Overview of Recent JLab Cryogenic Operations

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Cryogenic Operations Workshop 2006

Abstract

Jefferson Lab operates six helium refrigerators which are located at three laboratory site locations. Four of these refrigerators operate continuously to support the accelerators and experimental halls since early 1990s and Test Lab since 1988. During the past two years, major long term maintenance activities were performed on a number of subsystems within these plants. An overview of these activities and their results, along with recent accomplishments in the areas such as electric power reduction, gaseous helium loss control, LN2 usage, and system reliability will be presented. Near future maintenance and development plans will also be addressed.

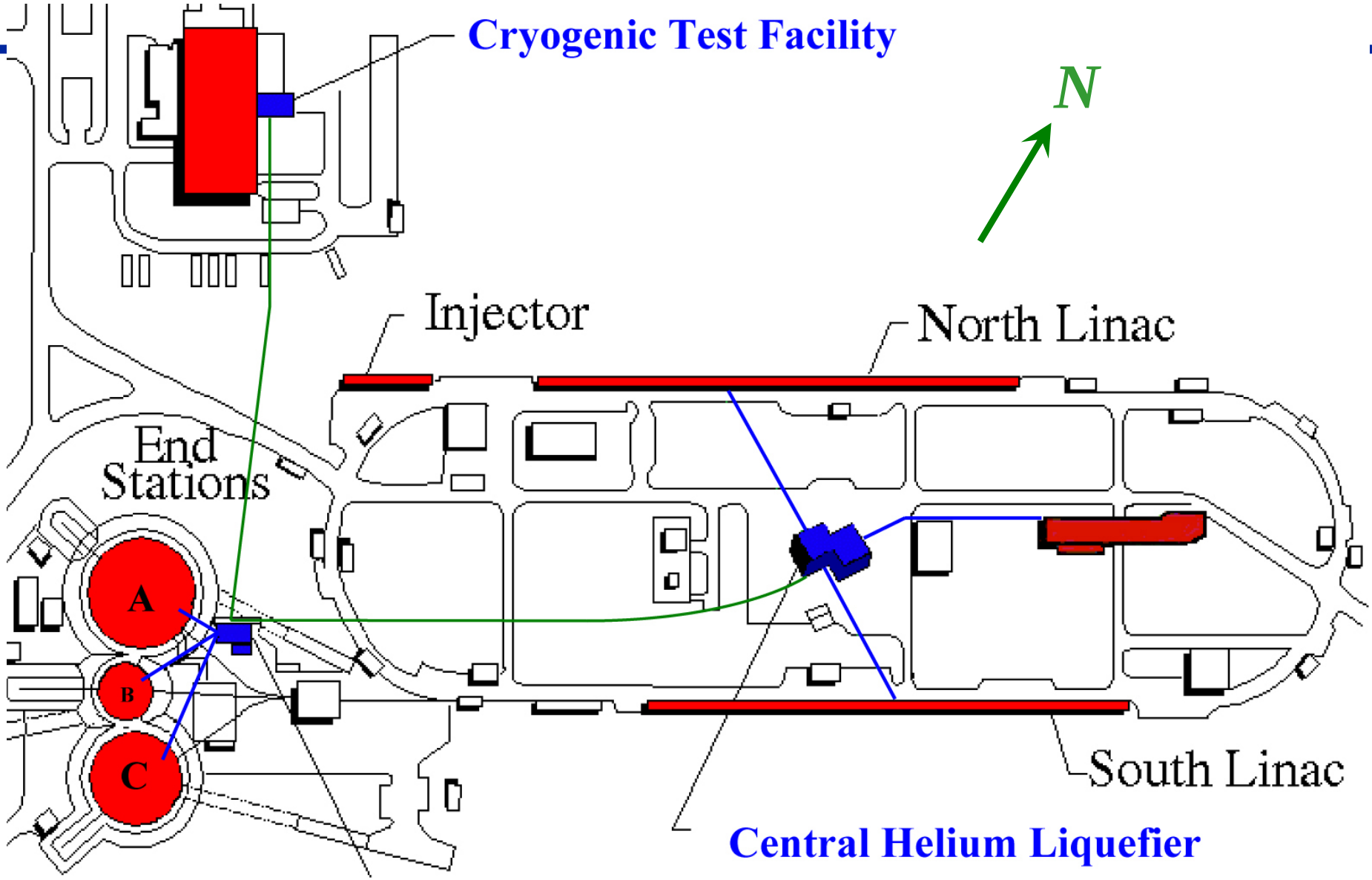
Agenda

- **Review JLab of Cryogenic:** reference 2004 presentations
- **Reliability Summary:** recent history
- **Cost Control Improvements:** electricity, LN2 & helium
- **CHL Major Maintenance**
- **Reliability Issues**

Cryogenic Plants & Customers (Users)

- **Central Helium Liquefier (CHL):** support two accelerators with superconducting RF cavities
  - Continuous Electron Beam Accelerator Facility (CEBAF)
  - Free Electron Laser (FEL)
- **Standby Refrigerator (SBR):** for rare CHL maintenance shutdown
  - January 1998, **before FEL** commissioning
  - August 2004 **with FEL** operational
- **End Station Refrigerator (ESR)**
  - Experimental Halls A, B and C
- **Cryogenic Test Facility (CTF)**
  - Cryomodule Test Facility (CMTF)
  - Vertical Dewar Test Area (VTA)
- **Thermal Loads:** Mostly Controlled by Individual Users

Cryogenic Plant Locations

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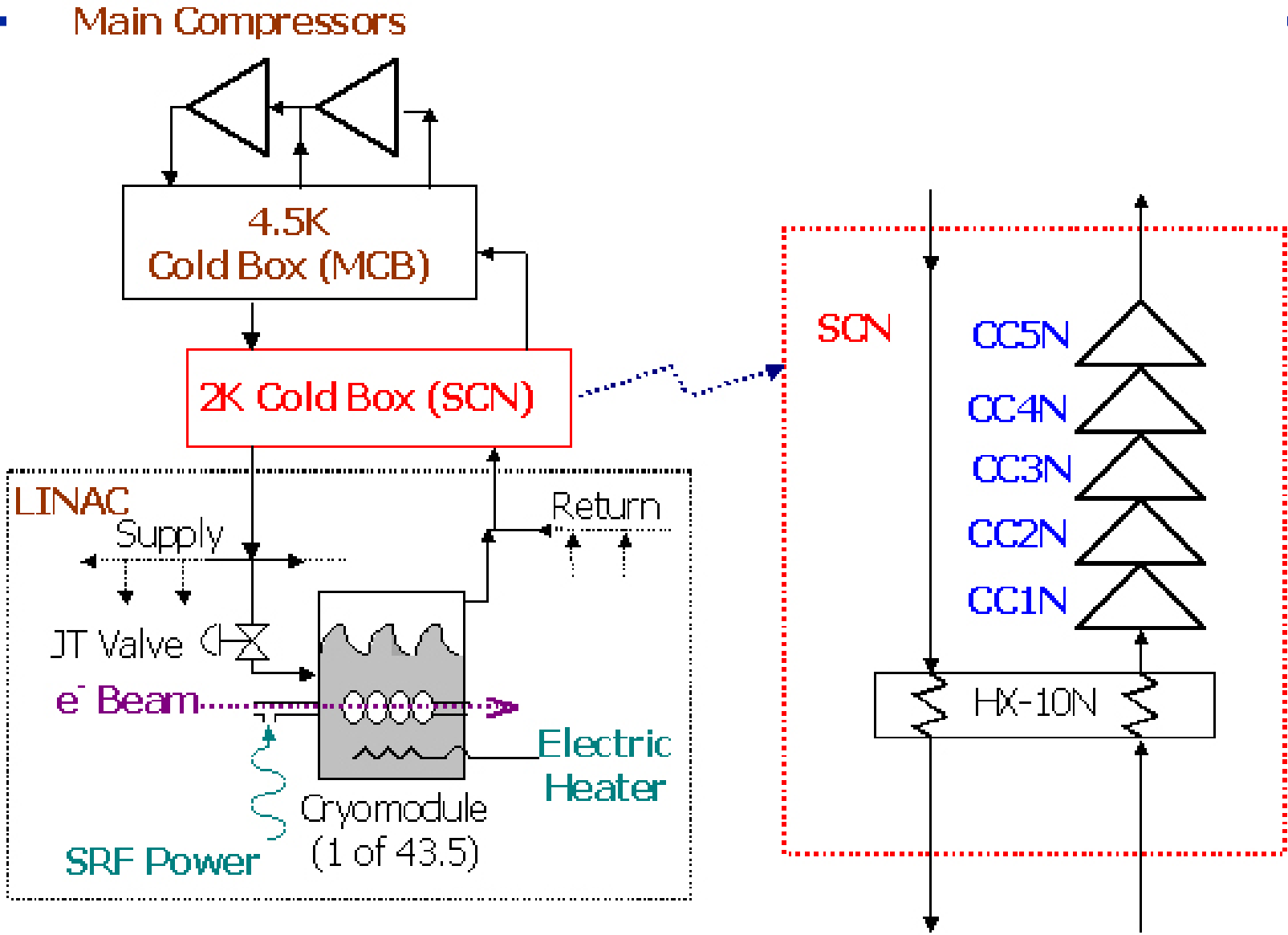
Central Helium Liquefier (CHL) Overview



CHL Equipment Highlights

- **Main Compressors:** Howden
  - 3 of 3 second stage online *(~ 122,000 hours)*
  - 2 of 3 first stage online *(~ 99,000 hours)*
  - 3 pressure streams
    - Low pressure: 1.05 atm
    - Medium pressure: 2.5 atm
    - High Pressure: manually adjustable between 17.0 and 20.2 atm
- **Main Cold Box (4.5K Cold Box):** CVI
  - LN2 pre-cooling
  - 4 turbines: Air Liquide
- **Subatmospheric Cold Box (2K Cold Box):** JLab
  - LN2 shield
  - 5 cold compressors (originally 4): Air Liquide
- **Auxiliary Systems**

SBR Highlights

- **4.5K refrigerator:** purpose is to maintain accelerator cryomodules liquid inventory during CHL maintenance shutdown (***i.e. overcome heat leaks***)
- **Main Compressors:** Howden
  - —One compressor per stage
  - —Spare compressors for CHL operations
- **Cold Box:**
  - —LN2 pre-cooling
  - —3 expansion stages
    - First two turbines in parallel
    - 4 turbines total (Air Liquide)

ESR Equipment Highlights

- **LBL 4.5K Refrigerator** (Helix Process Systems 1500 Watt Refrigerator)
- **Main Compressor:** Sullair
  - 1 dedication skid of each of 2 stages
    - Original 2nd stage replaced: ~ Feb05 @ ~ 70,000 hours
    - Original 1st stage is still operating
  - 1 skid ("Swing Compressor"): spare for either stage *(~14,000 hr)*
- **Cold Box:** modified
  - 2 Sulzer turbines
  - External 80K beds
- **10,000 liter dewar** with submerged HX between cold box and loads
- **Support from CHL**
  - GHe storage tanks
  - Purification system
  - 4.5K GHe: capacity boost during heavy loads

ESR Loads

3 Experimental Halls operate independently

- **Superconducting magnets** in each experimental hall
  - —4.5K LHe
  - —80K LN2 shield
- **Cryogenic Experimental Targets:** different types
  - —Each hall's schedule requires varying configuration of targets: planned changes are several times per year
    - The thermal load of any target can vary
    - Sometimes no cryogenic target is required
  - —Hall A and Hall C target options
    - 4.5K
    - 15K
  - —Hall B: 4.5K only

CTF Compressor Systems

- **Main Compressors** (*average ~ 94,000 hr.*)
  - —**Common GHe headers support several cold boxes**
  - —**3 main compressors:** two stage Mycom
- **Recovery Compressors:** part of purification system
- **Process Vacuum Pumps:**
  - —**Main Vacuum Pump** for both CTF Users: Liquid Ring Pump and Blower: Kinney Vacuum Co.
  - —**Auxiliary Vacuum Pumps** (Pair Pumps): option for VTA

CTF Cold Boxes

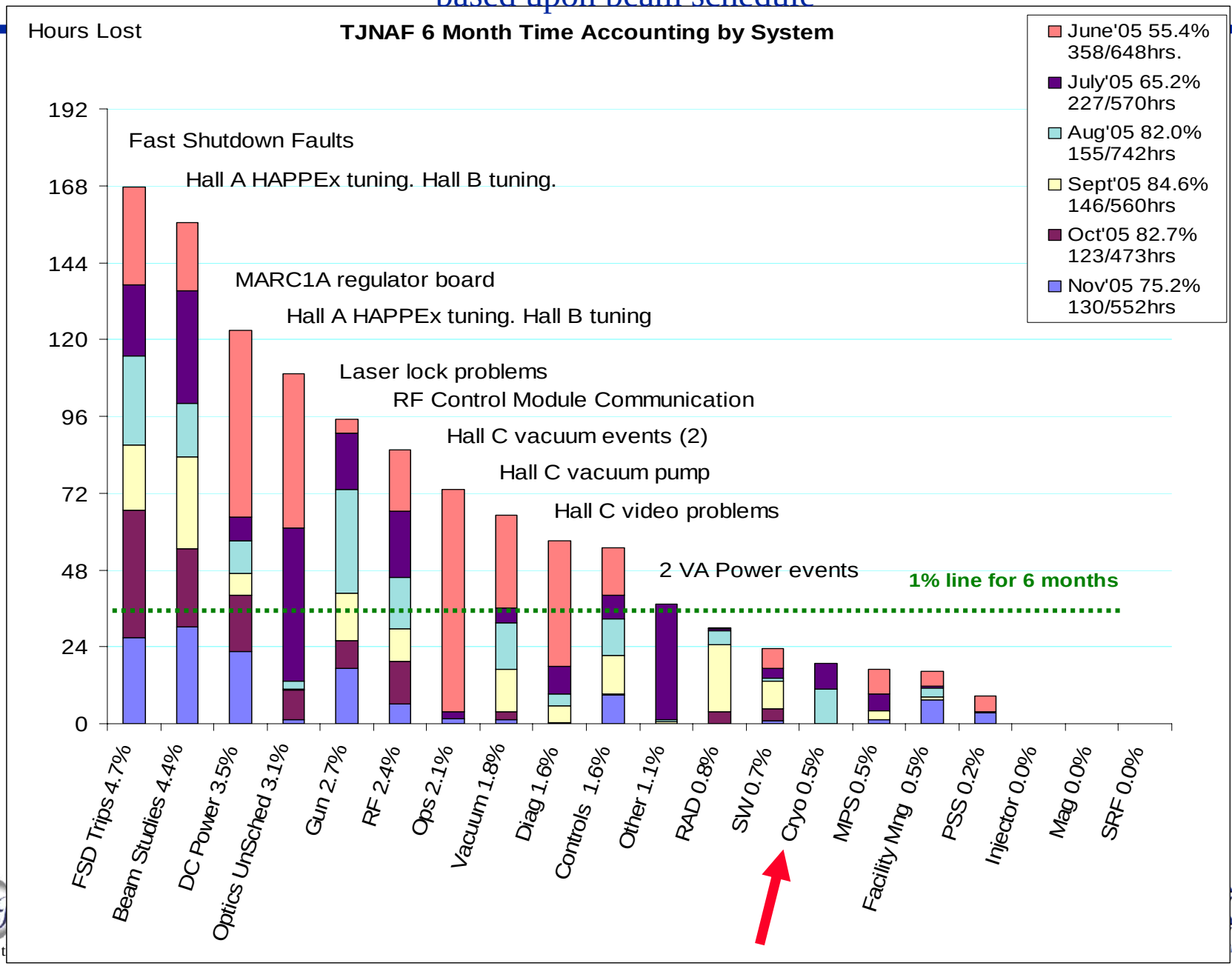
- **Cold Box 1** (40K shield cold box): *capacity ~1kW*
  - LN2 pre-cooled heater exchangers
  - Single Koch reciprocating expander *(~ 120,000 hr)*
    - Two 3” cylinders, parallel flow
- **Cold Box 2** (main liquefier): Koch Process Systems Model 2200
  - LN2 pre-cooled heater exchangers
  - Two expanders: same as Cold Box 1 *(each ~ 120,000 hr)*
  - *Liquefier mode capacity: 5.3 g/s*
- **Cold Box 3** (liquefier booster): *used for load 1988-96*
  - CTI- Cryogenic Model 2800
  - LN2 pre-cooled heater exchangers
  - Two Sulzer turbines
  - *60 liter/hr. (August 2001 brief test indicates greater capacity)*
- **Cold Box 4:** refrigeration recovery heat exchangers

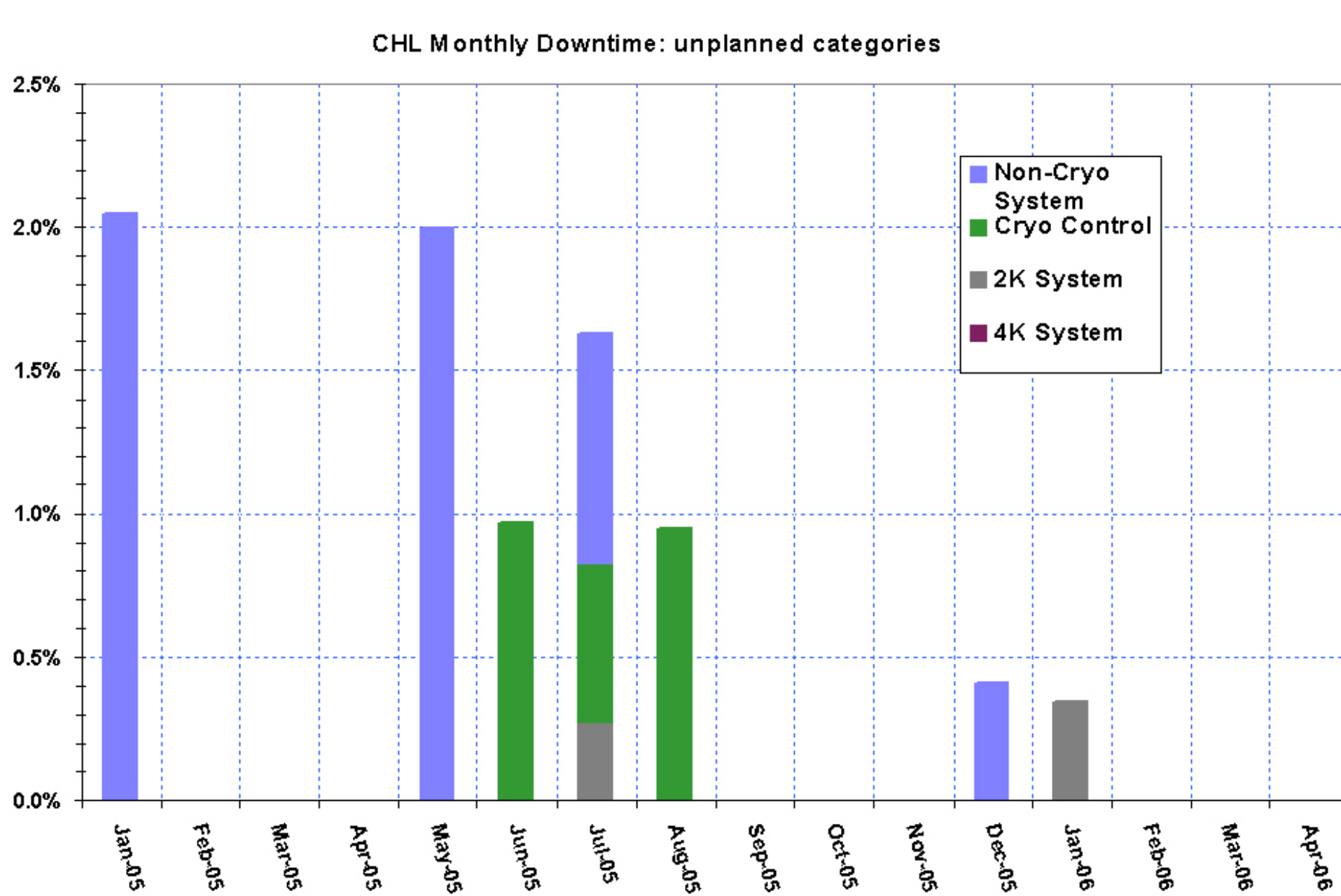
CTF Loads: in Test Lab

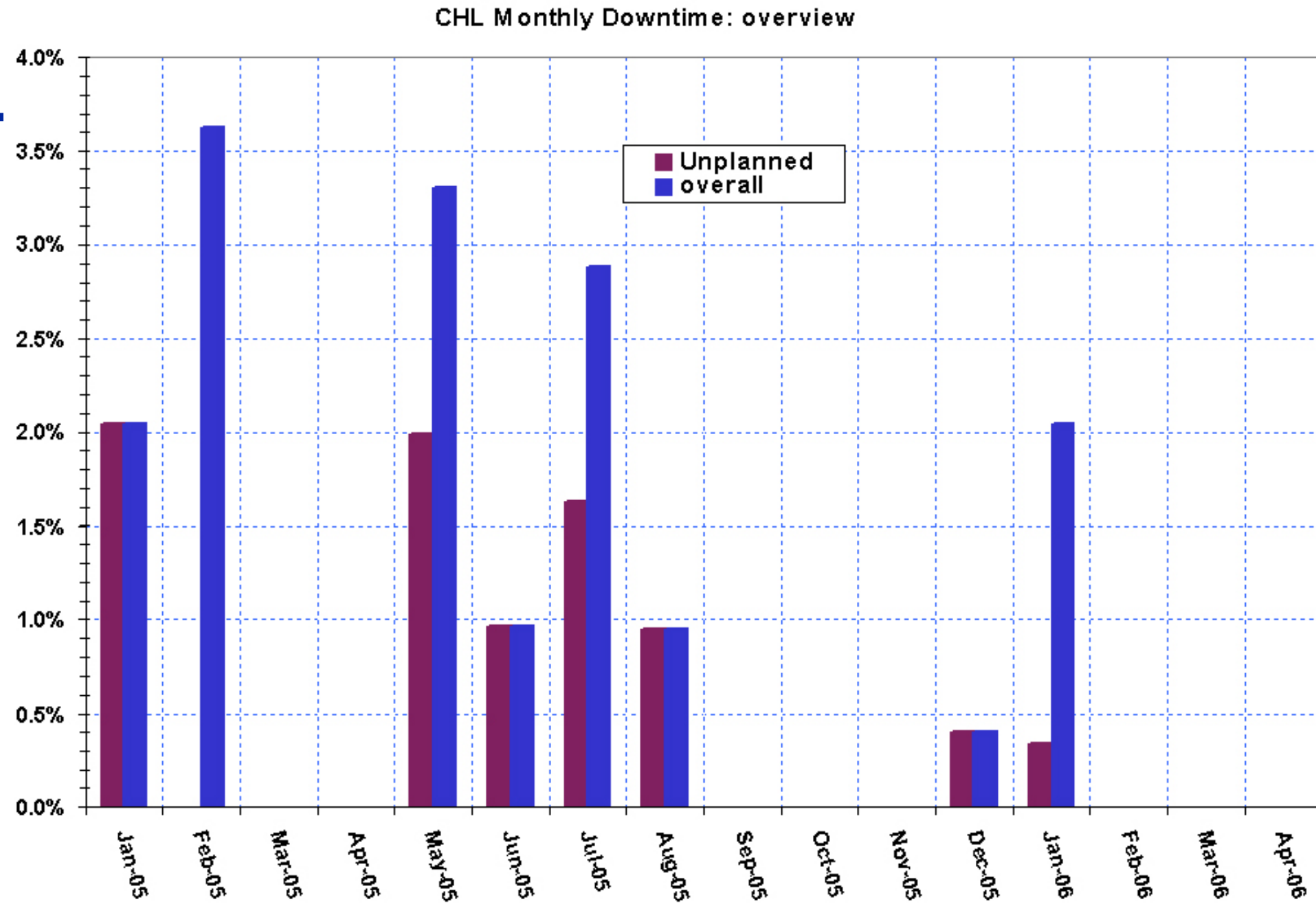
- **Cryomodule Test Facility (CMTF)**
  - —Test one cryomodule at a time
  - —2K liquid (primary circuit)
  - —40K gas (thermal shield circuit)
- **Vertical Dewar Test Area (VTA)**
  - — 8 individual dewars
    - Total design capacity 4600 liters
    - Size range: 130 liters to 1200 liters
  - —2K liquid for testing superconducting cavities and other components
  - —Batch fill at 4.5K then vacuum pump
  - —Test Dewars at ambient temperature: routinely open to atmosphere
- **Load Transients**

CEBAF: largest customer of CHL & ESR

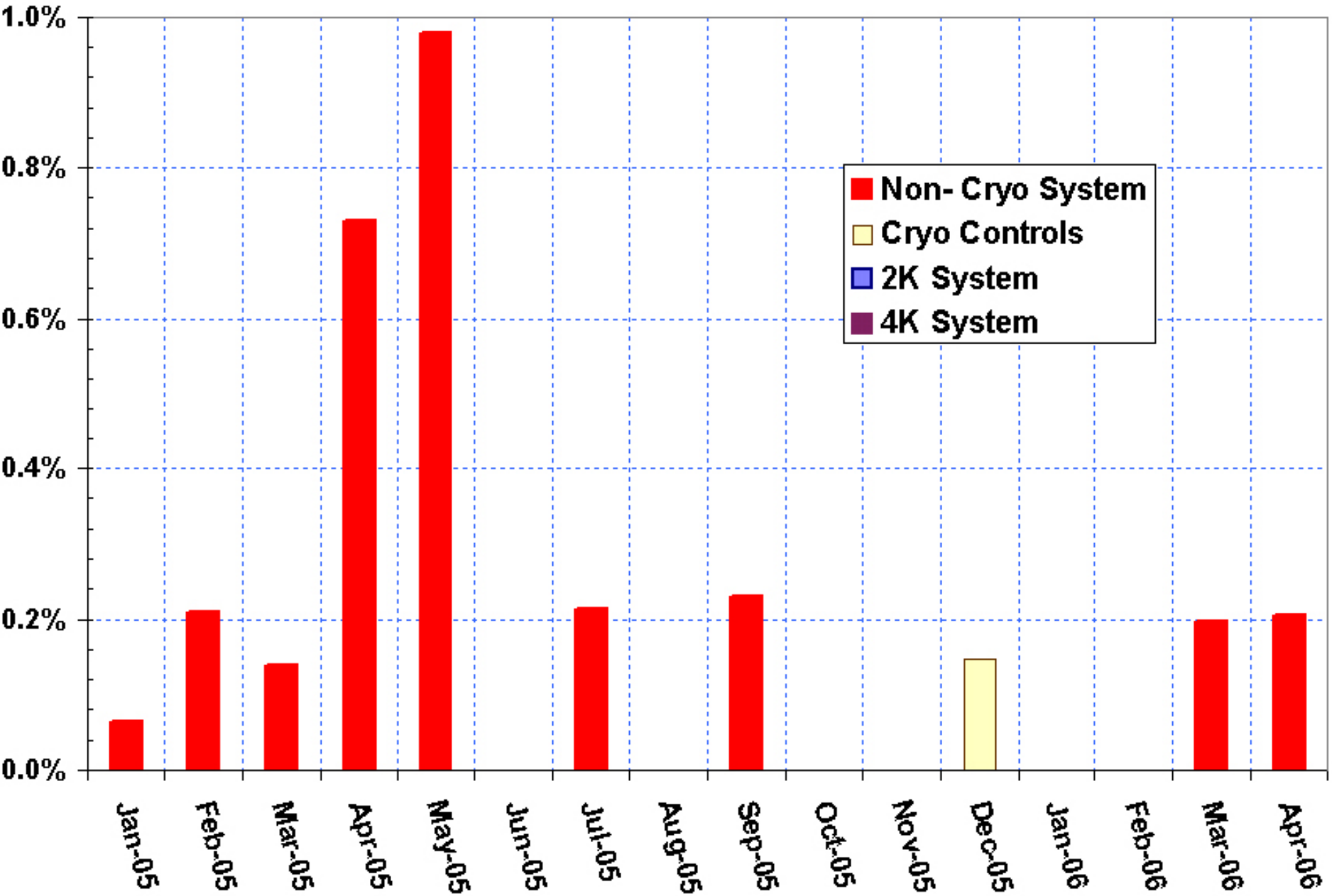
based upon beam schedule



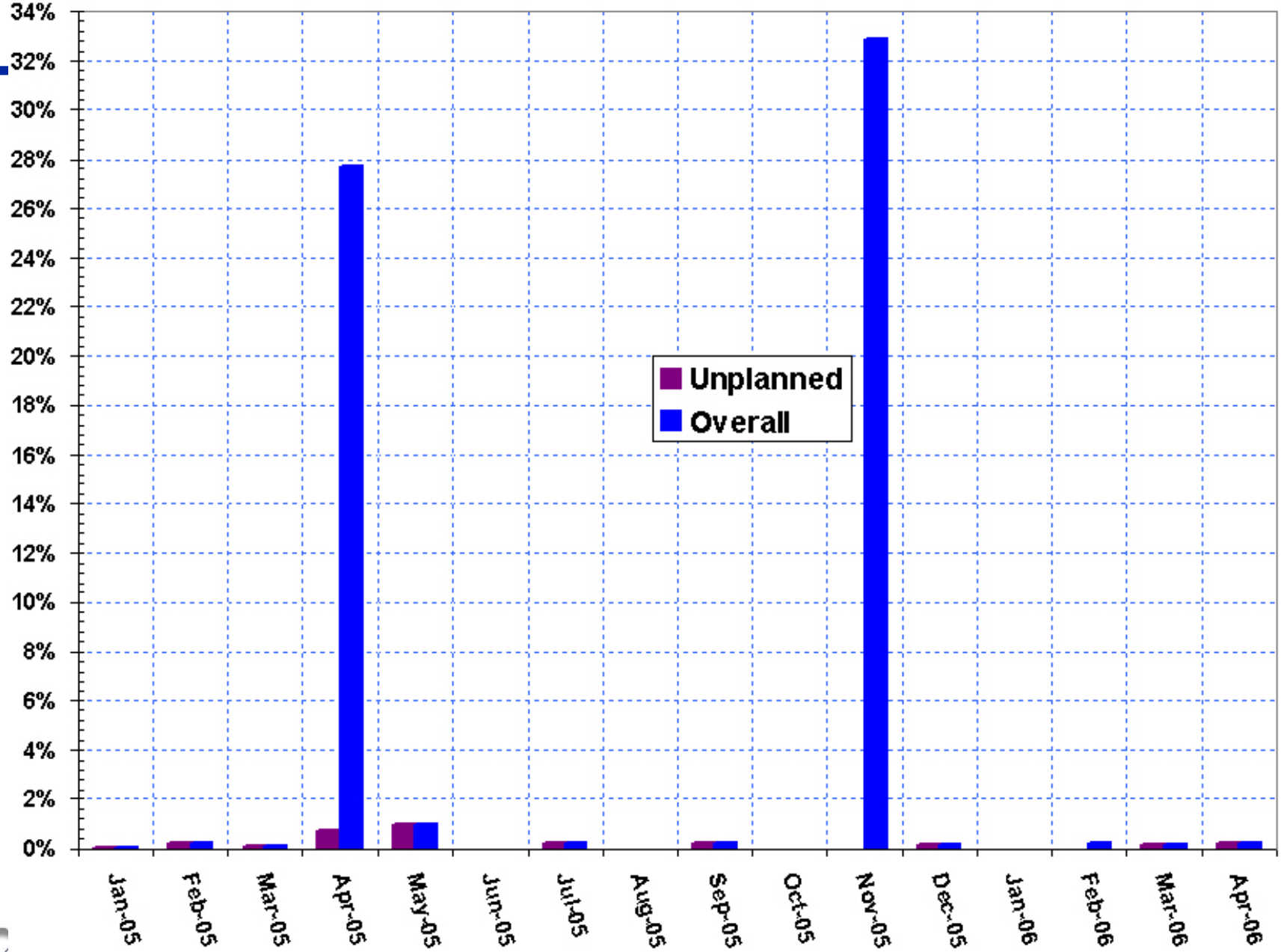

CHL Monthly Downtime: unplanned categories
2.5%
2.0%
1.5%
1.0%
0.5%
0.0%
Non-Cryo System
Cryo Control
2K System
4K System
Jan-05
Feb-05
Mar-05
Apr-05
May-05
Jun-05
Jul-05
Aug-05
Sep-05
Oct-05
Nov-05
Dec-05
Jan-06
Feb-06
Mar-06
Apr-06

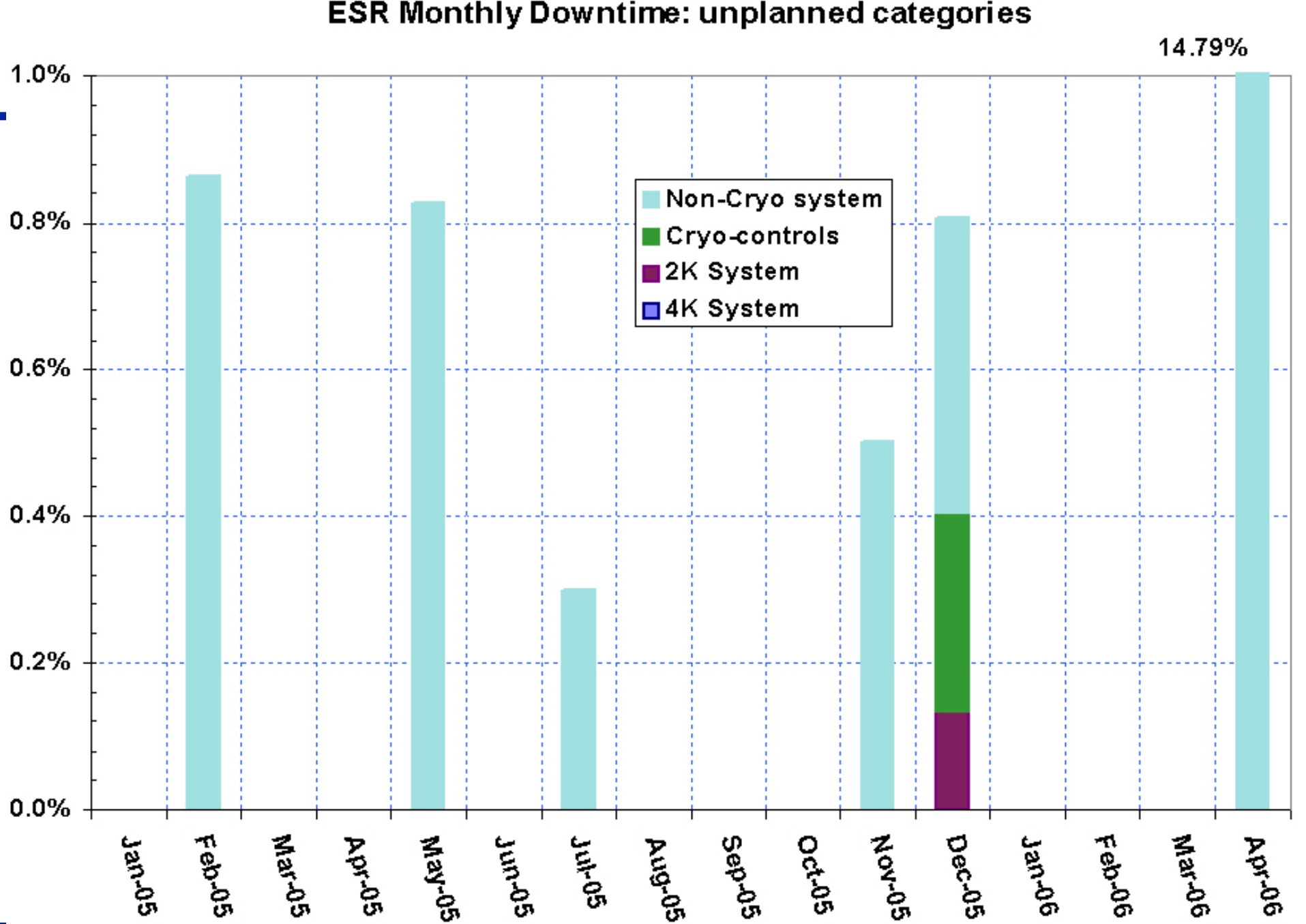

CHL Monthly Downtime: overview
Unplanned
overall
4.0%
3.5%
3.0%
2.5%
2.0%
1.5%
1.0%
0.5%
0.0%
Jan-05
Feb-05
Mar-05
Apr-05
May-05
Jun-05
Jul-05
Aug-05
Sep-05
Oct-05
Nov-05
Dec-05
Jan-06
Feb-06
Mar-06
Apr-06

CTF Downtime: unplanned categories

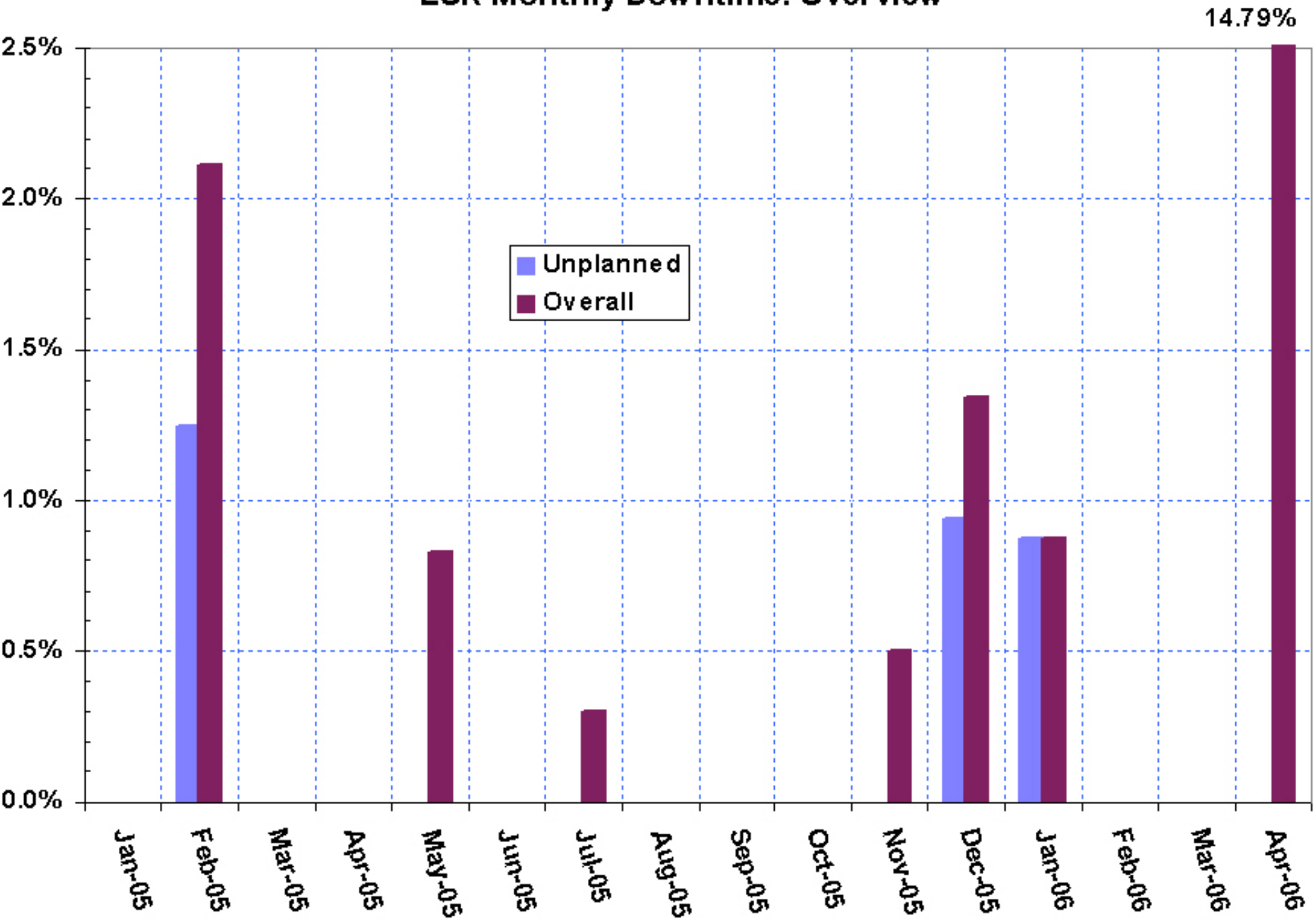


CTF Downtime: overview




ESR Monthly Downtime: unplanned categories
14.79%
1.0%
0.8%
0.6%
0.4%
0.2%
0.0%
Non-Cryo system
Cryo-controls
2K System
4K System
Jan-05
Feb-05
Mar-05
Apr-05
May-05
Jun-05
Jul-05
Aug-05
Sep-05
Oct-05
Nov-05
Dec-05
Jan-06
Feb-06
Mar-06
Apr-06

ESR Monthly Downtime: Overview

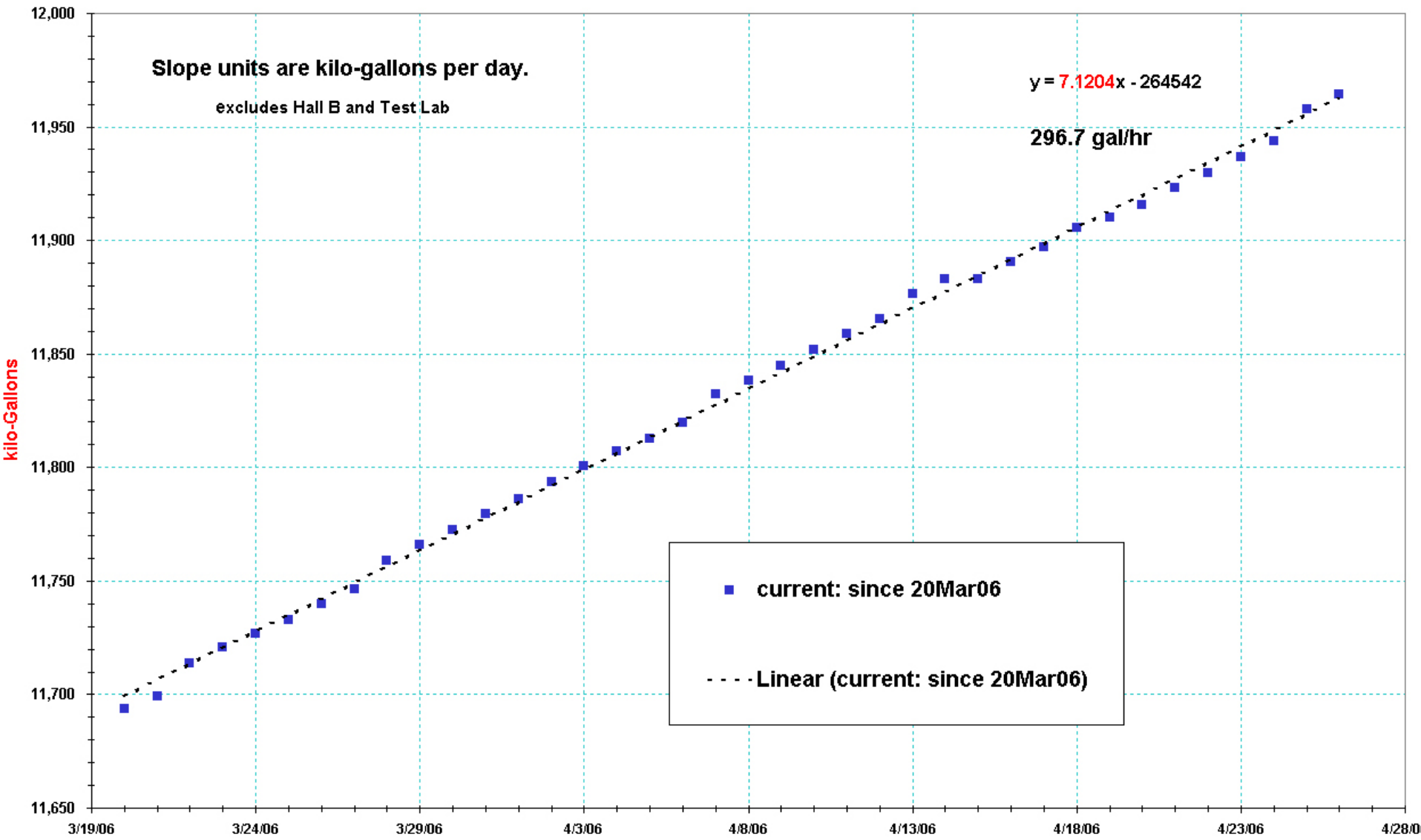


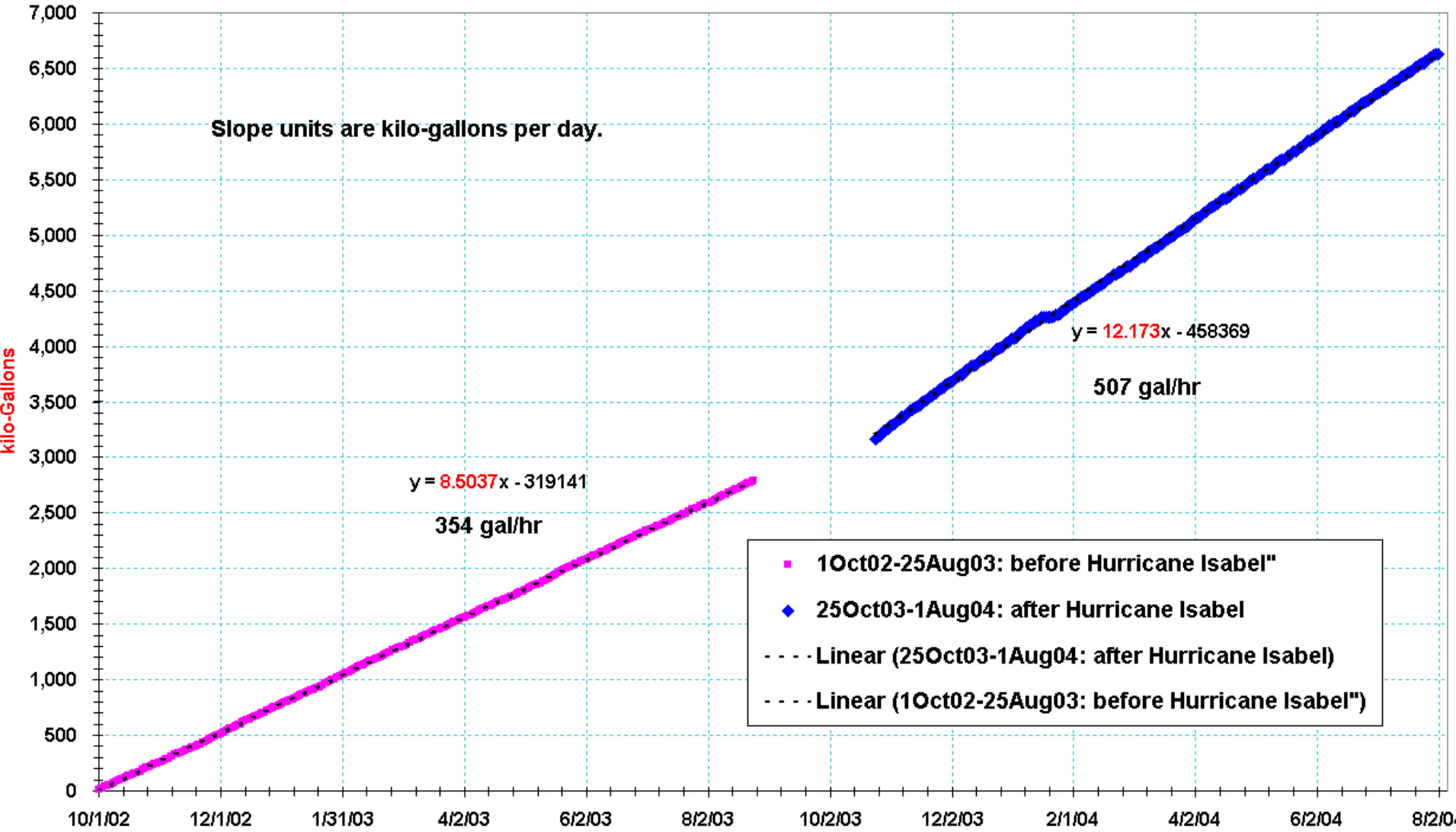
Helium & LN2 Inventory: Tracking Methods

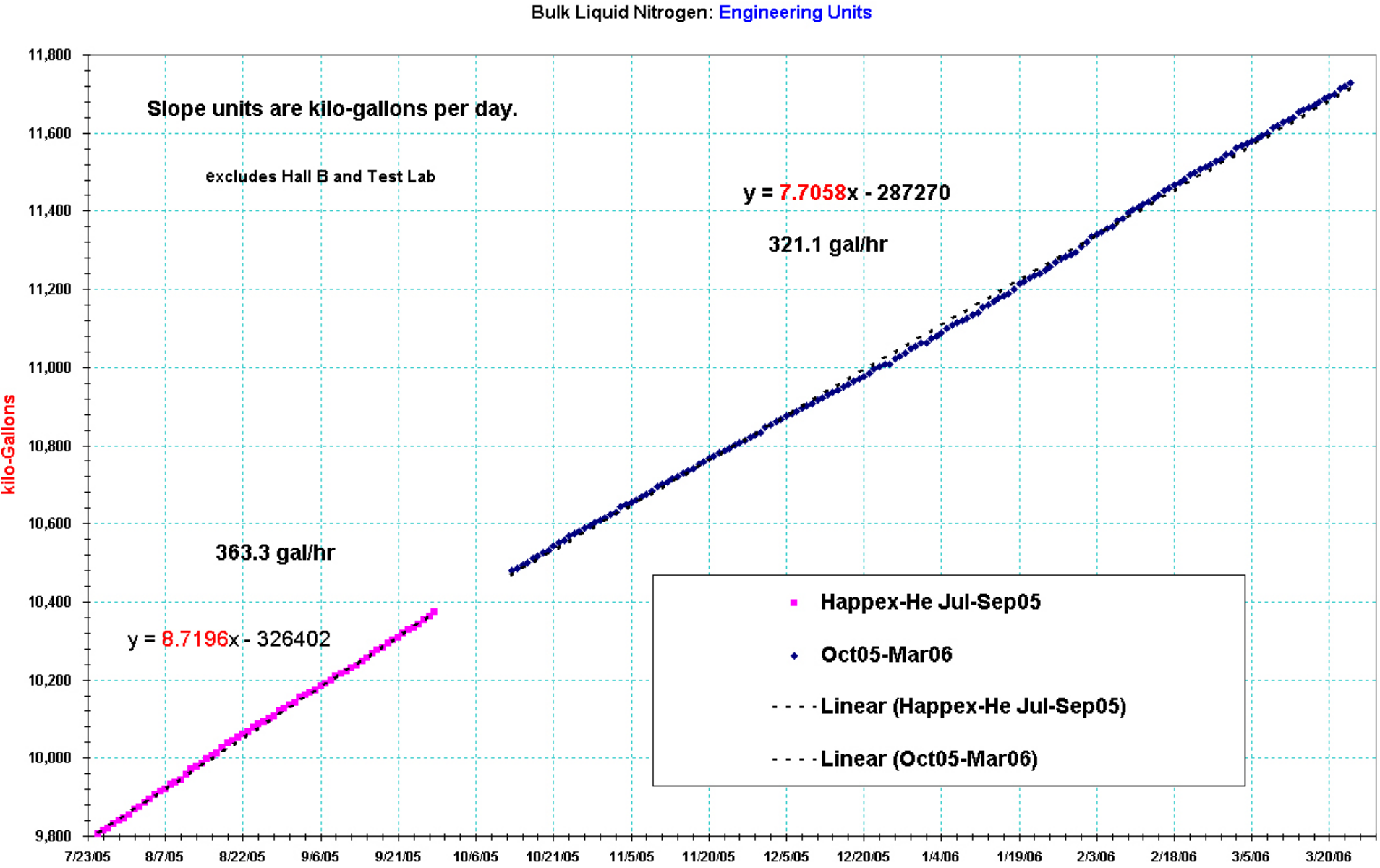
- **Short term trends StripChart (Real-time Plot)**
  - —Tank pressures
  - —Dewars, cryomodule and etc.
- **Routine User Input of inventory**
- **Long term trends**
  - — daily inventory spreadsheet: LN2 and Helium
    - Treat entire lab as single helium container
    - ~ 8AM: reduce ambient temp. affects
    - Sum individual storage vessels: 4.2K liquid liters of helium
    - Track deliveries
    - LN2 units: gallons
  - —Archived data retrieval: check suspicious periods

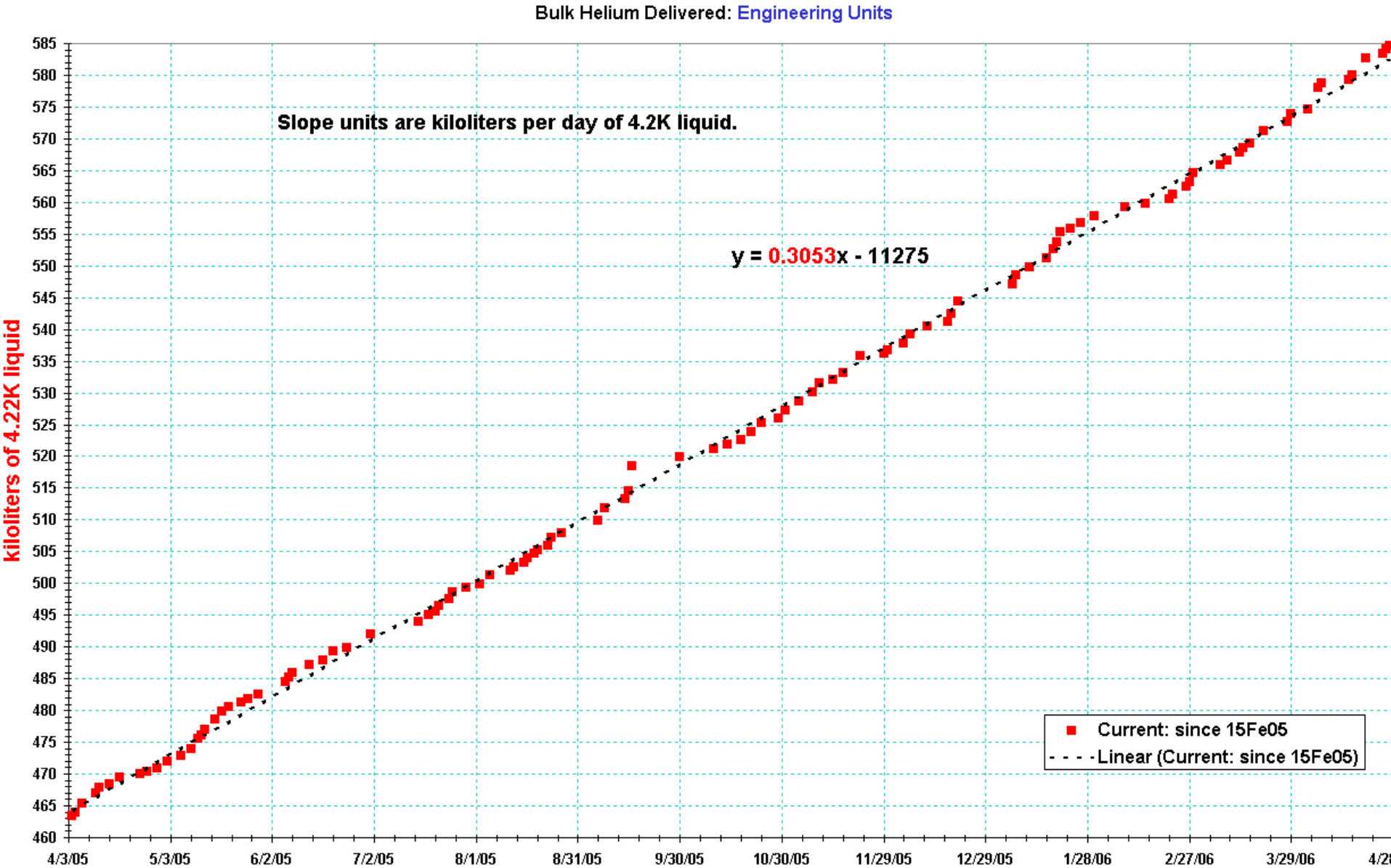
Helium & LN2 Inventory: Reasons

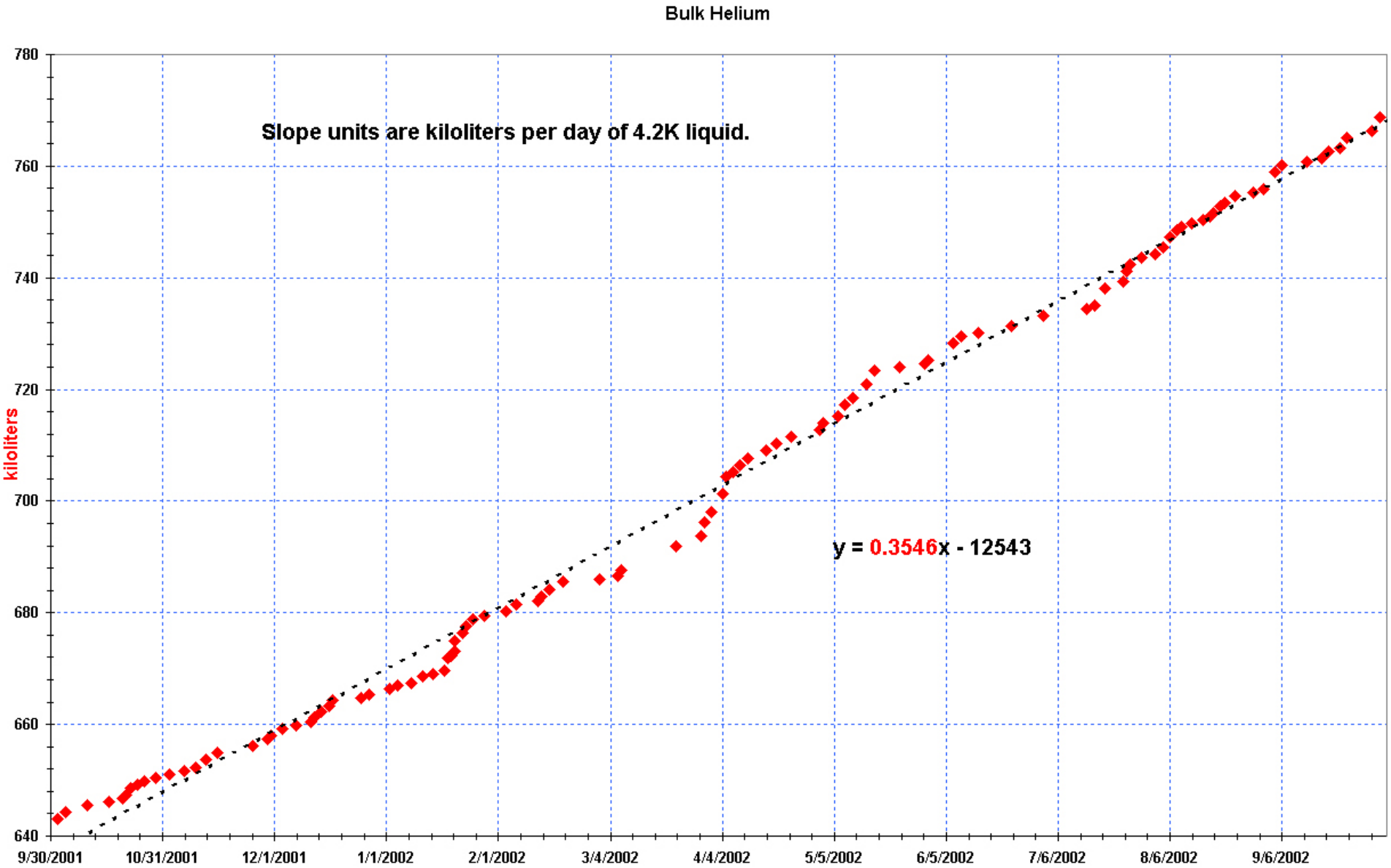
- **Part of Overall Health Check of Cryogenic Systems**
  - —Tracking consumption of LN2 and helium identified problem
  - —Key trends may indicate a developing problem
    - Leak
    - Equipment Performance change
      - Heat exchanger
      - Expander
      - Customer problem (equipment or procedural)
- **Cost of Various Configurations**
  - — more LN2 for helium liquefaction modes
  - — verify customer estimates of helium demand
  - — Plan (weekend & holiday) manpower to check status of tanks and dewar; maybe accept addition delivery

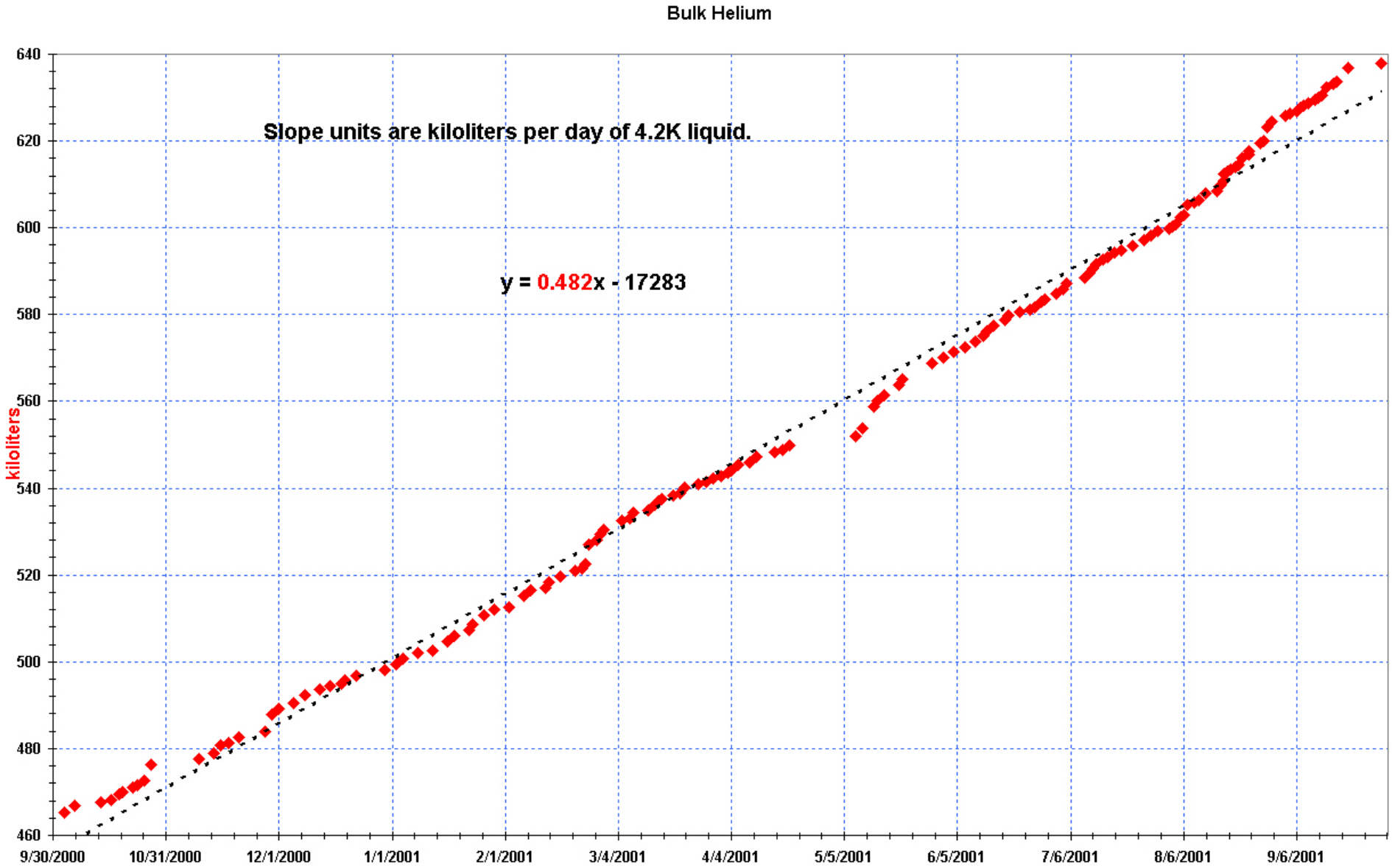

Bulk Liquid Nitrogen: Engineering Units
Slope units are kilo-gallons per day.
excludes Hall B and Test Lab
y = 7.1204x - 264542
296.7 gal/hr
kilo-Gallons
12,000
11,950
11,900
11,850
11,800
11,750
11,700
11,650
3/19/06
3/24/06
3/29/06
4/3/06
4/8/06
4/13/06
4/18/06
4/23/06
4/28/0
current: since 20Mar06
Linear (current: since 20Mar06)

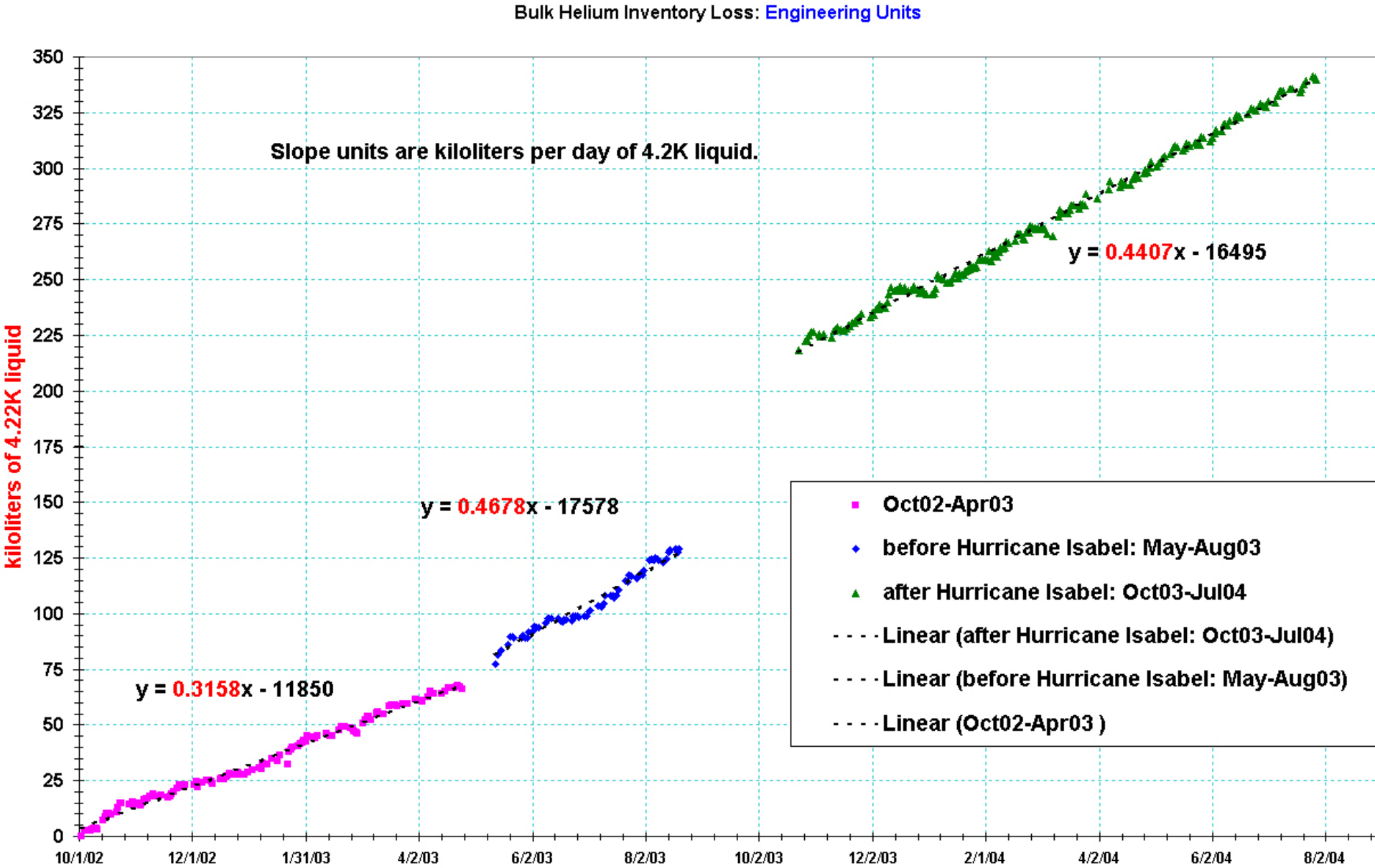

Bulk Liquid Nitrogen: Engineering Units
Slope units are kilo-gallons per day.
y = 8.5037x - 319141
354 gal/hr
y = 12.173x - 458369
507 gal/hr
kilo-Gallons
7,000
6,500
6,000
5,500
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
10/1/02
12/1/02
1/31/03
4/2/03
6/2/03
8/2/03
10/2/03
12/2/03
2/1/04
4/2/04
6/2/04
8/2/04
1Oct02-25Aug03: before Hurricane Isabel"
25Oct03-1Aug04: after Hurricane Isabel
Linear (25Oct03-1Aug04: after Hurricane Isabel)
Linear (1Oct02-25Aug03: before Hurricane Isabel")

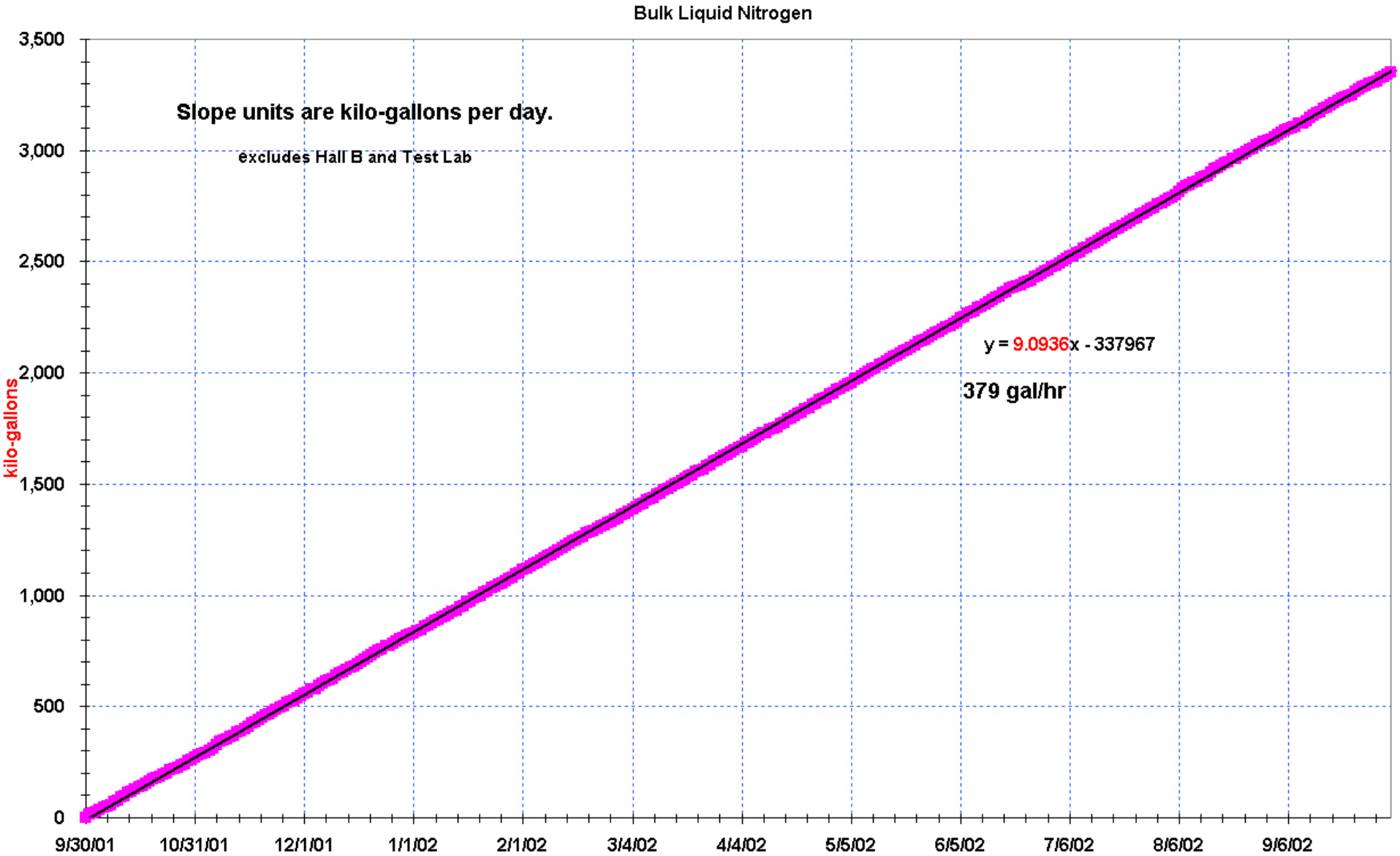

Bulk Liquid Nitrogen: Engineering Units
Slope units are kilo-gallons per day.
excludes Hall B and Test Lab
y = 7.7058x - 287270
321.1 gal/hr
363.3 gal/hr
y = 8.7196x - 326402
kilo-Gallons
11,800
11,600
11,400
11,200
11,000
10,800
10,600
10,400
10,200
10,000
9,800
7/23/05
8/7/05
8/22/05
9/6/05
9/21/05
10/6/05
10/21/05
11/5/05
11/20/05
12/5/05
12/20/05
1/4/06
1/19/06
2/3/06
2/18/06
3/5/06
3/20/06
Happex-He Jul-Sep05
Oct05-Mar06
Linear (Happex-He Jul-Sep05)
Linear (Oct05-Mar06)

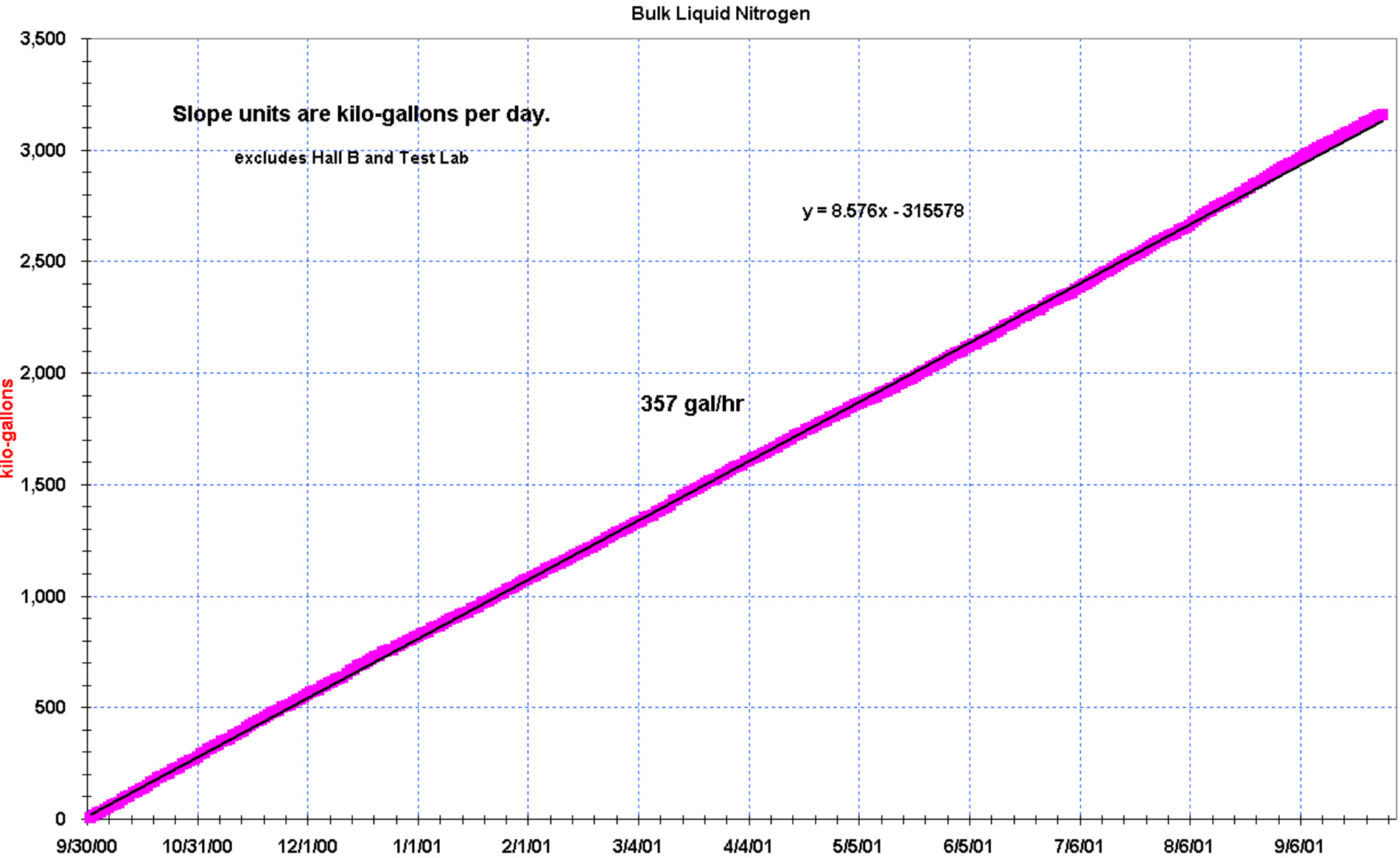

Bulk Helium Delivered: Engineering Units
Slope units are kiloliters per day of 4.2K liquid.
y = 0.3053x - 11275
kiloliters of 4.22K liquid
585
580
575
570
565
560
555
550
545
540
535
530
525
520
515
510
505
500
495
490
485
480
475
470
465
460
4/3/05
5/3/05
6/2/05
7/2/05
8/1/05
8/31/05
9/30/05
10/30/05
11/29/05
12/29/05
1/28/06
2/27/06
3/29/06
Current: since 15Fe05
Linear (Current: since 15Fe05)


Bulk Helium
Slope units are kiloliters per day of 4.2K liquid.
y = 0.3546x - 12543
kiloliters
780
760
740
720
700
680
660
640
9/30/2001
10/31/2001
12/1/2001
1/1/2002
2/1/2002
3/4/2002
4/4/2002
5/5/2002
6/5/2002
7/6/2002
8/6/2002
9/6/2002


Bulk Helium
Slope units are kiloliters per day of 4.2K liquid.
y = 0.482x - 17283
kiloliters
640
620
600
580
560
540
520
500
480
460
9/30/2000
10/31/2000
12/1/2000
1/1/2001
2/1/2001
3/4/2001
4/4/2001
5/5/2001
6/5/2001
7/6/2001
8/6/2001
9/6/2001


Bulk Helium Inventory Loss: Engineering Units
Slope units are kiloliters per day of 4.2K liquid.
kiloliters of 4.22K liquid
y = 0.4407x - 16495
y = 0.4678x - 17578
y = 0.3158x - 11850
Oct02-Apr03
before Hurricane Isabel: May-Aug03
after Hurricane Isabel: Oct03-Jul04
Linear (after Hurricane Isabel: Oct03-Jul04)
Linear (before Hurricane Isabel: May-Aug03)
Linear (Oct02-Apr03)
350
325
300
275
250
225
200
175
150
125
100
75
50
25
0
10/1/02
12/1/02
1/31/03
4/2/03
6/2/03
8/2/03
10/2/03
12/2/03
2/1/04
4/2/04
6/2/04
8/2/04


Bulk Liquid Nitrogen
Slope units are kilo-gallons per day.
excludes Hall B and Test Lab
y = 9.0936x - 337967
379 gal/hr
kilo-gallons
3,500
3,000
2,500
2,000
1,500
1,000
500
0
9/30/01
10/31/01
12/1/01
1/1/02
2/1/02
3/4/02
4/4/02
5/5/02
6/5/02
7/6/02
8/6/02
9/6/02


Bulk Liquid Nitrogen
Slope units are kilo-gallons per day.
excludes Hall B and Test Lab
y = 8.576x - 315578
357 gal/hr
kilo-gallons
3,500
3,000
2,500
2,000
1,500
1,000
500
0
9/30/00
10/31/00
12/1/00
1/1/01
2/1/01
3/4/01
4/4/01
5/5/01
6/5/01
7/6/01
8/6/01
9/6/01

Electrical Power Savings: reduces machinery stress and wear

- **Established Methods**
  - CTF and ESR compressor discharge pressure automatically varies as a linear function of LHe dewar level, which is load indicators (~ almost a decade):
  - CTF and ESR cooling water pump impeller sizing reduction: more flow and less power
- **Recent: CHL 2K operations**
  - During CEBAF maintenance & FEL operating:
    - Stop shield flow to CEBAF cryomodules
    - Minimize 2K flow
    - Stop CHL 4.5K flow to ESR
    - Shutdown a CHL 2nd stage compressor: **1.5 MW savings, Jan06**
  - During CEBAF low beam energy operation
    - Run SBR 2nd stage compressor instead of a CHL 2nd stage: **0.7 MW savings, Jan-Apr06**
    - Determine minimum allowed CHL compressor discharge pressure
- **Future:**
  - CTF compressor
    - Install variable speed motor control: automatic modulation of **400 hp** motor
    - Compressor capacity automatically responds to wide variation in customer demands
  - CHL LHe dewar: automate compressor discharge pressure response to load
  - Install 1/3 mile pipe: CTF and CHL share recovery compressors: 0.1-0.2 MW savings
  - CTF Cold Box 3: direct support of load instead of filling a second dewar

CHL Major Maintenance Goals: August 2004

- **Standby Refrigerator:** keep 4.5K LHe & 40K shield in LINAC
  - Last used in Jan98 during previous planned CHL shutdown
- **New Charcoal Adsorber installation:** original vessel supported nearly continuous compressor operation since 1991
- **Cooling Water Distribution:**
  - replaced corroded and leaking pipe fitting
  - Added isolation valve to various pipe branches
  - temporary fire hose connection via “hot taps”
- **Replaced a 2nd stage compressor** with recently overhauled machine
- **Replaced rusty pipe flange assemblies:** compressor medium pressure
- **Other 2nd stage compressors**: routine maintenance
- Support customer’s maintenance of cryomodules

Standby Refrigerator Load during CHL shutdown 2004

- During CHL planned shutdown**, SBR goal is maintenance LINACs' 4.5K LHe inventory** (1700 W) **and 40K** (12 kW) shield circuit
- SBR capacity tested prior to CHL shutdown
- 2004 load comparison to 1998 load
  - addition of FEL transfer line and cryomodules
  - Addition of 2L21
  - some cryomodules (~ 6) off-line for planned maintenance
- Actual load was larger than expected
  - conflicting priorities about load reduction, which cryomdules to warm (~ 6 more): largest heat load vs. customer maintenance vs. post-maintenance schedule

CHL Main Compressor 5 (Howden) : reliability issue

Although reliable, the failure rate was higher than other compressors

- Middle 1990s: crushed ball bearings (1 ½ inch diameter)
- Historically, difficult to align motor with compressor
- May03: planned compressor replacement with overhauled machine
- Jan05: thrust bearing failure
  - within several hours, power demand linear increase from 1.4 MW to 1.8 MW
  - rotating screws contacted casing
  - Initial suspected cause: related to motor magnetic center and coupling installation
- **Root Cause:** Motor mounting surface was never parallel with compressor mounting surface
  - Survey crew measured surface elevations
  - Contactor milled the motor mounting surface
- Variable volume ratio compressor installed Jan06:
  - JLab's first, because this feature was unavailable during CHL construction
  - After oil piping modification, testing determined the best setting

Other CHL Significant Reliability Challenges

- **4160 Volt AC phase imbalance: Jan05**
  - recurring problem trips CHL 2nd stage compressor motors
  - Power company repaired voltage regulator at onsite substation
- **Variable speed drive oil pumps 480V motors:** CHL 2nd stage compressors, **Dec05**
  - control cabinet: most limiting component during a a power glitch
  - May eliminate variable speed cabinet: optimistic about occasional compressor performance test and oil flow adjustments
- CHL **subatmospheric control valve bellow seal failure: Oct04**
  - 2K Heat Exchanger contamination
  - Replaced valve stem assembly
  - At bellows vent port
    - Was open to atmosphere
    - Connect to low pressure ambient helium to all similar valves
  - lessons learned about vendors' valve design

Oil Carry-over Mitigation

The key is routine observation: visual and audible

- **CTF main compressors:** individual coalescer per compressor
- **Daily check sightglass level:** coalescer & compressor
  - learn pattern of normal changes in levels
- **CHL, ESR and SBR:**
  - oil coalescers shared by entire compressor system
  - oil return header valves determines which single compressor get coalescer return, usually 2nd stage machine
  - CHL: alternate coalescer return among 2nd stage machines
  - occasionally transfer oil from 2nd to 1st stage
- **Experience:**
  - leaky oil transfer valve vs. carry over
  - oil collection in gas piping
    - Change in sightglass patterns
    - Gas pipe sound change

ESR Compressor Issues

- In Early Sep03 just prior to Hurricane Isabel, ESR was planned shutdown for piping modification to support a pending customer requirement. Minor maintenance was done.
- Approx. Feb05, **ESR Compressor 2: performance degrading**
  - — max. attainable oil pressure slow decline
  - — The original compressor (~ 1977) then JLab 1994: reaching end of life
  - — difficult replacement: ESR running with back-up ("swing") compressor
    - Swing Compressor (C3): new oil leak at fitting, get worse
    - C2 developed leak during testing
  - — Repair Crew distracted by pending problem with CHL C5

Contamination Challenge: present & future

- **ESR main compressor adsorber:**
  - — Original vessel near continuous service since 1994
  - — Replacement scheduled Sep06: shutdown for 2 days
- **CHL and CTF Purification System:**
  - — design & parts procurement for replacement & upgrade is underway
  - — CTF vessel operational since ~ 1988
  - — CHL vessels operational since
    - ~ 1990 for one pair
    - ~ 1993 for other pair
- **ESR Event Apr06: customer with subatmospheric device**

CTF Expanders: modification

- Koch reciprocating expander issues *(over 120,000 hr)*
  - Two 3” cylinders, parallel flow
  - 1 of 3 had deformed cylinder
  - There was no spare expander
  - DC brake motor-generator with power return to electric power grid
    - No longer supported by vendor
    - Brushes wear was a limitation
- Actions:
  - new expander purchased
  - Add safety feature
  - one at a time an expander was replaced and overhauled
  - AC brake motor-generator replaced DC units
    - Initially power dissipated via resistors
    - Later modification permit power return to electric power grid

New CTF Cooling Tower

- **Originally, CTF cooling water provided by Test Lab Cooling Tower, which had several loads.**
- **Reason for new cool tower**
  - **accelerator site's new chiller water supported by Test Lab cooling tower**
  - **old tower, new operating mode: Seasonal variation in cooling water temperature setpoint**
  - **CTF compressor performance required constant oil temperature: plans to modulate CTF water flow was unreliable**
  - **Best Option: dedicated CTF cooling tower**
  - **Operational Oct05**

Thank You!

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