FRIB Cryogenic Control System

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Overview

- Control system design, build, and install were governed by 3 key aspects with focus on 6 approaches of implementation that will be discussed
- Key aspects
  - Personnel protection
  - Equipment protection
  - Automation
- Methods to accomplish key aspects
  - Electrical power planning
  - System communications
  - Equipment control system design
  - Standardization
  - Troubleshooting
  - Alarm handling

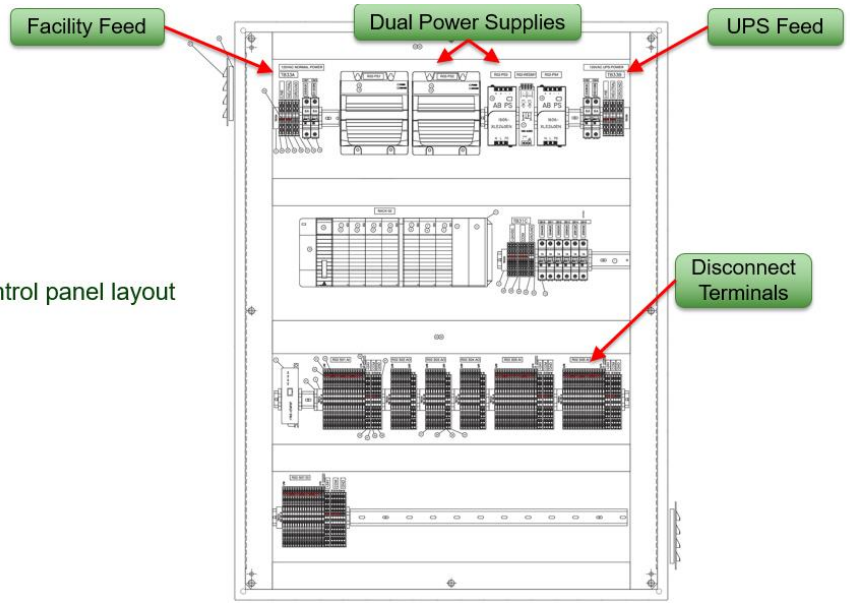
Key Aspects

- Personnel protection
  - National Electrical Code and recognized good engineering practices guided decisions in personnel protection
  - Safety disconnect switches were used for all electric motors, heaters, pumps, etc.
  - National Electrical Manufacturers Association electrical panels were employed to provide arc flash protection
  - Work control and LOTO programs are in place to safely perform work
- Equipment protection
  - A hierarchy of alarms, interlocks, and trips ensure the equipment operates within safe bounds
  - If alarms are not addressed in a timely manner, an interlock or trip will occur to prevent or mitigate equipment damage
- Automation
  - Unattended continuous operation is required for the FRIB cryo-plant
  - Alarms are the primary signal that operator involvement is needed

Electrical Power Planning

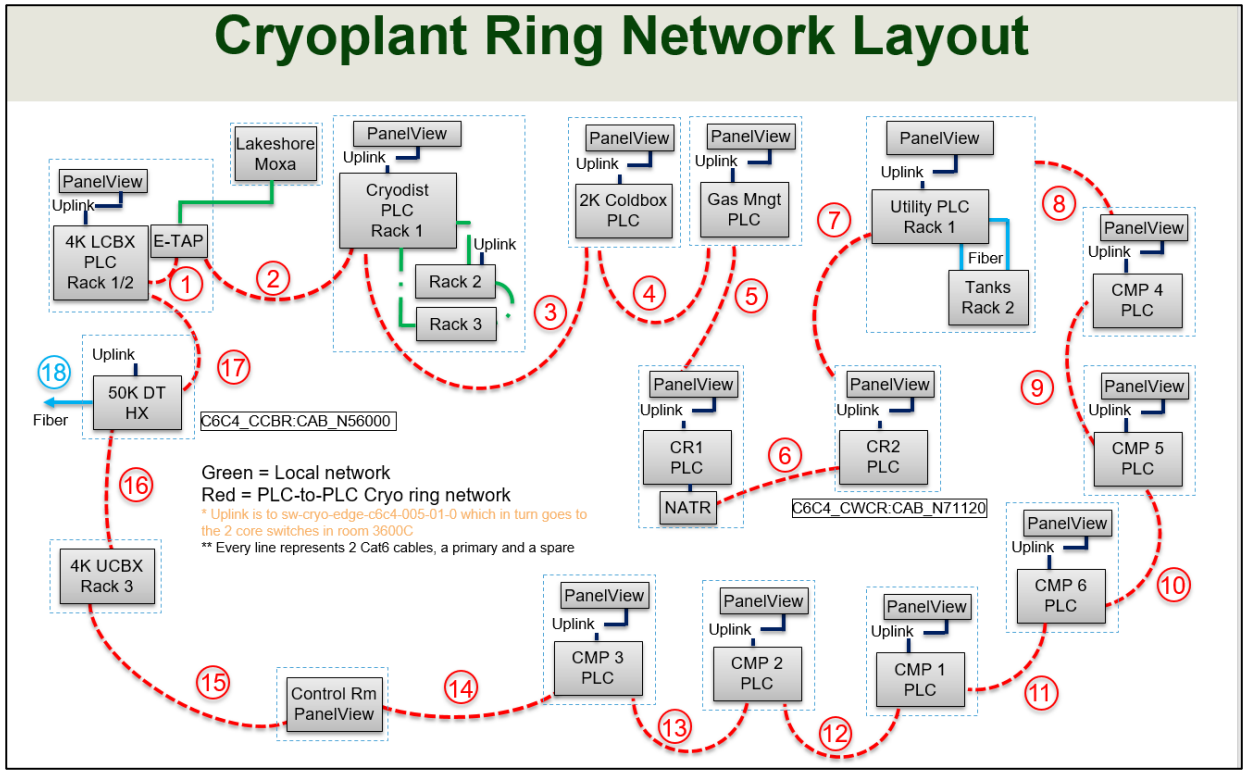
- Controls was responsible for developing the electrical power plans, including conduit and cable tray routing and the requirements for uninterruptible power sources (UPS) and emergency generators
- A detailed under-floor conduit plan was developed to keep electrical routing as concealed as possible
  - Space allocation competition with large helium piping, overhead crane, and maintenance access to equipment were key considerations
- Normal power and UPS is supplied to all control system PLC enclosures, workstations, and network components
- A 3 MW backup supply can restart warm compressors if power shuts down
- A generator system is used for restarting remaining equipment

Typical control panel layout



Control System Communications

- Communication to the rest of the FRIB controls system is through a channel access (CA) gateway which allows specific read-only data to be accessed outside of the FRIB cryogenics controls network
- Communication among PLCs is accomplished through a separate I/O PLC-to-PLC device-level ring network via produced and consumed tags and Common Industrial Protocol (CIP) messaging
  - This provides the cryo-plant with a robust data transfer system to share PVs across PLCs

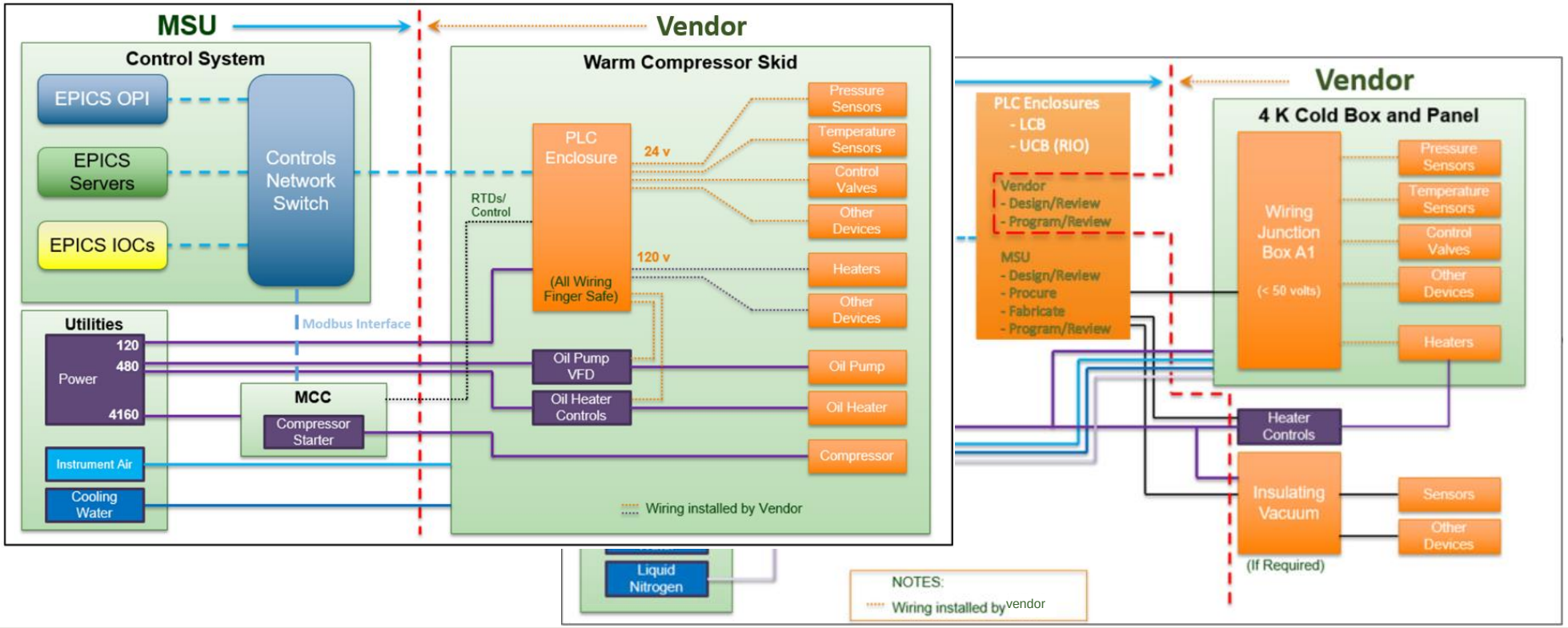


Equipment Control System Design

- Start-up and commissioning of the cryo-plant was accomplished over a three year period, and was essentially separated in the following order: utility systems (e.g., helium gas storage, helium purifiers, and liquid/gaseous nitrogen), warm compressor system, 4.5 K cold box, cryo-distribution system (LS1 first), and the sub-atmospheric cold box
- Instrument air, helium purifiers, process cooling water, gas analysers, and gas distribution systems are all controlled by the utility PLC, while the recovery compressor skids for the purifiers each have a separate-dedicated PLC
- Cryo-plant instrument air is provided by primary and back-up facility air compressors
  - In the event of low instrument air pressure, an alarm is generated and an interlock activated to isolate the facility supply and automatically start the cryo-plant instrument air system
  - Back-up system operation is checked periodically by the utility PLC

Equipment Control System Design (cont.)

- All six main warm helium compressors each have their own PLC allowing independent operation
  - A separate-dedicated PLC is used for the main compressor gas management control valves
- A manufacturer provided control cabinet for the 4.5 K cold box is hardwired to the turbine strings and shuts the turbines down if a trip condition occurs
  - Upper cold box is a remote I/O rack to the cold box PLC which is located next to the lower cold box
    - » This allowed separate teams to work on the installation and component testing

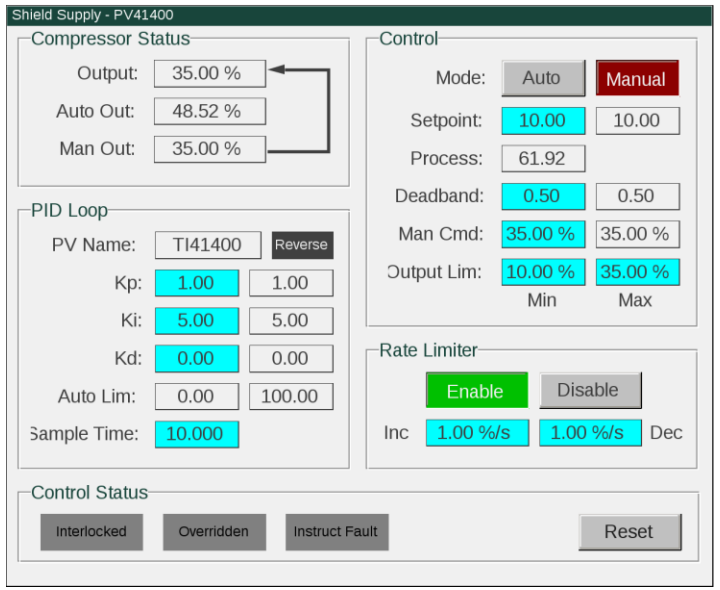


Equipment Control System Design (cont.)

- Cryo-distribution control system monitors and controls the components for the three FRIB Linac transfer line segments, and the transfer line system to the experimental system (ES) magnets
- In the Linac, each cryomodule has a similar set of instrumentation and control equipment and the same is true for each Linac superconducting magnet (SCM)
  - Each ES SCM also has a similar set of instrumentation and control equipment
- Sub-atmospheric cold box has an independent PLC system
- Manufacturer for the cold compressors supplied control cabinets that house the hardware necessary for the control of the motor VFDs and active magnetic bearings
- During installation, the FRIB controls group tested all signal I/O and control communication among the PLC cabinet and the vendor provided equipment

Standardization

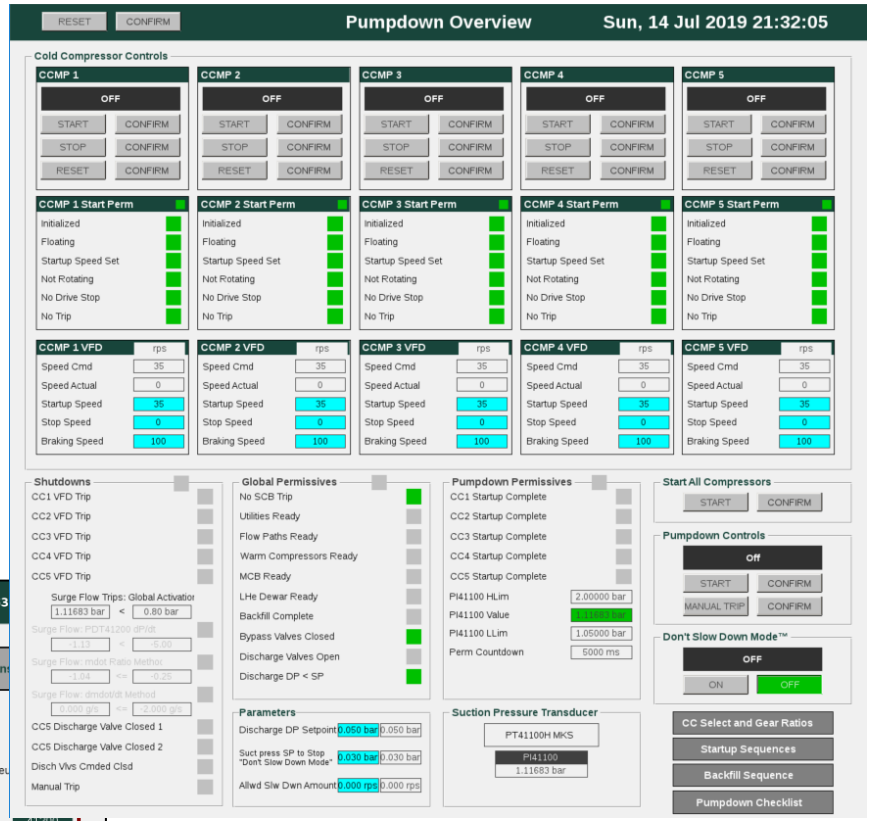
- A standard set of hardware, PLC firmware/software versions, program format, and user interfaces provide consistency across all cryo-plant control systems
- Each PLC has a dedicated Allen-Bradley PanelView allowing operators to locally monitor/operate the plant in the case of a total network failure

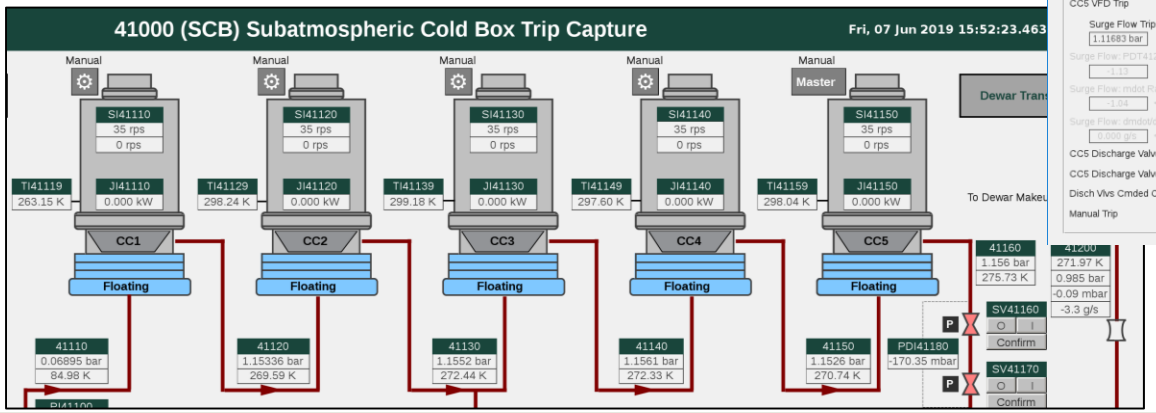


- Standard Add-On Instructions (AOIs) were developed that provide an easy way to buffer I/O, create a standard set of functions for each signal, and streamline signal scaling and troubleshooting
- Use of the velocity form of the proportional-integral-derivative (PID) algorithm was standardized across all PLCs in the cryo-plant

Troubleshooting

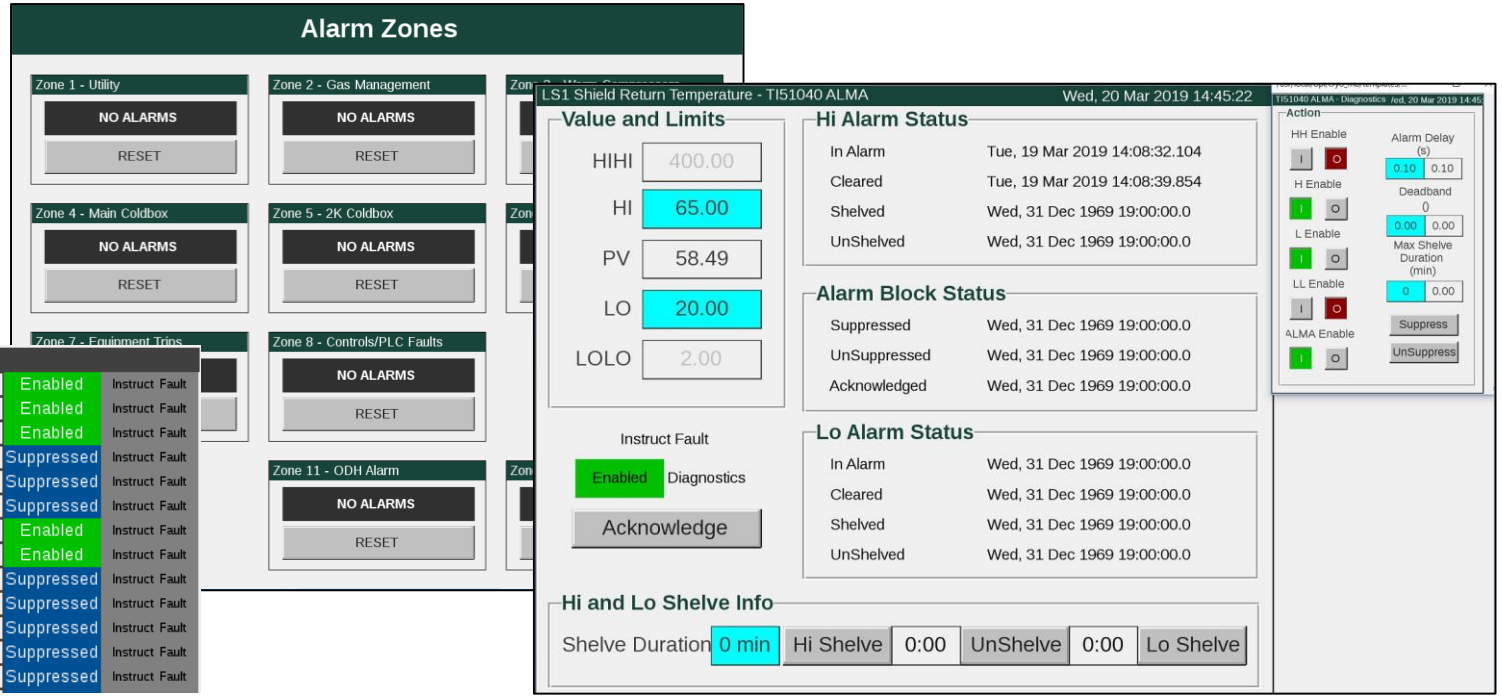
- All PLCs are time synchronized across the PLC-to-PLC communications Ethernet ring network
- Since alarm timestamps are captured in the PLC, EPICS read time limitations are eliminated and the EPICS archived data becomes a useful tool for troubleshooting
  - A large portion of the code and screens are dedicated to troubleshooting by capturing system states and fault data





Alarm Handling

- Every condition requiring operator action has an associated alarm which triggers an automated phone dialer system
- FRIB cryogenic alarm handling is based on the International Society of Automation (ISA) 18.2 standard which facilitates acknowledgements, shelving, suppressing, and timestamps
  - Timestamps are synchronized throughout the cryo-plant and cryo-distribution systems to within the scan time of the PLC of about 5 milliseconds
  - All alarms and timestamps are archived using the EPICS archiver
  - Enabling/disabling alarms, and setting alarm delay, deadband, and shelve duration requires a password



	HiHi	Hi	Current	Lo	LoLo	Delay		
PI41005	0.10	0.05	0.00	0.00	0.00	0.10	Enabled	Instruct Fault
PI41010	0.80	0.20	0.00	0.00	0.00	0.10	Enabled	Instruct Fault
PI41030	0.80	0.20	0.00	0.00	0.00	0.10	Enabled	Instruct Fault
FI41200	160.00	150.00	-3.91	90.00	80.00	0.10	Suppressed	Instruct Fault
FI41500	20.00	10.00	0.62	5.80	5.50	0.10	Suppressed	Instruct Fault
FI41510	20.00	10.00	0.24	5.80	5.50	0.10	Suppressed	Instruct Fault
PI41100L	0.09	0.08	0.07	0.01	0.01	0.10	Enabled	Instruct Fault
PI41100H	2.00	1.60	1.11	0.06	0.05	0.10	Enabled	Instruct Fault
PDI41180	50.00	25.00	-129.48	-25.00	-50.00	0.10	Suppressed	Instruct Fault
PI41400	1.80	1.60	1.32	1.00	0.90	0.10	Suppressed	Instruct Fault
PI41500	1.20	1.10	1.65	1.00	0.90	0.10	Suppressed	Instruct Fault
PI41510	1.20	1.10	1.10	1.00	0.90	0.10	Suppressed	Instruct Fault
TI41101	20.50	19.00	130.02	5.80	5.50	0.10	Suppressed	Instruct Fault

Conclusions

The FRIB cryogenic control system

- Supported around the clock, unattended, safe, and efficient operation of the FRIB cryo-systems for more than a year
- Has demonstrated that it achieved the goals of personnel protection, equipment protection and automation
- Control system flexibility also provided the means for operators to easily transition between the various modes of cryo system operation
- Concisely and clearly conveyed all the information necessary for process operation and troubleshooting activities during the stepwise commissioning of each of the cryo sub-systems including the cryomodules and superconducting magnets