AN OVERVIEW OF THE RHIC REFRIGERATOR SYSTEM UPGRADE

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RHIC Refrigeration System Upgrade

- A program was initiated by BNL in early 2003 in collaboration with the cryogenic system group at JLab to upgrade the RHIC cryogenic system.
- The upgrades are for improving the cryogenic system in the Areas of:

Efficiency

Reliability

Operational flexibility

System Stability

RHIC REFRIGERATOR SYSTEM UPGRADES

- The Upgrade is Proceeding in Phases.
- Phase 1 and 2 have been completed.
- Phase 3 is partially implemented, it will be completed during the summer 2006.
- Phase 4 is in design process, hope to install it in summer 2007.

RHIC Refrigerator System

- Built initially for the CBA (ISABELLE) project with a capacity of 25 KW @ 3.8K and 55 KW @ 55K (1980).
- It was essentially a Claude cycle that incorporates 10 heat exchangers, 5 expansion stages (with 7 turbine expanders), and 2 cold compressors.
- It works as a refrigerator/liquefier.
- It uses oil flooded screw compressors. 20 first stage and 5 second stage compressors with a total power of 14.5 MW.
- The system was adapted to meet present RHIC load condition i.e
  - Refrigeration 8.2 kW at 4.5K
  - Liquefaction 32 g/sec
  - Shield 25 kW at 55K.

The RHIC Cryogenic System

Cooling Towers
(Waste Energy Dump)

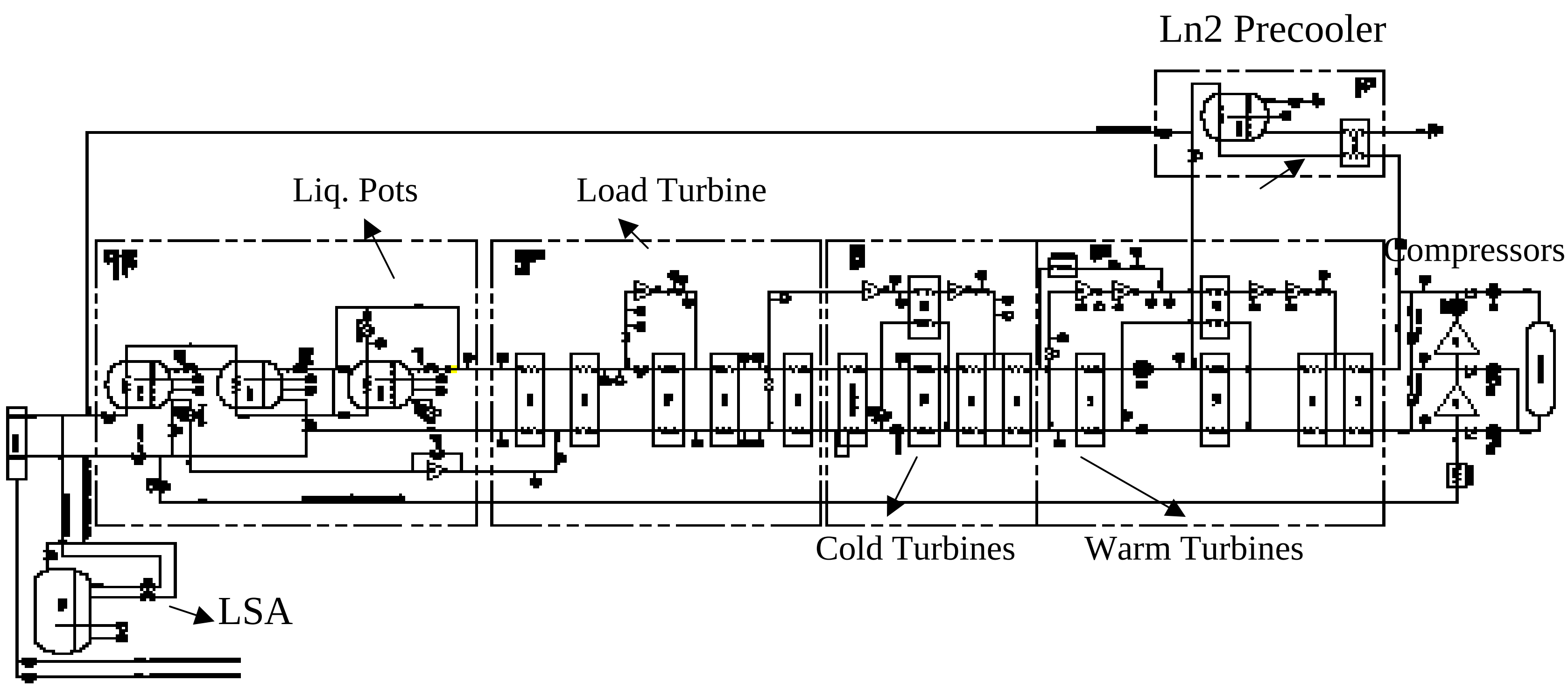
Compressors
(Energy input)

Turbines
(Refrigeration Production)

Cold Boxes
(Heat Exchangers – Energy Exchange)

RHIC
(Load)

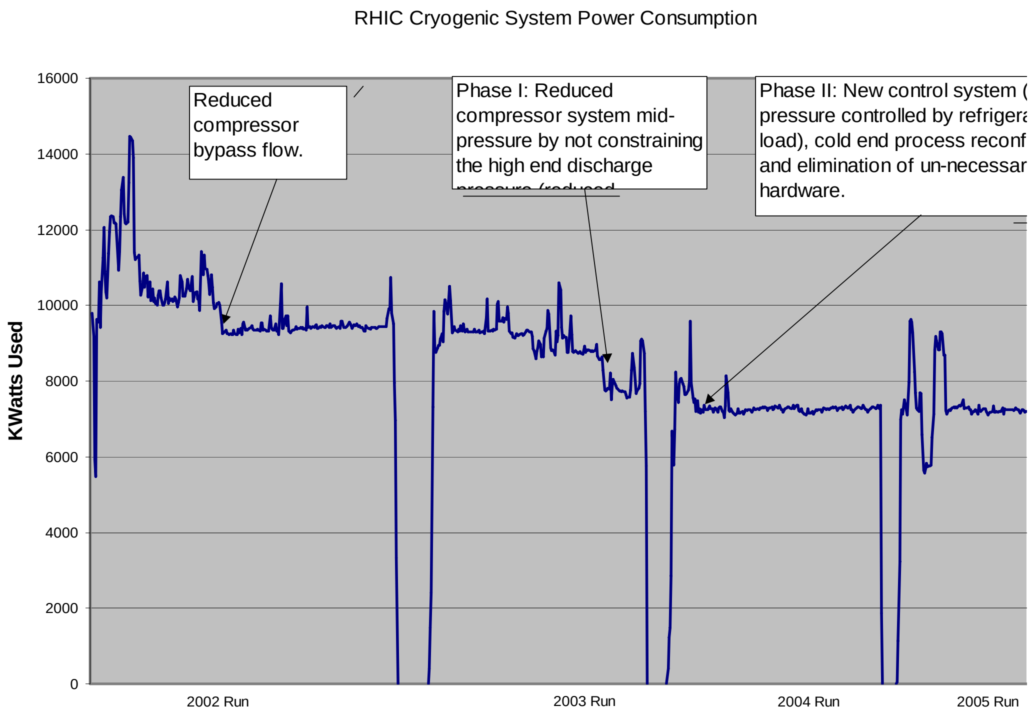
Process Flow Diagram for Upgraded RHIC Plant



Phases I & II Upgrades

Phase I and II addressed the largest effect for the minimal cost plant modifications which resulted in increased reliability and stability with immediate operating cost savings for the cryogenic plant.

- Included a new process control philosophy and oil removal modifications.
- No new components added to the system.
- Reduced the total compressor power by 2 MW (22% of total).



Phase III Upgrade

Phase III Consists of Further Improving the Efficiency and the Reliability of the RHIC Cryogenic System.

- Load (wet) turbine and heat exchanger system to the cold end of the last cold box for efficiency improvement of the plant. (Focus of this paper)
- Re-configure the helium supply to eliminate the use of the cold circulators in the accelerator rings.
- Modify Cold Box 5 to Reduce Helium inventory and flow restrictions

Phase IV Upgrade

Phase IV Consists of Further Improving the Efficiency and the Reliability of the RHIC Cryogenic System.

- Cold Expander Train (5/6) Upgrade for Efficiency Improvement of the Plant.
- Improve the quenching handling and inventory handling capabilities by integrating the Liquid storage (LSA)

Work Plan For Phase III

1. Thermal process analysis of the present RHIC system to identify the changes necessary to meet the RHIC cryogenic loads with increased efficiency.

2. Develop a specific work scope document that addresses and outlines the physical changes necessary. (June 2005 Project Review).

3.Size and specify the required system components.

4. Develop the technical equipment specifications for procurement of the components.

5. Procure components via competitive bid.

6. Install and commission new systems.

STATUS OF PHASE III UPGRADE

- Modify cold box 5 to reduce flow restrictions.
  (Completed in Summer of 2005)
- Eliminate the use of two helium dewars and re-insulated the 3rd. (Completed in Summer of 2005)
- Re-configure the helium supply to eliminate the use of the cold circulators in the rings. (Completed in Summer of 2005)
- Add load turbine expander and heat exchanger system to the cold end of the last cold box.

  (New hardware being built, will be installed in Summer of 2006)
- Add a quench recovery system by integrating the helium dewars. (Summer 2007)

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Cold Circulators By pass

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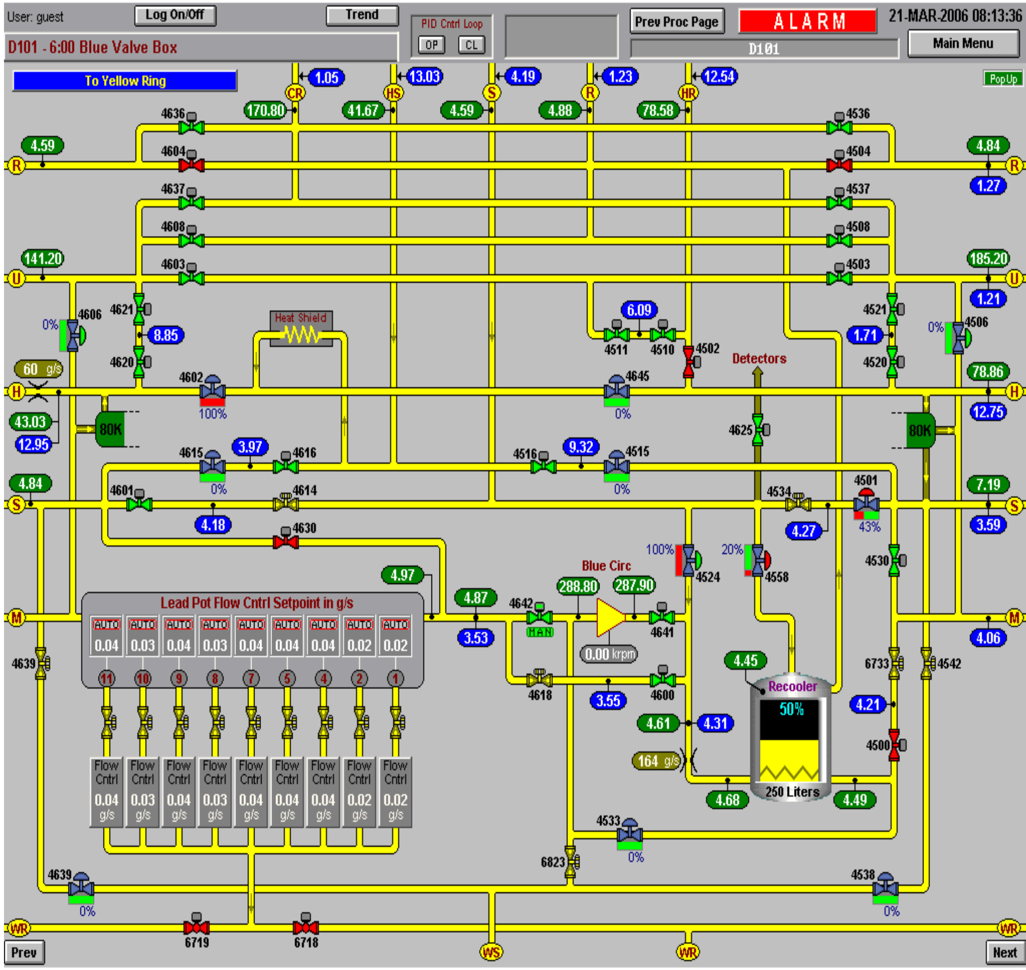
- Increased flow thru magnet lines from:

~120g/sec (last year) to

~170 g/sec (this year)



- Reduced average magnet temperatures by almost ~ 60 mK

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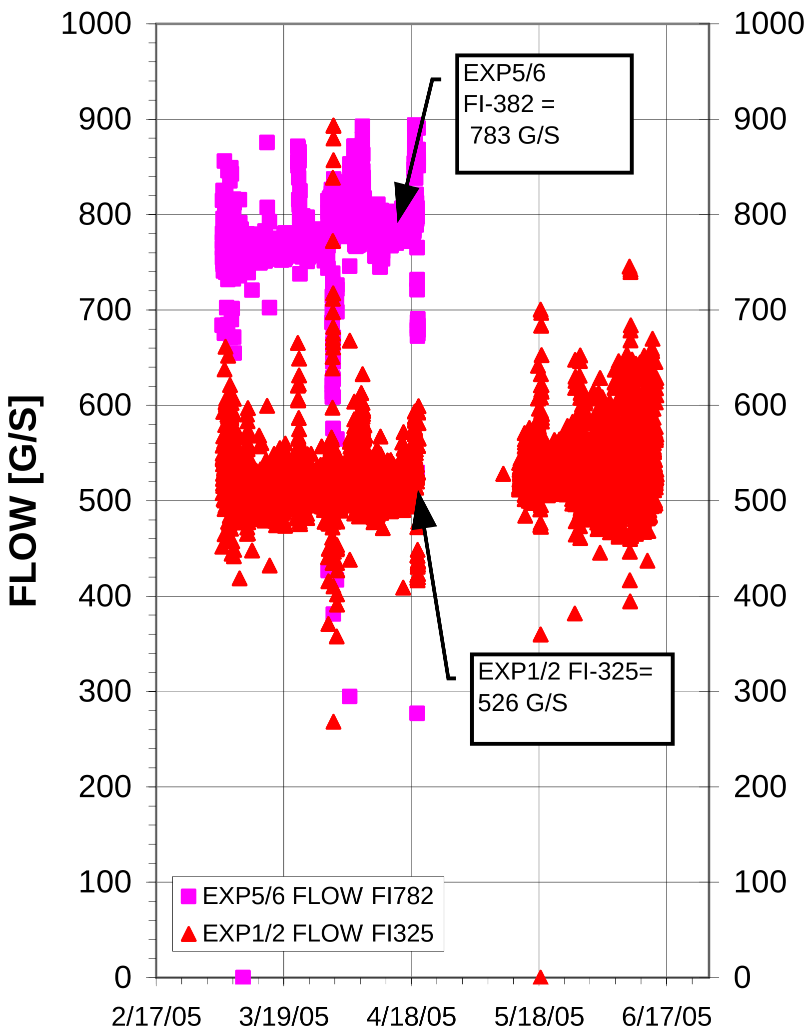
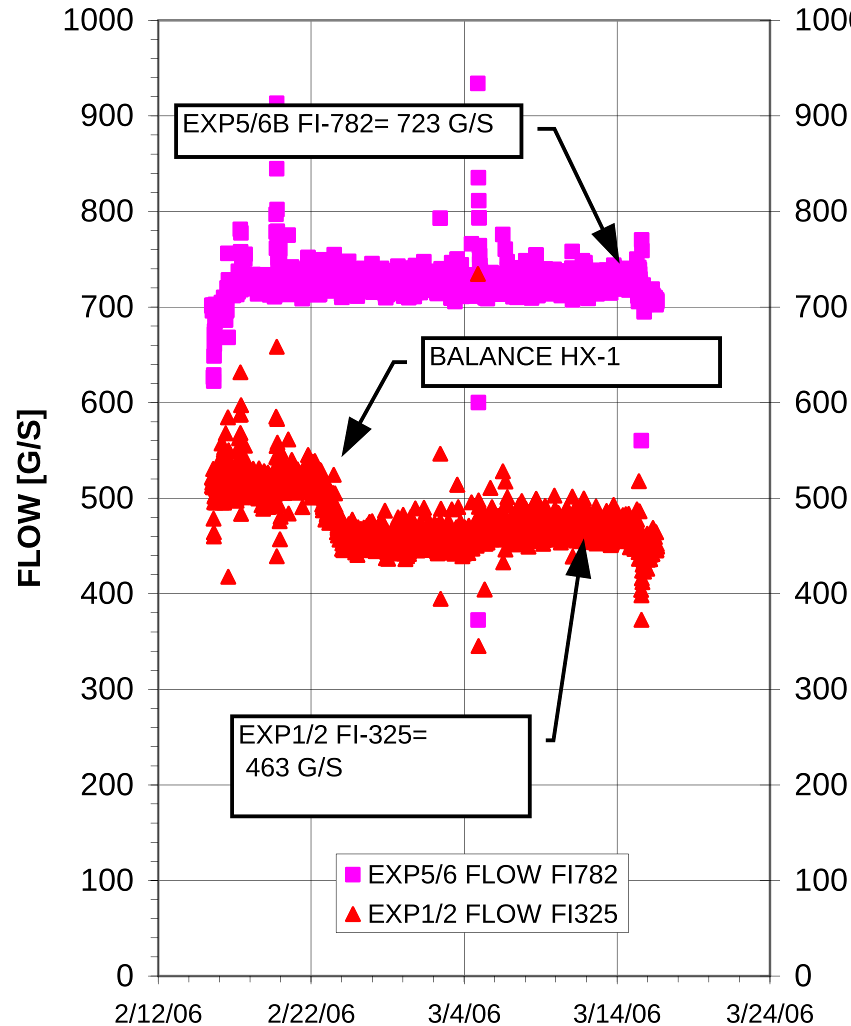
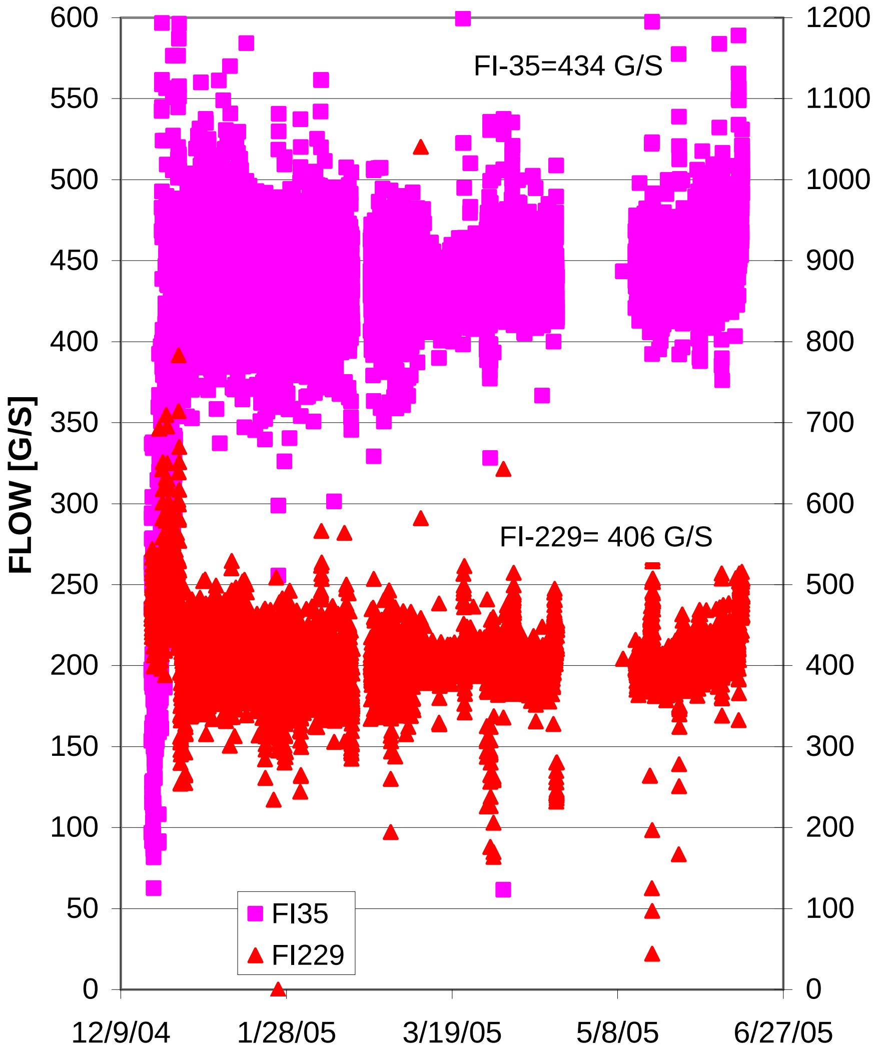
FY' 2005 RUN
Expander Flows



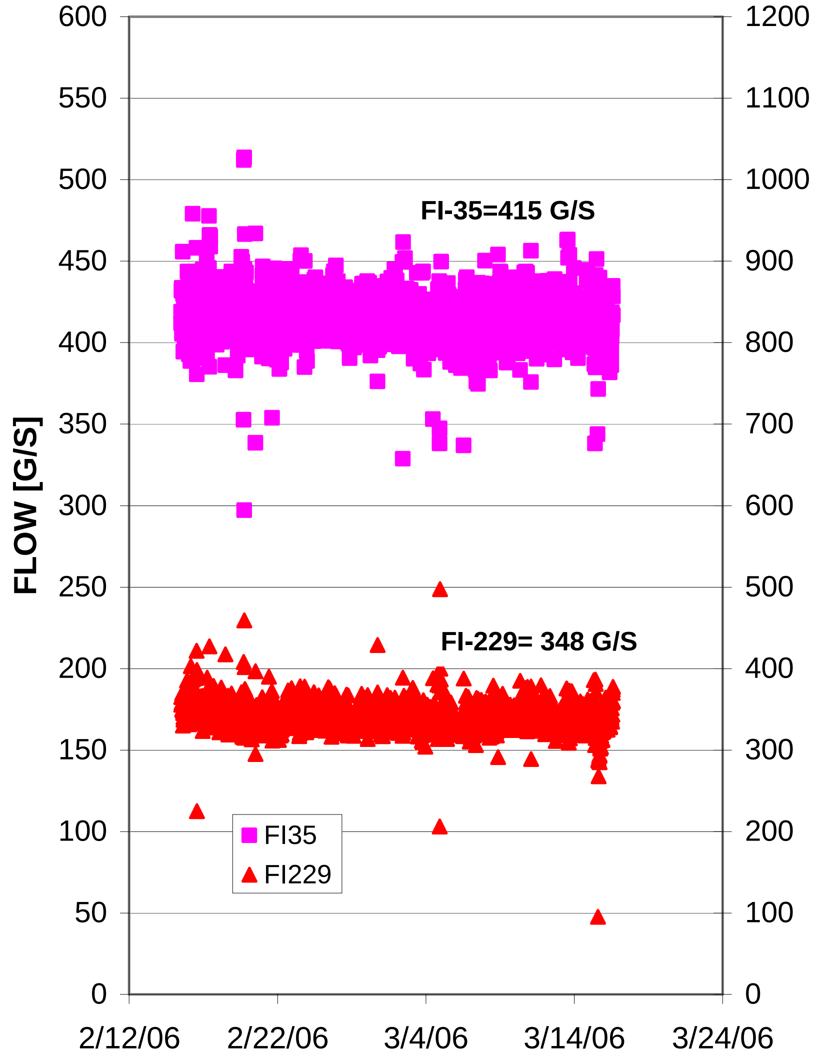
FY' 2006 RUN
Expander Flows

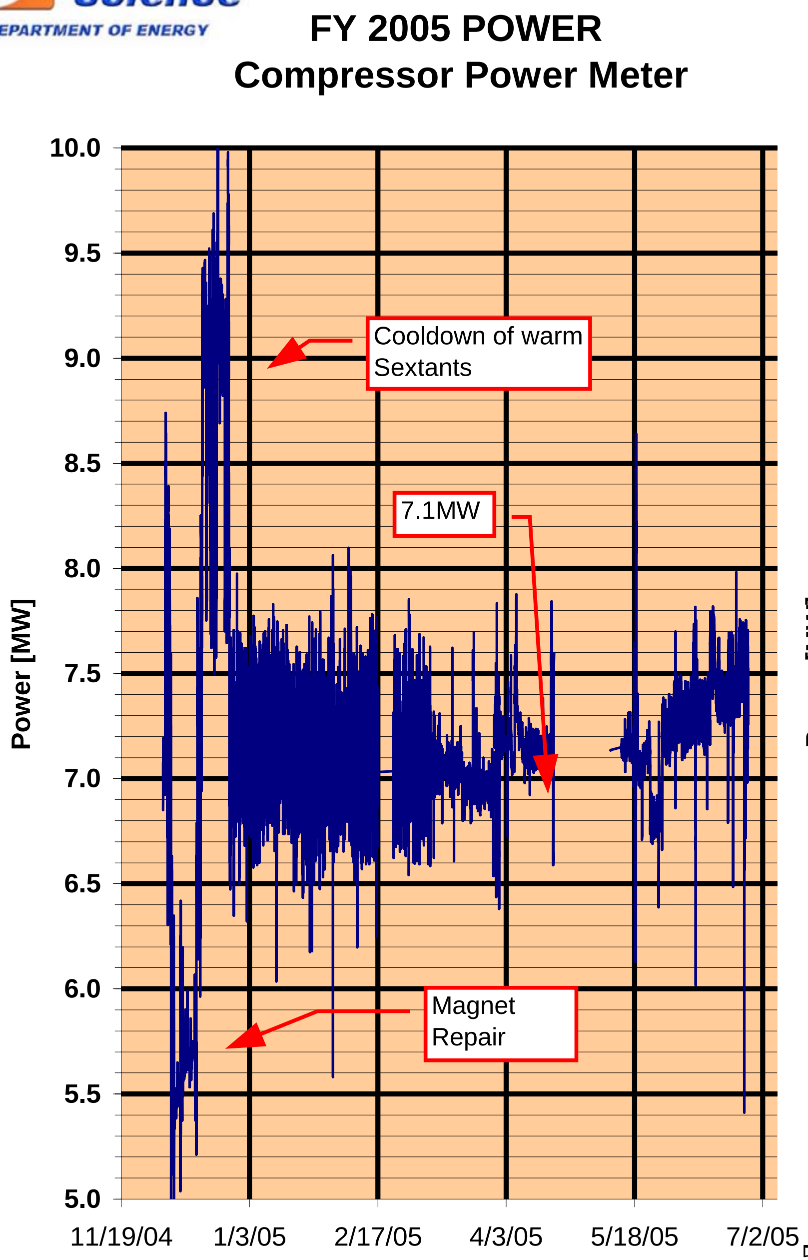


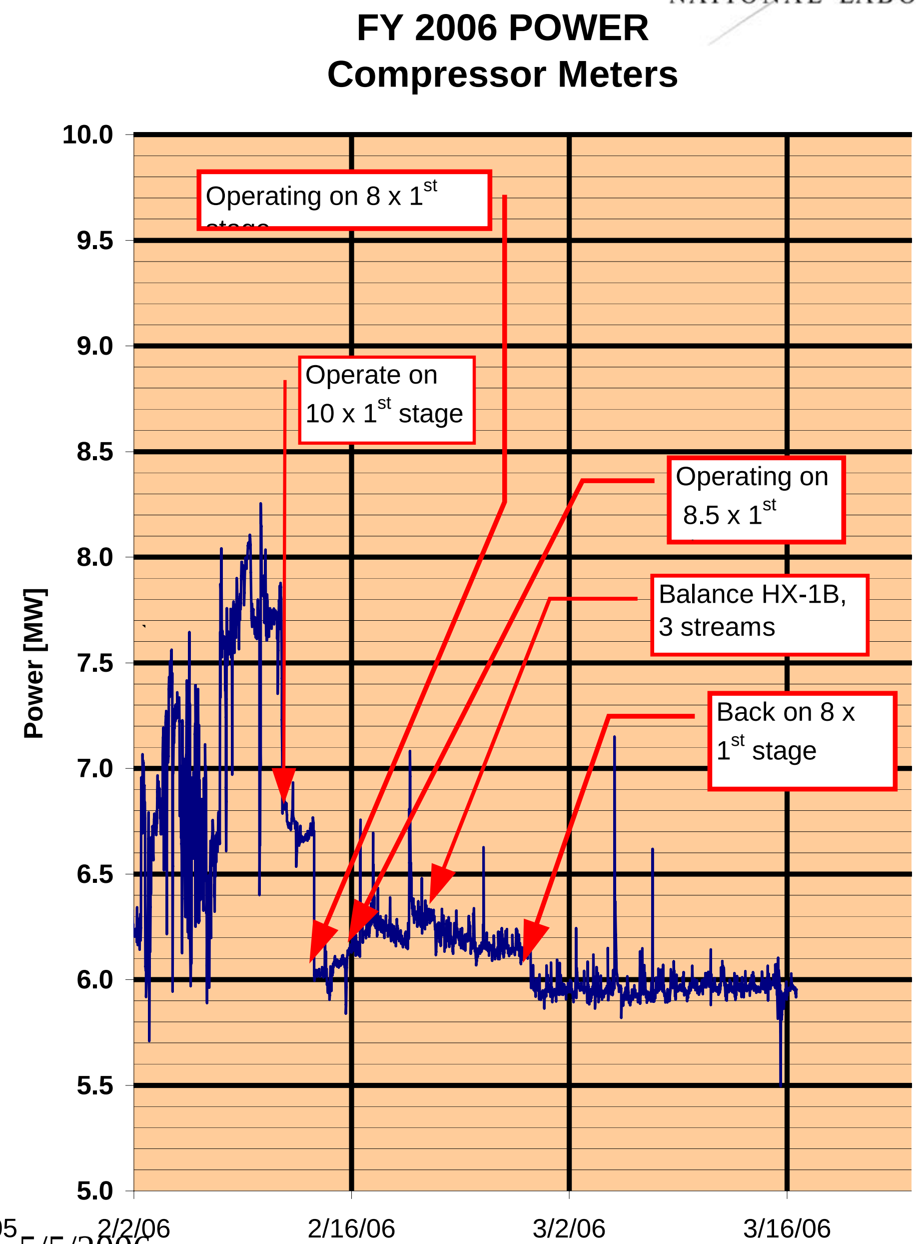
FY' 2005 RUN Cold End Flow Load flow + JT Flow



FY' 2006 RUN Cold End Flow Load flow + JT Flow




FY 2005 POWER
Compressor Power Meter
Cooldown of warm Sextants
7.1MW
Magnet Repair
Power [MW]
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
11/19/04
1/3/05
2/17/05
4/3/05
5/18/05
7/2/05


FY 2006 POWER
Compressor Meters
Operating on 8 x 1st stage
Operate on 10 x 1st stage
Operating on 8.5 x 1st
Balance HX-1B, 3 streams
Back on 8 x 1st stage
Power [MW]
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
2/2/06
2/16/06
3/2/06
3/16/06

RESULTS FROM SUMMER 2005 MODIFICATIONS

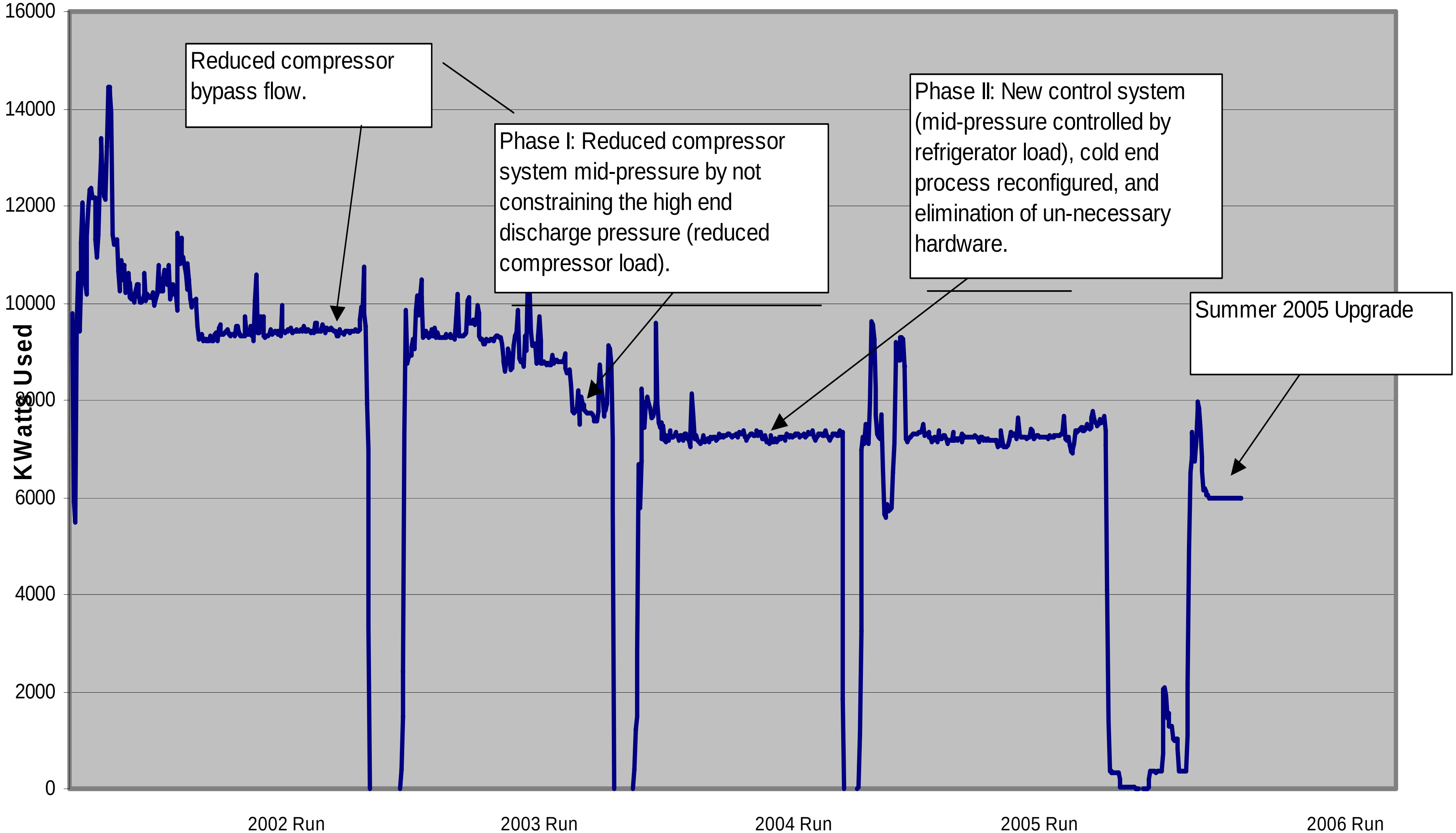
- **Saved another 1.1 MW of compressor input power.** (Total of 3.2 MW achieved to date).
- **Improved reliability.** (Eliminating the need for the cold circulators and reduced running compressors from 13 to 11 this year).
- **Improved Safety**. (Less liquid inventory in the refrigerator and insulating the mid-pot in cold box 5).
- **Operating the accelerators rings at lower pressure** (from 5 atm to 4.2 atm) **resulted in:**

Improved efficiency ***Increased the stability***

Reduced helium leaks ***Improved beam Quality***

Long Term

RHIC Cryogenic System Power Consumption Progress



Addition of a Load Turbine System

- Increase overall plant efficiency by adding a “load” or “cold” end turbo-expander.
  - Expand from high pressure (16-13 bar) to 4.2 bar.
    - Collider minimum operating pressure of 3.5 bar in the magnet cooling loop + 0.5 bar magnet loop pressure drop.
- Reduction in cold end flowrate, and therefore compressor flow.
- Reduction in recycle flows of other expander trains because of the decrease in overall flow.

1St Level Evaluation Of the Plant For the Load Turbine Upgrade

General philosophy of what changes to implement:

- Plant operating with four Carnot Steps; **i.e., 1st: HX-1 to 4 & T1-4 and 2nd: HX-5 to 8 & T5/T6**
- Add a 5th Carnot step using a load turbine stage (T7), extracting work at the coldest (practical) temperature.
- Estimate based on improving the cold end of plant based on a Carnot analysis gives at least 1 MW reduction in power.
- This 1st level evaluation did not consider factors such as heat exchangers (UA) and turbine turndown performance.
- Actual plant was characterized for better prediction and sizing of upgrade components

Plant Characterization & Upgrade Model

Purpose of Plant Characterization:

- Predict how subcomponents perform over operating range.

Including at lower capacity/flows expected after upgrade.

- Confirm plant load - Collider He flow requirement.

- Determine best operating point for new components.

Size T-7 Load Turbine (fixed nozzle) and heat exchangers.

- Predict Future Power consumption

with T-7 Load Turbine upgrade and with future T5 and T6 upgrade

Thermal Studies

- Established the new operating pressure and load (refrigeration capacity) requirement for the rings.
- Bench marked all the refrigeration system major components.
- Established a cycle model for the present plant and developed correlations under present performances of major components.
- Established a cycle model for the upgraded plant that incorporate projected performances of major components under improved system efficiency.
- Established the system efficiency improvement(s).

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Load Turbine System

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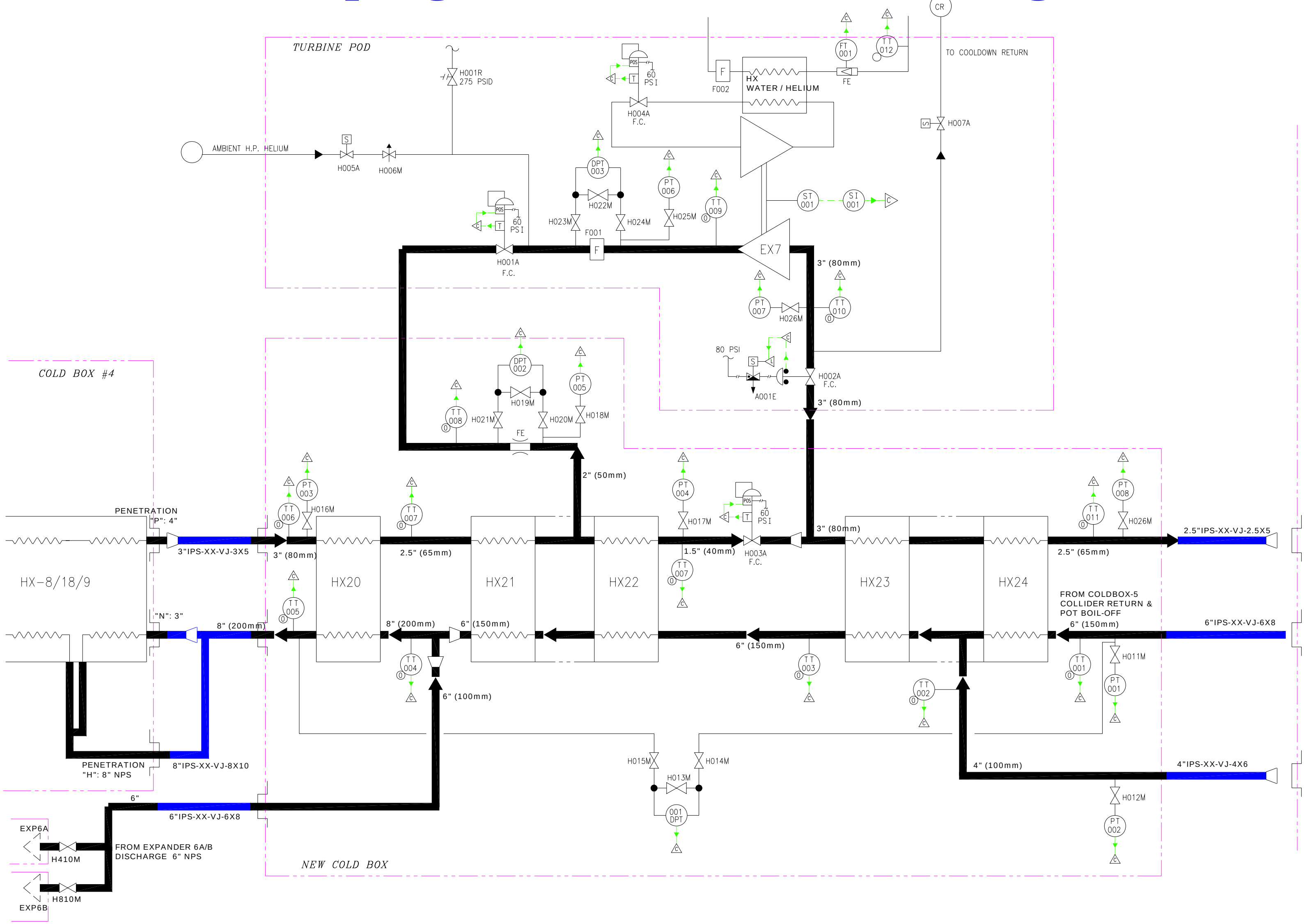
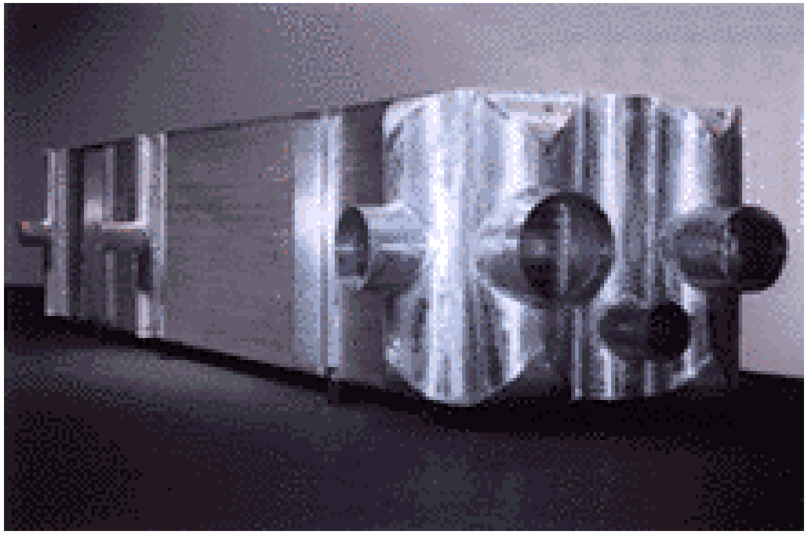
Piping & Instrumentation Diagram

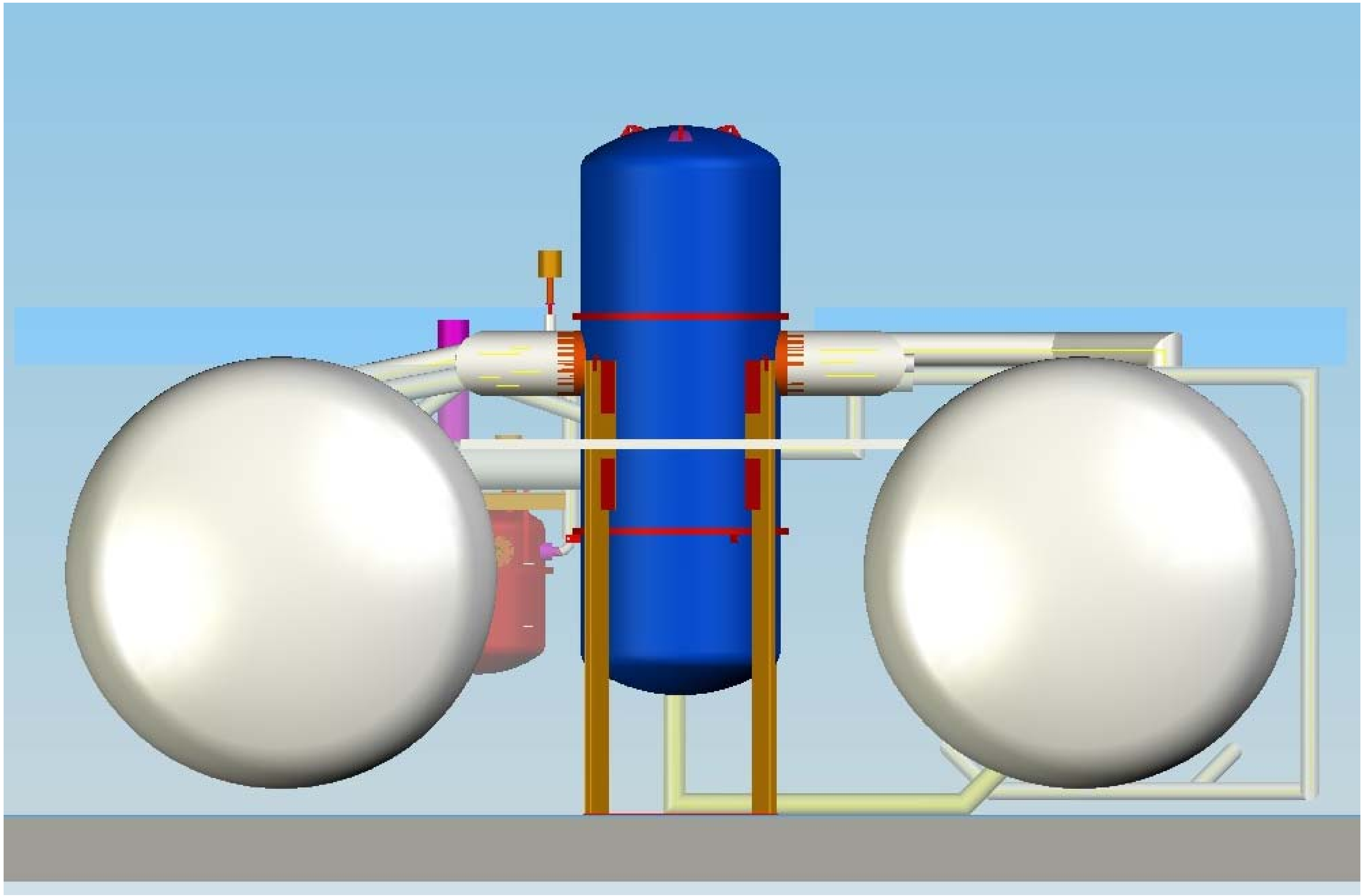


Heat Exchanger Cold Box Section

- Brazed Aluminum Plate-fin Heat-exchangers
- Vacuum brazed
- Oriented Vertically



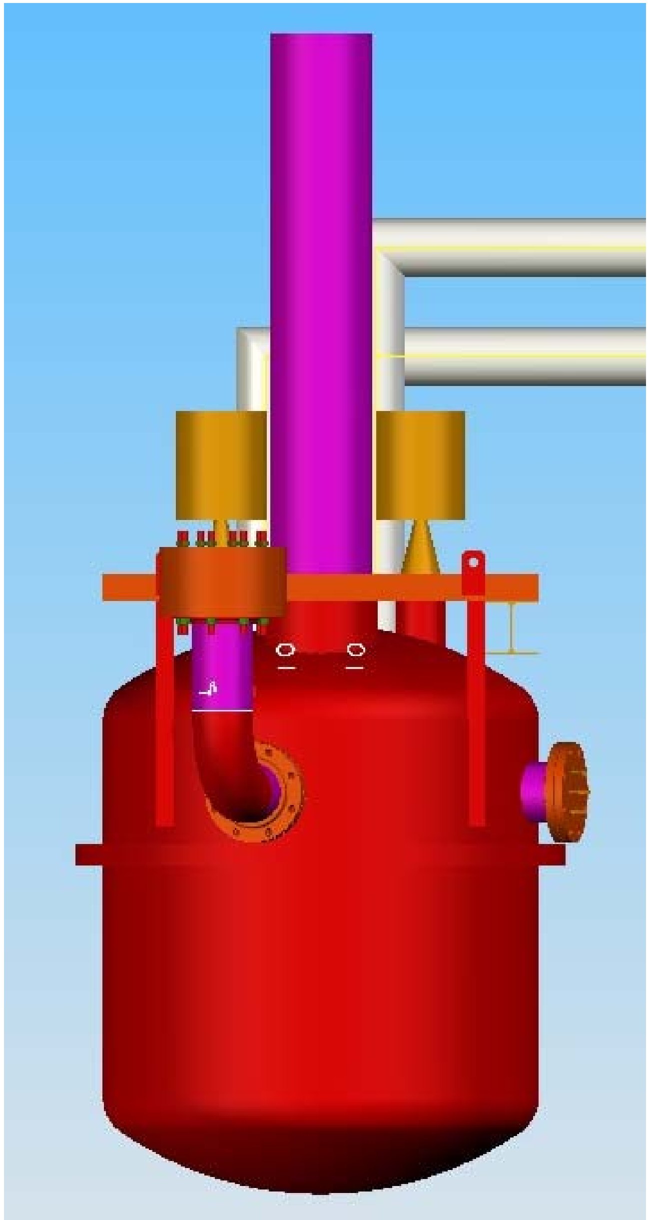
New Cold Box Location

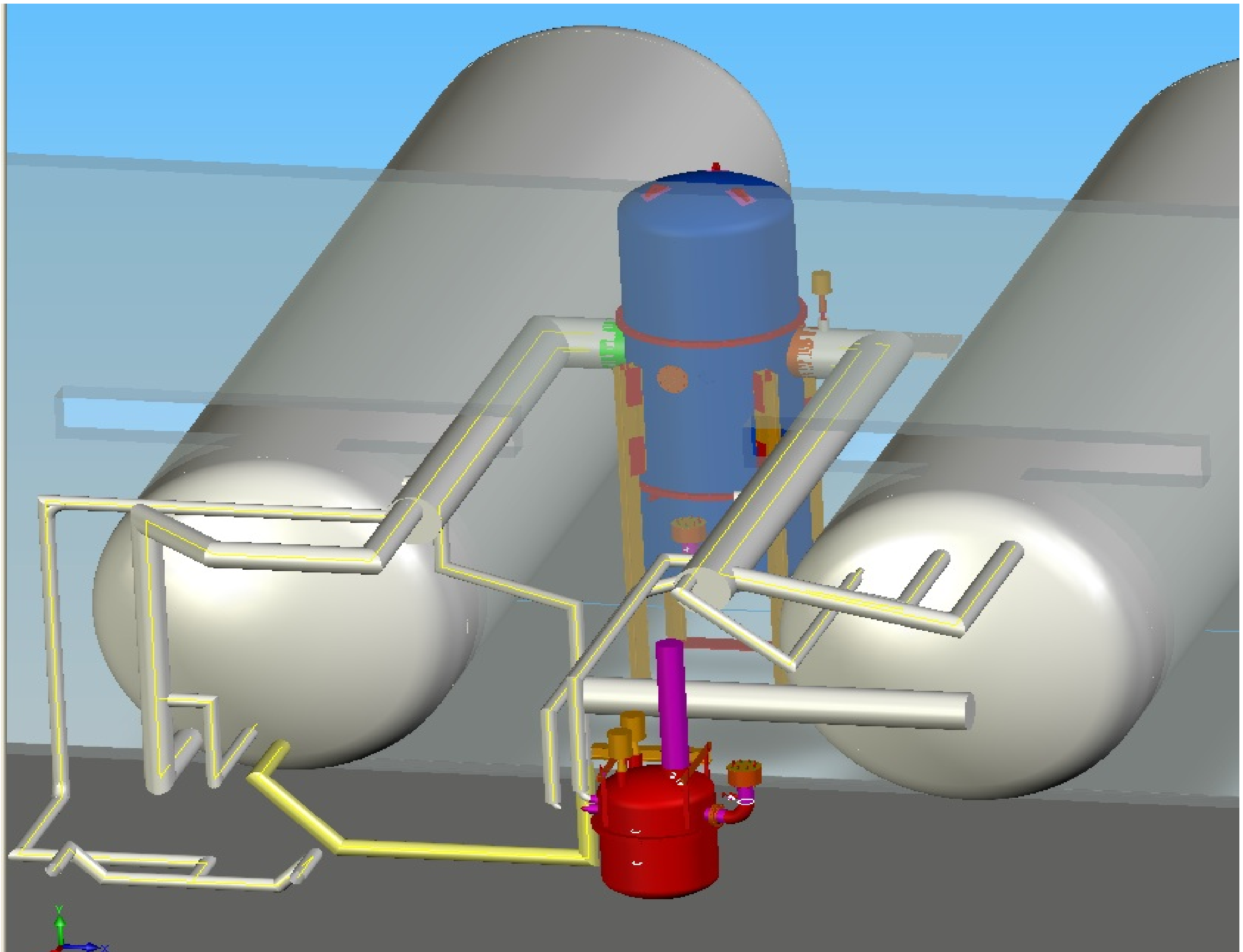


New Cold Box Location:
2006 summer shutdown

Turbine Pod

- Gas Bearing Turbo Expander
- Fixed Nozzle
- Brake End: Gas turbo-compressor





Summary

- Characterized the main components in the plant.
- Developed a plant-process computer model based on actual component characteristics to predict the present and the upgraded plant performance.

We expect the following additional power reductions:

- Load Turbine ~ 1.0 MW
- Load Turbine + Improve Cold Turbines ~ 1.5 MW

  (Further testing is needed to confirm this)
- New equipment installation in the 2006 summer shutdown.

Phase IV to Follow