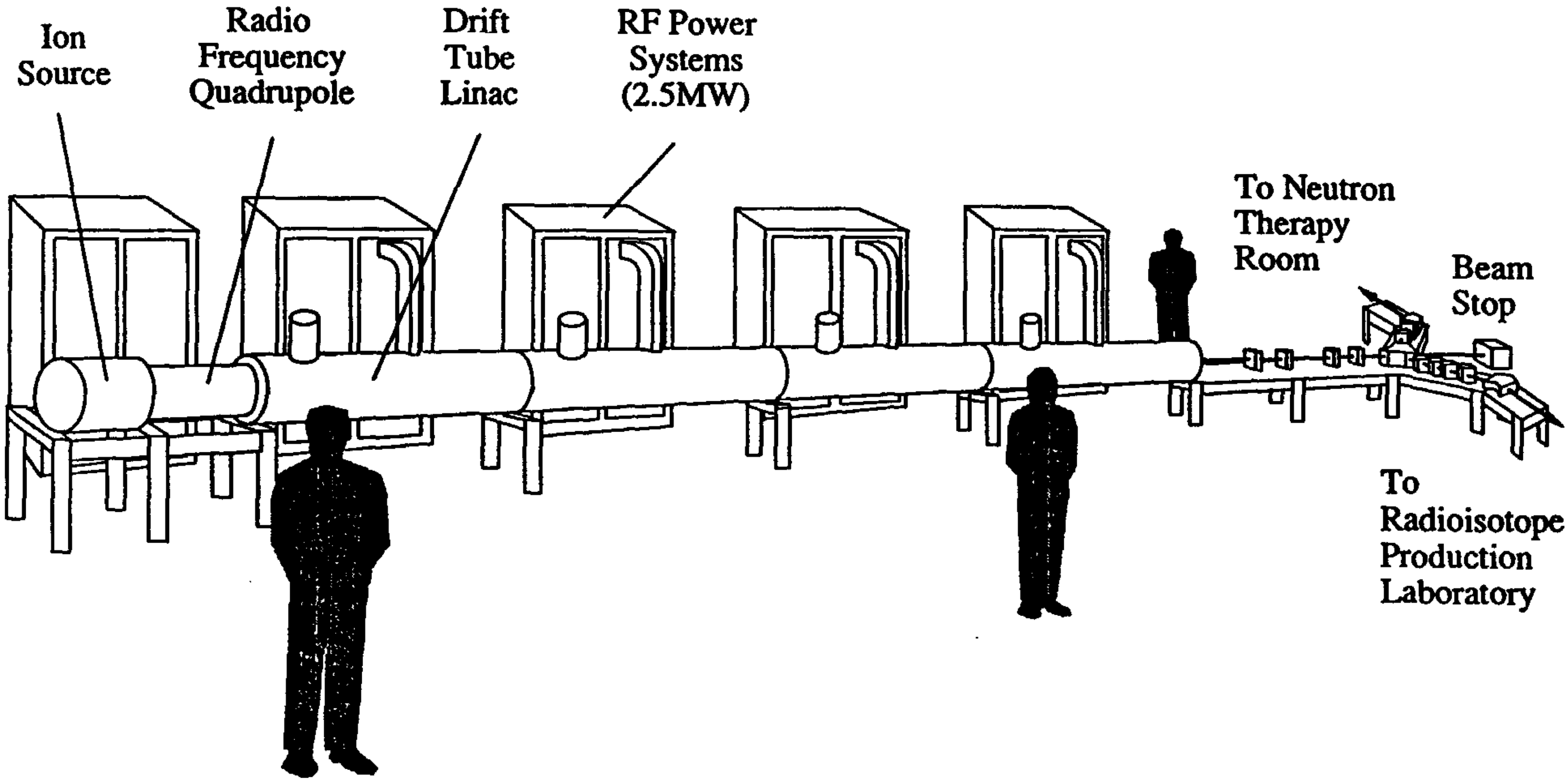


Figure 1. Artist's conception of a proton linac for neutron therapy and radioisotope production.

## Clinical Options

The intense beam available in a linac makes it possible to use the beam for other applications during treatment times. In fact, the normal mode of operation at Fermilab allows beam to be diverted from therapy to the physics research program once every 2.5 seconds without interrupting treatments. The controls system mentioned above handles the beam switching automatically, without intervention from an operator. The same controls system could be used to divert beam from therapy to isotope production during treatments. This means that isotope production could be scheduled as needed during the day, independent of the treatment schedule. A 70 MeV linac is best suited for producing medically useful isotopes such as $^{52}$Fe, $^{123}$I and $^{127}$Xe[14][15]. Some of the more commonly used isotopes, such as $^{11}$C have maximum production cross sections at proton energies around 8 MeV, while $^{111}$In, which could be used in the manufacture of monoclonal imaging products, has a maximum production cross section at 20 MeV.[16] Our design makes several intermediate energies available in order to minimize the amount of energy wasted and the amount of radioactive contamination produced when beam is degraded to the lower energies needed for some isotopes. One technical question which must still be resolved is the design of targets for producing the isotopes. It is likely that some existing designs could handle the 180 microampere average current but more engineering must be done to develop targets that can withstand the 50 milliampere peak current.[17]

Protons produced by this machine are energetic enough to be used for proton therapy of ocular melanomas. Implementation of this therapy would require installation of a collimating or diffractive scattering system to reduce the intensity of the beam to which the patient is exposed. An appropriately designed switchyard and beam transport system would allow both, the proton and neutron beams to be directed into the same treatment room if the anticipated patient load made the construction of two separate treatment rooms economically impractical.

## Conclusion

This study has shown that it is possible and practical to use a proton linac for neutron therapy in a hospital setting. Compared to typical medical cyclotrons, linacs can produce more protons, with less radioactive contamination, at a lower cost. The machine we have designed can be used for fast neutron therapy, proton therapy for ocular melanomas, and radioisotope production. The ability to run at several proton energies provides flexibility and efficiency in preparing isotopes. Hence, we recommend that future neutron therapy facilities use proton linacs to produce their neutron beams.

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Fred Mills and Frank Cole provided encouragement and technical advice. Rudy Risler and Robert Hamm shared the benefit of their experiences with related accelerators. Albert Tsang did the research on isotope production cross sections using proton beams.

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