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- atom which is produced by stripping in the gas of the 50 MeV H+ linear accelerator. A stripping fraction of about \(3 \times 10^{-5}\) 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 have been reported biannually at the small accelerator conference at North Texas State University in Denton. Most notable has been the application to the treatment of cancer which has had considerable success at the Harvard Cyclotron. The availability of beams in this energy range, to further the understanding of their applications, has been quite limited and costly to provide.

**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 nA of 50 MeV H+ beam at a 30 Hz rate with a pulse width of typically 60 usec.

Although the linac vacuum is typically 2-4 \(10^{-7}\) Torr, the high energy end and the transport lines have a vacuum of 1-2 \(10^{-6}\) Torr. The cross section for the charge exchange reactions have been measured for energies up to 20 MeV. By assuming an energy dependence inversely proportional to energy, the cross section for the H- to H+ reaction can be extrapolated to 50 MeV to yield \(\sigma = 3 \times 10^{-14} \text{cm}^2\) (for the dominant H2O gas fraction). The fraction of H+ produced from gas stripping can be calculated from

\[
\frac{\sigma}{\sigma_{-1,0}} = 1.22 \times 10^{16} \frac{P}{1 \text{ Torr}}
\]

where \(P\) is gas pressure in Torr and \(\sigma\) is path length in vacuum (cm). For \(z = 150\) cm, the 50 MeV H+ fraction is expected to be about 2 \(10^{-7}\) or 1.8 \(10^{-11}\) per second. This intensity is capable of treating a 2 cm x 2 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 \(2 = 1.50\) 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.

**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 \(10^{14}\) protons per pulse. With the calculated 9.1% transmission efficiency of the beamline this indicates a gas stripping fraction of 3.8 \(10^{-14}\), 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 \(2\) 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...
The uniformity of the dose over this 6 cm² area appears to be ±10% or better from preliminary measurements. By placing a high Z scattering foil in the beam this uniform area of exposure can be increased to ±1 cm, with larger areas available outside the experimental area.

Future Uses of the Beam

The major use of the beam will be for the radiotherapy of ocular melanomas. Preparation for this treatment will involve several radiobiological studies which are being planned. Another use considered for this beam is to study the proton induced x-ray emission from atoms, for material and trace element analysis. The 50 MeV proton beam has several advantages over lower energy proton beams: higher cross section, deeper penetration and the ability to radiate in air rather than in vacuum.

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 μsec/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.