A POSSIBLE STOPPING π^- BEAM FOR CANCER THERAPEUTICS

M. Awschalom

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Introduction

In this note an estimate of the pion dose from a stopping π^- beam is made. Dose rates of 15 krad·gram/min are obtained. These are adequate for clinical use.

Discussion

The present 200 MeV linac is regarded as an injector to a booster of about 400 to 500 MeV. The final energy is chosen to maximize π^- production in the 60 to 90 MeV pion energy range. The actual energy will depend on actual target geometries and methods to minimize muon and electron contamination of the pion beam.

Such parameters as energy bite and solid angle acceptance of the beam transport system have been taken from the LAMPF study of Langham and Groce.[1]

Although the type of booster is not specified, the one in mind at this time is a side coupled linac. In this estimate, the capture efficiency of the booster is assumed to be one hundred per cent.

The target material is assumed to be graphite. A low-Z material will reduce electron contamination and in this case it will produce little remanent radioactivity and it will be able to dissipate large amounts of energy.

The pion beam transport system is visualized as achromatic and symmetric and consisting of a focusing doublet, two bending magnets, and a second focusing doublet. A focus would exist between the bending magnets. At this focal point slits and a lead filter may be located to control the beam shape and reduce the electron contamination. The beam would be located at about zero degrees. The acceptance of the transport line is quoted[1] as 0.025 sterradians.

The momentum bite is taken[1] as ±11% (or an energy bite of ±22%).

The doubly differential cross section for the $p + C \rightarrow \pi^- +$ anything, is taken from Lillenthun[2] as reported by W. Hirt.[3] These measurements were carried out at 21.5°. Hence, the zero degree yield may be slightly underestimated in this calculation.

$$d^2\sigma/dEd\Omega = 5.0 \ \mu b/MeV \ sr$$

The linac and the booster are assumed to operate at 15 Hz, 120 μsec wide pulses, 70 mA peak current, with a duty cycle of 3 seconds every 4 seconds.

With these parameters and a six meter long pion transport system, an average dose rate of 15 krad·gram/min is estimated.

For treatments in which 60 to 100 rads are delivered to a tumor, irradiation times would last between 4 and 13 minutes (assuming 1 to 2 kg of tissue).

Future Possible Improvements

It might be possible to widen the pulse length to 180 microseconds and the pulse current to 140 mA. This type of operation will now be referred to as the hoped-for-beam. Then, the dcse rate would be trebled and the treatment time would decrease to 2 to 4 minutes.

Comparison With the LAMPF Beam

The LAMPF beam is nominally one milliampere. However, there are various users and the biological target has been promised only 50% of the beam. This makes the LAMPF beam an effective 0.5 mA beam from the point of view of clinical use. Also, the pion production cross section is down by about 20%, at 750 GeV[3], then the pion yield would correspond to a proton current of 0.4 mA at 400-500 MeV. The hoped-for-beam is 0.4 mA too.

Conclusions

A 400-500 MeV proton accelerator is proposed. This accelerator would use the present NAL linac as an injector. The protons would be used to produce stopping π^- beams for biological purposes such as cancer therapy. Adequate dose rates are expected. These dose rates may be comparable or equal to those expected at LAMPF.

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APPENDIX

Calculations

1. proton current = $(3/4)\times(120\times10^{-6}\ \text{sec})\times(70\times10^{-3}\ \text{Amp})$
$\times 15\ \text{Hz}/1.6\times10^{-19}\ \text{coul/proton}$
$= 5.9\times10^{14}$ protons/sec
2. production cross section = $(5.0\times10^{-6}\text{b/MeV sr})\times(25\times10^{-3}\text{sr})$
$\times(28\text{MeV})$
$= 3.5\ \mu\text{b}$
3. non-elastic cross section[4] = 0.254b
4. target length = one non-elastic mean free path
5. yield = $(1-e^{-1})\times(3.5\times10^{-6}\text{b})/(0.254\text{b})\ \ \pi^-/p$
$= 8.7\times10^{-6}\ \pi^-$/incident proton
6. pion current at target = $(8.7\times10^{-6}\ \pi^-/p)\times(5.9\times10^{14}p/\text{sec})$
$= 5.1\times10^{9}\ \pi^-/\text{sec}$
7. decay length = 8m at 65 MeV
8. transport system length = 6m
9. stopping pions at patient = $(5.1\times10^{9}\ \pi^-/\text{sec})*\exp(-6\text{m}/8\text{m})$
$= 2.4\times10^{9}\ \pi^-/\text{sec}$
10. flux-to-dose conversion factor[5] = 1.1×10^{-7}rad/stopping pion
11. dose rate = $(2.4\times10^{9}\ \pi^-/\text{sec})\times(1.1\times10^{-7}\text{rad}/\pi^-)$
$= 2.6\times10^{2}\text{rad}\cdot\text{gram/sec}$
$= 15\ \text{krad}\cdot\text{gram/min}$

REFERENCES

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5. J. Dutrannois and G. Turner, private communication.