Progress Toward an ERL CryoPlant Design

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ERL director's Review

August 3, 2007

Outline

- Where we've been: our current operation
- Where we're anticipating for ERL
- What's happened so far
- Current ideas
- Plea for advice

Current cryo operations

Staffing

• 2.5 FTE technicians/designers (talented people)
•1.5 physicist supervisors (RDE, ENS)
• Good support from lab: welding, procurement, etc.
• Weekday dayshifts staffed, call in emergencies

Plant

• 3 600W (at 4.5K), 2 100W reciprocating fridges
• These support CLEO solenoid, 4 RF cavities,
2 SCIR quads, 12 wigglers, anti-solenoids.
• Spare fridges/compressors always available (ping-pong).
• Economical: run with ~ 5% excess capacity.
• ~ 1kW (effective) refrigeration load.
• LN2 used for fridges and radiation shields

Current Op's: continued

How we'll handle the ERL injector tests

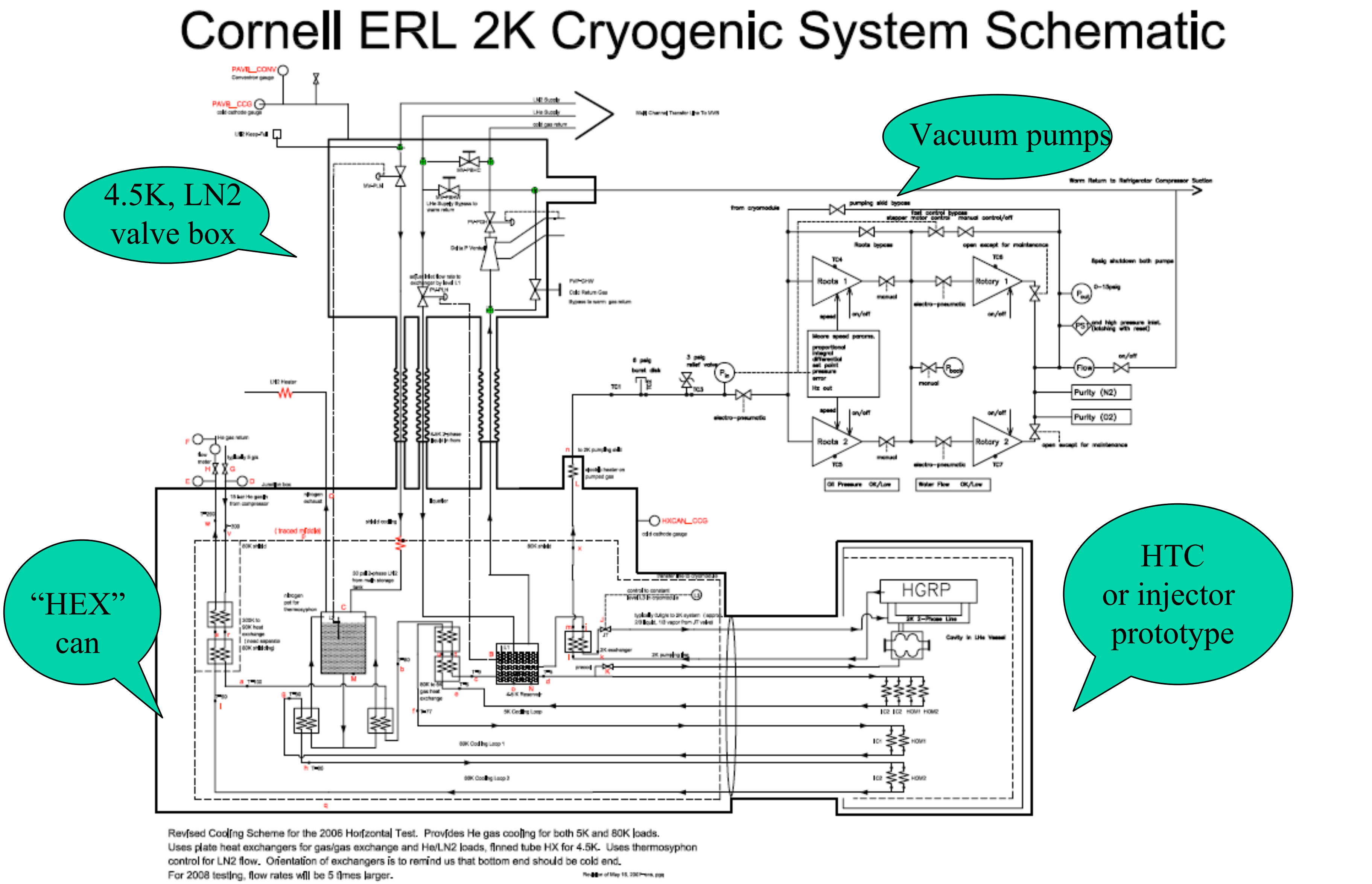
Use excess plant capacity, (warm) vacuum pumps to get to1.8K

- We send 4.5K, 1.2 bar LHe, ~ 7 bar He gas, LN2 to heat exchanger can (HEX can); deliver 1.8K to cavities (via JT) and 80K, 5K coolants for shields, HOM loads and input couplers. LN2 in heat exchange, not in cavity cryostat.

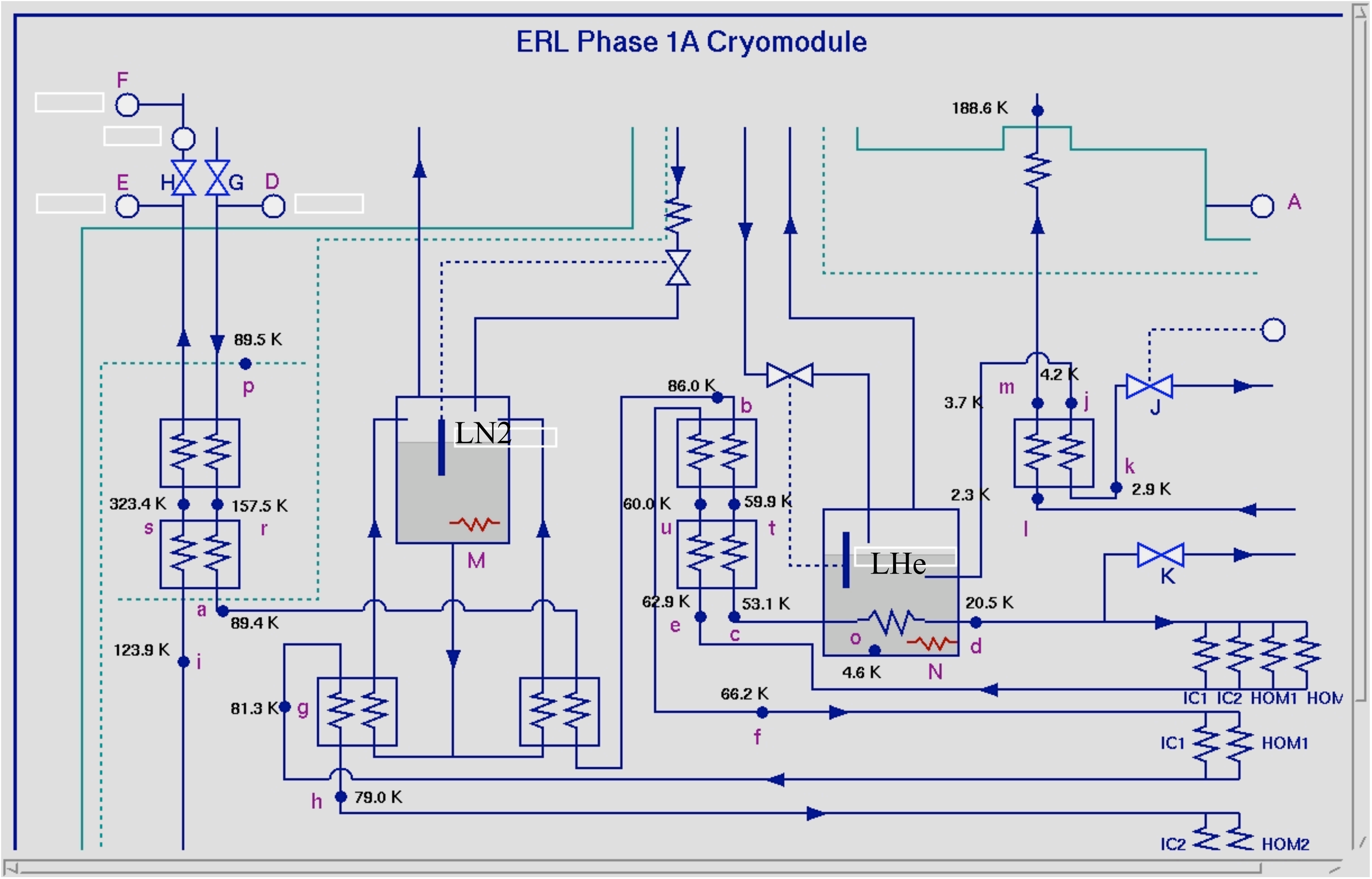
- 2000l storage dewar can supply extra short term capacity. The typical Phase 1a load should require less than one 600W fridge.

- Tuthill/Kinney booster/rotary piston combination can move ~4g/s at 1.8K. Only one of two packages needed for (current)horizontal cryostat test.

The injector test cooling scheme



1.8K operation with dummy cryostat



Current Op's (continued)

Expected heat loads (max)* for each (pre-ERL)phase

	1st test(HCT)	Phase1a	"transition"
2°K	~ 10W (0.4g/s)	~25W (1.1g/s)	~75W(3.3g/s)
4.5°K	25	60	100 ?
80°K	300 ?	900	2000 ?

Equivalent CCI watts at 4.5K are, taking 1.2 X 2° mass flow as pure liquefaction load

1st test: 57W + 25W=72W We'll waste the 2K gas
Phase 1a: 190W + 60W = 250W, or ~ .5* one fridge
Transition : 570W + 100W = 670W, or more than one fridge

* no X1.5 "safety factor" in above

How the ERL needs differ

The cryogenic plant is a major concern for the ERL:

- The ERL is large: 2K cold mass of ~44 metric tons

- The ERL is very cold : 1.8K

- Making 1.8°K is expensive, thermodynamically, and in $$$
    - Carnot efficiency is 1/166
    - Realistic efficiency is typically 1/5 to 1/4 of Carnot
    - ~ 1MW of wall-plug power/(kW spent at 1.8°K)

1998 CERN formula suggested cost of plant > $30 million
And a yearly power bill of ~6$ million!

Furthermore: knowledge of loads is still evolving!

ERL Linac Cryogenic Loads

From Eric Chojnacki's talk:

likely vendors

Item	Nominal Load	+ 50% Margin	Linde and Air Liquide + 50% Margin
1.8K Static/Cavity	0.5 W		
1.8K Dynamic/Cavity	10.5 W		
1.8K Total/Cavity	11 W		
1.8K Total/Linac	**4.2 kW**	**6.3 kW**	**7.5 kW**
5K Static/Linac	2.3 kW		
5K Dynamic/Linac (HOM)	3.1 kW		
5K Total/Linac	**5.4 kW**	**8.1 kW**	***13.5 kW***
80K Static/Linac	5 kW		
80K Dynamic/Linac (HOM)	60 kW		
80K Total/Linac *	**65 kW**	**97.5 kW**	**105 kW**

40-80K in studies

Evolution!

* 80K may not be the optimal intermediate temperature

Cryogenic load predictions will be tested in the HTC: Soon!

ERL plant :likely features

•Even the "nominal" load is more than can be supplied by a single LHC-sized cryoplant (18 kW at 4.5K+ 2.5kW at 1.9K), hence,we expect 2-3 big machines, with attendant cold and warm compression.

•What we've done so far:

1) Estimated loads, decided on safety margin
2) Decided operating cost /capital cost relationship
3) Defined "operating year": 5000 hrs at 1.8K, remainder "standby"
4) Solicited design studies from Air Liquide and Linde Kryotechnik AG in Aug. '06.

Charge (paraphrased):

Optimize design for sum (10 yrs. operating + capital), neglecting civil construction. Avoid unsightly gas storage…. Present process diagrams, equipment "vital statistics", plant footprint. Present cost-scaling algorithm to allow for evolution in load estimates. Discuss de-livery and installation. Cost estimates to be accurate to ± 20%.

The design -study reports

Both reports were received in Dec. 2006. They were very useful

Air Liquide- Linde comparison

Page one: scope, cost, delivery

Air Liquide Scope	Linde Scope
1) 2 (identical) systems with 2-stage compressor + sub-atmospheric station, NO MCC included (14 kV !)	1) 2 different fridges: "shield" (1 coldbox) , 1.8K (2 coldboxes), 2-stage compressors + sub-atmospheric, MCC included
2)Valve box including all cold compressors, HEX's phase separators, and ~ 44 cryogenic valves	CC's are in coldbox 2, NO VB discussed
3)2 13,000 liter liquid-storage dewars (Lhe)	3) NOT supplied
4)1 10,000 l LN2 storage tank + xfer lines	4) NOT supplied
5)All LHe XFER lines (~$5M) to/from ERL and Dewars	5) NOT supplied
6)full He recovery and gas management system, including purifier and medium pressure storage, gas-bag(s), and heater	6)External purifier, storage NOT inluded
7)all process control hardware and instrumentation including CPU's	7)Full (Siemens) control system, programming + profibus interface.
8)all warm SS plumbing	8) parts and installation and leak check

(continued)

Design-studies (cont.)

Note: Coldboxes weigh 10^5 kg! Compressors $0.5 \cdot 10^5$ kg

9)transport to seaport in US, NOT to site

10)a)Installation advice only, startup and com-missioning period, 5 days training post startup

11)Not included

Air Liquide Costs: 150% of design

$72.9 Million, $66.4 (option 2, coldboxes at tunnel)
assumes 1.3276$/Euro
Delivery+ installation time: Air Liquide
26 months + installation + commissioning

10 year operating cost: Air Liquide ("design" year)

$60.27 Million (includes maint. costs)

Diesel or NG generator surely needed, 100kW?

9) Transport to ERL site

10) erection of steel structures, commissioning, startup test

11) Gas drying equip., adsorber regenerating syst.

Linde Costs: 150% of design

67.9 M CHF $57.0 Million
at .84 CHF/$
Delivery+ installation time:Linde
38-42 months (total)

10 year operating cost: Linde

$64.5 Million including $6.8 Million labor for crew
$57.7 Million without operating crew

Conclude: 1) Within ± 20% accuracy, identical pricing!
2) 10-year op. cost = capital cost!

Design-studies (cont.)

Utilities comparison

AC power, H2O, Air: Air Liquide

Item	kW	kW	water, 72°F	dry air
	480 V	14kV	m^3/h	(6.5 bar)
C:VLP(2)	460		40	
C:LP (2)	190	2208	200	
C:HP(2)	190	9700	720	
fridges(2)	210		30	
C:recovery	158			
VB	64		1	
He dewars(2	16			
purifier	7			
total	**1295**	**11908**	991	40
			4365	**24**
			GPM	**CFM**

AC power, H2O (°F?), Air: Linde

Item	kW	kW	water	dry air
	480	14kV	m^3/h	
C:VLP		780		
C02, C03		4200	402	
CO4	500			
C51,52		4700	341	
fridges			31	50
	980	**9680**	774	50
			3409	**29**
			GPM	**CFM**

Note: above numbers are for recommended INSTALLED capacity at full load . Less will be actually used.

note, also, for Air Liquide, only 18°F RISE IN WATER!

Linde design is somewhat less power hungry

Key features: Air Liquide study

- **Two identical** systems each (roughly)LHC sized, "cross-connectable".
- Each fridge distributes to two of four "half-linacs"
- **Mixed** warm and cold compression on 1.8K return (3 cold compressors/fridge)
- Valve box at surface level contains all CC's and1.8K phase separators to provide gravitational head for distribution. Placed close in all options.
- 13,000 liter cold storage associated with each fridge: easy re-liquefication, and recovery possible?
- Extra LN2 HEX for aid in cool-down
- **~500m of transfer line** in event that cold-boxes are remote
- Purification system for recovered shield-gas helium (expander bearings, seals)
- **Realistic-looking, but large** , suggested plant footprints
- **Cool 3-D videos** of proposed plants.

Main contact: Pascale Dauguet

Our general impression: the study was responsive to our charge, the design is pleasingly redundant, COP's good, but not as good as Linde's. A lot of work was done on plant location. They suggest costs scale ~ (4.5K-POWER)^0.6

Linde Features

• One dedicated, 1.8K machine (5CC's, 1.5 cold boxes) PLUS
• One dedicated "shield" fridge producing 4.6K and 40-80K coolant (Note that shield fridge is priced at ~60% of 1.8K : no CC's, simpler control, despite greater 4.5K equivalent refrigeration.)
• Very good COP's: 588 at 1.8K, 150% load:3.5 X Carnot
700 at expected operating load
• more compact plant footprint than Air Liquide : only 35m X 65m !
Is this realistic? They defend it.
Principal contact: John Urbin
• Cost scales as (roughly) (4.5K refrigeration power)^0.4

We have a comparably favorable impression of Linde's work. We hope for a useful competition. Expected somewhat more detail on plant layout.

Where will it go?

- 3-level, underground!

~close to middle of linac

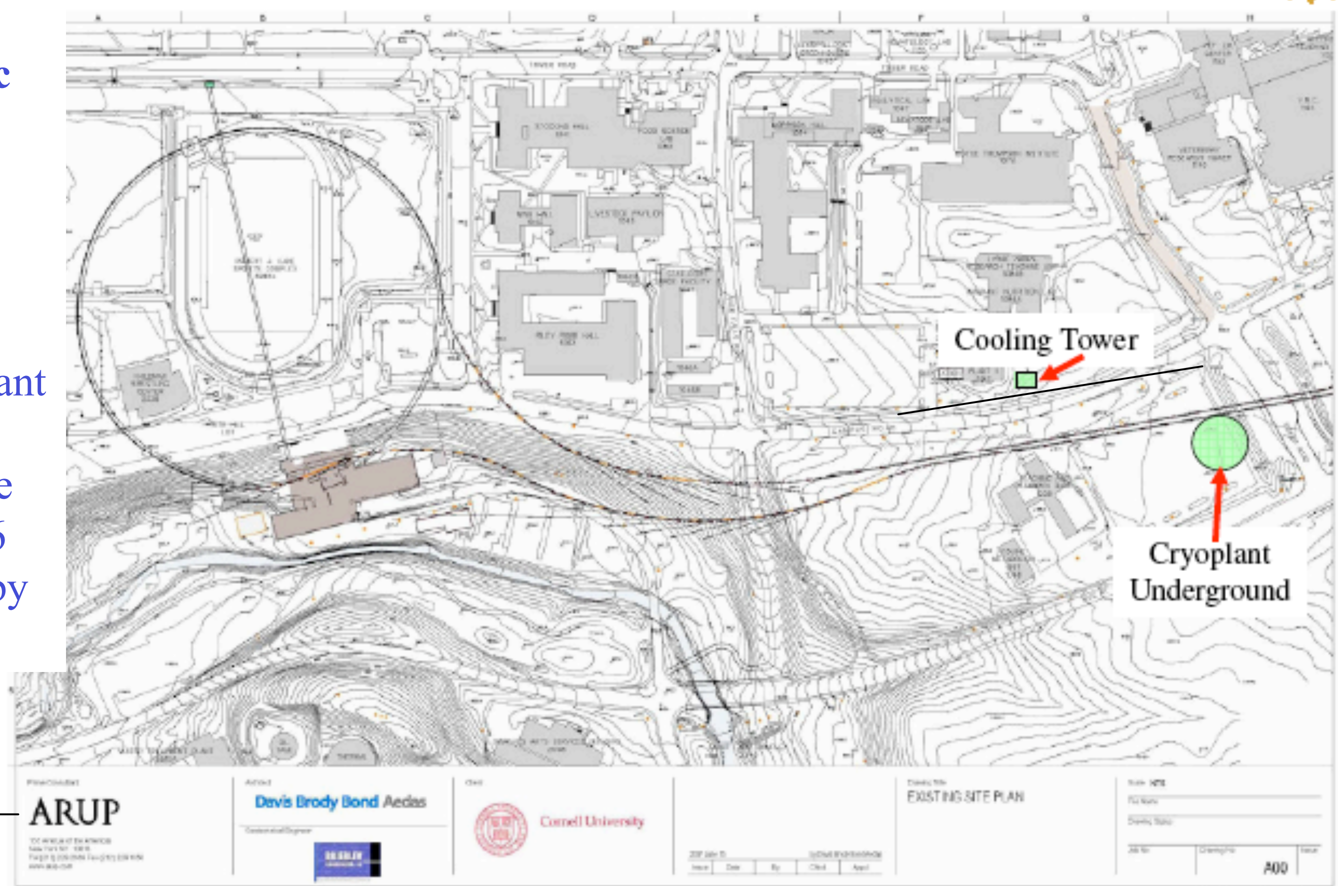
- beneath valuable parking lot.

- Other options:

1) small coldbox-only plant near linac.
2) Long cryo transfer line from plant across Rt. 366
3) Fix parking situation by other means.

CU's civil Construction consultants ←

Building #3, Cryoplant

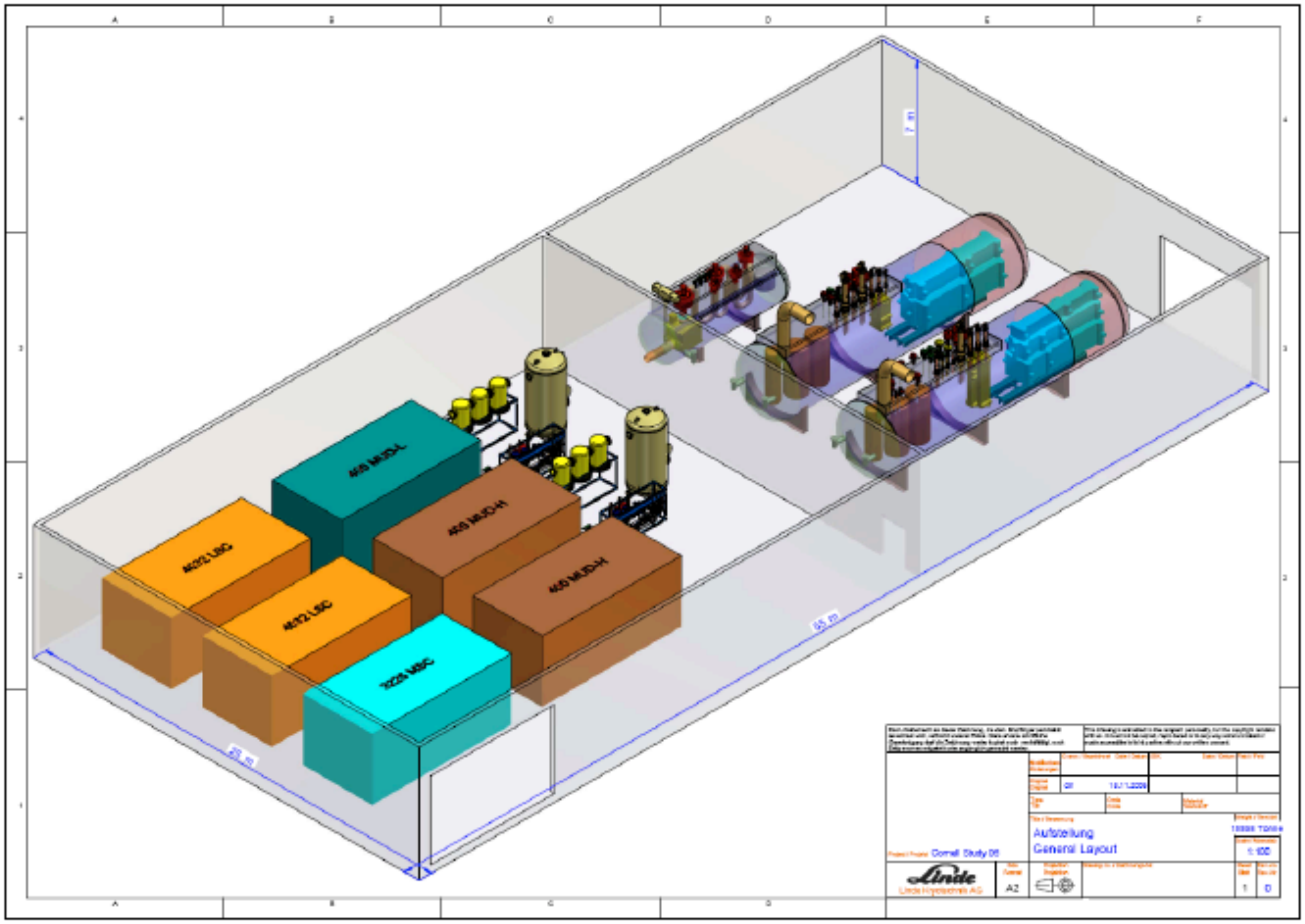


Cornell University
Cornell Laboratory for Accelerator-based Sciences and Education

Director's Review of ERL@CESR, August 2-3, 2007

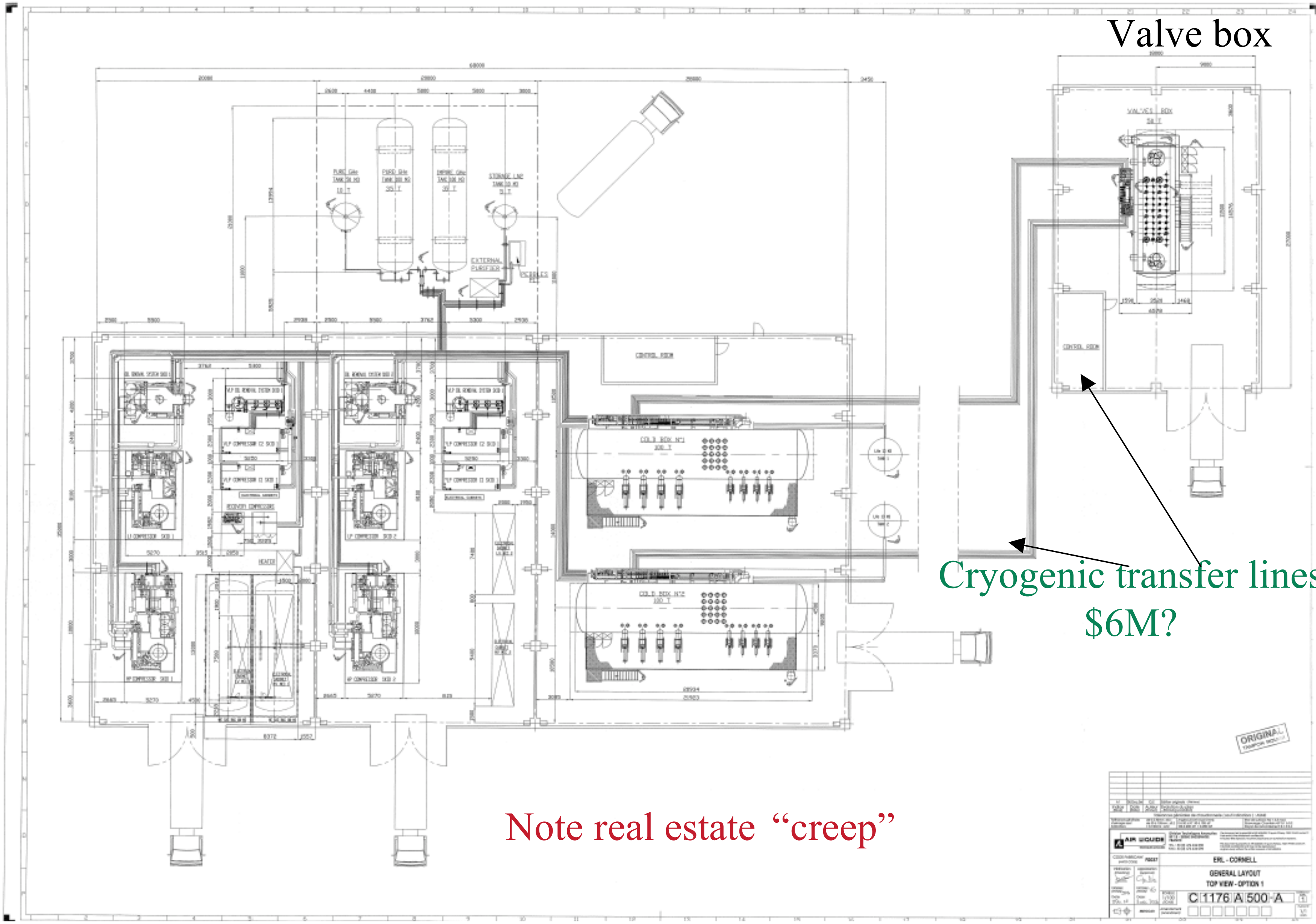
Linde's Plant

Doesn't show truck access, gas storage, purifiers…



CORNELL-STUDY06 A3.11 Layout Drawings

One Air Liquid layout



Our inclinations

•We'll work to optimize choice of "80K" shield temperature. Broad optimum?

•We dislike difficult, expensive power outages. We worry about escalating helium pricing.
•We know that CU will not like unsightly gas storage for 20,000 l (equivalent) Hence, we favor liquid storage with possibility of rapid transfer of inventory to/from cryomodules, even with power outage. This needs much more work, but **could** save ~1 week of science and 10,000 liters*???$/liter per occurence.
Please comment

• We favor above ground location of 1.8K phase separators vs major cold box with JT's in tunnel. Doesn't gravity head help?
Please comment

•We are very skeptical about ARUP plan for underground 3-story plant. Can we reject this out of hand? Safety? Mechanical loading? Vibration!
Please comment

More questions, ideas

•We worry about the real cost of remote refrigerator plant with long cryogenic lines running across campus. Under Rt. 366? Maintainability of buried lines? What about non-cryogenic lines between compressors and cold boxes?
How strongly should one argue for proximity to mid-tunnel?
Please comment

•Are separate, smaller, transfer lines to the four "half-linacs" preferable to a single large one?
Please comment

•What degree of parallel feeding of cryomodules (vs series cooling) of 5K and 80K loads is best? Potential control problems?

• LN2 is useful for purifier, extra help in cooldown. Not otherwise.
Do you agree?