

# THE BROOKHAVEN LINAC ISOTOPE PRODUCTION (BLIP) FACILITY RASTER SCANNING SYSTEM FIRST YEAR OPERATION WITH BEAM\*

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## Abstract

Brookhaven National Laboratory’s BLIP facility produces radioisotopes for the nuclear medicine community and industry, and performs research to develop new radioisotopes desired by nuclear medicine investigators. A raster scanning system was recently completed in December 2015 and fully commissioned in January 2016 to provide improved beam distribution on the targets, allow higher beam intensities, and ultimately increase production yield of the isotopes. The project included the installation of horizontal and vertical dipole magnets driven at 5 kHz with 90 deg phase separation to produce a circular beam raster pattern, a beam interlock system, and several instrumentation devices including multi-wire profile monitors, a laser profile monitor, beam current transformers and a beam position monitor. The first year operational experiences will be presented.

## INTRODUCTION

The purpose of the recently completed raster system at BNL’s BLIP facility is to “paint” the proton beam on the target in a circular pattern in order to provide a more even distribution of beam on the target material. At IBIC 2014 we reported on the overall system architecture and presented specific details for each system component [1].

This report will focus on results with beam during the first year of operation with the new system.

The beam instrumentation devices were installed in the fall of 2014 and commissioned with beam during the 2015 beam run from January to July 2015. The raster magnet and associated power supplies were installed during the fall of 2015, and full system commissioning was quickly completed in January 2016, four months ahead of the schedule that was already shortened by one year. The system was reliably operated with beam for the entire 2016 beam run from January to July 2016.

The new BLIP beam-line layout is shown in figure 1.

## BEAM RASTER PATTERNS

The horizontal and vertical raster magnets are driven continuously with sine waves at 5 kHz and 90 deg. phase separation to provide a circular or elliptical beam pattern [2]. The amplitude of the magnet current controls the amplitude of the beam motion.

The raster pattern is programmed using a circular table of horizontal and vertical magnet current amplitudes. The output current changes to the next amplitude in the table after each 450  $\mu$ s long Linac beam pulse, which occurs every 150 ms. The table size can contain more than 100 values and the amplitudes of the horizontal and vertical values do not need to be equal, thus allowing both circular

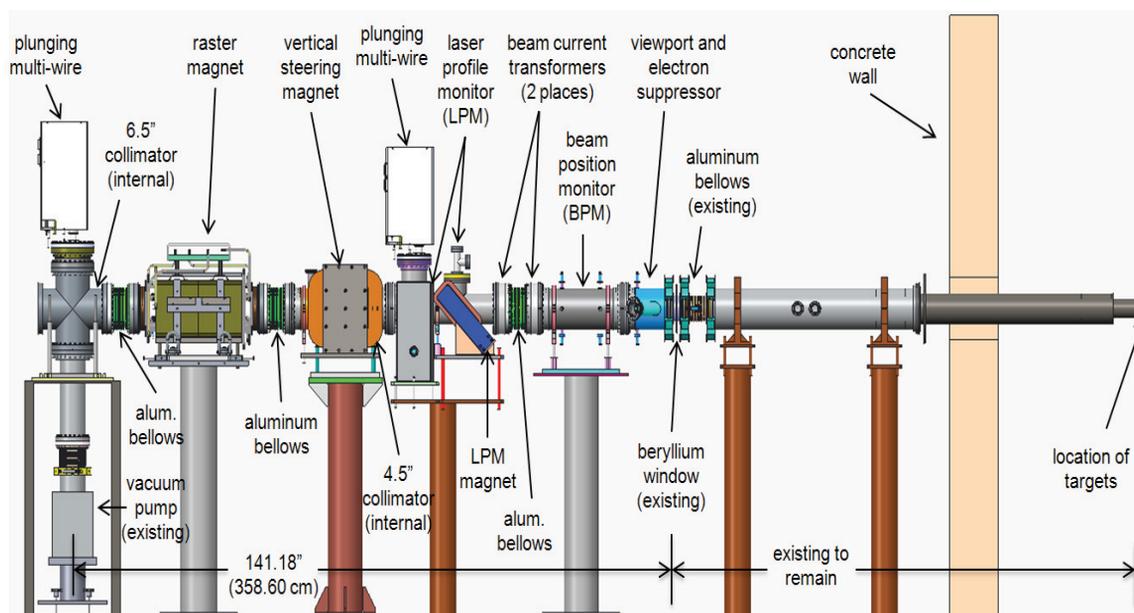


Figure 1: New BLIP beam-line layout.

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and elliptical patterns. With a Linac pulse length of 450  $\mu$ s and 5 kHz sine wave raster frequency, the beam makes about 2.25 rotations per beam pulse. A photo of the raster magnet installed in the beam-line is provided in figure 2.

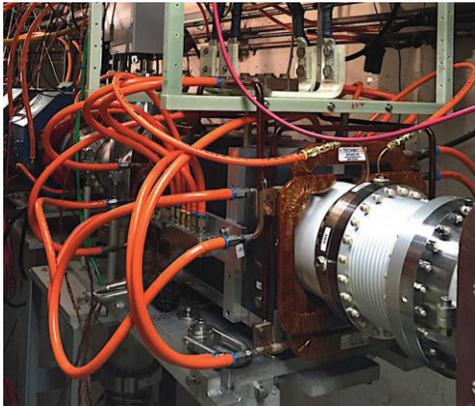


Figure 2: Photo of raster magnet installed in beam-line.

Based on early simulations, the anticipated repeating raster pattern was 3 consecutive beam pulses at 19.5 mm radius followed by one beam pulse at 6.5 mm radius. However, the actual beam size in terms of full width half max (FWHM) and full width tenth max (FWTM) is significantly larger than the beam size used in the early simulations. Therefore, in order to limit beam spill off the target, the maximum large radius used for production has been limited to 12.5 mm (Fig. 3).

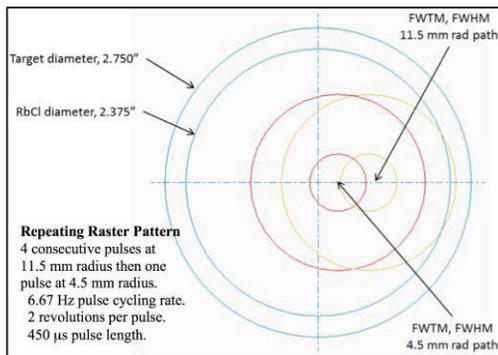


Figure 3: Diagram of beam images on target plotted at the right most positions for each radius of the circular raster pattern used during 117 MeV  $^{82}\text{Sr}$  production from January 2016 to March 22, 2016. On March 22, 2016 the 117 MeV beam size was reduced from 13 mm FWHM and 40 mm FWTM to 10 mm FWHM and 23 mm FWTM, and the raster pattern was changed to the repeating pattern of 4 beam pulses at 12.5 mm radius and 1 beam pulse at 5.5 mm radius.

Figure 4 compares rastered and non-rastered beam profiles on the target. Although the non-rastered beam widths vary with different beam conditions including energy, a 2-radius pattern has proven to be quite adequate for providing good beam distribution. Optimum raster patterns will continue to be explored.

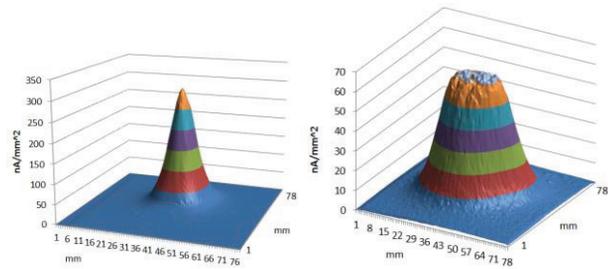


Figure 4: Beam profile on target without raster (left) and with repeating raster pattern of 4 Linac pulses at 11.5 mm radius and 1 Linac pulse at 4.5 mm radius, 117 MeV, 100  $\mu$ A, Dec. 24, 2015. The integral of the beam distribution is equivalent for both profiles. Note that the y-scale for the non-rastered profile is about 5 times the y-scale for the rastered profile.  
 Non-rastered beam FWHM: 13 mm, FWTM: 40 mm  
 Rastered beam FWHM: 32 mm, FWTM: 60 mm

### BEAM INSTRUMENTATION

All of the new beam instrumentation devices have been successfully operating as expected with beam and are providing reliable, high quality measurements. These new devices have proven to be directly attributable to improved beam stability. Figures 5-8 provide plots of beam data from each of the new devices.

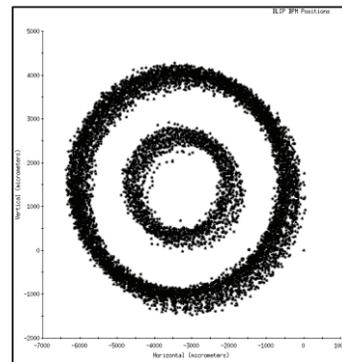


Figure 5: Beam position monitor data [3], horizontal vs. vertical (~100 points per beam pulse), March 30, 2016, 117 MeV beam and repeating raster pattern radii of 12.5 mm and 5.5 mm at the target. The actual positions at the BPM are about 1.8 times that shown in the plots.

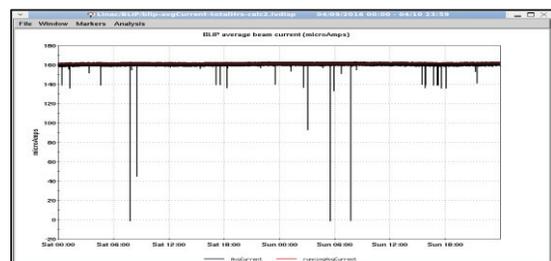


Figure 6: A 48-hour period (April 9-10, 2016) of the average beam current for 117 MeV  $^{82}\text{Sr}$  production with the raster system on. Note that the average beam current is nearly steady at 160  $\mu$ A for the entire period.

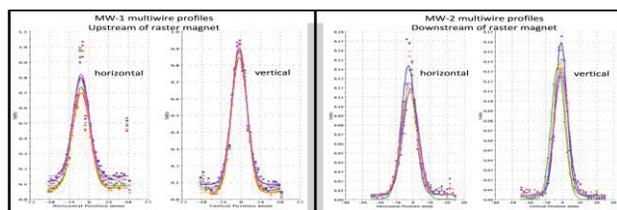


Figure 7: BLIP horizontal and vertical multi-wire profile measurements for MW-1 (left) and MW-2 (right). Profiles for six beam pulses are overlaid in each plot. The y-scale is the integrated signal strength for each wire. The wire spacing is 3.175 mm and each plane has 32 wires. These profiles were taken with 117 MeV and with the raster on. Note that all overlaid profiles for MW-1 (which is located upstream of the raster magnet) are well aligned, while the overlaid profiles for MW-2 (which is located downstream of the raster magnet) are shifted with respect to each other. This is the expected beam raster behavior.

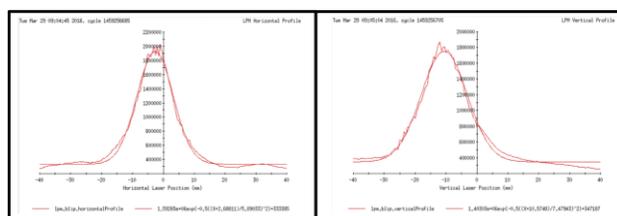


Figure 8: Horizontal (left) and vertical (right) BLIP laser profile monitor data with curve fits, with raster on. The y-scale is arbitrary units and is proportional to the number of electrons collected at each laser position. In these scans, the distance between each data point is 0.5 mm. A total number of 161 laser positions are provided. Each position value is the average of 24 points, where each point is a narrow slice of one beam pulse.

### BEAM INTERLOCK SYSTEM

The beam interlock system defined in Ref. 1 has been implemented and has proven to be very reliable for machine and target protection. If the raster magnet power supply currents or magnetic field measurements indicate that the raster system is not operating as expected, then the beam is inhibited to protect the targets. The algorithm is fairly complex to allow a variety of raster radius patterns while ensuring that for example, a small radius does not continue for longer than an acceptable period of time.

Several other interlocks can also inhibit the beam to provide the required protection, including high beam current, plunging multi-wire device in mid-travel position, collimator temperature high and raster magnet water flow error.

### ISOTOPE PRODUCTION RESULTS

In previous years with the non-rastered Gaussian beam profile, targets such as RbCl melted only in the region of highest beam intensity. This caused a large local density reduction leading to reduced and erratic production yield.

The rastered beam distribution has resulted in higher yield of isotopes, especially the critical isotope  $^{82}\text{Sr}$ .

In addition, improved beam distribution on targets with the raster system has allowed higher integrated beam current levels to be applied to the targets. In previous years integrated current levels were limited to about 135  $\mu\text{A}$ ; and in 2016 with the raster system operational and with the implementation of other Linac upgrades, the typical integrated current applied to the targets was 160  $\mu\text{A}$ . Figure 9 compares total beam currents to BLIP for the 6-year period from 2011 to 2016.

The higher total current on target directly translates to higher production yields, and the improved distribution of beam on the target with the raster system has been calculated to improve the yield (in  $\text{mCi}/\mu\text{Ah}$ ) by an additional 9%.

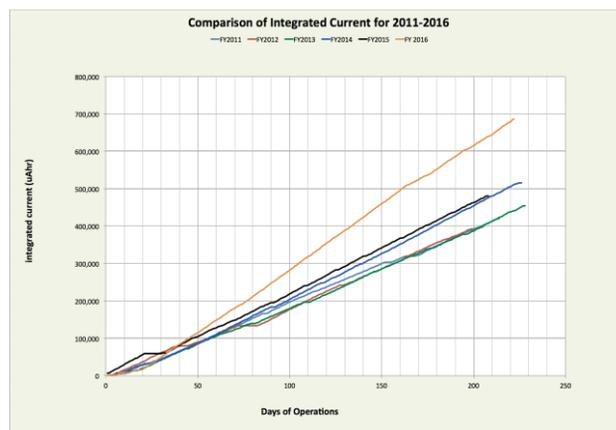


Figure 9: Plot of annual BLIP integrated currents from 2011 to 2016. The total integrated current increased 48% from 2015 to 2016.

### ACKNOWLEDGEMENTS

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### REFERENCES

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