

## A negative ion cyclotron using 11 MeV protons for the production of radionuclides for clinical positron tomography

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A radioisotope delivery system (RDS) for cost-effectively producing short-lived, positron-emitting isotopes in a clinical setting meets the following objectives:

- computer-controlled operation to reduce personnel requirements
- compact, self-shielded configuration to minimize facility requirements and efficient, economical targetry and chemical processing to maximize yields of radiochemical products.

The 11 MeV negative hydrogen ion ( $H^-$ ) cyclotron is equipped with four external beam ports through which collimated 1 cm diameter beams pass into the targets as shown in figure 1. Fifty microamperes of protons are routinely obtained on targets which are located just beyond the collimators. One hundred microamperes of collimated beam has been achieved. In tests, an 80  $\mu A$  proton beam has been split between two ports simultaneously. Beam splits of 50/50 or 95/5 were readily achieved. Using the IBM PC/AT computer control system, the cyclotron has established beam on target, maintained the beam at a specified level for a specified time, and shut itself down without operator intervention.

An energy of 11 MeV was chosen because it was predicted that, with suitable target development, adequate quantities of  $^{11}C$ ,  $^{13}N$ ,  $^{15}O$  and  $^{18}F$  could be produced. Experimental results <1-7> have validated this choice as shown in figure 2. A model calculation was carried out to determine the amount of polyethylene shielding required to give 0.5 mrem of radiation outside the shield when one Curie of  $^{18}F$  is produced. At 17 MeV the required thickness was 160 cm, at 11 MeV it was 95 cm, and at 8 MeV it was 85 cm ( see figure 3 ). Based on these results it appears inadvisable to increase the energy beyond 11 MeV if a practical self-shield is to be realized.

Negative hydrogen ion acceleration makes possible multiple exit ports, dual simultaneous beams, and no operator intervention. To extract a proton from the cyclotron's internal beam, it is only necessary to pass an  $H^-$  ion through a thin carbon foil, which removes the two electrons (see figure 4). The force exerted by the cyclotron's magnetic field on the ion changes from inward to outward and the resulting proton is immediately extracted. Thus, negative ion cyclotrons have three key features:

- 100 % of the beam is extracted
- the beam may be extracted from inside beam resonances located near the edge of the magnet thus simplifying control the foil extractors are small, permitting several to be used.

Concomitant features include:

- low beam loss at high energy thus reducing prompt radiation and induced activity
- a short, weakly focussing path through the cyclotron's fringe field which simplifies beam shaping
- a uniform beam intensity distribution which does not contain hot spots

Each beam extractor consists of three thin carbon foils equally spaced on a carousel. To extract, a foil is rotated into the beam. To let the beam pass on to another extractor, the carousel is rotated an additional  $60^\circ$ . The beam is steered by small adjustments of the foil about the nominal extraction position. After leaving the extraction foil, the beam passes through the cyclotron's fringe field in a short path nearly parallel to the field gradient. This results in a weak vertical defocussing and weak horizontal focussing forces which, combined with a weak magnetic channel, produces a round spot at the collimator in front of the target. The spot size may be controlled by the strength and position of the magnetic channel. Spot sizes which give from 50 % to 95 % transmission through a 10 mm collimator have been produced. A spot giving about 80 % transmission has been found to be satisfactory for most target work.

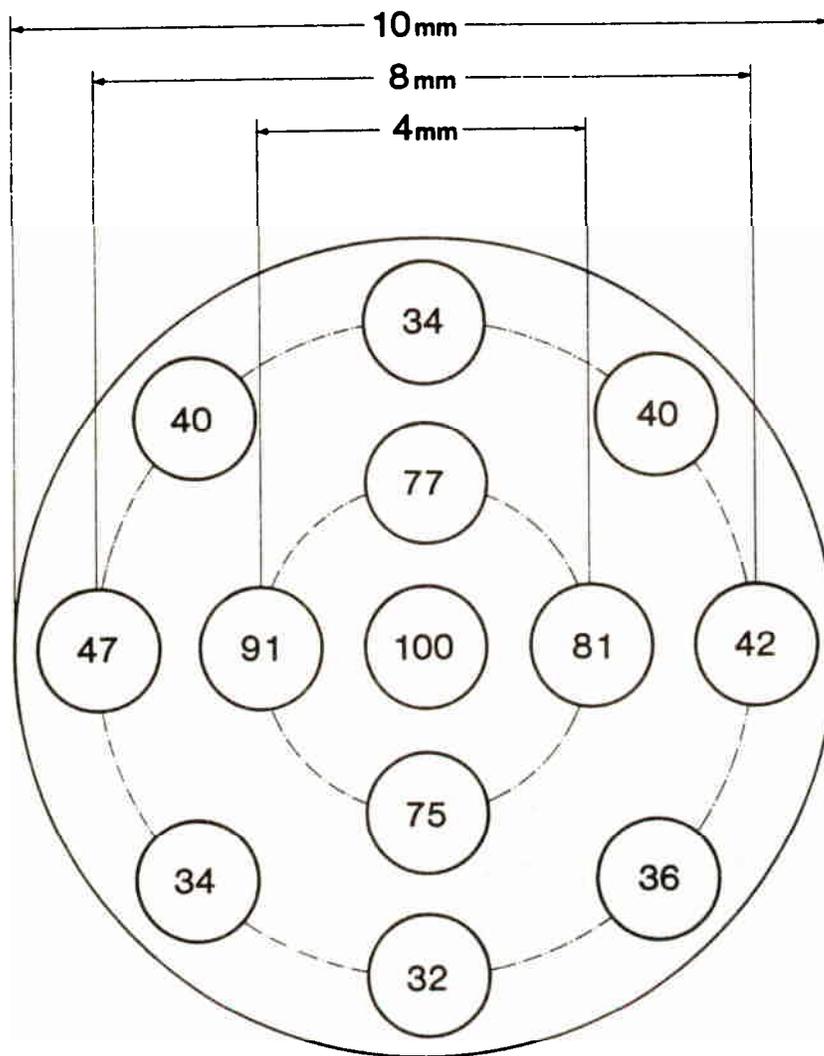
Extraction foils ranging in thickness from  $5\ \mu\text{m}$  to  $25\ \mu\text{m}$  have been used. Some spot shape dependence on foil thickness has been observed. Three foils have served for our entire beam and target development program of approximately 500 hours of beam time. Three years of experience with the CP-42 cyclotron at TRIUMF indicates that at  $50\ \mu\text{A}$  one would expect a 50-hour lifetime for each foil. Carbon is used for the extraction carousels and the foils, which almost completely eliminates prompt and induced activity from these parts.

The 10 mm collimator is located only 2 cm from the target which assures that beam passing the collimator strikes the target. The collimator itself is split to give beam position information which is used to automatically control the foil rotation. The collimator material is tantalum which, at 11 MeV, produces very little prompt radiation and induced activity.

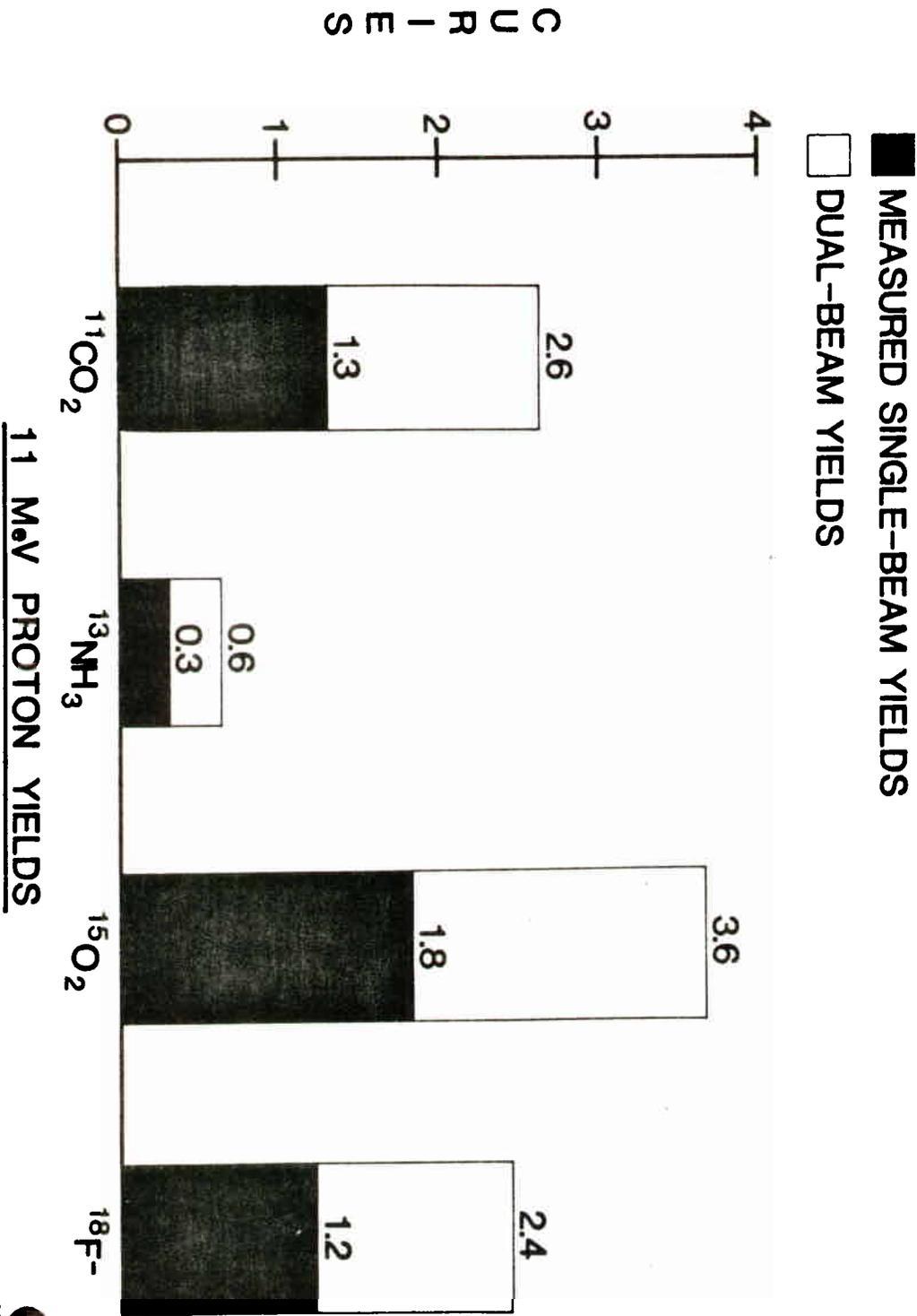
The total beam current being extracted can be monitored by measuring the current produced by the two electrons removed by the stripping foil. This current can be compared to the sum of the currents picked up from the collimators and the target. In our beam tests and target experiments these currents have agreed within experimental error indicating no beam loss in transport.

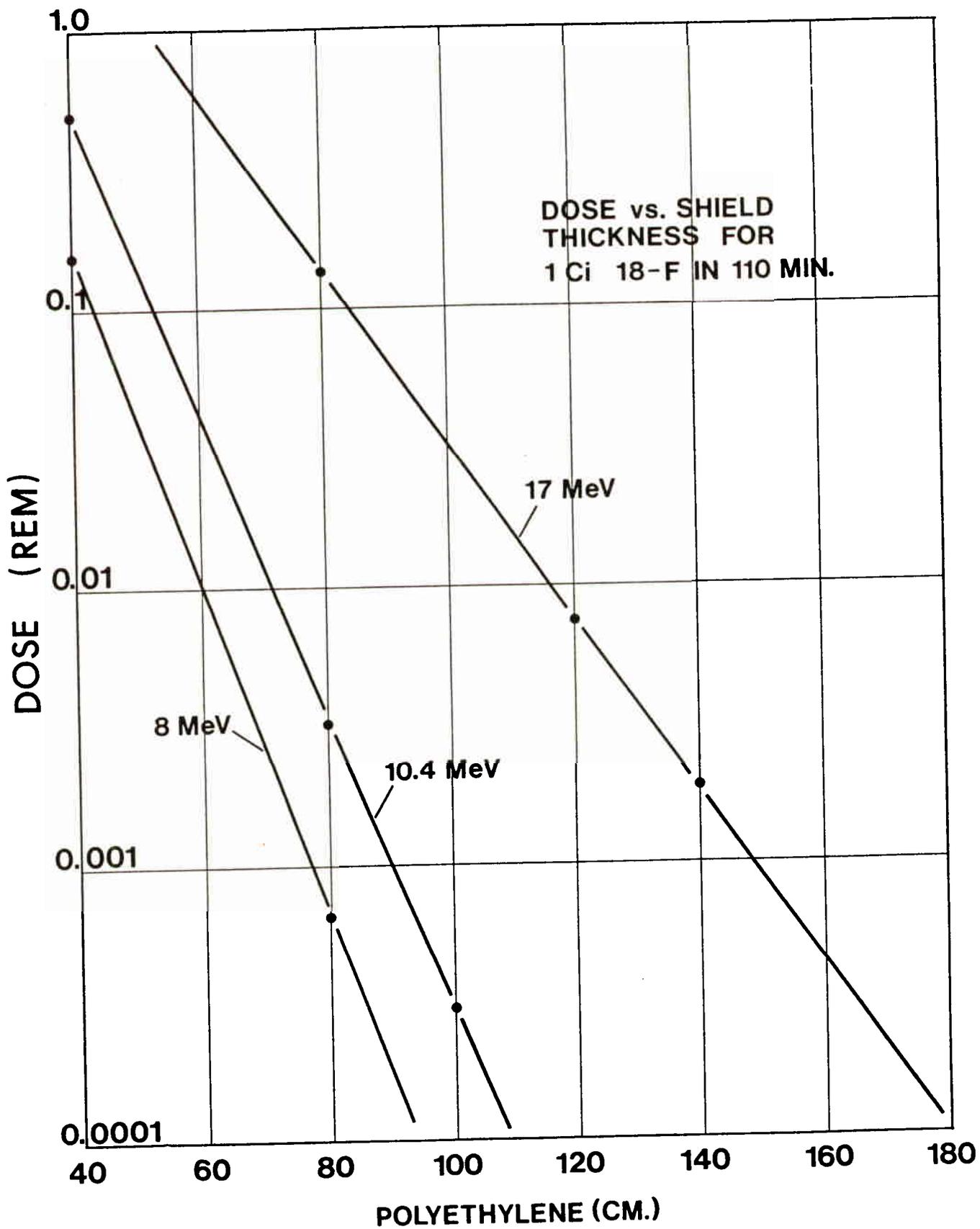
Beam intensity distribution is an important factor affecting target performance. Radiographs made under many different conditions indicate that the beam does not have hot spots. To quantitate beam intensity distribution, an aluminum profile monitor having thirteen 1 mm holes was constructed. The holes were located at the center, on a 4 mm diameter circle and on an 8 mm diameter circle. Behind each of the collimator holes was placed a piece of 1.6 mm copper wire. The entire assembly uses the same mount as is used for the targets. After irradiation by the beam, the copper pins are removed and the resulting  $^{63}\text{Zn}$  activity is counted in a dose calibrator. Measurements made on a beam with 80 % transmission through the 10 mm collimator showed a ratio of three between the hottest and the coldest pin sampled ( see figure 5 ). The same measurement indicated circular symmetry within about 20 %. This beam spot has proven to be reproducible and has been used for most of the target tests.

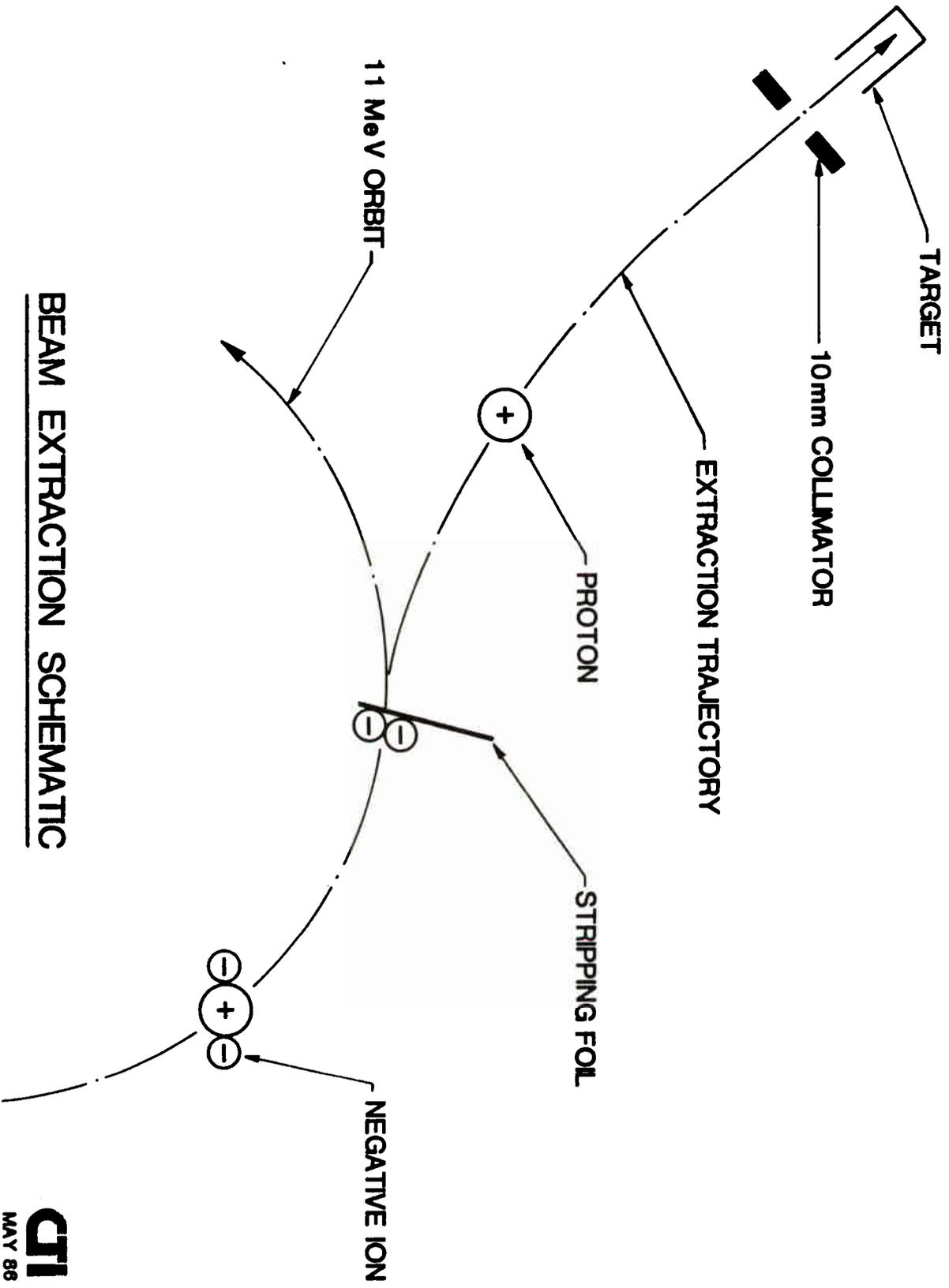
The above results demonstrate that a negative ion cyclotron using 11 MeV protons will economically produce sufficient quantities of  $^{11}\text{C}$ ,  $^{13}\text{N}$ ,  $^{15}\text{O}$ ,  $^{18}\text{F}$  to support a clinical PET program.



BEAM INTENSITY DISTRIBUTION  
AT TARGET (%)







BEAM EXTRACTION SCHEMATIC

## References

1. Hendry GO, Straatmann MG, Carroll LR, et al: J. Nucl. Med. 27:1018, 1986.
2. Wieland BW, Schmidt DG, Bida GT, et al: "Efficient, Economical Production of Oxygen-15 Labeled Tracers with Low Energy Protons", presented at the VI International Symposium on Radiopharmaceutical Chemistry, Boston, Mass., June 29-July 3, 1986.
3. Bida G., Wieland BW, Ruth TJ, et al: "An Economical Target for Nitrogen-13 Production by Proton Bombardment of a Slurry of C-13 Powder in O-16 Water", presented at the VI International Symposium on Radiopharmaceutical Chemistry, Boston, Mass., June 29-July 3, 1986.
4. Wieland BW, Hendry GO, Schmidt DG: "Design and Performance of Targets for Producing C-11, N-13, O-15, and F-18 with 11 MeV Protons", presented at the VI International Symposium on Radiopharmaceutical Chemistry, Boston, Mass., June 29-July 3, 1986.
5. Wieland BW, Fowler JS, Wolf AP: "Design and Operation of Small Volume O-18 Water Targets to Produce Aqueous F-18 Fluoride by Proton Bombardment", in preparation.
6. Hendry GO, Carroll LR, Wieland BW: "RDS - A Radioisotope Production System for Clinical PET", in proceedings of the Workshop on Radiopharmaceutical Production System for Clinical Uses of Positron Tomography, Washington, D.C., February 12, 1986, to be published.
7. Wieland BW, Hendry GO, Schmidt DG, Bida GT, Ruth TJ: Efficient Small Volume O-18 Water Target for Producing F-18 Fluoride with Low Energy Protons, presented at the VI International Symposium on Radiopharmaceutical Chemistry, Boston, Mass., June 29-July 3, 1986.