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A LOW COST/LOW INTENSITY 50 MEV PROTON IRRADIATION FACILITY

1985 Particle Accelerator

S.L. Kramer and R.L. Martin
Argonne National Laboratory, Argonne, IL 60439

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Abstract

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Protons have been proposed as one of the most useful particles for radiation therapy, but have found limited use due to the cost and scarcity of medium energy proton accelerators. However the highly successful program on the Harvard Cyclotron has increased interest in expanding the number of treatment facilities. In order to demonstrate that high intensity proton accelerators are not required and to gain experience with treating patients using protons, a low cost and low intensity source of 50 MeV protons was developed at Argonne. Although the beam penetration is limited to 22 mm, the beam is capable of treating a major fraction of the ocular melanoma tumors treated at the Harvard Cyclotron. This beam operates parasitically with the Rapid Cycling Synchrotron at Argonne using a source of 50 MeV H^+ atoms which are produced by stripping in the gas of the 50 MeV H^+ linear accelerator. A stripping fraction of about $3-5 \times 10^{-5}$ is observed and yields a 0.4 namp beam of protons. Results on the properties and operation of this parasitic beam are presented.

Introduction

The applications of low intensity, medium energy proton beams for material science, chemical analysis and medical applications has been reported biannually at the small accelerator conference at North Texas State University in Denton.¹ Most notable has been the application to the treatment of cancer which has had considerable success at the Harvard Cyclotron.² The availability of beams in this energy range, to further the understanding of their applications, has been quite limited and costly to provide.

During previous work³ on a non-destructive beam emittance measurement instrument, a measurable fraction of 50 MeV H^+ atoms was observed exiting the Argonne National Laboratory H^+ linac accelerator. The intensity of this beam was found to be useful for studying several of the above applications. The major use of this beam is planned for a prototype facility for treating ocular melanomas.⁴ The experience gained from such a study will be instrumental in developing an adequate source of protons for a hospital-based facility.

Description of the Facility

The 50 MeV linear accelerator at Argonne National Laboratory is now used exclusively as an injector for the Rapid Cycling Synchrotron (RCS), the proton source for the Intense Pulsed Neutron Source. The linear accelerator provides a beam current of more than 14 namps of H^+ beam at a 30 Hz rate with a pulse width of typically 60 μ sec.

Although the linac vacuum is typically $2-4 \times 10^{-7}$ Torr, the high energy end and the transport lines have a vacuum of $1-2 \times 10^{-6}$ Torr. The cross section for the charge exchange reactions have been measured⁵ for energies up to 20 MeV. By assuming an energy dependence inversely proportional to energy, the cross-section for the $H^+ H^+$ reaction can be extrapolated to 50 MeV to yield $\sigma_{1,0} = 4 \times 10^{-17} \text{ cm}^2$ (for the dominant H_2O gas fraction). The fraction of H^+ produced from gas stripping can be calculated from

$$f_0 = 3.22 \times 10^{16} P \sigma_{1,0}^4$$

where P = gas pressure in Torr
 l = path length in vacuum (cm).

For $l = 150 \text{ cm}$, the 50 MeV H^+ fraction is expected to be about 2×10^{-4} or 1.8×10^{10} per second. This intensity is capable of treating a $2 \text{ cm} \times 2 \text{ cm}$ tumor with a dose rate in excess of 1,000 rads per second. This intensity is considerably greater than that required for treating ocular melanomas and can be reduced significantly. Since this beam results from a distributed line source over a length $l = 1.50 \text{ cm}$, the beam distribution is expected to be more uniform in transverse phase space, a property which is of interest for the radiotherapy use of this beam.

Figure 1 shows the schematic layout of the beam transport line for the 50 MeV H^+ beam. The intense H^+ beam is separated from the H^+ by a bending magnet and the H^+ drifts through the injection beamline to the previous Zero Gradient Synchrotron area. An intensity collimator and halo foil reduce the lower energy H^+ beam contamination while reducing the 50 MeV H^+ intensity only a factor of 5. After 14.3 meters of drift, 50% of the H^+ beam is converted to H^+ using a 6 μ m thick mylar foil and momentum separated by means of a 50° spectrometer magnet. The beam enters an experimental enclosure which provides radiation safety protection from the primary beam. The beam pipe and magnets also have sufficient radiation shielding to reduce exposure levels to a value such that access to any point is permitted during normal operation. Changing to a narrower foil ahead of the spectrometer magnet, provides the ability to reduce the H^+ beam intensity a factor of 10 or more, by intercepting less of the H^+ beam.

A single quadrupole permits the vertical beam size to be adjusted. The horizontal beam size is dominated by the momentum spread of the incident beam but the 50 MeV component is equal to the foil size in quadrature with a $\pm 3 \text{ mm}$ momentum dispersion. Lower energy components are down at least an order of magnitude due to the lower vacuum in the linear accelerator tank and decreased solid angle.

Operational Results

This beam was first operational in January 1984 with subsequent realignment yielding a factor of three more beam intensity. During typical operation of the 50 MeV linear accelerator the measured 50 MeV H^+ beam intensity is about 0.4 namps or 7.3×10^7 protons per pulse. With the calculated 9.1% transmission efficiency of the beamline this indicates a gas stripping fraction of 3.8×10^{-4} , in excellent agreement with that predicted by the average vacuum measurements. Figure 2 shows the measurement of the beam intensity using a Faraday cup and a planar ionization chamber. The intensity variation arises largely from variations in the H^+ source intensity. By selecting lower moments with the bending magnet, a signal has been observed down to an energy of 30 MeV, but the intensity drops to about 1% of the 50 MeV value.

Figure 3 shows the dose rate of this beam with a vertical beam size of $\pm 5 \text{ mm}$. A lucite absorber was varied ahead of the ionization detector in order to measure the dose distribution as a function of depth (Bragg curve). This dose rate decreases a factor of 2.5 times when the vertical beam size is increased to

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Future Uses of the Beam

The low cost of operation and ease of access to this beam will make it possible to complete many other studies of the application of protons, which might not have been carried out with more conventional sources.

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Fig. 1 Schematic Layout of Low Intensity 50 MeV Proton Beam.

Fig. 2 50 MeV Proton Beam Signal From Ionization Chamber (upper trace) and Faraday Cup (lower trace) with 10 $\mu\text{sec/cm}$ time scale on horizontal axis.

Fig. 3 The Measured Dose Distribution from the 50 MeV Proton Beam with a 1 cm x 1 cm Spot Size as a Function of Depth in Water.

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