Experience with Cryogenic Operations During the Fermilab Collider Program

Topics to Cover

- History of the Tevatron and the Fermilab Collider Program
- Overview of the Cryogenics Systems at Fermilab
- Responsibilities for Cryogenic System Operations
- How the Cryogenics affected Operations
- Lessons learned during the last decade of collider operations
- Questions

History of the Tevatron and the Fermilab Collider Program

The Tevatron History

- First large scale superconducting accelerator
- Construction started in the early 1980s
- First beam in 1983
- Anti-Proton Source construction also happened at the same time
- First Proton / Anti-Proton Collisions in 1985
- First Collider engineering run in 1988 (1 year)
- Split time between fix-target and collider running, with the last decade being exclusively collider.
- Turned off October 2011

The Tevatron Numbers

- 4 miles in circumference (6.4 km)
- ~775 magnets (This number changed over time as the machine was modified)
- Split into 6 sectors
- RF, Injection, Extraction, and Detectors were installed between the sectors
- Each sector was further sub-divided into 4 houses. This also matched the cryogenic system. 24 houses total

View of the Tevatron Tunnel

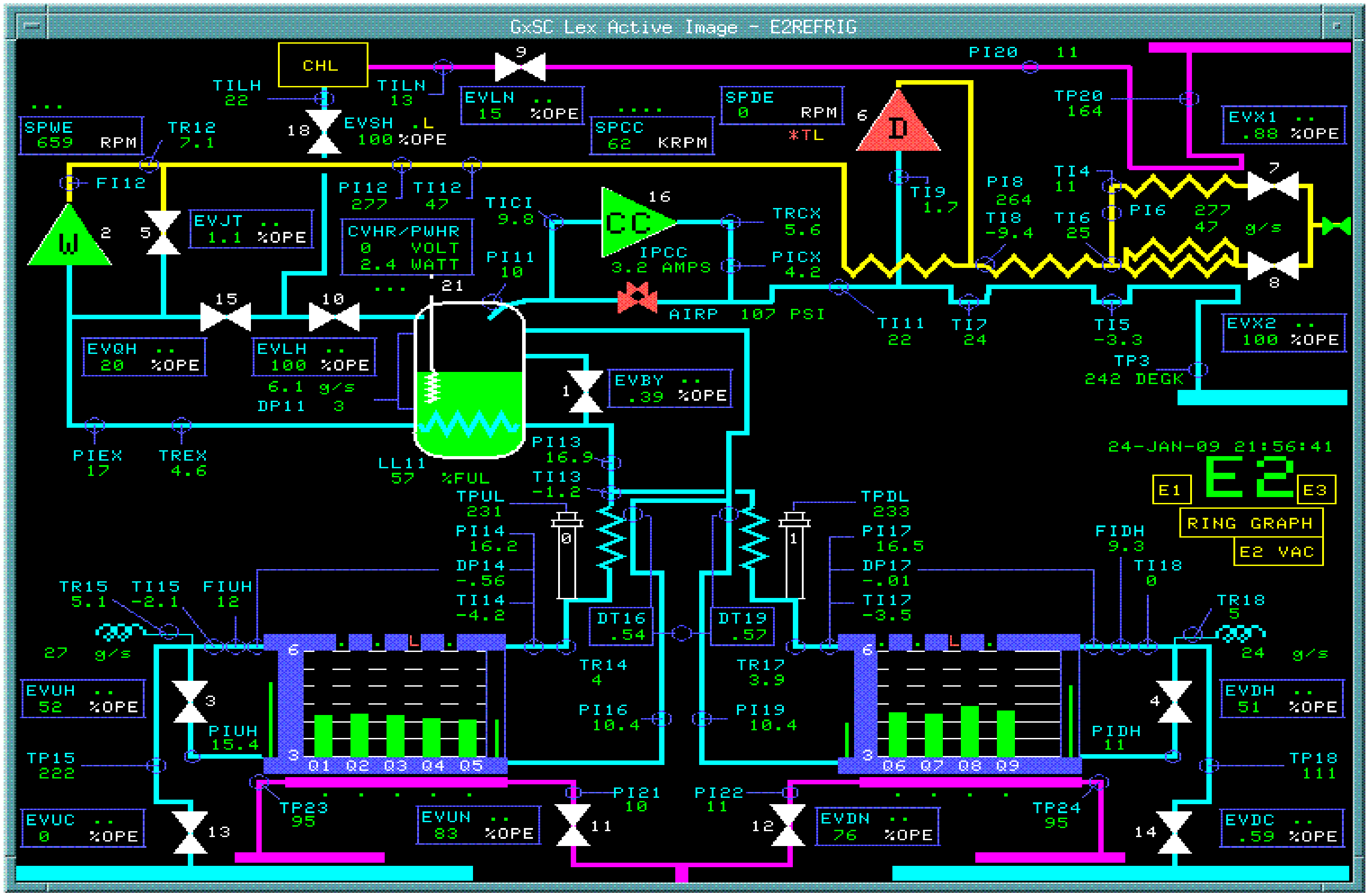
Overview of the Cryogenic Systems at Fermilab

- Largest in the world when built
- Named a International Historic Mechanical Landmark in 1993
- Accelerator cryogenics has it's own support department. Separate experimental cryogenics support.
- Cryogenics support included engineering, technical, and operational support.

Cryogenic Numbers

- Cryogenic system uses liquid helium with a liquid nitrogen shield to cool the magnets
- 4.4K to 4.6K at the magnet coils
- One large central helium liquefier
- 24 satellite refrigerators around the machine
- 6 locations with either 4 or 8 helium compressors
- Other cryogenic equipment in the accelerators also supported

Cryogenic Theory in 1 minute



Responsibilities for Cryogenic System Operations

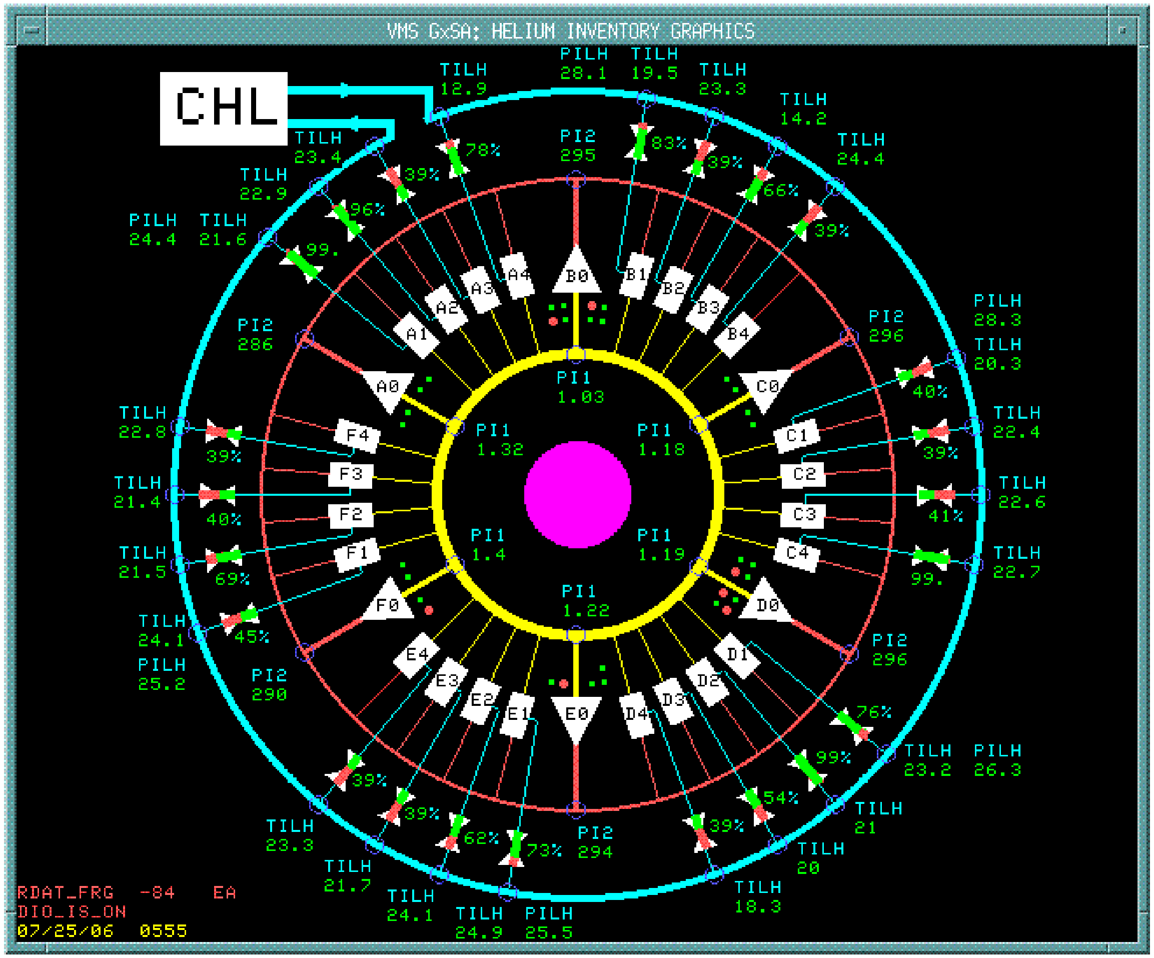
- The Cryogenics Support Group is responsible for:
  - Operating the Central Helium Liquefier, which is manned around the clock
  - Engineering support for any modifications
  - Cryogenics inventory
  - Technical support and maintenance of the satellite refrigerators and helium compressors
  - On Call operational support to the Main Control Room

Central Helium Liquefier

Operations Group support for cryogenics

- Operate and monitor the Tevatron Cryogenics systems. Done with support from the Cryogenics group
  - Monitor system to insure parameters are in operational tolerance
  - Recover the machine from a magnet quench (superconductor going normal)
  - Insure cryogenic operations before machine turn on
  - Assist as needed with cryogenic repairs
  - Assist as needed with cryogenic emergencies. The accelerator tunnel and some building are ODH (an Oxygen Deficiency Hazard)

Global Schematic of Tevatron Cryogenic System



Shared effort between Groups

- Manpower on the evening and overnight shift.
- Cryogenics engineers would provide training classes as needed.
- Cryogenics group would provide documentation and procedures for the system.
- Cryogenics and operations worked together with the Controls group to insure the proper operational software was available.
- Good communication between the groups

Interactions between the Operations Group and the Cryogenics Group

- During machine operation, both groups had a control room manned around the clock. The Main Control Room (MCR) for operations, and the Central Helium Liquefier (CHL) control room for Cryogenics.
- Only the Main Control Room was manned during long maintenance periods.
- Both groups maintained a electronic log book that was readable by the other control room.
- Cryogenics provided an on-call engineer as a single point of contact for problems .

Question: How can interactions between the groups affect operations

- Communication between the groups is critical since failures can be very time consuming.
- Two Control Rooms means areas of responsibilities must be clearly defined, but it also allows for cross training and manpower swaps when needed.
- Single point of contact for the Main Control Room to the On-Call Cryogenic Engineer was critical during failures.

Cryogenics, Machine operation, and Success

- The accelerator has to be running reliably for there to be a successful physics program
- In a superconducting machine the cryogenics must be reliable for the machine to operate.
- Failure can happen in the cryogenic system itself or in some system that affects the cryogenic system.
- In a superconducting accelerator almost everything affects the cryogenics

Definitions

- Quench – When the superconductor in the magnet goes normal and it is no longer safe to power the magnet system.
- Quench Protection System (QPM) – System designed to detect a quench, de-power the accelerator, and spread out the heating in the magnet string. The system would also signal the cryogenic system to start recovery.
- Refrigerator recovery – The process of cooling the magnet string down to an operational temperature.
- Failure – For the purpose of this talk, it is any thing that causes the Quench Protection System to de-power the machine

How was cryogenic operations different from other sub-systems?

- Duration of failures. Most failures had a long recovery time. Once the failure was fixed, the system needed to be recovered.
- Quench Protection system always assumed worst case
- Quenches always had the potential to break something
- Injection field quench recovery 15 to 30 minutes
- High Field quench recovery 2 to 3 hours
- Low beta magnet insertion at high field 4 + hours
- Complete helium expansion engine overhaul 8 to 12 hours

Causes of Quenches

- Beam induced quench. Beam is steered into a magnet inducing heating.
- Magnet / Component Failure. Long recovery time.
- Failures in other interacting system that induce a quench or is interpreted as a quench
- Failures in the cryogenic system itself.

Beam Induced Quenches

- Beam or beam loss induces a quench in the system
  - Beam is steered into cryogenic magnet
  - Beam losses during acceleration
  - Beam loss due to tight aperture

Reduction of Beam Quenches

- Automatic beam orbit correction between beam stores
- Magnet alignment during maintenance periods
- Collimation at loss points
- Better simulations to help with orbit tuning

Failures in other systems that affect cryogenics

- Power supply failure can induce a quench
  - Loss of regulation in the power system usually resulted in a quench
  - Power system shutting down usually would not induce a quench but could if conditions were right.
  - Correction element power supply failure or other power supply failure usually resulted in a beam induced quench.
- Failure in the quench protection system
  - The quench protection system tried to protect against itself. It monitors for hardware failure and could induce a quench depending on the failure

Magnet /Component Failure

- Components usually fail during a quench
- Quenches and component failures were both documented and analyzed.
  - Long term solutions that are critical for stability
  - At least once lead to a redesign and modification of the Tevatron magnets
  - At times has lead to changes in the way we operated the Tevatron

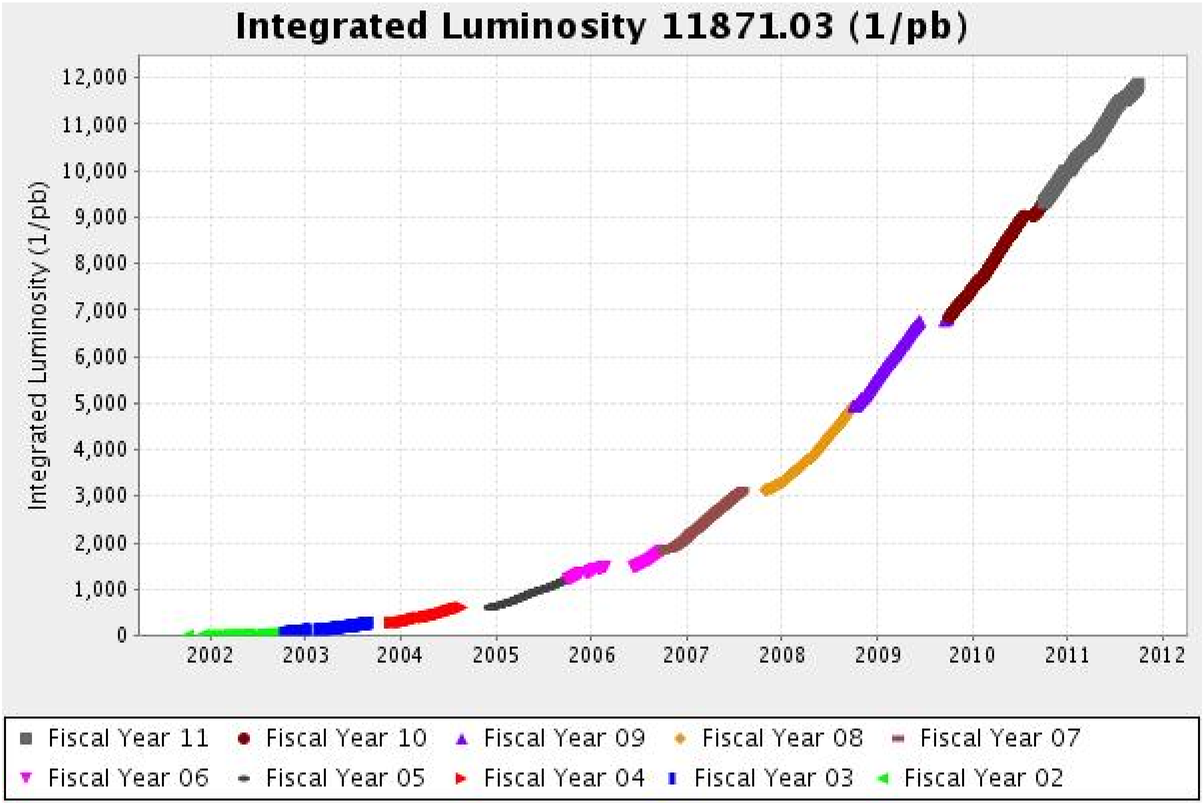
Cryogenic system failures

- The cryogenic system has a large number of moving mechanical components: helium compressors, expansion engines, and cold compressors.
- Moving components regularly fail and required maintenance.
- Regular inspection helped catch failing components and could reduce repair times.
- Regular cryogenic maintenance improved the collider uptime. This was not historically how we scheduled maintenance on other systems.
- Failures are time critical

Lessons Learned

- Need a stable accelerator to be successful
- Cryogenic failures are time consuming
- Communication is critical
- Maintenance of the cryogenic system should be planned
- Protect the cryogenic component by knowing the beam orbit and controlling it
- Analyze failures and make long term fixes

Measure of Success

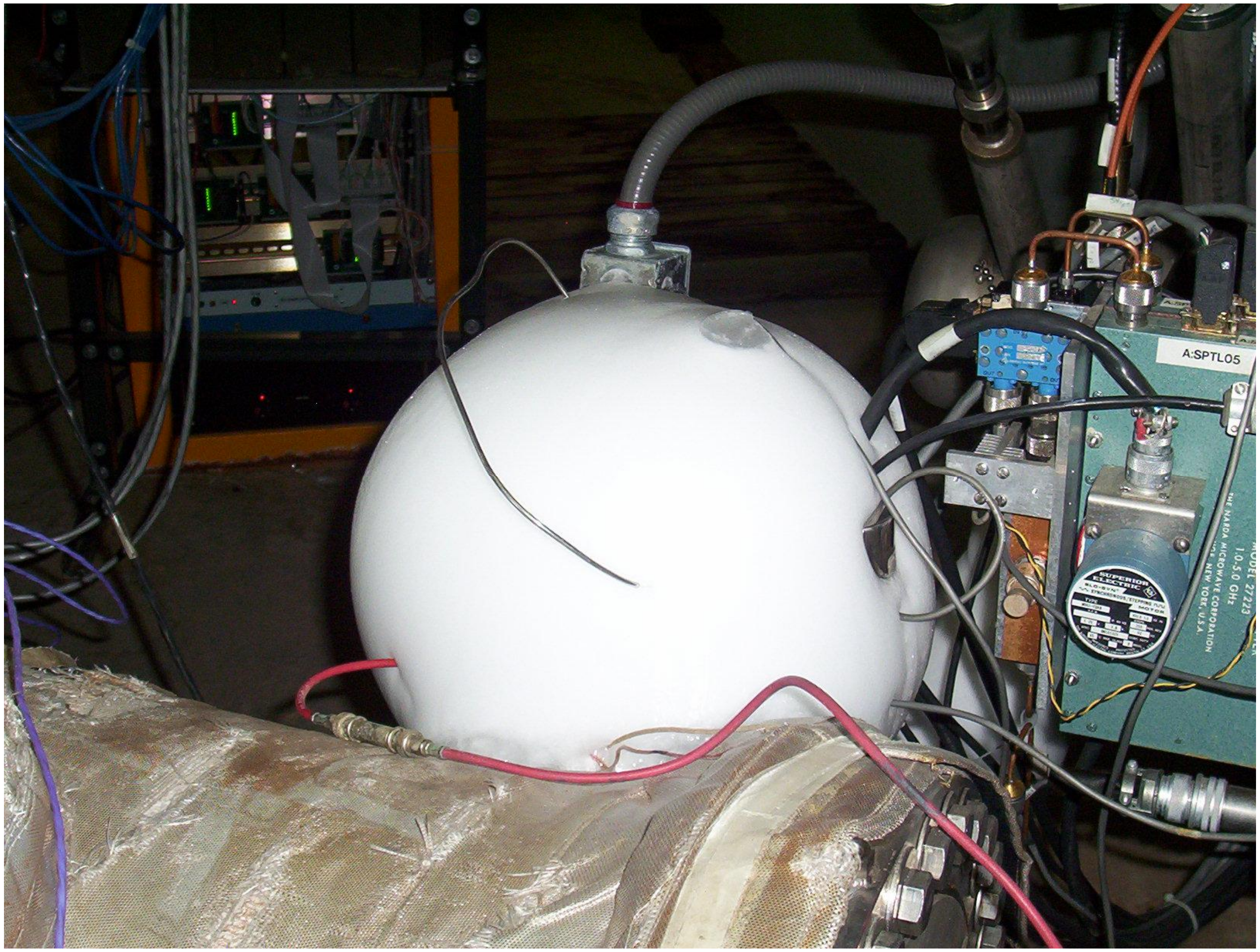


Questions

Extra Pictures

Satellite Refrigerator Building

Ice Ball

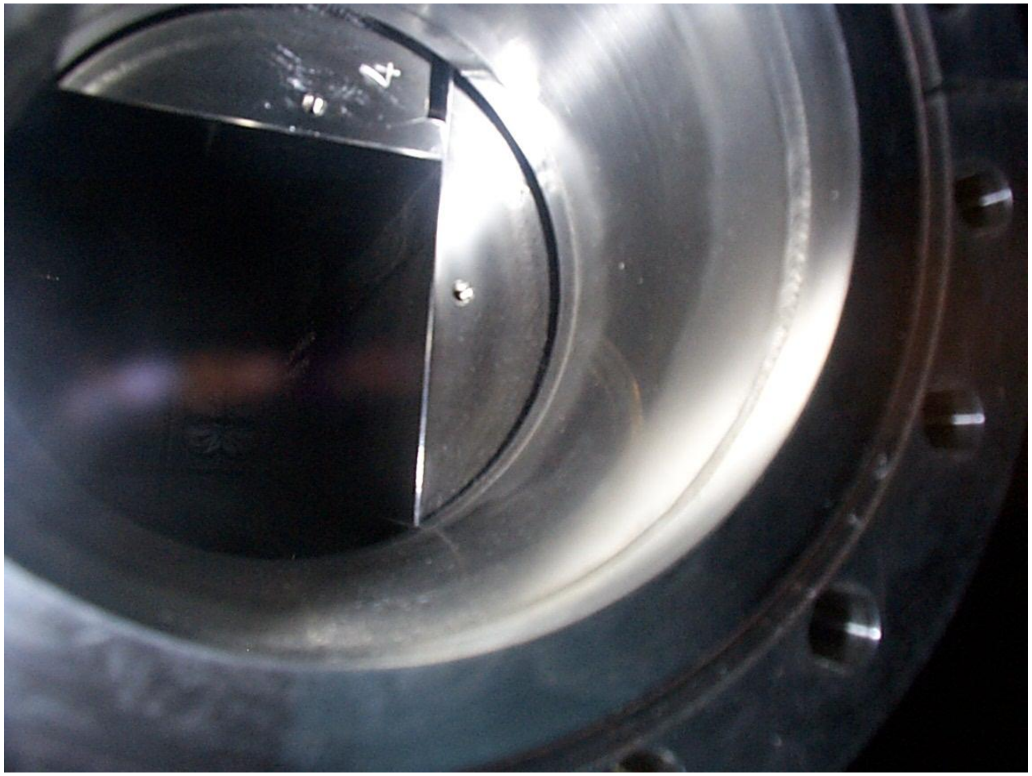


Damage from an Ice Ball

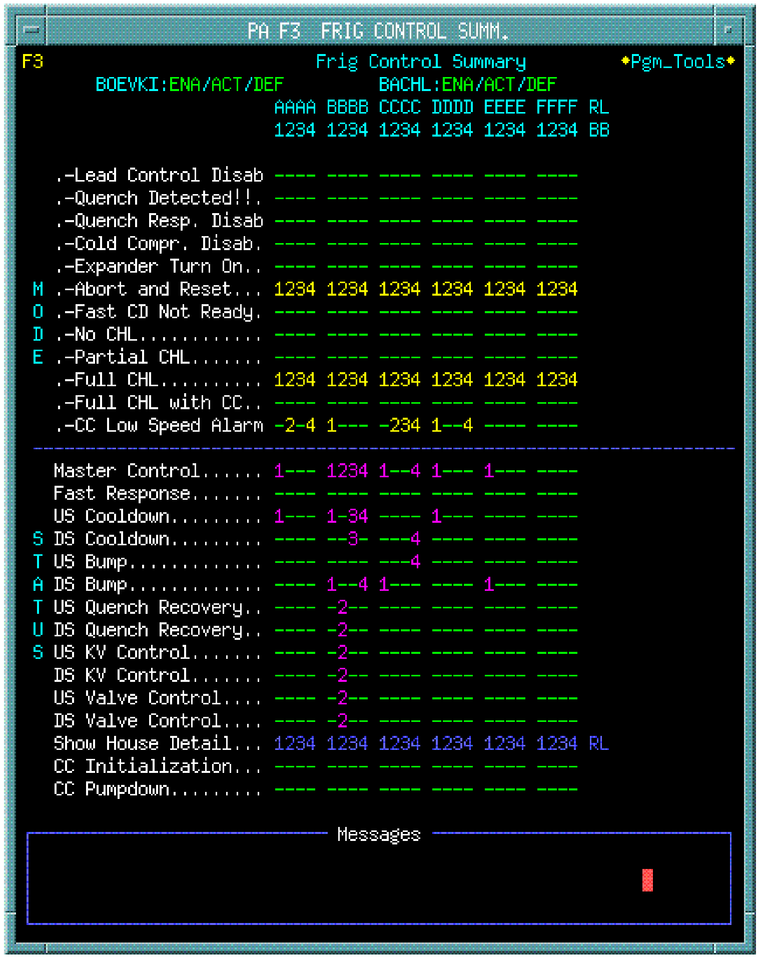
Ice Ball at Turnaround Box

Cryo Leak

Beam Damage



Frig Control Summary



Control Loop