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LLNL-TR-716098

Neutron Imaging Control Report: FY 2016

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December 21, 2016

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

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During the 2016 fiscal year, work began on the supervision and control systems for the neutron source currently under construction in the B194 accelerator caves. This source relies on a deuteron beam colliding with a high-speed stream of deuterium gas to create neutrons, which poses significant technical challenges. To help overcome those challenges, an integrated, operator-focused control architecture is required to collect and assimilate disparate data from a variety of measurement points, as well as provide the means to remotely control the system hardware.

Overall Controls

Logical Architecture

The neutron imaging machine is conceptually divided into three major systems that are largely independent of each other, as shown in Figure 1: 1) the accelerators, 2) the gas circulation system, and 3) the imaging system. Those systems each have subsystems that are more closely integrated. There is limited communication required between these system; so far only a synchronization trigger from the rotational valve, and beam current/neutron flux info to the imaging system have

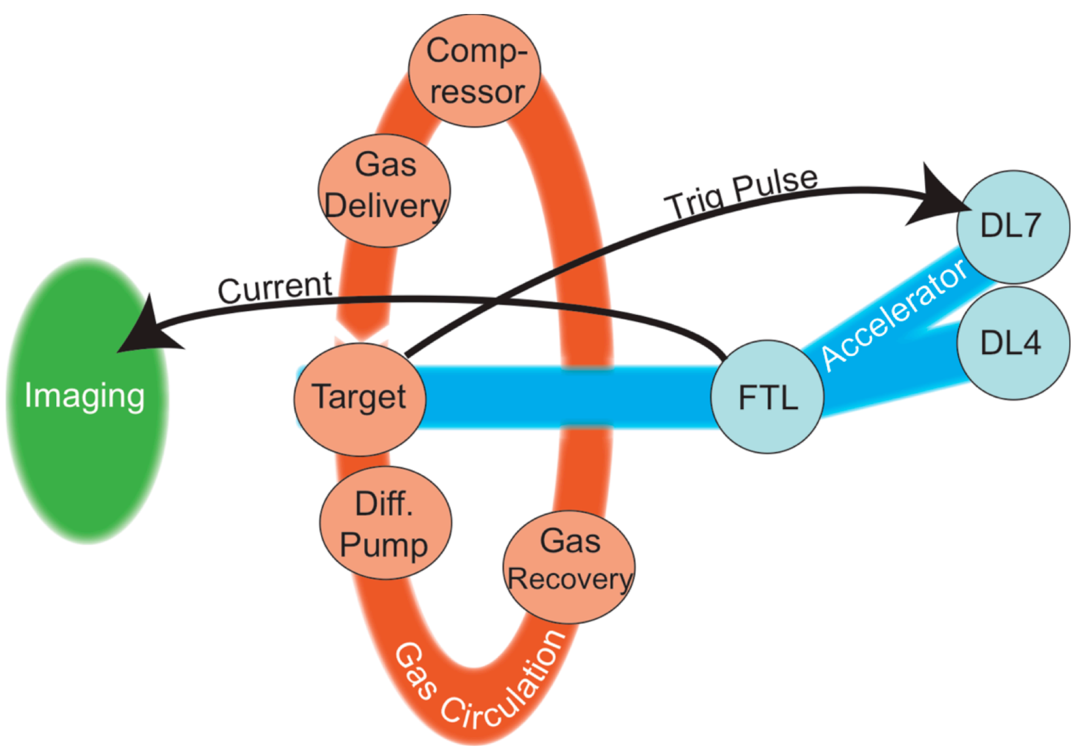

Figure 1 – Conceptual model of the neutron imaging architecture, showing the three systems and their key subsystems.

been identified as necessary. In this report we are discussing only the work to date on the accelerator and gas circulation systems. The imaging system is being developed independently.

Physical Architecture and Integrated Control

The hardware for the source is distributed over multiple floors and buildings, with the compressors in the B194 modulator building, the accelerator in the North Cave underground, and the operator's work station in the main building of B194. To integrate these systems local computers will be installed in each area to interface with the hardware components there, and will be connected via a dedicated private network. By having an isolated network, security concerns are lessened and the frequent patching on operating control systems can be avoided. This network will also be separate from the private networks running the main S-band accelerator in B194 as well as the X-band system in the South Cave, to avoid any network congestion when all the machines are running. Figure 2 shows the top-level diagram of the overall system; this figure is extracted from the controls documentation package.

Interfacing between the sensor and control hardware and the operation software will be mostly performed via the National Instruments Compact RIO (cRIO) platform. This system relies on local controllers running a real-time operating system to provide deterministic run times where needed, as well as an FPGA system to handle the direct interface and do some high-speed processing (e.g. serving machine-protection functions that can run independently of the rest of the system). The interface between the FPGA and the control and measurement signals is provided by a variety of commercially available analog and digital input/output modules. The current vision is to use three cRIO systems, one for the gas circulation hardware in the Mod Building, one for the magnets along the beamline, and one for the rest of the basement diagnostics (vacuum control, gas circulation/recovery downstairs, ICT, BPM, and Gaussmeter readout, etc.). A fourth unit might be needed

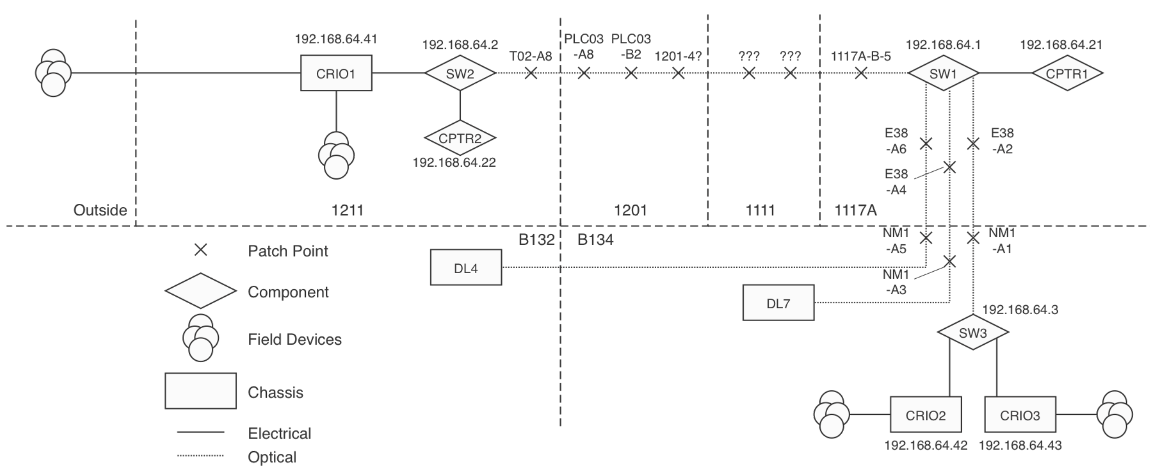

Figure 2 – Top level diagram of the control system network showing supervisory and control hardware.

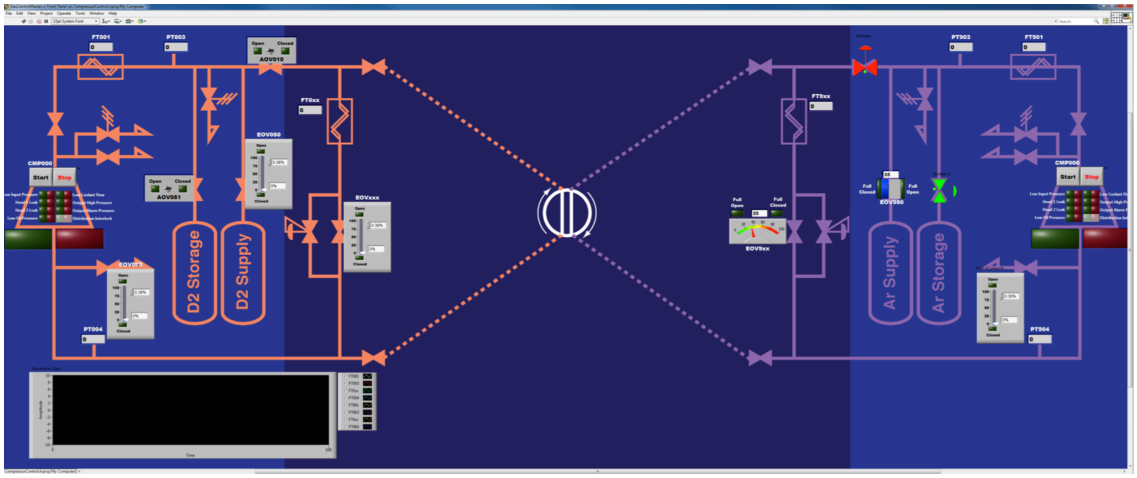

Figure 3 – Draft Operator screen for the gas circulation system

to supplement the basement diagnostics depending on the final number of control points. Additionally, the commercially-built DL7 deuteron accelerator relies on several cRIO units internally to control the accelerator; this further motivated our choice to use cRIO, to harmonize the controls across the entire range of devices.

The data collected by the local controllers will be made available in the LabView environment, mostly making use of their Shared Variable engine. LabView was selected because it is a commercially available system and is relatively easy to use, allowing rapid implementation of controls as new hardware is chosen and avoiding the need for a permanent, dedicated controls engineer. Because this is an R&D project, the requirements and diagnostics are frequently changing with operational and modeling experience, so the flexibility of LabView is useful.

A control computer will provide access to all the control and measurement points to a single operator station in the B194 control room. Figure 3 shows a sample operator interface screen for the gas circulation system. Currently the plan is to have 4 monitors, providing control of: gas circulation, the DL4 or DL7, beam transport hardware, and the imaging system. In addition to providing human interface, the control system must also store data in a useful way. The goal is to have all data (commands and measurements) logged and time-stamped so that operational correlations can be studied.

The architecture also allows for local operating stations. We plan to have a touch-panel display in the modulator building to allow control of the gas compressors and valves, and pressure and flow readbacks, while in the field. Similarly, the DL7 and DL4 offer local control options in the caves which, while not likely to be accessible during neutron operations, might be convenient for initial commissioning of the machines from downstairs.

Documentation

In order to make documentation and requirements clear, a consistent naming system has been implemented, taking inspiration from the ISA-standard naming conventions used for P&IDs. The major subcomponents have names and abbreviations:

Transport Beamline	BL
Compressors/Circulation	CMP
Accelerators	ACC
Rotary Valve	RV
Differential Pumping	DPL

and individual objects have names and a variable name abbreviating the function and loop number that corresponds to a logical or physical location in the system, for example:

D2 Supply Valve	CMP-EOV-050 (000s=D2 compressor, 900s=Ar compressor)
DL4-Q1	BL-MQ-421 (400s = DL4 line, 700s=DL7 line, 100s = Final Transport)

CMP-EOV070	ModBldg/CRIO01	Valve Position Command	AO	4-20 mA	EOV050-CMD		Set Valve Position
		Valve Position Actual	AI	4-20 mA	EOV050-STAT	Current Valve Position	
		Valve Open Switch	DI	24V	EOV050-OPENED	Valve Fully Open	
		Valve Closed Switch	DI	24V	EOV050-CLOSED	Valve Fully Closed	
		Manual Handwheel Engaged	DI	24V	EOV050-MANUAL	Handwheel is engaged	
		Motor Power Disabled	DO	24V	EOV050-POWEROFF		Turn off power to moto
		Motor Power Status	DI	24V	EOV050-POWERED	Power is applied to motor	

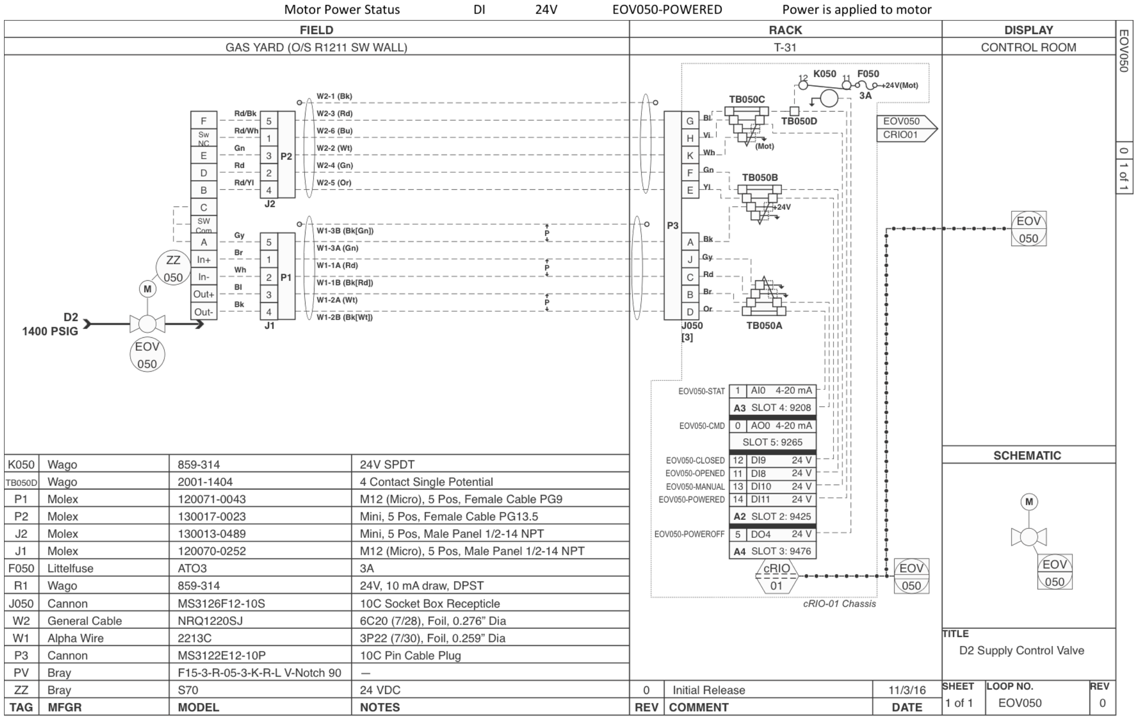

Figure 4 – Sample control point list (top) and loop diagram (bottom) for one of the electrically-operated valves in the gas system.

This name is used throughout the control system and documentation. Documentation is mostly accomplished with tables of control points for each object in the system, along with a loop diagram showing how that object is electrically connected to the system (wiring, cRIO channels, etc.). Examples of the table and a loop diagram for the valve EOV050 is shown in Figure 4.

Detailed Systems

Gas Circulation

Gas Circulation controls are defined largely by the Piping and Instrumentation Diagram for the system, shown in Figure 5, which also serves as the basis for the operator interface for this system. The current lack of detail in the center of the operator controls shown Figure 3 is due to the fact that current efforts to understand the performance of the rotary valve are underway, so the final controls are not yet determined. The current control and measurement hardware for the rotary valve are not part of the scope of this report, as that work is done by that team independent from the overall control system.

The D2 and Ar compressors, which provide the target and beam stop gasses to the interaction, are from a commercial vendor (PDC), and came with standard industrial relay-logic controls. All the control relays had a spare set of contacts that we can tie into with the 24V logic of the cRIO chassis to allow the operator in the control room

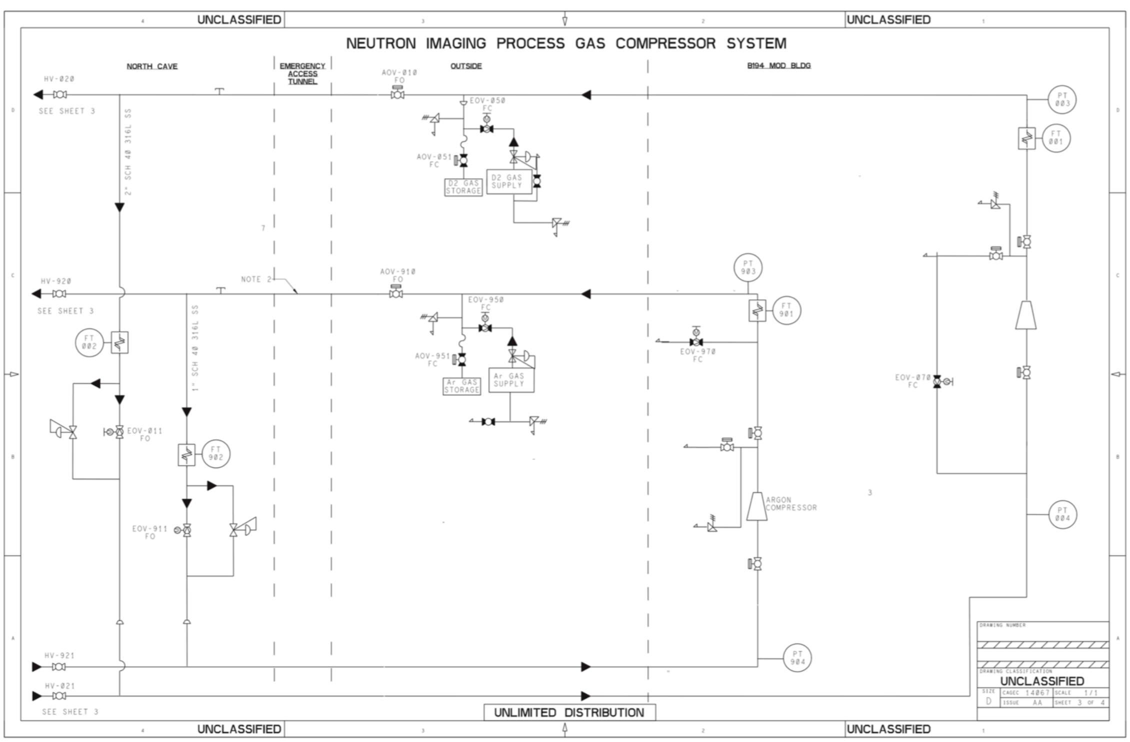

Figure 5 – A version of the gas circulation P&ID, simplified to show only control system-relevant points

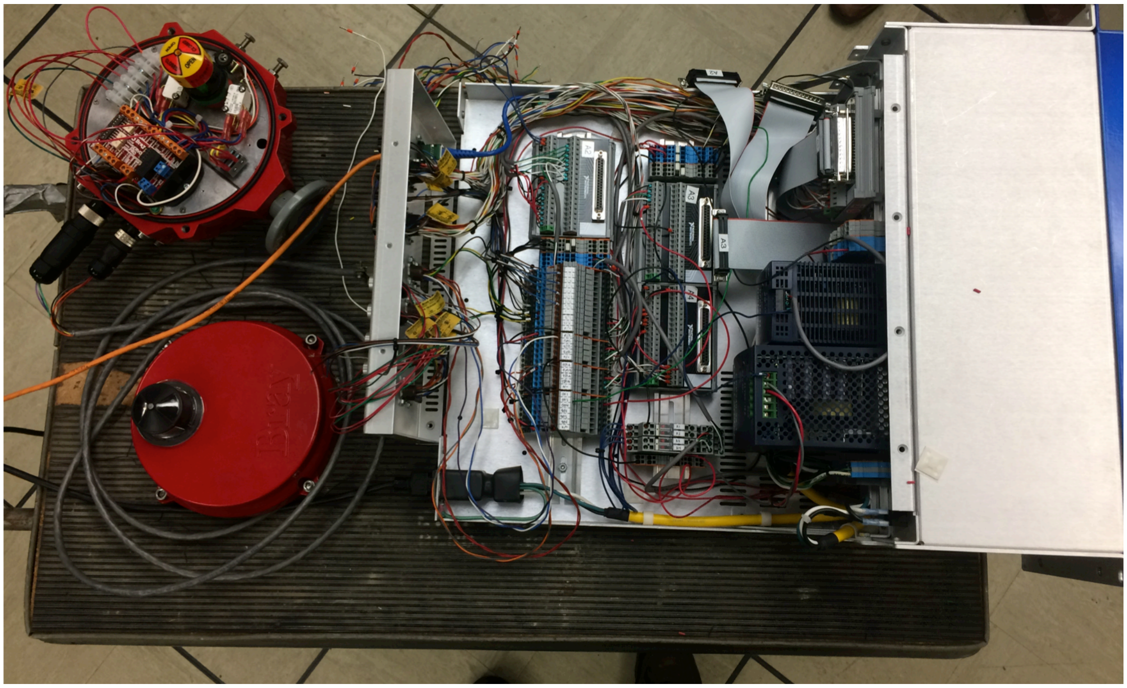

Figure 6 – Chassis cRIO-01, which will control all the gas circulation components above ground, open and connected to an electrically operated valve undergoing testing.

to be notified of the current operation status of the system (Off, On, or Alarm), and to start and stop the machine as if at the control panel in the mod building. It also provides indication any error conditions (e.g. over pressure at the output, under pressure at the input, low oil level, etc.), a feature unavailable with the vendor supplied controls.

The rest of the gas circulation loop is based on the cRIO controller interfacing with a variety of pneumatically and electrically operated valves and pressure, flow, and temperature transducers. Initially the system will accept operator commands and report data with minimal processing, but the hope is once we have sense of how the system performs, some operations can be automated. For example, feedback loops can be implemented to adjust feed and bypass valves to maintain a commanded flow rate through the rotary valve.

Individual gas control components are now being tested with the control system; Figure 6 shows one of the EOVs being testing with the cRIO interface chassis. Once all the hardware is known to work the chassis can be cleaned up and mounted in the control rack in the magnet cave.

Accelerator

The two deuteron accelerators that will be used for the source, the DL4 and DL7 from AccSys, come with their own control hardware and software that is designed to allow turn-key operation of the system. In the initial phase of the project we don’t

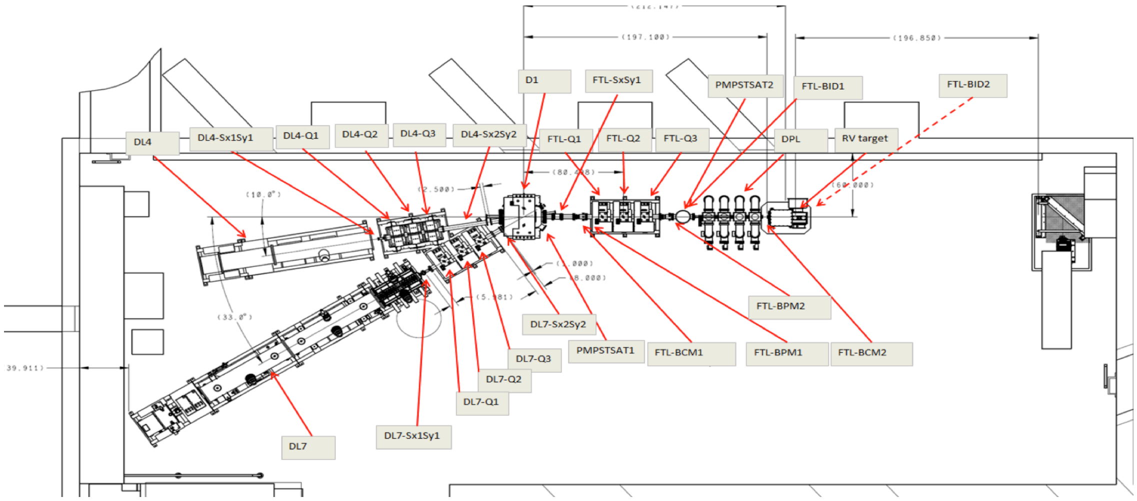

Figure 7 – Diagram of the deuteron beam transport line, showing the current expectation of control and diagnostic points.

anticipate making any changes to those systems. The operator in the control room can use the Microsoft Remote Desktop functionality to connect to the local control machine and operate the system. We can request customization to the control system to enable message passing between our hardware and the AccSys hardware, for example streaming key parameters to log or act on. Based on our experiences with the DL4, we expect to request such a service from the DL7 control system.

Following the accelerators, there is a beam transport system, shown schematically in Figure 7. The main control points in this system are the bending dipole, focusing quads, and steering magnet field strengths. The power supplies for these magnets are controlled by a dedicated cRIO module that interfaces with the Genesys supplies for the quads, the Sorenson supply for the dipole, and the BiRa corrector supply cards for the steerers, allowing command of the current and readback of the current, voltage, and supply fault status.

Diagnostics along the beamline include vacuum gauges, non-intercepting beam position monitors, and integrating current transformers, which are all commercial products that will be read via the cRIO architecture. The other key measurement is the beam intercepting diagnostic, to provide a beam profile measurement. This diagnostic is still undefined, so the interface to the control system is a task for the next fiscal year. None of this experimental hardware is yet in hand, but the control hardware is. Once hardware starts arriving, the controls build-out for this system can begin.

Next Steps

Several critical tasks remain for the next fiscal year. The interface to the gas circulation system has a good detailed design and software is already in development for the operator interface. As that system develops, adding in additional control points shouldn't be difficult. The accelerator system, while a good conceptual design is in place (control point list and hardware definition), the detailed design (loop diagrams, connector types, etc.) remains to be completed.

Another major software need is to implement data logging. Requirements on what needs to be recorded, with what frequency, need to be defined and a software architecture put in place to automate the collection as much as possible. The current concept is to have each cRIO chassis offer a stream of data that the control computer will archive when the operator interface is running, as we don't anticipate a need to collect data while the system is shut down. There may be certain cases where this isn't true (e.g. accelerator vacuum levels), but they can be addressed as needed. The control system in place for the X-band accelerator in the South cave provides an example solution.