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modifications***

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The New BLIP Raster System and Associated Target Modifications

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Introduction

Among the most important isotopes produced at Brookhaven Linac Isotope Producer (BLIP) are Sr-82 and Ac-225, and demand currently exceeds our capacity. Efforts to improve supply with increased intensity have been difficult. The beam is pulsed and the instantaneous beam current can be as high as 50mA with plans to increase further. Combined with a sharply peaked Gaussian-shaped beam intensity profile this creates very high power density at the beam spot center ($>4 \text{ kW/cm}^2$) and has caused target reliability and lifetime issues due to overheating, as well as somewhat erratic isotope yields. A raster scanning system has been installed to provide a better distribution of the proton beam on the targets, allow higher beam intensities to be used, and ultimately increase production yield of the isotopes. The upgrade consists of horizontal and vertical dipole magnets sinusoidally driven with 90 deg phase separation to produce a circular raster pattern, and a suite of new instrumentation devices to measure beam characteristics and allow adequate machine protection. Modifications to the targets for Sr-82 and Ac-225 were implemented to adapt to the new beam profile.

Material and Methods

The raster system sweeps the H^+ beam in a circular pattern at 5 kHz, which corresponds to 2.25 revolutions per 450 microsecond beam pulse. Using only a single sweep radius generates a donut intensity pattern that is not optimum. Therefore a dual radius repeating pattern was developed as follows: 3 consecutive beam pulses at a radius of 12.5 mm, then 1 pulse at a 5.5 mm radius. Figure 1. shows the initially planned raster pattern. In order to optimize the thermal profile for different targets it is possible to vary the radius value, the number of beam pulses for each radius and even the shape (eg. elliptical). In this manner near uniform energy deposition and temperature on the target can be achieved. The layout of the new BLIP beamline section is shown in Fig. 2. A beryllium window converts the H^+ beam to just protons on target.

Figure 1. Diagram of circular raster pattern on target.

The new instrumentation systems include two plunging multi-wire profile monitors, a laser profile monitor, two beam current transformers, and a beam position monitor. An elaborate interlock system was designed as a combination of machine protection and target failure prevention upon raster malfunction. Sensors monitor raster magnet amplitude, frequency, phase, current, temperature, and more.

The raster magnet consists of one horizontal pair and one vertical pair of water-cooled coils surround on an 8" OD ceramic beam tube with transitions to stainless steel flanges at each end. The coil/tube assembly is housed in ferrite. A ceramic beam-tube was selected to limit eddy currents produced by the 5 kHz sinusoidal oscillations of each magnet coil. The interior of the ceramic beam tube has a thin conductive coating to dissipate static charge. Four small coils were installed in the magnet to monitor the induced magnetic field.

Power amplifiers in combination with a custom-resonant circuit were designed to deliver 225 A RMS (318 A peak), 470 V RMS (664 V peak), 105 KVA apparent power to the magnet. Low resistance Litz wire (4/0 gauge) with polyimide insulation for radiation resistance was used. The power supply controls are based on National Instrument's PXIe system and Labview. Frequency feedback loops were implemented to keep the frequency on resonance with software feedback loops for amplitude control. More detail on the raster components can be found in reference 2.

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Figure 2: New BLIP beam-line layout. Length from vacuum pump center to beryllium window flange is 141.18".

Sr-82 is produced by irradiating two RbCl pressed pellet targets. RbCl has poor thermal conductivity, and with the previous fixed Gaussian beam spot (FWHM 22mm) the salt melts only in the beam strike area. Upon melting the RbCl expands 20% and moves outward, refreezing into void space on the target's periphery, and thus reducing the amount of RbCl remaining in the irradiation zone by an

estimated 10%. This effect also shifts the proton energy on downstream targets higher than optimum leading to reduced and variable Sr-82 yield. The raster parameters, 5 kHz sweep with dual radius, are driven by the thermal properties of RbCl. In addition the raster should minimize material creep as most of the target is consistently molten, but with lower overall temperatures than previously achieved.

Figure 3: a) & b) Beam distribution on target.

Our most important research effort involves irradiation of thorium metal targets at 200 MeV to produce Ac-225. The target type used was an aluminum clad bolted design with an active diameter of 27.9mm. The use of the raster would mean considerable beam outside the Th diameter. Therefore a larger Inconel clad electron beam welded target was fabricated with a 60mm Th diameter, 0.38mm thick.

Results and Conclusion

Dual radius raster scanning has been demonstrated in late December 2015 and has been used routinely since early January 2016. Under the present and foreseeable future beam operating conditions, we do not expect to require a radius as high as the initially planned 19.5 mm. The adopted sequence was a repeating raster pattern was 4 linac cycles at 11.5 mm and 1 linac cycle at 4.5 mm. The measured beam distribution on target, with and without the raster is shown in Figure 3a,b. The average power density has decreased more than 4 fold.

A computational fluid dynamics code (ANSYS FLUENT) was used to model the thermal profile of the RbCl target irradiated for 20 seconds of beam with the above raster parameters as shown in Figure 4. Even this quickly over 70% of the target volume is predicted to melt. An increase of the raster sweep radii was then implemented to 12.5mm outer radius and 5.5mm inner radius. Visual observation of RbCl targets irradiated at 150 μ A with these raster parameters showed complete melting had occurred. Production efficiency (mCi/ μ Ah) has improved by 9% compared to past non raster irradiations. In addition the large diameter Th target was irradiated successfully with the raster.

Figure 4. Transient thermal profile of RbCl target

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