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# RECENT ENHANCEMENTS TO THE LOS ALAMOS ISOTOPE PRODUCTION FACILITY*

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*Abstract*

Isotopes produced at Los Alamos National Laboratory (LANL) are saving lives, advancing cutting-edge research, and helping to address national security questions. For the past two years LANL's Accelerator Operations & Technology Division has executed a $6.4M improvement project for the Isotope Production Facility. The goals were to reduce the programmatic risk and enhance facility reliability while at the same time pursuing opportunities to increase general isotope production capacity. This has led to some exciting innovations. In this paper we will discuss the engineering designs for an upgraded beam raster system, a new beam diagnostics capabilities and our new collimator, which is both adjustable and 'active' (beam current and temperature measurements). We will also report on results obtained and lessons learned from the commissioning phase and initial production run.

## INTRODUCTION

The Isotope Production Facility (IPF) is located on the northwest side of the Los Alamos Neutron Science Center (LANSCE) accelerator complex and consists of a dedicated beamline, target and hot cell as shown in Figure 1. Beam from the LANSCE 100 MeV drift tube linac (DTL) is directed through a shield wall in the main accelerator tunnel to a separate beamline in the IPF tunnel that connects to the IPF target.

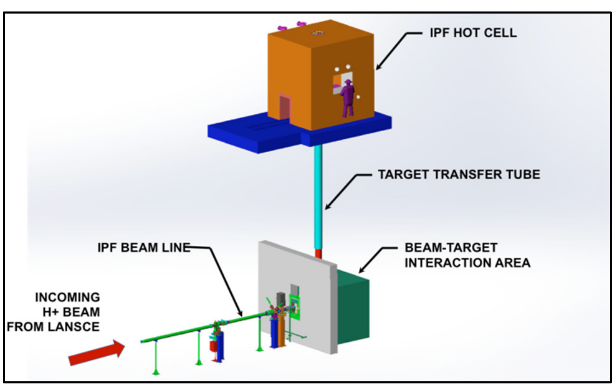


Figure 1: Layout of IPF Facility.

The overarching motivation for the IPF Accelerator Improvement Project (AIP) was

- To *reduce programmatic risk* with respect to beam window failure (which is a consumable)
- To *enhance IPF facility reliability* with improved diagnostic capabilities while at the same time pursuing opportunities
- To *enhance* general isotope *production capacity*.

## PROJECT GOALS

Based on the overarching motivation four Focus Areas with associated goals were developed. The first is aimed at improving the beam window design to reduce programmatic risk associated with a target window failure. This is listed here for completeness but will not be discussed any further in this paper.

The second is aimed at improving the beam rastering system to ensure that the beam-power is distributed optimally across the surface of each target.

The third is aimed at developing and installing improved beam diagnostics in the IPF beamline to better predict the beam size and position at the target window and target therefore *enhancing the reliability* of IPF. This requires transverse emittance characterization of the beam, the measurement of rastered and unrastered beam profiles, accurate beam current measurement over a larger dynamic range and time-of-flight energy measurements at the nominal operational energies of 41, 72 and 100 MeV.

The last area was focused on the development of an active & adjustable collimator. The collimator is divided into four active-segments with a beam-spill current and temperature measurement for each segment. Furthermore, we will enable the use of larger diameter targets to *increase the production capacity* of various radioisotopes at IPF by replacing the fixed-diameter collimator with an adjustable aperture unit.

## BEAM RASTER

The Beam Raster System is using an existing pair of Elgar SmartWave Switching amplifiers/power supplies which run at 4950 Hz AC. One complete raster cycle is drawn in 202 µs. During the nominal 625 µs beam macropulse 3+ revolutions of the same diameter are drawn. There is 1 master and 3 slaves for the horizontal and vertical rastering which are connected respectively to the horizontal and vertical raster magnets in the IPF beam line. The master power supplies are synchronized together in phase offset by about 89 degrees.

The raster system provides three distinct functionalities, all implemented in a redundant configuration using two National Instruments cRIO systems, shown in Figure 2.

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### *Run Permit – System Ready*

- Water Flow in both Magnets
- Magnet Temperature
- Magnet Ground Fault (current)
- Sine-Wave Generator On
- Power Supplies On
- System Health heart beat making sure that system has not stalled or locked up

### *Fast Protect – Fast Beam Turn Off*

- Current of horizontal & vertical waveform amplitude
- Frequency of AC waveform
- Phase between vertical & horizontal AC waveforms
- IPF Beam Raster Gate
- Following desired output raster pattern
- Digital Fault Indicator of Elgar Power Supply
- Voltage across magnets. Trip when calculated impedance changes >5 %

### *Beam Raster System (BRS) – Raster Producing System Must Be*

- Capable of producing at least 100 different levels on successive macropulses.
- Able to produce up to ~3 rastered circles in one macropulse that are the same size.
- Remotely controllable. Parameters should be set in an expert screen rather than on the main IPF control screen.
- Able to limit the waveforms that are selectable.
- Capable of on-the-fly adjustment to account for variation in the day-to-day beam spot size. This requires independent adjustment of X and Y amplitude, +/- 10 % in one percent step sizes.

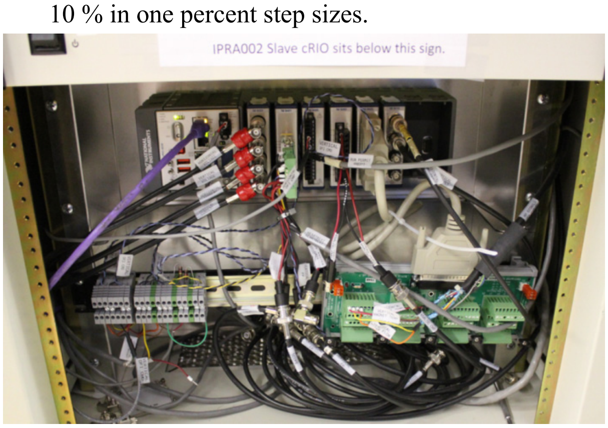


Figure 2: One of two National Instruments cRIOs.

The Fast Protect system's main focus is to protect the beam window. Worst case is 41 MeV, 450 µA, 1.4" aperture non-rastered beam. The beam window may not exceed 200°C. Thermal-mechanical modelling results have indicated that, under worst case scenario, the beam needs to be shut off within 200 µs. The Fast Protect system has proven to achieve this level of protection.

## BEAM DIAGNOSTICS

The addition of multiple diagnostic capabilities at IPF is expected to have a significant effect on enhancing the reliability of the IPF facility and potentially increasing the lifetimes of future beam window designs by years. Given that many IPF production targets operate very close to their thermal limit, the addition of a wire scanner, the upgrade of the multi-wire *beam profile* device (Harp), and installation of emittance measurement capabilities will reduce the probability of target failure from poor registration of the beam on the face of the target, enable improved calculation of beam power density for enhanced thermal modelling, and provide real-time feedback to operators in the process of tuning facility parameters during a production run cycle.

The old IPF current monitor system was accurate at high current, i.e. tens of µA's and higher, but not at 100 nA, where some irradiations need to be performed. We developed an enhanced front-end electronics using the existing toroid-based system in the IPF beamline for 1 % accuracy of *low current measurements.*

Realization of recent work to employ routine *beam energy* (Time of Flight) monitoring with time-of-flight measurements will reduce the risk of un-optimized beam energetics, which confound precious experimental irradiations, enhance the precision with which nuclear data can be collected at the IPF, and reduce the probability of beam spillage into unwanted longitudinal locations in the target stack to negligible values. All systems will be now discussed in turn.

### *Beam Profile and Emittance Measurements*

The project utilized an off-the-shelf slide table design with a common actuation stage for all profile measurement relevant devices. Modifications were then made to the carriage mount for each interceptive application. The combination of Slit and Harp provides the Emittance Measurement capabilities.

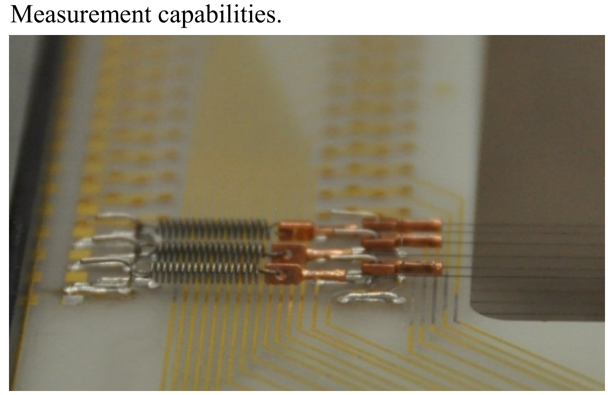

Figure 3: Spring loaded wires of Harp Head.

Figure 3 show the high packaging density Harp Head hosting 77 Silicon Carbide wires at 1mm pitch. A hook, spring, and collet configuration maintains sensor tension and placement on the circuit board while also maximizing sensor density. Signals induced in the sensors travel along the Harp circuit board's traces, through two high-density connectors, along Kapton insulated cables, to two mil-spec vacuum feedthroughs prior to interfacing with the Harp's facility cabling. This combined with a 1 millimeter resolution dual actuator stepping system as well as the

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ability to perform synchronized data acquisition of waveforms with a custom analog front end board design and application of specific field-programmable gate arrays (FPGA) software code allows IPF to do time-dependent emittance measurements rather than just single time slice. The advantage is that the system can now do a whole series of measurements all at once.

Each axis of the emittance-measurement system is operated by cRIO-9038 embedded controllers in a one master - two slave relationship. The master-controller is configured to acquire the 77 channels of Harp sensor waveform data and controls the sequence of positions for data collection. The two slave-controllers function as actuator motion control systems to control the positioning of the emittance system's slit and harp heads. The synchronized data acquisition system with the custom analog front end board design is shown in Figure 4 below.

Figure 4: Data acquisition system.

The synergistic relationship of the controllers allows for high-density sensor waveform acquisition with associated motion control, enabling such data acquisition methods as single-axis emittance measurements, single-axis Harp measurements, and, when used in coordination with the controllers of the orthogonal axis; a two-axis, Harp based, transverse profile measurement. Furthermore, the importance of these measurements is compounded by the beam-rastering capabilities of the IPF beamline.

Key features of the new beam profile system.

- Harp (replaced system: 2.4 mm vs 1.0 mm resolution; stationary vs moveable; 34 wires / axis vs 77 wires / axis; 250 µs vs 10 µs sample rate)
- Emittance Monitor (new system - vertical and horizontal Harps & Slits)
- Wire Scanner (new system; 1 mm resolution; 17-inch aperture, 8 inch stroke)

### *Beam Current Measurement*

The Beam Current Measurement system is using existing current toroids (IPCM 3 & 4) and pre-existing preamp electronics. A new average current electronic derived from the existing current limiter digital circuitry has been developed for a NIM-Bin module form factor (Figure 5).

In order to maintain noise immunity we are using a simple Manchester coding unidirectional data stream scheme, transmitting digitally the data from the low current measurement card into a binary module of the control system for decoding which will maintain the high accuracy of the measured signal that the low current measurement NIM-Bin module acquired.

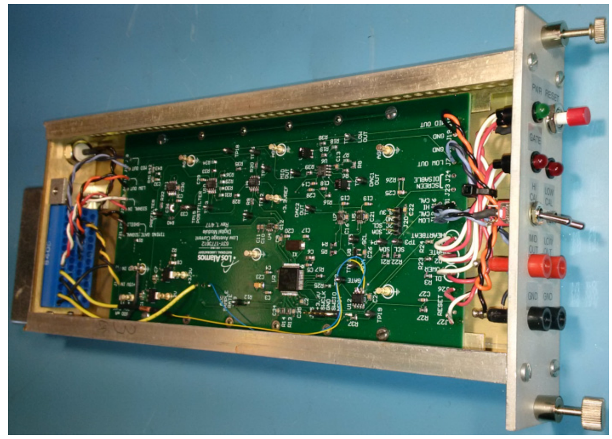

Figure 5: NIM-Bin module.

The beam Current Measurement System itself utilizes the STM32 which belongs to the family of 32-bit microcontroller with integrated circuits (System on a Chip (SoC)) by STMicroelectronics. Internally, each microcontroller consists of the processor core, static RAM memory, flash memory, a debugging interface, and various peripherals.

The system has been designed with the following performance criteria:

- Measurements with 1% accuracy or better over a range from 100 nA to 450 µA.
- Additional capability of near real time (second time scale) beam current monitoring with 5% accuracy or better at low beam currents.

The 1% resolution for the low range channel at lower readings was measured at 12 Hz, adding up 10 reported samples and then averaged. This gives a sample set of 120 readings, showing the mean falls within 1% of the actual value. The 1% full spectrum of the high range channel is achieved by running at 120 Hz with various currents and pulse widths. At 1Hz the system was well within the 5% accuracy for low beam currents.

### *Beam Energy Monitoring (Time of Flight)*

The production system under test is currently utilizing two existing Beam Phase and Positioning Monitors (IPPM 04 & 08). A third BPPM will be added (IPPM 07) as part of the Transition to Operation plan for the 41- and 72 MeV measurements yet to be performed. The system takes advantage of different path lengths to remove ambiguity and achieve the 50 keV resolution for the given magnitude of the measurement (41, 72, and 100 MeV). The electronics system architecture shown in Figure 6, has been developed. It uses a high speed digitizer coupled with a FPGA mounted in a VPX chassis and is capable of

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measuring position, phase and bunched-beam current of the IPF beam.

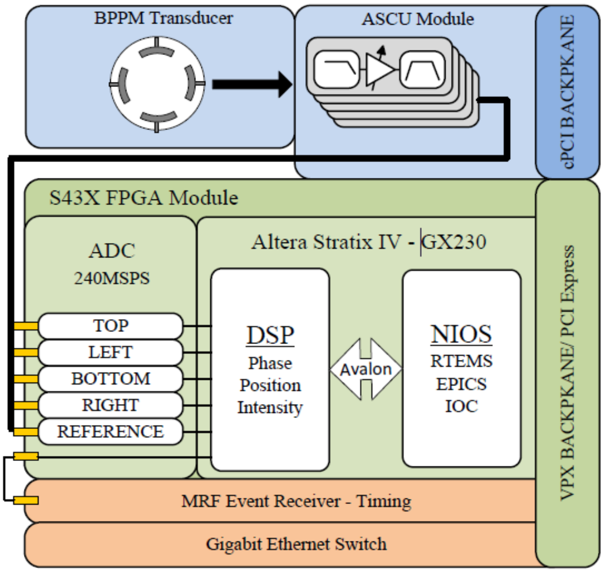


Figure 6: cPCi/VPX BPPM architecture.

The system captures signals from 4-electrodes of a BPPM along with the accelerator reference signal. The signals are then conditioned and filtered to pass the 201.25 MHz RF component. The five signals are then digitized by a high speed digitizer at 4-nanosecond time increments in to order analyse beam position and phase variations that occur throughout the 1-millisecond pulse cycle. A FPGA is being used for the DSP to analyse these signals in different timing modes. A soft core processor, which resides in FPGA fabric, hosts the EPICS database that stores the results and makes them available to beam operators and other users. Timing for synchronous measurements between BPPMs and beam specific information is provided by an event receiver connected to the master timer via optical links. The BPPM results are then stamped with the timing and beam species information prior to submission to the EPICS database. A real time operating system is used to collect data and match it with the correct timing information for each cycle of the beam. The Beam Energy system with cPCI data acquisition and VPX based data processing in housed in one customized chassis [1]. Figure 9 shows the IPF beamline with diagnostic equipment.

## ACTIVE & ADJUSTABLE COLLIMATOR

A collimator narrows a beam of particles and is in most cases passive and fixed. As part of this project we developed an active (measuring signals) and adjustable (changeable aperture size) collimator.

Narrowing a beam means stopping any beam outside the desired aperture. We designed and installed a system capable of stopping an equivalent of 500 W of average beam power by providing water cooling while simultaneously measuring beam current and associated temperature of each segment, providing feedback on beam alignment.

The segment assembly design consists of a graphite block, a Shapal insulator and a water cooled cold-plate for thermal management. The assembly is connected through solder joint and additionally secured by stainless steel screws with Macor inserts and washers to maintain the required electrical insulation (Figure 7). Two of the three center holes at the top edge serve as mounting points for the thermocouple (left) and beam signal (right). All other holes (including top center) host screws used to secure the cold plate to the graphite segment. In total, 8 active segment assemblies have been installed (two for a fixed preceding the 4 for the adjustable collimator).

Figure 7: Active segment assembly.

Figure 8 shows the adjustable part of the collimator assembly. It has two graphite segments each covering a little over 90° of a ring. There are two of these collimator assemblies. The second assembly is turned by 90° to provide 360° of collimation.

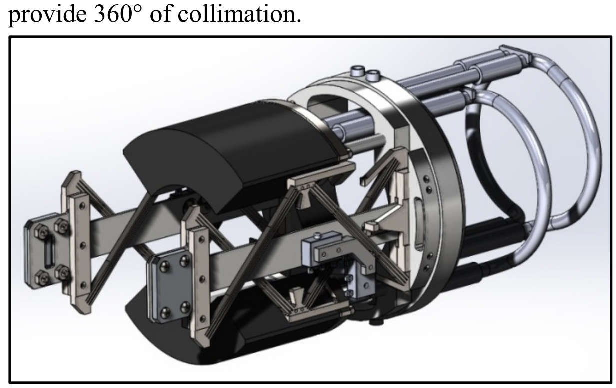

Figure 8: Adjustable collimator assembly.

A Water Cooling Skid that provides cooling for the 8 active segment assemblies was developed. The system provides 2 water pressure monitors, 4 water flow meters and 14 type K thermocouples. The system is installed in the beam tunnel near the beam line [2].

The newly developed Collimator Electronics (Figure 10) ensure effective control and active feedback for each segment by simultaneously providing beam current and temperature measurements. All segments have high voltage bias applied to minimize secondary emission.

In order to achieve this we employed ungrounded thermocouples and provided AC coupling to the signal conditioning circuitry which blocks any DC signal.

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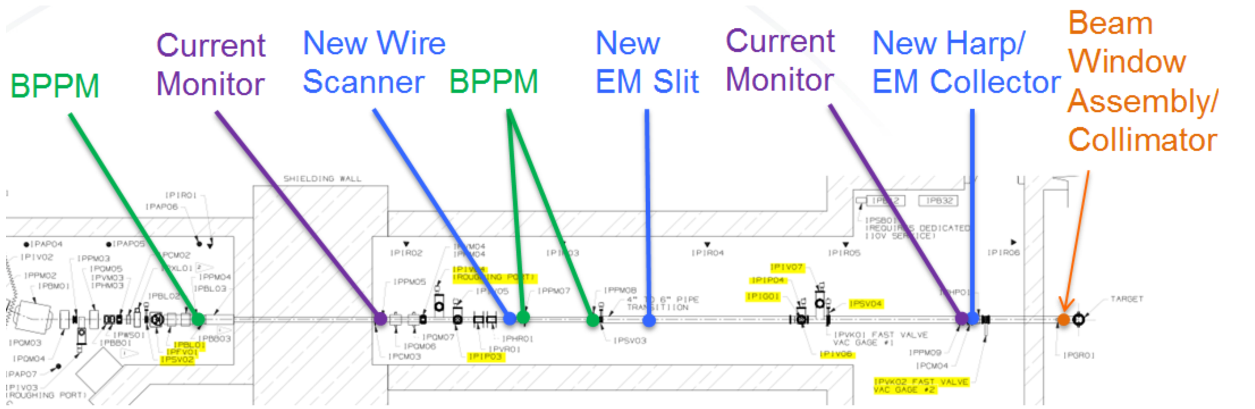


Figure 9: IPF Beamline with new or enhanced diagnostic equipment.

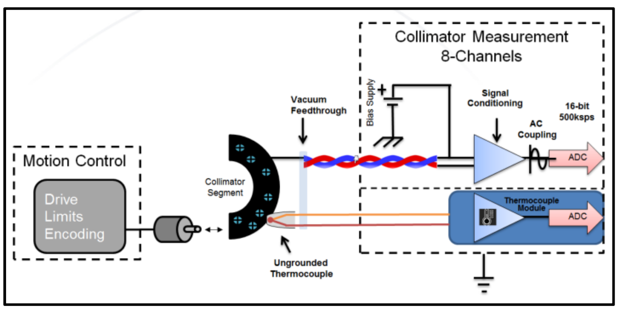


Figure 10: Electronics chassis overview signal flow.

Secondly we provide stepper motor motion control through a closed loop system that consists of a motor driver and a rad hard motor, brake, and assembly resolver.

## COMMISSIONING

For commissioning the high level goals using IPF's 100 MeV beam were to

- Operate and demonstrate functioning beam diagnostics, raster system and active collimator.
- Demonstrate 1-circle, 230 µA rastered beam to IPF target
- Demonstrate 3-circle, 300 µA rastered beam to IPF target

We started with a "safe" low current unrastered beam; 2 Hz x 150 µs peak beam of 4.8mA resulting in 1.3 µA average beam. Using this beam we "touched" each device with beam for pre-commissioning checkout to find and fix obvious issues, e.g. broken software, missing signals, etc. This was followed by four weeks of intermittent commissioning as beam and people were available and when it did no conflict with general LANSCE accelerator tune-up activities.

During the later part, numerous problems were encountered but subsequently fixed during or after the commissioning phase. For example, for the Harp beam profile measurements we encountered a 20 kHz noise that we addressed with a Low-Pass Filter in the FPGA. Hardware improvements in the future will hopefully allow us to eliminate the filter and regain the bandwidth the system is capable of. Since the Emittance program is using data from the Harp we did encounter the same noise problem. Furthermore, the position data for the Harp and Wire Scanner were inconsistent with the ones from the BPMs. New alignment survey data will be used to correct these issues. The low current signals accuracy has been validated on the benchtop but need to be confirmed with beam. Work continues on enhancing software applications to match the technical capabilities of the hardware. This will be tested in upcoming beam development periods. As we learn more and more about the capabilities of these systems, future beam development time will further increase the capabilities of these systems and therefore their usefulness to IPF.

## CONCLUSION

There were six project key performance parameters, all of which have been met. There were also six project ultimate performance parameters (stretch goals), three of which are completed. The capability for the remaining three have been established but not executed due to the unavailability of the facility for sole use or the unavailability of appropriate higher current targets or test time.

## ACKNOWLEDGMENT

This was a LANL Accelerator Operations & Technology division wide effort with great support from the IPF team. The team is to be commended for successfully completing the scope of work on schedule and under budget. We wouldn't have achieved all of this without all the people that have worked tirelessly to make this IPF Accelerator Improvement Project a success. - Thank You!

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