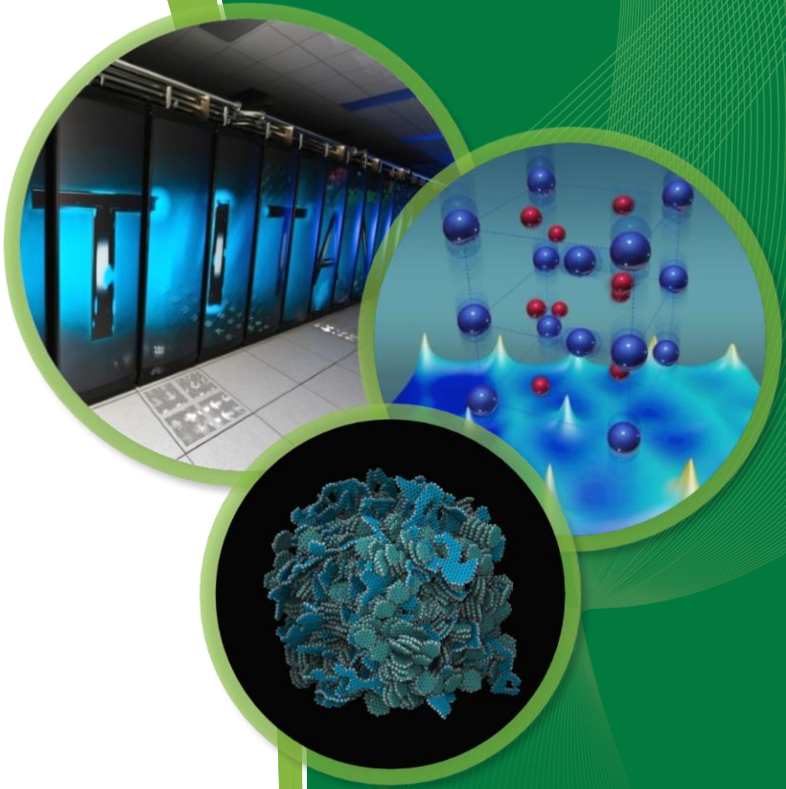
SNS Helium Cryogenic Plant Instrument and Controls Experience and Future Considerations



Presented at the
Cryogenics Workshop 2016

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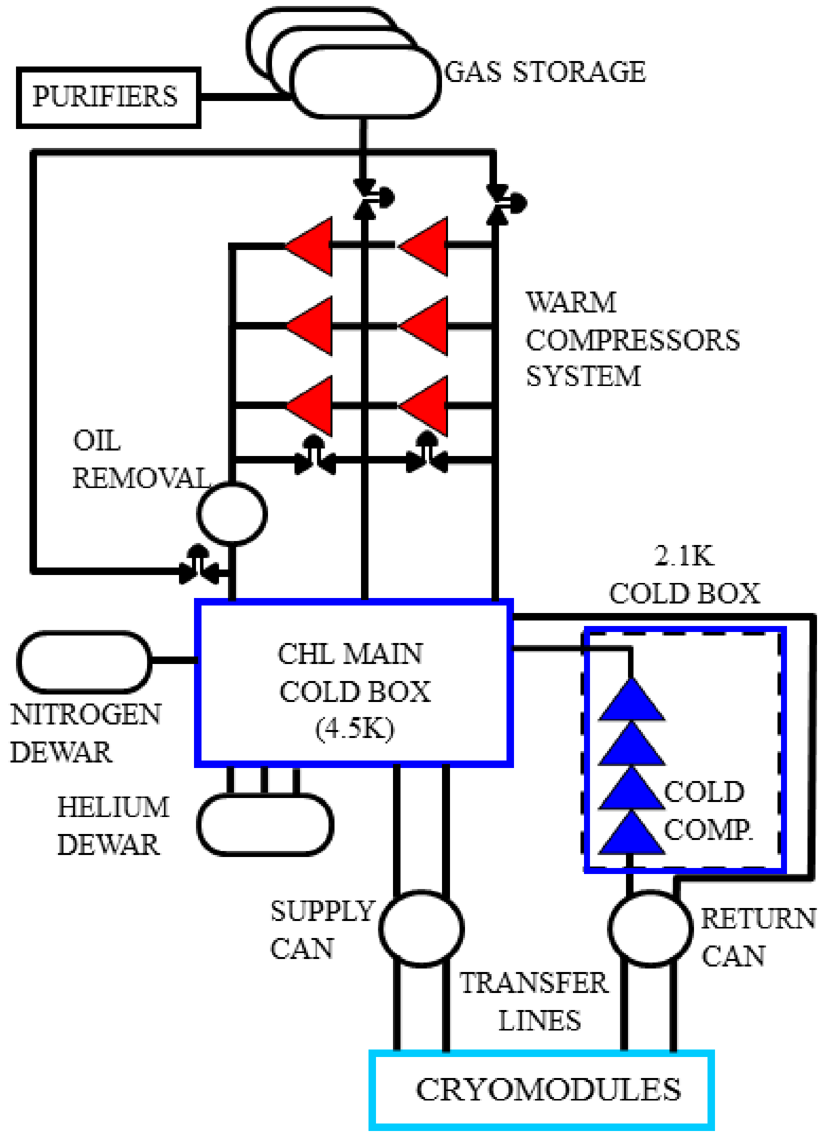
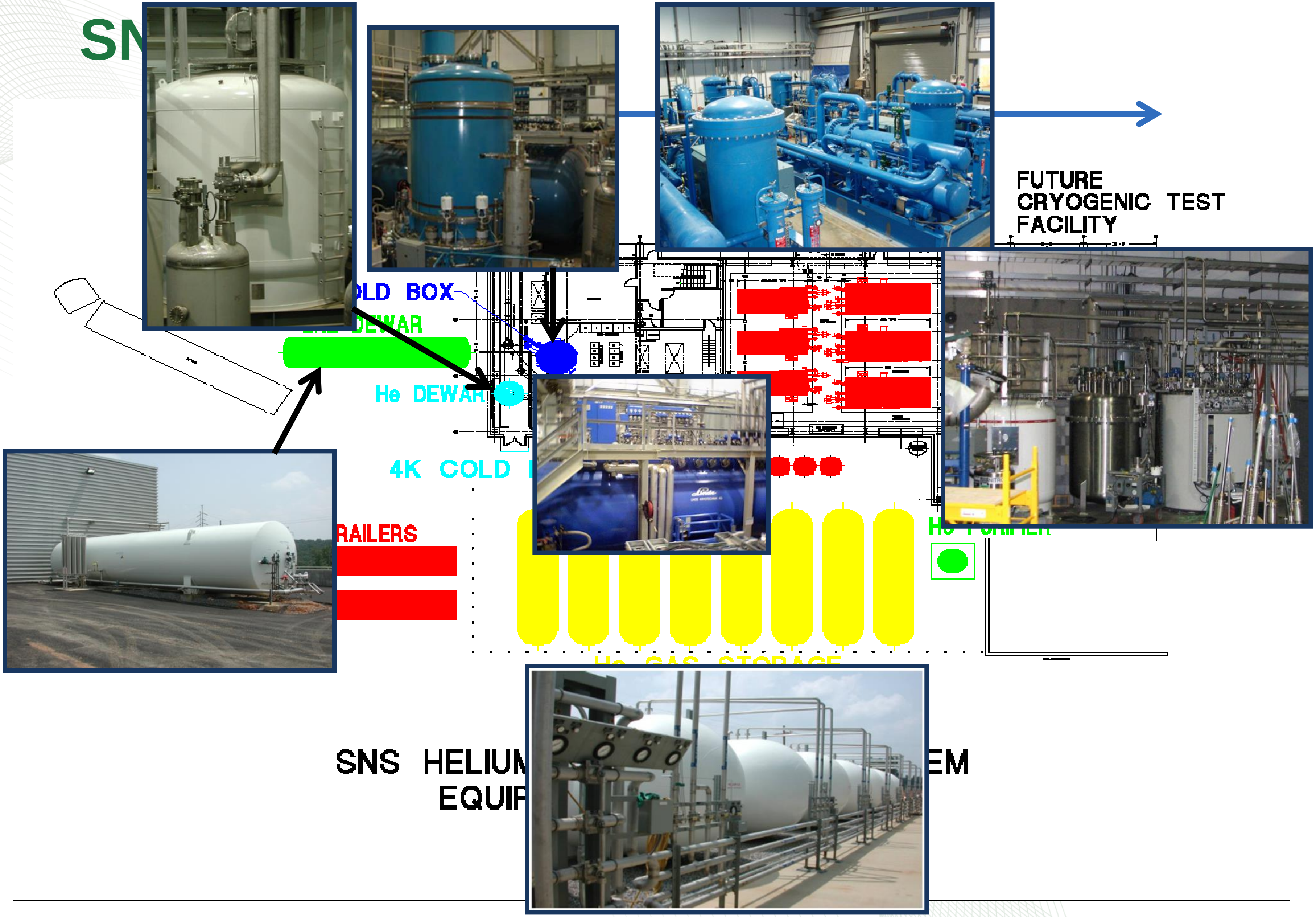
Outline

- SNS cryogenic system overview
- Cryogenic control system implementation
- Control sequence descriptions
- Control system Instrumentation
- Vendor Interface
- Failure Modes and Effects Analysis (FMEA)
- Lessons Learned
- Redundancy considerations
- Recommendations
- Summary

SNS CHL

- Design
  - 2400 watts at 2.1 K
  - 8300 watts shield cooling
  - 15 g/s liquefaction load for coupler cooling
  - Adequate margin for upgrades
- Provides cooling to the SCL
  - 11 medium beta cryomodules each housing three SCRF cavities
  - 12 high beta cryomodules each housing four SCRF cavities
  - 9 additional slots in linac for future upgrades




SN
FUTURE
CRYOGENIC TEST
FACILITY
OLD BOX
DEWAR
He DEWAR
4K COLD
RAILERS
SNS HELIUM
EQUIP
EM

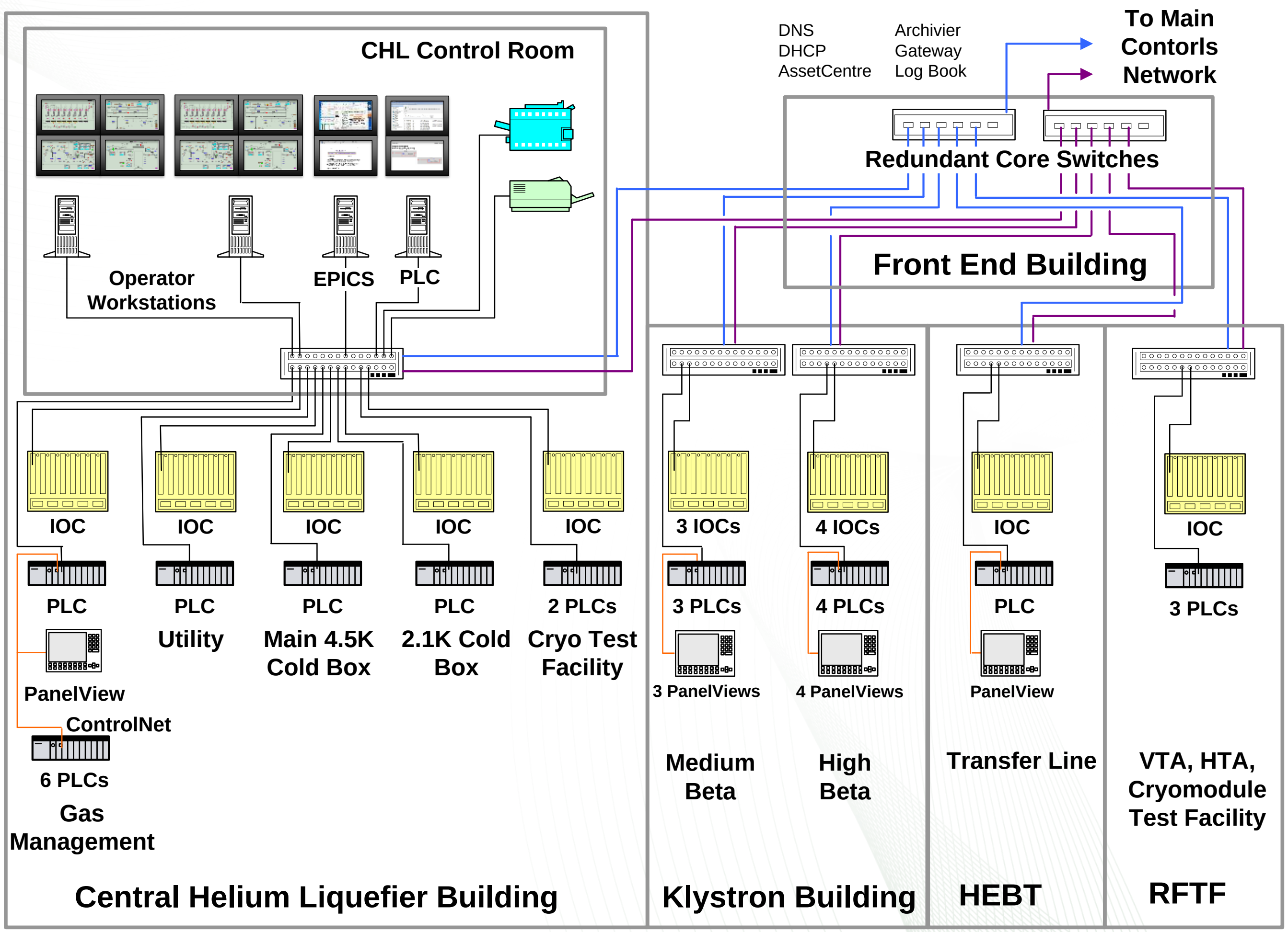
The SNS CHL Design Specifications

	Primary	Secondary	Shield
Supply Temperature	4.5K	4.5K	38K
Return Temperature	2.1K	300K	55K
Supply Pressure	3bar	3 bar	4 bar
Return Pressure	0.041bar	1.05 bar	3 bar
Static Load	850 W	5.0 g/s	6070 W
Dynamic Load	600 W	2.5 g/s	0
Capacity	125 g/s	15g/s	8300W

Control System Implementation

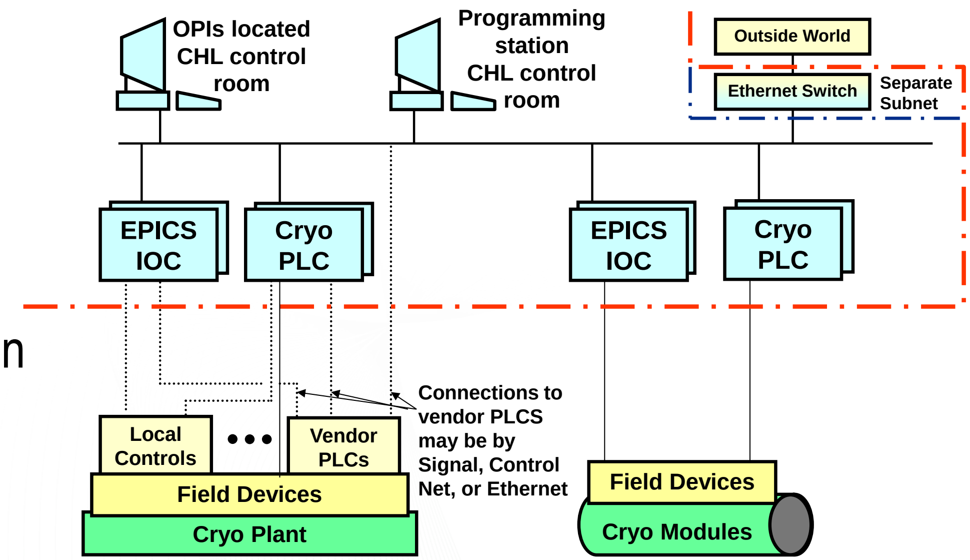
- EPICS based controls
- Requirements and features based on JLab cryo control system
- Dedicated network hardware and configuration
- EPICS VME IOCs (14)
  - Implement most subsystem upper level controls
  - Silicon Diode temperature sensor modules
  - LVDT position sensor modules
- Allen-Bradley ControlLogix PLCs (23)
  - Implement Interlocks and low level controls
  - Input/Output modules for monitoring sensors and controlling actuators
  - Profibus Communication modules for some devices

Cryogenic Control System Block Diagram



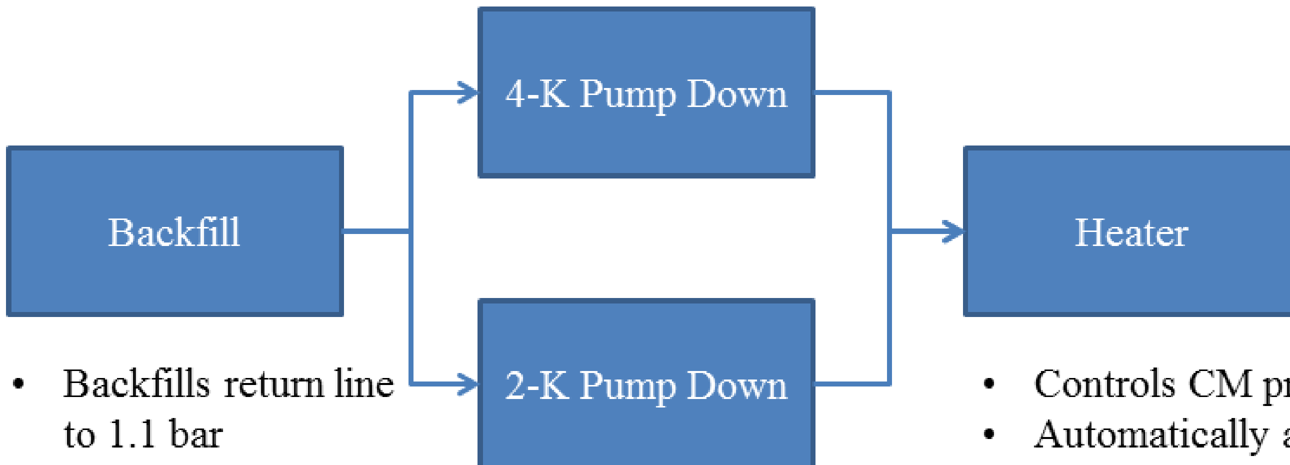
Control System Implementation

- Modular implementation using an IOC and PLC pair for each major subsystem
  - Main warm gas management, warm compressors
  - 4K Cold Box, 2K cold box, utility
  - Cryomodules
  - Minimizes overall system impact when working on one subsystem
- UPS power, backup power via Automatic Transfer Switches
- Soft IOCs (Linux based) Implement
  - Upper level sequences
  - Alarm notification



2K Control Sequences

- Controls cryomodule settings
- Controls 4-K plant



- Backfills return line to 1.1 bar
- Cools 2K cold box
- Starts cold comp. at min. speed

- Establishes loop control of 2-K flow using CC4
- Sets gear ratios of CC1 – CC3

- Controls CM pressure
- Automatically adjusts heat when RF is applied to cavities

Control System Instrumentation

- Pressure
  - Moderate accuracy/resolution for most of plant
  - High accuracy/resolution for 2K return at cold box inlet
  - Radiation tolerant for cryomodule and Linac tunnel (strain gauge)
- Flow
  - Venturi (differential pressure) for most helium applications
  - Ultrasonic for some cooling water flows
  - Coriolis for high accuracy helium flow
- Temperature
  - Thermocouples or RTDs for "room temperature"
  - Silicon Diodes for cryo temperatures (standard curve)
  - Cernox for cryo temperatures (some individual curve, must track serial number, radiation resistant)
  - TVO; Russian developed carbon-aluminum oxide sensor (individual curve, must track serial number, radiation resistant)
  - CLTS; Cryogenic Linear Temperature Sensor

Control System Instrumentation

- Level
  - Differential pressure (mostly for LN)
  - AMI liquid helium level probe and meter (2K and 4.5K versions)
- Speed
  - Magnetic sensor with signal conditioning
  - Frequency signal from VFDs
- Power
  - Dedicated power transducers for system capacity testing
  - MCC power transducers
  - Heater controller power signals

Vendor Interface

- Control system general requirements provided to vendors
  - Signal levels
  - Power available
  - Required documentation listing
  - Acceptable sensors and actuators
  - NRTL requirements
- Data received from vendors
  - Assembly and wiring drawings
  - Software descriptions
  - Operational descriptions
  - Interlock and control requirements
  - Test plans and procedures
  - Sample PLC logic
  - Sensor installation details (range, serial number, location, etc.)
  - Recommended spare parts list

Failure Modes and Effects Analysis of the CHL

- Breaks work down to task level for analysis
- Systematic approach asking two questions
  - How could this fail during this process task?
  - If it does fail, what is the effect based on severity, probability, and detection?
- This process delivers
  - Weaknesses in our process
  - Ranked items in need of focus
  - An opportunity for a group to focus on a process
  - A driving force to produce action

- Results of the FMEA
  - Probability X Severity X Detection = Risk Priority Number (RPN)
  - 60% decrease in RPN
  - Reduction of high risk items from 76 to less than 20
- Consider all modes of operation

Assigning Values and Calculate RPN

Potential Failure Mode	Potential Effect(s) of Failure	Severity	Classification	Potential Cause(s) of Failure	Current Process: Control Prevention	Current Process: Occurance	Current Process: Controls Detection	Current Process: Detection	RPN
Trip a second stage compressor	Unable to maintain required flow to refrigerator, delayed trip of 4KCB	7		Oil Pump Trip	Preventative Maintenance	1	na**	7	49
		7			Monitor Temperature, Pressure, Oil Level, Visual Inspection	1	na**	7	49
		7		Skid PLC Failure	na**	10	na**	7	490
		7		High discharge pressure	System Controls	1	System alarm	1	7
		7		High discharge temperature	na**	1	na**	10	70
		7		High oil temperature	na**	1	na**	10	70
		7		Low oil inventory in skid separator	Procedural & Operator Training	1	Daily checksheet & Log	7	49

Lessons Learned

- Calibration Program initiated during commissioning
  - Stainless devices in stainless wells take a cheater bar
- Calibration records used numerous times during start-up and commissioning to verify proper system operation
- Difficult to calibrate instruments after system in operation
  - Usually requires system to be shut down
- Developing logic and screens to compare similar instruments to determine calibration needs
  - If all instruments on low pressure header read similar except one, go check the one

PT00041 — CHL_GM:PT11004:P — Cal- –

Bar Code No. — **Signal Name** — **Calibration Number**

Signal Range 0 - 20.0 Units atm (sensor rang 0 - 34.023)
Required Accuracy 0.4 Units atm
Signal Input Range pressure sensor 4-20 Units ma (v, ma)
Authorized by ____ Operations representative authorizing removal from service

Measurement and Test Equipment

	Description	ID	Calibration Date
1	Druck MCXII	M210225	10/30/2002
2	Druck Pressure Module	3083	6/12/2003
3			
4			
5			

Physical Inspection Complete X

As Found Data
Initial Reading 1.05 atm Before removal from service Time 10:34

% Range	Calibration Values				As Measured	
	psia	atm	+ / -	actual	PanelView	
0	0	0	0.4	na	na	
25	73.5	5.0	0.4	na	na	
50	147.0	10.0	0.4	na	na	
75	220.4	15.0	0.4	na	na	
100	293.9	20.0	0.4	na	na	

As Calibrated Data

% Range	Calibration Values				As Measured	
	psia	atm	+ / -	actual	PanelView	EPICS
0	0	0	0.4	0.00		0.12
20	58.8	4.0	0.4	4.00		4.11
50	147.0	10.0	0.4	10.01		10.12
80	235.1	16.0	0.4	16.04		16.13
100	293.9	20.0	0.4	20.05		20.12
80	235.1	16.0	0.4	16.06		16.17
50	147.0	10.0	0.4	10.06		10.2
20	58.8	4.0	0.4	4.09		4.23
0	0	0	0.4	0.00		0.12

Final Reading 1.08 atm After return to service Time 10:45

Calibration Label Completed X

Calibration Completed Scott Bunch (By) 903178 (Badge) 8/28/2003 (Date)

Low Pressure Header
(Main Comp Suction)
Expect 1.1000 +/- 0.2000 atm

Warm Cmp 1st Suct	PT21102	1.0147	
	PT21202	1.0286	
	PT21302	1.1318	OFF
Warm Gas	PT20103	1.0491	
	PT20501	1.0499	
4 K Cold Box	PT31610	0.8827	
	PT31106	1.0094	
	PT31119	1.0545	
	PT31136	1.0715	
	PT31159	1.1390	
	PT31190	1.0765	
	PT31198	1.0752	
2 K Cold Box	PT41140H	1.2348	
	PT41161	1.1612	

Lessons Learned

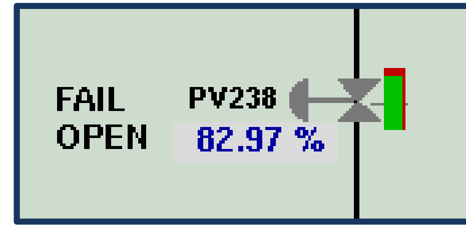
- Cryogenic control system must be implemented with cryo system operation requirements in mind
  - Modular, single subsystem per PLC/IOC
  - Highly reliable and available
  - Include test, calibration, and validation points and signals
  - Monitor operation of the control system itself
  - Communication errors, module status, signal status …
  - Take appropriate action on detection of error
  - Easy to troubleshoot and quick to repair
- Global control system must support cryo control system operation
  - Servers must be available 100% of time
  - Network must be available 100% of time
  - Once cryo system starts, alarm handler and archiver for cryo cannot be stopped

Lessons Learned

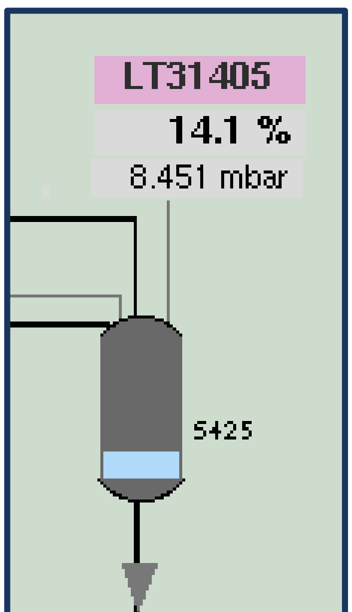
- Communications
  - IOCs and PLCs must include logic to take appropriate action in the event of loss of communication
  - If the signal from sensor “X” is not valid, perform
    - Action A
    - Action B
  - If PLC “Y” cannot communicate with PLC “A”, perform
    - Action C
    - Action D
  - Use FEMA process to determine appropriate actions
- Alarms, Auto-dialer or automatic personnel notification
  - For many cryogenic system disturbances, the appropriate automatic response is almost impossible to determine
  - Human intervention is required
  - Provide means for the control system to notify (with verification) appropriate personnel

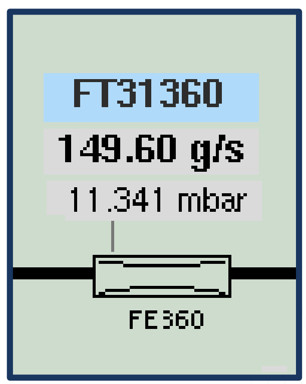
Lessons Learned

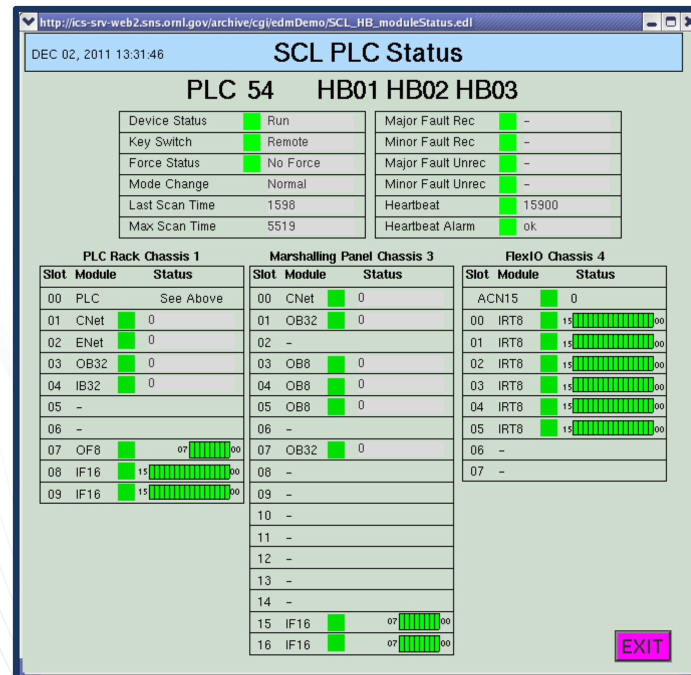
- Displaying “Fail” state of valves (open – closed)



- Displaying valve % on overview screens
  – Is the value an actual or a command?
- Displaying raw values for signals in addition to converted values
- Displaying control system hardware status

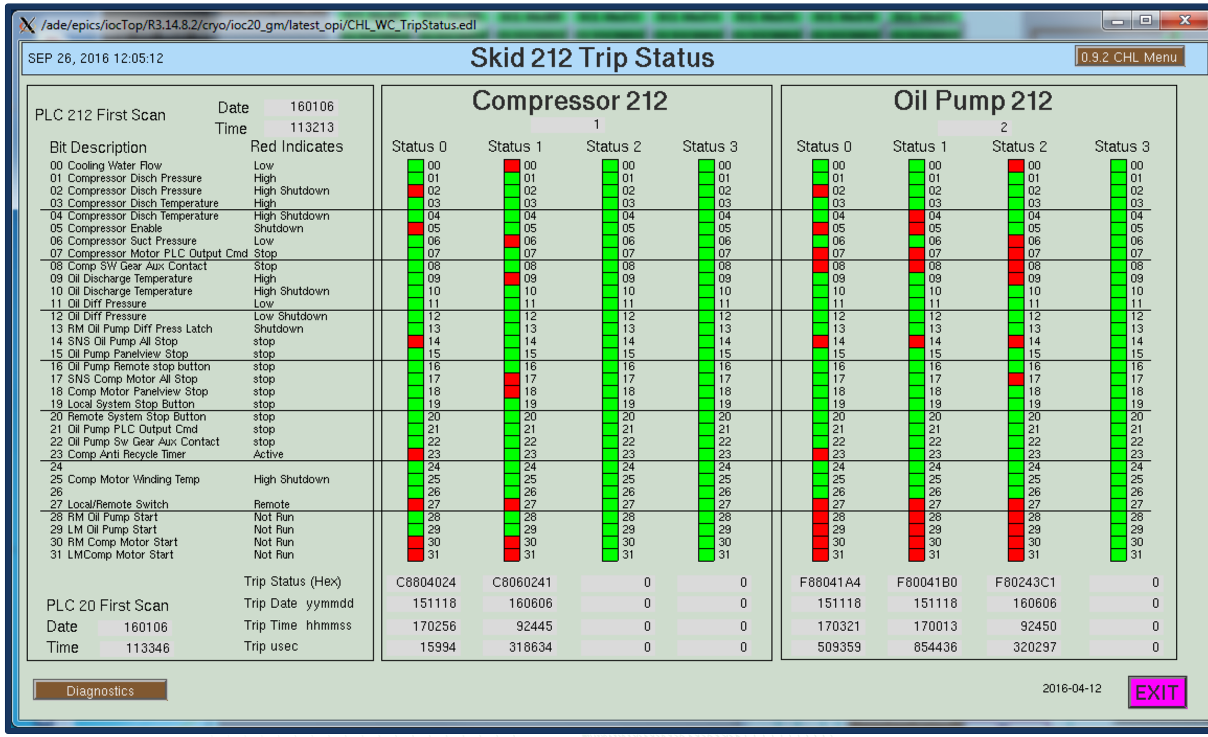






Lessons Learned

- Include a status word(s) for every device that has automatic trip logic
  - Status work has a bit for every signal that can cause a trip
    - 0 = condition OK
    - 1 = condition bad
  - Include
    - Trip Time/Date
    - First Scan Time/Date



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Redundancy considerations for control system

- Core and Aggregator switches
- Communication links from core/aggregator to edge switches
- Installed spare edge switches
  - Just move patch cables from failed switch to installed spare
- Power feeds for controls equipment
  - Equipment with dual power supplies preferred over Automatic Transfer Switches
- PLC processors for subsystems – "hot" spare
  - Enables system update during operation
  - 4 K cold box
  - Cryomodule
  - Linac Distribution System
- PLC communication to Input/Output chassis
  - Continue running and repair communication problems on maintenance days
- Process instrumentation

Redundancy considerations for control system

- For 2K plants, primary return pressure
  - Low range pressure sensors at 2K box inlet (3 would be better to allow voting)
  - Ability to switch control functions between sensors during operation
- Cryomodule instrumentation
  - Helium level probes
  - Temperature sensors

Recommendations General

- For electrical safety considerations
  - Use NRTL equipment if available
  - Use 24 vdc signal and control devices
  - Use < 50 vdc heaters, actuators, if possible
- Use Ethernet communication to devices where possible
  - Avoid configuration issues
  - Do not use DeviceNet communication
  - Avoid ControlNet communication
    - Limits our ability to add new control system equipment
- Wiring terminals
  - Screw terminals are easy to over torque, under torque, intermittent connections
  - Spring clamp terminals have almost no intermittent connections
- Move more control to the PLC

Recommendations, Standardization

- PLC system
  - Pick a vendor and stay with them
  - Even if the “standard PLC” is overkill for a function, having standard programming software and spare parts is valuable
  - Pick “standard” I/O modules for each type signal (AI, AO, BI, BO)
- Instrumentation
  - Lots of good instrumentation vendors, try to stay with 2 or 3
- Include PLC and instrumentation requirements when procuring “turn-key” systems

Summary

- We have learned much about the cryogenic control system throughout the first ten years of operation
- The system has proven to be robust and reliable but there are opportunities for improvement
- Consider all modes of operation when developing the control system
- Answer the question of “how are we going to maintain this system?” during design
- Redundancy and standardization are key characteristics of a control system