THE BROOKHAVEN LINAC ISOTOPE PRODUCTION FACILITY (BLIP) RASTER SCANNING UPGRADE*

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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 is being installed to provide a better distribution of the H^- 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 at 5 kHz 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. The instrumentation systems include multi-wire profile monitors, a laser profile monitor, beam current transformers, and a beam position monitor. An overview of the upgrade and project status will be presented.

INTRODUCTION

The purpose of the raster system currently under development at BNL's BLIP facility is to "paint" the H^- beam on the target in a circular pattern in order to provide a more even distribution of beam on the target material. At present, with a Gaussian beam profile, targets such as RbCl melt only in the region of highest beam intensity. This causes a large local density reduction leading to reduced and erratic production yield. The improved rastered beam distribution is expected to result in higher yield of the produced isotopes, especially the critical isotope Sr-82.

The BLIP H^- beam parameters are shown in table 1.

Table 1: BNL LINAC H^- Beam Parameters at BLIP

Energy options:	66, 116, 139, 181, 200 MeV
Repetition rate:	6.67 Hz
Pulse width:	450 microseconds
Peak beam current:	50 milliAmps
Max integrated current:	135 microAmps

The plan is to raster the beam in a circular pattern on the target at 5 kHz, which corresponds to 2.25 revolutions per 450 microsecond beam pulse. A repeating pattern as follows will be generated: 3 consecutive beam pulses at a radius of 19.5 mm, then 1 pulse at a 6.5 mm radius (ref. Fig. 1). Flexibility will be provided to vary the radius value and the number of beam pulses for each radius. In this manner near uniform deposition on the target can be achieved.

The concept of the BLIP raster system is based on the system that has been in operation at the Los Alamos National Laboratory Isotope Production Facility (IPF) [1]. However, several differences exist between the facilities, including increased magnet power requirements at BLIP due to a larger kick angle (3.3 milliRadians for BLIP, 1.5 milliRadians for IPF), and rastering with 2 different radii at BLIP for improved beam distribution.

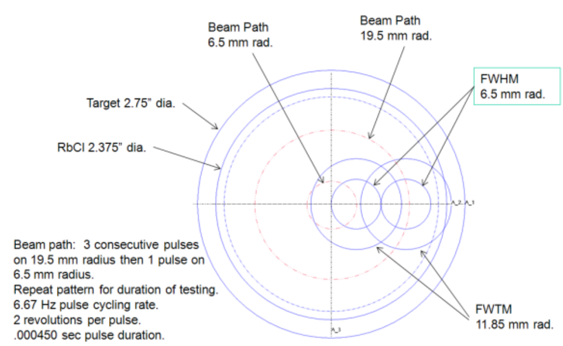

Figure 1: Diagram of circular raster pattern on target.

VACUUM COMPONENTS

The layout of the new BLIP beamline section is shown in Fig. 2. To the extent possible, aluminum components are used instead of stainless steel because aluminum has a shorter half-life and will present fewer activation issues in this high radiation area. The high radiation is primarily caused by back-scattering off the beryllium window that is used to isolate the upstream higher vacuum section from the downstream lower vacuum section.

Most the beam-line pipe is 8" OD. A 6.5" ID graphite collimator will be installed just upstream of the raster magnet to protect the magnet from being damaged by mis-steered particles, and a 4.5" ID graphite collimator just upstream of the multi-wire/LPM crosspiece to protect the beam current transformers. The BPM pipe is 8" OD with 4.5" ID pickups. Graphite is installed between the BPM pickups and the inner pipe wall to help shield the beam current transformers from backscattered particles from the beryllium window. Three aluminium bellows will be installed to facilitate assembly and alignment. A viewport section is in place for thermal imaging of the beryllium window in the future. Included in the viewport section is an electron suppressor ring that will prevent backscattered electrons from interfering with the BPM and current transformer measurements.

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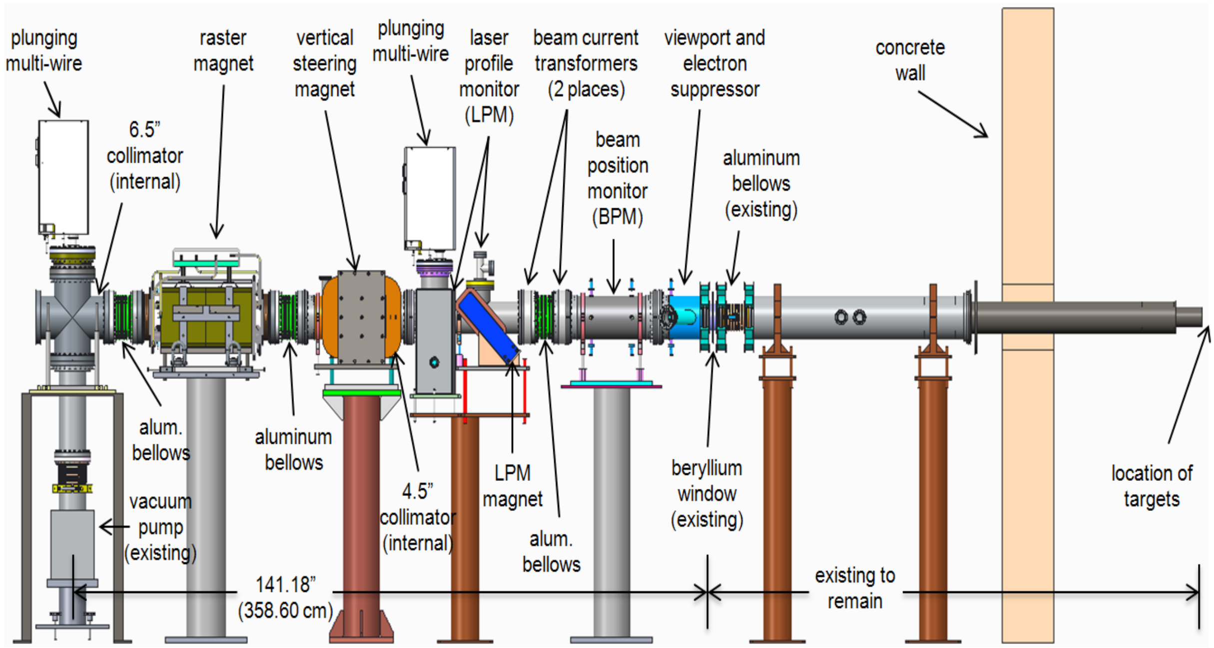

Figure 2: New BLIP beam-line layout.

RASTER MAGNET

The raster magnet consists of one horizontal pair and one vertical pair of water-cooled coils wound on an 8" OD ceramic beam tube with transitions to stainless steel flanges at each end. The coil/tube assembly is housed in ferrite (Fig. 3). 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 will be installed in the magnet to monitor the induced magnetic field.

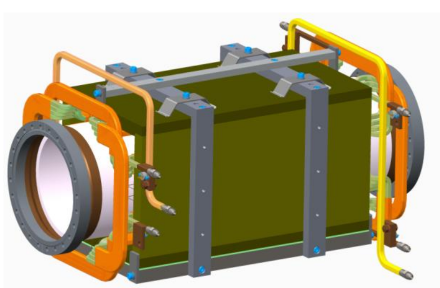

Figure 3: Image of BLIP raster magnet assembly.

RASTER MAGNET POWER SUPPLIES

The horizontal and vertical raster magnets will be driven continuously with a sine wave at 5 kHz and 90 deg. phase separation to provide the circular beam pattern. The amplitude of the signal will control the radius of the beam motion.

Pacific Power Source model 160AMX-UPC12 6 KVA power amplifiers will be used in combination with a custom-designed resonant circuit to deliver 225 A RMS (318 A peak), 470 V RMS (664 V peak), 105 KVA apparent power to the magnet [2]. 4/0 gauge Litz wire with polyimide insulation for radiation resistance will be used. Litz wire was selected because it has much lower resistance than standard wire at our 5 kHz operating frequency.

The power supply controls will be based on National Instrument's PXIe system and Labview. With a Q of about 50, slight frequency shifts off resonance will result in significant amplitude decrease. Therefore, frequency feedback loops will be implemented to keep the frequency on resonance. Software feedback loops will also be used for amplitude control. Other functions of the controls include maintaining 90 deg. phase separation between the horizontal and vertical signals, and interlock safeties for magnet over-temperature, low cooling water flow, etc.

MULTI-WIRE PROFILE MONITORS

Two plunging multi-wire devices manufactured by Princeton Scientific will be installed at the locations shown in Fig. 2. One is upstream of the raster magnet to provide profiles of the non-rastered beam, and the other is downstream of the raster magnet to provide profiles of the rastered beam. The combination of these two devices can also be used to provide a measurement of the beam trajectory angle through the beam-line.

The upstream device is mounted on a 10" OD flange with 7.74" ID pipe and has a stroke of 200 mm, with 300 mm distance from the beam axis to the mounting flange. The downstream device is mounted on an 8" OD flange with 5.75" ID pipe and has a stroke of 150 mm, with 240 mm distance from the beam axis to the mounting flange.

Each multi-wire unit consists of 32 horizontal and 32 vertical tungsten wires, with diameter 0.1 mm and spacing of 3.175 mm. Kapton-coated copper wiring will

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be used internal to the device and brought to 50-pin D-sub connectors with PEEK insulator.

The devices will be pneumatically controlled to plunge into the beam path for a limited time period while the profile measurement is taken. This will extend the longevity of the wires by preventing extended exposure to the beam. The existing BLIP multi-wire device has been problematic because it is stationary in the beam path and must be replaced approximately every two years due to broken wires from continuous beam exposure.

BNL Collider-Accelerator department standard 8-channel integrator modules will be used to process the signals (Advanced Technology Laboratories, Inc part number 22490001). One channel will be connected to each wire, for a total of 128 integrator channels (32 wires per plane, 2 planes per device, 2 devices).

LASER PROFILE MONITOR (LPM)

One laser profile monitor will be installed at the location shown in Fig. 2. This device is very similar to the LPM that is currently installed at the BNL LINAC upstream of the BLIP beam-line [3]. Valuable operational experience was gained with the existing LINAC LPM during the FY2014 beam run.

The purpose of the LPM is to produce profiles of the rastered beam. While this is similar in function to the multi-wire units, the LPM does not have components in the beam path that can be damaged by the beam. The expectation is that the LPM will produce profile measurements approximately several times an hour.

The LPM uses the Quantel Ultra 50 Q-switched Nd:YAG 100 mJ/pulse laser, with 10 ns pulse width. The laser is triggered once per 450 microsecond beam pulse, and will be stepped horizontally and vertically across the beam to provide average profiles for each plane. An average of many beam pulses will be taken at each laser position. Three Arun Microelectronics Ltd. LTVL100-UHV radiation hardened translation stages will be used - one to sweep the horizontal mirror, one to sweep the vertical mirror and one to insert/retract the mirror that directs the laser to each plane. The LPM chamber and optics/motor assembly is shown in Fig. 4.

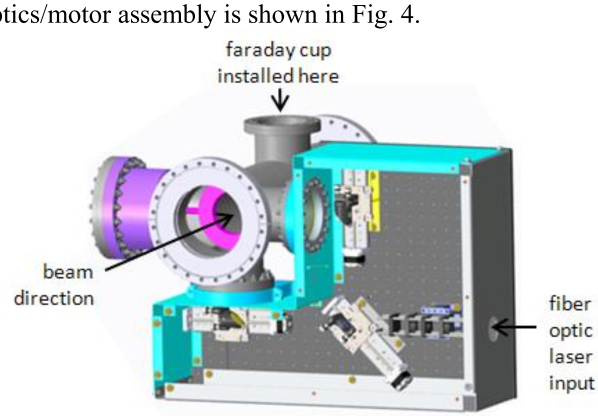

Figure 4: BLIP LPM chamber and optics/motor assembly.

A detector magnet powered by a Sorenson DCS-20-60, 0-20V, 0-60A power supply directs electrons released by the laser to a faraday cup that uses a Stanford Research SR-570 current preamplifier and Tektronix MDO3034 oscilloscope for measurement. Standard VME controls hardware will be used for motor control, triggering, and digital and analog I/O; and Labview will be used for sequencing the profile scans. A Modicon momentum PLC will be used for the Sorenson power supply control.

BEAM CURRENT TRANSFORMERS

Two Bergoz model ACCT-CF10”-147.6-40-UHV-CAW1-H beam current transformers will be installed. These devices are flange mounted with 10” OD and 5.75” ID. The Bergoz ACCT-E-RM-100mA-WB electronics module will be used to convert the current transformer signal to an analog voltage, where +/-5V output corresponds to +/-100mA beam current. Radiation hardened 20 meter cable was purchased from Bergoz for the connection from the current transformer in the beam tunnel to the electronics module in the control room.

BEAM POSITION MONITOR (BPM)

A split cylinder, electrostatic-type capacitive pickup BPM has been custom-designed for the BLIP beam-line and modelled after the BNL AGS Booster BPM [4]. An image of the internals of the device is shown in Fig. 5. A calibration ring is provided for each plane to allow a simulated signal to be induced on the pickups for testing and calibration of the electronics. The 4.5” ID end pieces will help maintain straight field lines at the end of the pickups before the transition to the 8” OD pipe.

BPM measurements will be challenging because for the lower energy operation the 200 MHz RF beam structure is not expected to be present since significant debunching occurs when the beam travels the long distance between the last driving RF tank and the BPM.

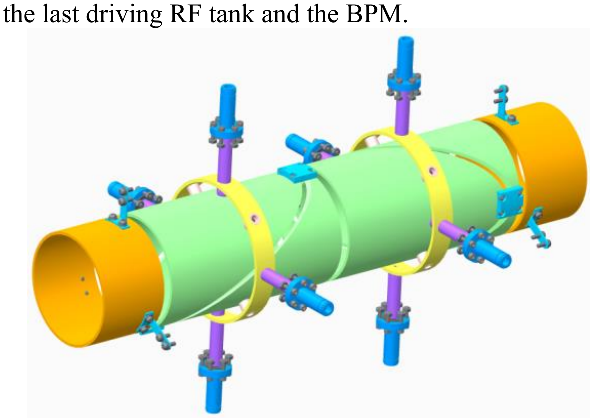

Figure 5: Image of BLIP BPM internal components.

A high input resistance, high gain electrometer-type analog circuit has been designed to measure the low energy debunched beam. An independent circuit will be used to measure the higher energy beam when the 200 MHz RF structure is present. Custom electronic hardware will be designed to process the BPM measurements and may be used to provide an interlock output signal to the beam inhibit system when the beam position is not rastering as expected.

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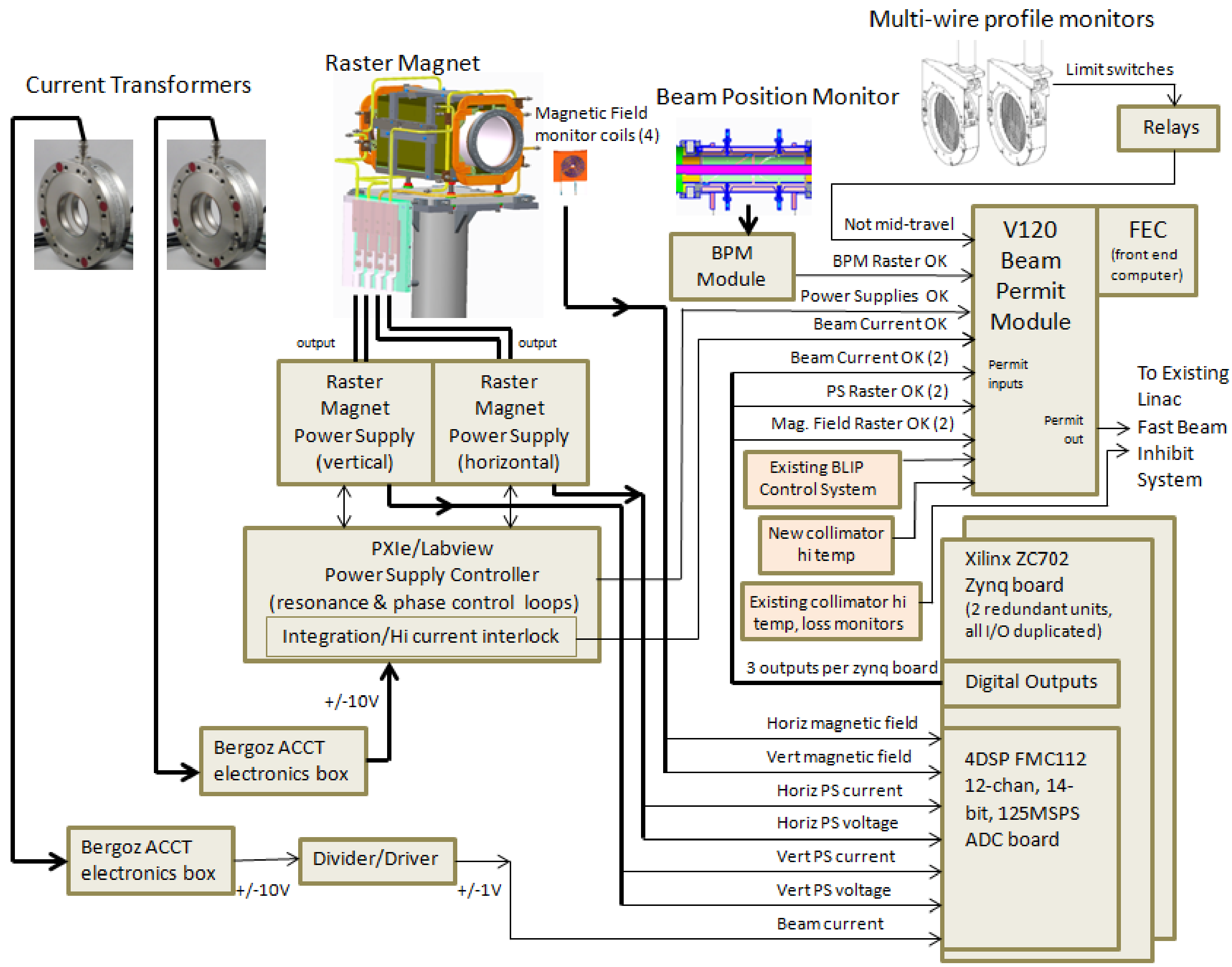

Figure 6: BLIP beam interlock system block diagram.

BEAM INTERLOCK SYSTEM

The purpose of the beam interlock system is a combination of machine protection and target failure prevention (Fig. 6). The present system uses a signal from the existing BLIP control system to inhibit the beam when alarm conditions occur. This signal is also used as a beam ready signal to allow beam to the BLIP targets, and is connected via a hard-wire cable to the LINAC fast beam interrupt (FBI) system.

Other direct signals to the existing LINAC FBI system include loss monitors and high temperature limits from thermocouples on the beam pipe where collimators are installed. These thermocouples are used as an indication that the beam is far off-center.

The signal from the existing BLIP control system will be rerouted into a standard BNL-designed VME-based V120 beam permit module [5]. This module will also be used to accommodate additional new signals as shown in the block diagram (Fig. 6).

Two redundant Xilinx ZC702 modules, each with a 12-channel, 125MSPS analog input module (4DSP FMC112) and 5 channel digital output module (FMC-DIO), running linux and custom gate array code will provide real-time processing of power supply, magnetic field and beam current signals to interlock the beam if any of the following conditions are not satisfied.

- Rastering is enabled and the horizontal and vertical raster magnet magnetic fields have the expected amplitude, 5 kHz sine wave, and 90 deg. phase separation.
- Rastering is enabled and the horizontal and vertical power supply currents have the expected amplitude, 5 kHz sine wave, and 90 deg. phase separation.
- Rastering is disabled and the beam current is below the programmed threshold.

The last condition is required for operating modes where beam rastering is not desired. In this case, the beam current is monitored and will cause the beam to be inhibited if the current exceeds a programmed threshold level in order to prevent target failure with high current beam.

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The FMC112 analog signals will also be capable of being displayed and logged via standard facility control system software tools.

The power supply control system and the BPM electronics module will also be capable of interlocking the beam. For redundancy, processing for one of the two beam current transformers will take place in the Labview PXIe system and can also inhibit the beam.

In addition, thermocouples will be installed on each quadrant of the 2 new collimator sections and will be capable of inhibiting the beam if any collimator temperature exceeds a programmed threshold, indicating that beam is far off-center.

Another signal will be provided to inhibit the beam if either multi-wire device is in the mid-travel position. This will guarantee that the frame of the multi-wire is not in the beam path when beam is present.

INSTALLATION PLAN

With the exception of the raster magnet and the associated power supplies, the entire new beam-line will be installed during the fall of 2014. A dummy spool piece will be installed in place of the raster magnet. The raster magnet and associated power supply will be installed one year later during the fall of 2015. This early installation of the beam-line and instrumentation will allow a full operational year to commission the instrumentation systems prior to beam rastering. The full system implementation is expected to be operational during early 2016.

STATUS

As of September 2014, nearly all of the required beam components have been received and are being mocked-up in the lab prior to installation in the tunnel (Fig. 7). The goal of the mock-up is to find and correct issues that arise prior to installation in the high radiation tunnel, thus limiting worker exposure during the tunnel installation.

The electronic equipment for the upgrade including the raster magnet power supplies, and instrumentation and control hardware will be installed in the BLIP control room, which is located above the end of the beam-line. Facilities work is in progress as shown in Fig 8.

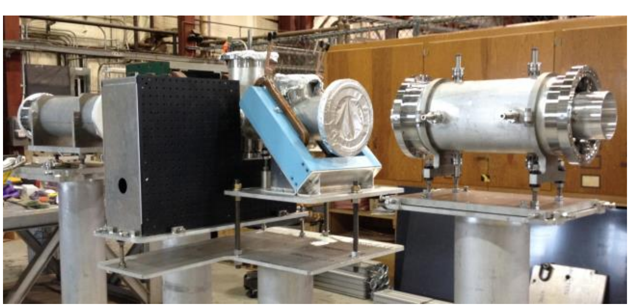

Figure 7: Beginning of mock-up of new BLIP beamline section including from left to right, the dummy raster magnet spool piece, the LPM with optics box (black side) and detector magnet (blue), and the BPM. Beam direction is left to right.

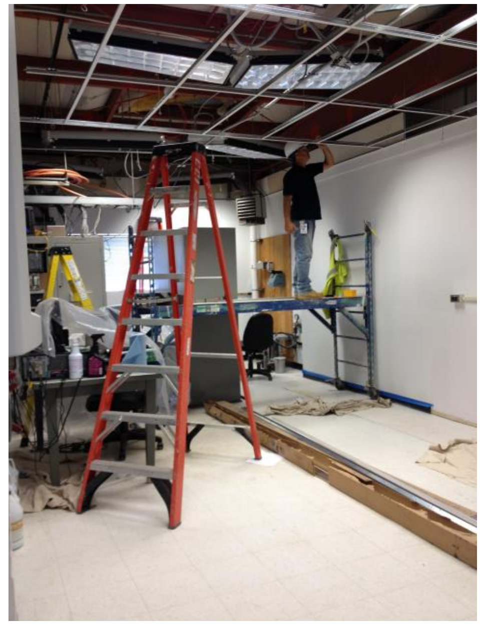

Figure 8: Photo of work in progress in the BLIP control room on September 8, 2014 where 7 new equipment racks will be installed to house the new electronics. Facilities work includes upgraded power, new ceiling and lighting, new air conditioning system, and cable trays.

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