CRYOGENICS OPERATIONS 2008

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Experiment Hall High Load Target Refrigeration Recovery at the ESR

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Jefferson Lab Thomas Jefferson National Accelerator Facility

Introduction

- **JLab has three experiment halls to which beam is delivered**
  - » Halls A, B, C
- **Cryogenic loads for these halls are supported by the End Station Refrigerator (ESR)**
- **Loads are:**
  - » 4.5-K magnet refrigeration
  - » Magnet lead cooling (4.5-K liquefaction)
  - » Cryogenic target; typically 13.5 K 12 atm supply and 20-22 K 2.5 atm return (for a hydrogen target)
- **ESR comprised of:**
  - » 1500 W cold box – built by CTI/Helix in mid-1970's – has LN pre-cooling & two Sultzer turbines (20-13 K, and JT expander)
  - » 250 Hp 1st stage & 1000 Hp 2nd stage Sullair compressors
  - » 10,000 liter liquid helium (LHe) dewar
  - » Associated distribution system (valve box, hall distribution cans)

Introduction

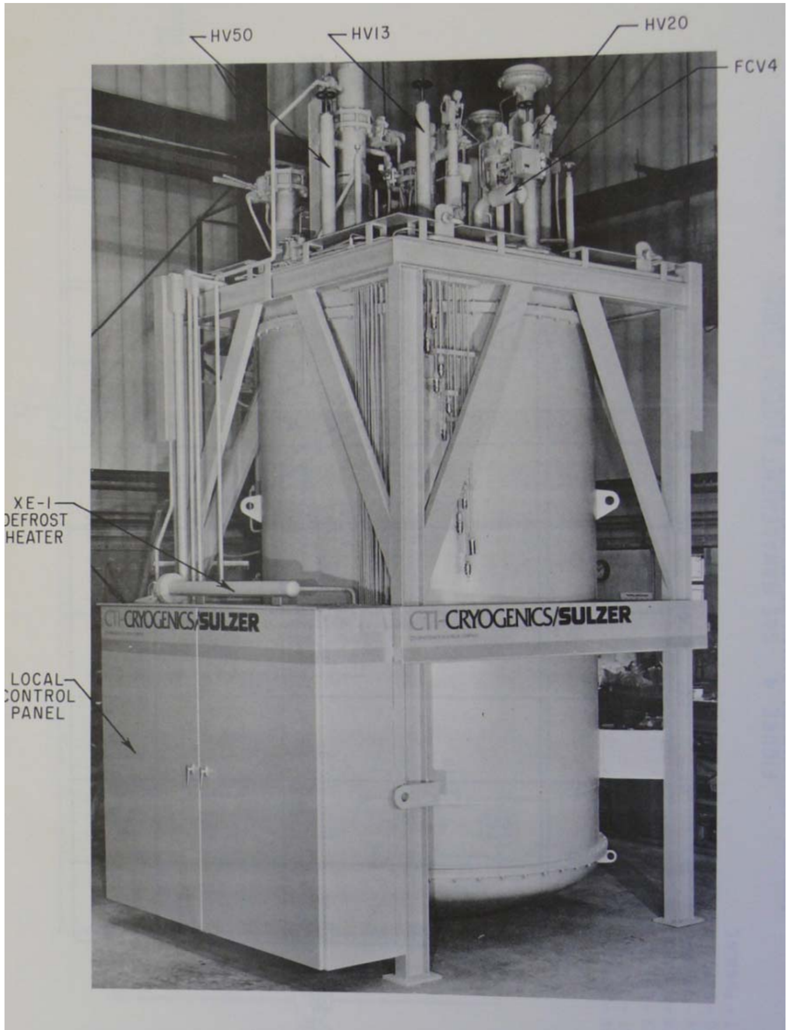
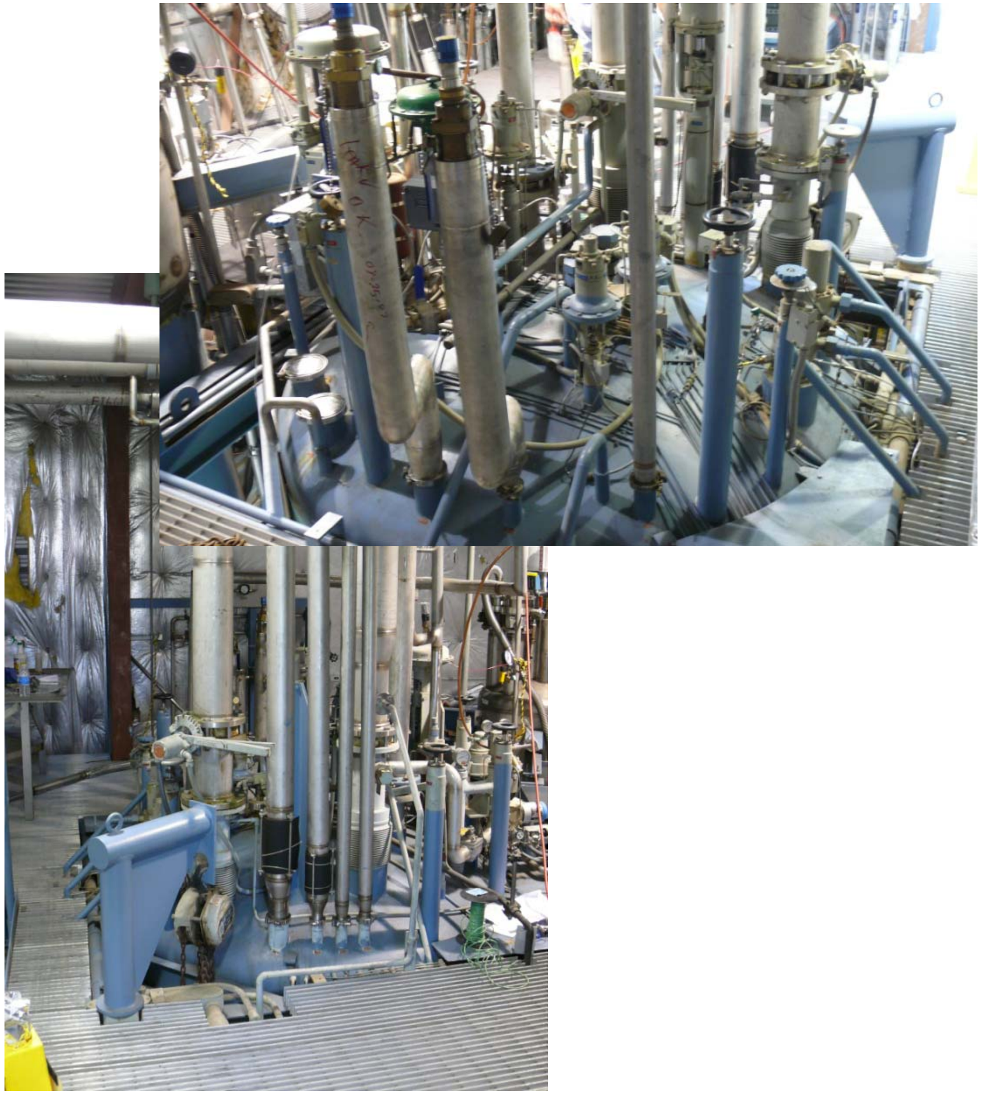


FIGURE 6. FRONT AND LEFT SIDE



Introduction

Introduction

- **ESR does not have the following systems; i.e., it depends on the Central Helium Liquefier (CHL) system for:**
  - » Warm gas purification system
  - » Gas storage system
  - » LN storage
- **CHL – ESR interconnections**
  - » 1100 ft. cryogenic transfer-line supplying LN and 4.5-K (nominal) LHe
  - » High pressure (HP) clean gas supply
  - » Low pressure (LP) clean and ‘dirty’ gas return
- **ESR capacity:**
  - » 1100 W 4.5-K refrigeration + 1250 W 15-K (non-isothermal) target load
  - » Present hall loads typically require an additional ~5 g/s of 4.5-K (3 atm) LHe from CHL

Introduction

- **During summer 2004 – single use, 1.5 week duration, high load target required some low cost modifications to ESR.**
  - » Mods included a large ambient air vaporizer
  - » Load is supported via. CHL transfer-line using 4.5-K 3 atm LHe, and returned at LP to CHL
  - » Since the initial 2 week run, there has been considerable usage of this capability totaling ~58 weeks
- **In fall of 2004,**
  - » Was apparent that usage of high power target capability would not only continue, but increase, and
  - » Need for further modifications to support Qweak experiment in mid-2009 – requiring an even higher target load (for two year run)
  - » Proposed concept and rough cost estimate for modifications to more efficiently support high load targets and provide for Qweak requirements

Introduction

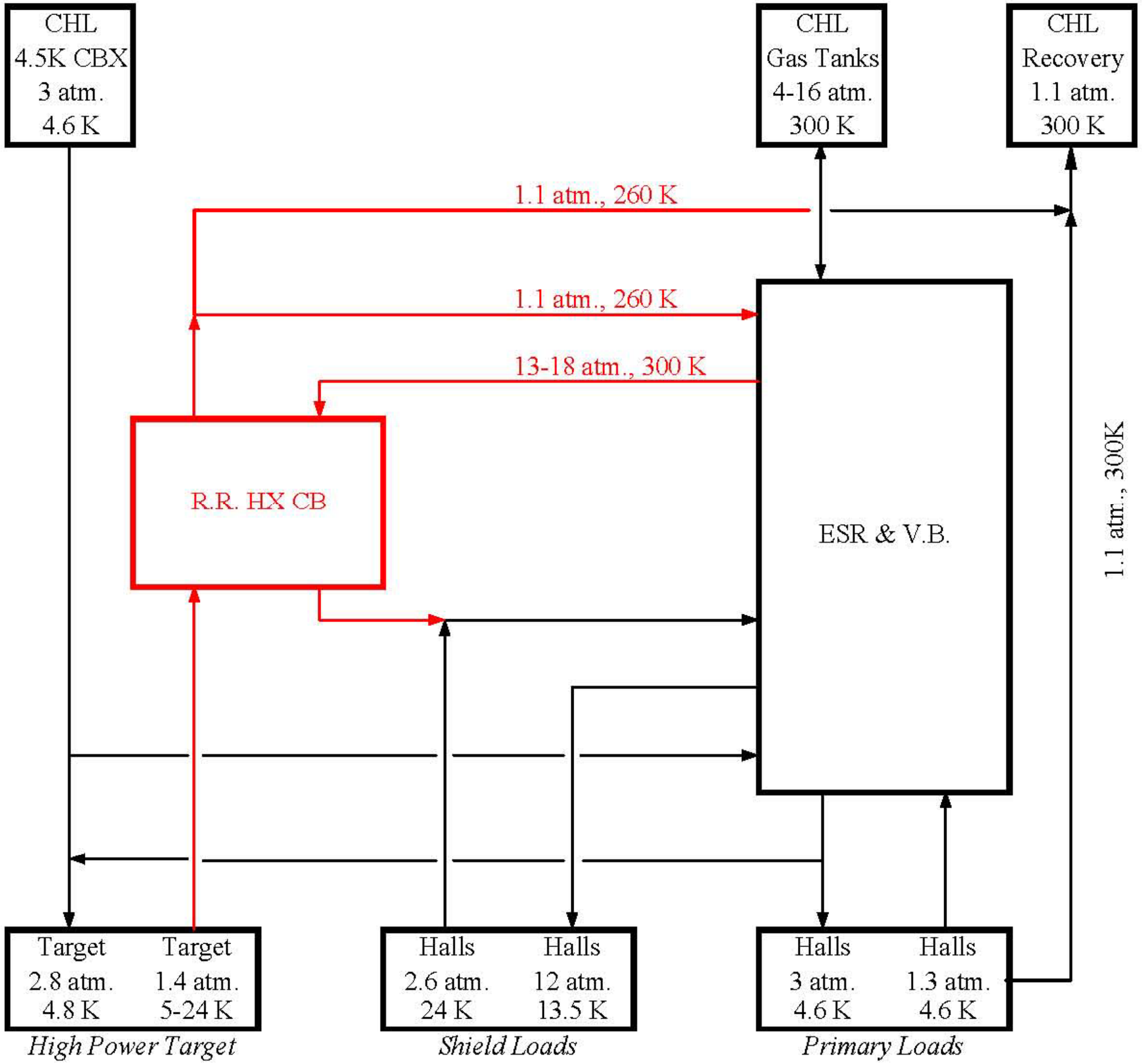
Concept

- **Proposed concept**
  - » Recover 7-20 K LP target return to cool slip stream from HP ESR compressor discharge, which is then injected at the first turbine temperature level in the cold box
- **For large 20-K targets (~2.5 kW or ~25 g/s from CHL) and Qweak experiment using two target HX's (4.5-K He, 15-K He)**
  - » Reduce 4.5-K 3 atm CHL supply by ~50%, allowing either
    - CHL to support loads at other locations (i.e., increased flexibility) or,
    - A reduction in CHL input electrical power of ~100 kW (~$4.2K/month) w/ corresponding increase in reliability
  - » Reduce LN usage
    - ~3.3 gph of LN per 1 g/s of 4.5-K He from CHL
    - ~20 gph at ESR (i.e., a reduction of ~50%)
    - Total of ~60 gph (at 12 g/s reduction from CHL) is ~$10K/month

Concept

- **For large 4.5-K targets (~500 W)**
  - » Reduce CHL 4.5-K supply LHe by ~20% (i.e., ~5 g/s of LHe)
  - » Reduce LN usage – same as for large 20-K targets
  - » Total of ~35 gph (at 5 g/s reduction from CHL) is ~$6K/month
- **Rough cost estimate for new hardware (in 2005)**
  - » $75K
  - » ~6 months of large 20-K target ops for pay-back
  - » One year from funding to initial operation if HX purchased in advance
  - » Long lead – brazed-Aluminum plate-fin HX
    - ~9-12 months
    - $30K

Concept



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Concept

- **Turbine T1 provides cooling required for HX ΔT losses, liquefaction load and target load between 13.5 and 80 K**
- **Enthalpy between 20 K (for a hydrogen target) and 80 K (since the CBX has LN pre-cooling) otherwise lost in the ambient vaporizer is recovered, freeing T1 refrigeration capacity for the target load**
- **Target load return at ~1.2 atm, but CBX T1 outlet pressure (i.e., MP stream) is at ~2.7 atm**
- **So, use portion of HP compressor discharge (13 to 18 atm) flow to recover refrigeration from target load, then drop to MP stream pressure**
- **Primary equipment limitations**
  - » 2nd stage compressor displacement (2905 m^3/hr, ~80% volumetric efficiency), and
  - » T1 flow coefficient {$w^*T_i^{0.5} / p_i \approx 33.2$ (g/s)-$K^{0.5}$/atm}

Concept

- **Basis for hydrogen target concept**
  - » w_{TG} - 4.5-K flow req'd from CHL *without* recovering refrigeration
  - » w_{TG}^{o} - 4.5-K flow req'd from CHL, recovering the refrigeration
  - » Let, $\omega = w_{TG}^{o} / w_{TG}$
  - » Exergy recovered from refrigeration (from 20 to 80 K, that would otherwise be wasted in the ambient vaporizer) = Exergy of additional 20 K target flow from ESR; $\omega_{\varepsilon} \approx 0.66$
  - » Enthalpy of refrigeration recovered (from 20 to 80 K) = 20 K target enthalpy from ESR; $\omega_{i} \approx 0.33$
  - » Actual ω will be somewhere in between these two values; so, use average, $\omega \approx 0.50$

Concept

- **Qweak target load estimate**

CHL T.L.:

q_{LK}	75	[W]	*CHL to ESR heat leak*

ESR 15-K:

q_{LK}	50	[W]	*15-K supply heat leak*

Target:

(de/dx)	4.8	[MeV-cm^2/g]	*Beam energy dissipation*
ρ	72.49	[g/ℓ]	*Target density*
ℓ	35	[cm]	*Target length*
I	180	[μA]	*Beam current*
q_B	2192	[W]	*Beam power on target*

w	1087	[g/s]	*Target loop (LH_2) mass flow*
Q	15	[ℓ/s]	*Target loop (LH_2) volume flow*
ρ	72.49	[g/ℓ]	*Fluid (LH_2) density*
Δp	0.136	[atm]	*Pump pressure rise*
η_i	40%	[-]	*Isentropic pump efficiency*
P_p	517	[W]	*Pump (shaft) input power*

Total Required:

q_{tot}	**2834**	[W]

Concept

(General) Hydrogen target load

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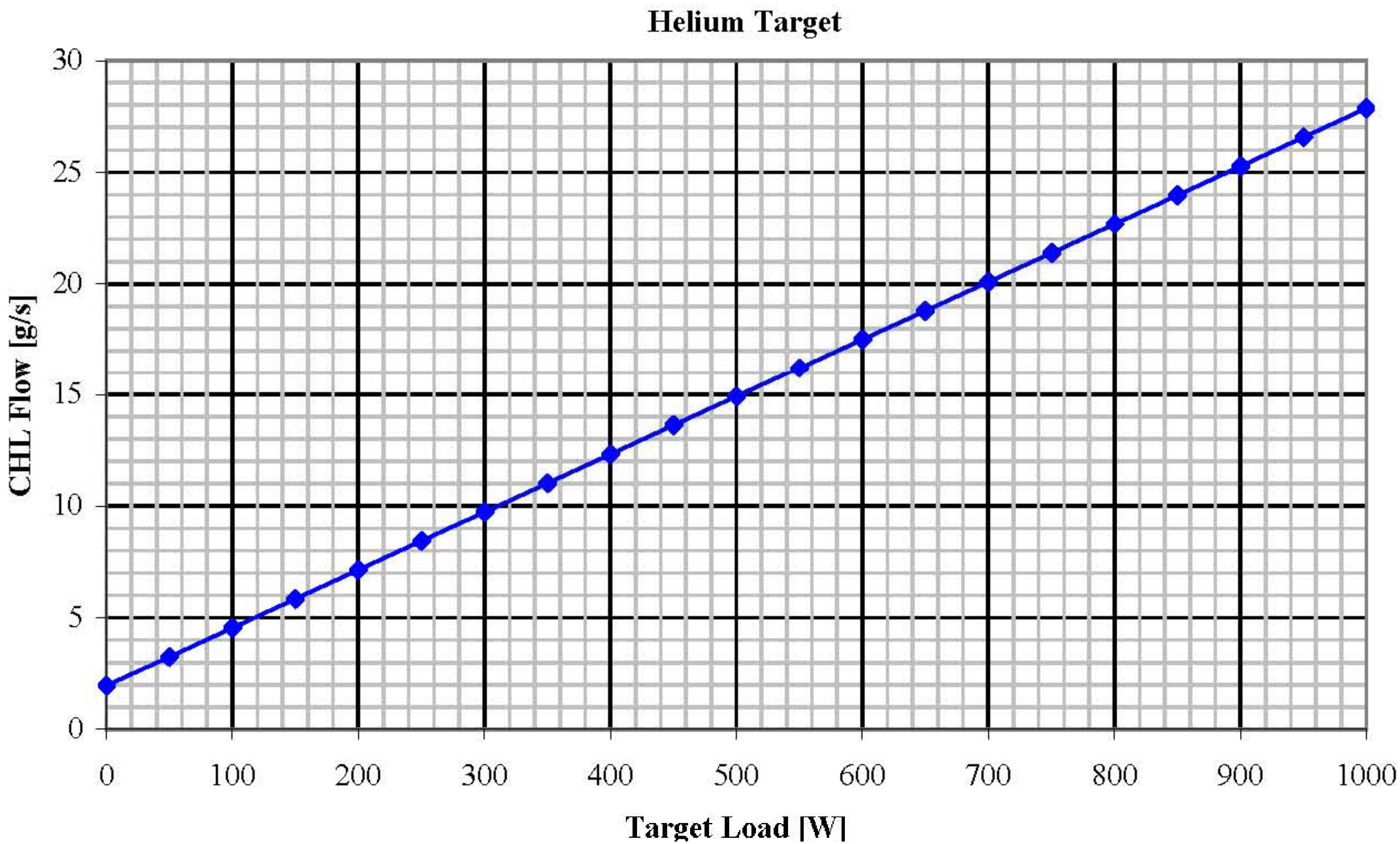
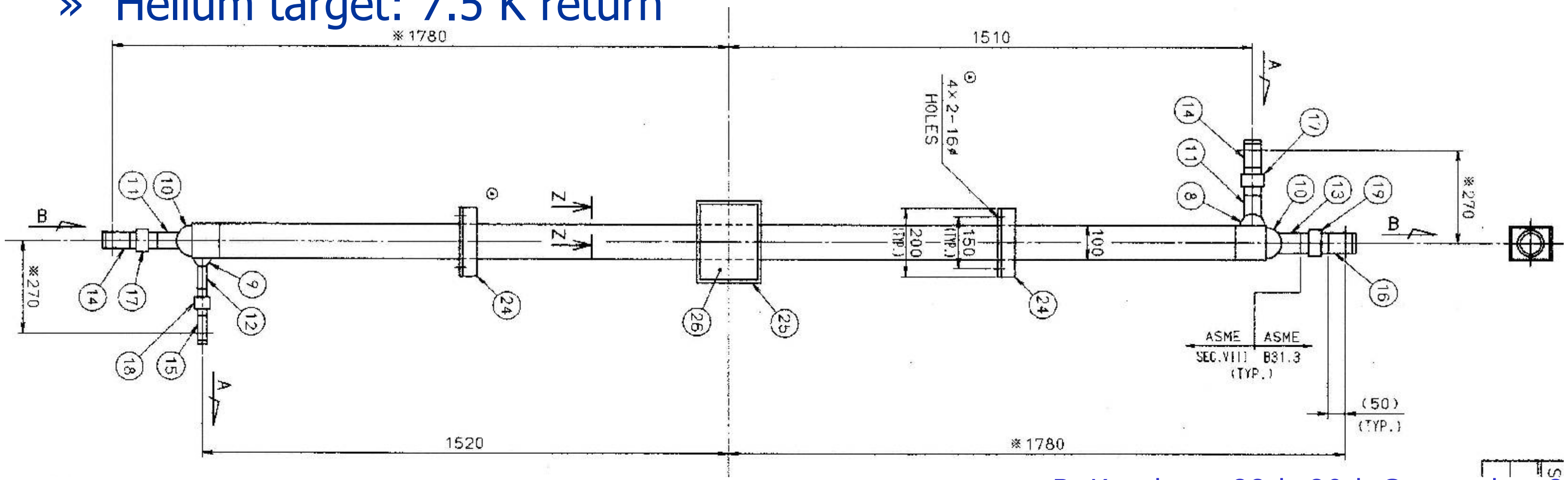
Concept

(General) Helium target load



Process Study

- **HX design**
  - » 30 g/s of target return flow (max.)
  - » Approx. 90% flow ratio
  - » 98.5% effectiveness
  - » Approx. 25 Ntu's (3 m long)
  - » HP stream: 14 atm, .02 atm Δp
  - » LP stream: 1.2 atm, .04 atm Δp
  - » Hydrogen target: 20 K return
  - » Helium target: 7.5 K return



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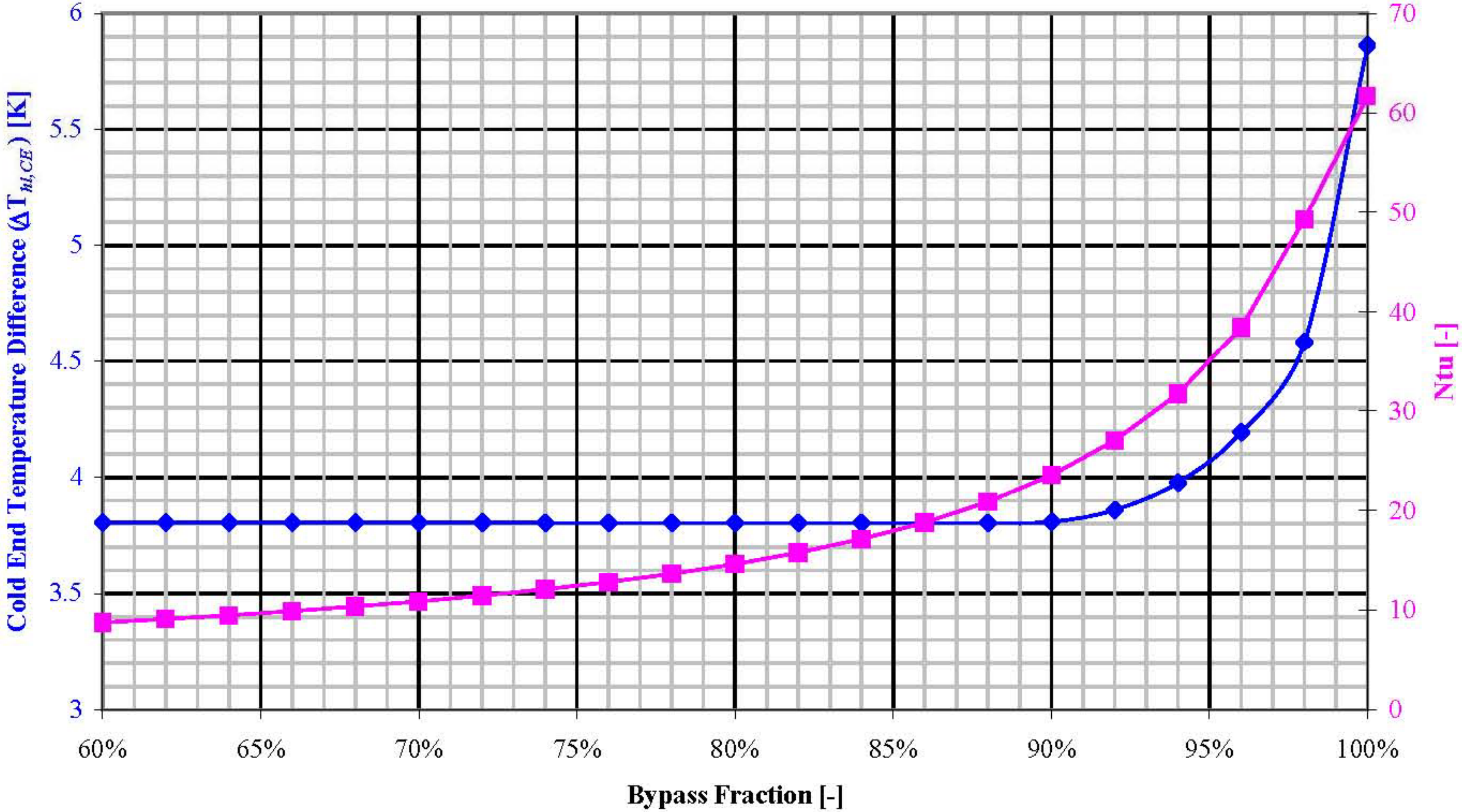
Process Study

HX Design: Hydrogen Target



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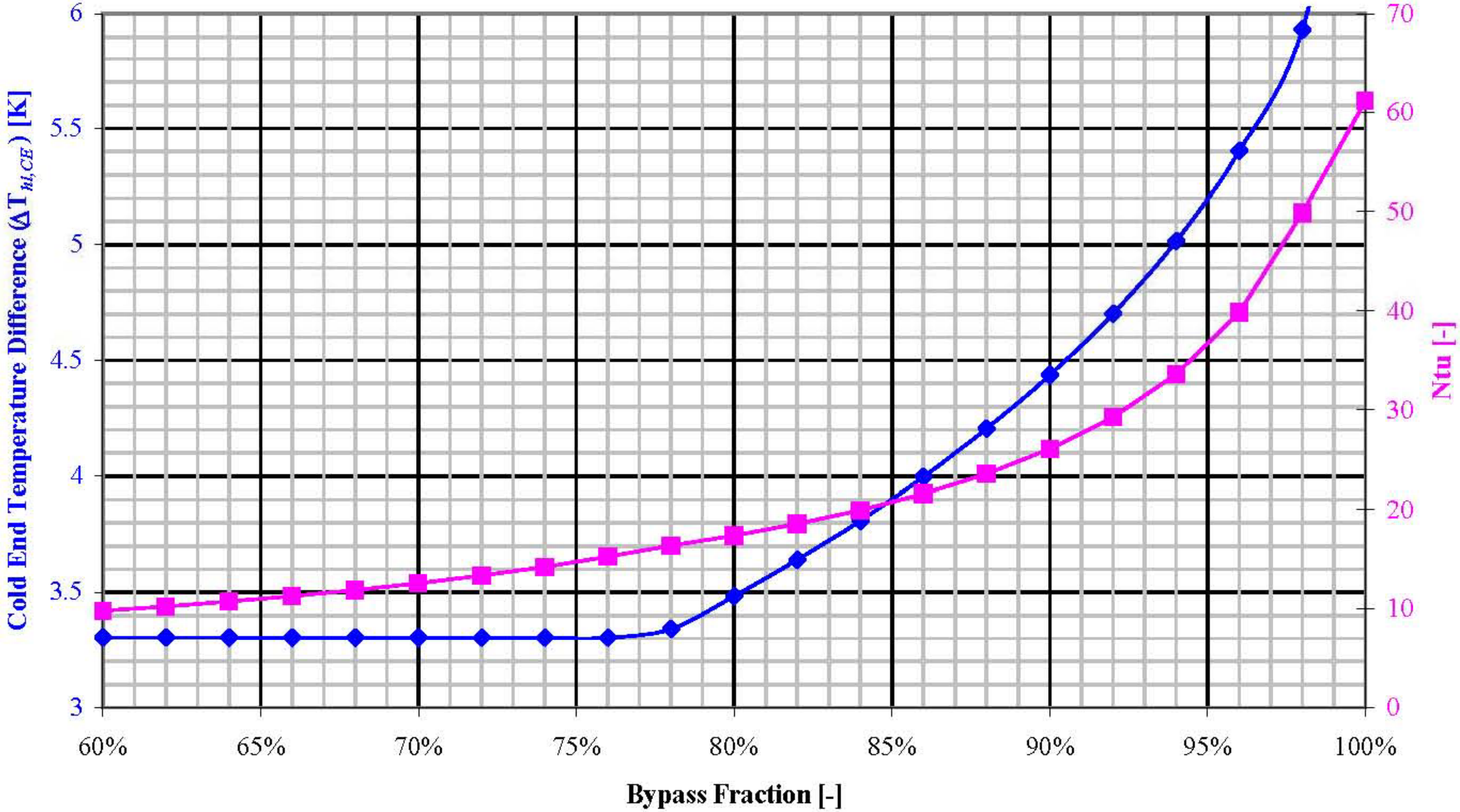
Process Study

HX Design: Helium Target



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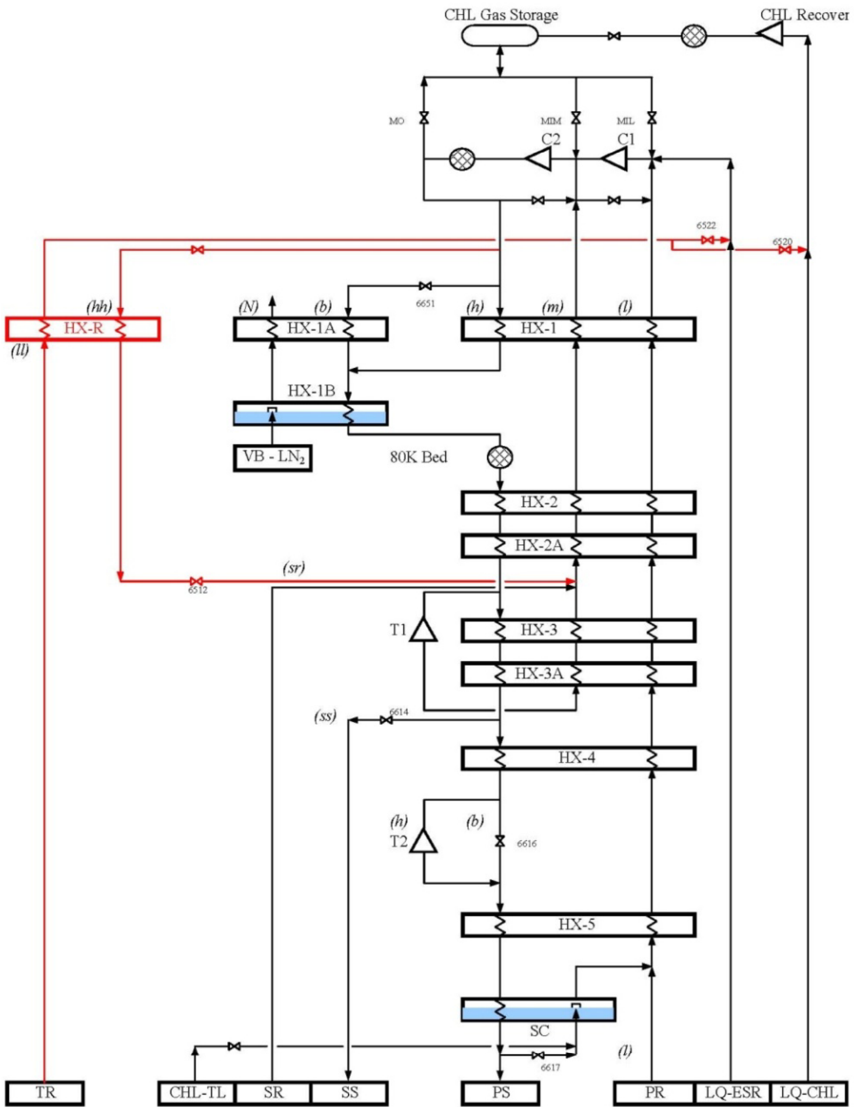
Process Study



- **Detailed process study was performed to verify the performance suggested by the concept and ascertain the behavior at less than full load conditions**

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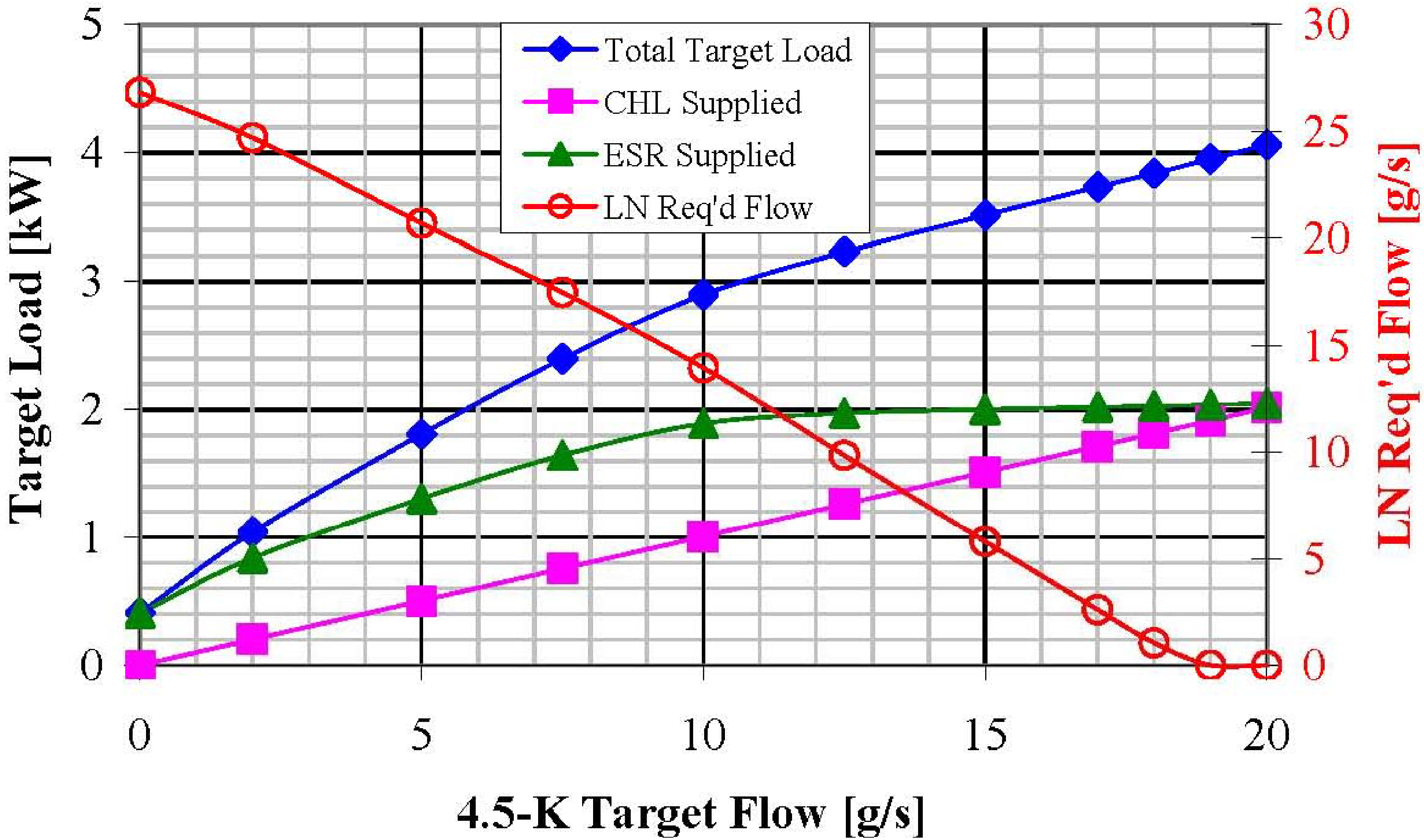
Process Study

Case #	4.5-K Target Flow [g/s]	CHL Supplied Target Load [kW]	ESR Supplied Target Load [kW]	Total Target Load [kW]	ESR LN Req'd Flow [g/s]	R.R. HX Flow Ratio [-]	Limiting Component
1	0	0.00	0.41	0.41	26.8	N/A	T1
2	2	0.20	0.84	1.04	24.7	89.3%	T1
3	5	0.50	1.30	1.81	20.7	87.9%	T1
4	7.5	0.76	1.64	2.40	17.5	86.6%	T1
5	10	1.01	1.89	2.90	14.0	85.6%	C2
6	12.5	1.26	1.97	3.23	9.8	84.6%	C2
7	15	1.51	2.00	3.51	5.8	83.6%	C2
8	17	1.71	2.02	3.73	2.6	83.2%	C2
9	18	1.81	2.03	3.84	1.1	82.9%	C2
10	19	1.91	2.04	3.95	0.0	82.6%	C2
11	20	2.01	2.05	4.06	0.0	82.3%	C2

Notes:

1. *Nominal ESR load of 1 kW 4.5-K refrigeration + 4 g/s 4.5-K liquefaction.*
2. *Assumed 20 K target return temperature*

Process Study



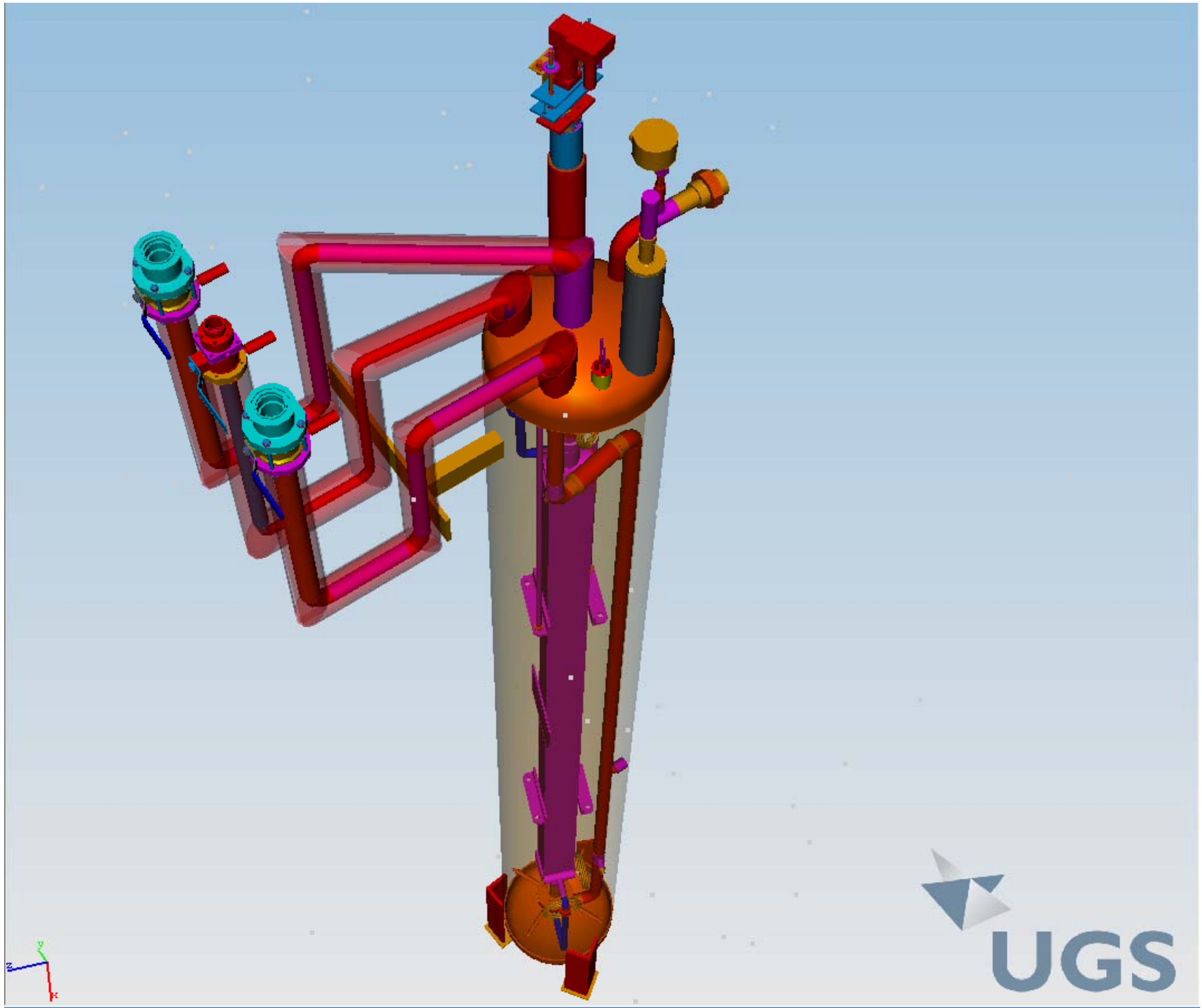
Process Study

- **Results indicate that to support a 3 kW target load (i.e., Qweak):**
  - » CHL supplied flow = 10.5 g/s (64% reduction from 29 g/s)
  - » LN req'd flow = 13.2 g/s (61% total reduction)
  - » HX flow ratio (HP to LP) = 85.4%
- **For a 2 kW target load (of the kind typical since 2004):**
  - » CHL supplied flow = 5.8 g/s (70% reduction from 19.6 g/s)
  - » LN req'd flow = 19.7 g/s (68% total reduction)
  - » HX flow ratio (HP to LP) = 87.5%

Mechanical Design

- **Major component – HX 'can'**
  - » Located on west side of ESR building; next to Hall A
  - » (4) process connections
- **Req'd existing system interfaces (5)**
  - » HP warm gas supply
  - » 15-K injection to ESR cold box
  - » LP cold target return from hall
  - » LP warm target return out of HX 'can' to CHL and/or ESR compressor suction

Mechanical Design



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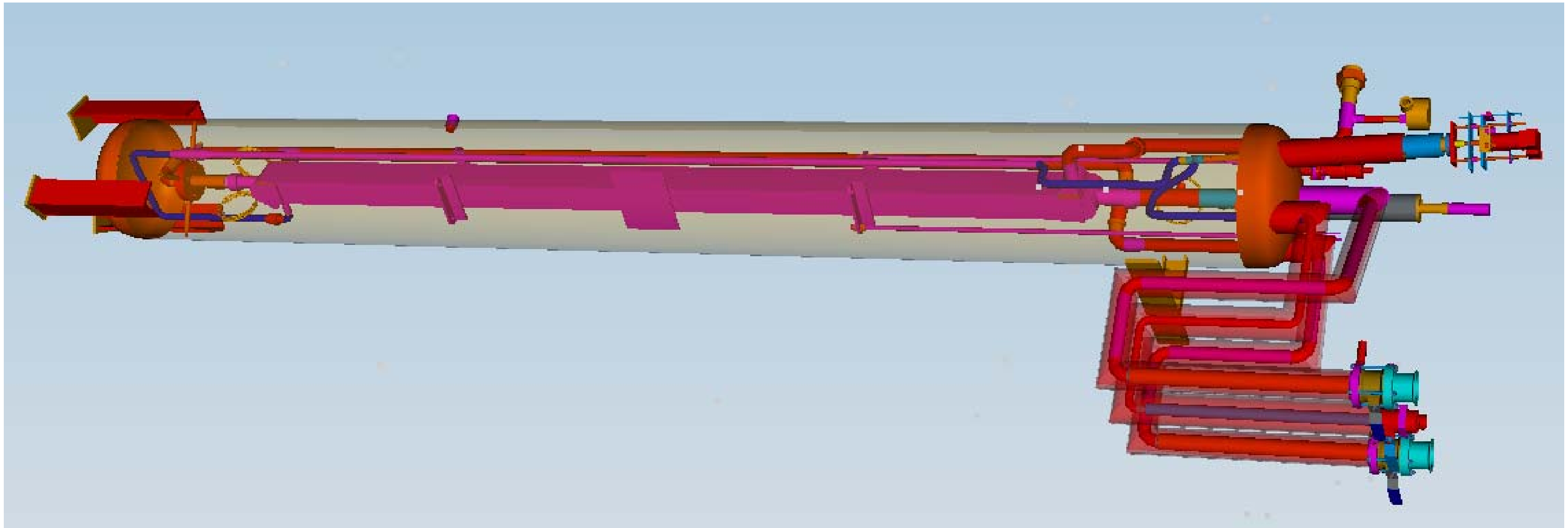
Mechanical Design



Mechanical Design

New Refrigeration Recovery HX 'Can'

Note: other equipment shown is existing

Status

- **Major component ($30 K)**
  - » HX purchased and on-site
- **Mechanical components ($22 K); i.e., shell/heads, valves, machined parts**
  - » All items either on-order or on-site
- **Piping fittings ($8 K)**
- **Instrumentation ($15 K)**
  - » All items either on-order or on-site
- **Design at 90%**
- **Fabrication: 4 months (Oct 2008 – Jan 2009)**
- **Installation: Jan – Feb 2009**
- **Commissioning (for Qweak): March 2009**