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A NEW OPTICAL DESIGN FOR THE BNL ISOTOPE PRODUCTION TRANSPORT LINE*

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Abstract

The 200 MeV linac at BNL has recently been upgraded. As a result, 2.5 times more average beam current can be delivered to the Brookhaven Isotope Resource Center (BIRC), formerly called BLIP, a facility which produces radionuclides and radiopharmaceuticals for the medical community, and also supports a research program seeking more effective diagnostic and therapeutic agents. The optics of the beam transport line to BIRC was redesigned to (a) reduce transverse fluctuations of the beam at the target due to any linac energy fluctuations, (b) produce a flat beam distribution at the target, in order to avoid melting certain target materials, and (c) handle the higher beam intensity while keeping radiation levels low. A profile monitor was also modified to monitor the flatness of the beam using the algebraic reconstruction technique (ART). The above improvements will be described, and results of the commissioning of the line during the 1996 running period will be discussed.

Introduction

The recent upgrade of the 200 MeV linac, reported in these proceedings[1], has resulted in a 150% increase in the average beam current that can be delivered to the BIRC facility, which is the largest consumer of the linac's pulses. The optics of the transfer line was redesigned in order to keep radiation levels within acceptable levels and to produce a flat, rectangular beam at the target location, in order to avoid melting certain target materials. The redesign also included making the two bends in the transfer line achromatic, as well as the addition of a third wire to an existing secondary emission monitor (SEM) to make possible a 3-D reconstruction of the beam profile using ART, also reported in these proceedings[2].

The constraints of the exercise were that the existing physical layout of the line would be retained, and existing equipment in the line and/or available equipment at the AGS, would be used whenever possible.

Most of the design effort went into producing a beam with a flat intensity distribution and rectangular cross-section at the BIRC target, and the rest of this paper will deal exclusively with this aspect of the project. Achromaticity of the two bends was provided for by mounting a second quadrupole between the bending magnets, while keeping the beam size small wherever possible minimized radiation levels.

Beam Flattening

Beam flattening exploits the aberrations introduced by non-linear lenses. In principle, any non-linear focusing elements, i.e., those for which the restoring force on the beam particles $\propto r^n$, where n =3, 5, 7..., will do. In practice, octupoles, n=3, are generally used. The principle of the method is to manipulate the beam envelopes in such a way that, at two suitable locations, the beam envelope is small (large) in one plane, and large (small) in the other. The octupole magnets are placed at these locations, and their strengths adjusted to give the required beam properties at the target. (This arrangement of having the beam small in one plane and large in the other at the octupoles, minimizes the horizontal/vertical coupling and makes tuning the octupoles easier; it also results in a rectangular cross section at the target.) The appropriate beam correlation coefficient, C12 or C34, at each octupole in the plane where the beam is large should also be very close to unity, in order that the intensity distribution at the target falls off sharply.

Experimental confirmation of this approach was obtained at BNL's Radiation Effects Facility[3].

A schematic layout of the new BIRC line is shown in Fig. 1. Total length of the line is 33.5 m.

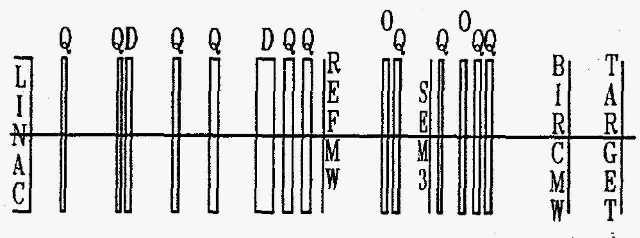


Fig. 1. Schematic layout of the BIRC beam line. showing quadrupoles (Q), octupoles (O), dipole magnets (D) and profile monitors. Total length is 33.5 m, and is to scale horizontally.

Software Tools

The following programs were used for the study: TRANSPORT[4], TURTLE[5], TRACE3D[6], and NSC[7]. TRANSPORT was used to find the first-order beam parameters required for flattening while determining possible locations of the octupoles. NSC, similar to TURTLE, was used to find the octupole strengths which gave the desired beam properties on the target. TURTLE repeated the third order calculations, but provided information to reconstruct the third-order beam envelopes in a straightforward manner. TURTLE, and TRACE3D were used to examine the sensitivity of the final design to misalignments and magnet imperfections, in particular, the (sub)harmonics of the octupole magnets.*

Fig. 2 shows the design beam envelopes for flattening. The corresponding phase space plots and profiles are in Fig. 3.

Commissioning

Commissioning was parasitic to other BIRC activities, hence it proceeded very slowly. The activation method of measuring beam profiles at the target location has a turn-around time of several hours at best, and several days at worst, thus making it impossible to tune the beam on target while monitoring it on a pulse-to-pulse basis. As a result, most of our studies concentrated exclusively on the multiwire profiles. (A 3 m drift separates the last profile monitor and the target.)

* Work performed under the auspices of the U.S. Dept. of Energy.

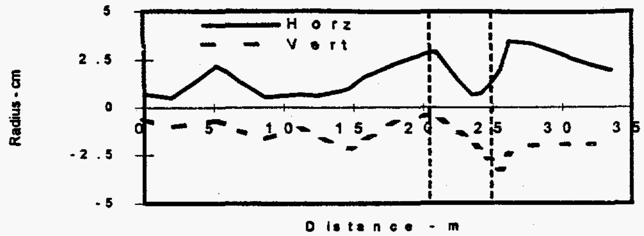
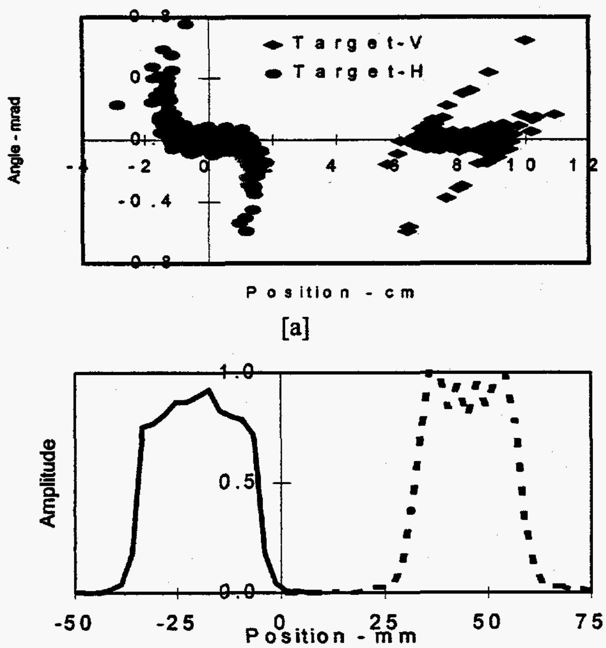


Fig. 2. The design beam envelopes for the new beam line.



[a]

[b]

Fig. 3. [a] Phase space of the design beam at the target. Vertical plot is displaced 8 cm to the right. [b] The corresponding beam profiles displaced to line up with phase space plots.

Diagnostic Equipment

Equipment used included: multiwire harps at locations REFMW and BIRCMW in Fig. 1, to provide horizontal and vertical beam profiles; a 3-wire SEM[b] at SEM3 which provides data for 3-D reconstruction of the beam intensity profile using ART; a system for exposing aluminum targets to the beam and measuring their activity profiles as a means of obtaining the 3-D beam profiles at the target. SEMs immediately after the Linac were used for emittance measurements, while radiation monitors along the beamline showed when and where beam was hitting the beam pipe.

The data collected consisted of the quadrupole and octupole currents, and the multiwire and irradiated target profiles. Beam emittance was measured infrequently.

Data Analysis

The magnet currents were converted to fields using measured, and for the last three quads, calculated characteristic curves. The fields were then used in the computer model of the line to obtain beam envelopes, and 2-D and 3-D profiles, which were compared to those measured.

Results

We mentioned earlier that most of our effort to understand the optics of the line was concentrated on beam profiles at REFMW and BIRCMW. The latter is of more interest because it is after the octupoles. Figs. 4 and 5 show observed and calculated beam profiles for a tune which produced a flat vertical profile and another tune with the octupoles off. The agreement between observation and theory(TURTLE) is excellent. The widths and relative heights of the measured and calculated profiles agree very well.

Discussion

The objective of a flat rectangular beam on the BIRC target needs more work to be fully realized. Progress has been slow due mainly to the slow feedback from profile measurements at the target and the absence of measured characteristics of the last three 6 in. ∅ aperture quads. Three-dimensional modelling of the quads has recently been used, first as a test on the original 4 in. ∅ aperture magnets, and then on the modified 6 in. ∅ aperture quads. It gave reasonably accurate characteristics which were used in the TURTLE model. (Radiation levels permitting, one of the quads may be removed for bench measurements during the present shutdown.) Work continues on finding a better and faster way to measure the profiles at the target.

We now know that the difficulty in flattening the beam horizontally was due to the smaller horizontal beam envelope and lower correlation, C12, at the first octupole. In the initial stages of commissioning, the line was retuned for a smaller envelope upstream of the second bending magnet because of high radiation losses. A first-order tune will be found to address this problem.

Acknowledgements

We acknowledge the very valuable and continuing contributions of Leonard Mausner and his team at BIRC, Brian Briscoe at the Linac, Dave Schlyer of the Chemistry Department for the activation measurements, and the staff of SIGMAPHI (France) for meeting our very tight schedule for manufacture and delivery of the octupole magnets.

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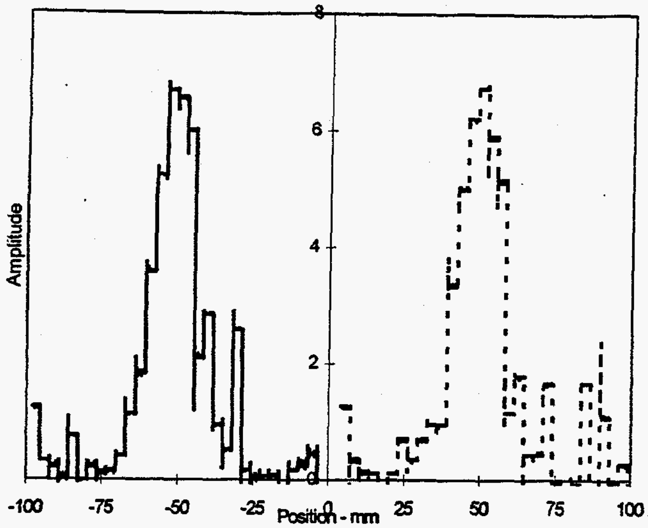

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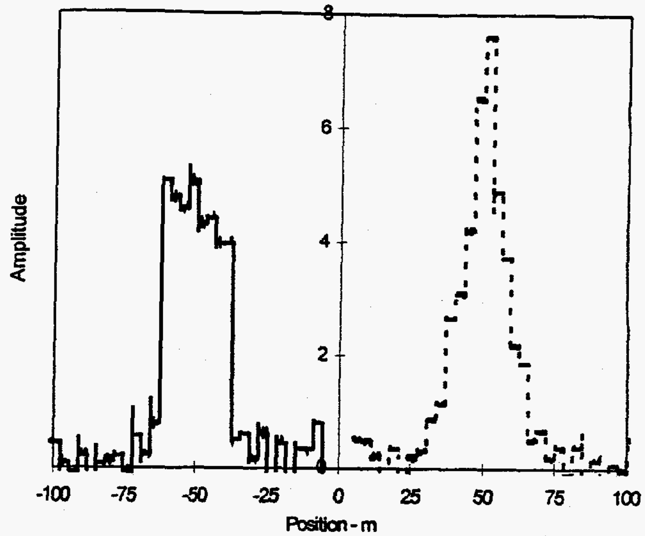

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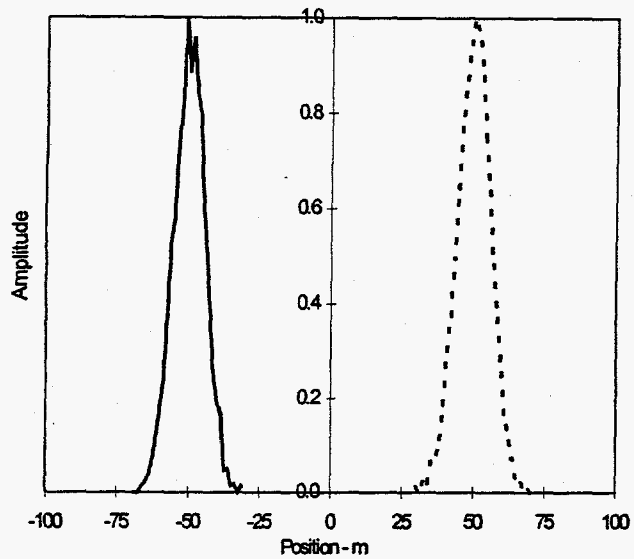

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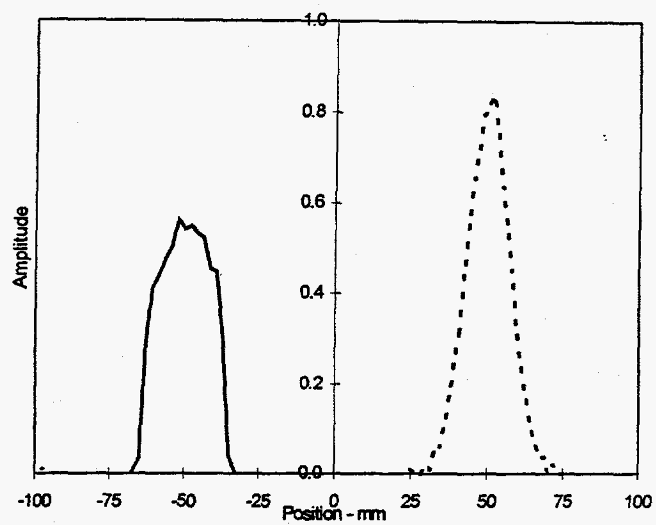

[b]

Fig. 4. **[a]** Observed horizontal profiles at the BIRCMW location in Fig. 1 with octupoles ON (left) and OFF (right). **[b]** The corresponding profiles predicted by TURTLE.

Fig. 5. **[a]** Observed vertical profiles at the BIRCMW location in Fig. 1, with octupoles ON (left) and OFF (right). The tilt of the vertical 'flat-top' was due to vertical mis-steering and could be removed or reversed with the vertical steerers. The downstream quads were set differently than in Fig. 3. **[b]** The corresponding profiles from TURTLE.

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[a] Supplied by SIGMAPHI (France). They have a 15.24 cm ∅ aperture, L_{eff} is 33.7 cm, and maximum pole-tip field is 6.3 kG.

[b] A typical SEM has two thin wires, mounted horizontally and vertically, which are stepped through the beam at an angle of 45° to the vertical, in a transverse plane to the beam, to give beam profiles. For ART, a third wire is mounted at 45°, co-planar with the other two.