

# RELIABILITY AND INTENSITY UPGRADE FOR BROOKHAVEN 200 MeV LINAC \*

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## Abstract

Brookhaven 200 MeV H<sup>-</sup> linac has been operating for the last 44 years and providing beams to nuclear physics and isotope programs. Three linac upgrades are in progress; (a) to make machine more reliable, (b) to double the intensity by increasing the beam pulse length and, (c) to produce more uniform beam current density on the target by raster the beam on the target.

## INTRODUCTION

The Brookhaven National Laboratory (BNL) 200 MeV drift tube linac (DTL) was built in 1970 [1] with following design parameters for proton: input energy 0.75 MeV, output energy 200.3 MeV, frequency 201.25 MHz, peak beam current 100 mA, beam pulse length (max) 200 μs, RF pulse length 400 μs, pulse repetition rate (max) 10 Hz. Over the 44 years of linac operations, it has gone through several improvements. The major upgrades were; (a) switch to 5 Hz operation [2], (b) change proton to H<sup>-</sup> [3], (c) addition of polarized H<sup>-</sup> source [4], (d) replacement of the Cockcroft-Walton by Radio Frequency Quadrupole (RFQ) [5], (e) new timing system [6], (f) new 12 inches pressurised coax system [6], (g) RF system improvements [6], new 50 kV power supply, eliminating of DC charge control at 60 kV, new rf control system, phase and amplitude servo redesign, (h) new polarized source OPPIS source and its upgrade, and [7,8], (i) reconfiguration of 35 keV and 750 keV transport lines [9,10,11,12,13].

At present linac provides H<sup>-</sup> beam at 200 MeV to polarized proton program for Relativistic Heavy Ion Collider (RHIC) and 66-200 MeV to Brookhaven Linac Isotope Production (BLIP). The RHIC program needs two pulses every AGS cycle (~4-5 sec), one for injection into the AGS booster and other for 200 MeV polarization measurements located in the High Energy Beam Transport line (HEBT). The rest of the pulses from high intensity source are delivered to BLIP. Requirements for these programs are quite different and they are following. (1) RHIC: 200 MeV, 600 μA beam current, up 400 μs pulse length, polarization as high as possible and emittance as low as possible, (2) BLIP: 66-200 MeV, 450 μs pulse length, current as high as possible (~45 mA), uniform beam distribution at the target, and beam losses as low as possible.

Many of subsystems of the linac are 45 years old and need to be replaced. Three upgrade programs; reliability, intensity, and beam raster, are in progress.

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Here, we will discuss only intensity and reliability upgrade program. Beam raster program will be discussed in the companion paper in this conference [14].

## RELIABILITY UPGRADE

Based on the down time of different systems we are upgrading following subsystems; RF system, beam loss monitors, beam current monitors, multi-wires, secondary emission monitor (profiles), control system, fast beam interrupt system. Schedules for these upgrades will depend on the availability of the funding. This summer we are starting with RF and beam loss monitor system. The major part of the linac down time is caused by linac RF system. Figure 1 shows the total down time since 1972 for the linac. The substantial reduction in down time was due to reducing repetition rate to 5 Hz in 1977 and changing to pressurized coax in 1996.

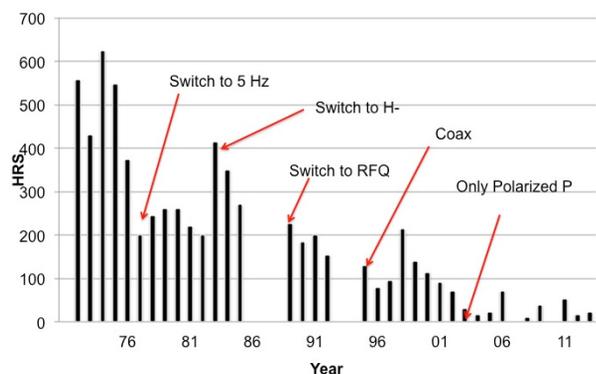


Figure 1: Total linac down time in hours since 1972 for HEP and RHIC operations.

We are replacing 5 kW Tetrode 7651, one of six tubes in amplifiers chain, by solid state amplifies. Since last year we are using similar solid-state amplifier for buncher in the 750 keV line. It is very reliable and down time for buncher is reduced to zero due to this change. We plan to replace all ten 7651-tubes with solid-state amplifies this summer. All amplifiers will be delivered by end of September 2014. Figure 2 shows the tube-based system on the right and solid-state amplifier on the left.

We are adding beam loss monitor for low energy operation of BLIP. BLIP wants to run at 66 MeV, the existing long radiation monitors are not sensitive for this low energy. We have tested (shielded with lead and cadmium) scintillator BC-400 for first three tanks and first bending magnet in the BLIP line. Figure 3 shows shielding configuration of the scintillator and Figure 4 shows location of these detectors along the linac.

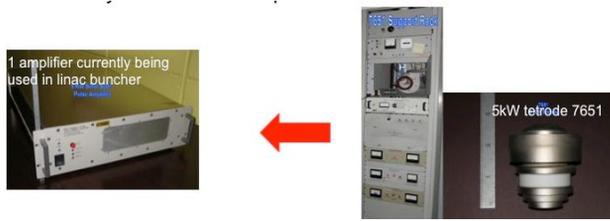


Figure 2: Tetrode 7651 and its power supply on the right and solid-state amplifier on the left.

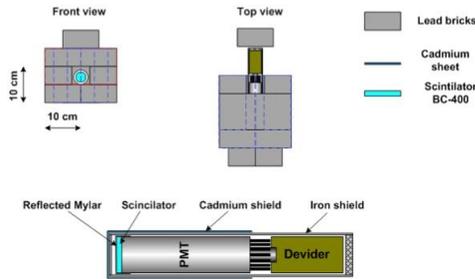


Figure 3: Lead and cadmium shielding configuration around scintillator BC400.

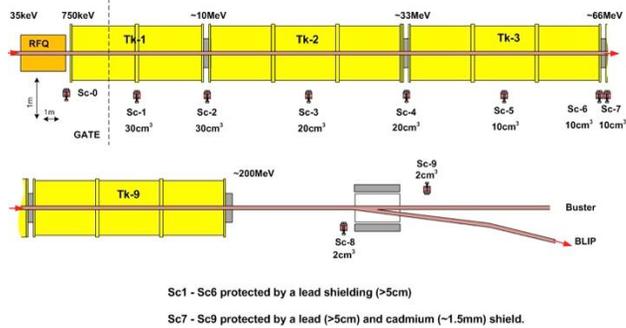


Figure 4: Detectors placement along the linac. Detectors have volume of 30, 20 10 and 2 cm<sup>3</sup> for tank 1,2 3 and BLIP bending magnet 1 respectively.

Figure 5 shows count rate recorded by these detectors while average current of 130  $\mu$ A was being delivered to BLIP. These detectors are very sensitive. They were able to catch losses due to gas stripping of H<sup>-</sup> during short vacuum spike from the ion pump as shown in the Figure 6. Based on the pressure changes in the DTL tank, we could calibrate the detector count per nA beam loss. The sensitivity of first 7 detectors are 30, 180, 1850, 950, 1280, 1280 and 60 counts per nA loss of H<sup>-</sup> beam. Losses in the linac are less than 0.1 %.

### INTENSITY UPGRADE

The average current delivered to BLIP has been increasing steadily over the years as shown in Figure 7. To increase the isotope production, there is strong desire to increase the linac current by factor of two by increasing the pulse length of beam. Table 1 summarizes linac parameters for design in 1970, operating 2014 and proposed to increase the intensity by factor of two.

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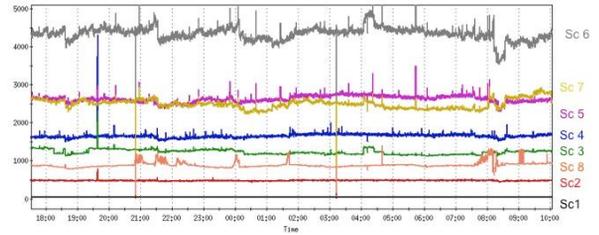


Figure 5: Detector counts rate during 130 $\mu$ A (average) beam to BLIP.

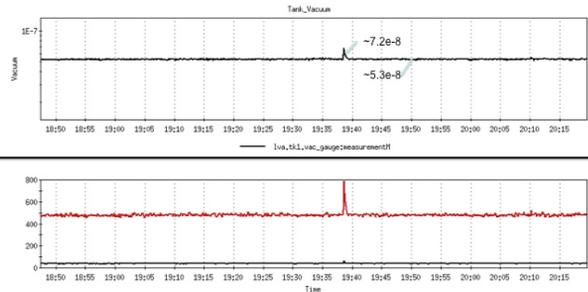


Figure 6: Rise in detector (Sc-2) counts during pressure spike due to ion pump in Tank 1.

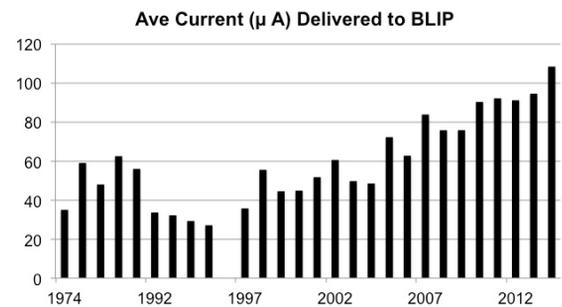


Figure 7: Average beam current delivered to BLIP.

All of the past progress has basically relied on improvements to the linac support systems and taking advantage of the engineering overdesign built into our original equipment. Additional increases would require the Linac Tanks to dissipate more power. Higher internal RF surface currents running through all its many hundreds of RF spring ring joints would result. Our Linac cavities were designed with multi-stem drift tubes. Each drift tube from tank 2 on has 2 or 3 attached stems to the tank sidewall. The purpose of these stems is to insure a mode free stable tank resonance at 201 MHz However it comes at a cost of lower Q, requiring greater RF power to both excite the cavity and compensation for beam loading. One of our biggest interruptions, in the past, to operations has been the repair of sparking joints and RF windows caused by our high RF power requirements. In addition the flattop currents on all the 750 keV and tank quads power supplies would have to be doubled. The original design called for a 250  $\mu$ s flattop. We were able to increase it to 500  $\mu$ s with no significant droop in current. These changes were compatible to the original pulser electronic design. This was done when we reduced

the RF rep-rate from 10 Hz to 5 Hz and doubled the beam length to 430  $\mu$ s. In order to reduce coax, RF window and RF spring joint failures. We would again have to double the flattop. This would add additional heat into the Linac internal drift tube quadruple magnets. Additional water flow may be needed to keep the tank on resonance. Replacing a tank drift tube with quadruple has never been done and would be an extremely difficult Work Plan in a high radiation environment.

Table 1: BNL 200 MeV Linac Parameters.

Parameter	Design 1970	Operation 2014	Upgrade
In. Energy (MeV)	0.75	0.75	0.75
Out. Energy (MeV)	200	200	200
Peak Cur. (mA)	100	45	45
<b>Beam PL (<math>\mu</math>s)</b>	<b>200</b>	<b>450</b>	<b>900</b>
<b>RF PL (<math>\mu</math>s)</b>	<b>400</b>	<b>650</b>	<b>1100</b>
Frequency (MHz)	201	201	201
Repetition Rate (Hz)	10	6.67	6.57

Accelerator improvement plan (AIP) has been approved for phase I of intensity upgrade. Phase I includes 15 % (5 % in the peak current and 10% in the beam pulse length) increase in average current and evaluations of the subsystem for doubling the current. Phase I should be finish by 2016 when raster upgrade program will be finished also.

The plan is to increase the peak current by optimizing the ion source parameters. We have revived the ion source test stand after ten years. The test stand source is now working and as good as the operational source. We have started optimizing the beam pulse out of source. Figure 8 shows the comparison of 2013 and 2014 beam pulse shape at Tank 9. The gain in the average current over last year was about 30%. Improvement pulse shape and width contributed about 20%.

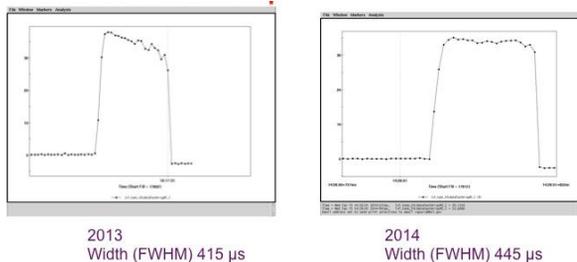


Figure 8: Comparison of beam pulses for BLIP in 2013 and 2014. The improvement in the average current over last year was about 20% due pulse shape and width.

We have tested the linac quads power supplies to increase pulse length by increasing the main and flattop cap bank with various configuration and determined that present power supply cannot support 900  $\mu$ s of beam pulse length. Measurement of RF rise time for all the 9

tanks has been completed (see Figure 9). This summer, we will optimize the coax length to reduce the rise time. With minimizing the RF rise-time and optimizing the beam delay. We are expecting a gain of 40-50  $\mu$ s in beam pulse length. We have planned to inspect water channel in tank drift tubes for erosion and blockage and upgrade test RF system (Mod 10) for 1100  $\mu$ s RF pulse length. We will also test ion source for 1100  $\mu$ s long beam pulses.

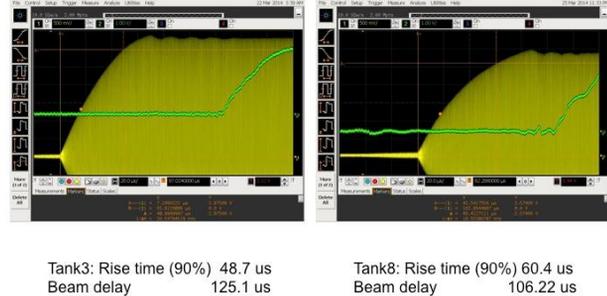


Figure 9: RF rise time measurement for tank 3 and 8. Yellow is RF signal and green is the beam pulse.

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