Cryogenics
@
JLab

By

JLab Cryo Group

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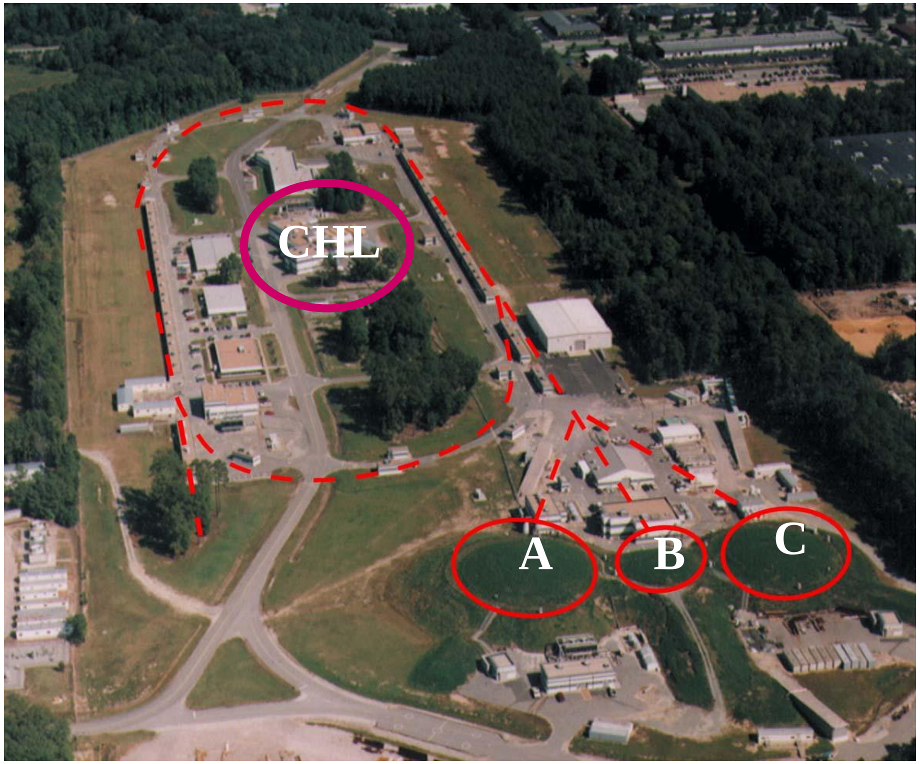
Outline

- JLab Overview
- What is Cryogenics?
- Applications of Cryogenics
- Temperature Choice for Jlab Linacs
- Overview and Operation of Jlab cryogenic plants
- Down Time
- Utility Costs
- Other cryogenic group activities
  - Education and R&D
  - Support to other Labs
- Summary

Jefferson Lab Overview

2000 member international user community engaged in exploring quark-gluon structure of matter

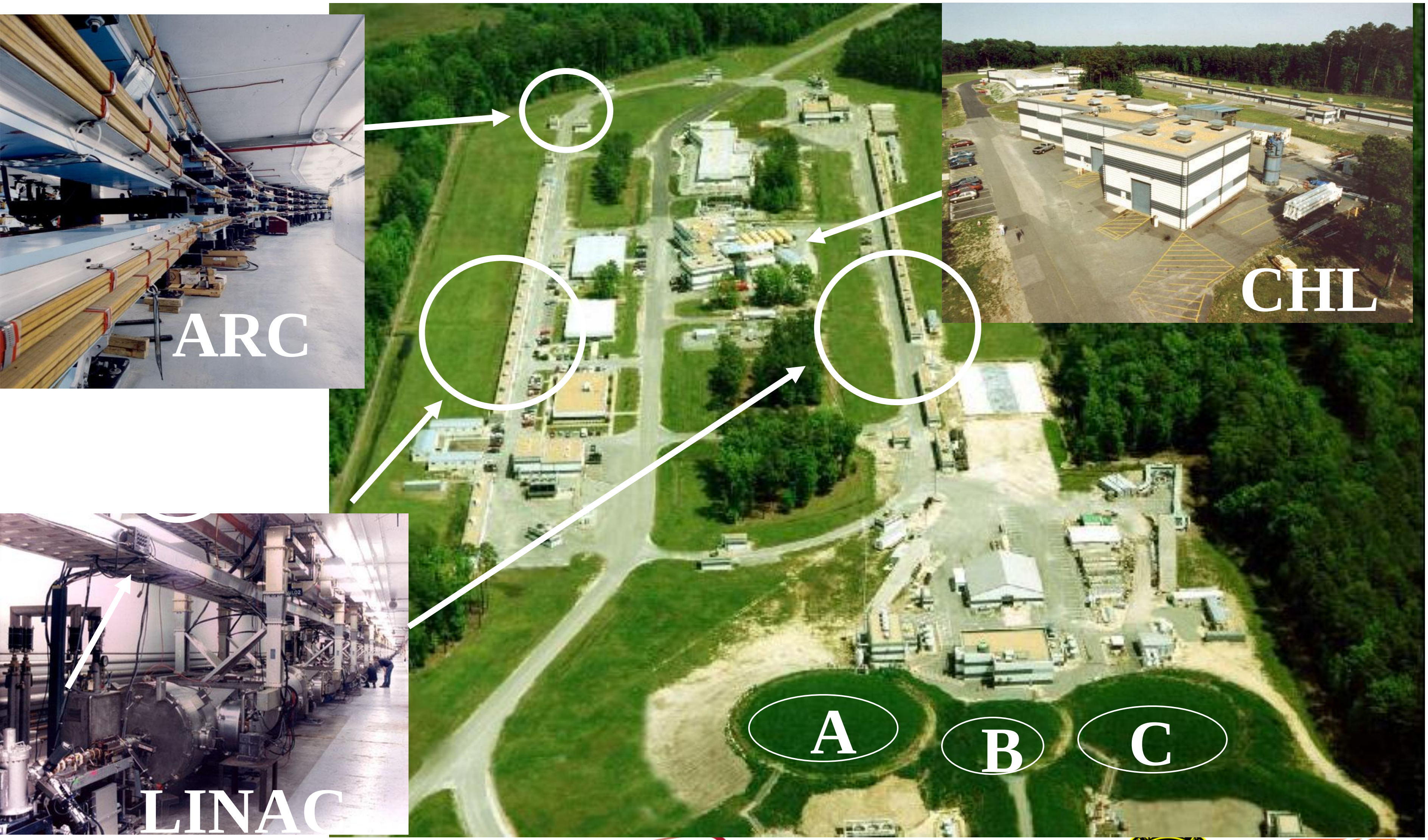


Superconducting accelerator provides 100% duty factor beams of unprecedented quality, with energies up to 6GeV and in future to 12GeV

CEBAF's innovative design allows delivery of beam with unique properties to three experimental halls simultaneously

Each of the three halls offers complementary experimental capabilities and allows for large equipment installations to extend scientific reach

JLab Site Overview



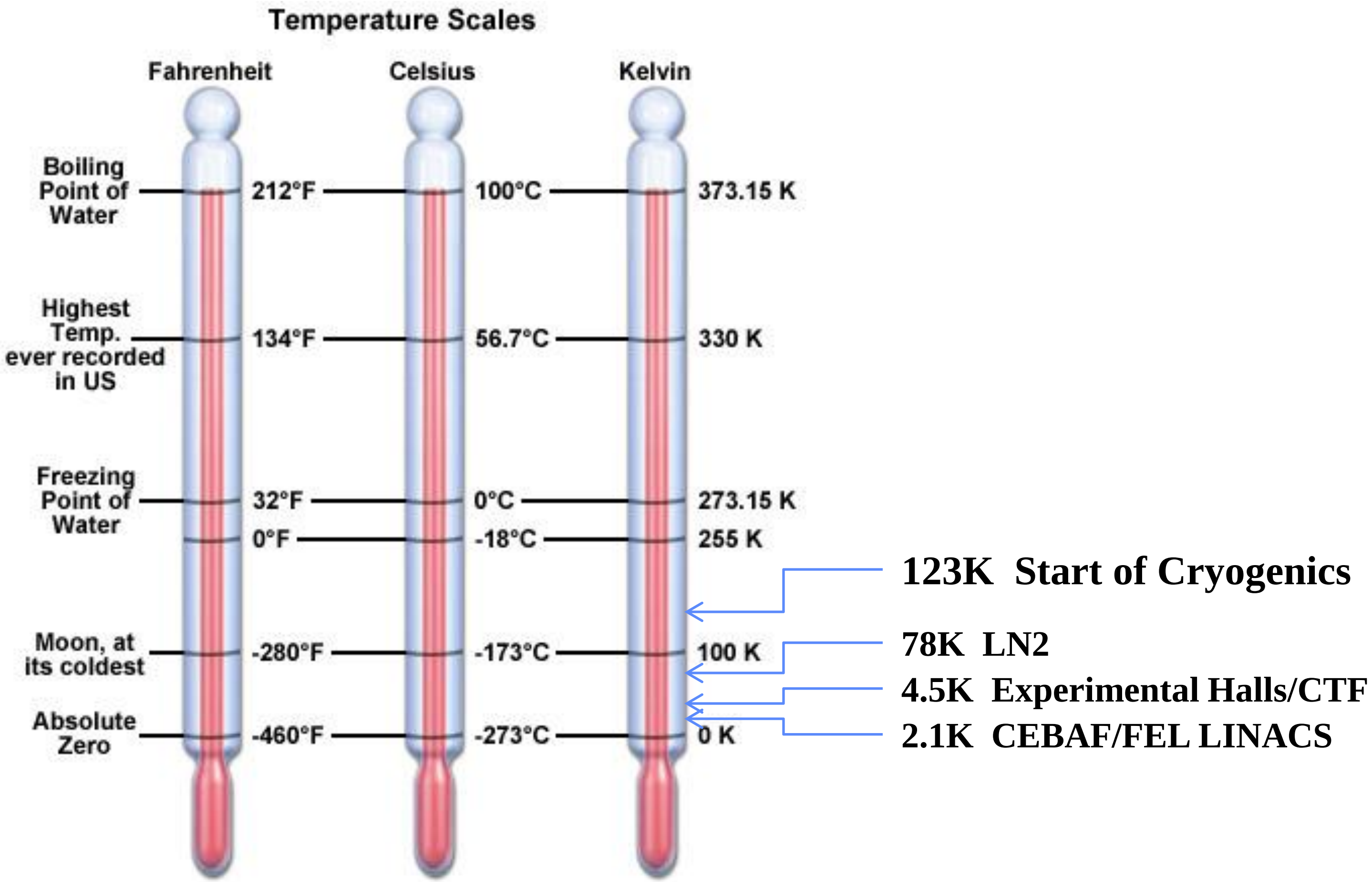
What is Cryogenics?

The production of temperature below 123 K (-150 °C)

Examples of Cryogenic Fluids

Cryogenic Fluid	T_{sat} @ 1 atm
	[K]
Helium	4.22
Hydrogen	20.28
Neon	27.09
Nitrogen	77.31
Argon	87.28
Oxygen	90.19
Methane	111.69

Temperature Scale Comparison



Applications of Cryogenics

Cryogenics was primarily used for

- Gas separation

Helium was first liquefied by Heike Kamerlingh Onnes on July 10th 1908, in Leiden (NL)

Onnes observed superconductivity in 1911 (100 Years ago!)

This lead to the application of Cryogenics to:

- Physics research
- Medical Applications (MRI Magnets)
- Instruments

Other applications are:

- Biological & Medical
- Space research
- Vacuum

Applications of Cryogenics

Superconductivity:

No resistance below a critical temperature

This allows:

(a) Low temperature super-conductors (below 20 K) used for magnets and RF cavities

(b) High temperature super-conductors (around 70 K Level) used for power leads

All these need Cryogenics

Applications of Cryogenics

Particle Accelerators use magnets and RF cavities

At room temperature the iron core saturates at about 2 T, where as the magnets built with super conductors can be designed for large magnetic fields like 10 T and more and are compact

High frequency (~100 MHz to 3000 MHz) RF cavity designs *typically* use low temperature environment for efficient and high quality beam operation although there are exception like room temperature RF used from AM radio, under 1 MHz, to 11.4 GHz

For a given energy, the accelerators designed with superconductors require:

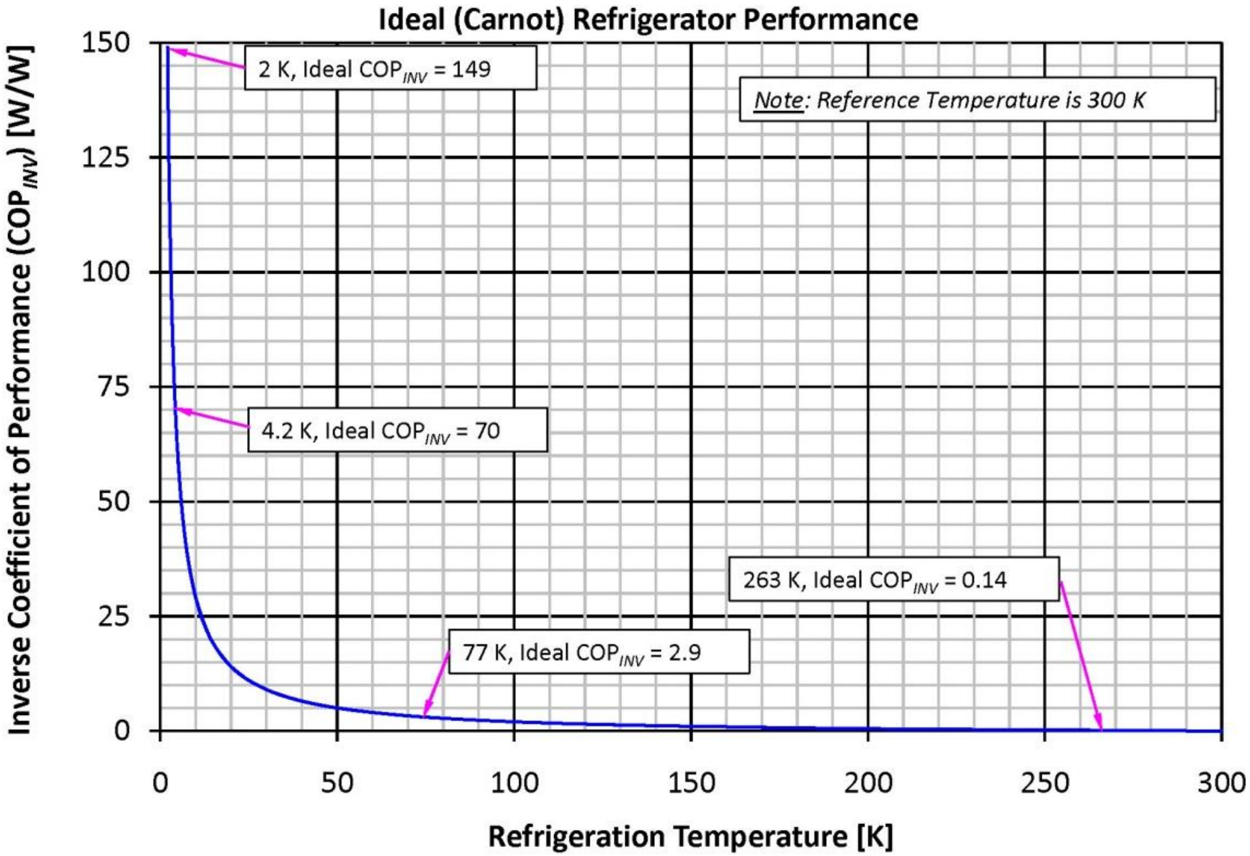
- **Lower capital cost**
  - **Since it requires fewer number of magnets and/or RF cavities**
  - **Less length of the accelerator**
- **Lower operating cost**

There fore for large accelerators, superconducting structures at cryogenic temperatures are a proven and cost effective

All large particle accelerators need Cryogenics

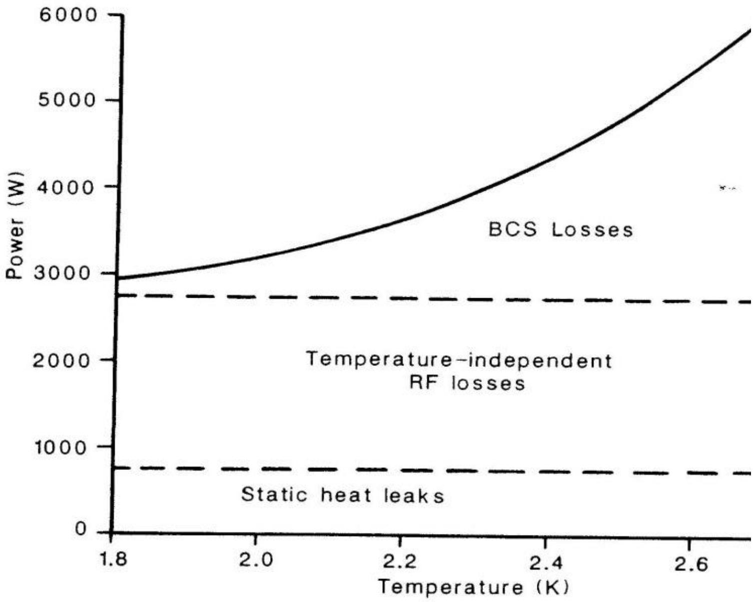
Carnot Work Required at Various Temperatures

Ideally (Min.) Required input Power per 1 W of Cooling (W/W)

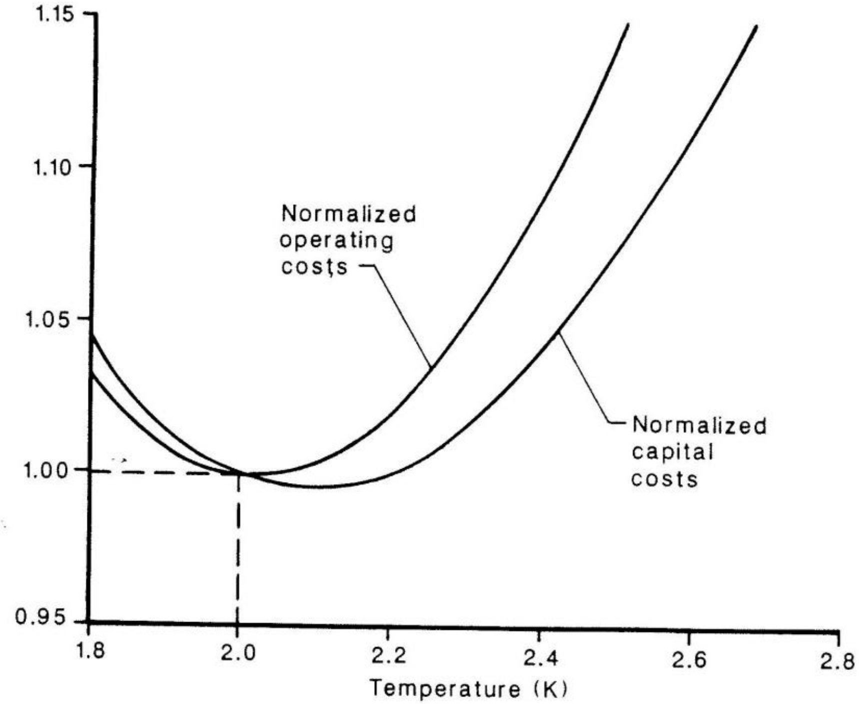


	T_load	Pcarnot
	(K)	W / W
A / C Sys.	263.0	0.14
Methane	111.7	1.69
Oxygen	90.2	2.33
Argon	87.3	2.44
Nitrogen	77.3	2.88
Neon	27.1	10.07
Hydrogen	20.3	13.79
Helium	4.2	70.09
Helium @Lambda	2.2	137.25
Helium @ 2.0 K	2.0	149.00

Operating Temperature Choice for CEBAF



Total heat load as a function of temperature.



Normalized refrigeration costs.

Ref. CEBAF Design Report May 1986

JLab Cryogenic Group Activities

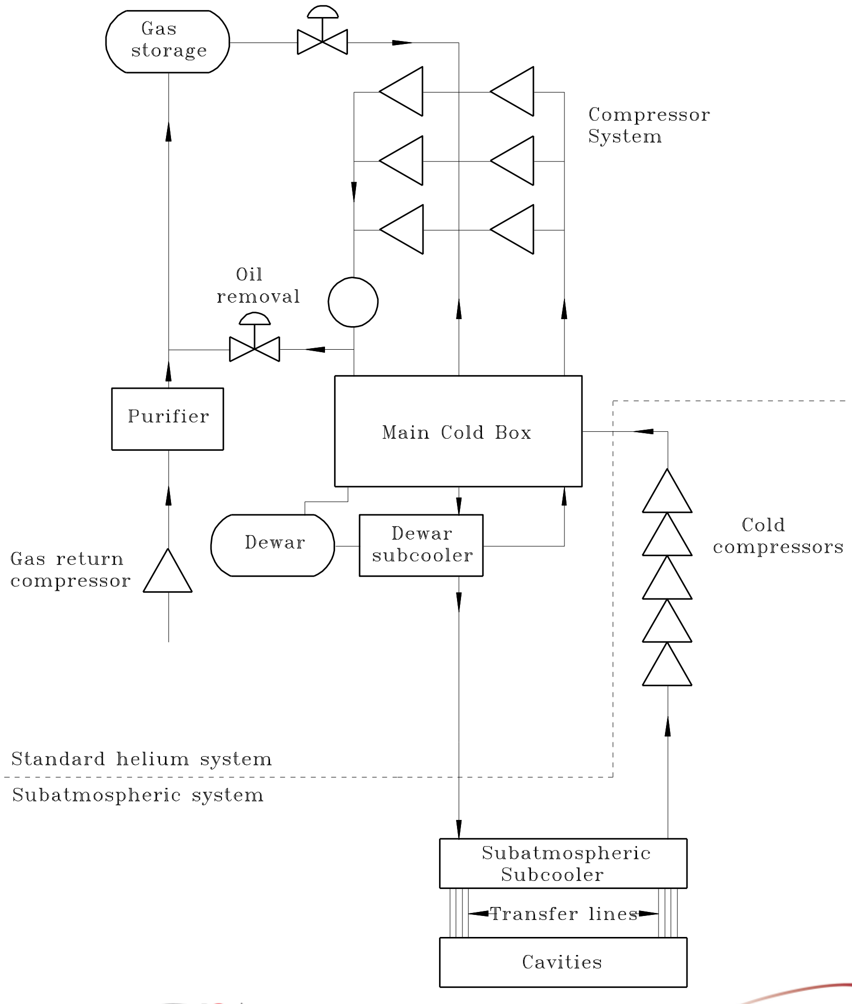
- **Operate existing plants**
- **Design new systems for JLab**
- **Design new systems for other labs**

    e.g., MSU, SNS, NASA, etc.
- **Optimize the operation of existing systems for JLab and other labs**

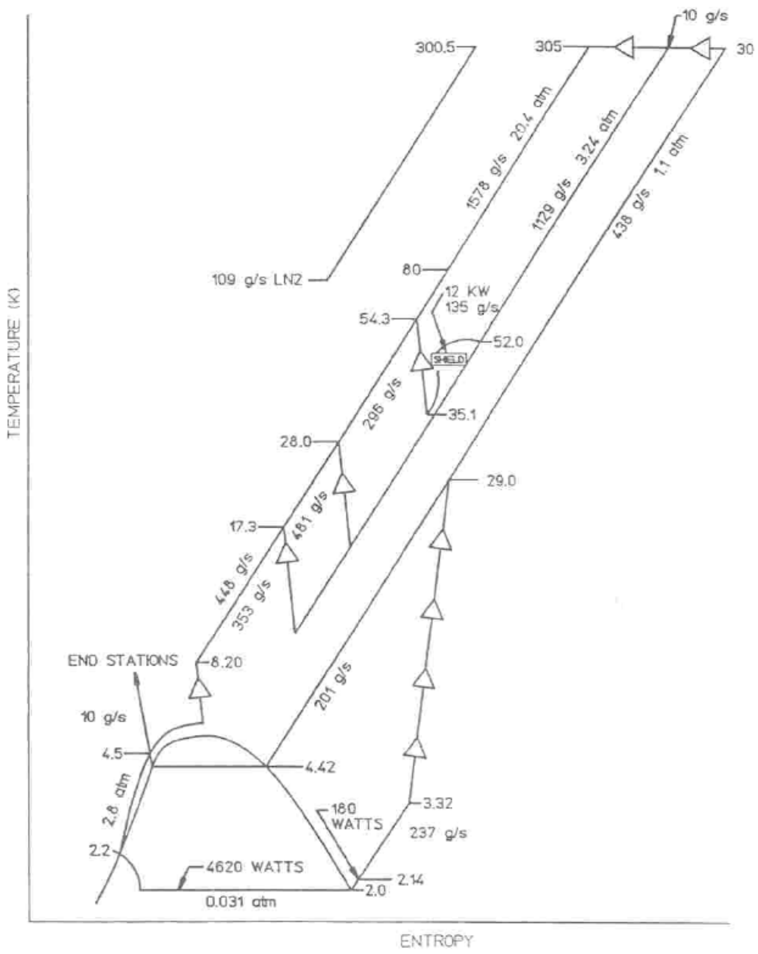
    e.g., MSU, SNS, BNL, NASA, etc.
- **Support cryo R & D**
- **Support education**

Operation of the Helium Refrigeration System

Central Helium Liquefier (CHL) at JLab



Original Design TS Diagram



Operation of the Existing Plants

- **Operate existing plants**

CHL	4600 W	@ 2.1 K (Accelerator)
ESR	1500 W	@ 4.5 K (Experimental Halls)
CTF	750 W	@ 4.5 K (Test Facility)

Support the Continuous unattended operations

24/7/365

2 K operations started in 1994

Only once LINAC has been warmed up to date

–Hurricane Isabel in 2003

Operation of the Existing Plants

- **Maintain the equipment**
  - e.g., compressors, motors, vacuum pumps, turbines etc.
- **Coordinate the maintenance activates on utilities**
  - e.g., cooling tower, electric power, etc.
- **Coordinate the LN2 & helium gas deliveries**
- **Modify the equipment configurations**
  - i.e., “U” tube changes
- **Operate the plants at the required capacity and at the optimum operating conditions to meet the needs of the various experiments and the accelerator maintenance plans**

CHL Cryo Plant Capacities

- **Existing CHL #1 supporting current 6 GeV**

  4.6 kW @ 2.1 K,

  12 kW @ 35 K - 55 K and,

  10 g/s liquefaction @ 4.5 K

- **New CHL #2 to support future 12 GeV**

  4.6 kW @ 2.1 K,

  12 kW @ 35 K – 55 K and,

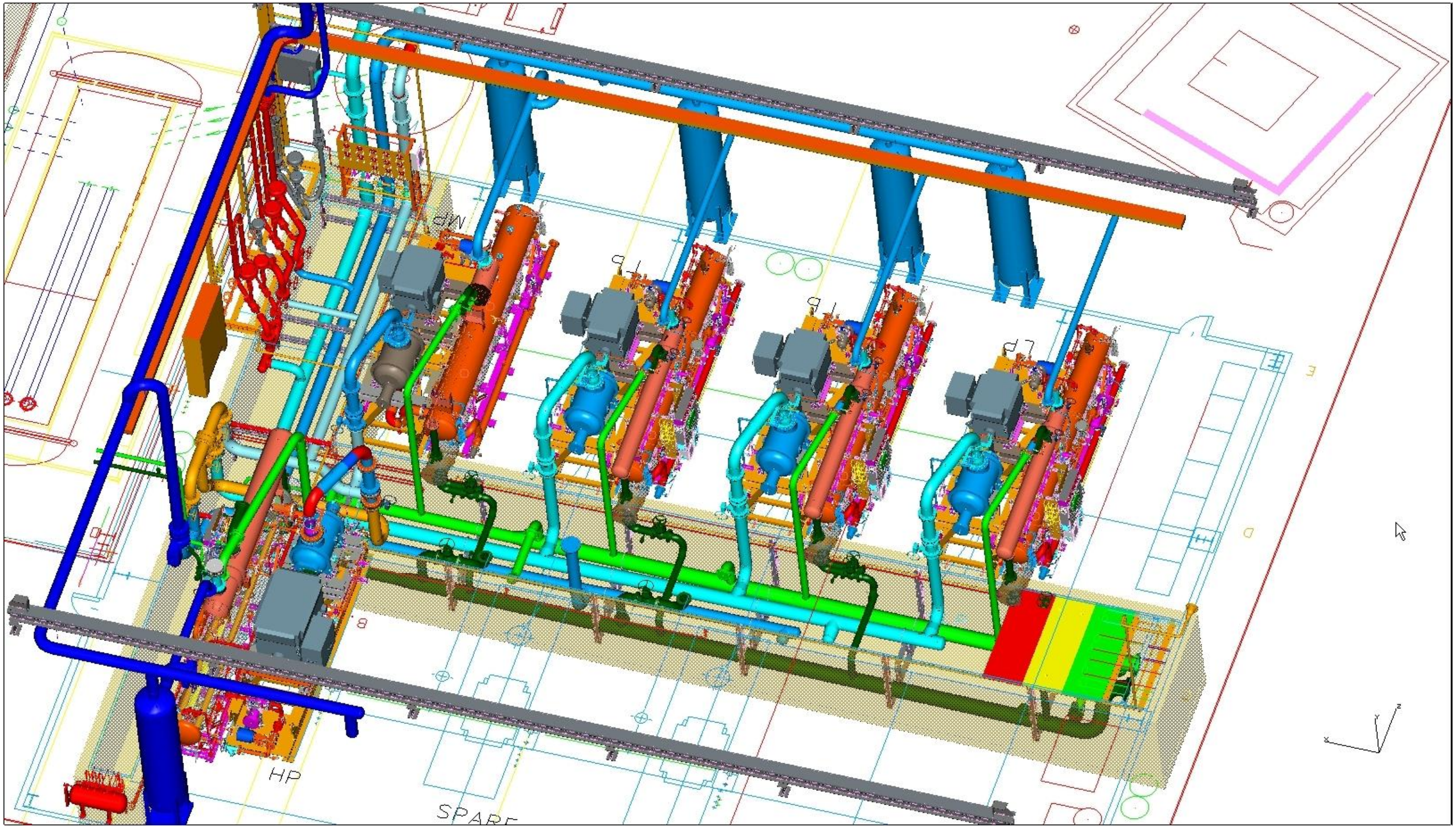
  15 g/s liquefaction @ 4.5 K

  (Presently Under Construction)

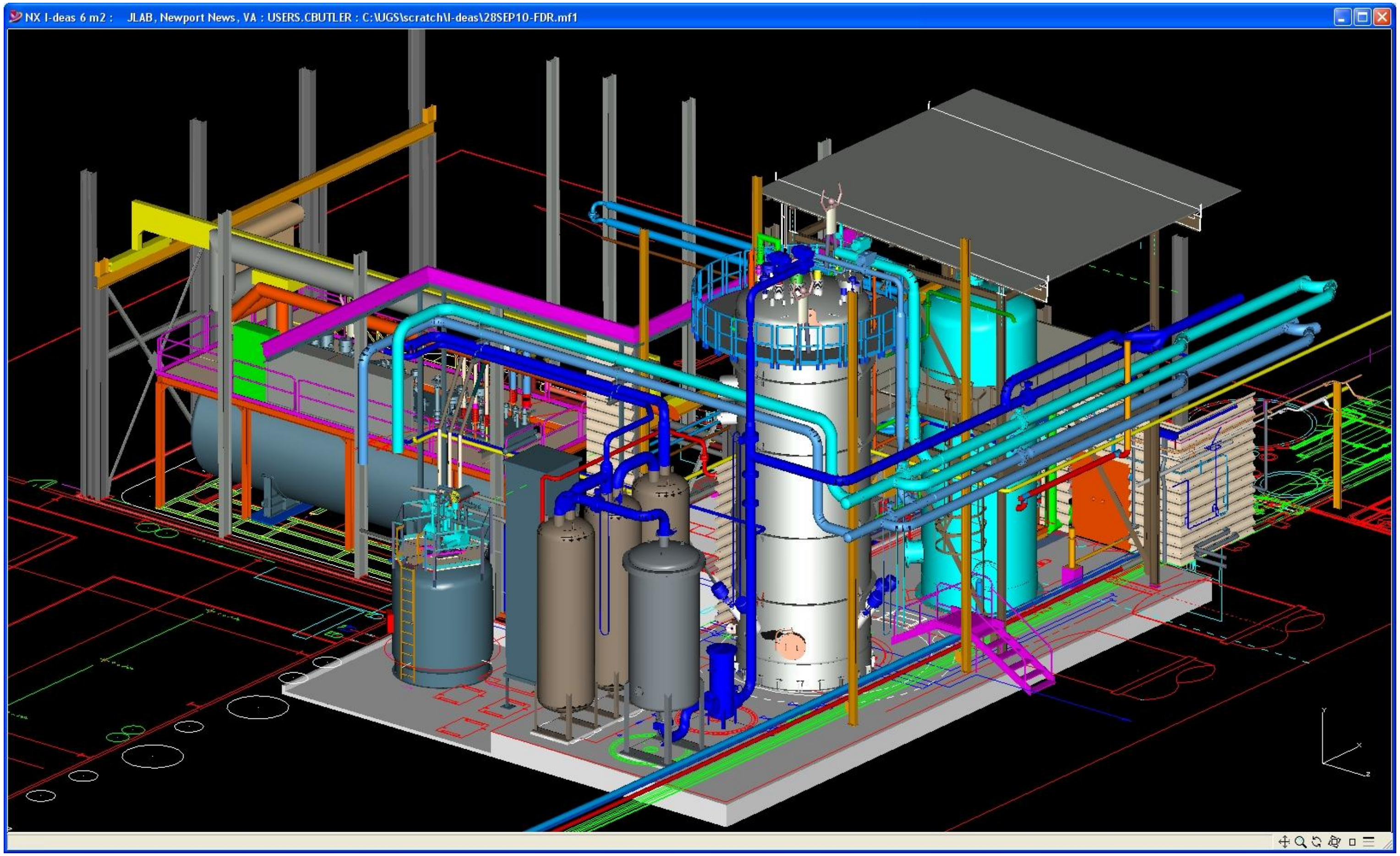
CHL-I Compressor Room

CHL-1 4.5 K Cold Box Installation

CHL-II Compressor Installation Plans



CHL-II Cold Box Installation Plans



Cold Compressors

TORE SUPRA was the first application that used the partial (2 stage) cold compressors for 15 g/s of 2K flow, assisted by warm sub atmospheric compression

CEBAF 2K design is the first one to use all (4 stage) cold compressors for the 2K flow of 235 g/s, which is more than 15 times that of TORE SUPRA, *resulted in substantial growing pains*

CHL-1 (4.5 K & 2 K CBX's)

Original "2 K" (SCM) Cold Box

During the commissioning process Jlab:

- **Added components** (e.g.,HX-9A, etc.)
- **Developed the new pump down process different from the original plans**

- **Cold Compressor - 2.1 K Operations to support CEBAF started in May of 1994**

- **Cryo system reliability & availability of ~75% was not acceptable to JLab operations**

New 2 K CBX (SCN)

Design Improvements:

- Five cold compressor stages in SCN
- Parallel LN2 thermo-siphon motor cooling
- Larger sub-cooler (4K to 2K) heat exchanger (HX-10N)
- Increased volume of inter-stage piping
- Circular inter-stage piping with flow straighteners
- Improved thermal isolation of compressors, valves, etc.
- Improved Ln2 heat shielding and heat stationing on valves and bayonets

2K Cold Box (SCN) Operational Improvements

- **Increased capacity > 10% (~500 W at 2 K)**
- **Increased operating envelope and stability**
- **Pump-down is fast and easy**

- **Commissioned in 3 days**
- **Continuously on-line since June 1999**

- **JLab modifying the original 2 K CBX (SCM) to include all of the improvements made to the SCN**

Present 2 K System Capacity (Using SCN)

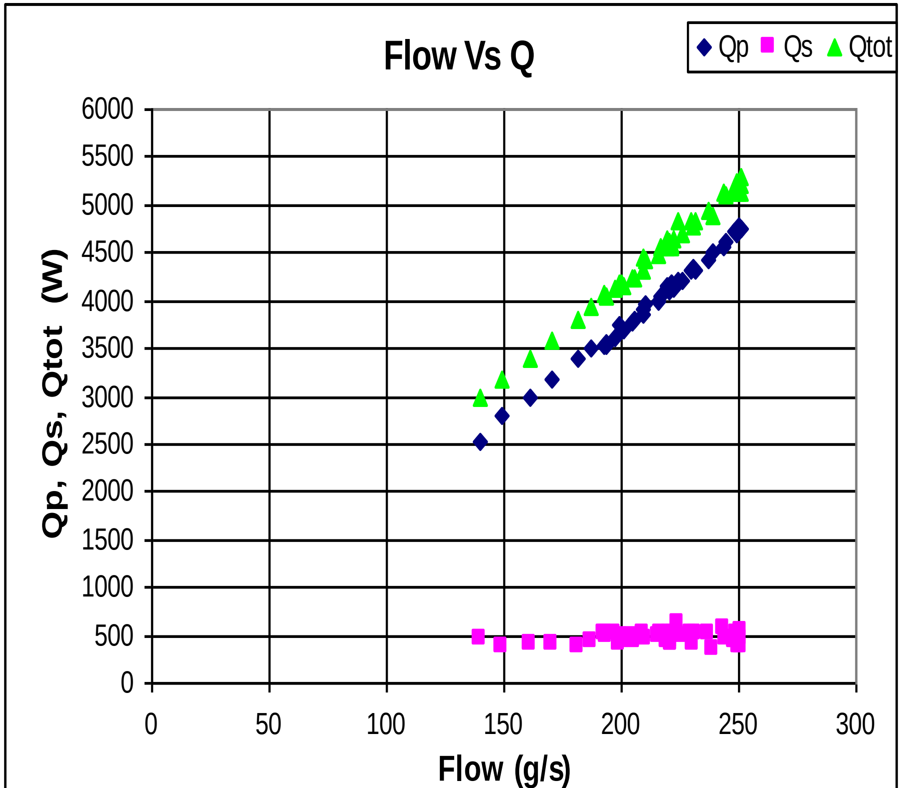


Figure-5.2.1a

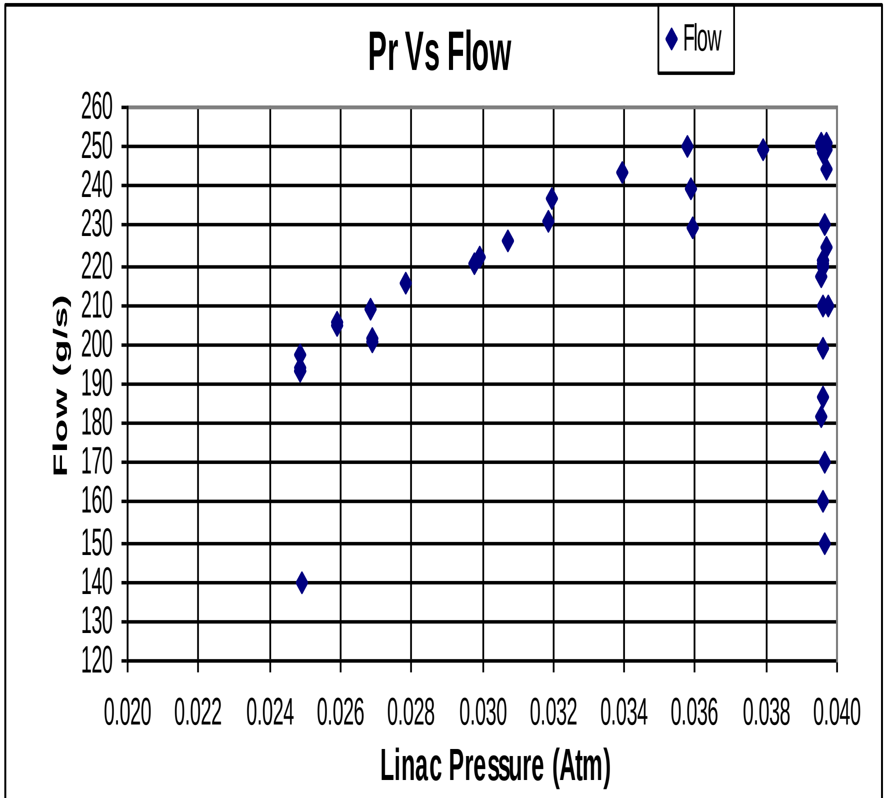


Figure-6.2.1

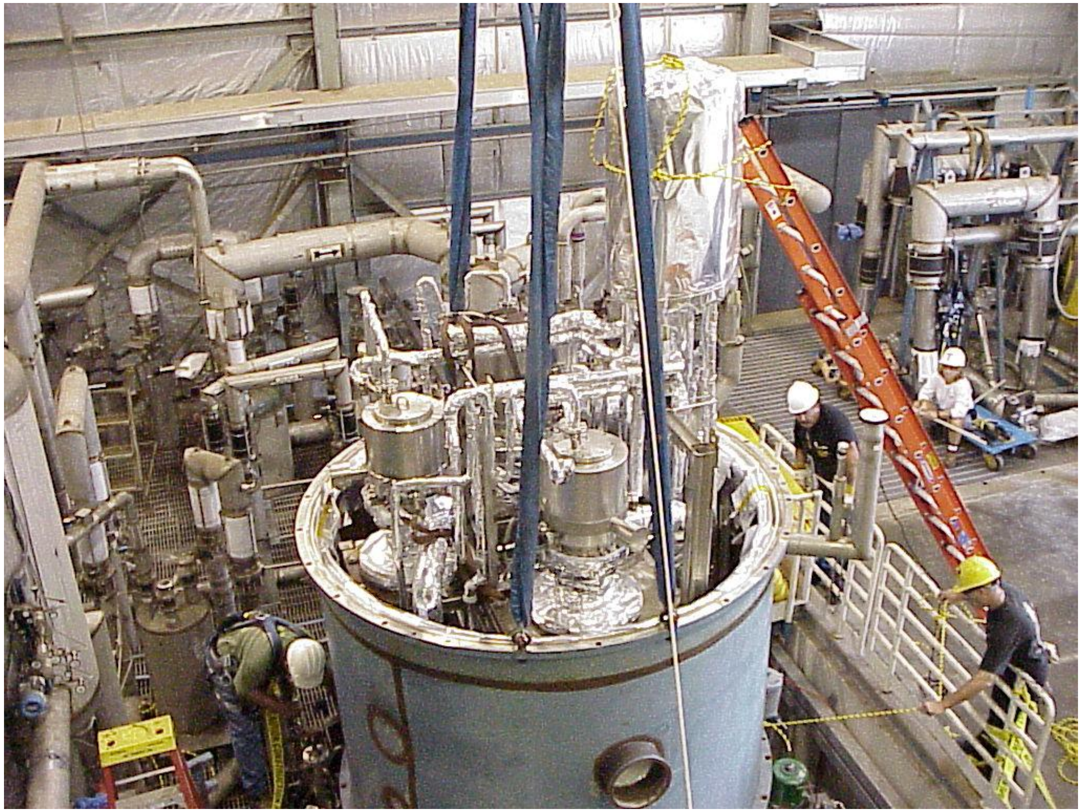
Modified "2 K" Cold Box (SCM)

Original "2 K" cold box w/ modifications:

Near duplicate of existing operating "2 K" cold box (SCN)

Removed unreliable, large Linac return valve

- **Nearly ready**
- **Requires cold check out**



2 K Cold Box (SCM) Internals

Modified Original 2K CBX (SCM) with CHL-1

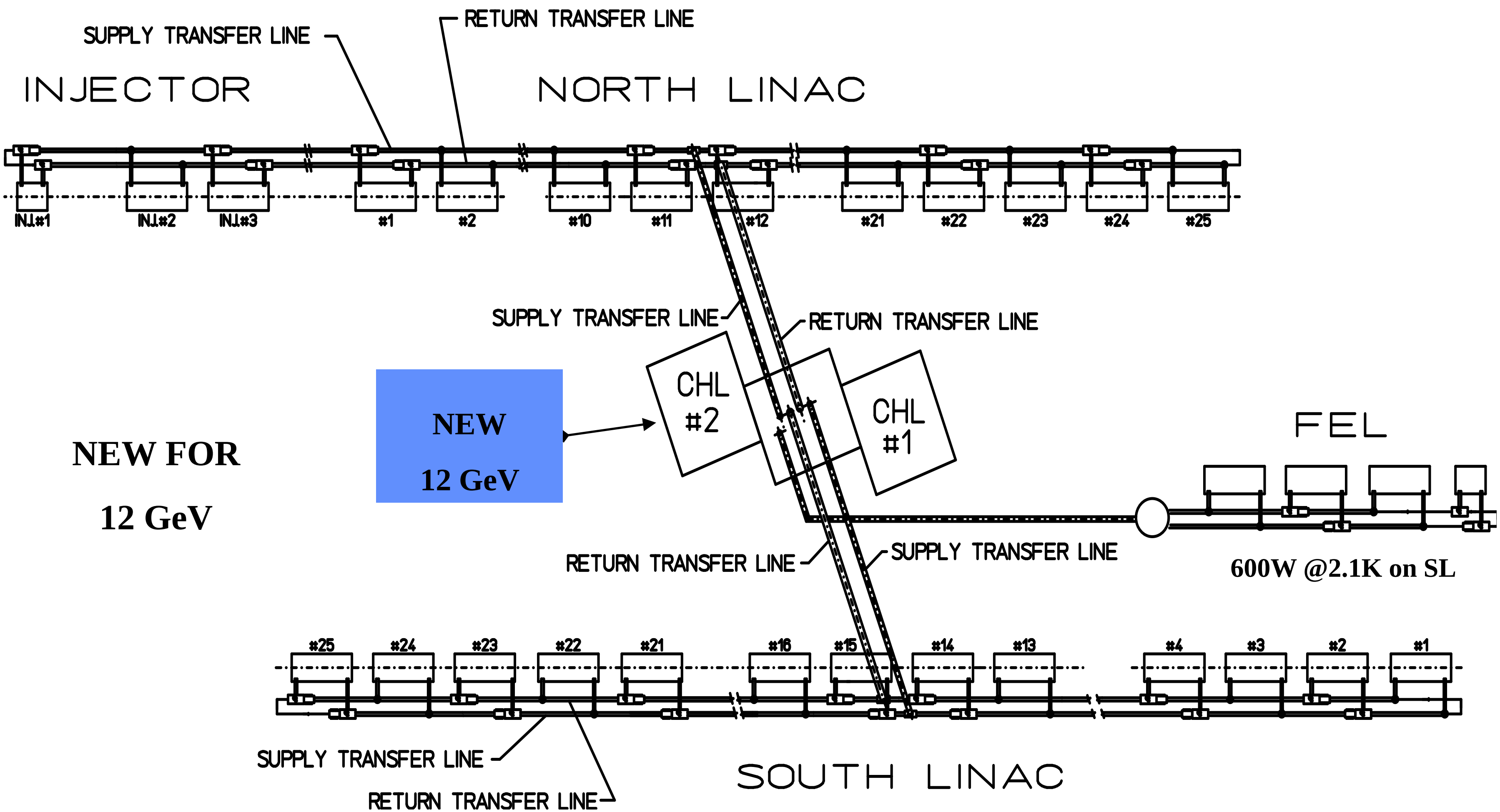
JLab 2K Cryo Technology

- **The 2 K Load of 4.6 kW is supported by a single plant; which is the single largest 2 K cryo plant to date**
- **All compression for the 2 K load flow from sub atmospheric condition to above atmospheric pressure is accomplished at cryogenic temperatures. Only JLab and the SNS plant (~ ½ the JLab cryo capacity) designed by Jlab use this technology**
- **JLab 2 K Cryo system has been operating since 1994. In 1999 JLab built and commissioned a new 2 K cold box (SCN) which improved the cryo system availability to >98%. It has a very long reliable 2 K operational history**

Behind CHL

Cryo Distribution at CHL to Linacs

LINAC Transfer Lines



NEW FOR

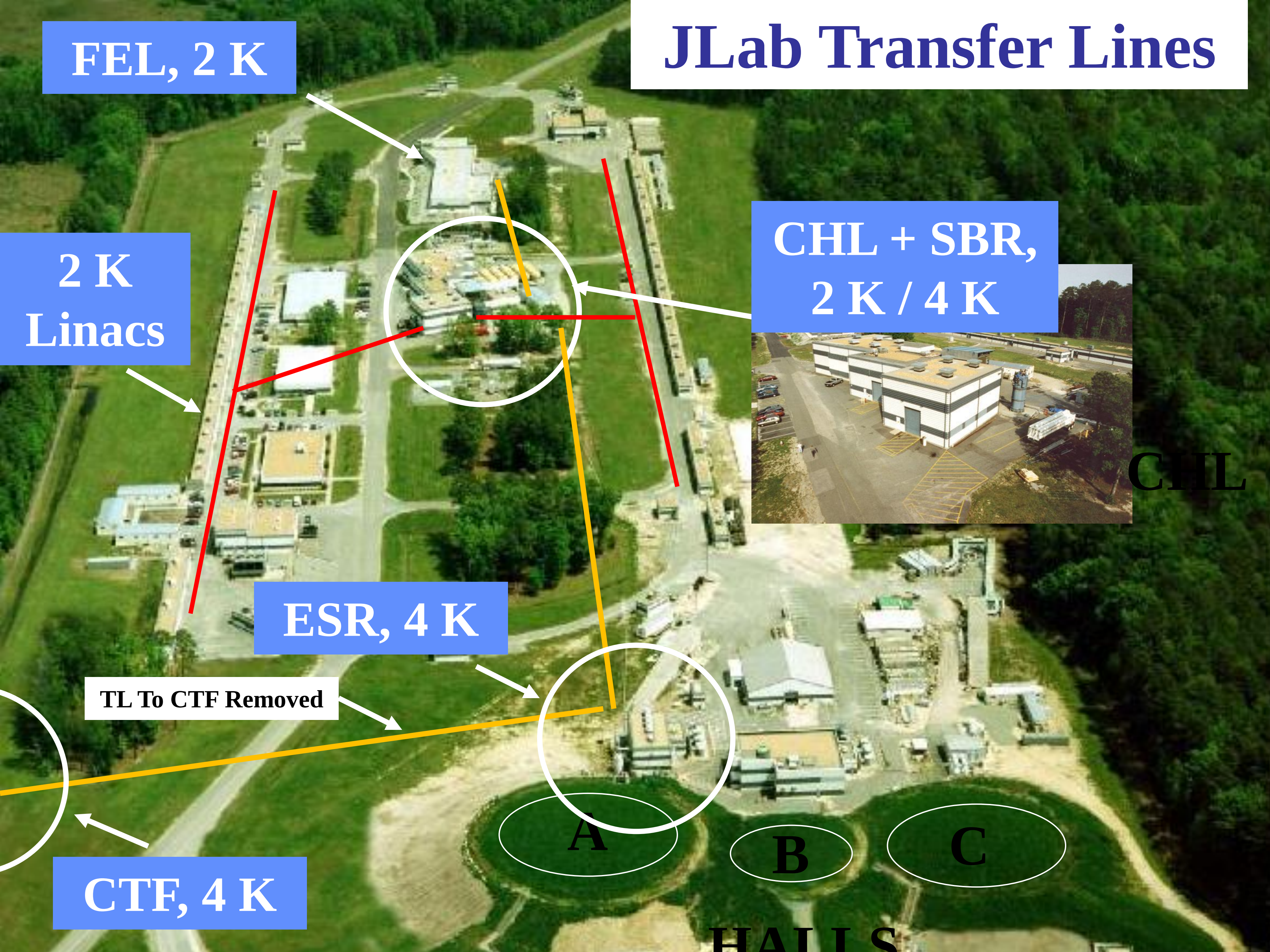
12 GeV

NEW

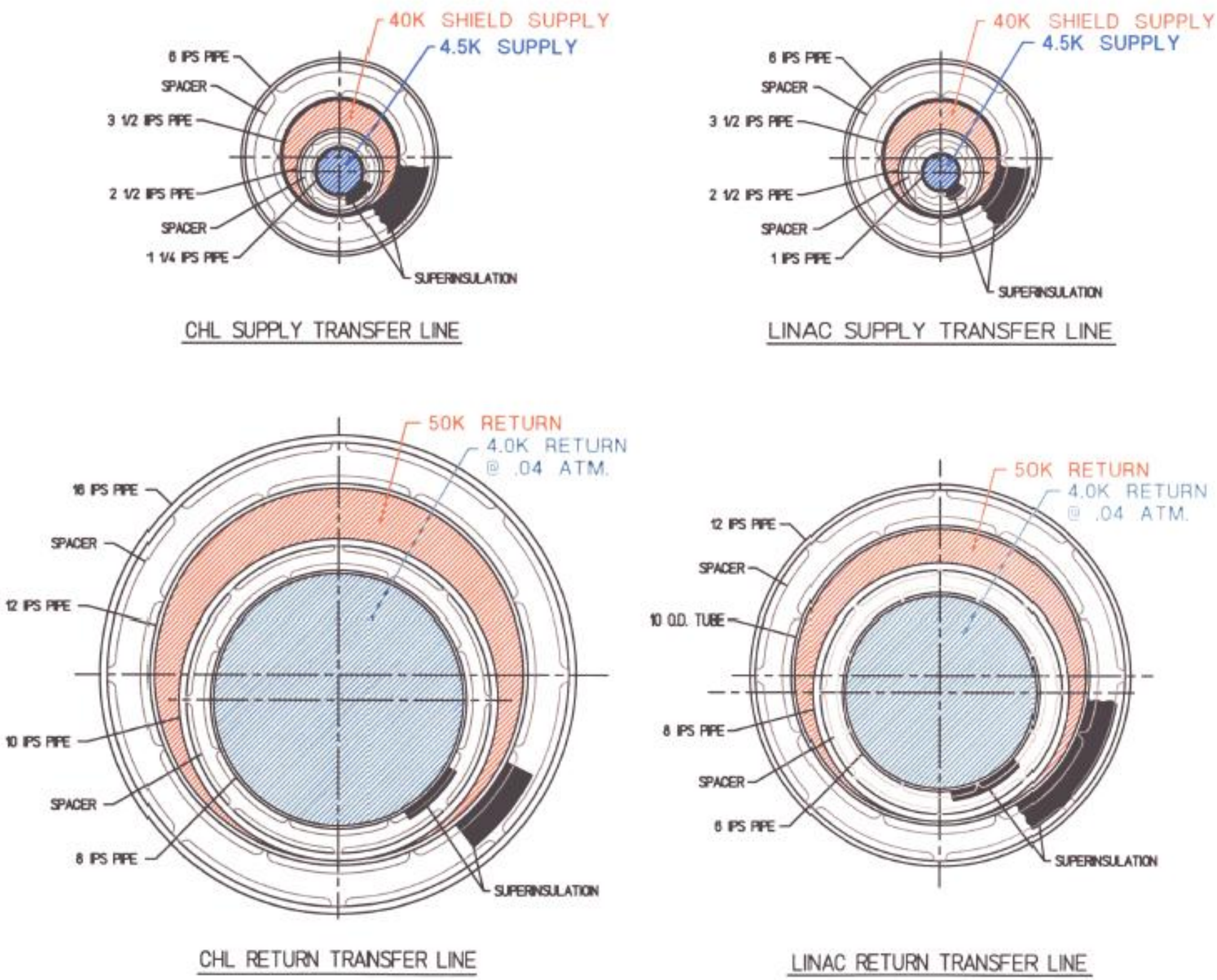
12 GeV

600W @2.1K on SL

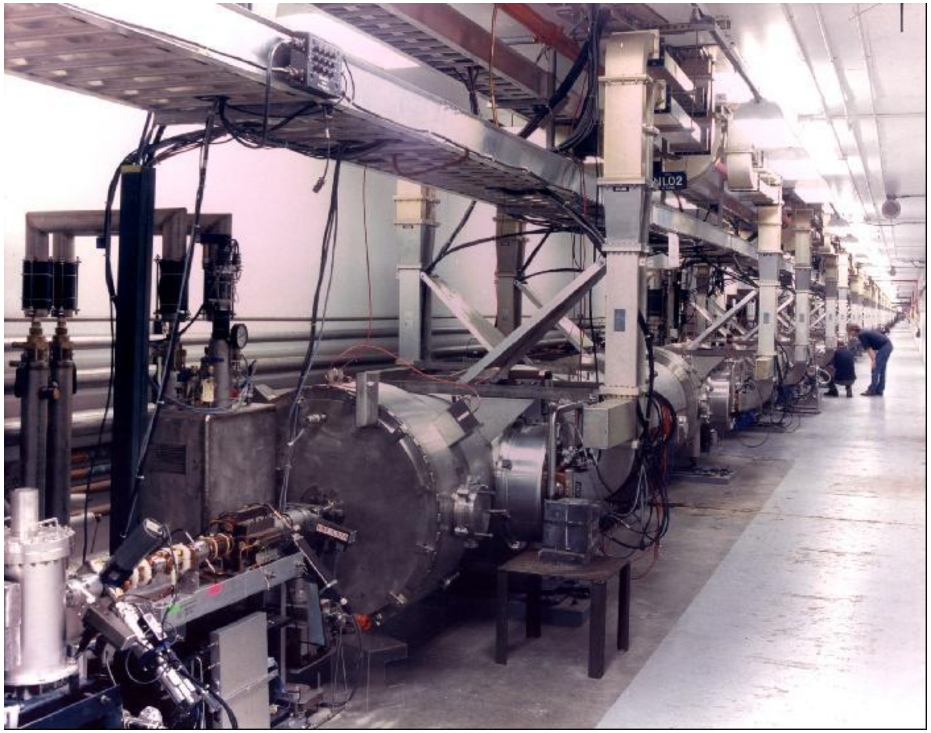
JLab Transfer Lines



Transfer Line Cross Sections



CEBAF Accelerator



LINAC TL Configuration

- **CURRENT 6 GeV:**

  CHL-1 supplies injector, north and south Linacs, FEL, and 10 g/s to ESR

- **NEW 12 GeV:**

  CHL-1: Injector, north Linac

  CHL-2: South Linac and existing FEL

NOTE: IN CASE OF A CHL-1 OR CHL-2 MAINTANENCE or FAILURE, THE LINACS CAN BE RECONNECTED TOGETHER INTO SINGLE REMAINING CRYO PLANT FOR 6 GeV BEAM OPERATION

Existing End Station Refrigeration System
for Cryo Support of Experimental Halls

ESR-1 refrigerator (built in 1978) serves experimental Halls A,B and C

Capacity of
1500 W @ 4.5 K helium refrigeration
OR
11 g/s 4.5 K liquefaction

(To support large target loads
the halls can also receive an additional
25 g/s 4.5 K liquid helium from CHL via. TL)

ESR-1 Compressors

ESR-1 Cold Box

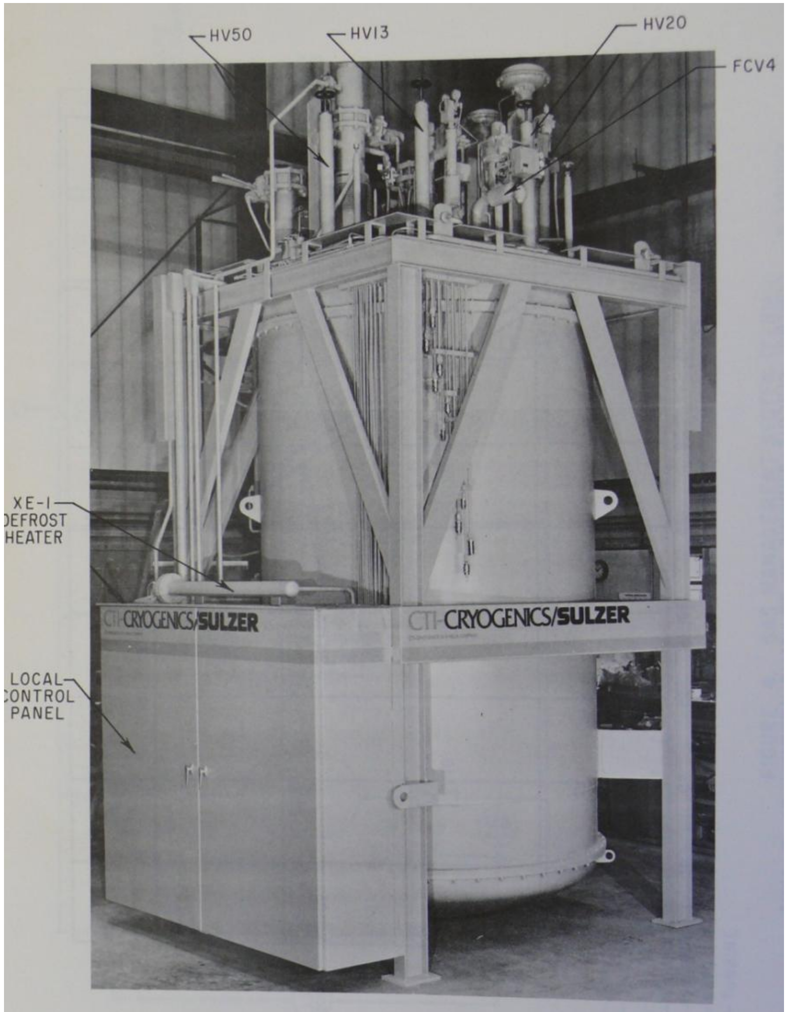
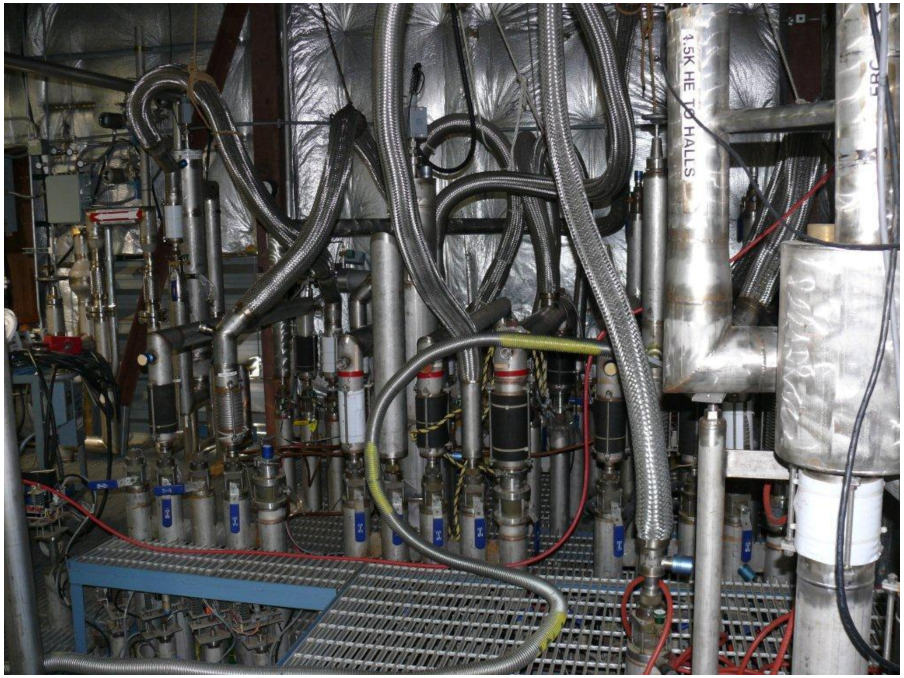


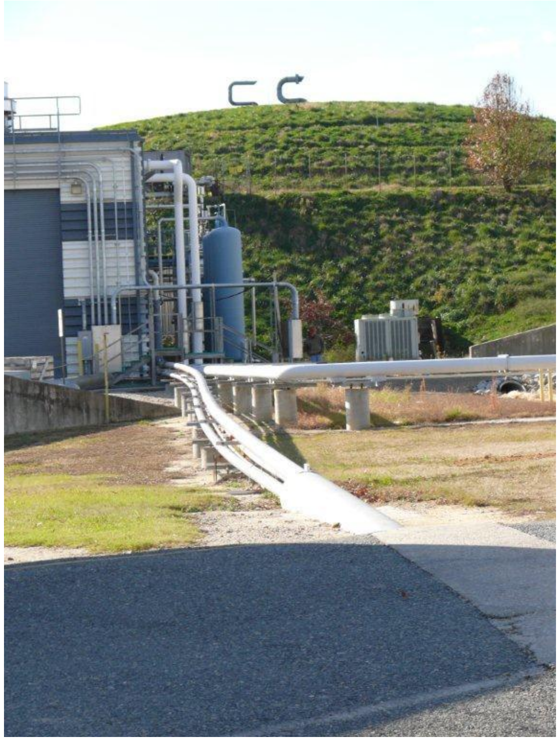
FIGURE 6. FRONT AND LEFT SIDE

ESR-1 Distribution and Hall Interfaces



ESR-1 Oil Removal & LHe Storage

Transfer Line between CHL and ESR



New ESR-2 Cryo Refrigeration System for Experimental Halls

Additional refrigeration capacity for experimental Halls A, B & C to support the 12 GeV program

SSCL refrigerator (fabricated in 1992)

has a capacity of

4 kW @ 4.5 K Helium Refrigeration

OR

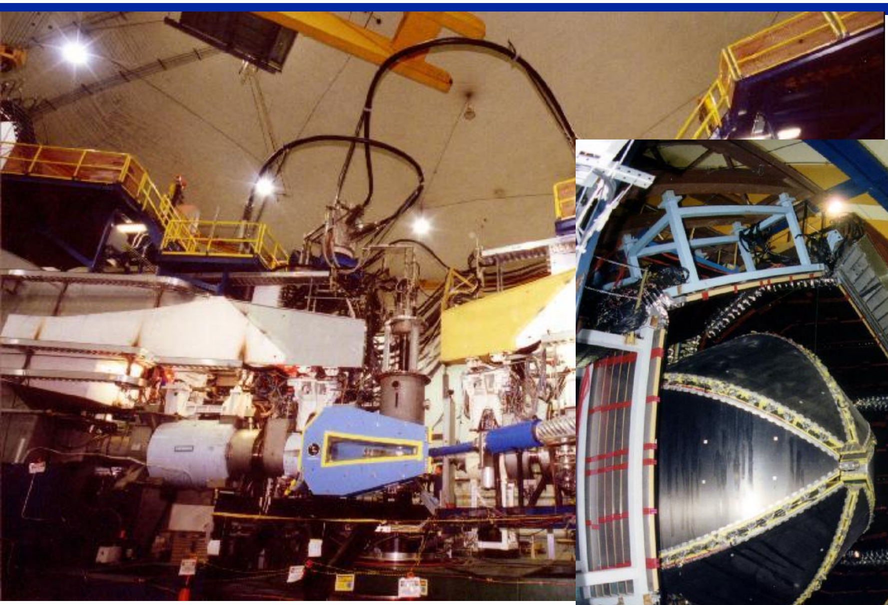
5 kW @ 20 K Helium Refrigeration

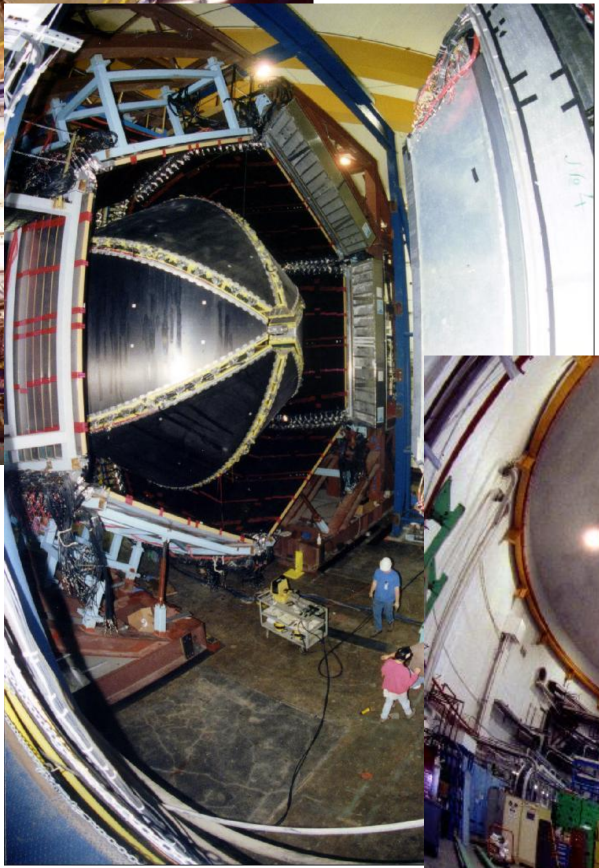
OR

40 g/s 4.5 K Liquefaction

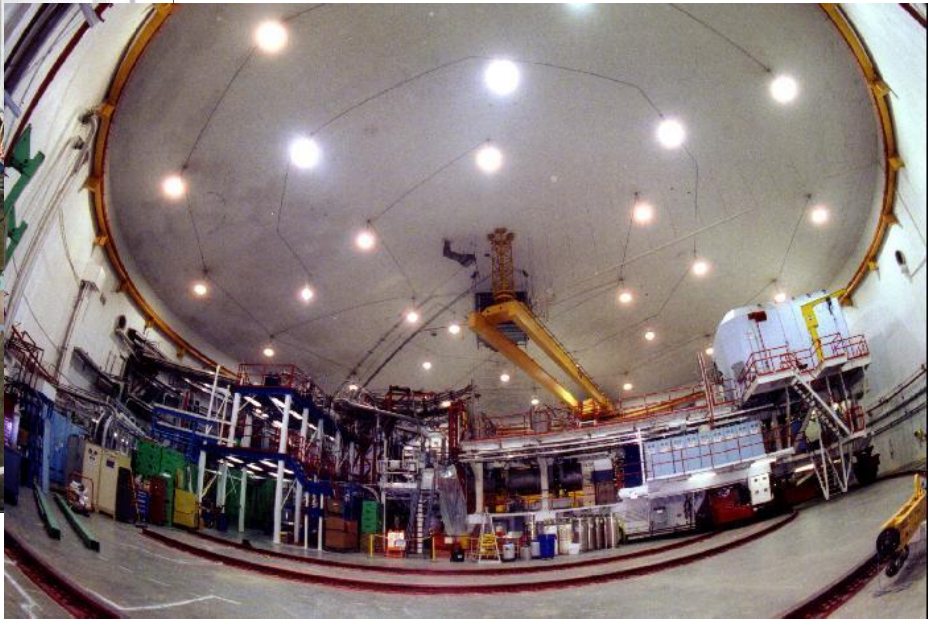
4 kW ESR-2 (SSCL Cold Box) Installation

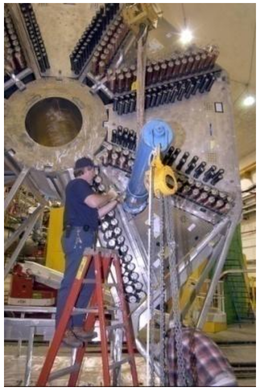
Experimental Halls A, B & C





Cryogens are supplied from ESR to Hall cryo magnets and cryo targets





Hall D Cryogenic System

Hall D 4.5 K Refrigerator (Built 1980)

Capacity is,

200 W @ 4.5 K Refrigeration

OR

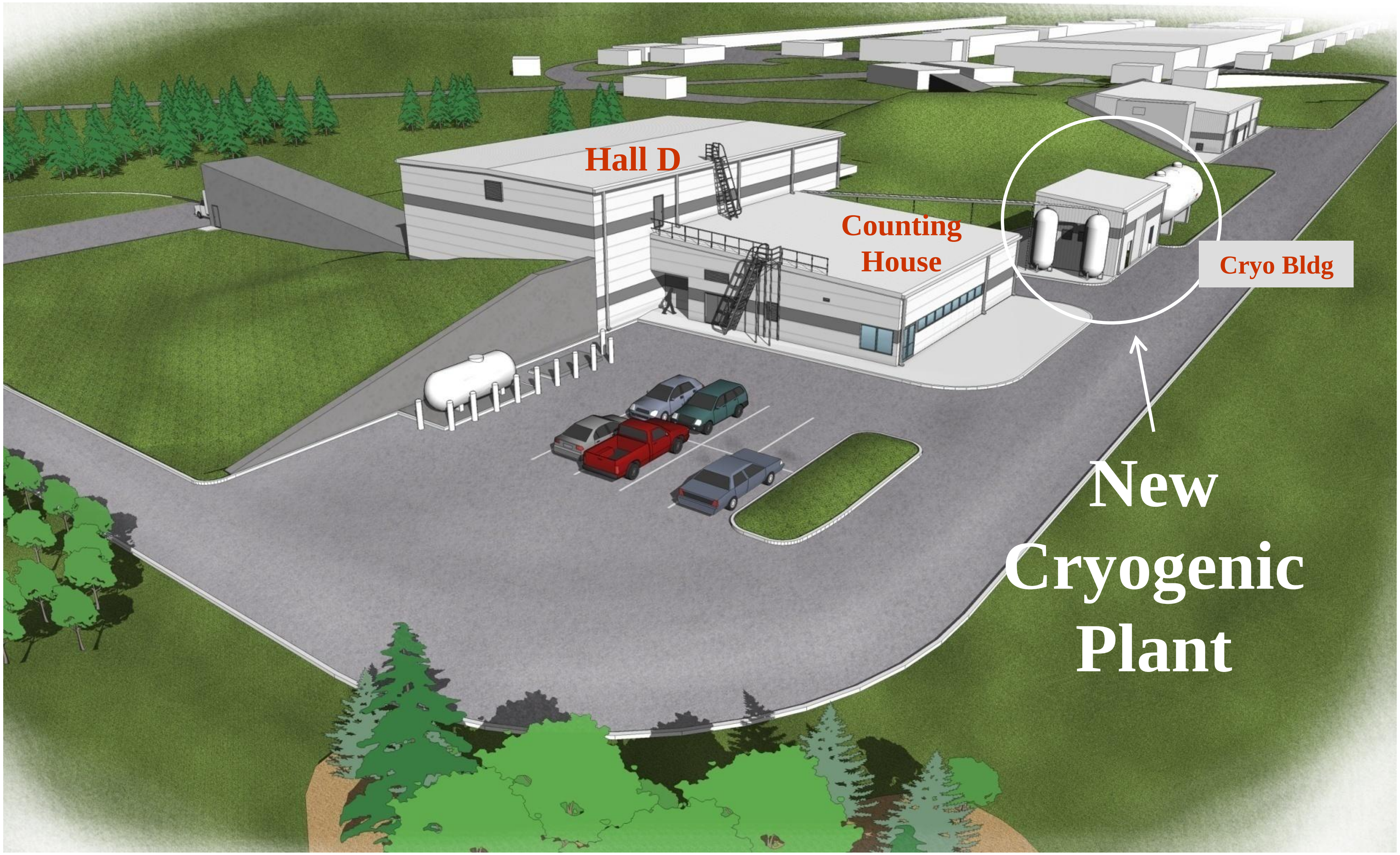
2 g/s 4.5 K Liquefaction

Hall-D mixed load…0.7 g/s liquefaction

+

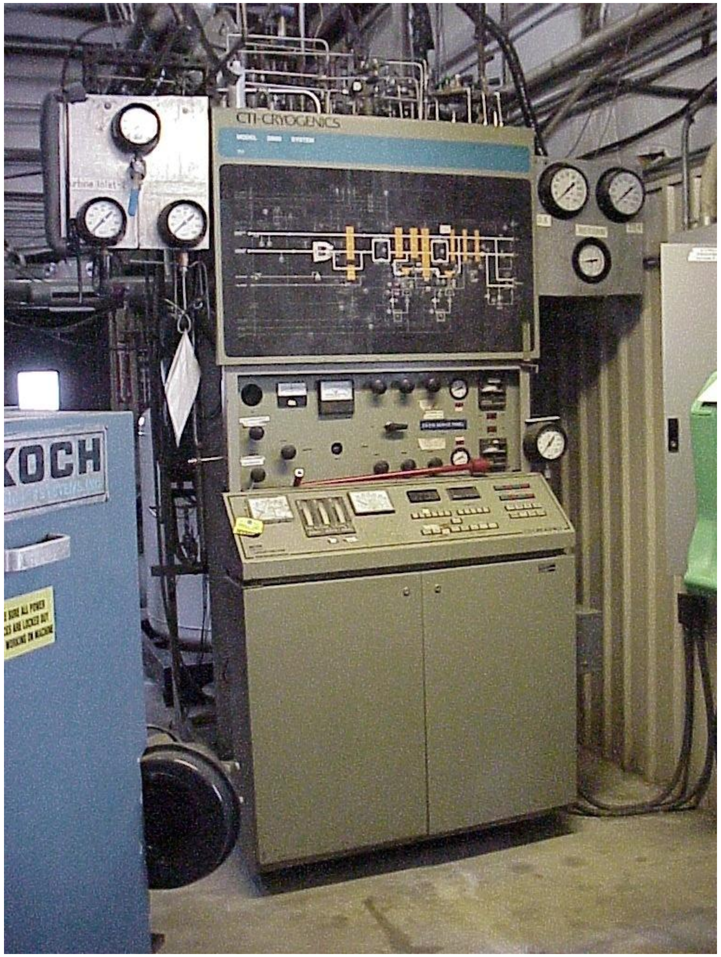
100 W Refrigeration (includes transfer line load)

Hall D Site Plan



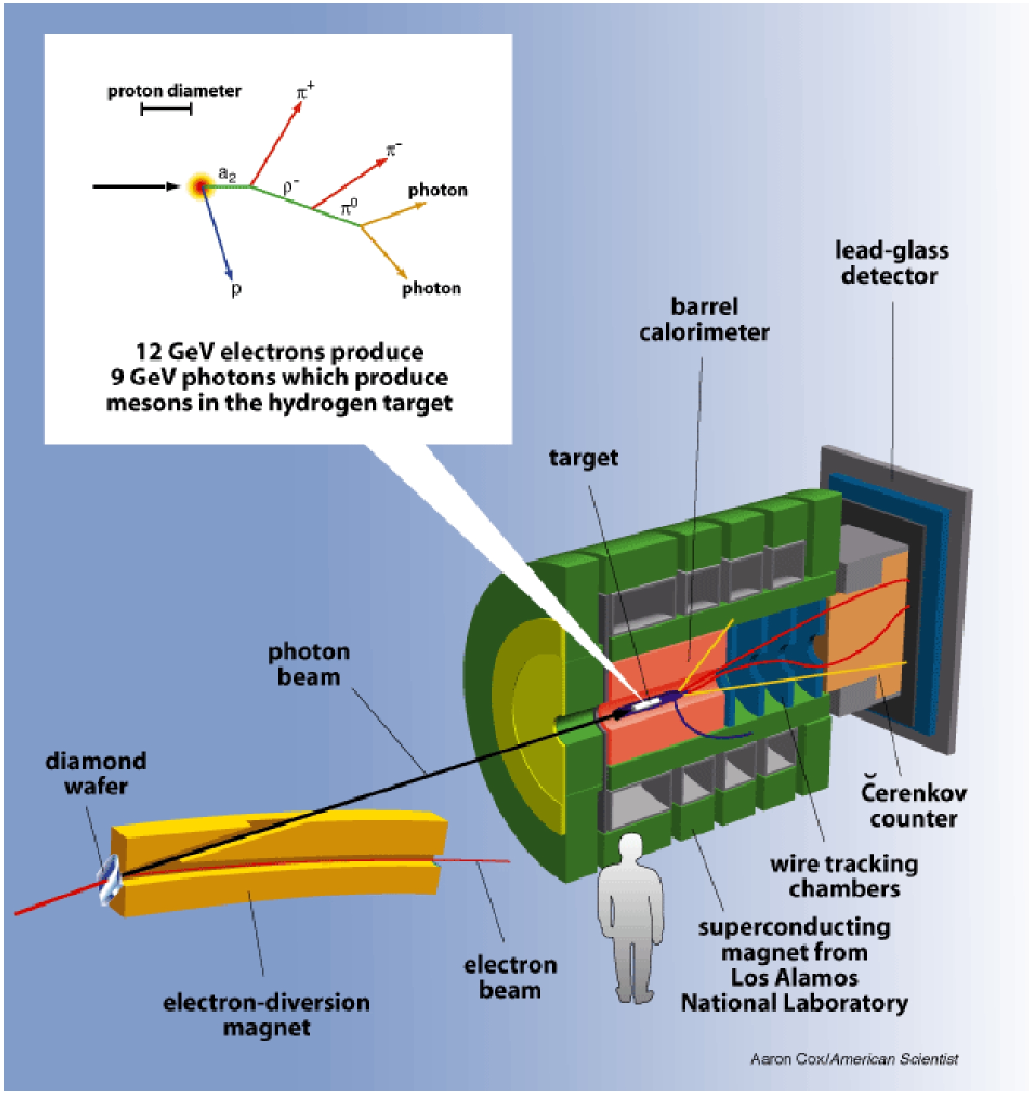
Hall-D Planned Refrigeration Equipment

Model 2800 Refrigerator



Helium Compressors

Hall-D Experimental Setup



Cryogenic Test Facility (CTF)

- **Commission date: 1989**
- **Main compressors:**
  (3) 250 kW Mycom compound screw compressors
- **Control system:**
  EPICS software, CAMAC hardware
- **Service duty:**
  24/7/365 continuous unattended
- **Operational hours to date:**
  > 170,000 hrs

Cryogenic Test Facility (CTF)

— **KPS M2200 Helium Refrigerator (Cold Box #2)**
- **4.5 K primary supply with warm vacuum pumping for 2 K cryo-module and superconducting cavity testing**
- **(2) reciprocating expansion engines**
- **Capacity, 700 W at 4.5 K, 4 g/s (120 L/hr) 4.5 K liquefaction**

— **CTI M2800 Helium Refrigerator (Cold Box #3)**
- **(2) Sulzer Turbine Expanders**
- **Capacity, 200 W at 4.5 K, 1.7 g/s (51 L/hr) 4.5 K liquefaction**

— **Helium Shield Refrigerator (Cold Box #1)**
- **35 K shield supply for transfer line and cryo-module shield**
- **(1) reciprocating expansion engine**
- **Capacity, 800 W at 35 K**

Vertical Test Area (VTA) and CM Test Cave

Meeting the Ever Increasing Cryo Demands

<u>Increasing CHL-I Capacity</u>

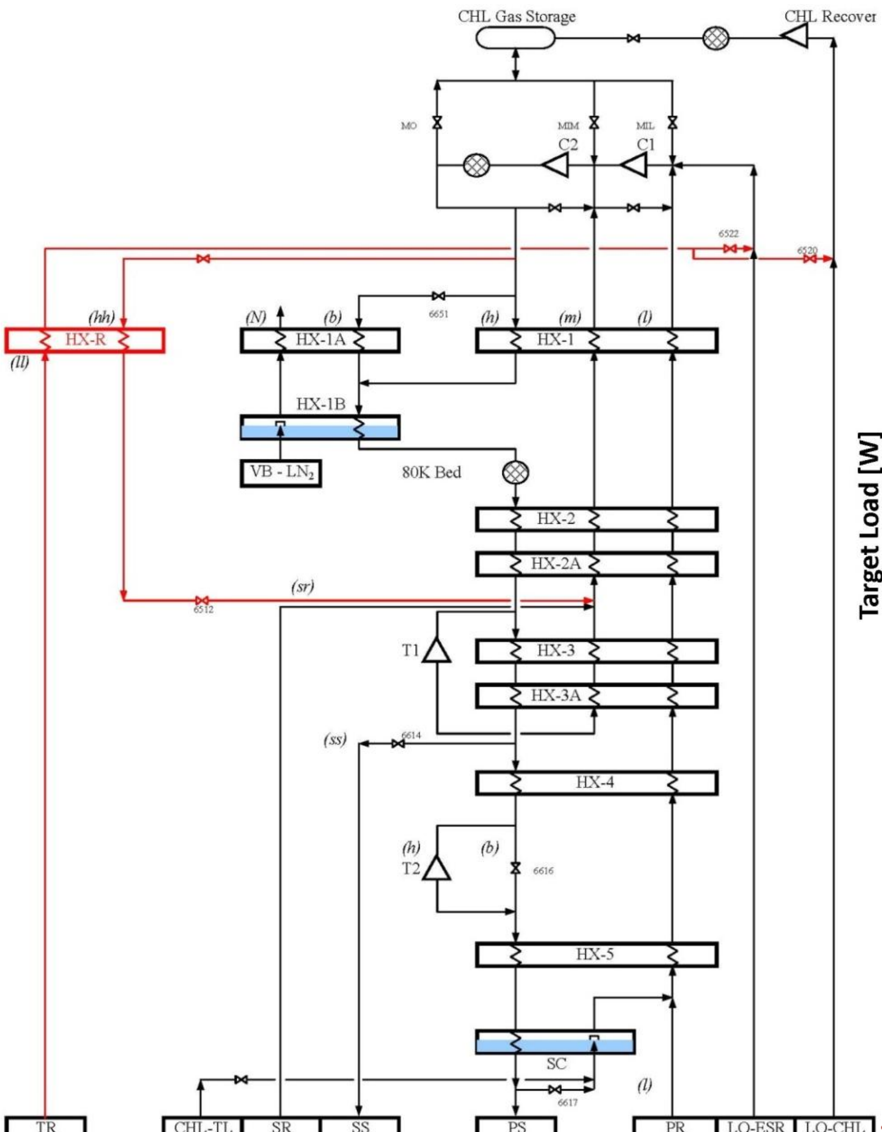
- Original operating conditions
  - At 4 GeV, 235 g/s at 2 K; i.e., the design with margin
  - Cryo plant was forced to run at max. design point
  - No redundant equipment (compressors or turbines)
- Improvements made:
  - Implemented Floating Pressure Ganni Cycle to meet the loads efficiently
  - Replaced the old 2 K cold box with JLab design (1999)
  - Added the Stand-By Refrigerator (SBR) cold box and compressors
- Present conditions
  - At 6 GeV (current max load), 235 g/s at 2 K
  - At 4 GeV, 190 g/s at 2 K

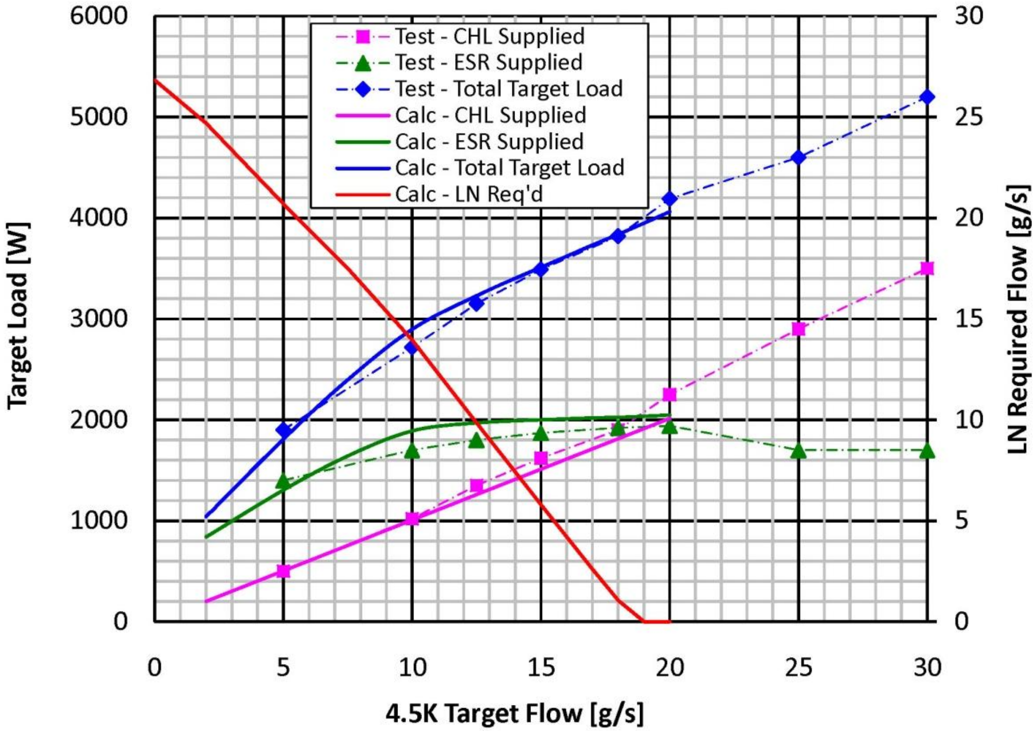
Meeting the Ever Increasing Cryo Demands

Innovative ideas to meet the ever increasing thirst for increased cryo capacity from ESR and CTF users

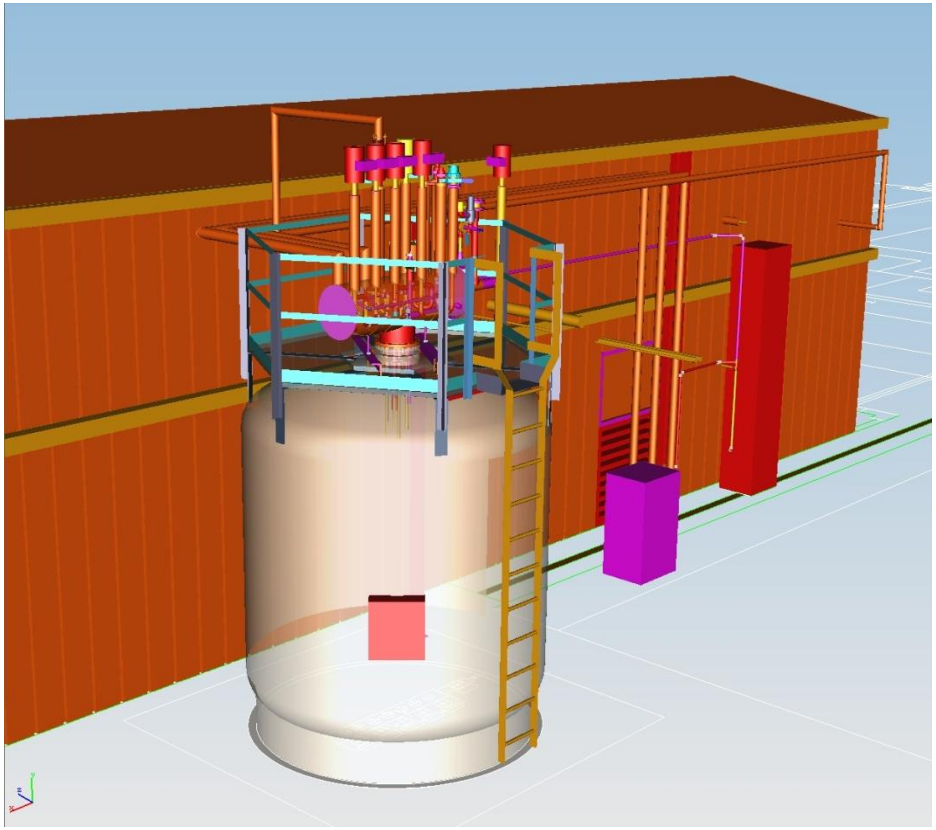
- **ESR: initial plan of 2 week operation of a 2 kW target in 2003 became routine**
  - **Used an air-ambient vaporizer at ESR**
- **ESR: Needed more capacity for Qweak experiment**
  - **Designed & installed Refrigeration Recovery HX, to increase capacity and efficiency**
- **CTF: Need more capacity for 12 GeV and ILC work**
  - **Have designed and will install 10 kL LHe dewar with sub-cooler ; anticipated to increase the available cryo capacity and cryo operational efficiency by a factor of two**

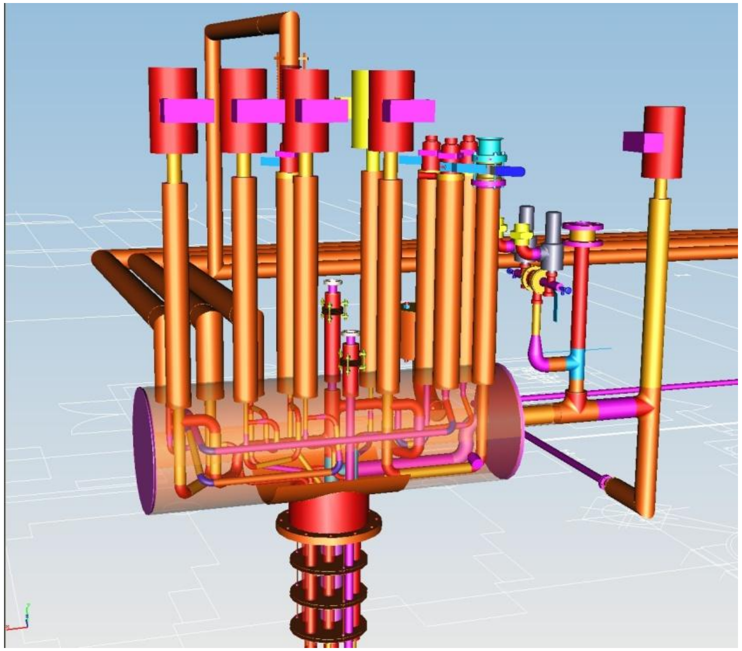
ESR – RRHX Process Study





CTF 10kL LHe Dewar





Cryo Down Time

- **Accounted as all time loss to scheduled beam operations due to the cryogenics system to return back to physics (data collecting)**
- **Includes time for the restoration of the entire plant**
  - **The amount of time to recover from an outage is exponential to the amount of time that the cryogenic plant is down**
- **Cryo down-time resulting in physics interruption**
  - **1999 through 2008 ~ 1.6% average down time**
  - **2008 to present down time ~ 2.5%**
    - Main compressor failure without redundancy
      - ~60 hours of down time
    - Problems with LINAC return flow oscillations during high ambient temperatures

Major Contributions to Down Time

- **Typical utility failures**
  - **—Electrical power**
    - **Power spikes**
    - **Phase imbalance**
  - **—Cooling water**
    - **Cooling tower accumulates debris**
    - **Pumping system failures**
  - **—Instrument (control) air**
    - **moisture contamination in pneumatic control valve positioners**

Major Contributions to Down Time (Cont.)

- **Control systems (CAMAC)**
  - — **Old technology, uses lots of power, generates lots of heat (more heat, higher failure rates).**
  - — **Laboratory grade hardware, not designed for industrial environment.**
  - — **Highest failure rates in control system; electric valve cards, crate controllers, power supplies.**
  - — **Replacement components are getting harder to find.**

- **Aging components in system**
  - — **Control cards**
  - — **Carbon purification systems**
  - — **Compressors**
  - — **Carbon steel components**
    - **Vacuum Jackets**
    - **Water Piping**

Utilities - Helium

- **Helium**
  - **—Is a very precious fluid**
    - **Low boiling point (4.2 K at 1 atm)**
  - **—Known reserves are very limited**
  - **—Mostly coexists with natural gas in a small percent**
  - **—Federal helium conservation program is shutdown**
  - **—We were the major exporters of helium so far but will start importing in a few years**

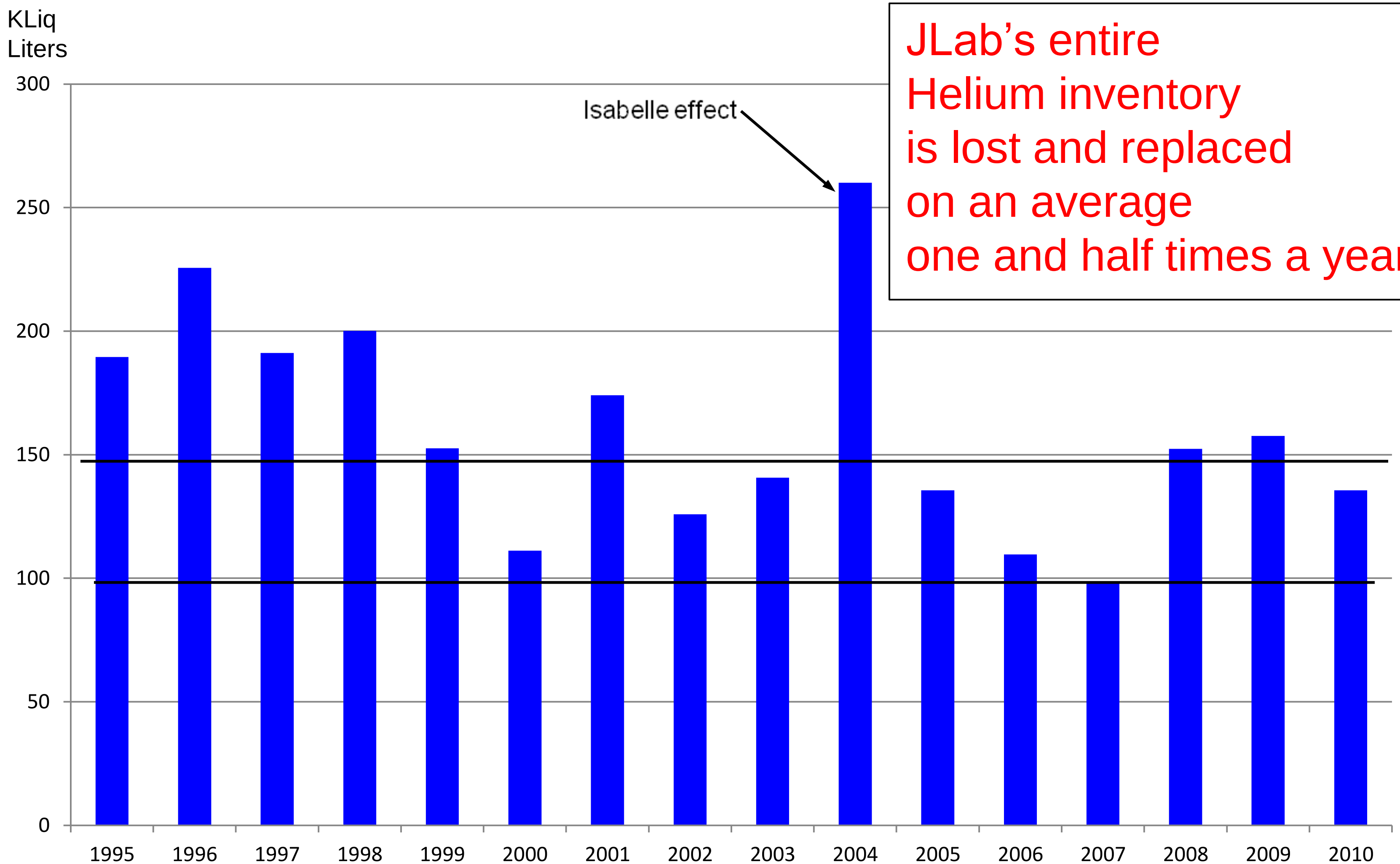
We need to conserve helium!

Helium Gas Delivery to CHL-1

Estimated Average Helium Inventory at JLab

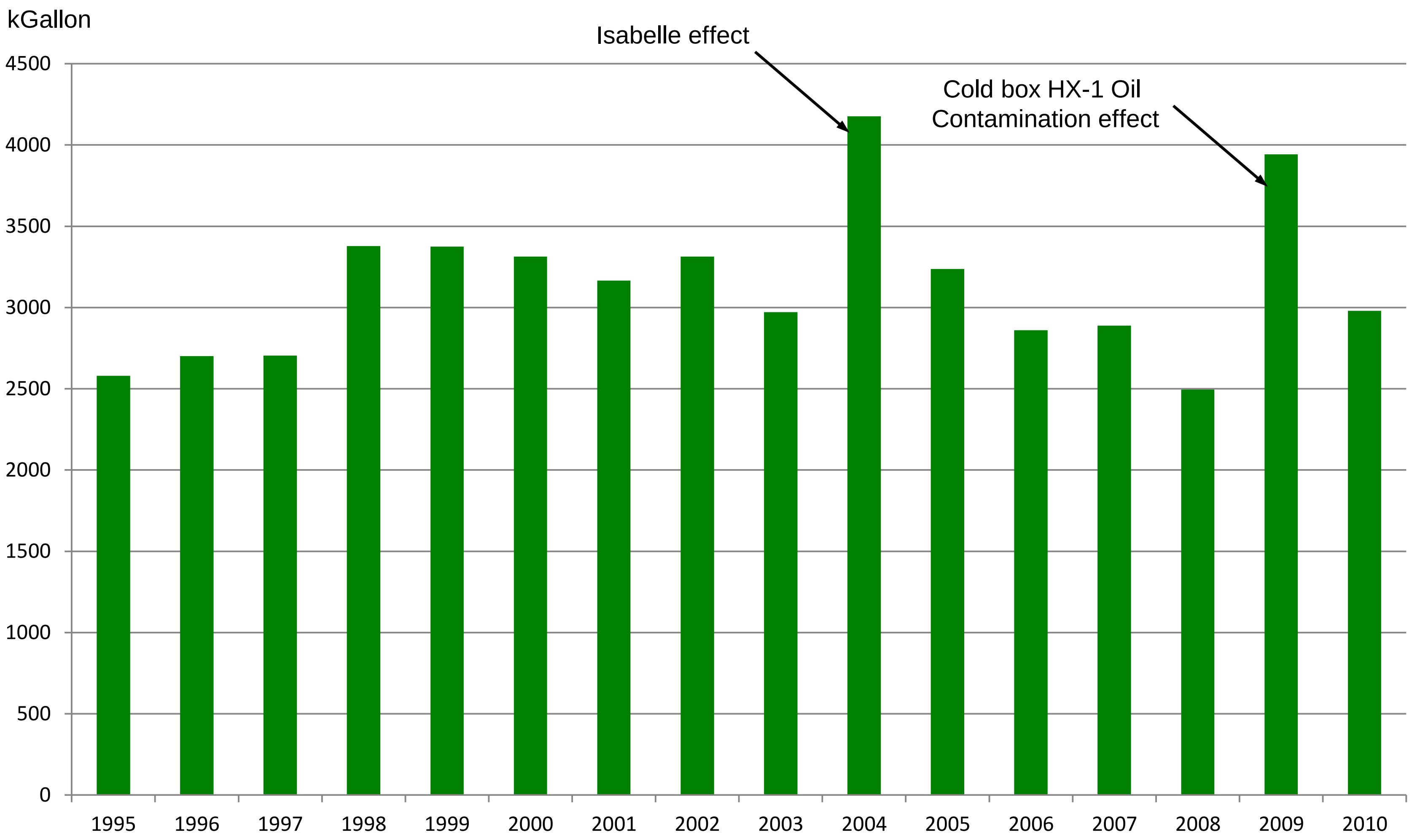
	Liquid Liters
CEBAF Linacs (North + South)	67600
FEL	5200
Halls A, B & C	6200
CHL	8000
ESR	5000
CTF	8000
Total	**100,000**

Helium Usage per Fiscal Year (in kilo-liquid liters)



JLab's entire
Helium inventory
is lost and replaced
on an average
one and half times a year

LN2 Usage per Fiscal Year

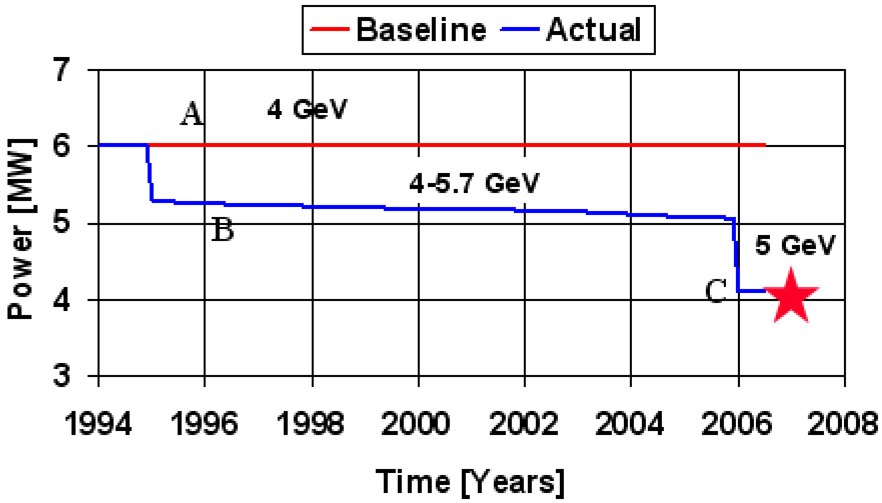


Utilities – Electric Power
Implementation of Floating Pressure Ganni Cycle

Through the years the Cryogenics Group has completed several phases of technological improvement which have,

(1) Increased the plants operational envelope while reducing the utility requirement per unit load and,

(2) Allow its capacity to automatically vary to match the cryogenic load.



As compared to the 1994, 4 GeV baseline, these improvements continue to save $ 500,000 to $1,000,000 per year depending on the operational demand.

Estimated Utility Use by Cryo Systems

(Including Isabelle effect in FY 2004)

	Max	Min	Ave
He Use			
kLiq-Liters/year	260	99	160
M$ /year	$ 0.707	$ 0.268	$ 0.435
LN2 Use			
kGal/year	4176	2496	3130
Equiv. Elec. Power (MW)	1.23	0.74	0.93
M$ /year	$ 0.991	$ 0.592	$ 0.743
Electric Power			
CHL (MW)	6.5	4.5	
ESR (MW)	1	0.7	
CTF (MW)	1	0.6	
M$/year	$ 3.72	$ 2.54	$ 3.13
Total (M$/year)	**$ 5.42**	**$ 3.40**	**$ 4.31**

Estimated Utility Use by Cryo Systems

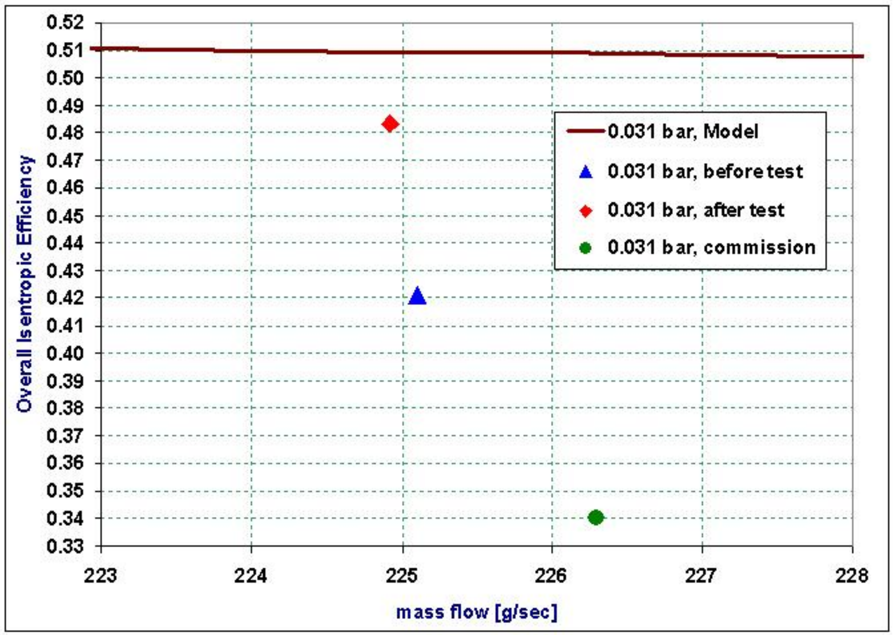
(Without Isabelle effect in FY 2004)

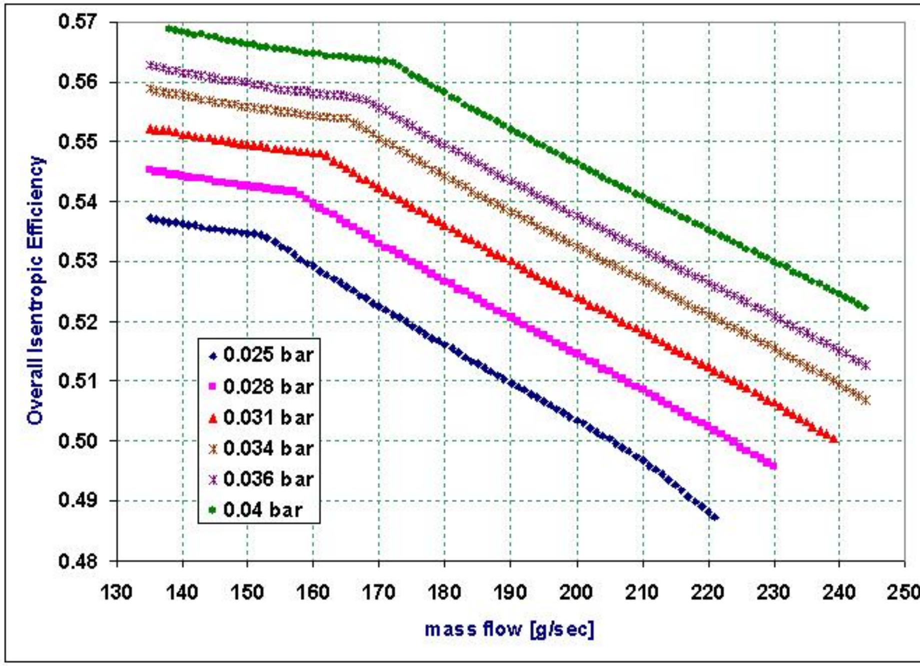
	Max	Min	Ave
He Use			
kLiq-Liters/year	226	99	153
M$ /year	$ 0.614	$ 0.268	$ 0.417
LN2 Use			
kGal/year	3943	2496	3061
Equiv. Elec. Power (MW)	1.17	0.74	0.91
M$ /year	$ 0.936	$ 0.592	$ 0.727
Electric Power			
CHL (MW)	6.5	4.5	
ESR (MW)	1	0.7	
CTF (MW)	1	0.6	
M$/year	$ 3.72	$ 2.54	$ 3.13
Total (M$/year)	**$ 5.27**	**$ 3.40**	**$ 4.28**

JLab Cryo Group R&D
and
Educational Efforts

Optimal Operating Parameters
for JLab Cold Compressors

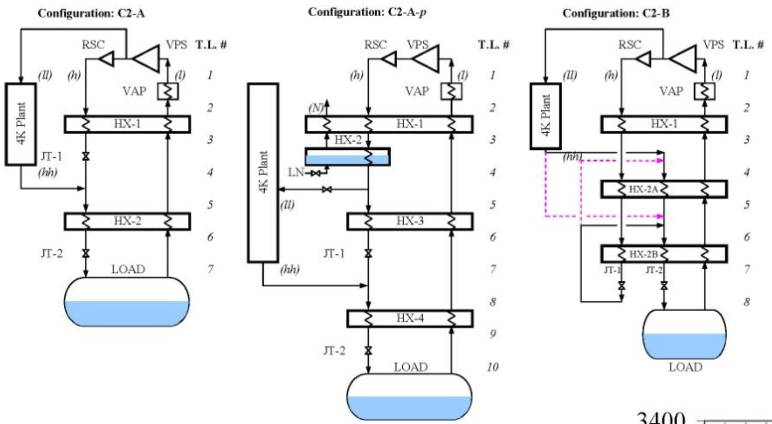
Masters Thesis: Joe Wilson Jr. (May 2003)



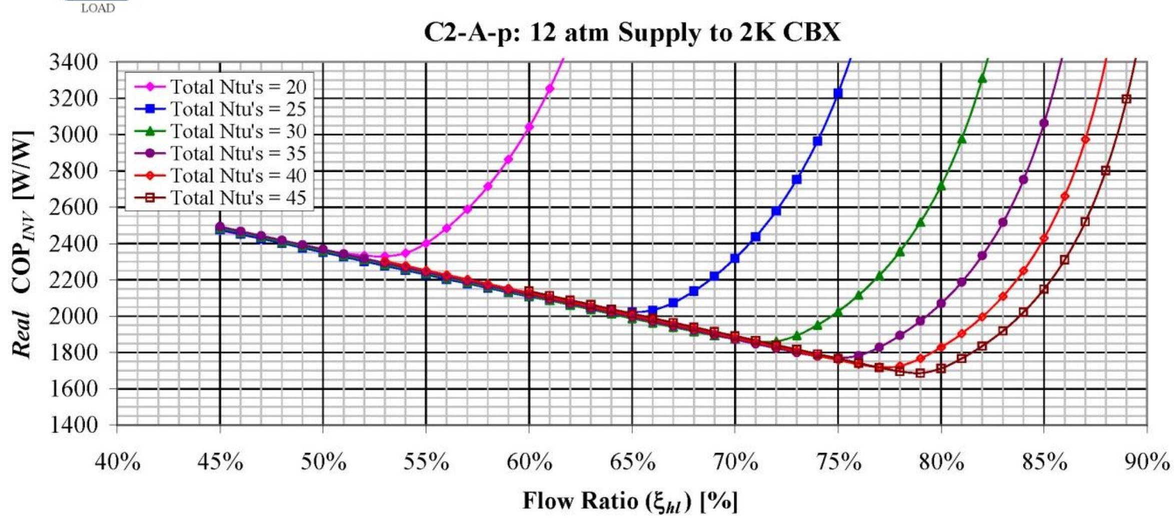


Design of a Small 2K Cryo System

Masters Thesis: Peter N. Knudsen (May 2008)



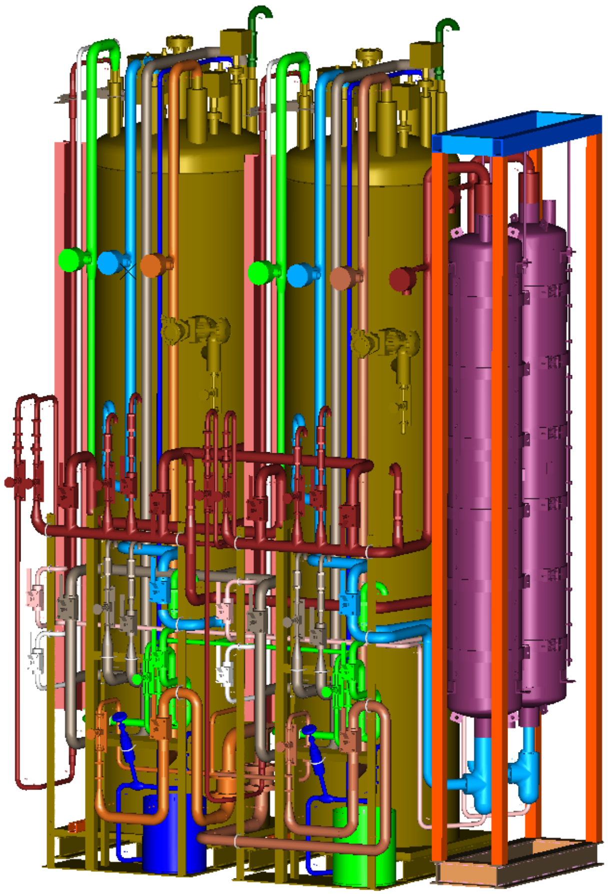
Configurations C2-A, C2-A-p and C2-B Flow Diagrams.

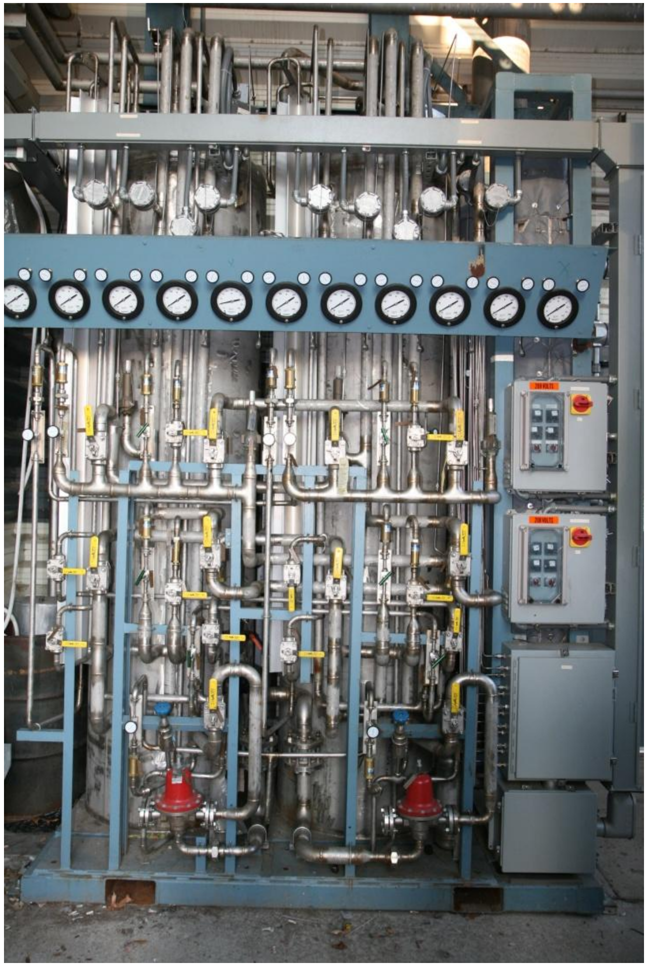


Configuration C2-A-p Real COP$_{INV}$ vs. Flow Ratio for 12 atm. Supply Pressure.

Design and Development of Helium Purifier

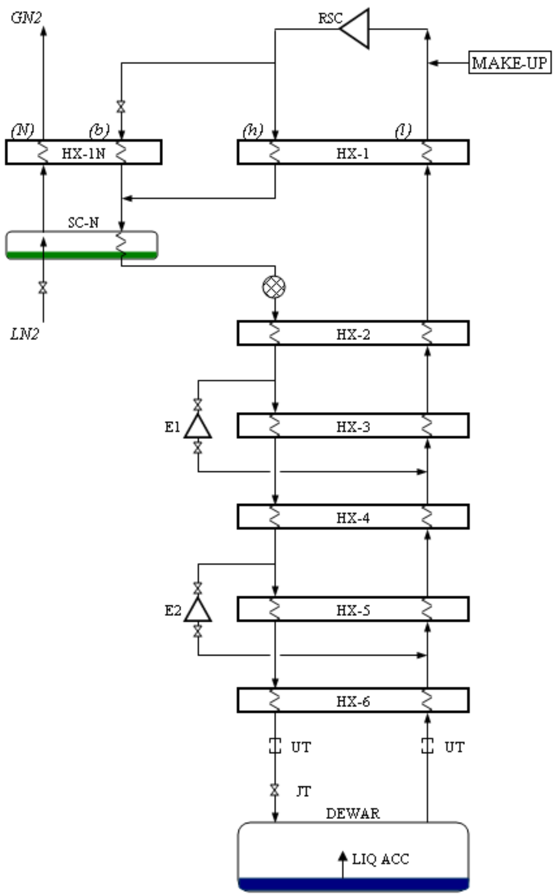
Masters Thesis: Mat. Wright (May 2009)





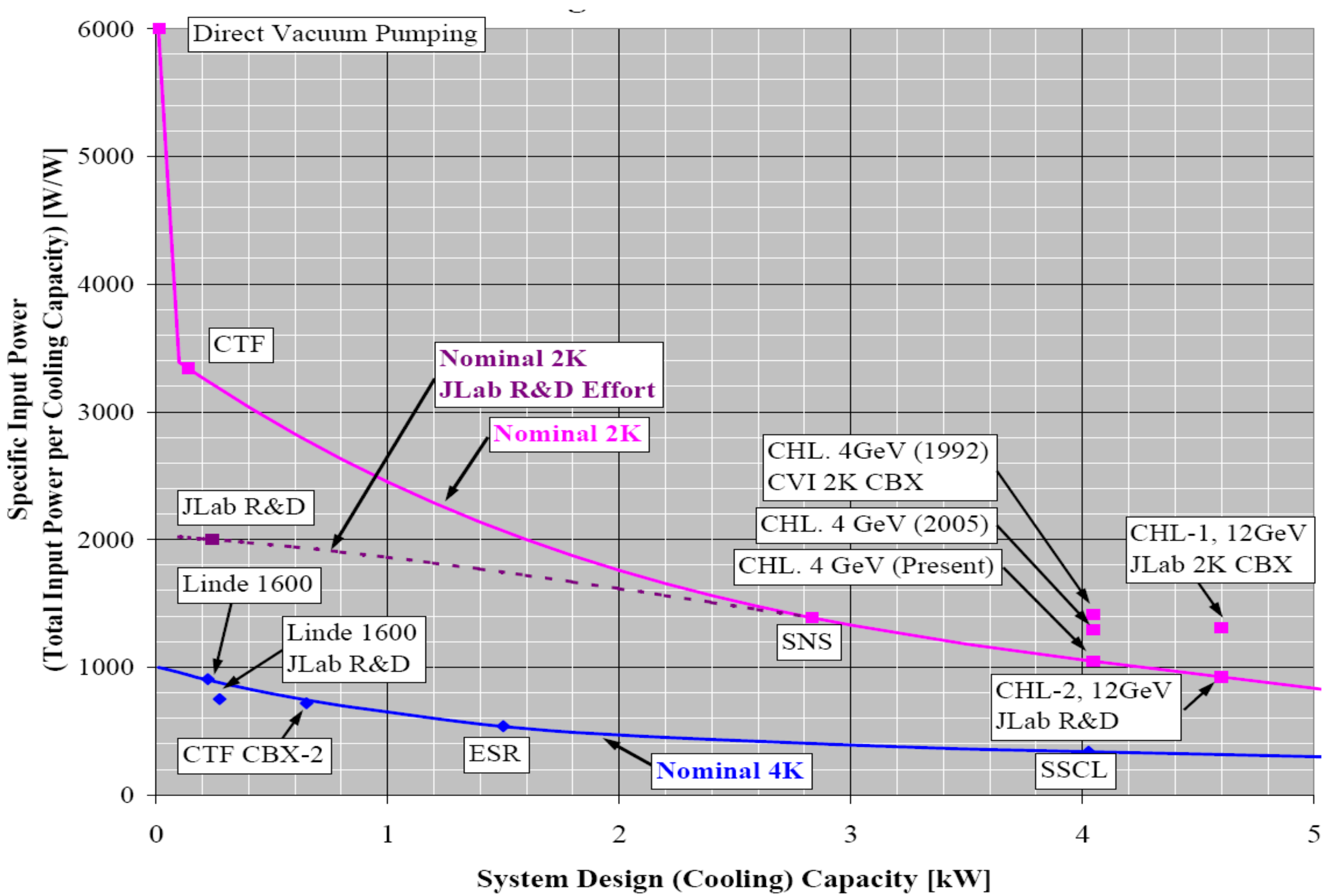
Capacity & Efficiency Improvements of a Small Cryo System

Masters Thesis: Errol Yuksek (Dec. 2009)



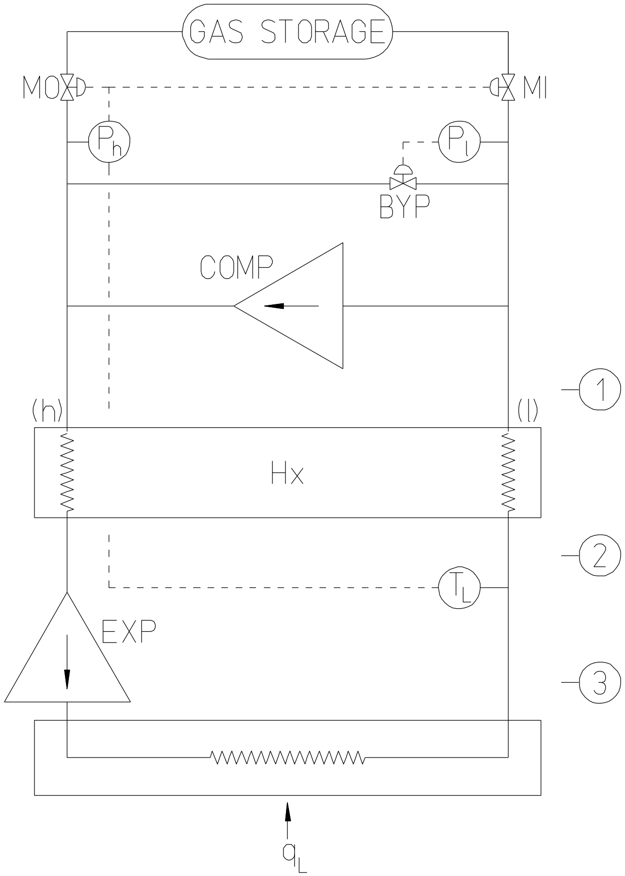
M1600 Summary	1610		1630	
	2-Comp	1-Comp	2-Comp	1-Comp
Unmodified				
Liq. Acc. [g/s]	2.45	2.11	0.00	0.00
Ref. Load [W]	2	2	201	152
LN2 Usage [g/s]	8.84	7.28	5.45	3.61
Make-up [g/s]	1.99	1.75	0.00	0.00
Input Power [kW]	180.17	109.85	182.76	111.42
Carnot Load [kW]	14.11	12.42	12.84	10.03
Useful Exergy [%]	7.13	9.99	6.63	8.46
Load Increase [%]	0.00	0.00	0.00	0.00
Efficiency Increase [%]	0.00	0.00	0.00	0.00
Mod-1				
Liq. Acc. [g/s]	3.10	2.23	0.00	0.00
Ref. Load [W]	2	2	236	158
LN2 Usage [g/s]	12.01	8.48	8.64	5.05
Make-up [g/s]	2.49	1.84	0.00	0.00
Input Power [kW]	182.76	111.42	186.85	113.90
Carnot Load [kW]	17.60	13.10	14.91	10.41
Useful Exergy [%]	8.52	10.21	7.31	8.40
Load Increase [%]	26.53	5.69	17.41	3.95
Efficiency Increase [%]	19.50	2.20	10.26	-0.71
Mod-2				
Liq. Acc. [g/s]	3.25	2.29	0.00	0.00
Ref. Load [W]	2	2	227	148
LN2 Usage [g/s]	12.26	8.55	8.40	4.88
Make-up [g/s]	2.60	1.89	0.00	0.00
Input Power [kW]	182.76	111.42	186.85	113.90
Carnot Load [kW]	18.36	13.43	14.38	9.74
Useful Exergy [%]	8.86	10.45	7.07	7.88
Load Increase [%]	32.65	8.53	12.94	-2.63
Efficiency Increase [%]	24.26	4.60	6.64	-6.86
Mod-3				
Liq. Acc. [g/s]	3.35	2.33	0.00	0.00
Ref. Load [W]	2	2	230	150
LN2 Usage [g/s]	14.54	9.76	11.02	6.14
Make-up [g/s]	2.67	1.92	0.00	0.00
Input Power [kW]	186.15	113.06	190.44	115.63
Carnot Load [kW]	18.89	13.66	14.52	9.86
Useful Exergy [%]	8.78	10.31	6.84	7.71
Load Increase [%]	36.73	10.43	14.43	-1.32
Efficiency Increase [%]	23.14	3.20	3.17	-8.87

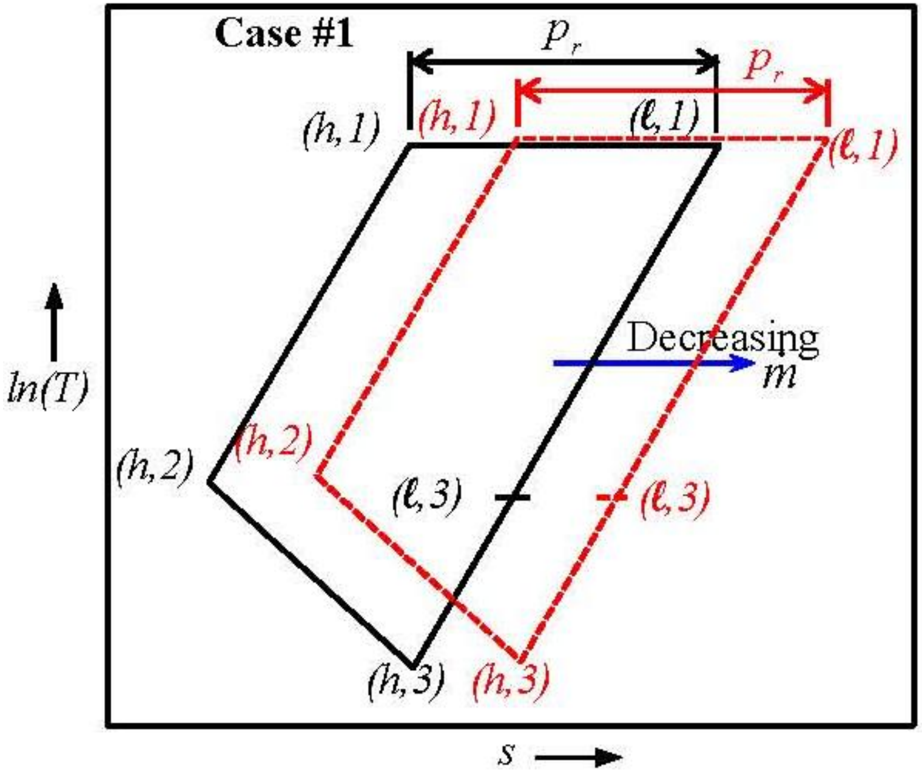
Helium Refrigeration Systems
Present State of the Art



Floating Pressure Ganni Cycle

The compressor and expander establish
an essentially constant pressure ratio and constant system Carnot efficiency





General Arrangement for Floating Pressure Process Cycle (*patent pending*)

Floating Pressure Ganni Cycle

As the "Claude Cycle" is essentially a *constant pressure process*

and, the "Sterling Cycle" is a *constant volume process*

the "Floating Pressure Cycle" is a *constant pressure ratio* process

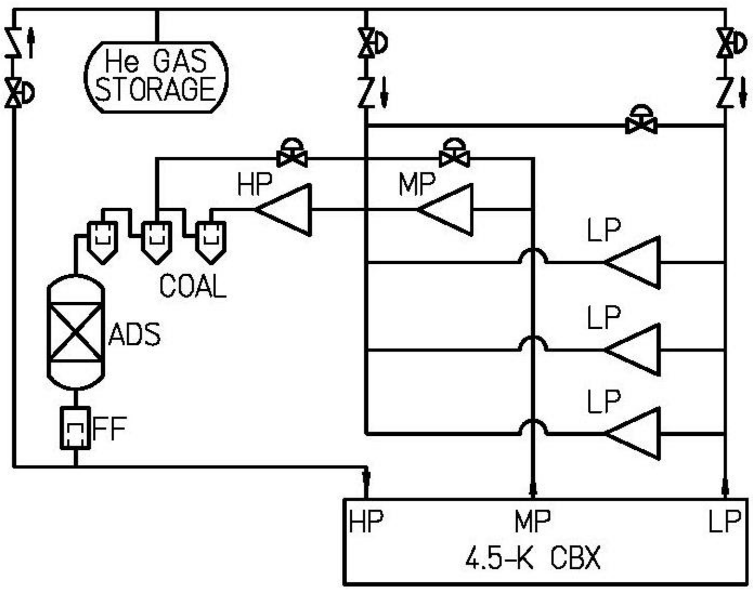
$$p_r \equiv \frac{p_{h,2}}{p_{l,1}} = \left(\frac{\eta_v \cdot Q_C}{\kappa_x}\right) \cdot \left(\frac{1}{\phi \cdot C_p}\right) \cdot \frac{\sqrt{T_{h,2}}}{T_{l,1}} \cong \text{Constant}$$

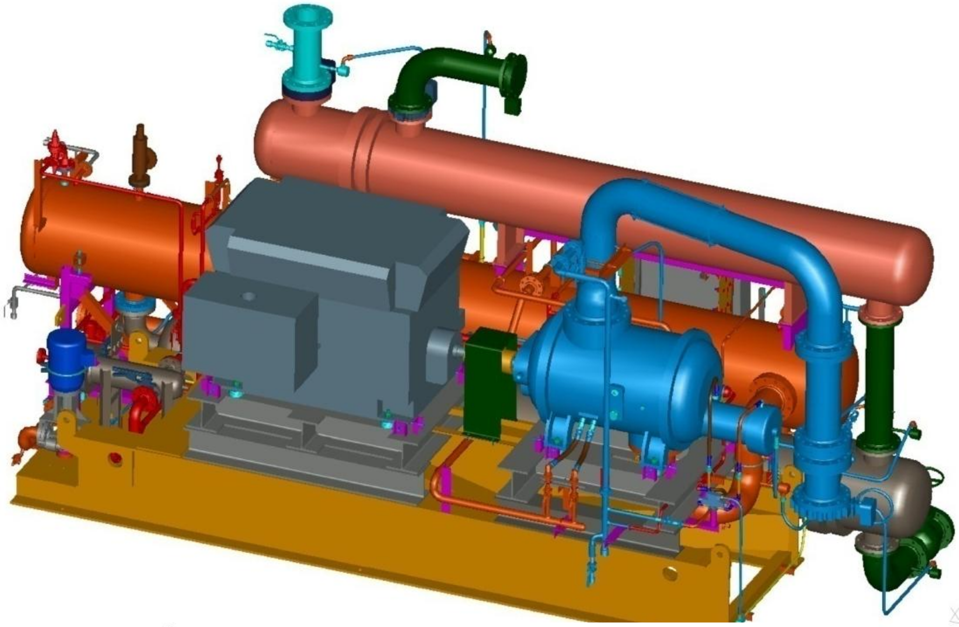
$$\eta_{carnot} = \frac{\mathrm{E}_L}{\dot{W}_C} = \frac{\Delta\varepsilon_L}{w_C} \cong \text{Constant}$$

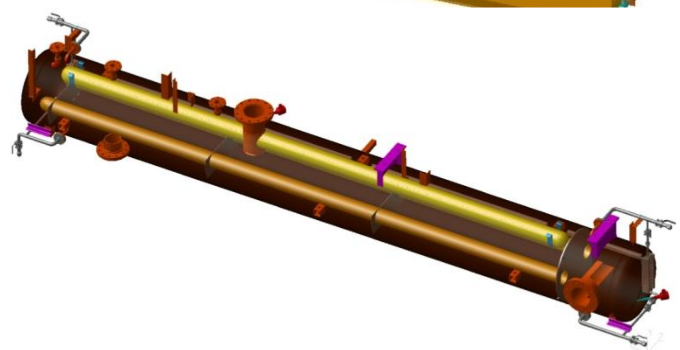
That maintains *essentially constant Carnot efficiency*
over a very wide operating range

(100% to ~ 40% of maximum capacity in practical systems)

Helium Screw Compressor System Advancements





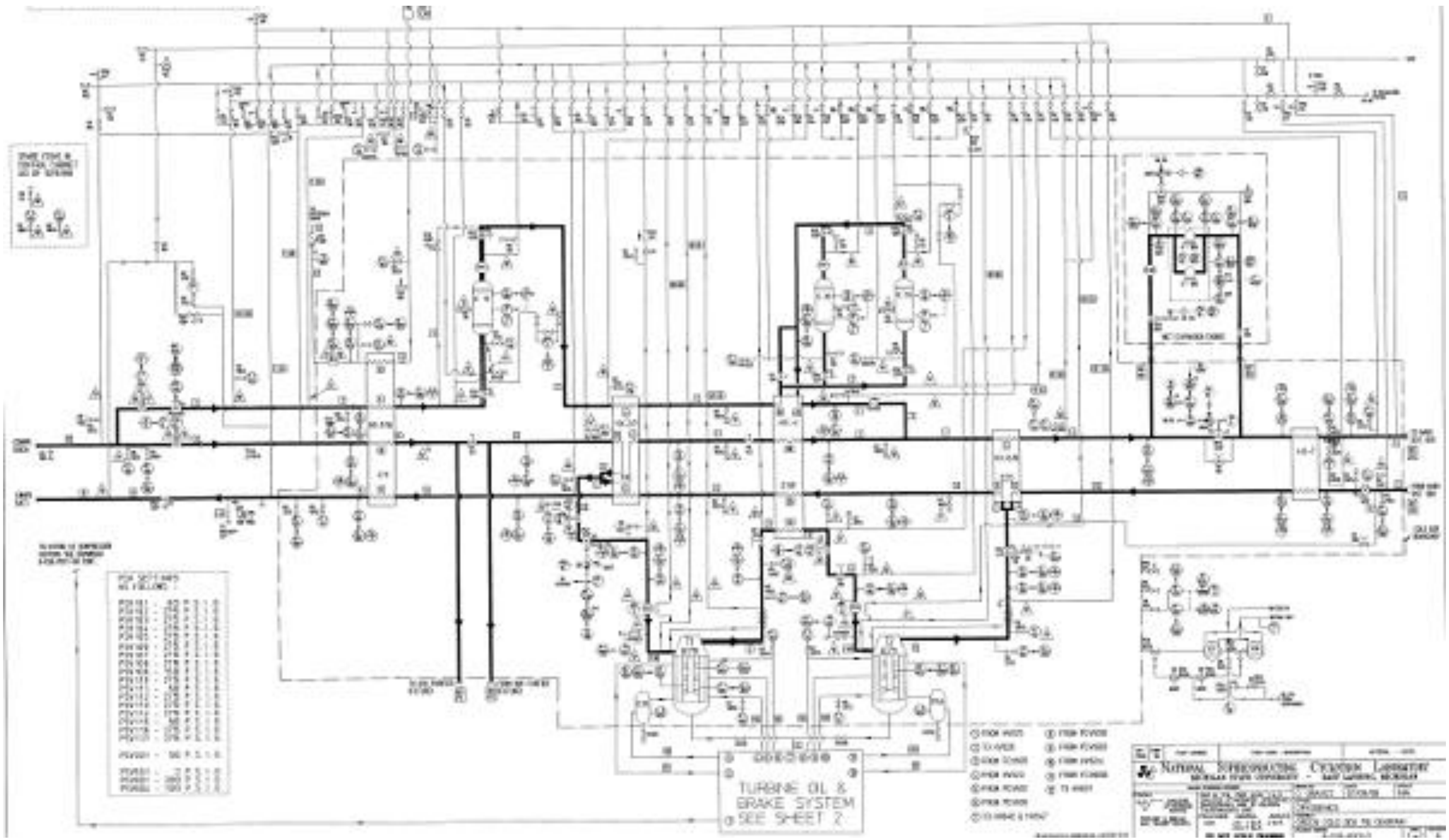


R& D Summary

- Jlab’s Collins Cryogenic Institute is actively supporting helium cryogenic applied R&D in support of the research community
- R&D is shared in collaborations with industry and other labs and are combined with engineering thesis work
- Focus areas include efficiencies of process cycles (existing and planned), utilities, equipment design, manpower, and maintenance/repair
- The derived technologies are being actively integrated into industry and a growing number of user facilities

JLab Cryo Support
to
Other Labs

Upgrade to MSU Helium Refrigeration System (Bureau of Mines Liquefier)

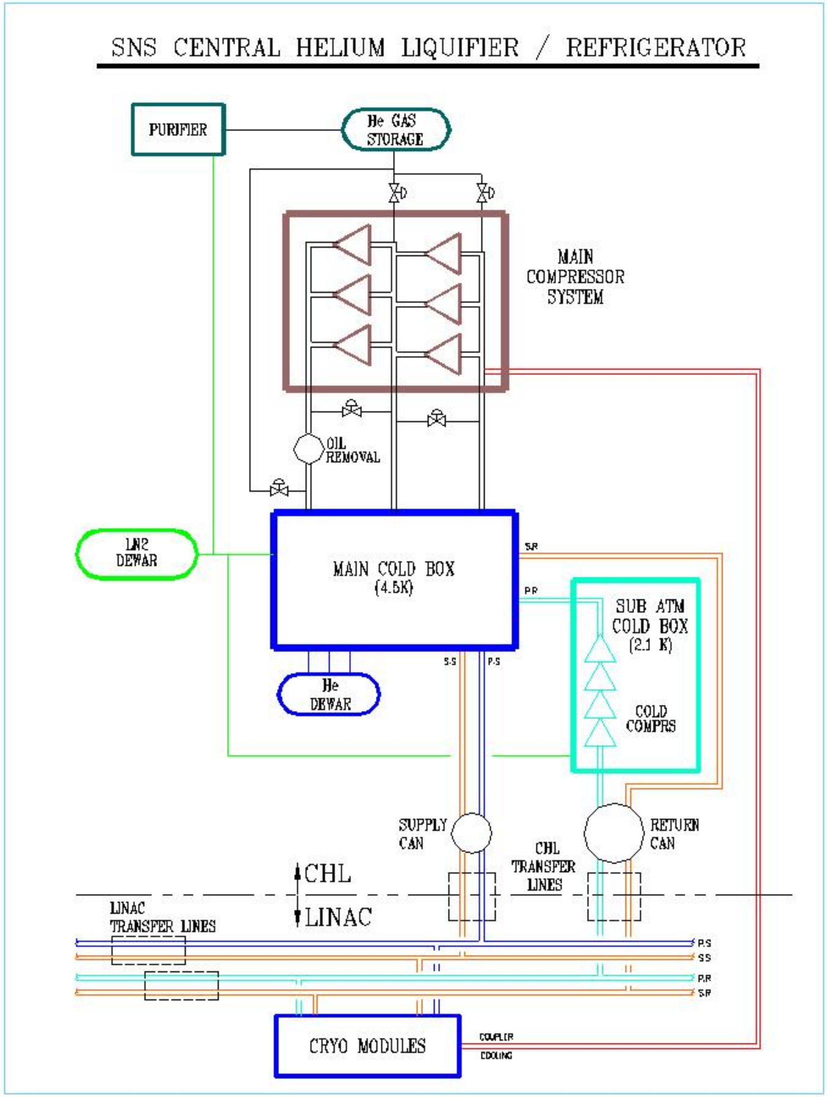


Upgrade to MSU Helium Refrigeration System (cont.)

Cryogenic system upgrade for the National Superconducting Cyclotron Laboratory (i.e., MSU):

- **Upgrade to MSU refrigerator was originally designed as a liquefier for the Bureau of Mines (BOM) in Amarillo, TX (1979).**
- **Original BOM plant was designed as a pure liquefier system but has been arranged (by JLab) to operate efficiently primarily as a refrigerator over varying load requirements and also to support a mix of refrigeration and liquefaction loads.**
- **Compressor discharge pressure follows the load requirement (floating pressure Ganni cycle), reducing the required input utilities at reduced loads as well as reducing the wear and tear on the equipment.**
- **System has been operating continuously for the past ten years with more than 99% system availability.**

Design and Optimal Operation of SNS Helium Refrigeration System



JLab Designed and Integrated SNS Plant and Sub-Systems

Helium Compressor

4.5 K Cold Box

LN2 Storage Dewar

SNS 2 K Cold Box

Oil Removal System

Gas Storage Vessels

Design and Optimal Operation of SNS Helium Refrigeration System (cont.)

- **JLab cryogenic group was responsible for the design, procurement, and fabrication of equipment, as well as, the integration and commissioning support for the SNS cryogenic system.**
- **SNS cryogenic system has been operating continuously since 2005**
- **System is presently set to operate at approximately optimum conditions for the majority of the operating modes by implementing the floating pressure – Ganni cycle.**

The SNS system would have used 3.8 MW of equivalent input power with out the floating pressure Ganni cycle technology and it can be turn down to ~70% (approx. 2.7 MW) of equivalent input power or anywhere in between based on the refrigeration needs of the accelerator.

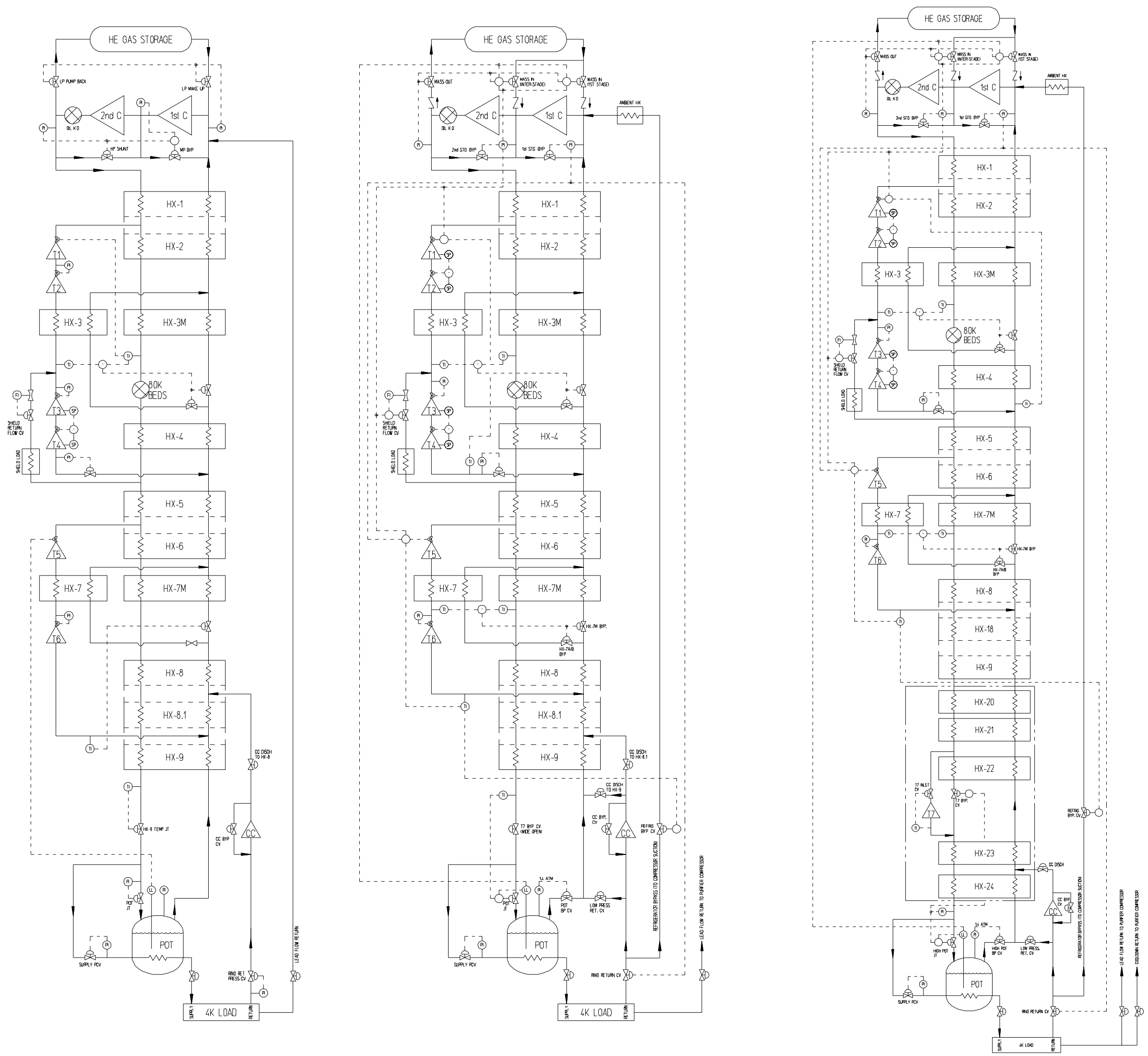
Modifications and Optimal Operation of BNL Helium Refrigeration System

- **Refrigeration system for Brookhaven National Lab (BNL) was originally designed for the Isabelle project with a capacity of 24.8 kW @ 3.8 K without LN2 pre-cooling and capable of supporting some 2.5 K temperature operations**

- **(Original) Isabelle refrigerator at BNL now used to support RHIC, which operates at 4.5 K (instead of 3.8 K) and requires a third of the system's original capacity**

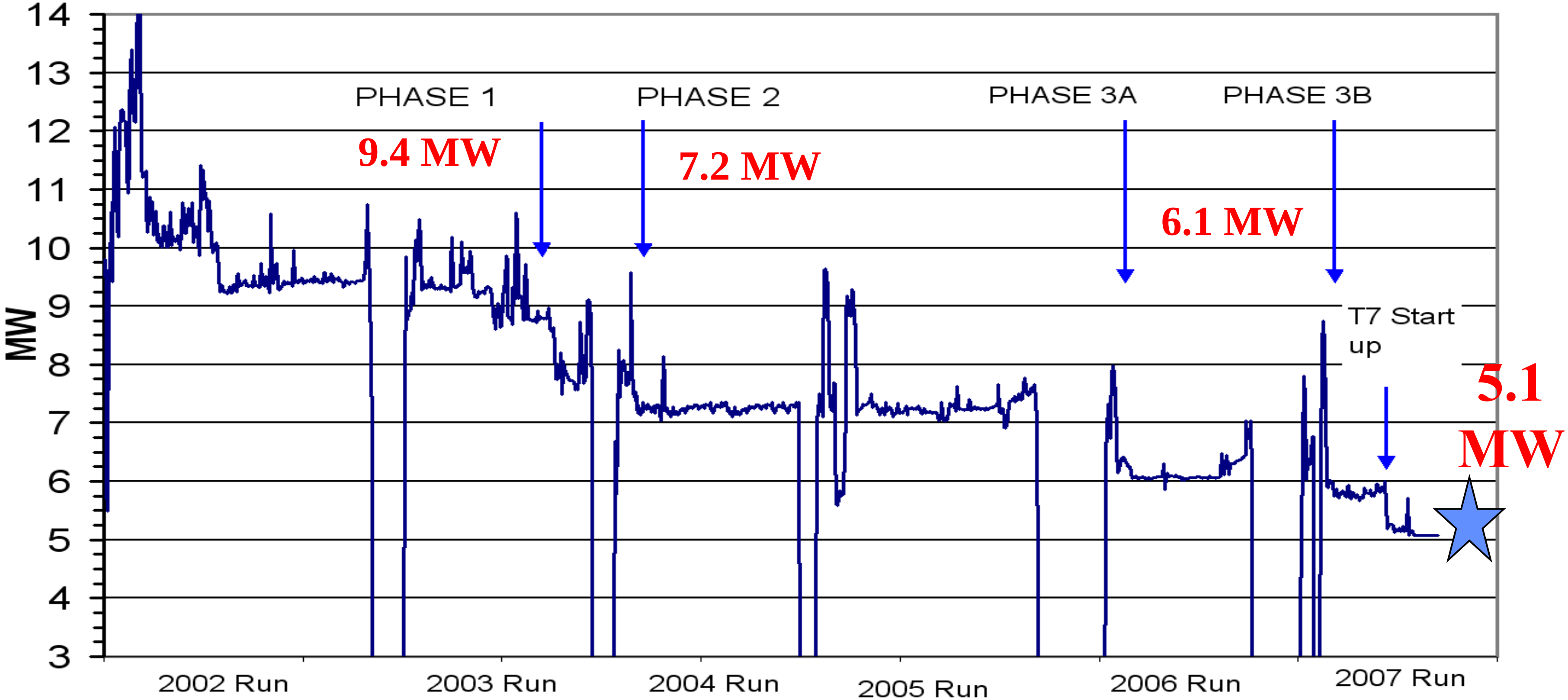
- **Project consisted of three phases (I, II and III).**

Modifications and Optimal Operation of BNL Helium Refrigeration System



BNL RHIC Energy Savings at the Completion of Phase III

Electric Power History Graph, (Phase III "Goal" 5.4MW)



Exceeded 2003 Goal of 5.4MW……46% Electrical Power Reduction Presently (2010) it is at 4.8 MW

NASA-JSC/JLab Collaboration

James Webb Telescope

Replaces Hubble
at ~1 million miles out

Telescope Mockup at the National Mall, D.C.

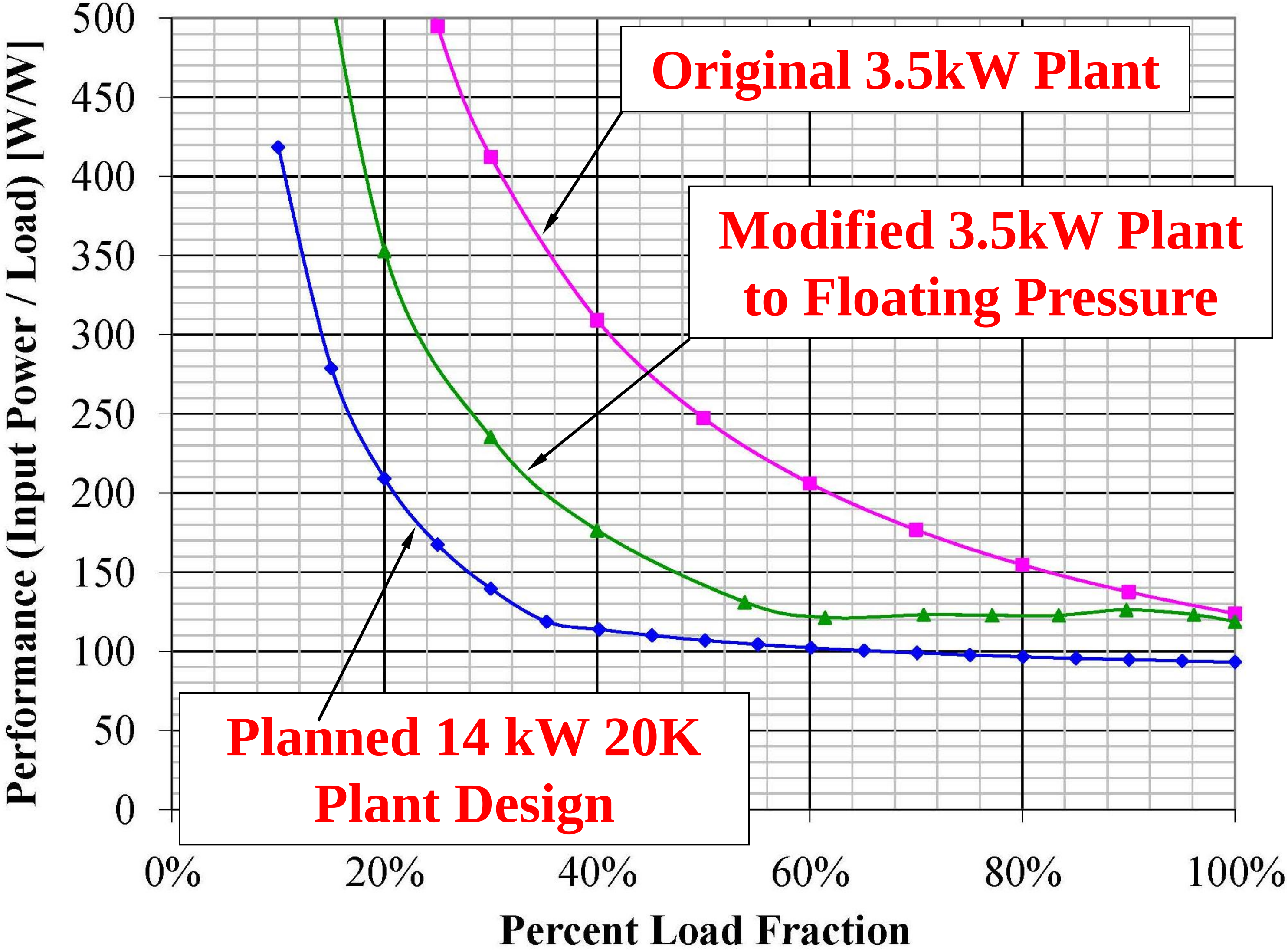
Floating Pressure Technology Used For Telescope Testing in the Environmental Space Simulation Chamber-A at JSC

Existing 3.5 kW 20K helium cryogenic system was converted to JLab's Floating Pressure Technology

Resulted in an improved temperature stability from 2.5 to 0.25 K and improved efficiency

New 14kW 20K helium refrigerator design is based on the Floating Pressure Cycle

NASA-JSC 3.5kW 20 K Refrigeration Test Results After JLab Mods (2008)



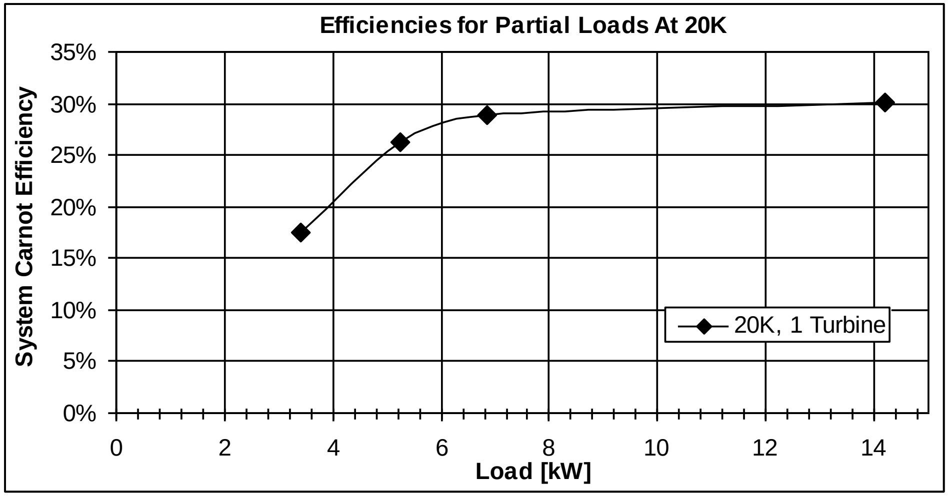
NASA-JSC 3.5kW Plant Test Results

Results for existing JSC 3.5 kW 20K refrigerator after change over to floating pressure – Ganni cycle

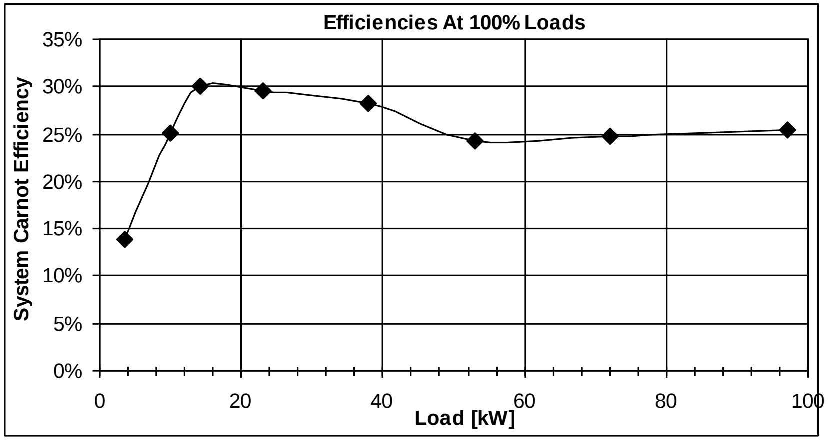
- Greatly improve the system performance
  - System Carnot efficiency is constant from 55 to 100% of the capacity
  - Power savings and reduced LN2 consumption

- Improved system operational stability
  - Improved load temperature stability ~2.5 to 0.25 K

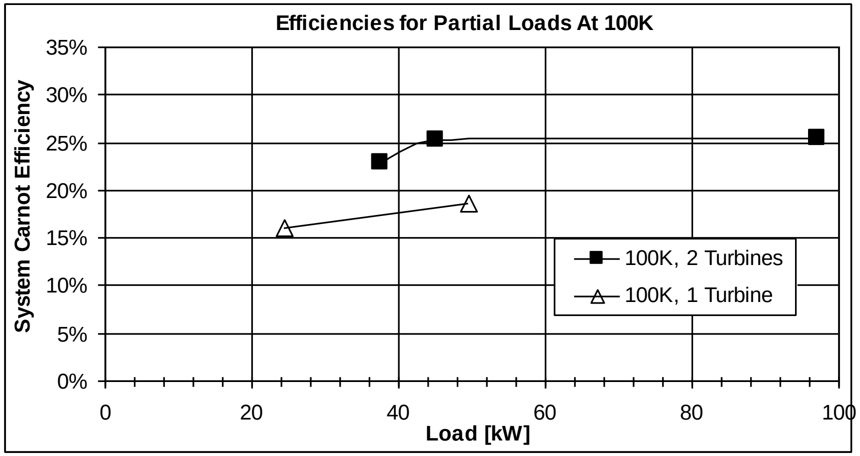
NASA-JSC New 14 kW 20K Plant Design



Turn-down at 20 K Load Return Temperature



100% Loads at Various Load Return Temperatures



Turn-down at 100 K Load Return Temperature

JLab Support to Other Labs (cont.)

Common in all these Jobs:

Floating Pressure operation, NOT forcing the plant to follow the design TS, is one of the key factors in being able to adopt to different load conditions efficiently

Summary

Jefferson Lab has established itself as the US technology leader in the cryogenic area by original, successful and repeated results in cryogenic systems design, fabrication, installation, commissioning, as well as, 24/7 operation expertise for more than 15 years of both 2 K and 4.5 K systems with an unprecedented cryogenic systems availability.

JLab provided the system designs for its own cryo systems like the 2 K cold box's (SCN and modified SCM), ESR and SBR, transfer lines, as well as, designing and supervising the installation of cryo and distribution systems at other labs; such as MSU and SNS.

JLab is the only one in the US (for both the laboratories and the industry) with 2 K system design, fabrication, installation and commissioning expertise that has been demonstrated multiple times.

JLab regularly participates in many other lab cryogenic system planning and development activities. These include the FSU, FERMI, MSU, SNS,BNL, and NASA.

Summary

Jefferson Lab developed and patented the floating pressure Ganni Cycle technology. Application of parts of this technology and other improvements to BNL resulted in ~50% reduction in power (more than $50K per week) in energy savings.

Jefferson Lab has applied the floating pressure technology to all the plants at JLab, MSU, SNS, BNL and NASA to minimize the operating power.

Jefferson Lab has multiple operating cryogenic systems. They all have been automated to operate at optimal conditions (minimal energy input to the system) for varying loads and with minimal operating staff as compared other labs.

JLab's senior staff has multiple decades of both industrial and lab experience in the process analysis, mechanical design, fabrication, installation, commissioning and optimal operation of large scale cryo systems.

JLab is presently involved in the cryogenic systems design for its own 12GeV upgrade, NASA James Web telescope testing, MSU FRIB project as others.

Awards

2006 DOE Office of Science
Pollution Prevention and
Environmental Stewardship P2
"Best in Class Award"

2007 White House
Closing the Circle Award
Washington, DC

Questions?