University of Michigan's Upgraded Large Vacuum Test Facility

IEPC-2019-653

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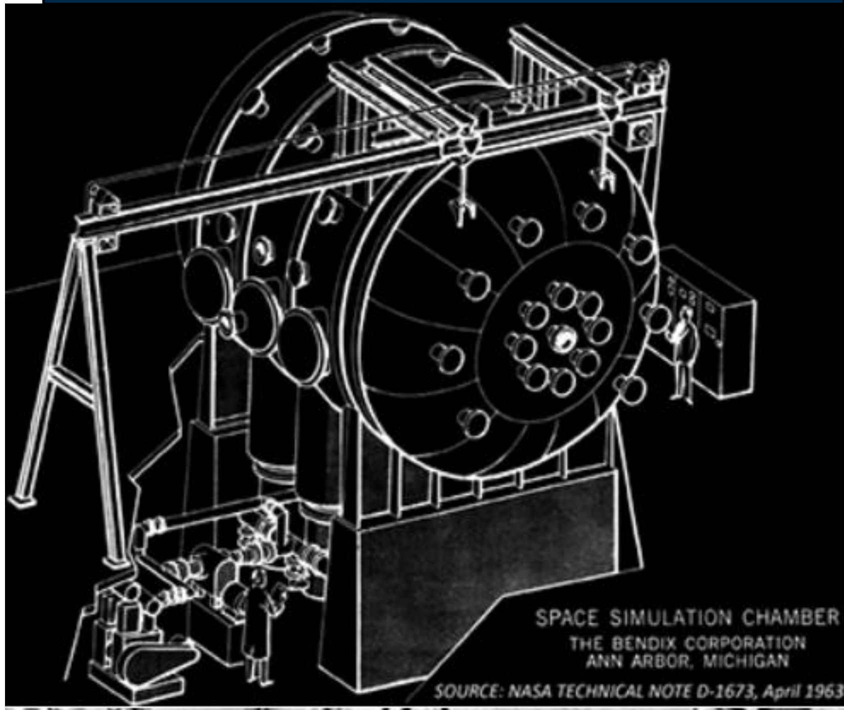
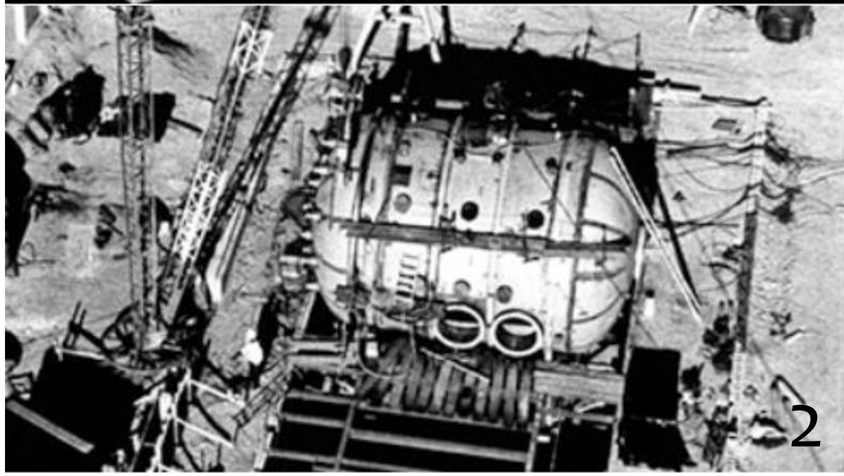
History

LVTF (2009) shown at 31st IEPC





LVTF is a six meter diameter by 9 meter length vacuum chamber constructed in 1961, Bendix Aerospace

Plasmadynamics and Electric Propulsion Laboratory in 1992, University of Michigan under Gallimore

MPDs, arcjets, gridded ion thrusters , hall thrusters, hollow cathodes, plasma physics, industry & government test campaigns

Motivation

UM X3 thruster – 100 kW class

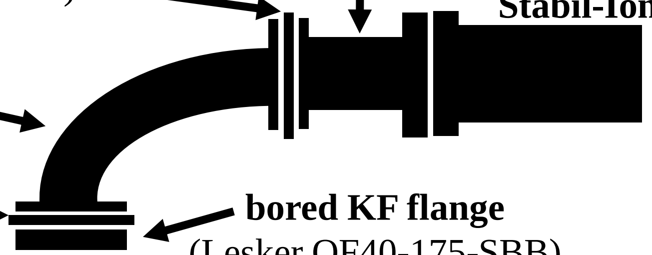
1. **Higher power thrusters**

flight thrusters range 5 kW – 12.5 kW
research thrusters as high as 100 kW

2. **Facility effects below 10 μTorr**

Background

Gauge Envelope Configuration



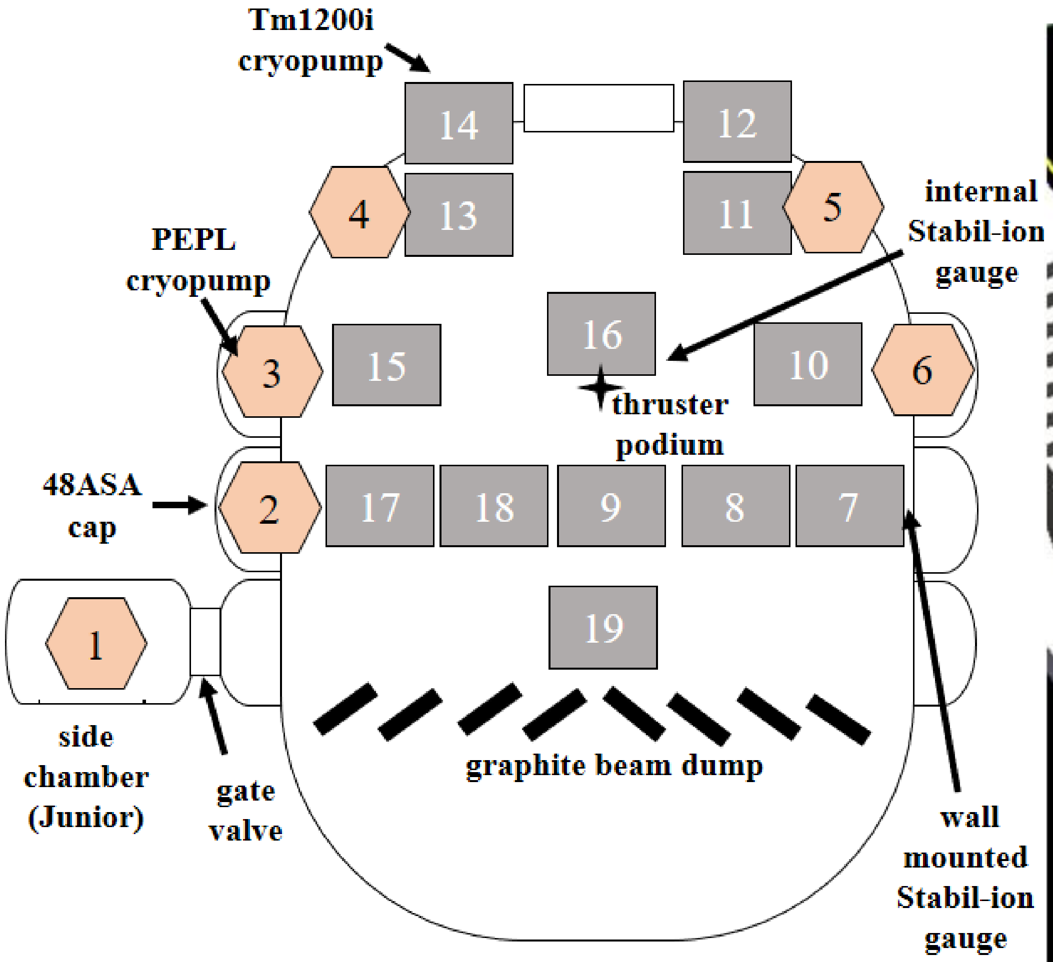
Effective Pumping Speed

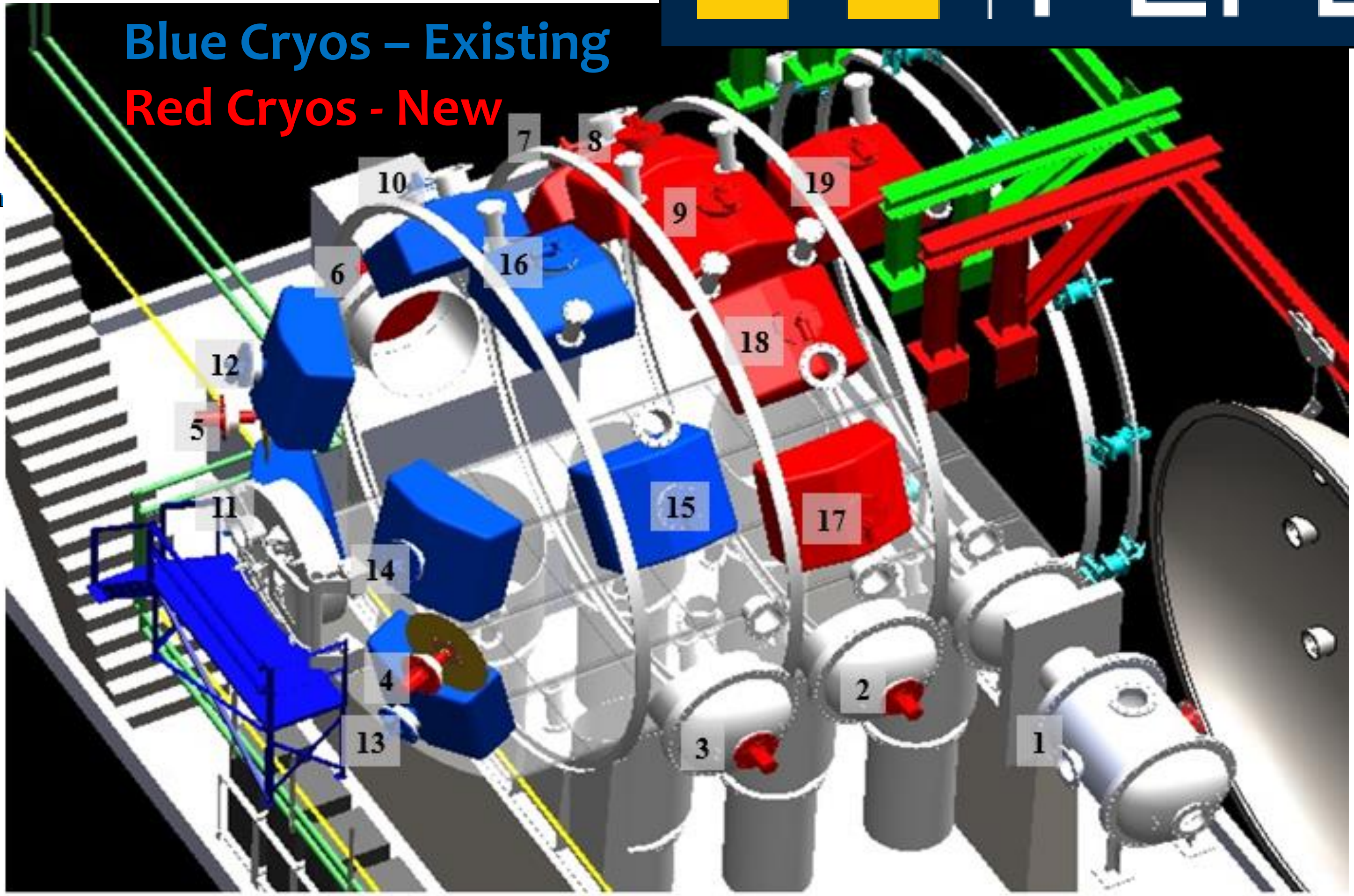
$$Pumping_{eff} = \frac{\dot{m}}{P_{measured} - P_{base}}$$

- Followed best practices reporting effective pumping speed*
- Mass flows in sccm (ref. room temp, **298 K**)
- Internal stabil ion gauge in shown gauge envelope
- Mounted in the exit plane near thruster

- J. Dankanich et al., "Recommended Practice … in Electric Propulsion Testing," Journal of Propulsion and Power, 2017.

New Facility Configuration





Layout driven by constraints of the facility's geometry
Added six additional TM1200i (35,000 l/s)
Installed six PEPL developed cryopumps (39,600 l/s)

Bottom line performance

Upgraded Large Vacuum Test Facility

Pre-upgrade specs

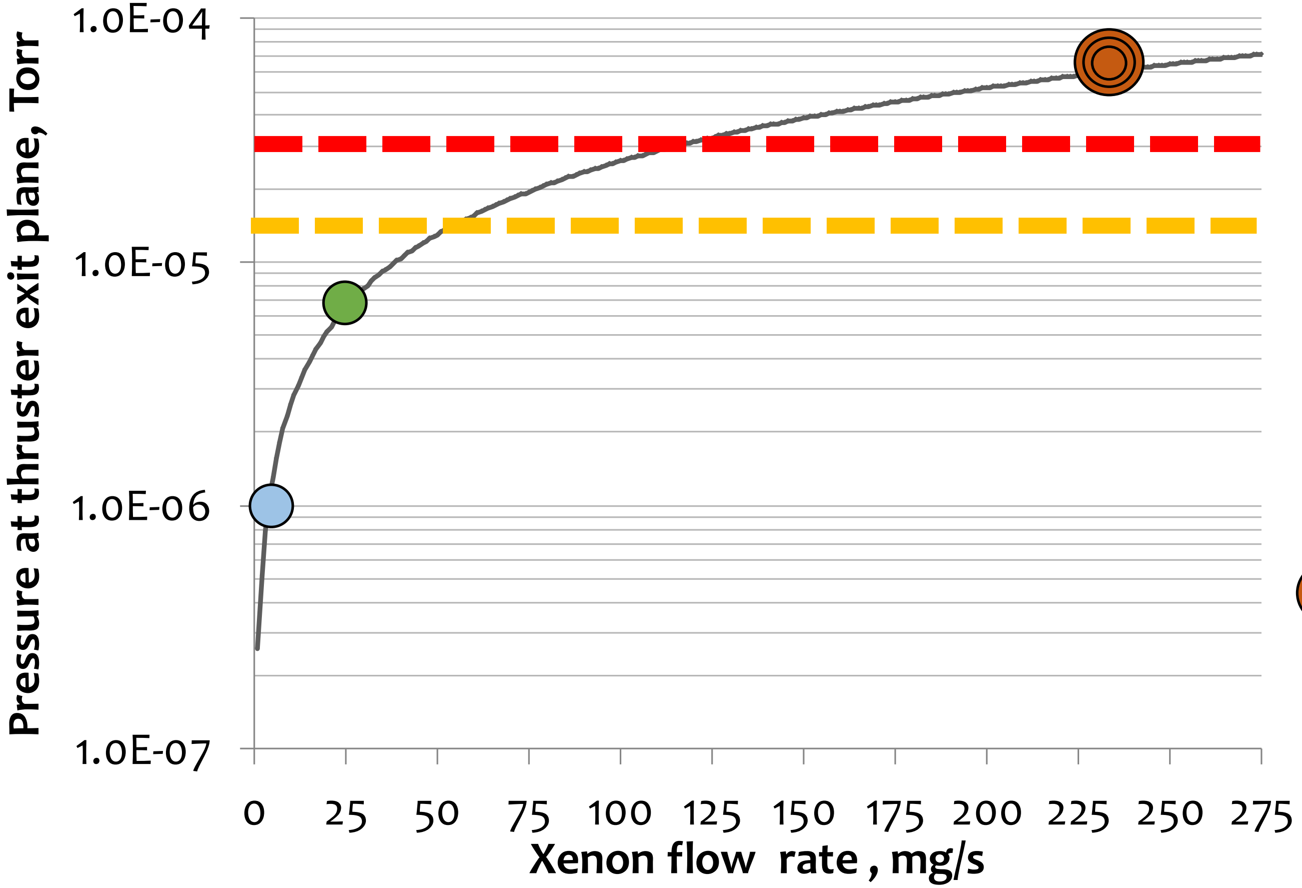
Seven Large Cryopumps
245,000 l/s (Xe) installed
~190,000 l/s (Xe) effective w/ thruster

Upgraded facility specs

Eighteen Large Cryopumps
653,000 l/s (Xe) installed
~500,000 l/s (Xe) effective w/ HET
600,000 l/s (Xe) effective cold flow
~600,000 l/s (Kr) effective w/ HET

LVTF performance

For 500,000 l/s effective pumping speed xenon



Small constellation hall thruster
1 kW, 3 mg/s, 400 v: **1 µTorr**

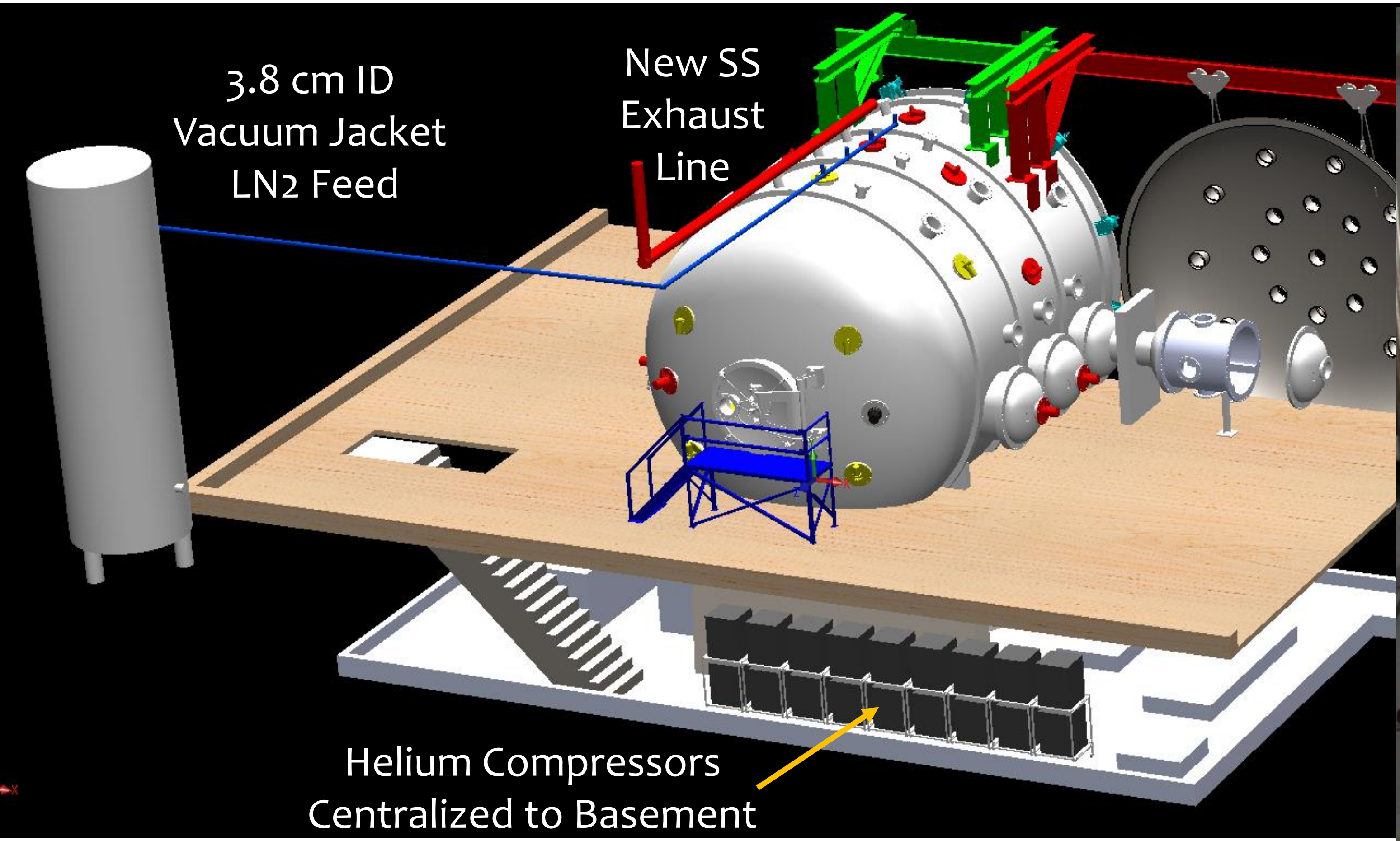
NASA AEPS, high power operation#
12.5 kW, 23 mg/s, 600 V: **6.5 µTorr**

X3, highest thrust point at NASA VF5*
99 kW, 236 mg/s, 400 V: **65 µTorr**
NASA VF-5 pressure: **42 µTorr**

Recommended maximum pressure targets
HET performance testing < 30 µTorr
HET near field plume measurements < 13 µTorr

Source: R. Hofer et al., IEPC-2017-231
* Source: S. Hall et al., IEPC-2017-228

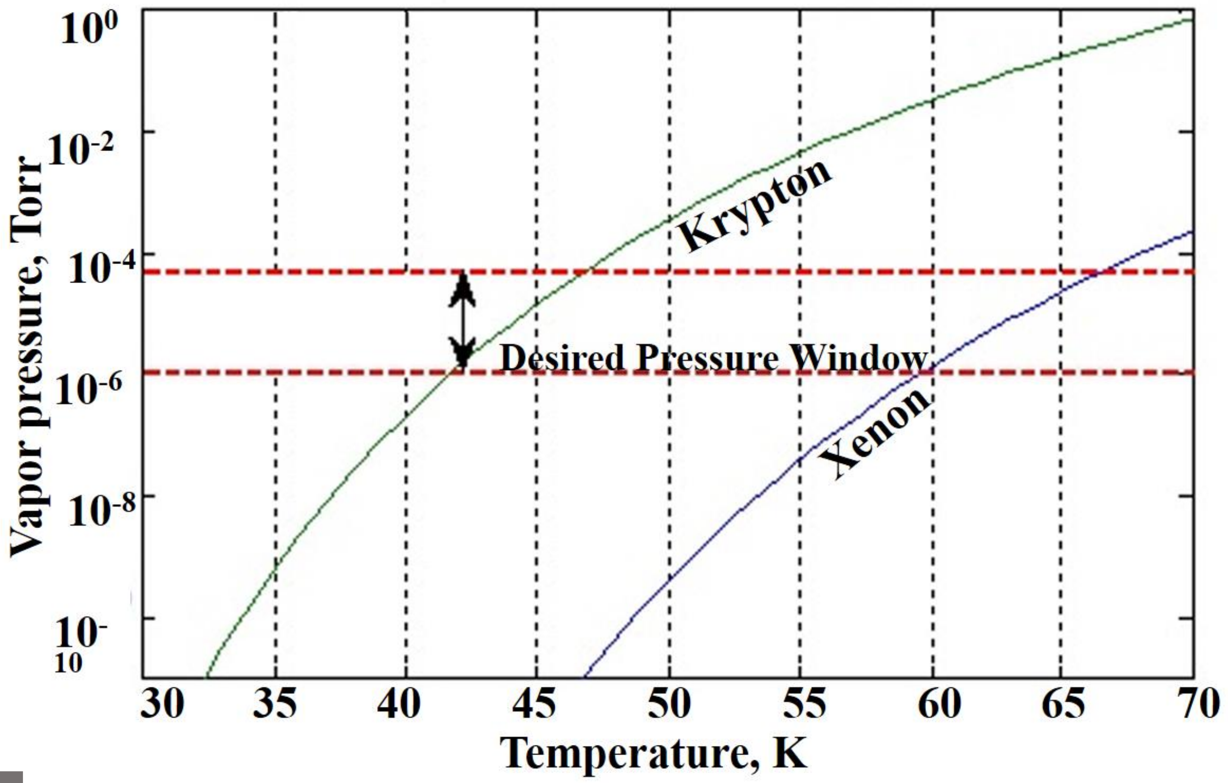
Supporting infrastructure



1. Significant Additional Capacity for LN2 for Thermovac Applications
2. Centralized process cooling water
3. Upgraded electrical circuits to support additional cryopumps

PEPL cryopump background

- Compact, high pumping speed cryopump for xenon and krypton.
- First demonstrated 1996 at JPL (C. Garner et al.)
- Shroudless operation is possible – LN 2 Free
- Thermal radiation dominates heat transfer
- Plate emissivity rapidly increases with ice



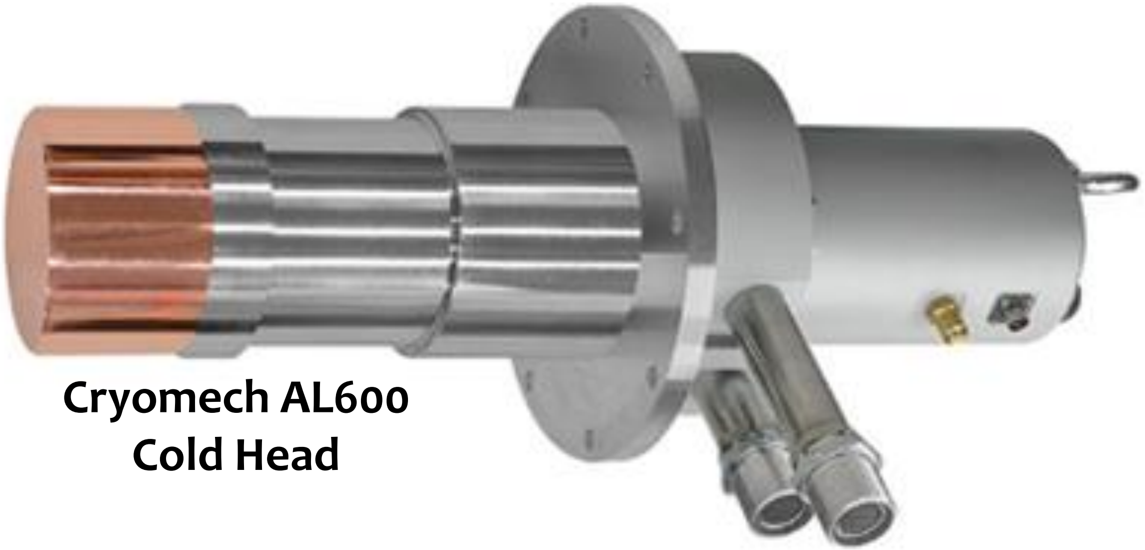
Pumping Plate
< 55 K pumping plate for xenon
< 43 K pumping plate for krypton

Gifford McMahon Cryocooler
High capacity, Single Stage
Optimized for 40-80 K

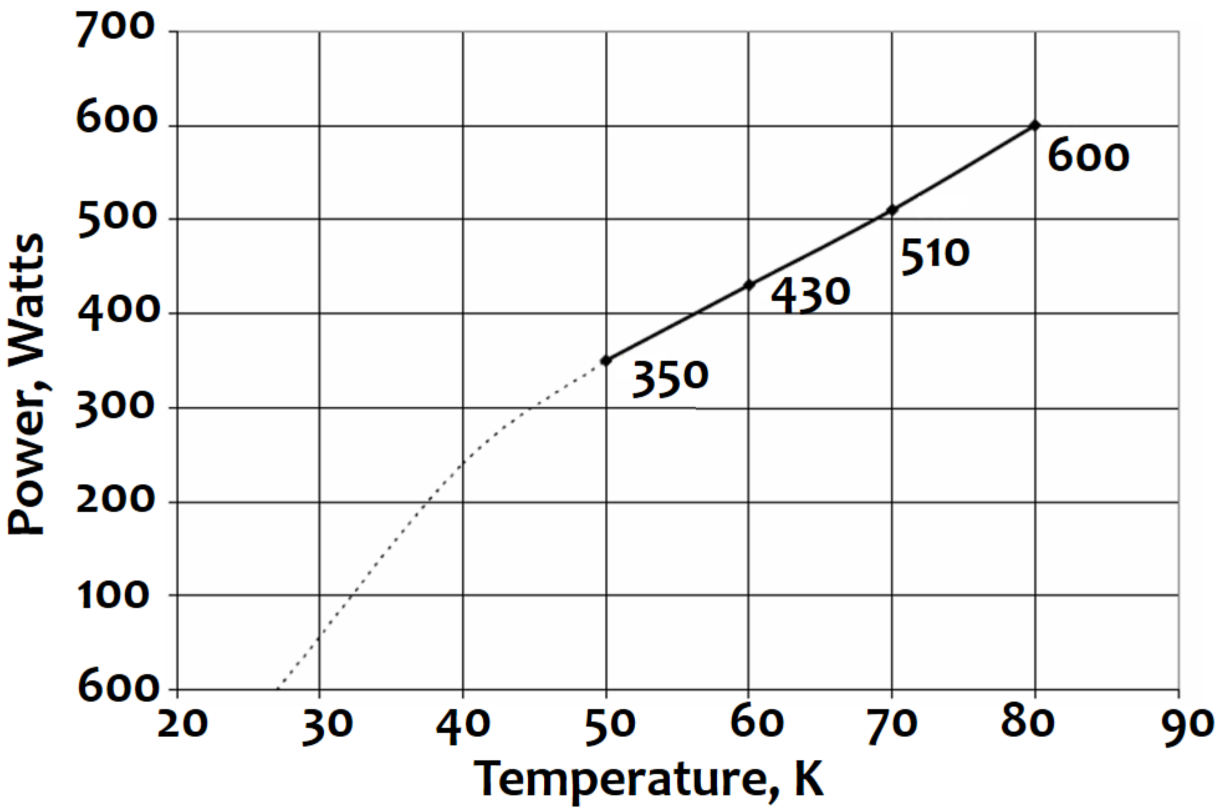
PEPL cryopump development

Design Targets for PEPL Cryopump

1. Liquid nitrogen free
2. Pump xenon and krypton
3. Performance > 35,000 l/s
4. Fit within 48ASA caps in LVTF

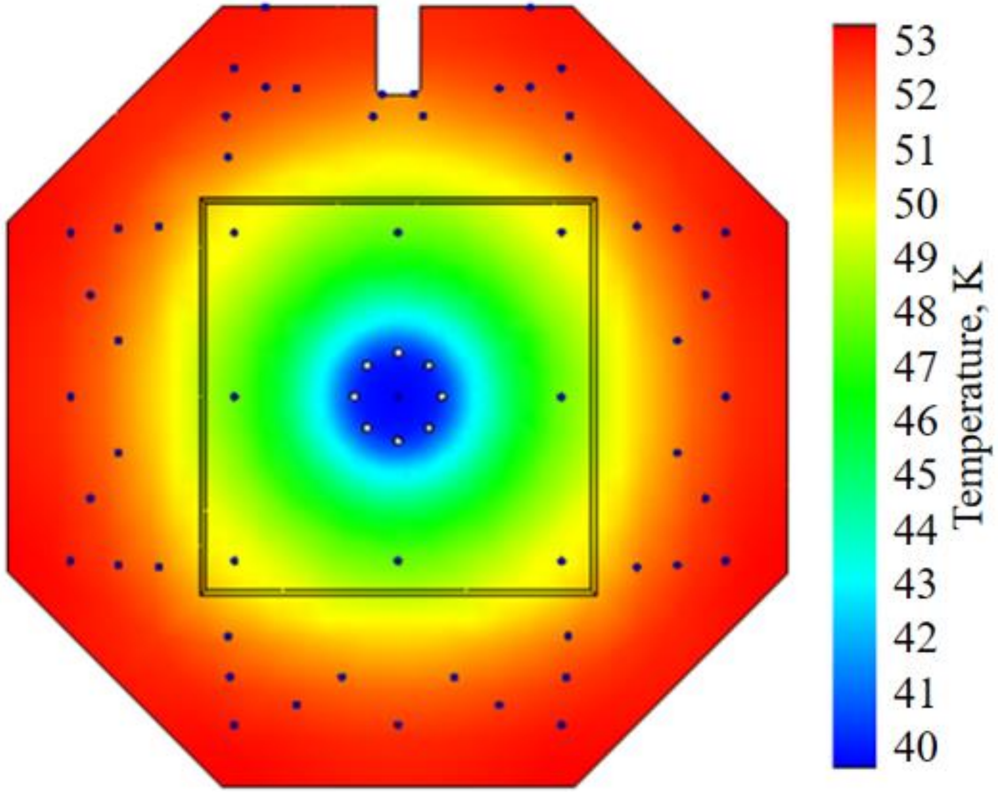


Cryomech AL600 Cold Head



Cryomech AL600, capacity chart adopted from manual

PEPL cryopump final design

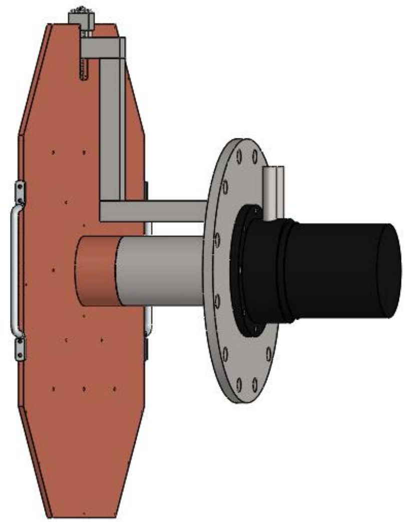


Theoretical pumping speed condensing gas

$$S_{th} = A\sqrt{\frac{T_i R}{2\pi M}}$$

Theoretical pumping speed for Xe @ 298 K:

$$S_{th} = 55{,}000 * A$$



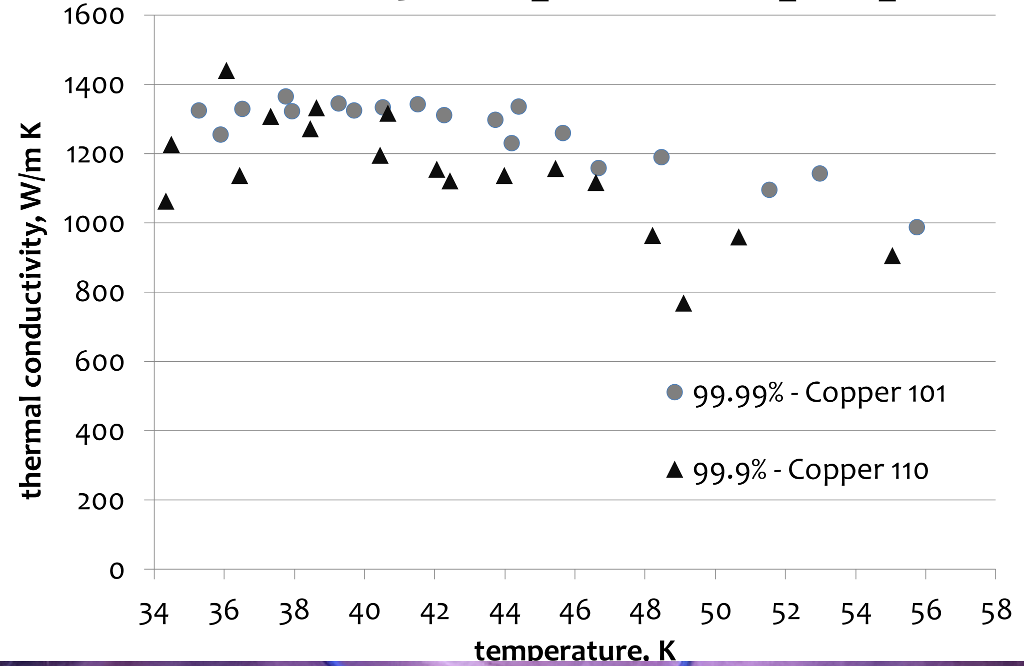
Modeling Details:
Emissivity = 1 (worst case), Copper TC = **400 w / m K** (worst case)
Pump Surface Area = 0.72 M2
Radiative Load = 335W
Delta T Across Pump = 13 K

Xe Pumping Speed for this plate: 39,600 l/s

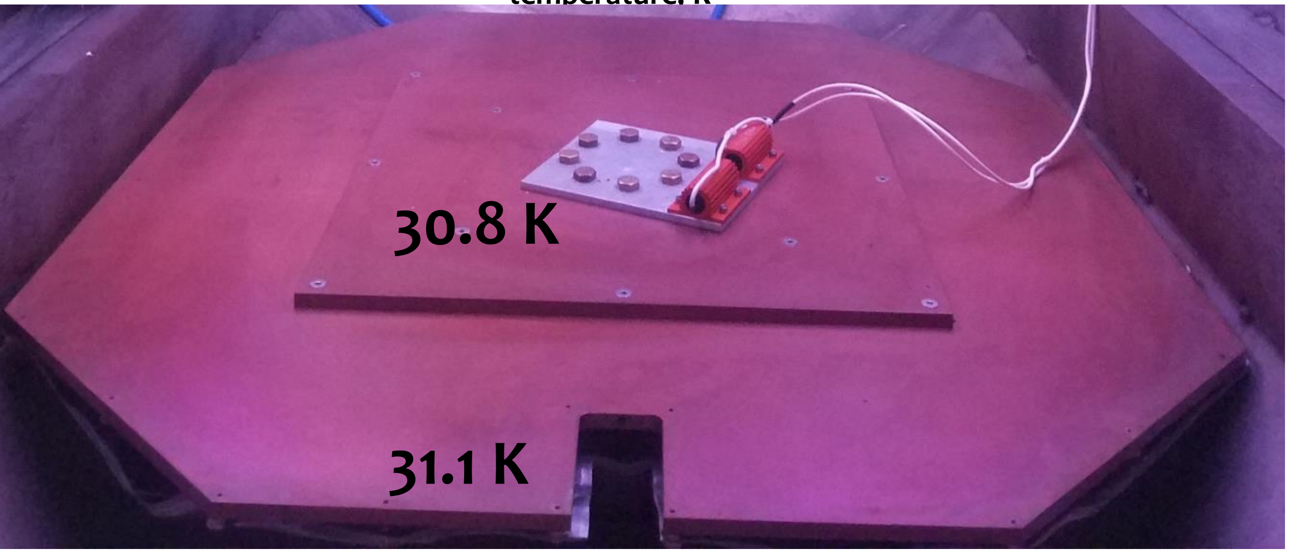
Final Design Thermal Model

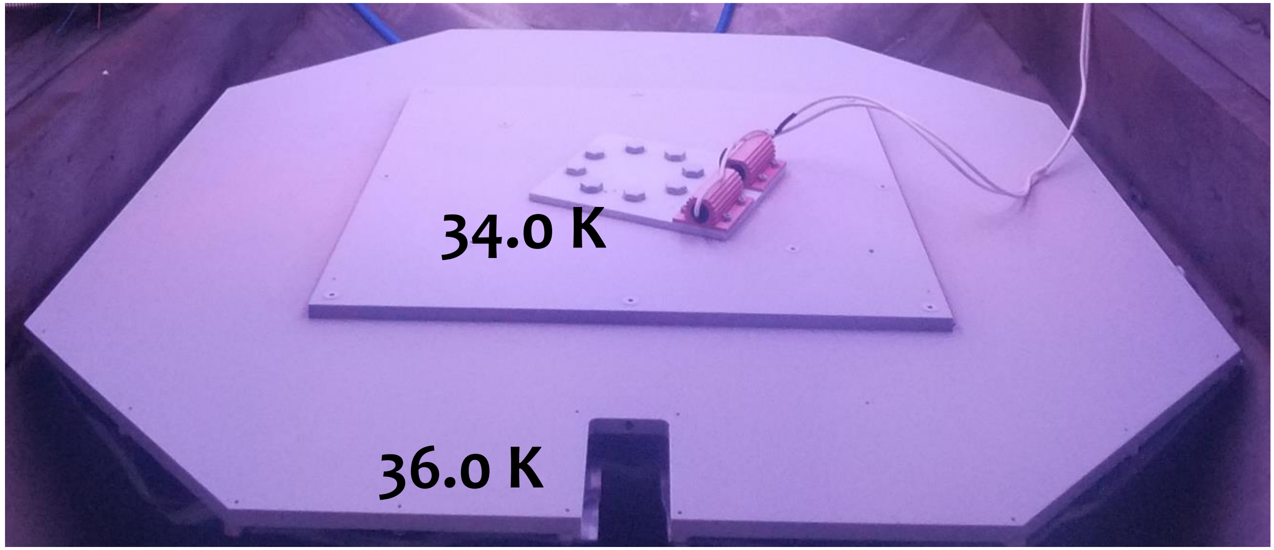
- 90 cm x 85 cm x 0.95 cm (backplate)
- 46 cm x 46 x 0.95 cm (top plate)
- Copper plate mass = 75 kg
- MLI on rear – Zero radiative heat transfer to back of plate

PEPL cryopump performance

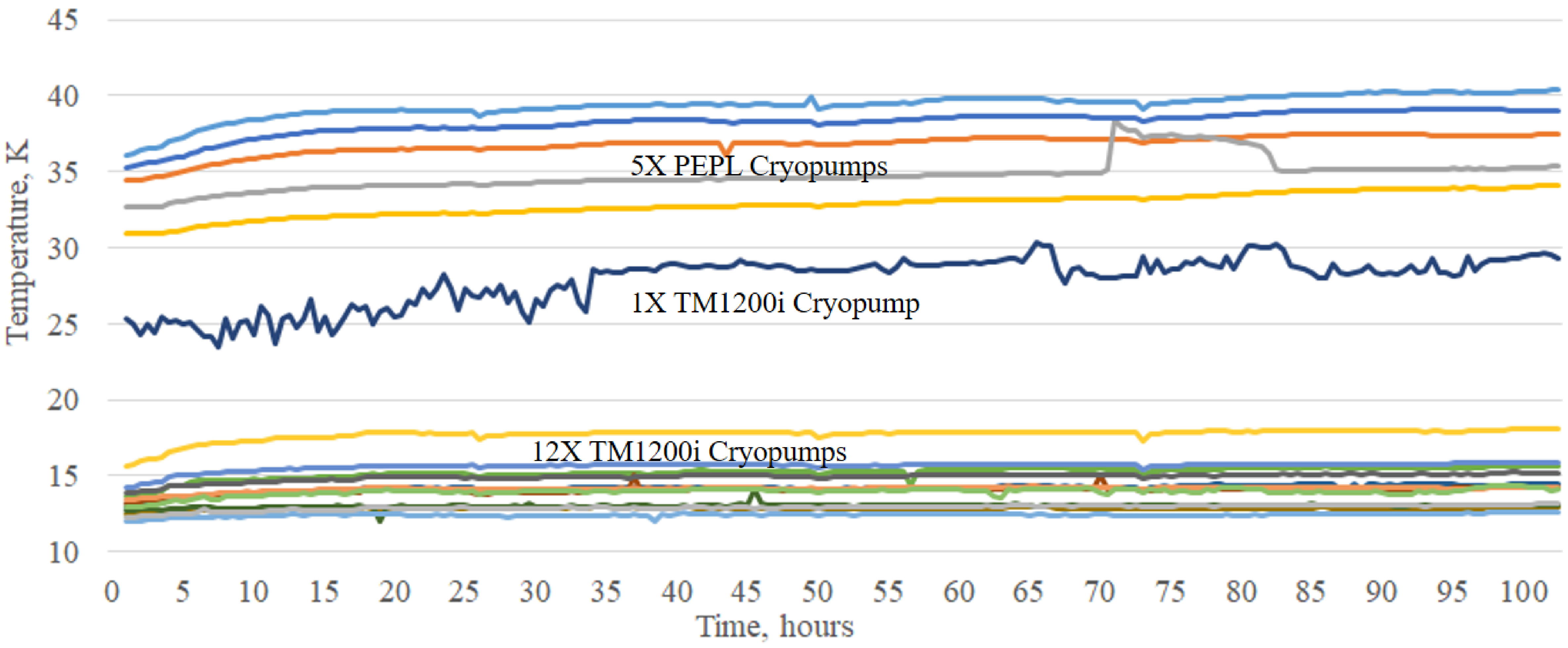


1. Eff. pumping speed near theoretical (39,600 l/s)
2. 120 L condensed xenon gave ΔT of 2 K on plate





7 kW, 100 hour, 1000 l test



14.8 mg/s total flow –4.3 µTorr Xe – Effective Pumping speed 484 kl/s

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Questions

This work is supported in part by the Air Force Defense University Research Instrumentation Program award no**. FA9550-16-1-0275** and a generous loan of four Tm1200i cryopumps from **NASA JPL**.

Thermal Conductivity Cu Alloys