RESULTS OF INTENSITY UPGRADE PHASE I FOR 200 MeV H- LINAC AT BROOKHAVEN*

D. Raparia#, B. Briscoe, C. Cullen, T. Lehn, V. Lodestro, A. McNerney, J. Ritter, A. Zelenski, Brookhaven National Laboratory, Upton, NY, USA

Abstract

The 200 MeV H- Linac has been operational for the last 45 years providing beam to the physics and isotope programs. There is eight folds increase in yearly-integrated intensity delivered to Brookhaven Linac Isotope Producer (BLIP) in the past decade. Recently we have finished intensity upgrade phase I, which resulted 48% more intensity for BLIP and reduced losses along the linac and transfer line to BLIP by several fold. We will present detail of the upgrade and future upgrades plan to further increase in the intensity by factor of two.

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 45 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^- [3], (c) addition of polarized H^- 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^- beam at 200 MeV to polarized proton program for Relativistic Heavy Ion Collider (RHIC) and 66-200 MeV to Brookhaven Linac Isotope Producer (BLIP). The RHIC program needs two pulses every AGS cycle (~4-6 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 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 (~55 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 [14, 15], are in progress. Here, we will discuss only intensity upgrade program for BLIP.

*Work performed under Contract Number DE-AC02-98CH10886 with the auspices of the US Department of Energy
#raparia@bnl.gov

INTENSITY UPGRADE

The average current delivered to BLIP is steadily increasing over the years as shown in Fig. 1. To increase the isotope production, there is strong desire to increase the linac current by factor of two. An Accelerator Improvement Plan (AIP) was approved for Phase I of intensity upgrade in 2014. Phase I includes 15 % (5 % in the peak current and 10% in the beam pulse length) increase in average current and evaluations of the linac subsystem for doubling the current [17]. Table 1 summarizes linac parameters for intensity upgrade Phase I (2014), operating 2016 and proposed to increase the intensity by factor of two, Phase II. Both the goals of Phase I, (1) increase in 15% current, and (2) evaluation of the linac subsystem for delivering 250 µA average beam current, were successfully completed on time and within the budget. We have concluded that the linac can deliver 250 µA with upgrades of subsystem describe in section below.

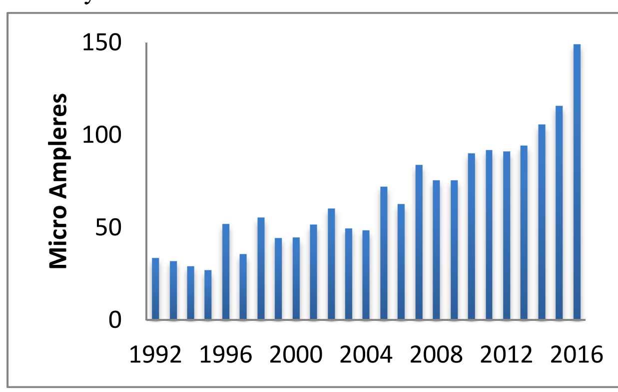

Figure 1: The average current delivered to BLIP for last 15 years (2002-2016).

Table 1: Linac Parameters for Intensity Upgrade Phase I (2014), Operating 2016 and proposed Phase II.

Parameter	**Phase I (Goal)**	**Operation 2016**	**Phase II (Goal)**
In. Energy (MeV)	0.75	0.75	0.75
Out. Energy (MeV)	200	200	200
Peak Cur. (mA)	45	55	45
Beam PL (µs)	**490**	**470**	**900**
RF PL (µs)	**650**	**620**	**1100**
Frequency (MHz)	201	201	201
Rep. Rate (Hz)	6.67	6.67	6.67
Ave. Current (µA)	140	165	250

Result of Phase I

The beam pulse width was gradually adjusted to the maximum value possible with the existing linac cavity quadrupole power supplies and RF systems. About 40 µs beam width was gain by placing beam earlier in the RF-envelop without increasing the total RF width. In addition, the peak value of the available beam current, through careful tuning of injection and accelerating parameters, was increased to 55 mA. As a result available average current to BLIP is greater than 165 µA. The maximum achieved average current and peak current were 173 µA and 57 mA respectively.

We have optimized Magnetron ion source operating parameters, namely, extraction voltage, gas flow and caesium temperature to maximize ion source performance and successfully increased the output current of ion source reliably to 110 mA from 90 mA. Optimized parameters are, extraction voltage 36.1 kV, caesium temperature 100° C and source pressures of 3. 10^{-6} Torr.

To transport such a high current to the RFQ, xenon gas was introduced to 2 meter long Low Energy Beam Transport (LEBT) to charge neutralized the H- beam. We maximized integrated beam current at 200 MeV by controlling the pressure in the LEBT. A typical pressure in the LEBT is about 4.2 x 10^{-6} Torr and in source about 3.6 x 10^{-6} Torr for maximum integrated current at the 200 MeV. Corresponding rise time about 52 µs and losses in the LEBT about 16%, assuming background gas 90% xenon and 10 % hydrogen. Figures 2 compares the pulse shape before and after the xenon gas injection in the LEBT [16].

.

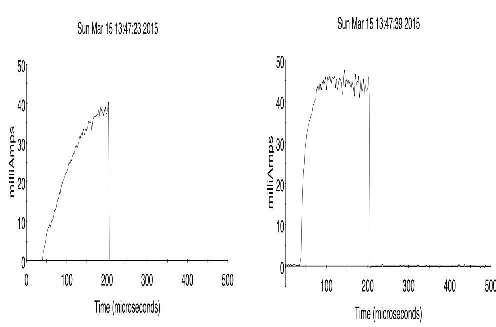

Figure 2: Pulse shape at 200 MeV without (left) and with xenon gas (right) injection in the LEBT.

Evaluation of Subsystems for Double the Pulse Length

Ion Source To achieve 900 µs beam pulse width ion source have to produce it first. We have demonstrated 1 millisecond long pulse from the source at the test stand. We are testing 1 millisecond long pulse from ion source for long-term stability in this summer.

RF System The stand-by 10th RF system was modified to operate at an RF pulse width of 1100 µs. This was accomplished by: (1) Increasing the 250 kW driver capacitor bank from 25 to 40 µF by replacing original capacitors with ten 4uF capacitors. (2) Increasing 7835-power amplifier anode power supply capacitor bank from 50 to 84 µF by replacing original capacitors with thirty-two 2.62 µF capacitors. (3) Several elements of the Modulator which supply pulsed dc power to the anode of the 7835 RF power amplifier were required to be redesigned to function at the wider pulse width. A prototype of each unit was built and successfully tested in the 10th RF system. They are listed below: (a) 4CW 25,000 Anode Power Supply (3kV) (b) 4CW 25,000 Cathode Power Supply (4kV) (c) Modulator A7 Low Level Electronics. We have tested 1 ms long RF pulse in tank 6 and 8, and have modify mod 5 to be tested year long for 1 ms long RF pulse.

Pulsed Magnet Power Supply System Modification of existing quadrupole power supplies was evaluated and it was determined it will be more cost effective to implement a complete redesign of the supplies with modern electronic components that do not use the "resonant" charge approach. Contact has been made with power supply vendors and preliminary design proposals are being evaluated and initial results indicate requirements can be readily met. We planning to build and test two power supplies in the next year.

Cooling Requirements Tests were done on a spare quadrupole magnet to evaluate magnet water-cooling requirements for the increased duty factor and it was found increased water-cooling is not required. Calculations have been completed for a "high power" accelerating cavity and indicate existing water-cooling flows and pressures are sufficient to maintain dimensional stability under the planned increase in duty factor.

Condition of Existing Cooling Channels The conditions of water quality and flow channels were evaluated for three typical cavities and only minor anomalies were found. We have found couple of drift tube flow measure were completely block providing no water flow to drift tubes. We also found several side stamp water channel were clogged.

RUN 2016 FOR BLIP

Linac provided record average and peak intensities for the BLIP program in 2016. Table II compares beam currents parameters for run 2015 and 2016 for BLIP.

Table 2: Beam parameters for run 2015 and 2016 for BLIP.

Parameter	2015	2016	Ratio
Int. Cur. (µA-h)	480970	712347	1.48
Run Ave. Cur. (µA)	115.8	148.5	1.28
Max. Daily Ave. Cur. (µA)	123.1	166.8	1.35
Max. Int. Cur. (µA)	147	173	1.18
Max. Peak Cur. (mA)	47	57	1.21

ISBN 978-3-95450-169-4

Figure 3 depicts the yearly-integrated beam power in MW-hours delivered to BLIP for last 15 years. With the help of newly install neutron detectors residual radiation is down order of magnitude in spite of about eight folds increased in yearly-integrated power.

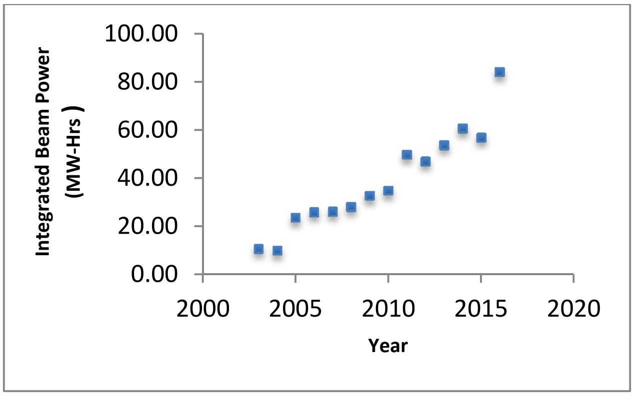

Figure 3: Yearly integrated beam power in MW-Hours for last 15 years (2002-2016).

Figure 4 compares the integrated beam current as function of number of days delivered to BLIP target for past 6 years (2011-2016).

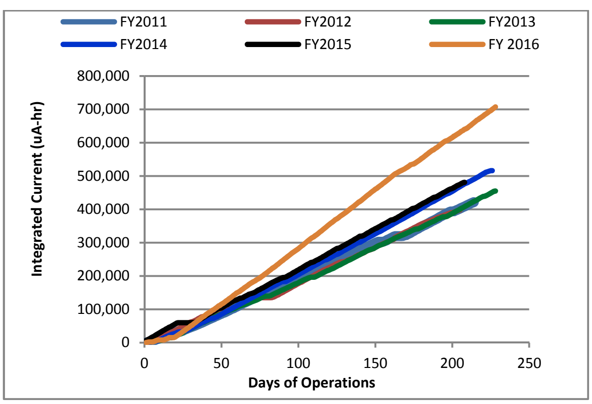

Figure 4: Annual integrated currents from 2011 to 2016 for BLIP. The total integrated current increased 48% from 2015 to 2016.

A companion upgrade programme for BLIP, scanning beam to provide more uniform power distribution on the target, was also completed for BLIP RUN 2016 [18]. Figure 5 compares the rastered and non-rastered measured beam footprint on the target.

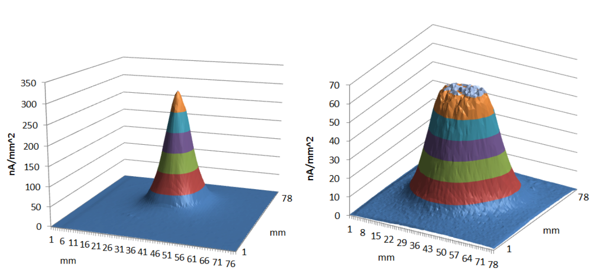

Figure 5: Measured beam footprint on the target without (left) and with raster (right). Note that the y-scale is 5 times smaller for rastered beam.

CONCLUSIONS

We have successfully completed linac intensity upgrade phase I, on time and in budget. We have concluded that the linac can deliver 250 µA with upgrades of linac subsystem. With beam scanning system in operation, 45-year old linac provided record intensities to BLIP in 2016. With about 50 % more current on the target in 2016 in compare to 2015, linac reliability did not suffer and remain about 96% as previous years. With careful tuning of the linac and transfer line, residual radiation level has fall down about order of magnitude over the years.

REFERENCES

[1]G. W. Wheeler *et al.*, “The Brookhaven 200 MeV proton linear accelerator”, Particle Accelerator, 1979, Vol. 9, pp. 1-156.
[2]N. M. Fewell *et al.*, “Operation of the Brookhaven 200 MeV Linac”, 1979 Linac Conference, Montauk, NY, pp 83.
[3]R. L. Witkover, *et al.*, “Conversion of the AGS linac to H- Acceleration”, PAC 1983, pp 3010.
[4]Y. Makdist *et al.*, “Acceleration of polarized H- in the BNL 200 MeV Linac” PAC 1985, pp.3166
[5]J. G. Alessi *et al.*, “Performance of the new AGS RFQ Pre-injector’, PAC 1989, pp.999.
[6]J. G. Alessi *et al.*, “Upgrade of the Brookhaven 200 MeV Linac”, Linac 1996, pp.773.
[7]A. Zelenski *et al.*, “Optically Pumped Polarized H- Ion Source for RHIC Spin Physics”, Rev. Sci. Ins. 73, 2002, pp. 888.
[8]A. Zelenski *et al.*, “The RHIC Polarized Source Upgrade”, PAC 2013, Pasadena, CA, USA, pp.49.
[9]D. Raparia *et al.,* “Proposal for Reduction of Transverse Emittance of BNL 200 MeV linac”, Linac 2004, Lubeck, Germany, 2004, pp.36.
[10]D. Raparia *et al., “*Results of LEBT/MEBT Reconfiguration at BNL 200 MeV Linac*”,* PAC09, Vancouver, Canada, pp. 441.
[11]D. Raparia *et al.*, “Low and Medium Energy Beam Transport Upgrade at BNL 200 MeV Linac”, Linac 2010, Tsukuba, Japan, pp.455.
[12]D. Raparia *et al.*, “Changes in LEBT/MEBT at the BNL 200 MeV Linac”, PAC 2011, New York, pp.1978.
[13]D. Raparia *et al.*, “Improvements at the BNL 200 MeV Linac”, Linac 2012, Tel-Aviv, Israel, pp.969.
[14]D. Raparia *et al.*, “Reducing Current Density for the BLIP Target at Brookhaven 200 MeV Linac”, Linac 2014, Switzerland, pp.850.
[15]D. Raparia *et al.*, “Reliability and Intensity Upgrade for Brookhaven 200 MeV LINAC” Linac 2014, Switzerland, pp.67.
[16]D. Raparia *et al.,* “Charged neutralized low energy Beam transport at Brookhaven 200 MeV Linac” Review of Scientific Instruments, 87, 02B935 (2015).
[17]D. Raparia *et al.*, “200 MeV H-Linac upgrade at Brookhaven” IPAC 2016, Busan, Korea, pp.968.
[18]R. Michnoff *et al.*, “The Brookhaven isotope production facility (BLIP) raster scanning system first year operation with beam” IBIC-2016, Barcelona, Spain.