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CHAMBER A- LN2 SYSTEM UPGRADE

FROM FORCED FLOW TO THERMO SIPHON

Jefferson Lab
Thomas Jefferson National Accelerator Facility

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Jonathan Homan, Mike Montz
NASA , JSC

Venkatarao Gann, Ahmed Sidi-Yekhlef, Peter Knudsen,
Jonathan Creel, Dana Arenius
THOMAS JEFFERSON LABORATORY, Newport News, VA

Sam Garcia
JACOBS ENGINEERING, Houston, TX

John Lauterbauch
GEOCONTROL SYSTEMS, Houston, TX

CERN

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FROM FORCED FLOW TO THERMO SIPHON

Background Information

- Liquid Nitrogen Shroud in Chamber A is 57 Ft in diameter by 92 ft high
  - » Divided into 28 zones
  - » Provides 80K background environment for LEO simulation
- Forced flow system utilizing three primary pumps and one auxiliary pump with 40 HP each
- *In excess of* 100 control and isolation valves, and 100 RV's and burst disks
- Six storage tanks with total capacity of 144,000 gallons
- One 6,000 gallon "Boil-Off-Tank" with vent stack

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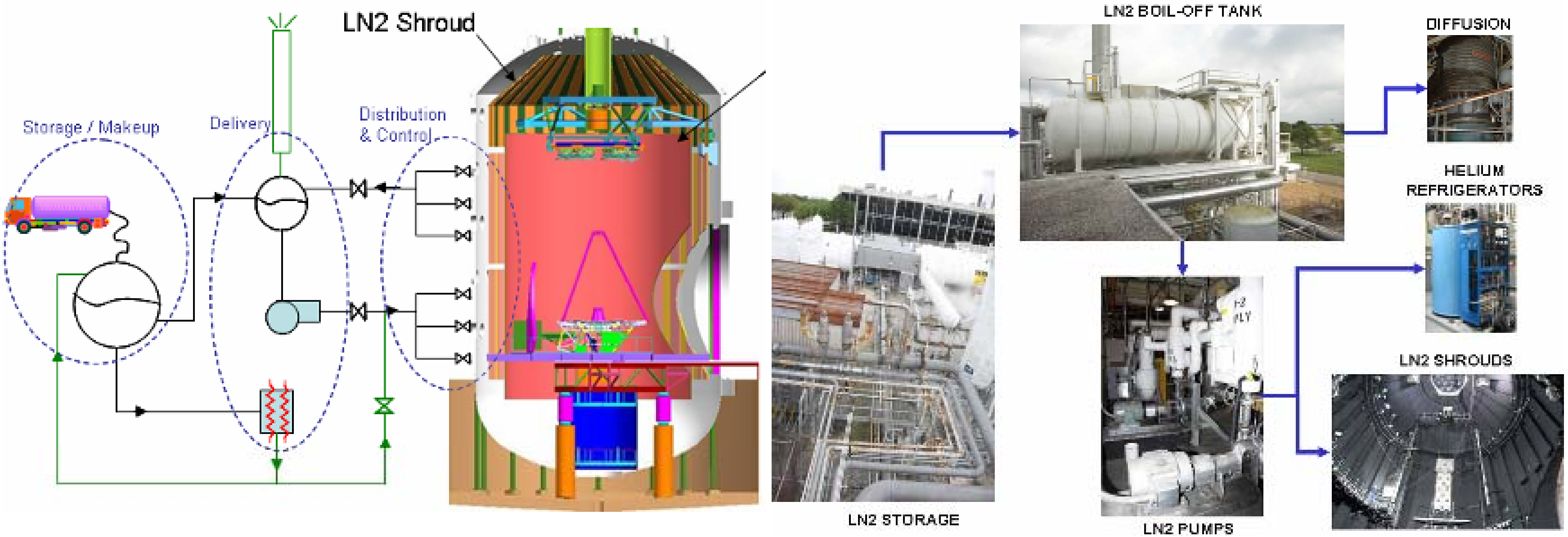
LN2 System- Currently



- Storage: 6 Vessels, 144,000 Gallons Capacity, two truck unloading
- Delivery: 3+ pumps, 6000 Gallon Separator, Steam/LN2-GN2 Vaporizer
- Distribution: 28 shroud control zones

Reason For Upgrade

- **A long duration test (such as JWST's 90 to 120 days) requires that all systems be highly reliable and robust**
  - » Current LN2 pumps have a maintenance cycle of approximately 300 hours while the James Web Space Telescope (JWST) timeline approaches ten times this amount
  - » System is electrical power dependant
  - » The large number of control valves and relief devices have resulted in low reliability for continuous operation
- **Thermal load, stability and uniformity of the internal 20K helium shrouds will depend upon a complete and uniform temperature LN2 shield**
  - » Failure of a control valve will disrupt uniformity of not only LN2 shroud but the internal helium shroud as well
  - » Too many valves to control for uniformity
- **System as it currently exists is not an efficient user of LN2**
  - » Up to eight loads (52,800 gallons) of LN2 per day at steady state

40 HP LN2 Pump

Control Valves on Inlet and Outlet of Each Zone

Initial Upgrade Approach

- Replace existing pumps with new cryogenic pumps having longer maintenance cycles
- Put the new pumps on emergency power to increase availability
- Rebuild or replace all of the control valves, pressure control and relief devises
- Rework the control system to maintain temperature uniformity at all chamber levels
- Repair or replace and re-insulate LN2 distribution lines to improve efficiency
- Convert one of the six supply tanks to a phase separator tank to increase the efficiency of the Boil-Off-Tank

Problems with Initial Approach

- Cost Issue Encountered at PDR
  - » Pumps with 3000 hour capability were expensive
  - » Installation of new pumps with double block and bleed capability required for real time maintenance was expensive
  - » Placing the pumps on emergency power was driving up the cost of a new generator (Backup system was growing towards 3 MW)
  - » Rebuild and/or replacement costs for the number of valves and pressure control devices was expensive
  - » Reworking the control system to maintain temperature uniformity at all chamber levels was a complex undertaking
  - » Converting a supply tank to a phase separator tank increased system complexity

Thermal Siphon A Fresh Approach

- While a gravity flow system had been discussed previously it had been discarded due to the perceived technical risk of gas blockage
- Concerns were also raised about elevated tanks in a hurricane prone area and their cosmetic appearance on the building
- After the PDR however, participants started to discuss this option again and to study the possibilities more seriously
- Jefferson Labs personnel performed analysis that showed the technical risk was much lower than originally thought

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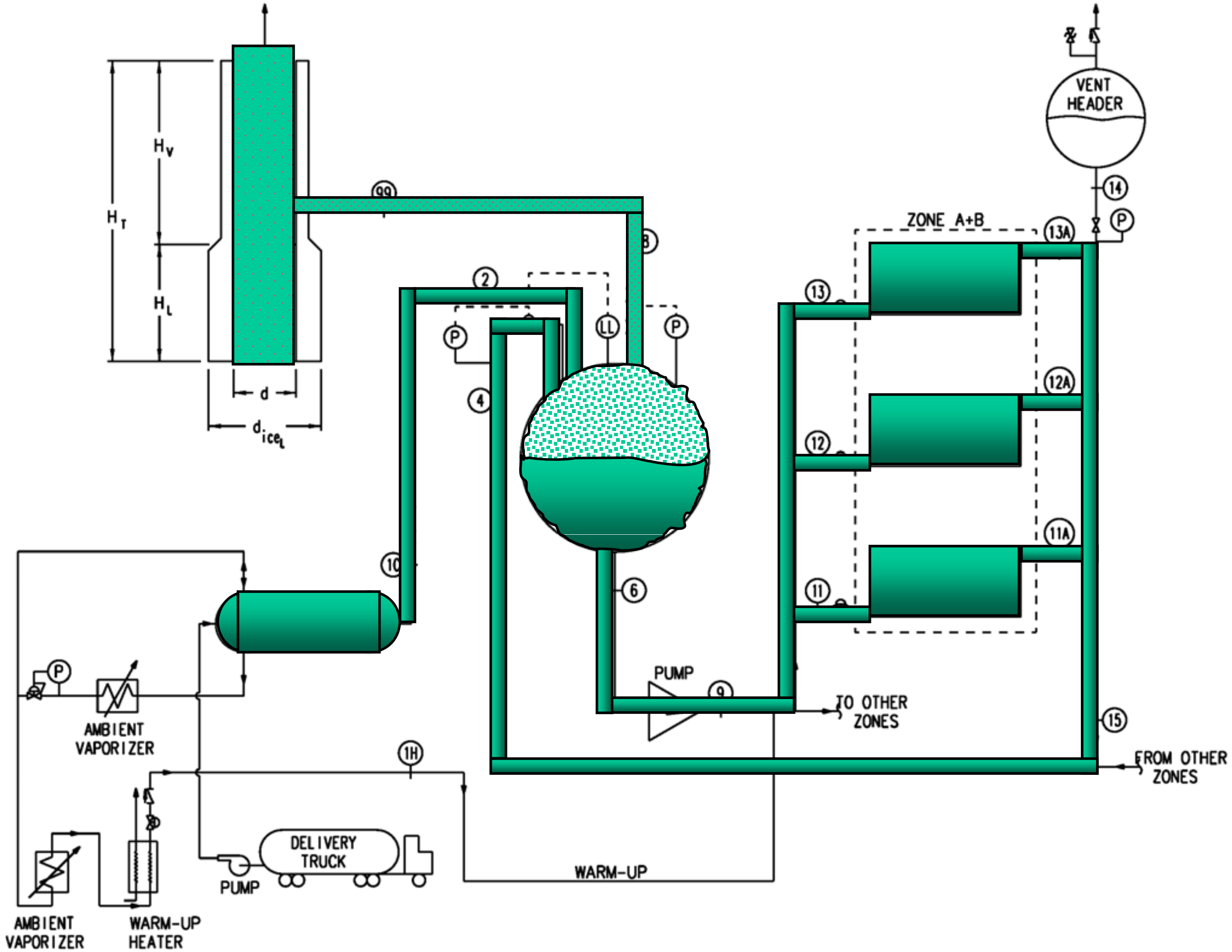
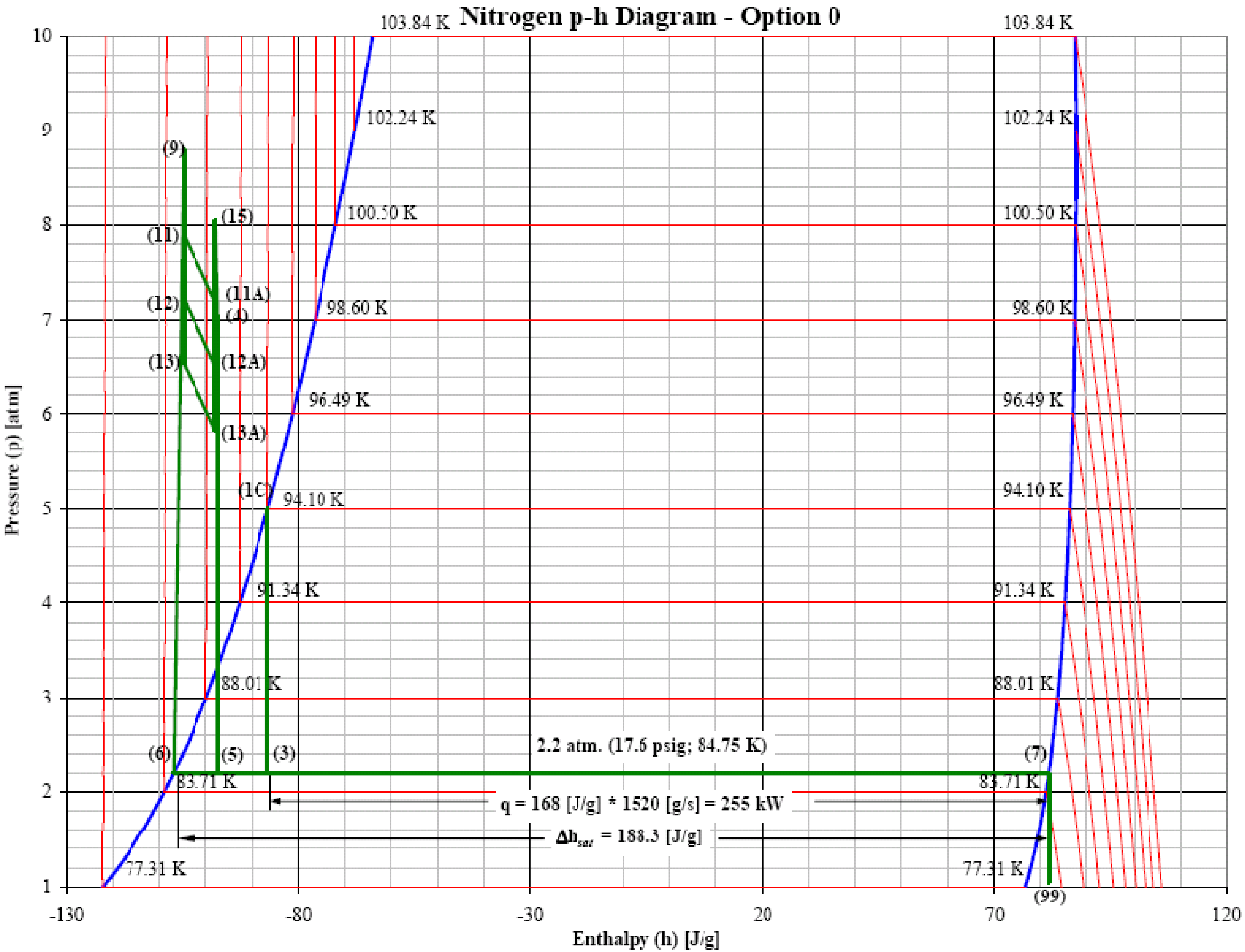
Existing Forced Flow System

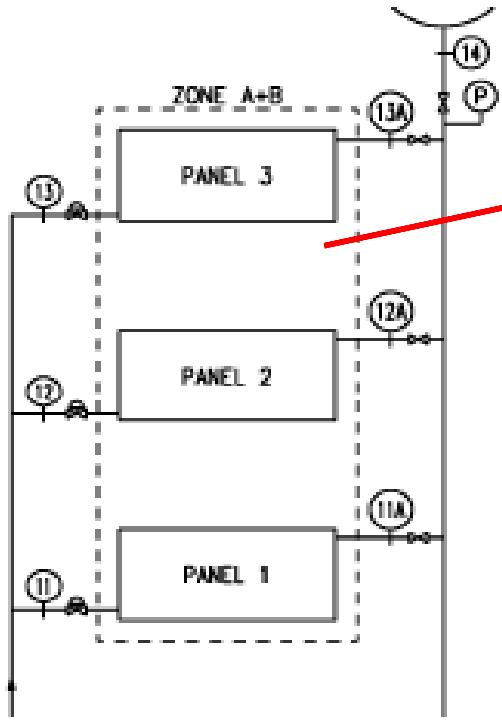


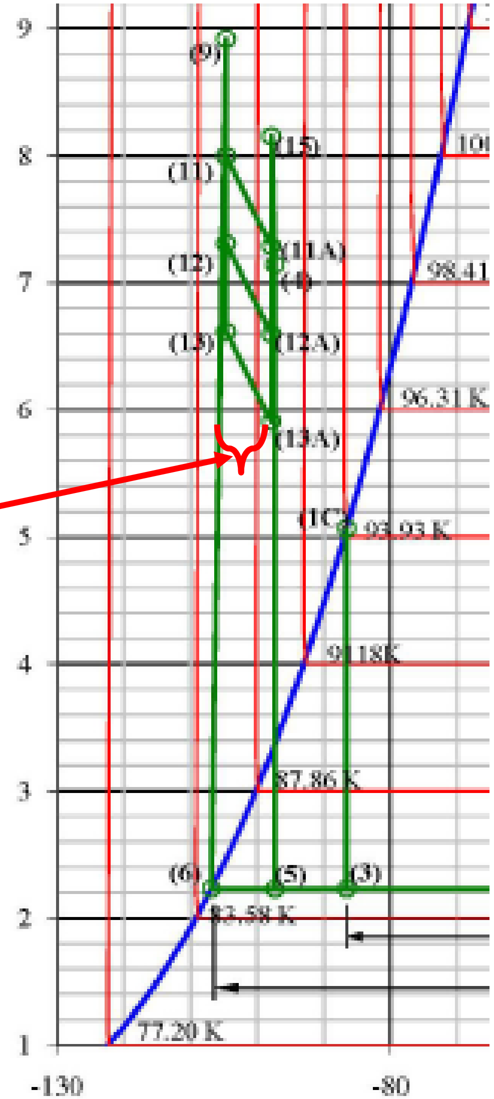


Nitrogen p-h Diagram - Option 0
103.84 K
103.84 K
102.24 K
102.24 K
100.50 K
100.50 K
98.60 K
98.60 K
96.49 K
96.49 K
94.10 K
94.10 K
91.34 K
91.34 K
88.01 K
88.01 K
83.71 K
83.71 K
77.31 K
77.31 K
(9)
(15)
(11)
(11A)
(12)
(4)
(13)
(12A)
(13A)
(10)
(6)
(5)
(3)
(7)
(99)
2.2 atm. (17.6 psig; 84.75 K)
q = 168 [J/g] * 1520 [g/s] = 255 kW
Δh_sat = 188.3 [J/g]
Pressure (p) [atm]
10
9
8
7
6
5
4
3
2
1
-130
-80
-30
20
70
120
Enthalpy (h) [J/g]

Pressure Enthalpy Analysis (continued)

- **Shroud panel temperatures will operate between 95K and 99.5K**





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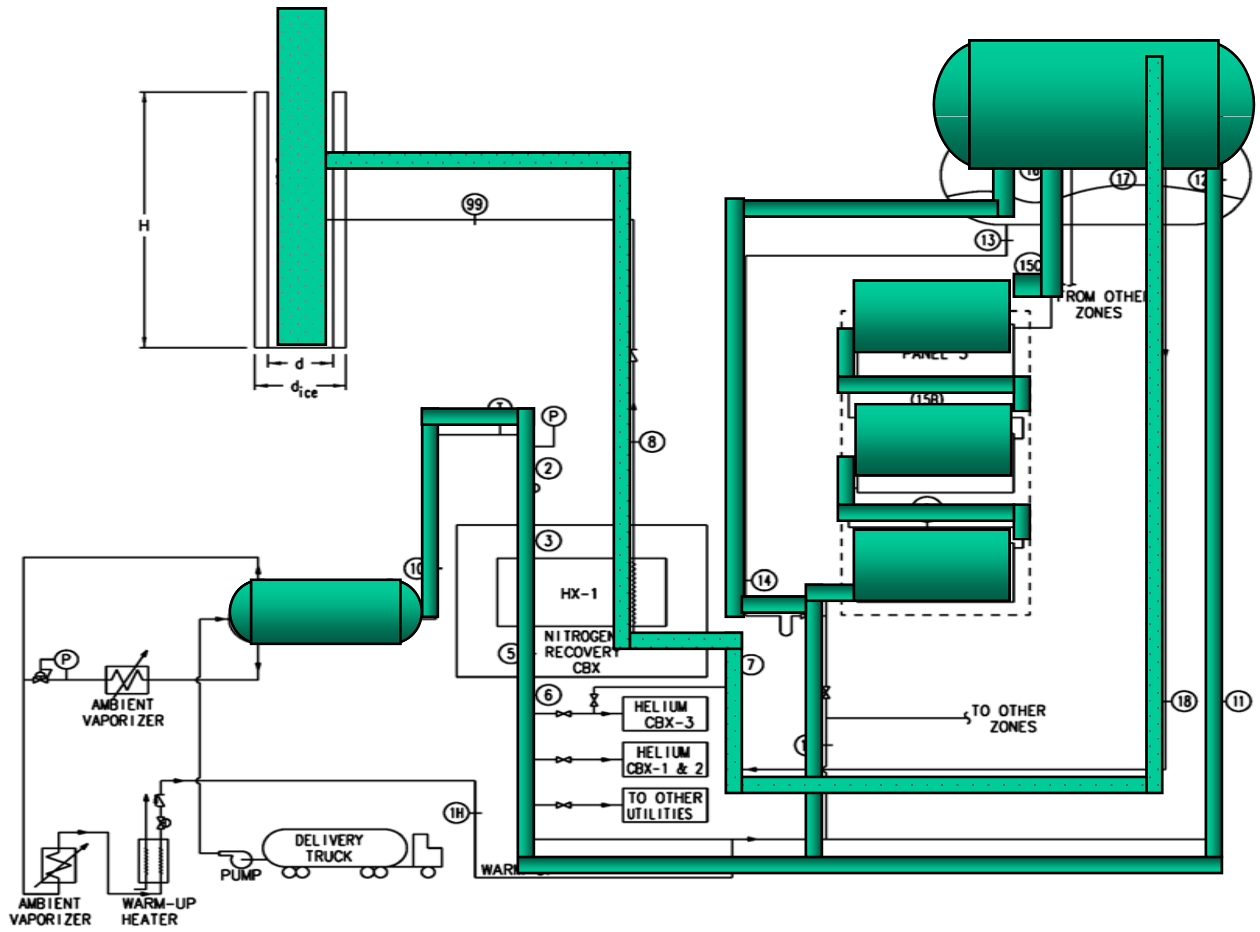
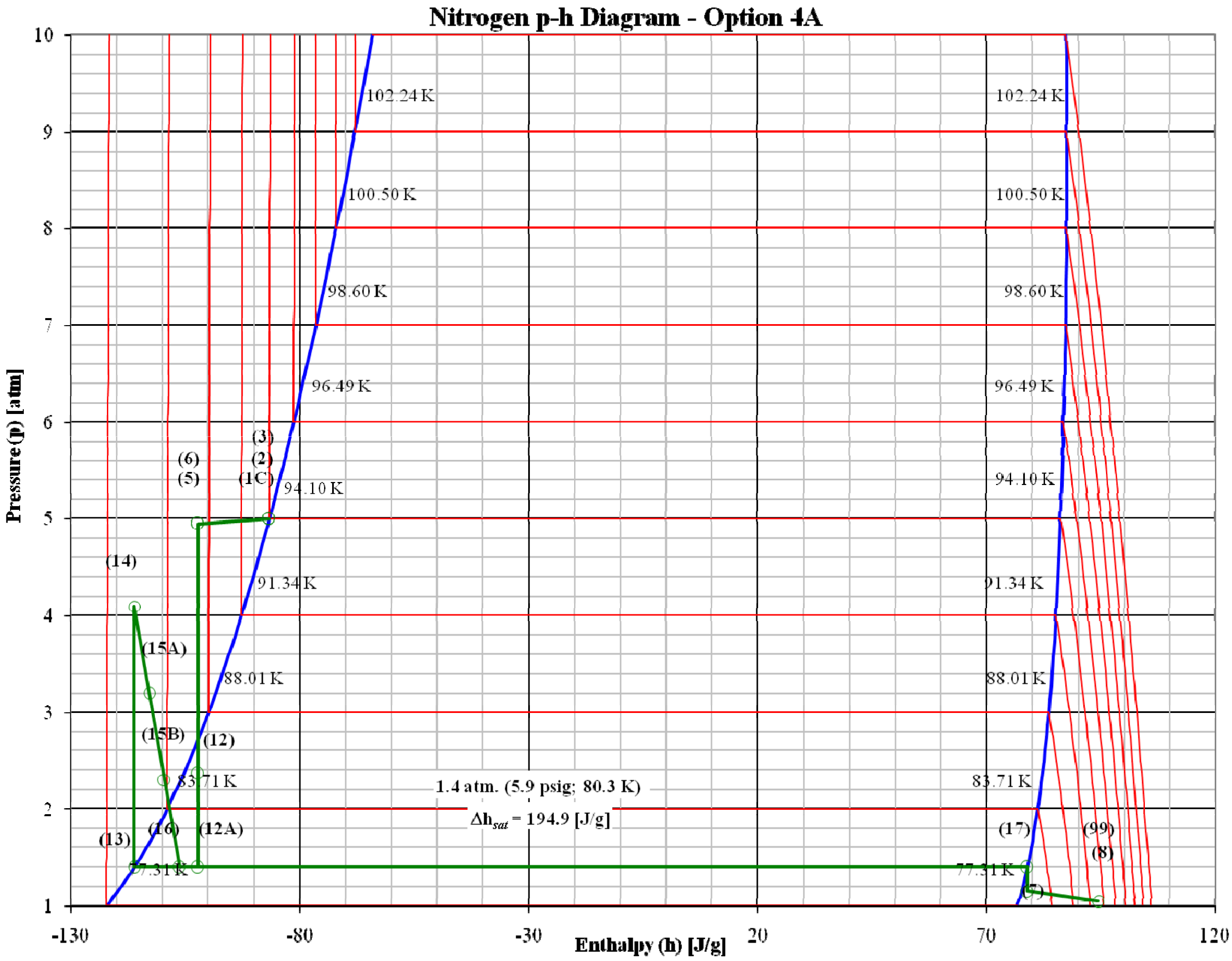
Thermo siphon Analysis



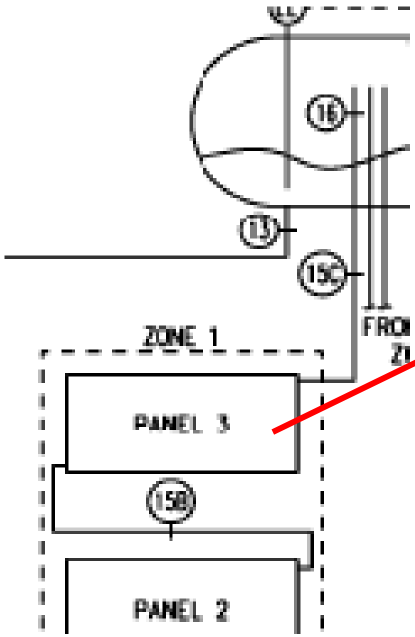
Proof of Concept

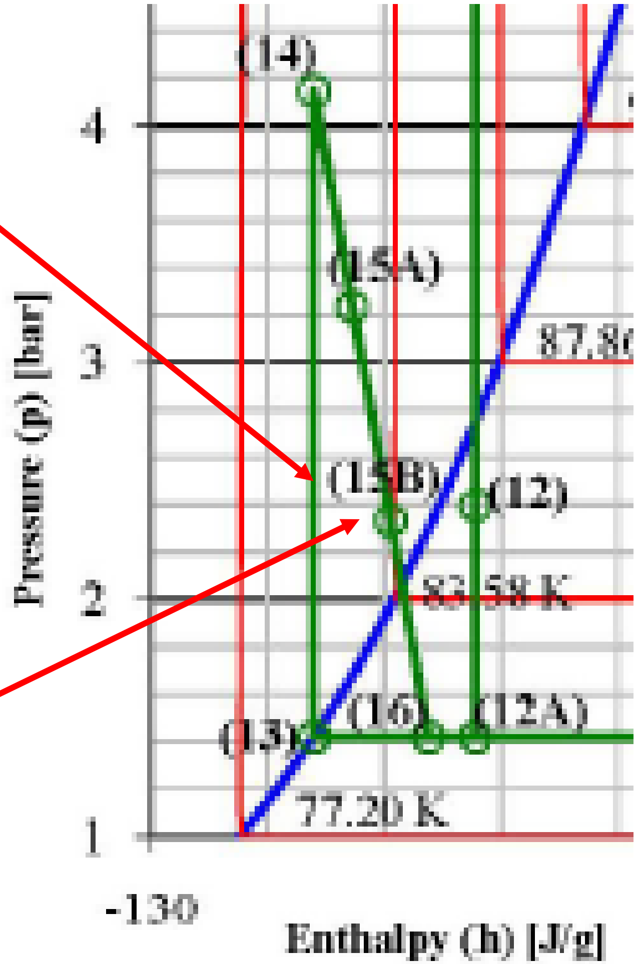
- Thermal siphon had been previously demonstrated on smaller facilities that were designed and built with that mode of operation in mind. Would it work on an existing large facility ?
- A thermal model was developed for the existing system
  - » The accuracy of the model was confirmed by comparison to actual LN2 usage history in order to develop confidence in the modeling methods
- A thermal model of the thermo siphon system was then developed and it showed that the concept was feasible
  - » Some features in the existing facility raised a concern
    - Transition lines between sections of elevated shroud panels were small in diameter and in some non-vertical positions
  - » Some features of the facility were very favorable
    - Supply tank pressure ratings were sufficient to allow the use of vaporizer pressure to push the LN2 to the phase separation tank on the roof
    - Most panel distribution lines and headers were large enough in diameter to operate in this mode
    - Building was tall enough to elevate the phase separation tank sufficiently to maintain sub cooled liquid well above areas where gas blockage would occur
    - System heat load was reduced significantly due to shorter transfer lines, fewer valves, and lack of pumps


Nitrogen p-h Diagram - Option 4A
Pressure (p) [atm]
Enthalpy (h) [J/g]
102.24 K
100.50 K
98.60 K
96.49 K
94.10 K
91.34 K
88.01 K
83.71 K
77.31 K
(3)
(2)
(1C)
(6)
(5)
(14)
(15A)
(15B)
(12)
(12A)
(13)
(16)
(17)
(99)
(8)
(7)
1.4 atm. (5.9 psig; 80.3 K)
Δh$_{sat}$ = 194.9 [J/g]
-130
-80
-30
20
70
120
1
2
3
4
5
6
7
8
9
10

Pressure Enthalpy Analysis

- Most critical transition piece (node 15B) remains in the sub-cooled region
- Increased heat load on shroud will decrease fluid density which automatically increases the fluid flow through the system





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			Zones												
Parameter	Units	Total	ZONE A	ZONE B	ZONE C	ZONE D	ZONE E	ZONE F	ZONE G	ZONE J	ONE H-I	LUNAR F	M. LOCKS	SPARE 1	SPARE 2
Load	kW	181	17.4	17.4	18.3	24.4	20.9	21.2	16	8.7	19.1	11	1.5	2.5	2.5
Ln2_Vap	g/s	919	88.4	88.4	93.0	124.0	106.2	107.7	81.3	44.2	97.1	55.9	7.6	12.7	12.7
Assumed quality	%	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Ln2_Suply	g/s	18385	1768	1768	1860	2480	2124	2155	1626	884	1941	1118	152	254	254
Ln2_Sup_Valve_CV	2"		54	54	54	54	54	54	54	54	54	54	54	54	54
Ln2_Warm-up_Valve	2"		54	54	54	54	54	54	54	54	54	54	54	54	54
Supply line _Dp	psi	5.74E-01													
Ln2_Sup_Valve_Dp	psi		0.4	0.4	0.4	0.8	0.6	0.6	0.3	0.1	0.5	0.2	0.0	0.0	0.0
Total Sup. Dp	psi		1.0	1.0	1.0	1.3	1.1	1.1	0.9	0.7	1.0	0.7			
Zone_Load_Dp(retur	psi		1.6	1.6	1.8	3.2	2.4	2.4	1.3	0.4	1.9	0.6			
Availabel_Dp	psi		6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3			
Dp_Margin	psi		3.7	3.7	3.5	1.7	2.8	2.8	4.0	5.1	3.3	4.9			
Dp_Ratio (Total/Avail	psi		41.2%	41.2%	44.2%	72.9%	55.7%	56.0%	35.6%	17.8%	47.2%	21.0%			

Parameter	Units	Total	ZONE A	ZONE B	ZONE C	ZONE D	ZONE E	ZONE F	ZONE G	ZONE J	ONE H-I	LUNAR F	M. LOCKS	SPARE 1	SPARE 2
Load	kW	181	17.4	17.4	18.3	24.4	20.9	21.2	16	8.7	19.1	11	1.5	2.5	2.5
Ln2_Vap	g/s	919	88.4	88.4	93.0	124.0	106.2	107.7	81.3	44.2	97.1	55.9	7.6	12.7	12.7
Assumed quality	%	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Ln2_Suply	g/s	9193	884	884	930	1240	1062	1077	813	442	971	559	76	127	127
Ln2_Sup_Valve_CV	2"		54	54	54	54	54	54	54	54	54	54	54	54	54
Ln2_Warm-up_Valve	2"		54	54	54	54	54	54	54	54	54	54	54	54	54
Supply line _Dp	psi	1.19E-01													
Ln2_Sup_Valve_Dp	psi		0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.0
Total Sup. Dp	psi		0.2	0.2	0.2	0.3	0.3	0.3	0.2	0.1	0.2	0.2			
Zone_Load_Dp(retur	psi		1.5	1.5	1.6	2.9	2.2	2.2	1.3	0.4	1.8	0.6			
Availabel_Dp	psi		12.2	12.2	12.2	12.2	6.3	6.3	6.3	6.3	6.3	6.3			
Dp_Margin	psi		10.5	10.5	10.4	9.0	3.8	3.9	4.7	5.7	4.3	5.5			
Dp_Ratio (Total/Avail	psi		13.8%	13.8%	15.1%	26.6%	39.4%	39.5%	24.4%	9.3%	32.0%	11.9%			

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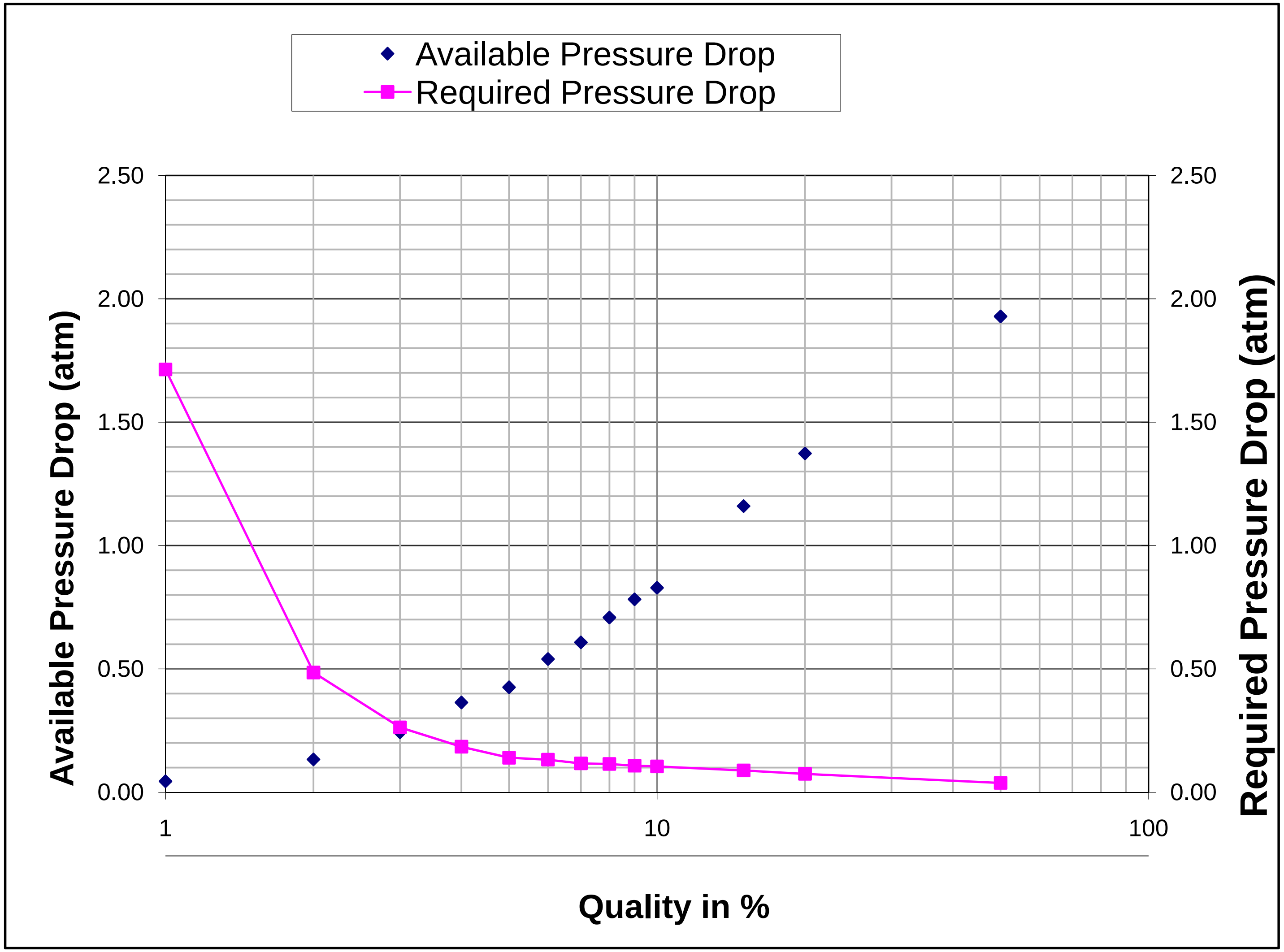

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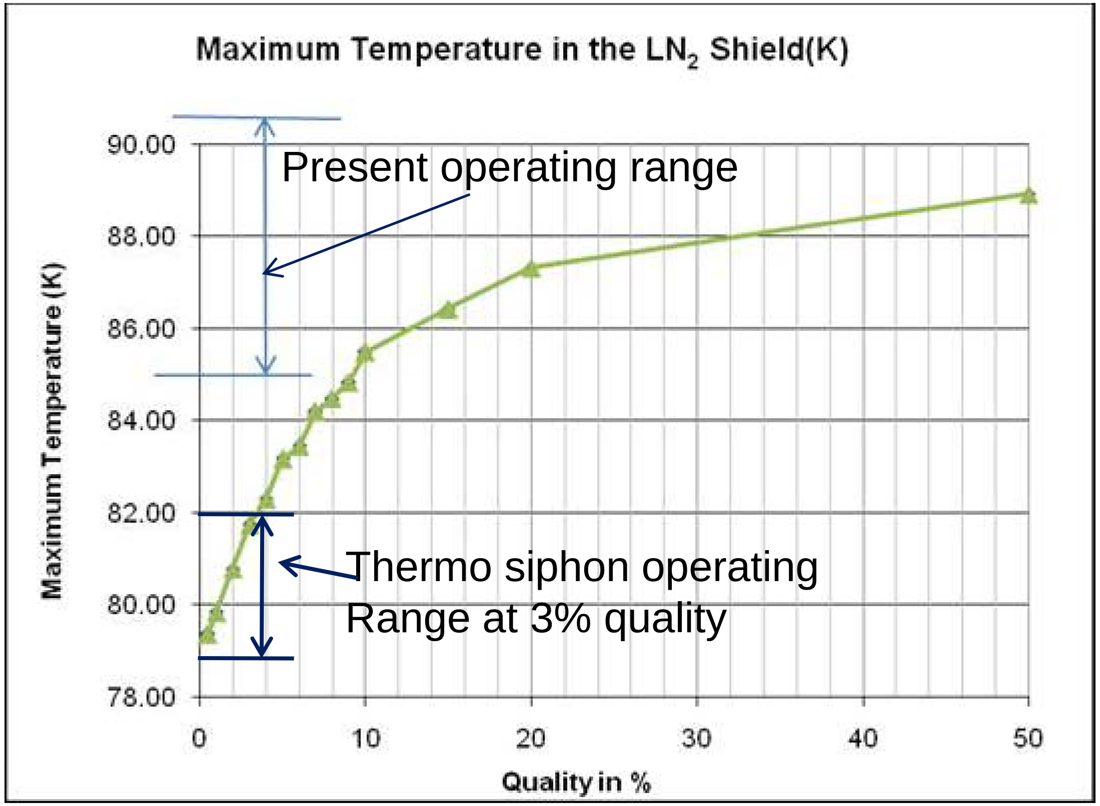

- **Analysis Comparison**

		Opt-0	Opt-4A
Chamber heat transfer	kW	176.0	176.0
Supply Transfer lines	kW	14.5	9.0
ReturnTransfer lines	kW	14.5	2.0
Ln2_Valves	kW	5.0	1.0
Ln2_connections	kW	1.0	1.0
Ln2_Pump	kW	36.6	0.0
Ln2_Heplant	kW	5.0	10.0
Phase Separator	kW	2	1
Estimated loads	kW	254.6	200.0
Supply P	kPa	507	507
Supply T	K	94	94
Ln2_Supply Enthalpy	j/g	-85.7	-85.7
Return P	kPa	222.9	101.3
Return T	K	84.75	93
Ln2_Return Enthalpy	j/g	82.3	94.2
Dh	j/g	168	179.9
Required Ln2 Flow rate	g/s	1516	1112
	lpm	125.8	92.3
Savings compared to Opt-0	lpd	-	48,256
	%		26.6

- Old System Daily Usage
  - 181,152 liters
  - 47,860 gallons
  - 159.5 tons
  - 7.25 truck loads
- New System Daily Usage
  - 132,912 liters
  - 35,110 gallons
  - 117.0 tons
  - 5.3 truck loads
- Daily savings of
  - 48,256 liters
  - 12,749 gallons
  - 42.5 tons
  - 1.9 truck loads
- Cost savings per test of $436,000 to $581,000

Advantages of Thermo Siphon System

- Eliminates rotating pump equipment and associated maintenance
- Eliminates 66% of control valves and 90% of relief valves and burst disks with associated maintenance
- System continues to operate during power outage with no emergency power system requirement
- Liquid in the Thermal Siphon tank and shrouds may be recovered into the supply tank at the end of test
- System installation is less expensive than the initial approach
- Fewer truck loads to off load each day and this may allow for missed delivery days that are bound to occur
- Saves LN2 so it saves costs during test

Conclusion

- NASA-JSC is progressing toward modifying the existing nitrogen system into a thermo siphon system
- Design for major components is complete
- The rest of the design is progressing