Cryogenic Equipment

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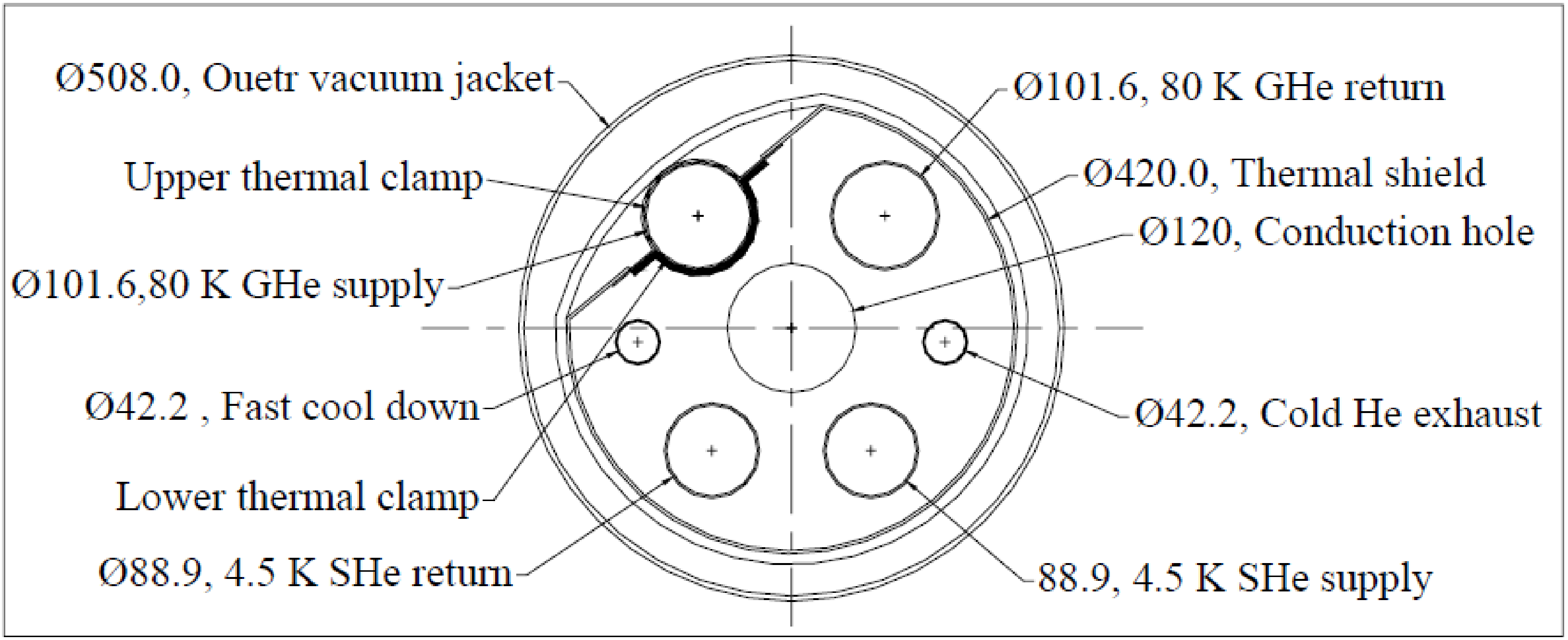
Goals

- Describe the nature, performance and design considerations of various components found in cryogenics
  - Transfer Lines
  - Connections
    - Bayonets
    - Flanges
  - Valves

Transfer Lines

- Vital part of a cryogenic system
  - Transfers cryogenic fluids between components
  - Essentially a long cryostat
  - Can be a significant part of system cost and heat leak
  - Can be acquired commercially or custom built
- Key design issues
  - Thermal contraction (significant due to long lengths)
  - Heat Leak (use of active thermal shields)
  - Forces generated by fluid pressure, thermal contraction must be managed so as to not impact alignment of components
  - Vacuum integrity (pump outs and relief valves)

Transfer Line Example
ITER



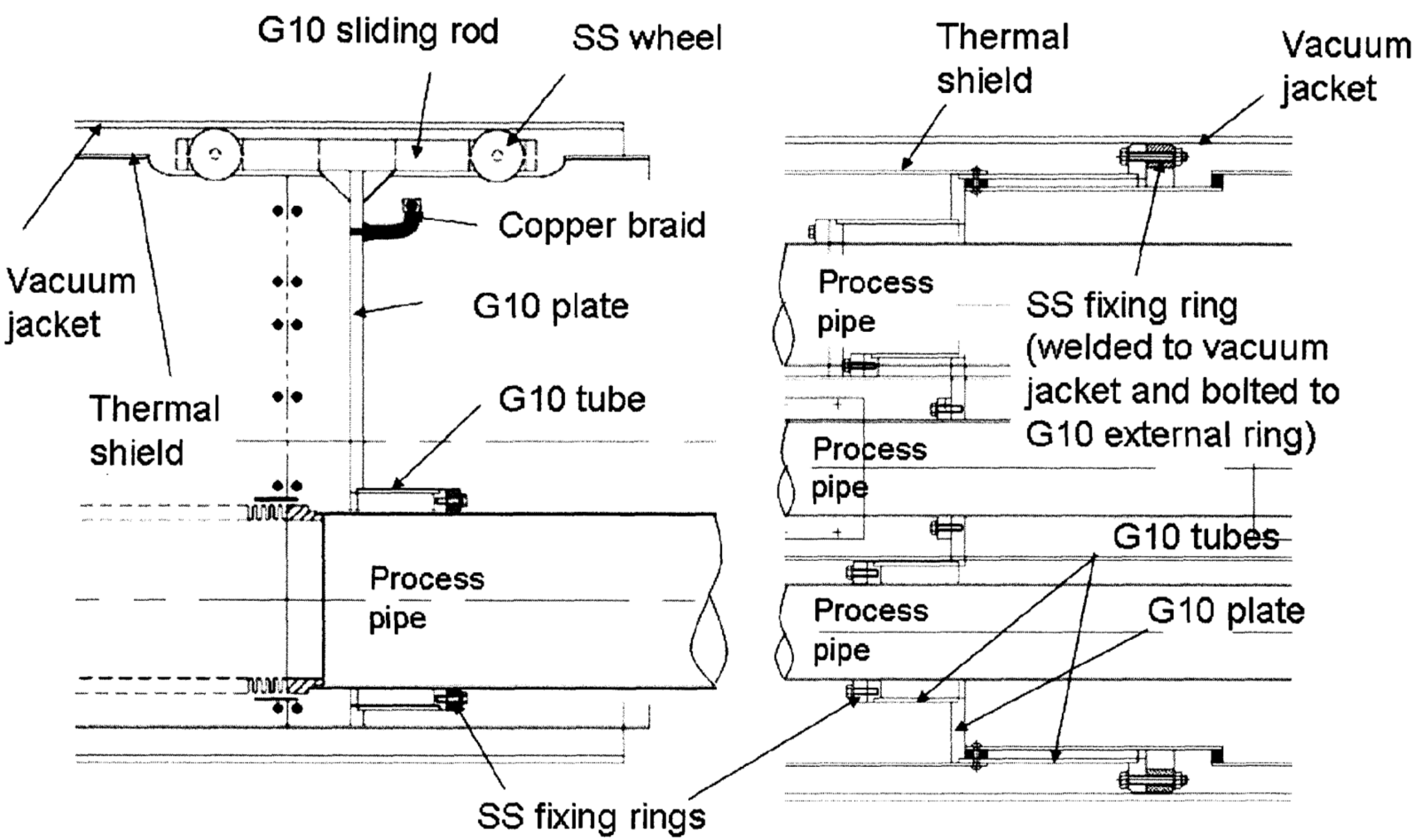
"Design, Analysis and Test Concept for Prototype Cryoline of ITER"
B. Sarkar et. Al
Adv. Cryo. Engr. Vol 53 (2008)

Transfer Lines

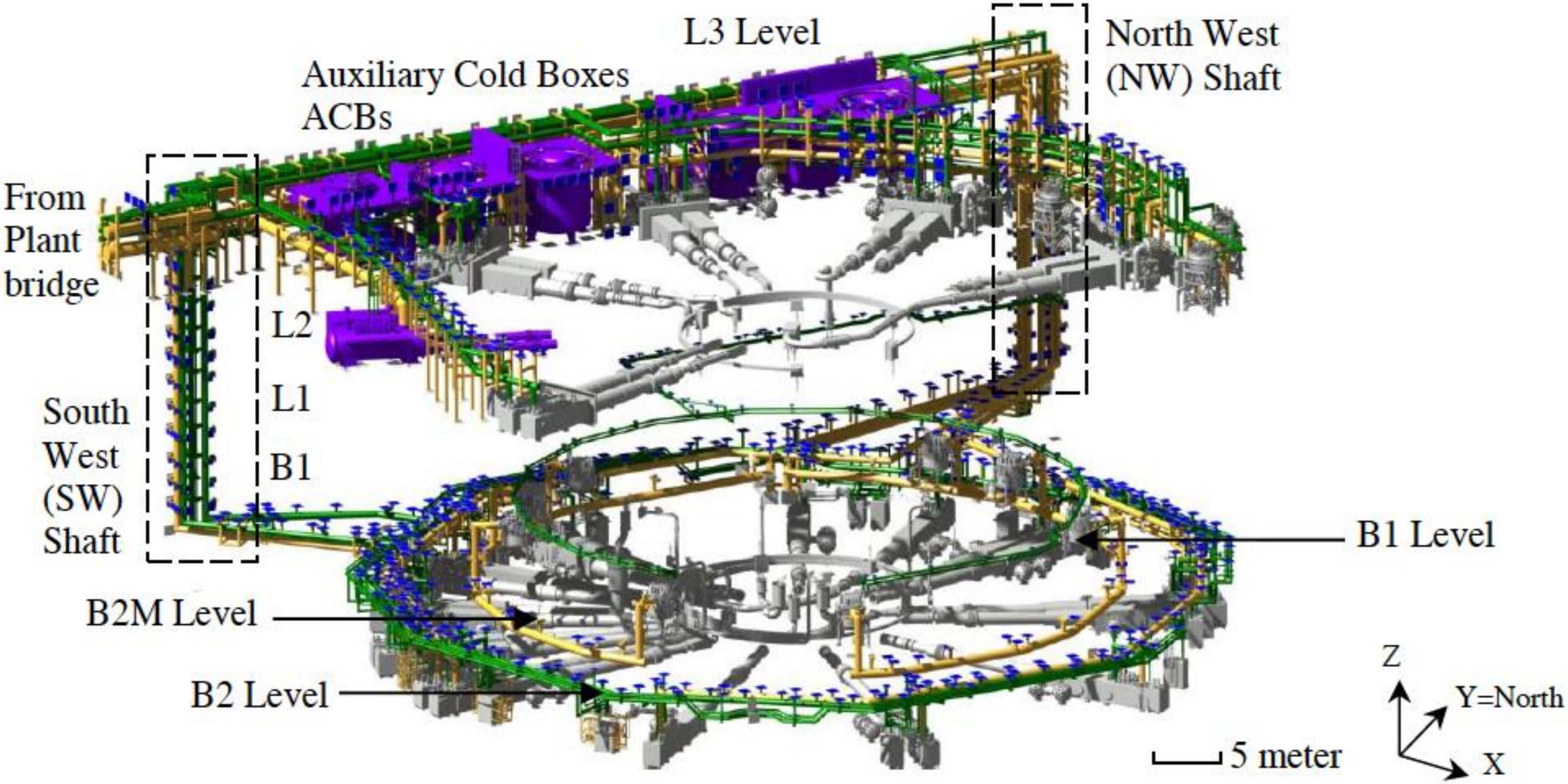
- Methods to address thermal contraction
  - Rigidly fix interior pipes to vacuum shell and install bellows on vacuum shell and on all pipes
  - Install bellows on cold pipes only
  - Use bends to allow interior pipes to contract
  - Use Invar pipes to reduce amount of thermal contraction (CERN/LHC)

"The Local Helium Compound Transfer lines For The Large Hadron Collider Cryogenic System"

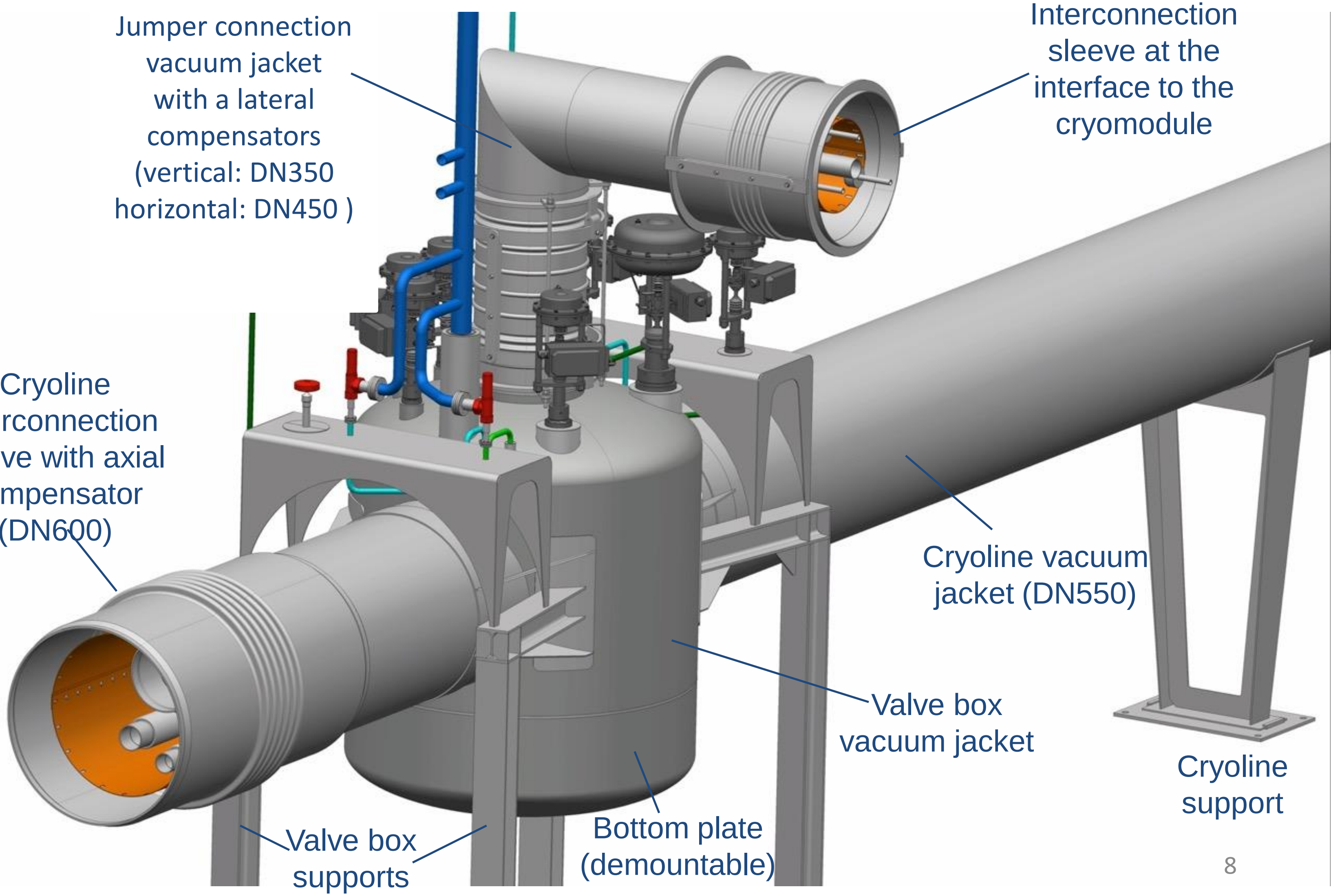
C. Parente et al. Adv. Cryo Engr. Vol 51 (2006)



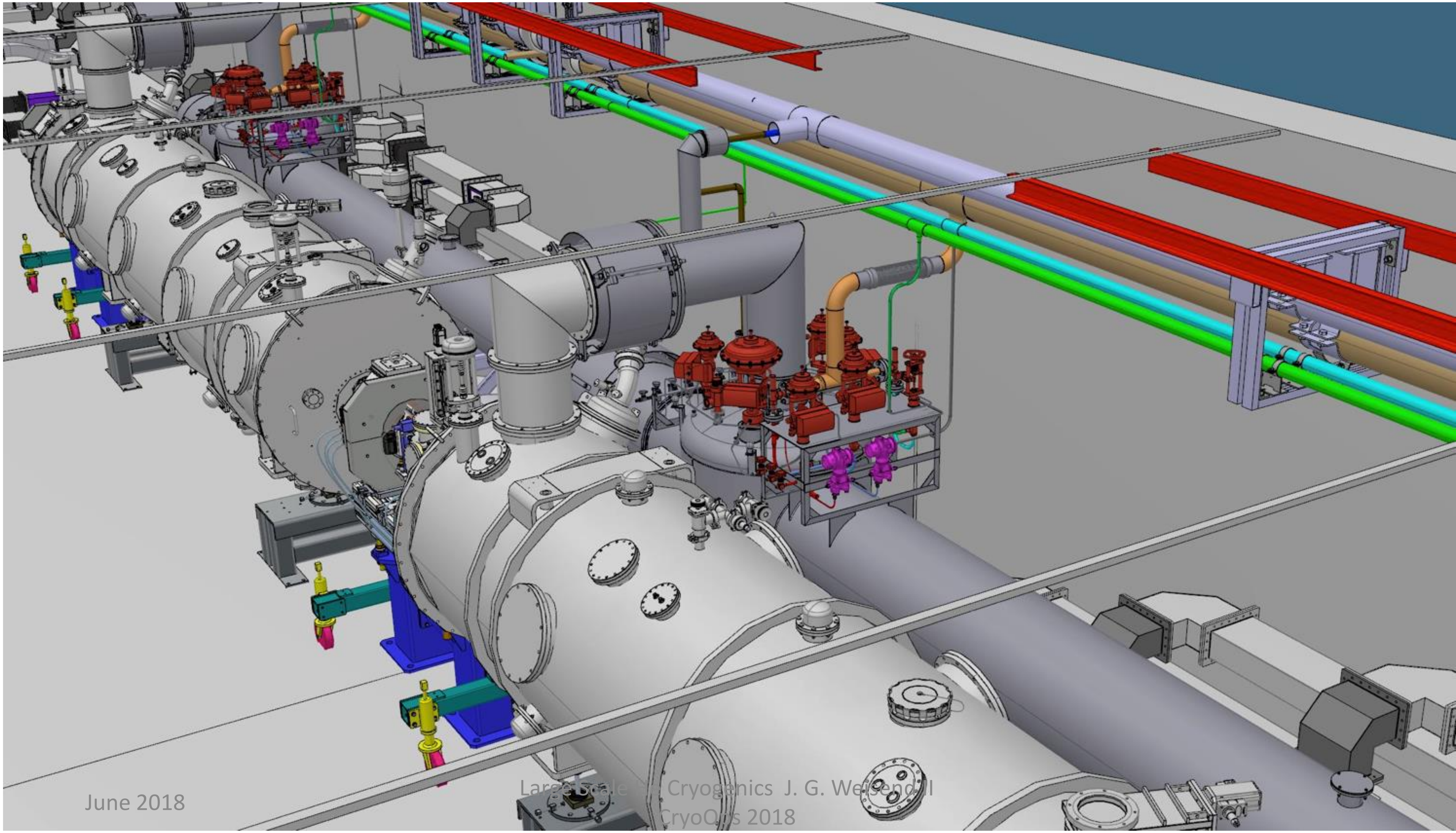
Transfer Lines Become Complicated Distribution Systems ITER Cryogenic Distribution System



Transfer Lines Become Complicated
Distribution Systems
ESS Cryogenic Distribution System



Integration Tunnel CMs – CDS (Sliding Sleeve Closed)



ESS Cryogenic Distribution System Under Installation

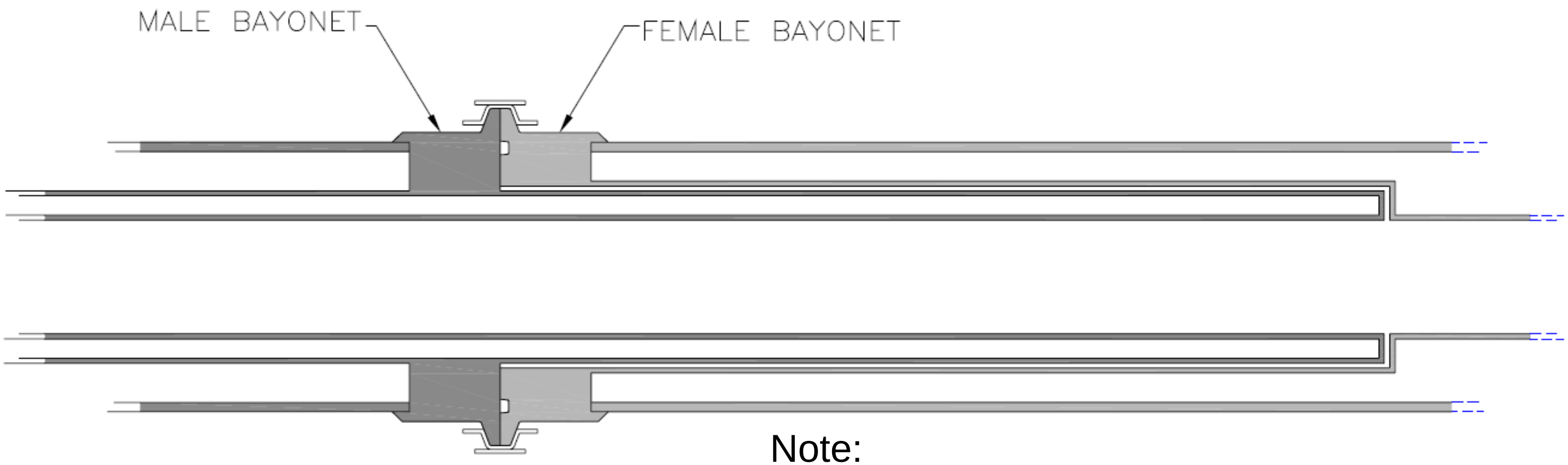
Transfer Lines

- In some cases, commercially produced transfer lines are the solution
- Nexans flexible, multiple flow transfer line

Bayonets

- Demountable piping joints that allow quick connections of cryogenic lines
- Very useful in connecting to replaceable cryogenic liquid supplies. Frequently used in "U-Tubes"
- Reentrant, low heat leak design
- Uses at least one 300 K gas seal and sometimes a cryogenic liquid seal (typically Teflon)
- Must be built to tight mechanical tolerances
- Receiving end must be lower or at least horizontal to delivery end to avoid convection

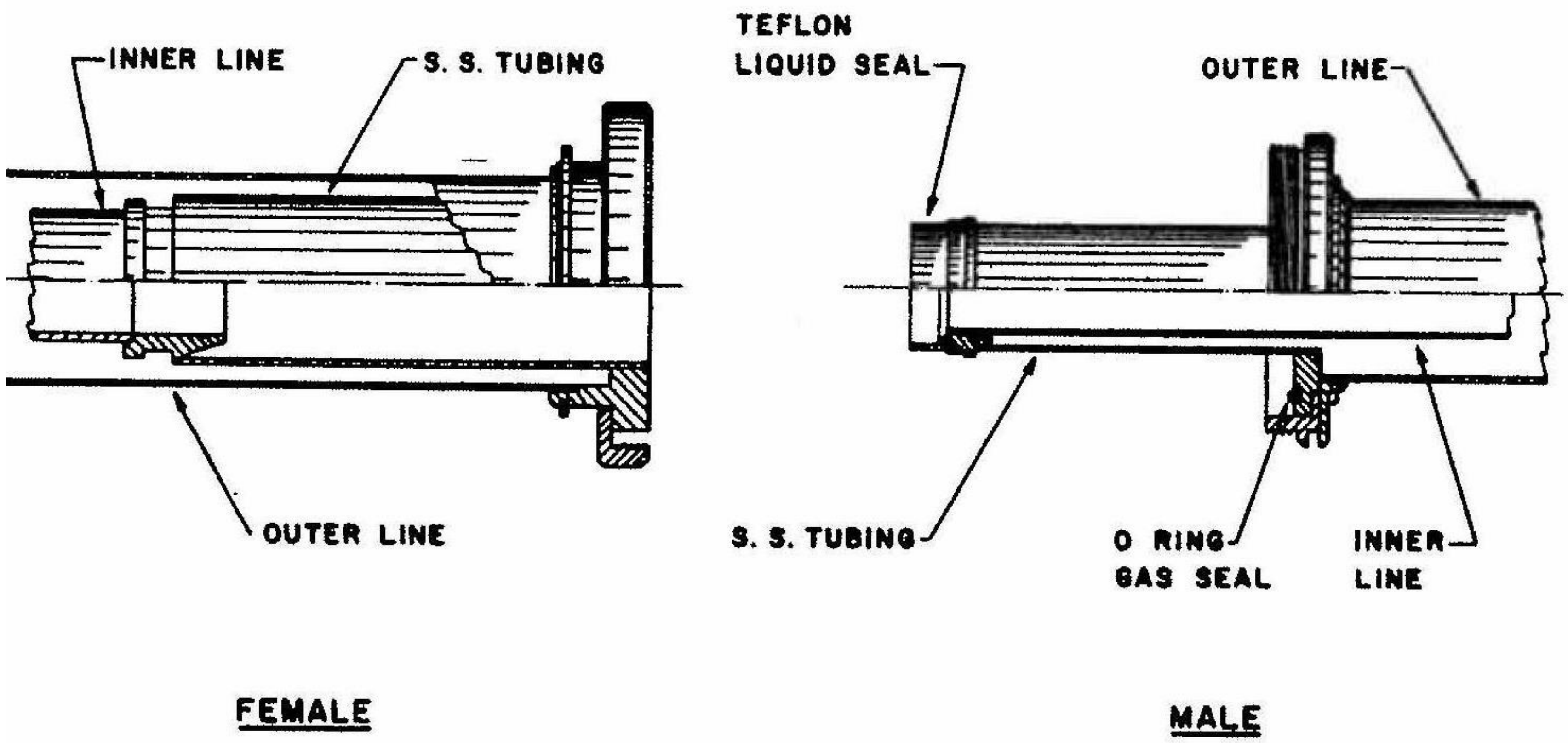
PBA Series Bayonet from PHPK Technologies



Note:
No liquid seal
Very tight tolerances between
male & female sides to minimize convection
Long, thin walls connect 300 K and 4.2 K

Air Force Style Hydrogen Bayonet

from "Cryogenic Equipment" – D. Daney Handbook of Cryogenic Engineering



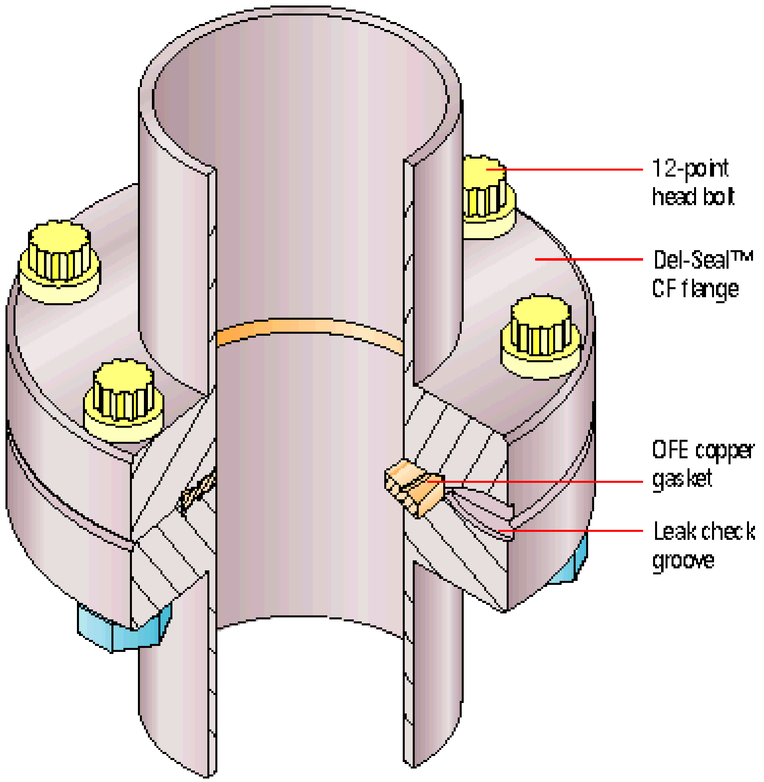
FNAL/SMTF Bayonet Can

SNS Refrigeration Plant showing U-tubes

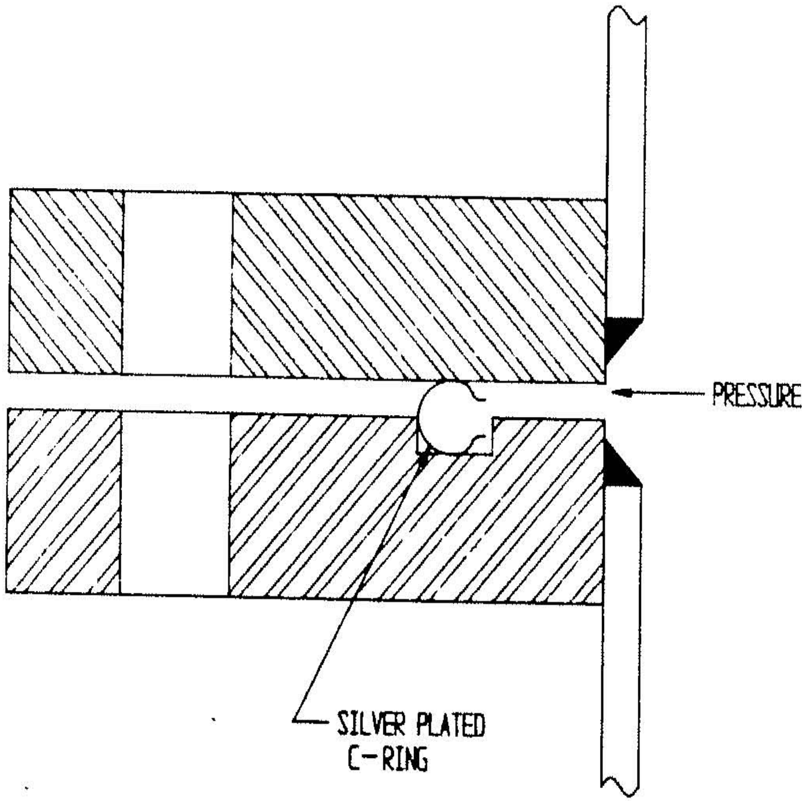
Flange Connections

- How else do we connect pipes at cryogenic temperatures?
  - Welding is almost always the most reliable approach but sometimes a demountable joint is required.
- There are a number of demountable flange options
  - Anything involving a polymer or rubber O-ring will clearly not work at cryogenic temperatures
  - Sealing options include
    - Flanges using a soft metal gasket (typically copper) such as Conflat flanges
    - Flanges using a metal “c” ring
    - Flanges using an indium o-ring – best used in test scenarios and typically home-made
  - With proper design and installation all of these approaches can provide leak tight joints down even at superfluid helium temperatures (< 2.2 K)
- Note that vacuum and liquid leaks are a major source of problems in cryogenics. Carefully thought out and reliable connections are a key to success

Examples of Flanged Connections for Cryogenic Use
(both are commercially available)

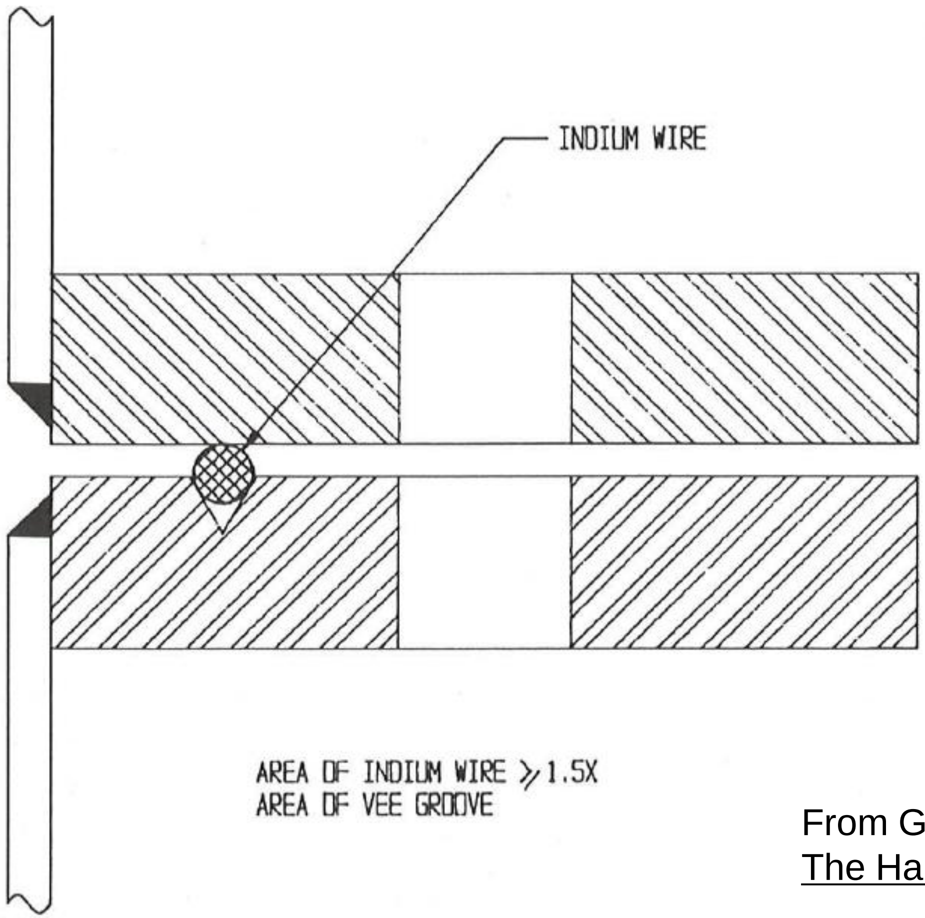


ConFlat Style
Soft Metal Gasket



C Ring Style

Example of Indium O-Ring Seal



(b)

From G. McIntosh in
The Handbook of Cryogenic Engineering

Use of Invar Washers

- If upon cool down the flange material shrinks more than the bolt material then the seal may open up and leak
- One way to prevent this is to use invar washers so that the seal actually tightens during cool down
- The goal here is to size the components such that the bolt shrinks more than the combination of the 2 flanges and the invar washer

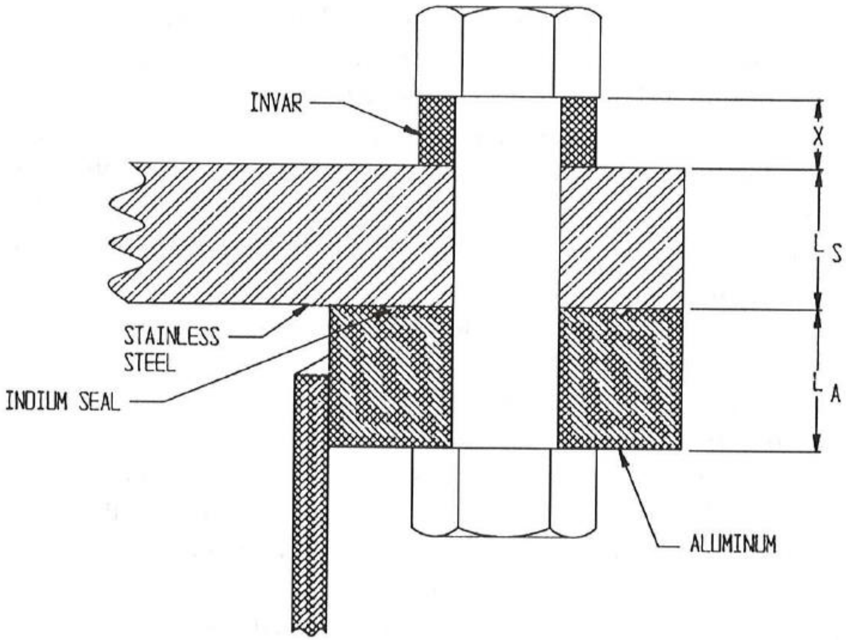


Figure 5-1 Flange joint with Invar washer.

Valves

- Valves are an important part of cryogenic systems
- Valves direct flows and control both flow rates and pressure drops
- Cryogenic valves have to operate at cryogenic temperatures and minimize the heat leak from room temperature
- Except in very specialized cases, cryogenic valves have room temperature actuators
- Valves can be manually operated or more commonly operated via a control system. The actuators for remote operation are typically electro pneumatic – a current or voltage signal from the control system regulates the pressure on the pneumatic drive that controls the valve position.
- A wide range of cryogenic valves is available in industry

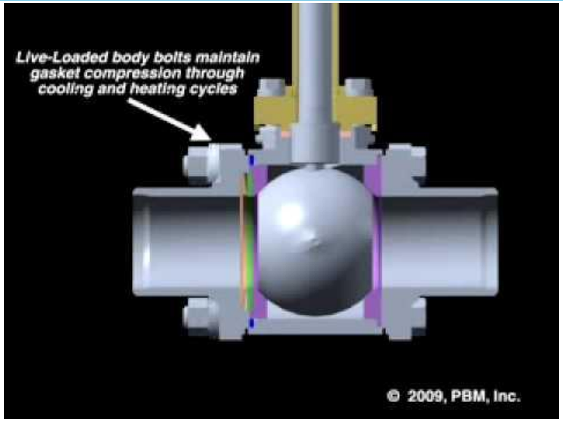
Basic Valve Types

(All can be implemented in cryogenic systems with proper design and materials)

Globe

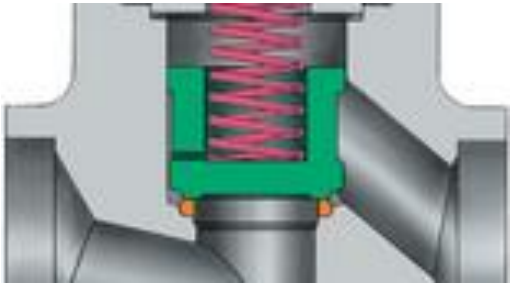
Gate

Ball



Butterfly

Relief



Check

Examples of Cryogenic Valves

CVI
Model 2060

Contains
vacuum jacket
Heat Leak reduced
via thin walled tubes

1 inch valve has a
measured heat leak of
1.3 W to 4.2 K

JT Valve

Cryocomp

½ inch IPS

Designed to be installed inside cryostats

Heat Leak to 4.2 K is ~ 1 W

Sizing of Valves

- Valves are typically sized using the parameter C_v
  - This parameter is defined as the number of Gal/min of water that passes through the valve with a pressure drop of 1 psi
  - This can be related to properties we care about in cryogenics by
  - Be sure to use appropriate properties
  - Note $^oR = (9/5)K$

Liquid Flow

$$C_v = \frac{Q_L\sqrt{G}}{\sqrt{\triangle P}} = \frac{7.2W_L}{\sqrt{G\triangle P}}$$

where:

C_v = Valve Flow Coefficient

³P = Pressure Drop (psi)

Q_L = Liquid Flow Rate (gpm)

G = Specific Gravity = $\frac{\text{density of subject fluid}}{\text{density of water}}$

W_L = Liquid Flow Rate (lbs/sec)

Gaseous Flow

$$C_v = \left|\frac{\sqrt{T}}{22.8}\right| \frac{Q_g}{61} \frac{\sqrt{G}}{\sqrt{P_1\triangle P}} = \frac{730W_g}{\sqrt{GP_2\triangle P}} \left|\frac{\sqrt{T}}{22.8}\right|$$

where:

C_v = Valve Flow Coefficient

$\triangle P$ = Pressure Drop (psi)

Q_g = Gaseous Flow Rate (scfh)

G = Specific Gravity = $\frac{\text{density of subject gas at stp}}{\text{density of air}}$

W_g = Gaseous Flow Rate (lbs/sec)

P_1 = Absolute Upstream Pressure (psia)

P_2 = Downstream Absolute Pressure (psia)

T = Absolute Temperature (^oR)

Note: When the pressure drop ($\triangle P$) is equal to or greater than 1/2 the absolute upstream pressure (P_1), substitute

$$\left|\frac{P_1}{2}\right| \text{ for } \sqrt{P_1\triangle P}$$

From Acme Cryogenics Catalog