A Look at some Cryogenic Equipment

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June, 2019

Outline

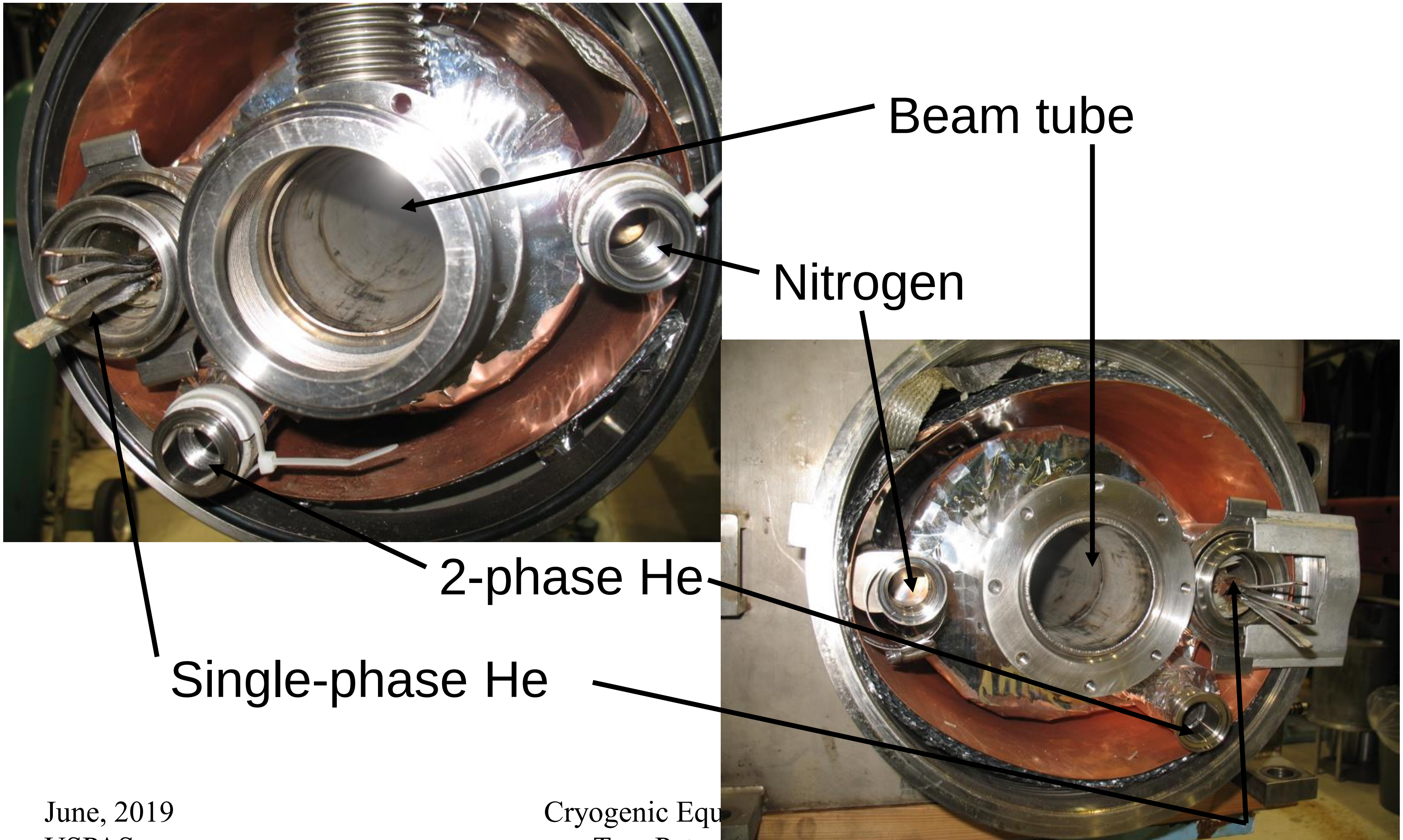
- Tevatron cold mechanical seals
- LHC test stand cold seals
- Valves and bayonets
- Compressors
- Turboexpanders
- Feed box fabrication sequence

Tevatron metallic cold seals

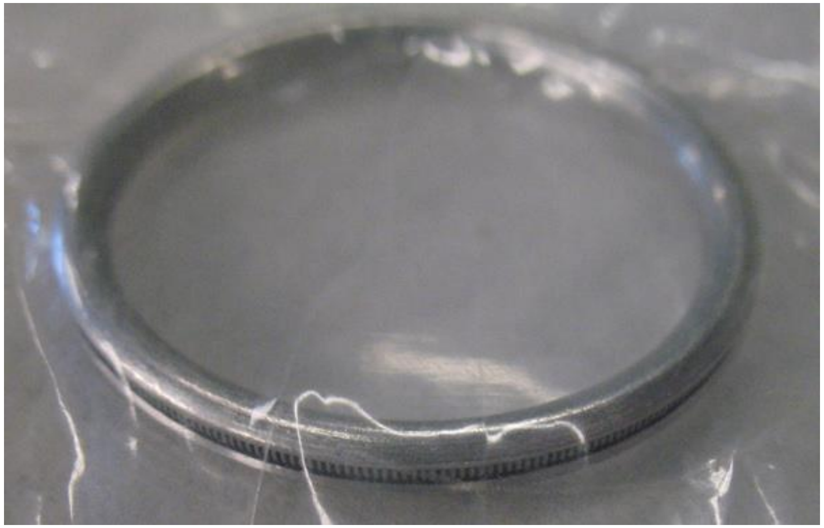
Thanks to Dave Augustine, Fermilab, for much of this info and history

- The Fermilab Tevatron includes about 1200 interconnects (magnet-to-magnet and magnet-to-endbox), each of which includes
  - An insulating vacuum to beam vacuum seal
  - A 4.0 K, 2 bar helium to vacuum seal ("single-phase seal")
  - A 4.0 K, 1.2 bar helium to vacuum seal ("two-phase seal")
  - An 80 K, 3 bar nitrogen to vacuum seal

Tevatron magnet interconnect

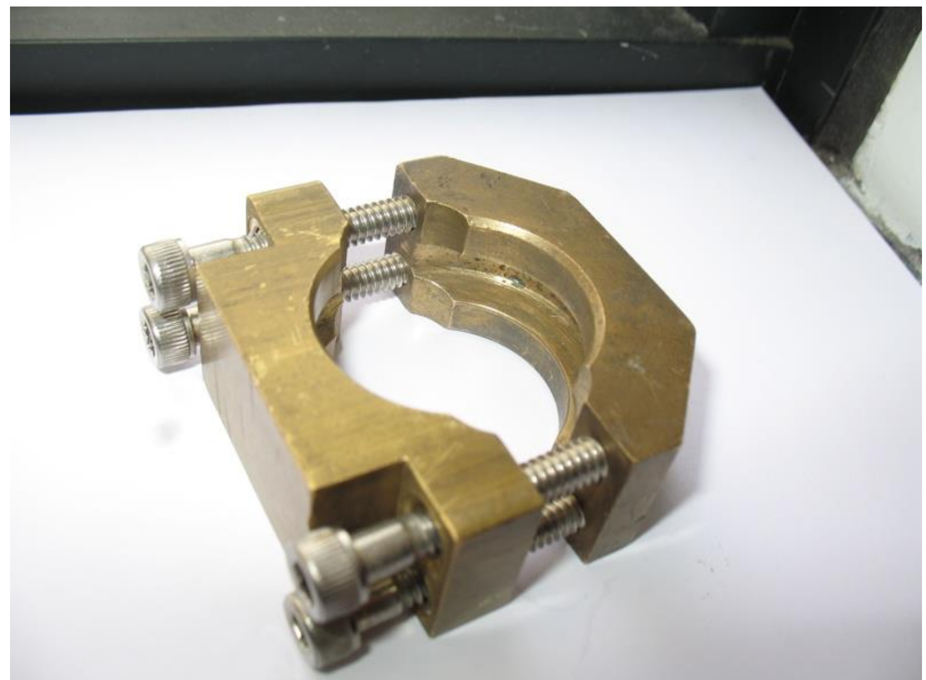


Nitrogen and 2-phase helium



Aluminum Helicoflex c-seal with internal inconel spring. Surface finish of flange is about 80 micro-inch (2 microns). Seal is designed specifically for this finish.

Fermilab-designed brass wedge clamp -- we like these brass wedge clamps at Fermilab



Nitrogen and 2-phase male flange

Single-phase helium

Stainless steel, elliptical "Conoseal" from Aeroquip Corp.
Silver coated 0.0005" (13 micron) thick plating. Coated locally.
Indium, copper, and gold plating each failed. (Indium creeps, gold had poor adhesion to the SS.)
Good success with silver, although if the silver corrodes, then it leaks.
Similar 4-bolt Fermilab-designed brass clamp on tapered flanges.

Cold Seals Comments

- Indium is popular but not universally endorsed for helium to vacuum metal joints
  - Indium seals used successfully for SF to vacuum seals at Fermilab's Magnet Test Facility
  - Tevatron experience suggested creep and long-term failure
  - Indium seals used extensively at Jlab for long-term seals (See paper by Benesch and Reece, Advances in Cryo Engineering, Vol. 39A, pg 597)
- A very sensitive and successful leak test generally results in a leak tight SF seal. Such a leak check requires a local test fixture around the seal or double-seal.
- "Cold leaks" (4.5 K) may be found which are likely just due to greater He density and leak rate cold.
- We have not seen "superleaks" (leak tight at 4.5 K but leaking below 2.17 K).

Cold Seal Conclusions?

- No consensus on a "formula" for successful cold helium-vacuum seals at Fermilab. (I hoped to provide one from Fermilab's extensive experience with cold mechanical seals.)
- Our experience for magnet tests concurs with H. Ishimaru and H. Yoshiki, KEK (Cryogenics, Vol 31) in that uncoated aluminum seals on stainless flanges closed with chain clamps tended to leak
  - Hence use of indium ribbon on those seals
  - But note Tevatron use of aluminum seals on 2-phase helium line.
- Indium creep? Yes for conoseal coatings, no for Jlab indium wire seals
- Subtle manufacturing and metallurgical details, such as rolling direction, alloy, have significant effects

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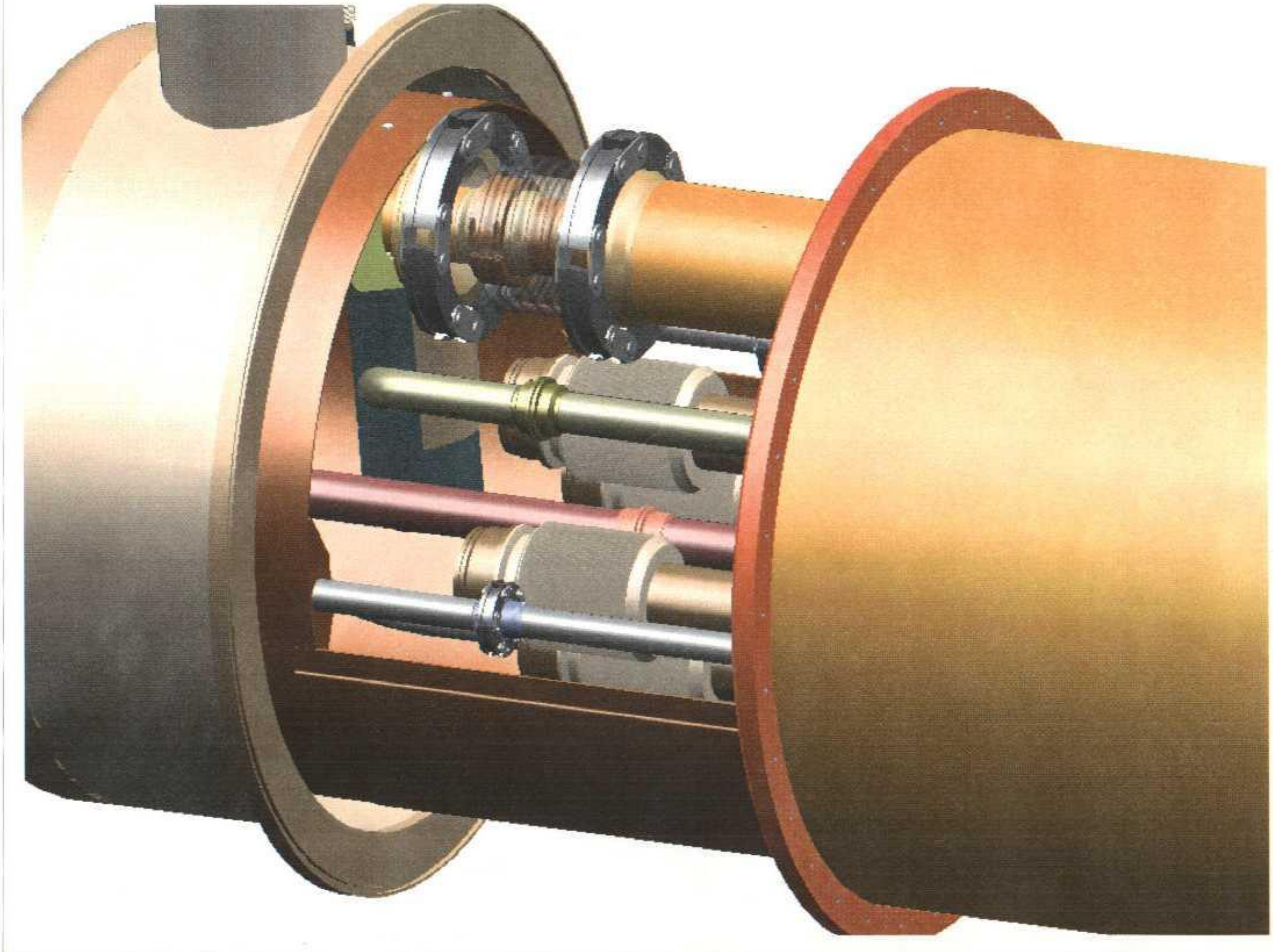
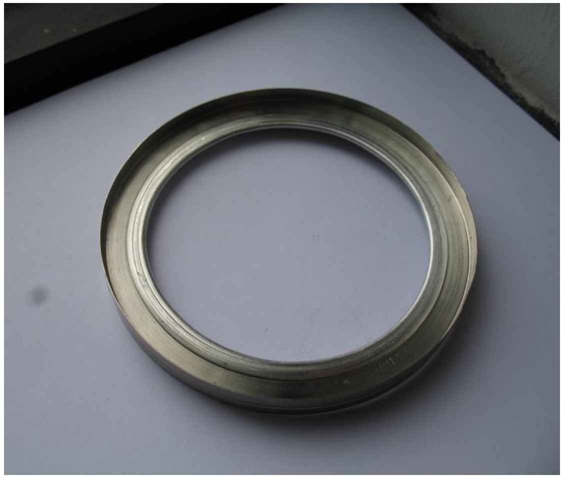
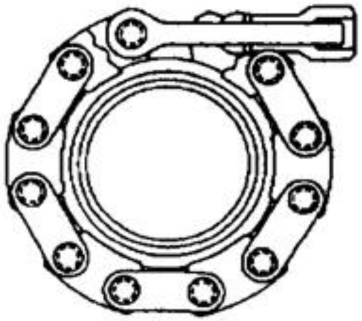
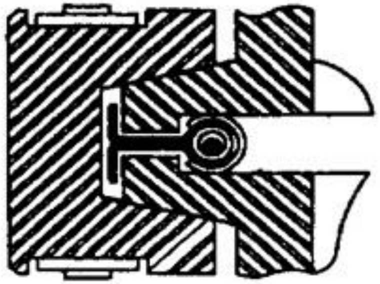


LHC IR Quad Interconnect

Test stand seals for superfluid to insulating vacuum

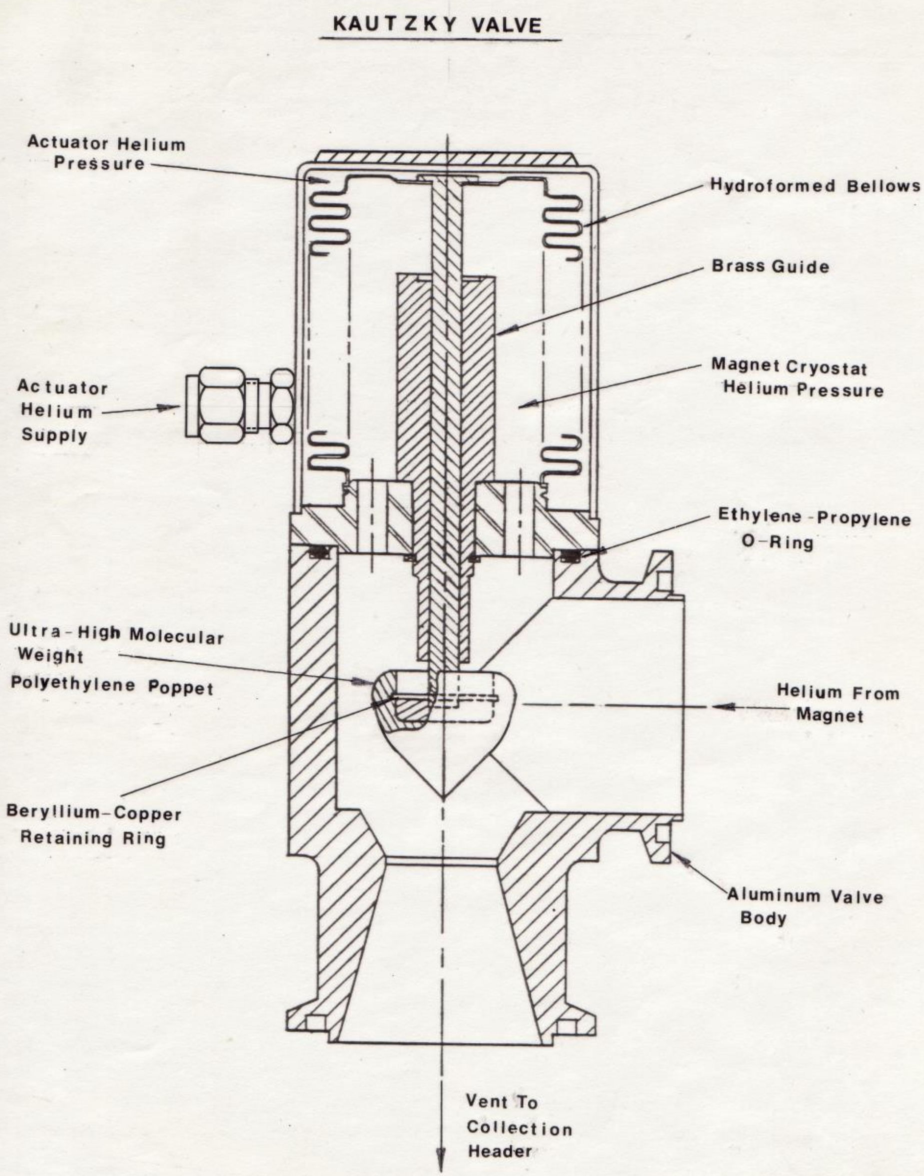






2.25 inch (57 mm), up to 6+ inch (150+ mm) ID, with ½ inch (12 mm) wide, 5 mil (0.13 mm) indium ribbon wrapped on aluminum seal. Chain clamp.

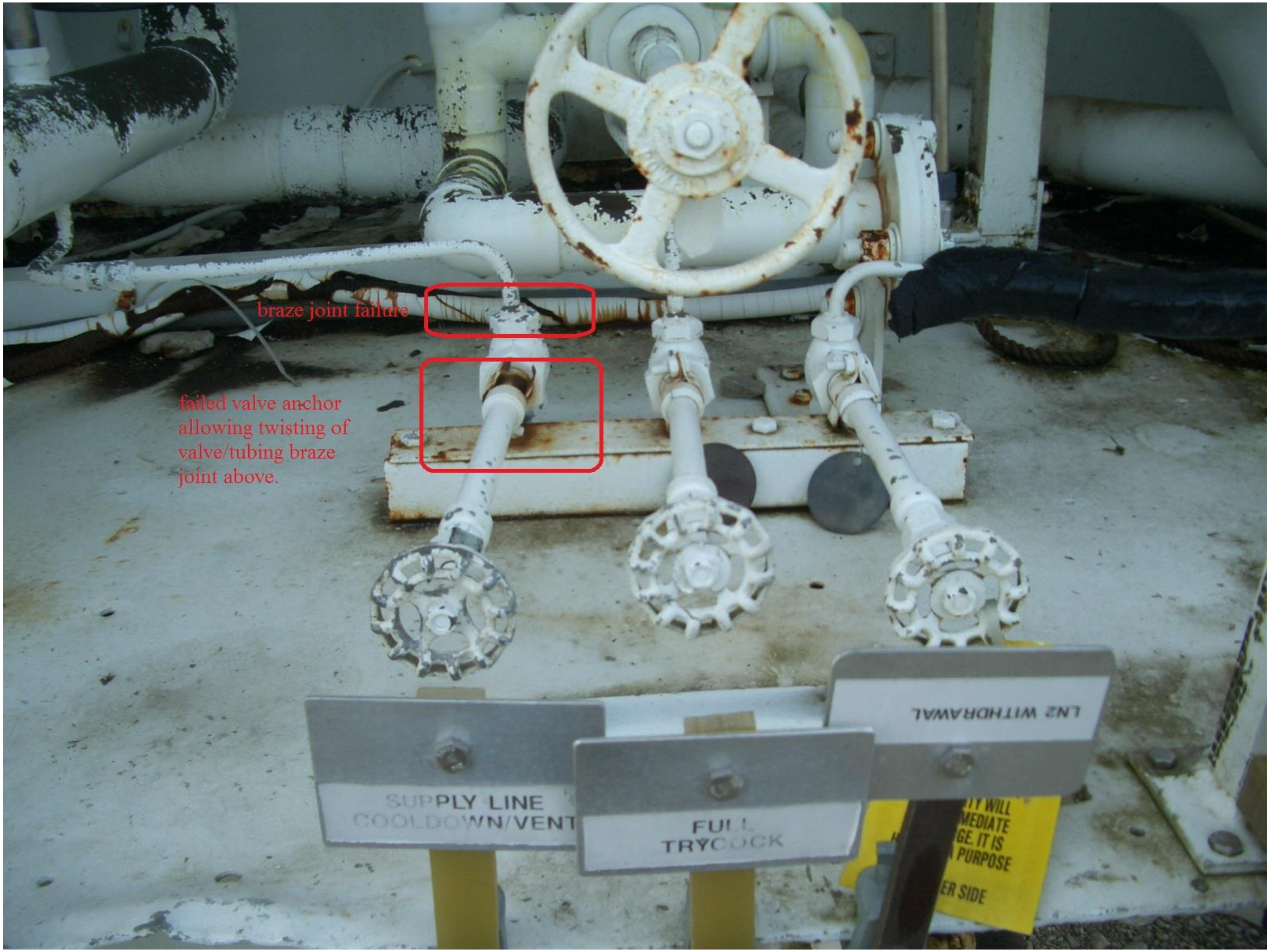
Reference for these seals: "Sealing performance of gaskets and flanges against superfluid helium," by H. Ishimaru and H. Yoshiki, KEK, in Cryogenics, Vol 31, June 1991.



"Kautzky Valve" (concept developed by Hans Kautzky, Fermilab) served as the primary quench vent valve for Tevatron magnets.

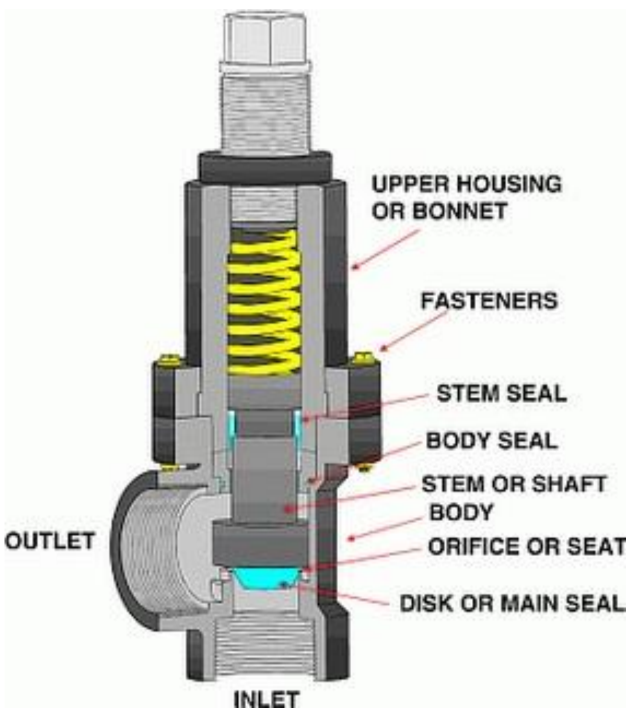
Valve illustrates the typical cryogenic valve configuration with a poppet in a valve body, stem with actuator (not extended in this case since valve normally warm).

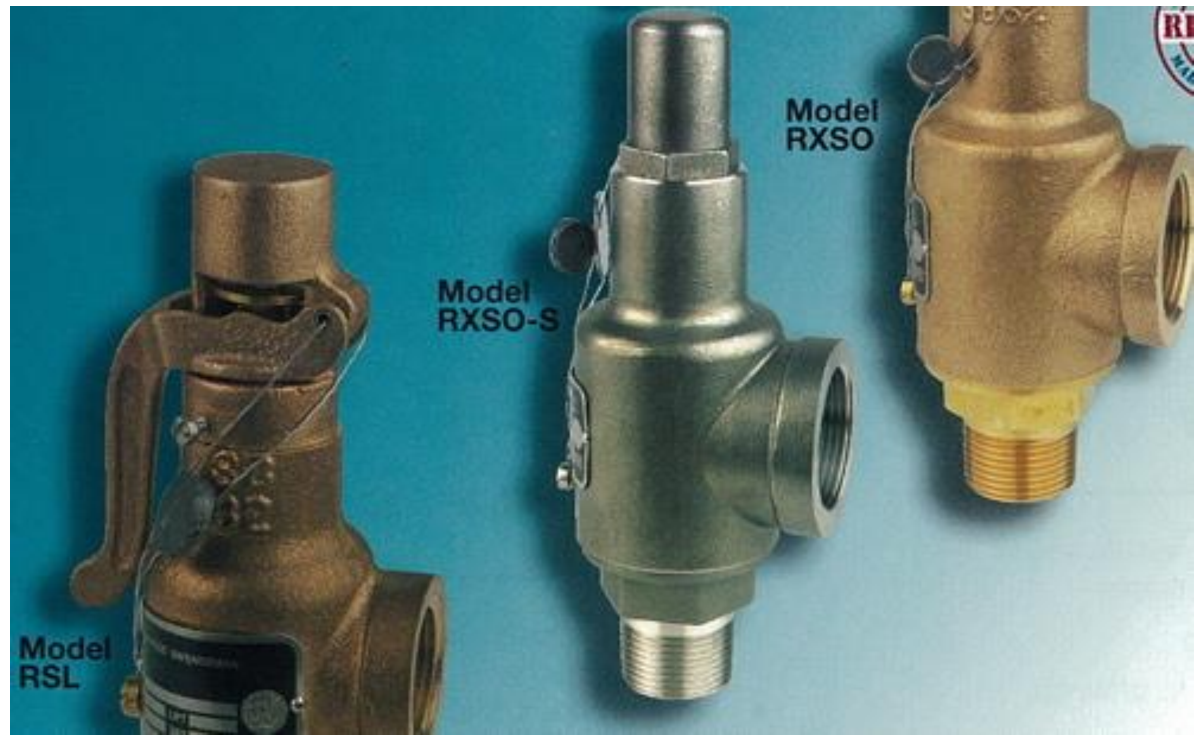
Flow would normally but up through the poppet but in some cases including this, may be down over the poppet. The latter case especially for 2 K JT valves, discharge side subatmospheric, so as to place the stem at positive pressure.

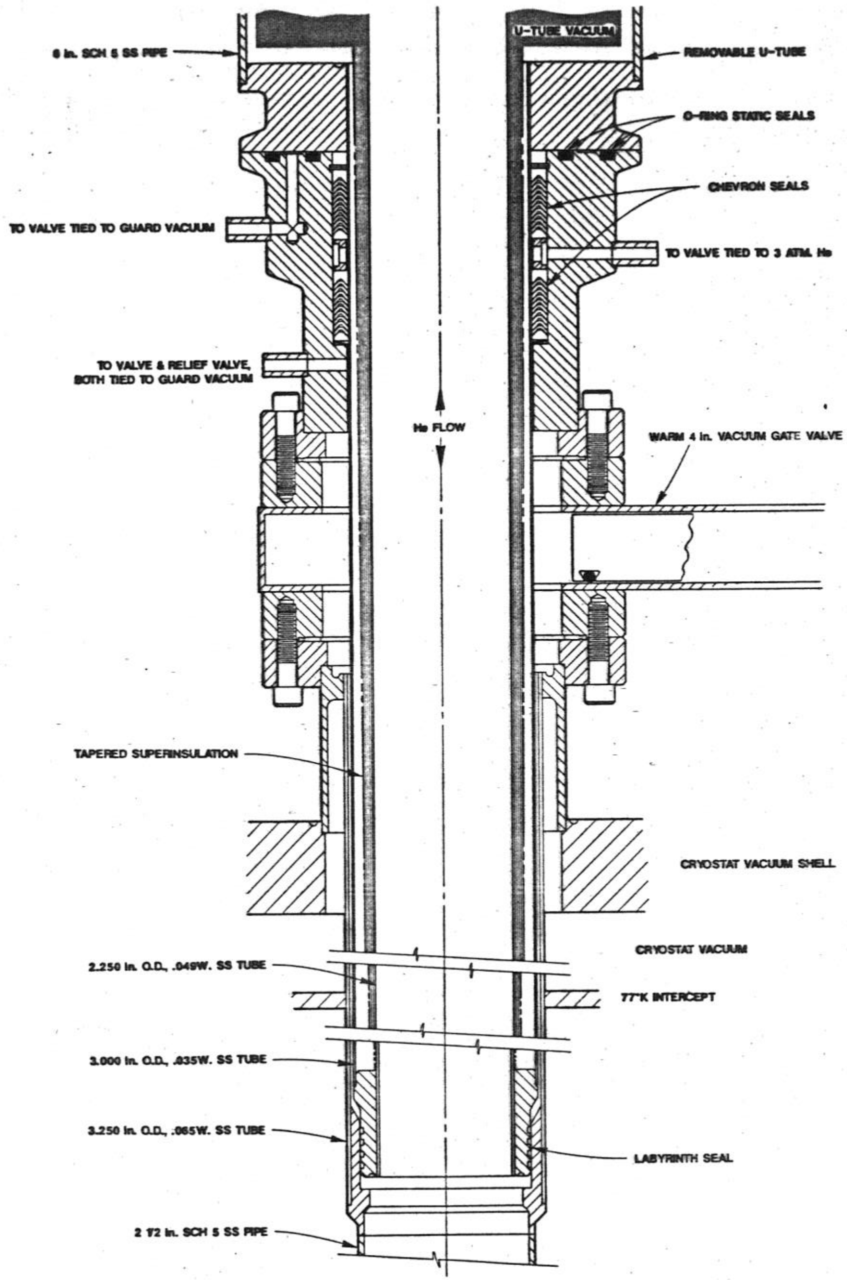


Extended stem hand valves typical of LN2 installation

Spring-loaded relief valves







3 1/4 in. SSC - CEBAF HELIUM BAYONET - SUBATMOSPHERIC
HALF SCALE

Bayonet – SSC/CEBAF design for subatmospheric operation.

Bayonet advantage is a mechanical disconnect with seals at room-temperature. A vacuum-jacketed tube fits into a second vacuum-jacketed tube with the adjacent vacuum jacket walls transitioning to room temperature.

Compressors

Compressor hall at DESY

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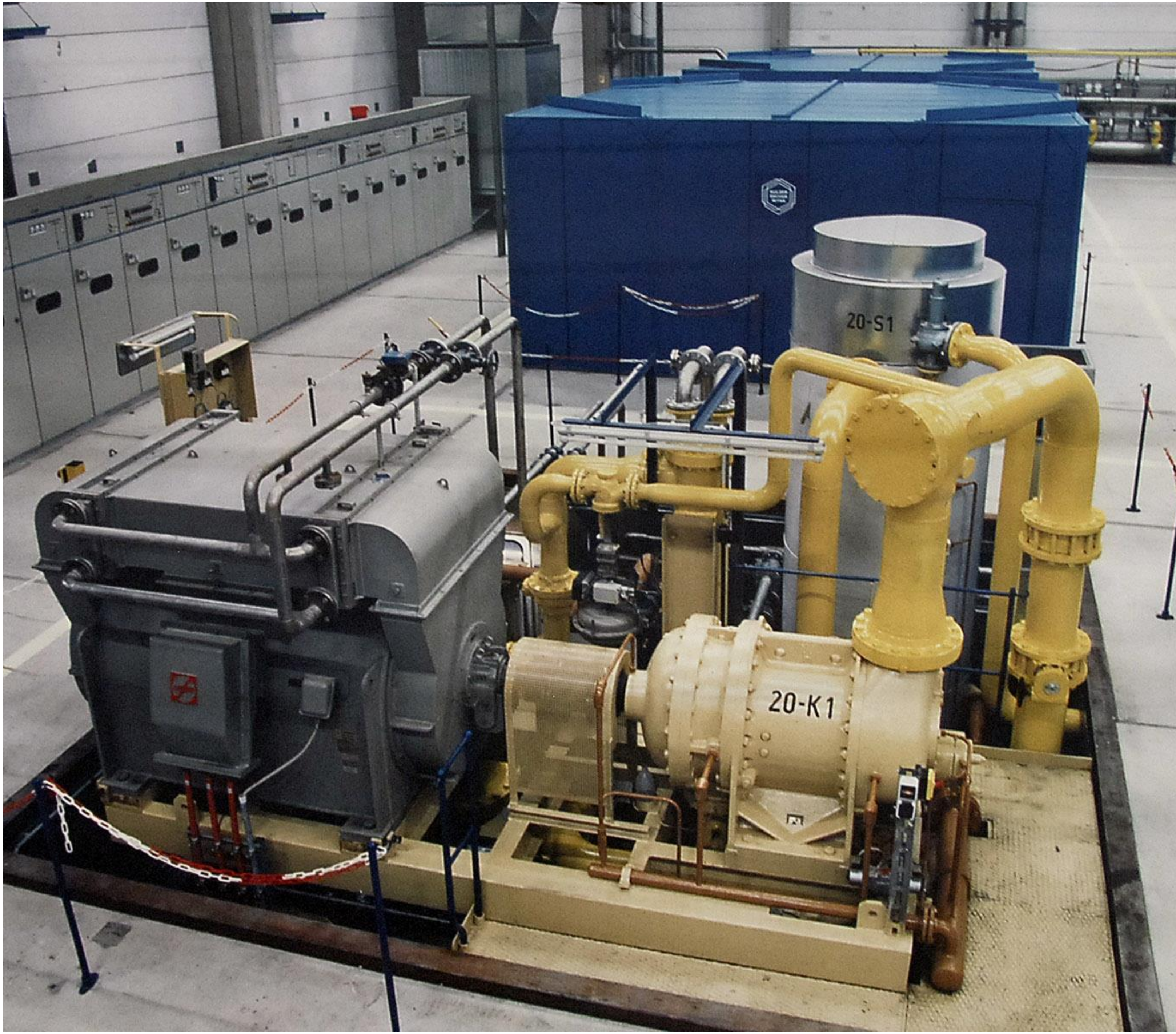
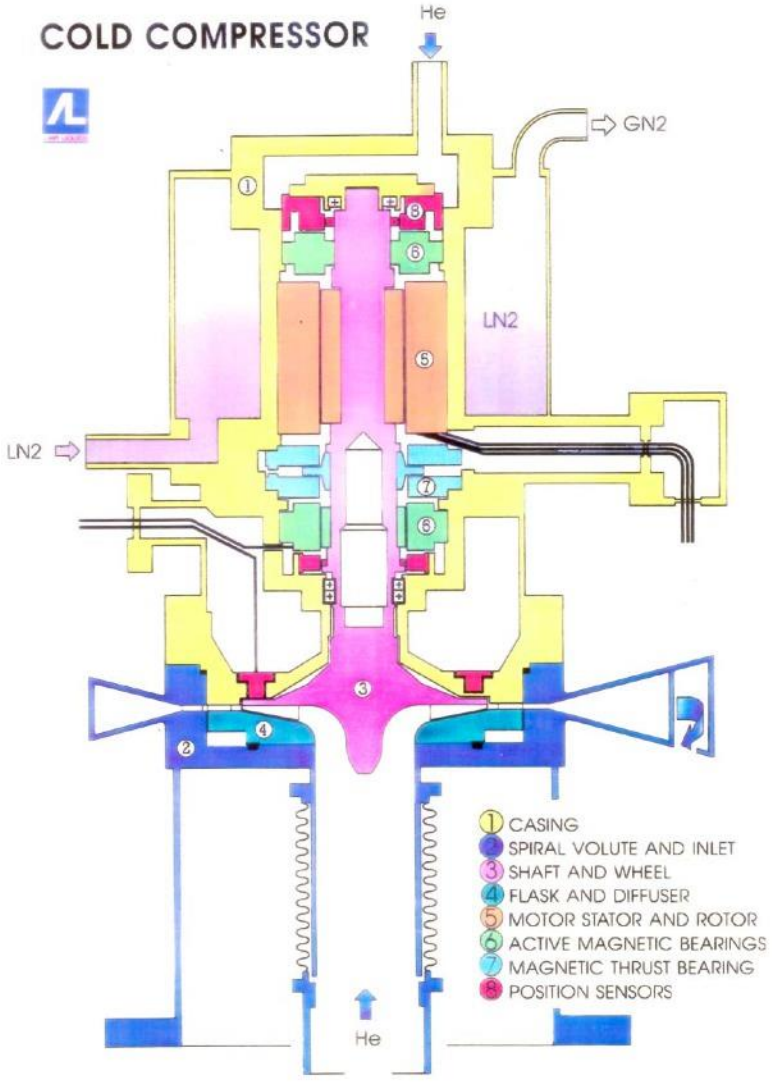


LHC (CERN) compressors



Example of a cold compressor with active magnetic bearings used at Tore Supra, CEBAF and Oak Ridge

Source: Air Liquide

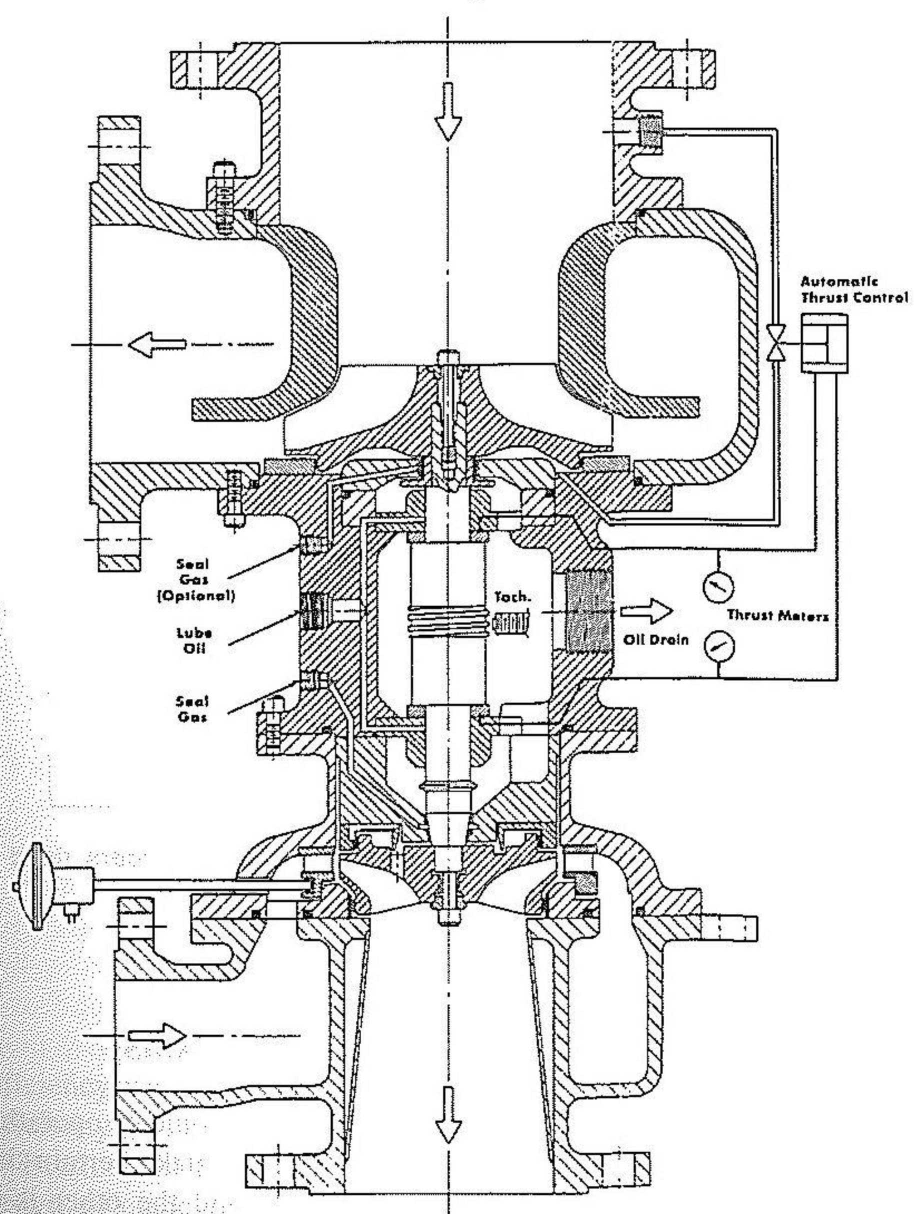


Figure 3-9. Expander-compressor cross-section. *(Source: Atlas Copco.)*

From Heinz P. Bloch, "Turboexpanders and Process Applications"

At the bottom is a radial-inflow turboexpander, driven by a turbo-compressor on top

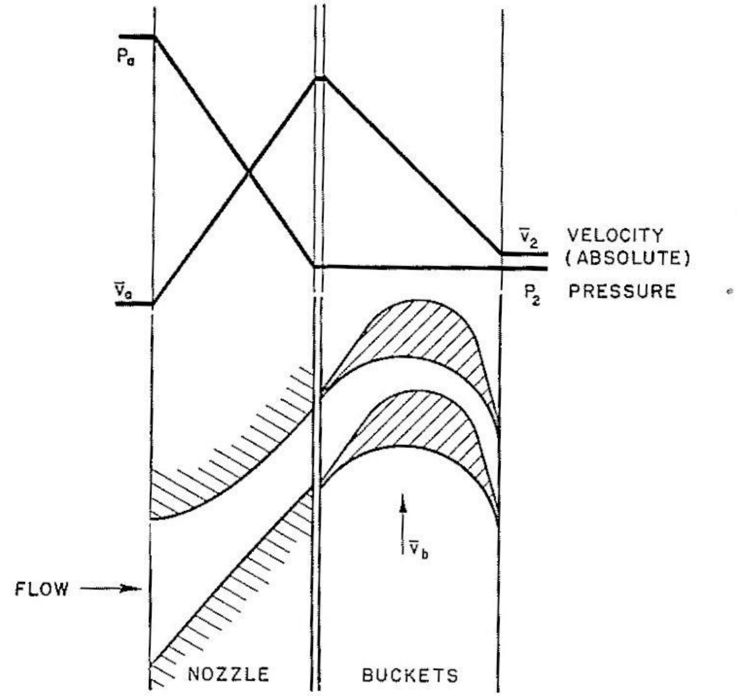


Fig. 18-11. Impulse stage.

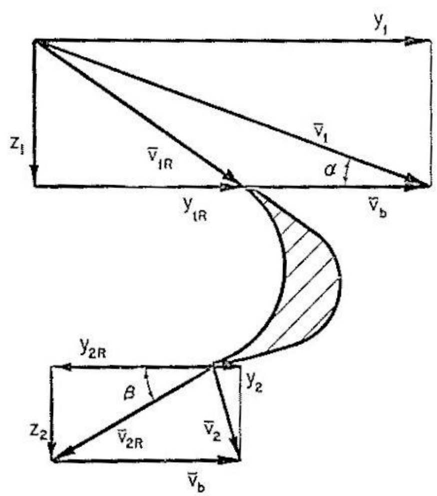


Fig. 18-12.

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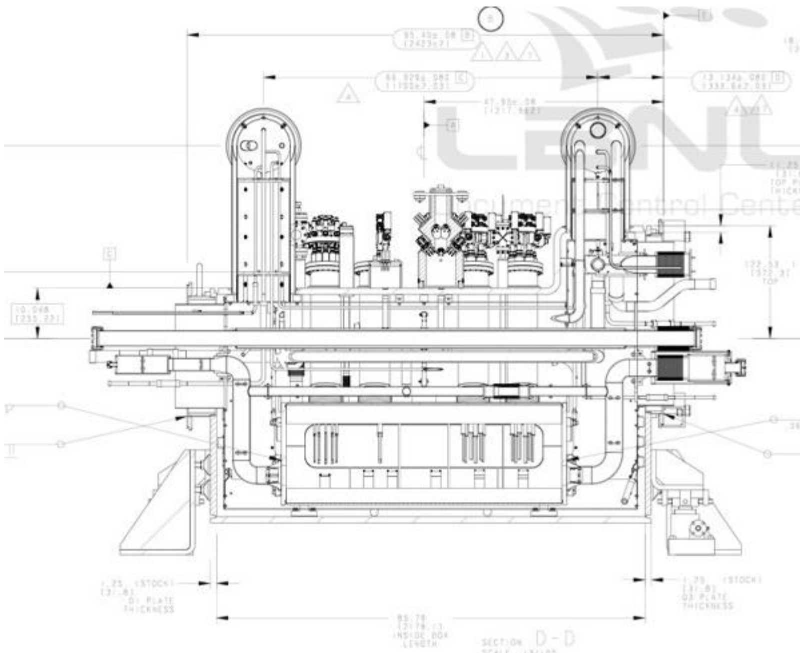
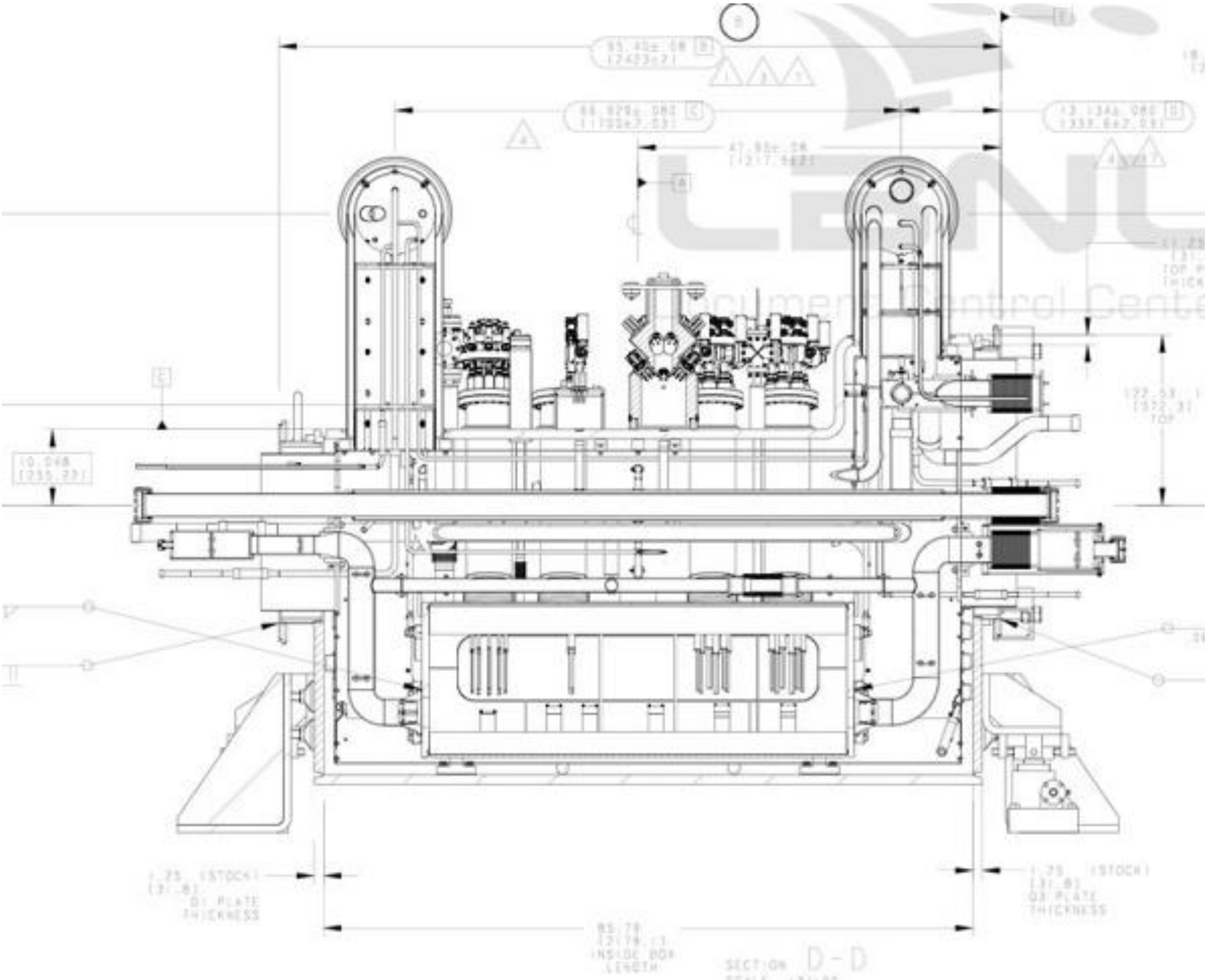
From David A. Mooney, “Mechanical Engineering Thermodynamics”

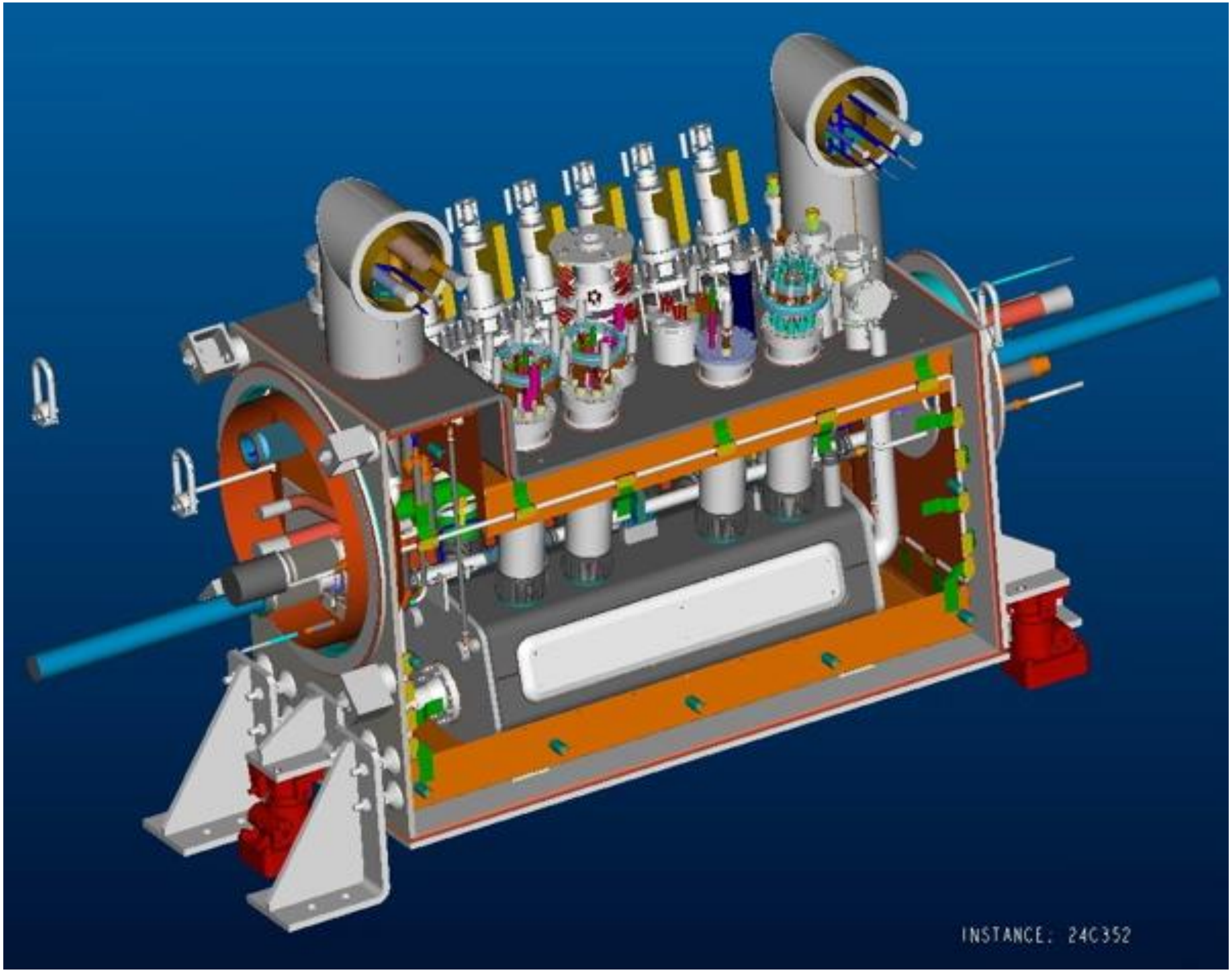
Illustrating how flow is accelerated through stationary nozzles imparting kinetic energy to turbine blades



Fabrication of a "feed box"

- The following photos illustrate the sequence of major steps in fabrication of a large cryogenic box in industry
- A "distribution feed box" or DFBX for the inner triplet magnets in LHC
- Eight boxes fabricated at Meyer Tool near Chicago and shipped to CERN




INSTANCE: 24C352

Build from top plate, down

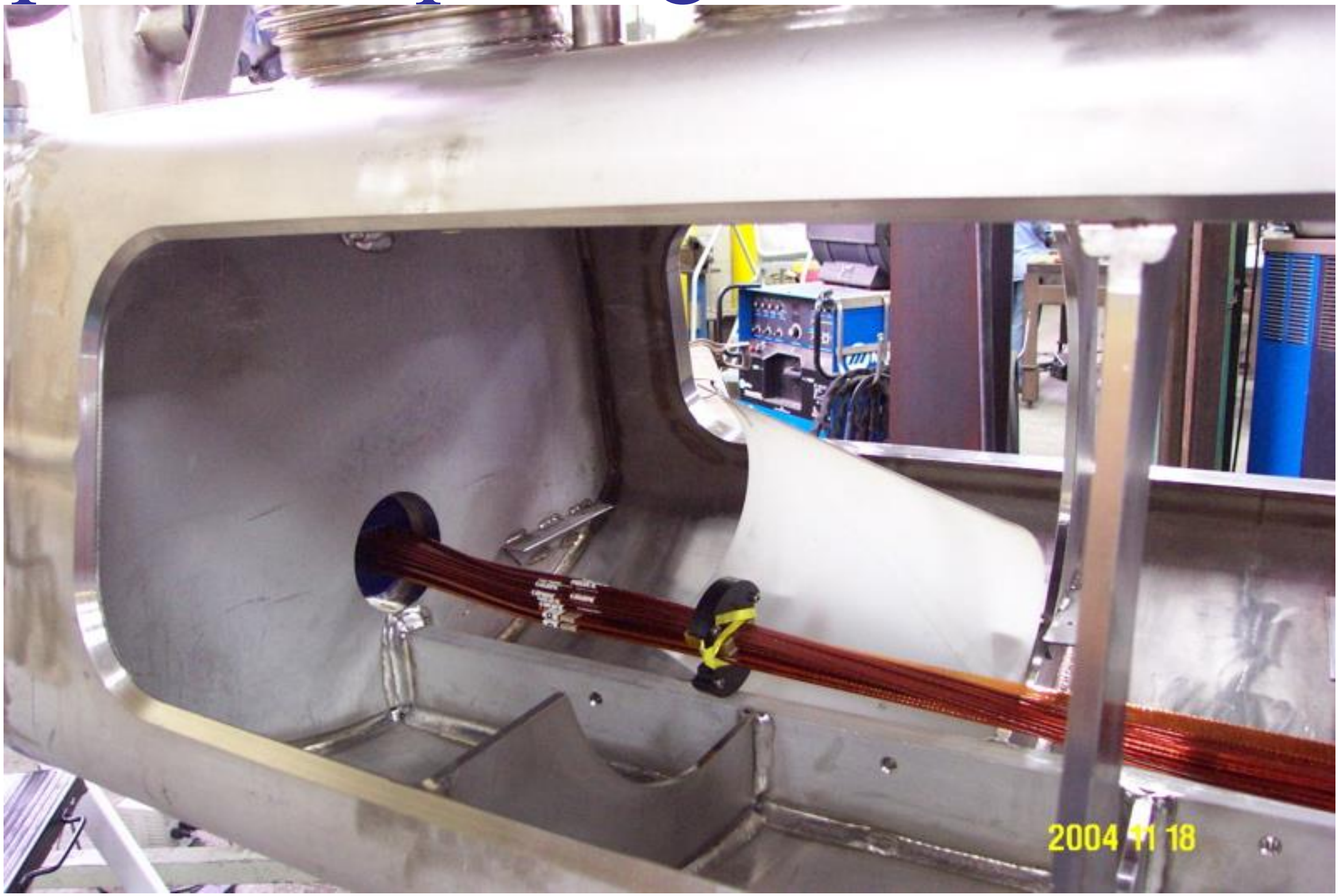
Hang helium vessel

Connect helium vessel

Prefabricated piping ("bus duct")

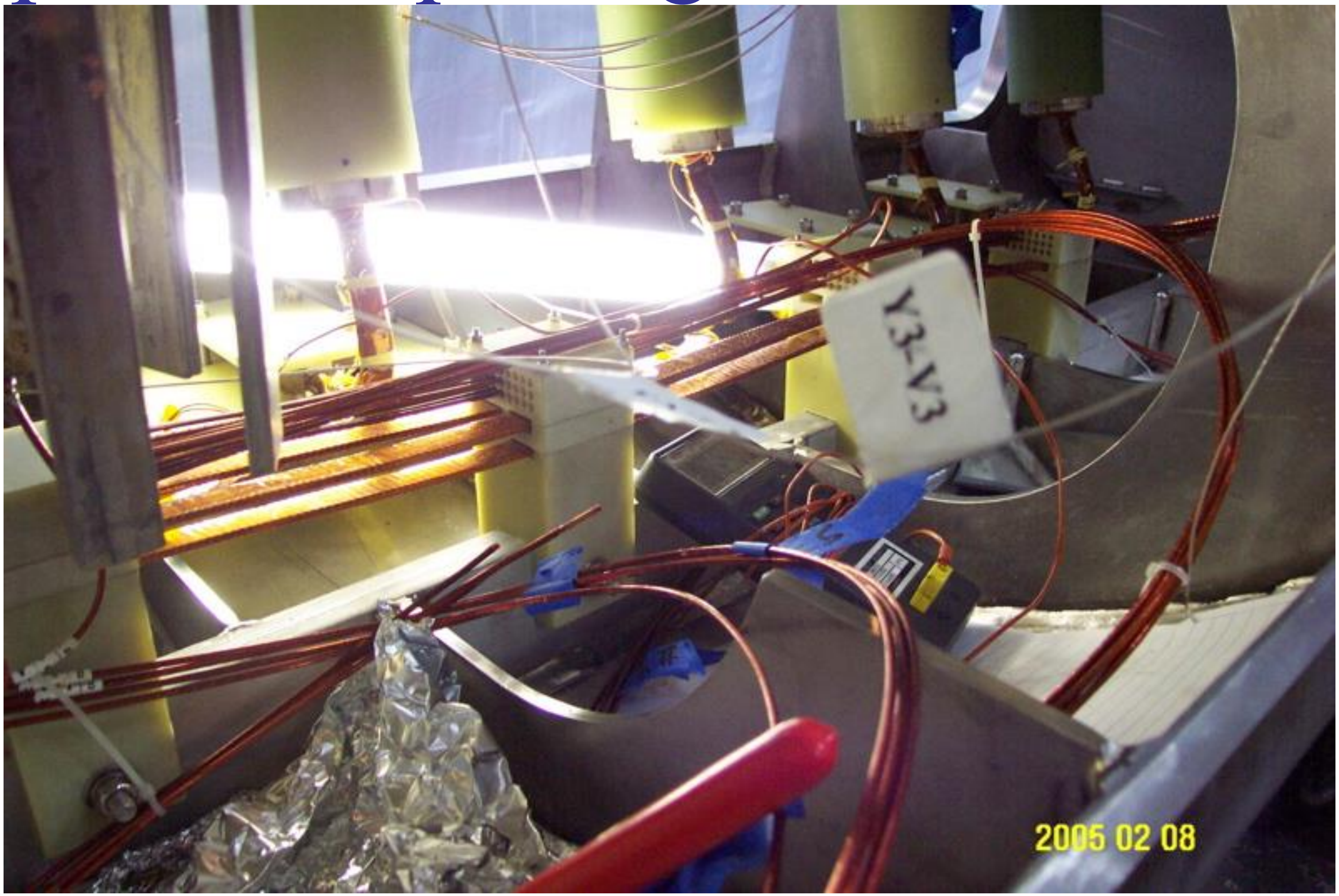
Install bus ducts

Splice and package internal cables



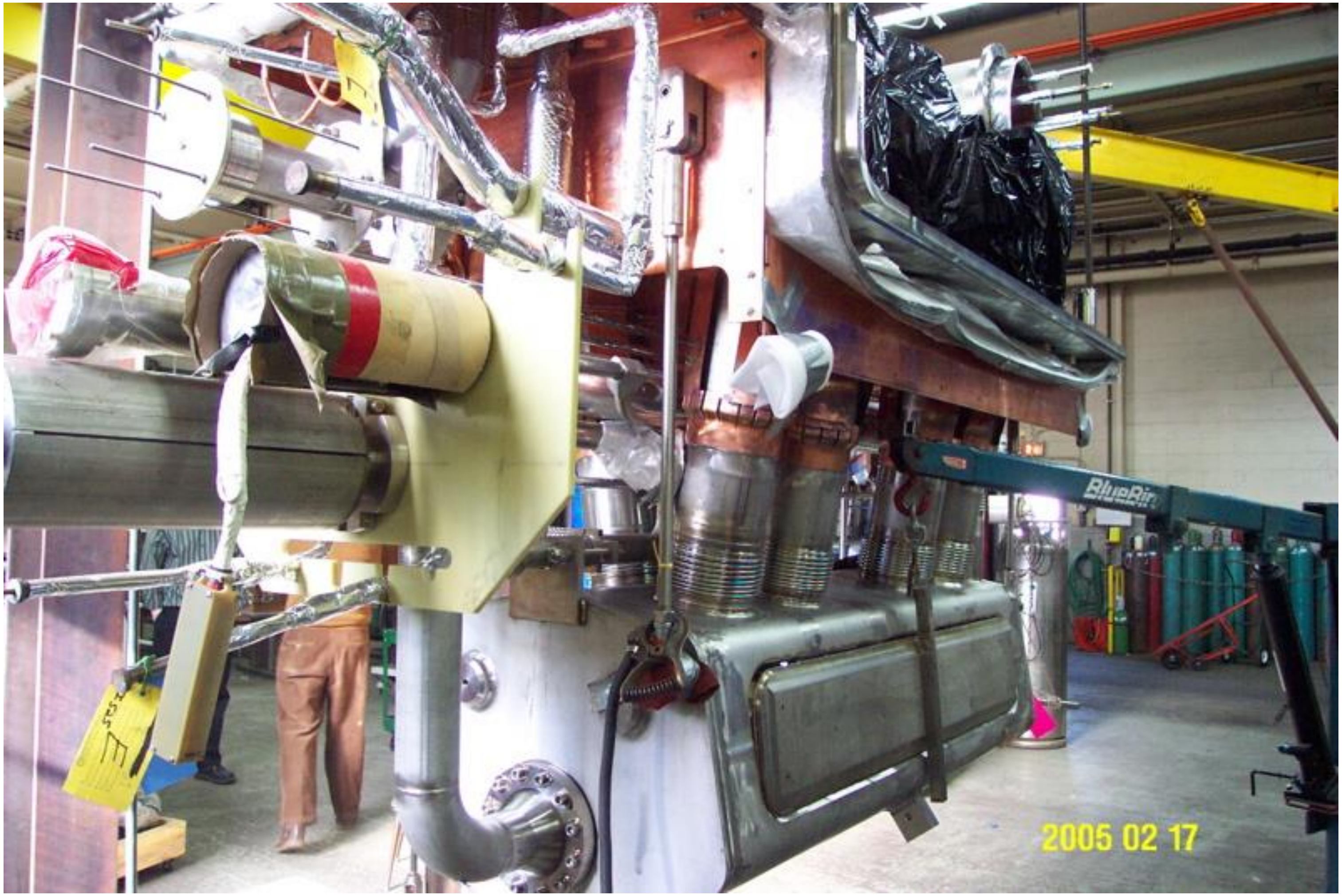
Splice and package internal cables

Splice and package internal cables

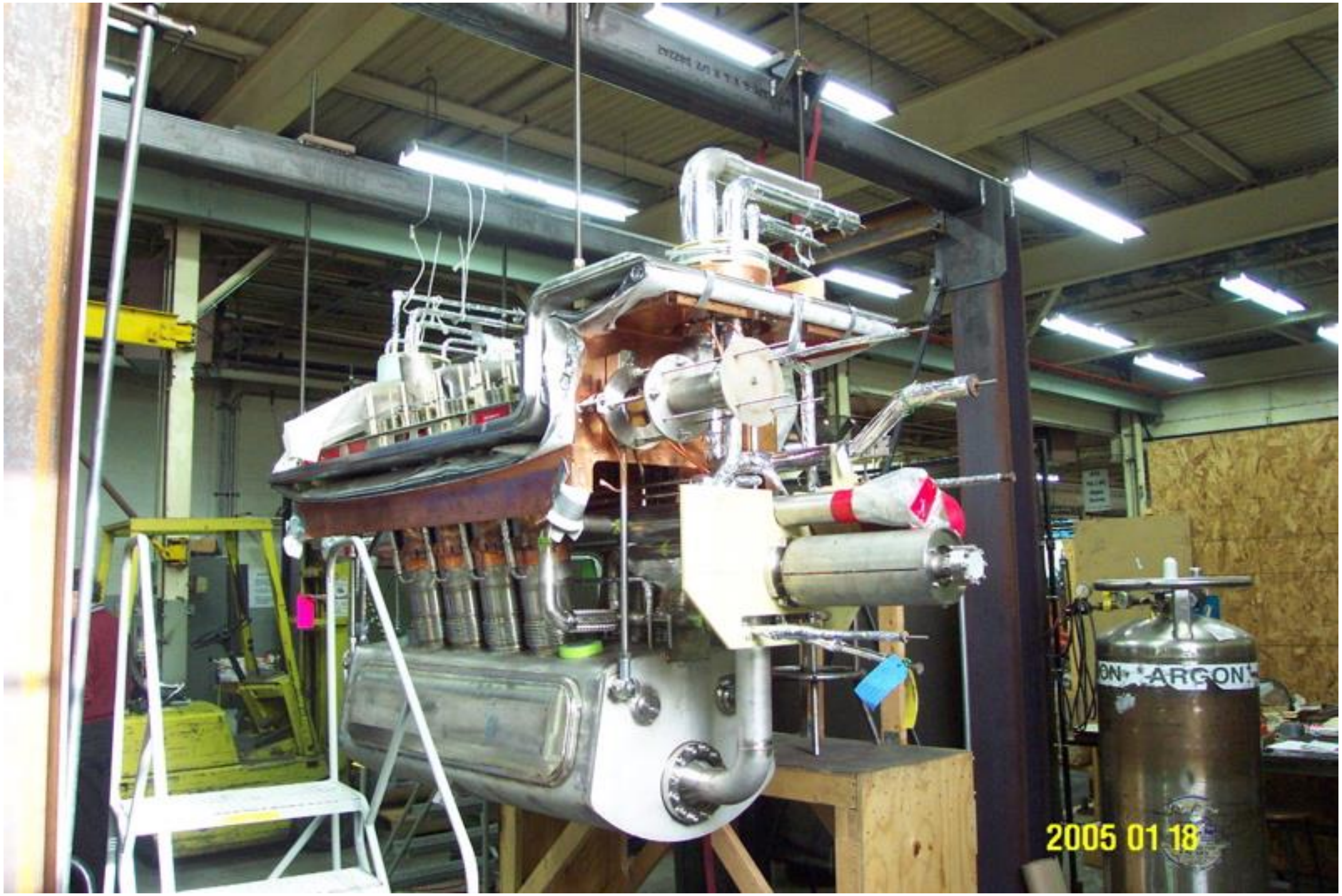


Install more piping

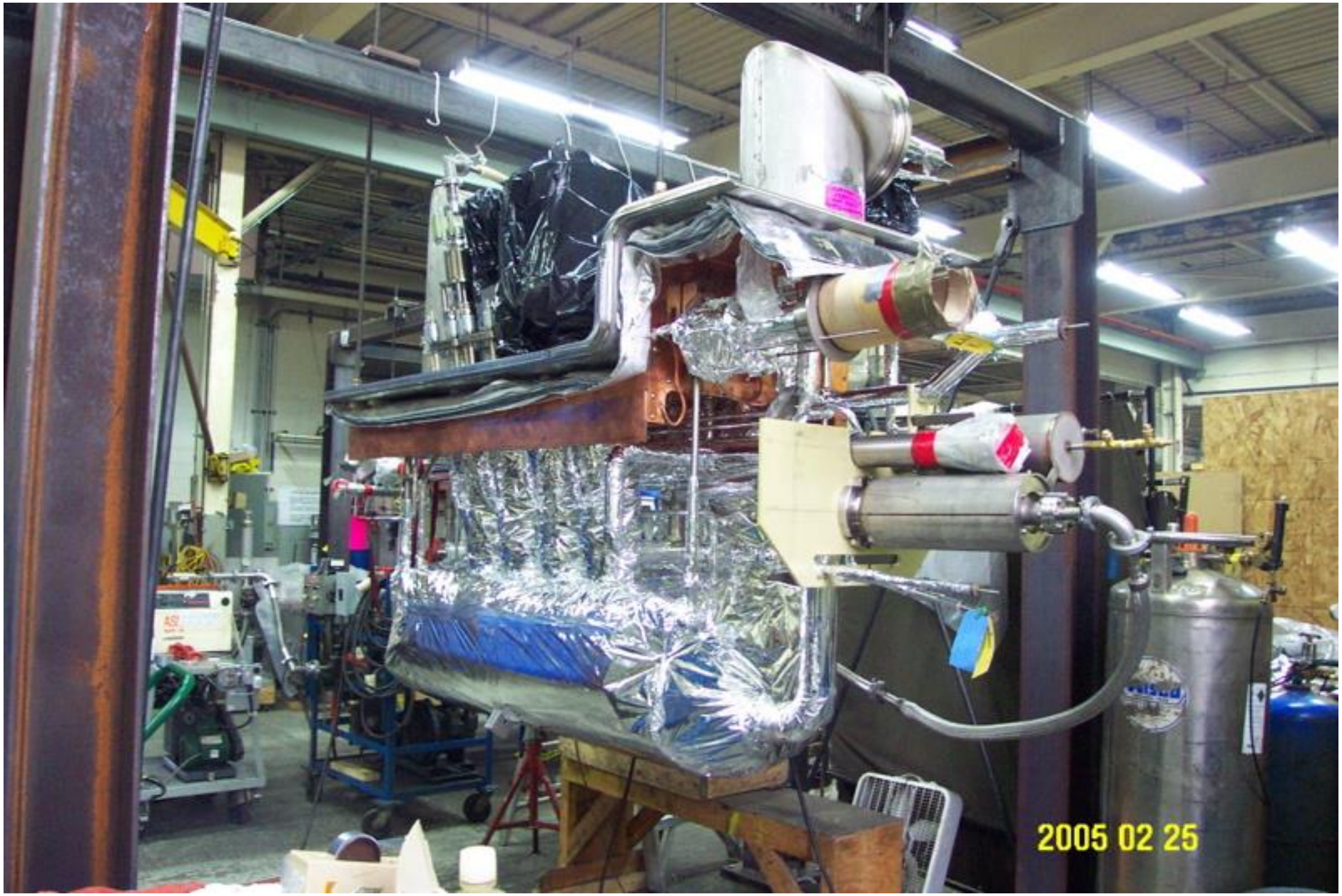
Weld closed helium vessel



Leak check He vessel



Wrap with MLI

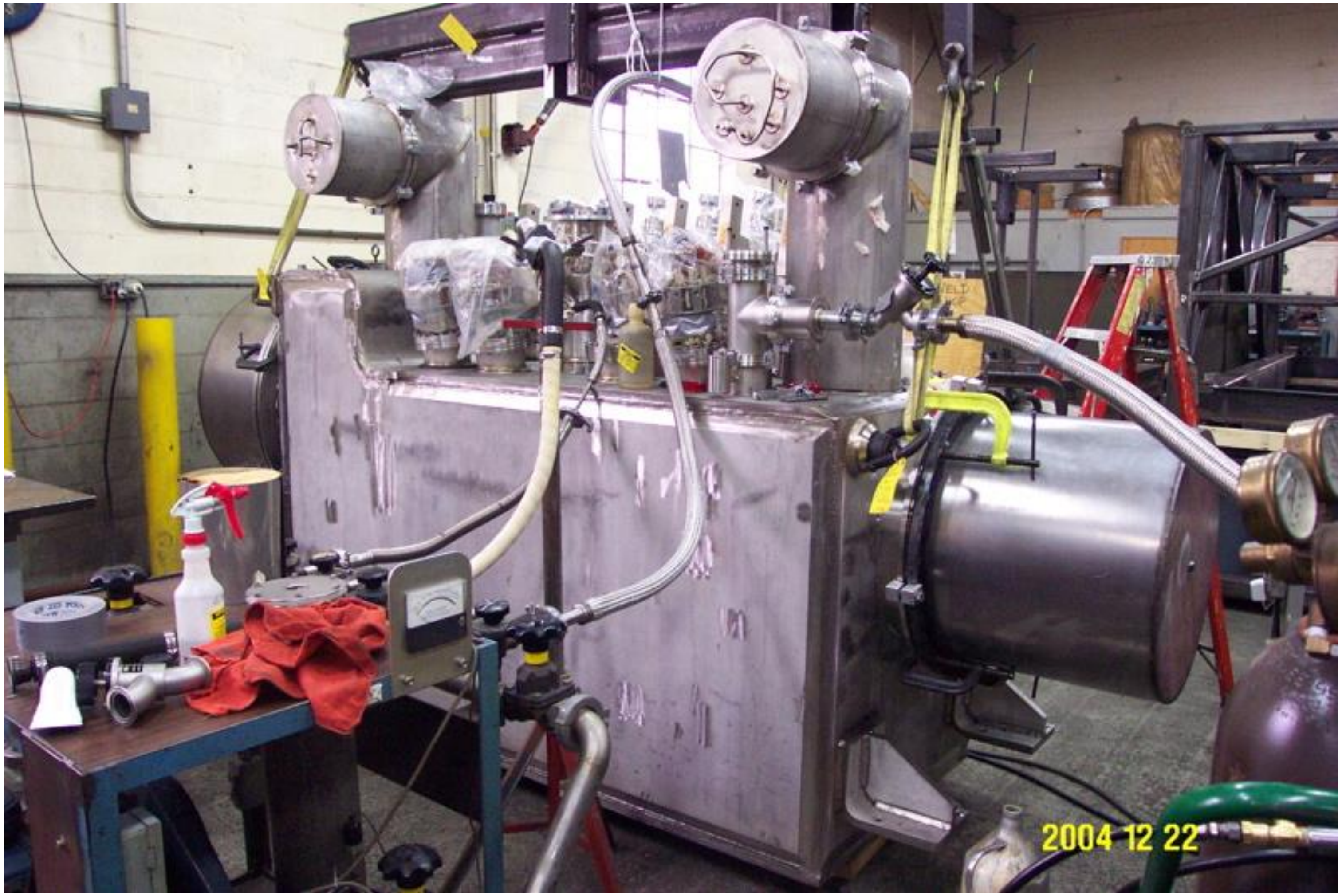


Prefabricated thermal shields

Install thermal shields

Weld vacuum shell

Final leak check and inspection



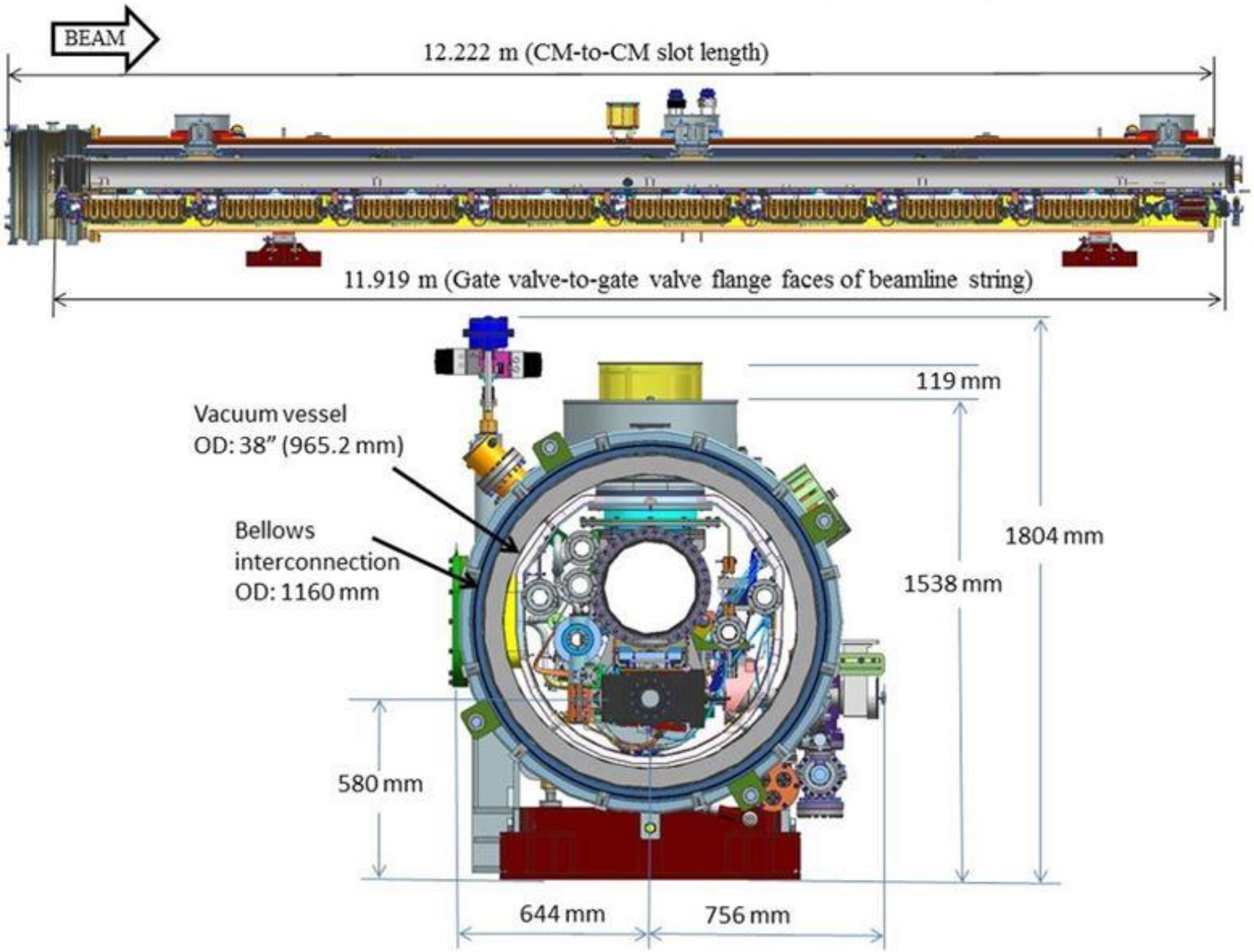
Completed feed box

Shock-absorbing shipping frame

SRF Cryomodule Assembly

- LCLS-II prototype cryomodule assemblies
- Photos from Jefferson Lab and Fermilab

LCLS-II cryomodule assembly CAD model



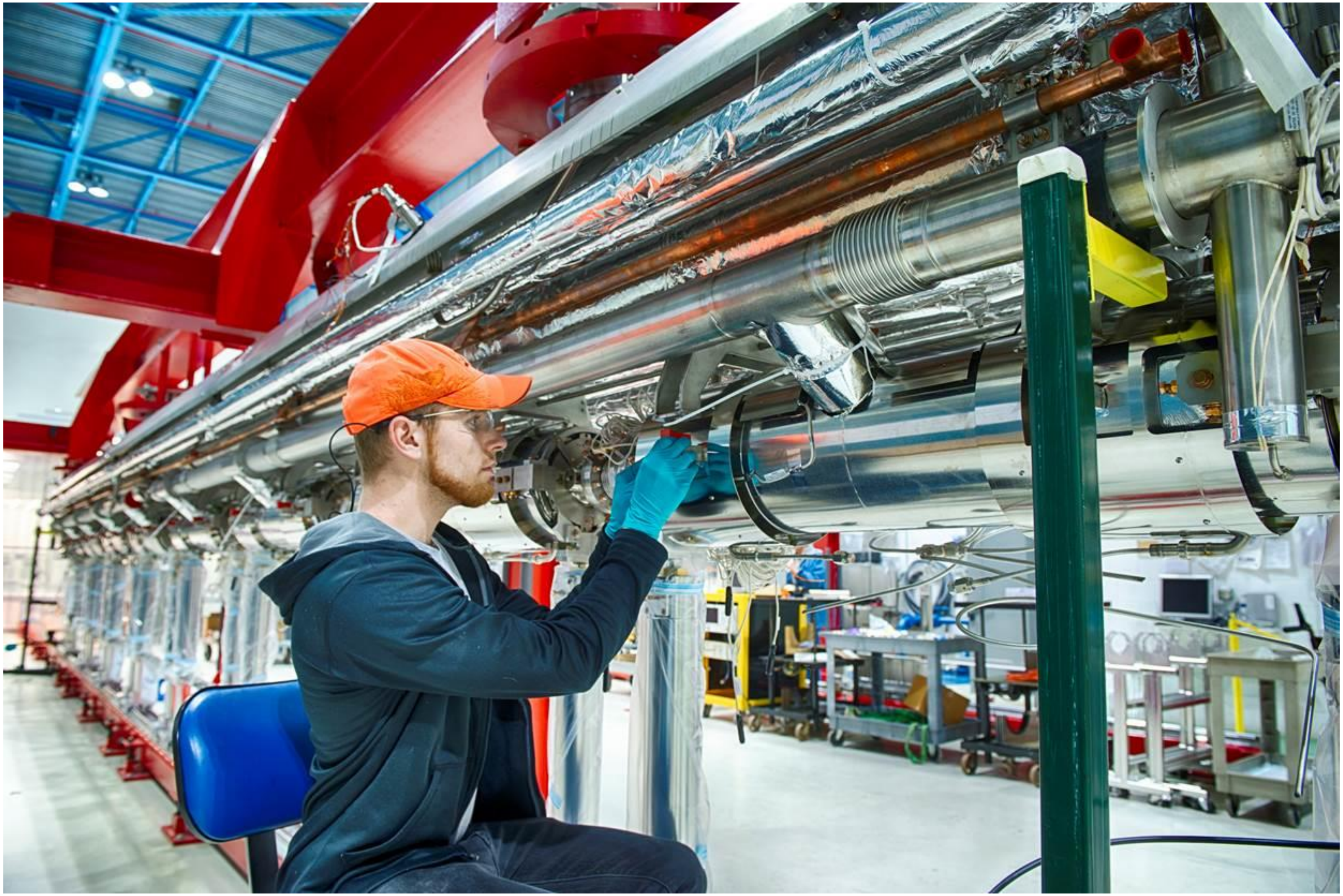
Cavity string – Jlab cleanroom

Cavity string out of cleanroom (Fermilab)

Welding and leak checking cryogenic pipes

Attaching cavity string to cryogenic structure

Integration of cavity string with cryogenic pipes and supports



Assembly at alignment and instrumentation station

Thermal shield installed

Multilayer insulation wrapped

Assembly into vacuum vessel

Instrumentation wiring

Final cryomodule assembly