national accelerator laboratory

TM-344
1182.201

A POSSIBLE STOPPING π^- BEAM FOR CANCER THERAPEUTICS

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February 1, 1972

Here, the present 200 MeV linac is regarded as an injector to a booster of about 400 to 450 MeV. The final energy is chosen to maximize π^- production in the 60-80 MeV pion energy range.

The booster is not specified although it could be a side coupled linac. Capture efficiency by and extraction efficiency from the booster are assumed equal to one.

The target material is assumed to be carbon as a compromise between low-Z for low electron contamination of the beam and the capability to handle large density of energy deposition.

The pion beam is now visualized as an achromatic, symmetric system consisting of a doublet, two bending magnets and a doublet. At the focus between the bending magnets a few radiation length thick lead filter would be placed to reduce the electron contamination of the beam. The acceptance angle of the beam transport system is assumed to be ten millisterradians. The central angle would be at zero degrees.

Operated by Universities Research Association Inc. Under Contract with the United States Atomic Energy Commission

The energy bite is assumed to be ±1% or 1.3 MeV in a 65 MeV beam.

The doubly differential cross section is taken from Lillethun[1] as reported by W. Hirt[2]. The measurements were carried out at 21.5°, therefore, the zero degree may be slightly underestimated in this calculation.

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

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

Then,

stopping π^-/sec	=	7.1×10^7
krad·gram/min	=	0.47
krem·gram/min	=	0.60

For small tumors (~ 100 grams) treatments would then last about 15 to 30 minutes. This is just barely acceptable. A factor of three in beam current (by the use of longer pulses, say 180 μsec, and greater current, say 150 mA) would make the beam clinically interesting.

Comparison with the LAMPF beam.

The LAMPF beam is nominally one milliampere. The "hoped for" beam of this scheme (180 μsec, 150 mA, 15 Hz) is 0.4 mA. On the other hand, the differential cross sections as given by Hirt[2] would indicate a slightly smaller production cross section (about 20% smaller) at 600 to 750 MeV. Hence, the LAMPF may produce only twice* as many stopping pions per second but likely with larger electron contamination.

Calculations.

proton current $= (3/4) \times 120 \times 10^{-6} \text{sec} \times 70 \times 10^{-3} \text{Amp} \times 15 \text{Hz} / 1.6 \times 10^{-19} \text{coul/prot.}$

$= 5.9 \times 10^{14}$ protons/sec

production cross section $= 5.0 \times 10^{-6} \times \text{b/MeVsr} \times 10 \times 10^{-3} \text{sr} \times 1.3 \text{MeV}$

$= .065$ μb/atom

non-elastic cross section[3] $= .254$ b

target length[3] = one non-elastic mean free path

Yield $= (1-e^{-1}) 6.5 \times 10^{-8} \text{b} / 0.254 \text{b}$

$= 2.56\ 10^{-7}\ \pi^-/\text{proton}$

pion current at target $= 2.55 \times 10^{-7} \times 5.9 \times 10^{14} = 1.50 \times 10^{8} \pi^-/\text{sec}$

decay length = 8m (at 65 MeV)

stopping pions $= 1.5 \times 10^{8} \exp(-6\text{m}/8\text{m})$

$= 7.1 \times 10^{7} \pi^-/\text{sec}$

dose/pion[4] $= 1.1 \times 10^{-7}$ rad/stopping pion

= 7.8 rad·gram/sec

= .47 krad·gram/minute

dose equivalent/pion[4] $= 2.7 \times 10^{-7}$ rem/stopping pion

= 19 rem*gram/sec

= 1.2 krem*gram/minute

* Thick target yields will very likely be higher for LAMPF than for NAL.

Acknowledgment.

Some useful discussions were held with R. Steining (NAL) and J. Dutrannois (CERN-ORNL).

REFERENCES

1) E. Lillethun, Phys Rev 125, 665 (1962)

2) W. Hirt, et al., CERN 69-24 (Sept. 5, 1969)

3) G. Belletini, et al., Nucl Phys 79, 609 (1966)

4) J. Dutrannois and G. Turner, private communication.