"Implementation and Enhancement of Safety measures in SST-1 Cryogenic System at 77 K and 4.2 K"

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Track: ICEC13: Safety Reliability and Standards

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Introduction

The branches of physics and engineering that involve the study of very low temperature below 123 K. Low temperature are achieved by the liquefaction of gases.

Some Typical Temperature	Temperature (° C)	Absolute (K)	Liquid to gas Expansion
Tropics	45	318	
Human Body	37	310	
Room Temperature	20	293	
Ice Point	0	273	
Home Refrigerator	-18	255	
Antarctic water	-50	223	
Solid Carbon-dioxide	-78	195	
Liquid Oxygen	-183	90	1 to 860
Liquid Nitrogen	-196	77	1 to 696
Liquid Helium	-269	4	1 to 757
Absolute Zero	-273	0	

Cryogenic Effects on Materials and Accountability in Design

- The mechanical and electrical properties change of many materials very drastically when cooled to 100 K or lower. (for example plastic, rubber extremely brittle)
- Freezing/Glassing (Liquids, Oil, Greases)
- Condensation/Liquefaction (Gases)
- Stainless steel (304,316), Cu, Al, Ag, and Brass are characterize very good mechanical properties at cryogenic temperature.
- The thermal contraction typically 3 to 5 mm/m for common structural materials between 300 K and 77 K (little additional change occurs < 77 K)
- Joints and supports must be able to handle induced thermal stresses and transitions between various materials
- An uneven cool down will create large thermal stresses within a vessel.

(Pipeline example: 30 m stainless steel pipeline would contract 8.4 cm on cool down to 77K)

Cryogenics Hazards and Its Causes

[1] Asphyxiation :

- Severely deficient supply of oxygen to the body
- Unable to breathe normally.
- It is due to released cryogens can displace oxygen in a room.
- Oxygen deficiency is defined as < 19.5% oxygen (OSHA)
- The symptoms of oxygen deficiency are :

19% - 15%	pronounced reduction of reaction / response speed
15% - 12%	deep breaths, fast pulse, co-ordination difficulties
12% - 10%	vertigo, false judgment, lips slightly blue
10% - 8%	nausea, vomiting, unconsciousness
8% - 6% :	death within 8 minutes, 4-8 minutes brain damage
< 4%	coma within 40 seconds, no breathing, death

[2] Cold Contact Burn/Frostbite:

Contact Burns – Skin exposure to cold liquid, gas or surface, similar to heat burns; can cause localized tissue damage can lead to frostbite

Frostbite – Freezing of skin or body parts resulting from exposure to low temperature

The causes of cold burns and Frostbite are:

- Cause of frostbite to the hands and body is contact with cold metal surfaces
- Especially when the skin is moist can lead to permanent damage
- Prolonged exposure to cold vapor can damage lungs and eyes
- Handling open cryogen containers, especially when cooling down warm vessels or objects
- De-choking vents/drains of cryogen handling system
- Doing connections/disconnection of piping /hoses

[3] Over pressurization and physical explosion

- Cryogen liquids do expand by a factor of 500 to 800 when evaporated and warmed up to room temperature.
- Heat input lead to significant pressure build-up to bursting of the cryogen container.
- Possible reasons for an elevated heat input are:

1. Fast cool down of components or cryogenic installations

2. Large heat production within the object to be cooled during a quench
3. Loss of the insulation vacuum,

(LHe has very low latent heat of vaporization (1/10th that of LN_2) so it will evaporate rapidly/explosively when heated)

[4] Air Condensation (Fire Hazards)

- Condensation of air/O_2 on combustible liquids or materials can create flammable/explosive mixture
- At temperatures < 82 K, metal surfaces will condense oxygen and form enriched air (50% O2 & 50% N2) to drip and pool on surfaces
- Un insulated pipelines provide this surface
- Air boils at 78 K (at 1 atm pressure) in a 6% O2-94% N2 vapour mixture, enriching the O_2 content

[5] ICE PLUGS

- Frozen plugs can form in Dewar plumbing if the cryogenic system is exposed to air.

- Moisture in air can also block lines, vent lines path to relief valves from releasing pressure from the Dewars as the cryogen vaporizes
- Over time this will result in a pressure build up that can cause structural failure of the Dewar

[6] ICE BUILD UP:

- Ice build up on uninsulated areas can cause damage to surrounding equipment
- Potentially embrittle sensitive materials
- Ice build up can block relief valves
- Ice build up can freeze O-rings and compromise insulating vacuum

Cryogenic Storage, High pressure and Safety Standards

- ASME Boiler and Pressure Vessel Code, Section VIII experimental equipment design and vessels construction
- Compressed Gas Association (CGA) dealing with handling of cryogenics
- P-1 Safe Handling of Compressed Gases in Containers
- S-1.1 Pressure Relief Device Standards Part 1
  (circular cross-sectional storage units)
- S-1.3 Pressure Relief Device Standards Part 3
  (permanently mounted units)
- ASME B31.1 Power Piping and ASME B31.3 chemical Plant and Petroleum Piping
- CGA G-4.1 Cleaning Equipment for Oxygen Service
- 29 CFR 1910.104 Oxygen (OSHA standard)

Over Pressurization to Blast Wave Dissipation

Blast Overpressure	Structural or Biological Response to Blast Effects
0.5 to 1 psig	Glass window shatter
1 to2 psig	Corrugated steel or Al paneling buckles
2 to 3 psig	Non-reinforced concrete or cinder block wall shatter
5 psig	Eardrum rupture
7 to 8 psig	Non-reinforced brick walls shear and fall
15 psig	Lung damage
115 ft/sec for a 10 gm glass projectile	Penetrates abdomen
10 ft/sec for a 75 Kg man	Skull fracture from impact

Distance (Feet)	Over pressure (psig)	T1 (msec)	T2 (msec)
2	320	0.2	0.8
4	70	0.8	1.6
6	28	1.8	2.4
8	15	3.0	3.0
10	9.6	4.3	3.2
20	3.0	12	-
40	1.2	29	-
100	0.35	82	-
200	0.13	169	-
400	0.05	346	-

T1 : Blast wave arrival time
T2 : Time required for the overpressure to decay back to zero

Cryogenics and High pressure Safety Guidelines

- Personnel are trained and certified for cryogenic tasks
- Have a checklist and use it for any task
- Ensure adequate warning signs are posted
- Complete a JSA and review with team operations and procedures prior to doing job
- Always work as a team of two or more
- Written policy to show commitment & assign responsibility at every level
- Safety extraction equipment is available and ready to use
- Identifying and evaluating all hazardous substances in the workplace
- Safety equipment and supplies should be readily available like: Emergency spill kit, Fire extinguisher, Ladders, Mobile light plants, Whip checks.
- Inform control room, identified personnel regarding emergency, safety In-charge for any accident, activation of emergency services like rescue, transportation of victims and calling fire brigade if necessary as a part of disaster management.

Protection and Prevention Measures (Cryogenics)

- Cryogenic liquids must be handled in well ventilated areas to prevent excessive concentrations of gas in enclosed spaces.
- Oxygen level detectors to be installed in enclosed spaces
- Any unprotected part of the body must never be allowed to touch uninsulated pipes or vessels containing liquefied gases.
- When pouring liquefied gases from one container to another, the receiving container must be cooled gradually to prevent thermal shock.
- To reduce air condensation is by applying an insulating material on system components.
- To eliminate high pressure releases of cryogenic vapors, containment systems with pressure relief devices and rupture "Burst Disks" to allow over pressures to release safely.
- Always store and handle liquid helium under positive pressure or in closed systems to prevent the infiltration and solidification of air or other gases.

Actions at Emergency Conditions

Emergency Measures (I. Case of confined space/Oxygen deficient condition)

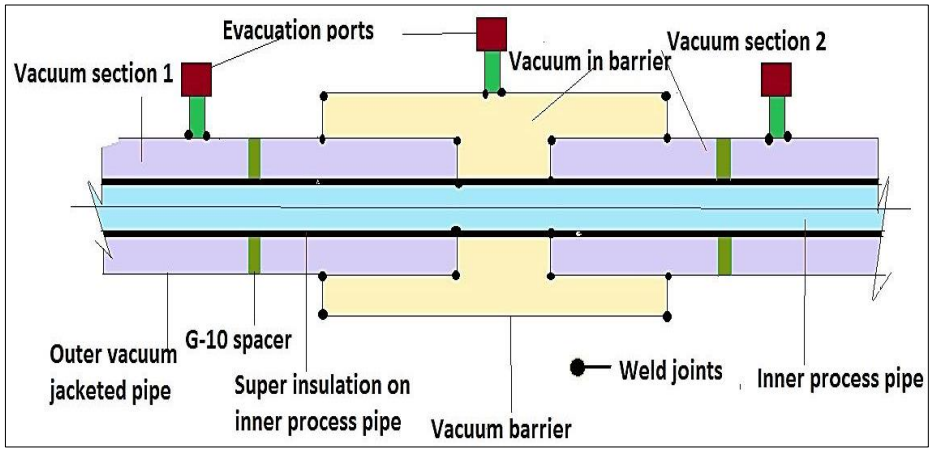
- Check the oxygen level in display and hear the alarm.
- Rescue personnel are equipped with breathing apparatus enabling them to enter the oxygen deficient space
- Remove the patient to the open air and administer oxygen from an artificial respiration.
- Continue resuscitation until person revives and send him for medical attention.

Emergency Measures (II. Case of cryogen pressure build up condition)

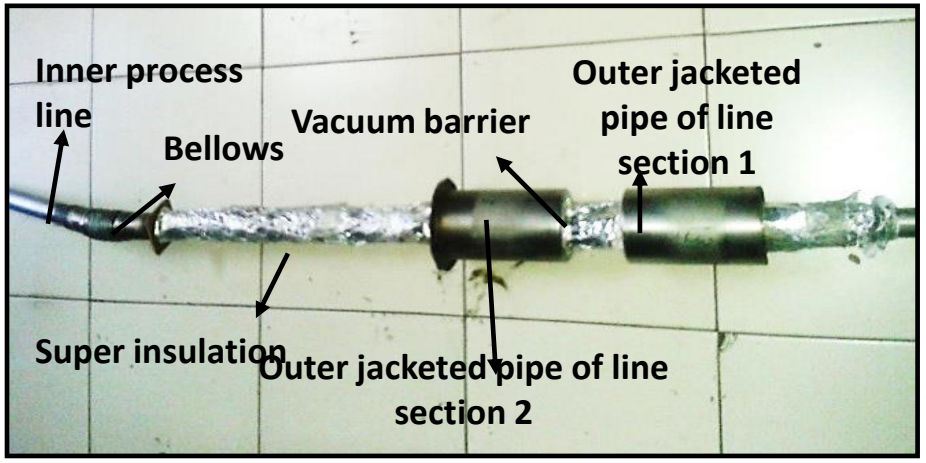
- Relief valve and Vent valve blocked/Ice plug of cryogenic Vessels/Dewar
- Heat leaks in the cryogenic system
- All pressure relief devices should be regularly inspected for leakage and frosting.
- LHe Dewar: 2 relief valve at 0.5 psi and 10 psi and 2 no. rupture disc set at 35 psi
- LN_2 Dewar: 1 relief valve 22 psi and rupture disc 180 psi

Practical Problems Experience and Its Solution

[1]Repairing of Main LN2 Cryogenic Transfer line of LN2 Distribution

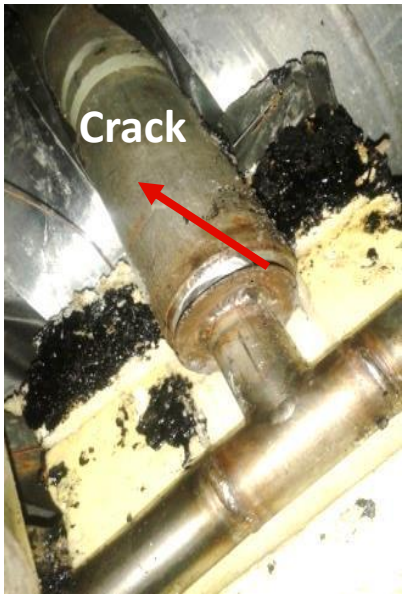


Schematic of LN_2 transfer line



Internal structure of LN_2 line

Return line leaks



Dish end crack

LN_2 dripping from main line

Crack in Bellows

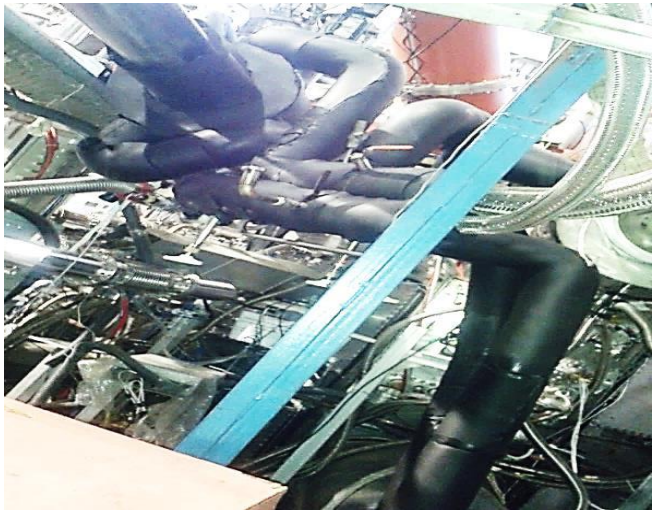
[2] Replacement of Old Insulation and Vacuum of Cryogenic Transfer Lines of 80 K Distribution System

Old glass wool insulation

Frosting ,condensation and leakages in 80 K system

NBI 80 K system

IFDC 80 K thermal shield



80 K Cryo pump hydraulics

Flexible Elastomer Nitrile & PUF Insulation in various systems of 80 K Distribution

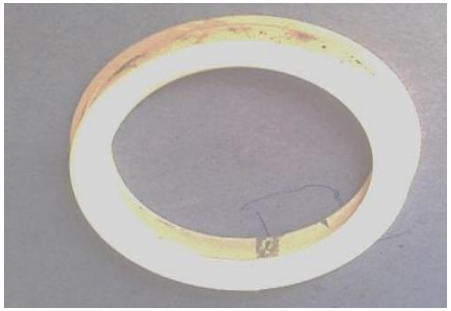
[3] Rectification and Mitigation of Helium leaks in Cryogenic Systems

- Leaks localized, mitigated and repaired at 14 bar pressure in safety valves, rupture discs, hand valves of high pressure helium gas storage vessels .
- Developed dissimilar metal (AL+PTFE) seals, elliptical type O ring and PTFE gasket as per standard.
- Prevented the risk of high pressure gas bursting at any leaked location.
- Helium leak rate $<10^{-6}$ mbar l/s , @100 bar

High pressure v/v of vessel

Rupture disc seal and He leak testing

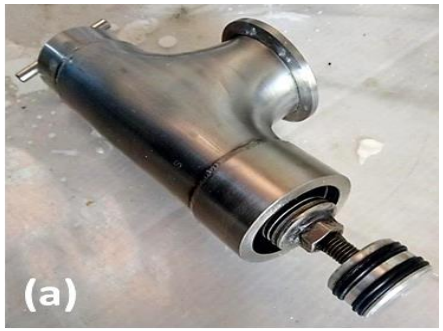
[4] Miscellaneous Leaks Mitigation, In-House Repairing, Innovation Solutions

High pressure v/v developed seal, ANSI 150 Flange 'O' ring and gasket sealing at 16 bar(g)



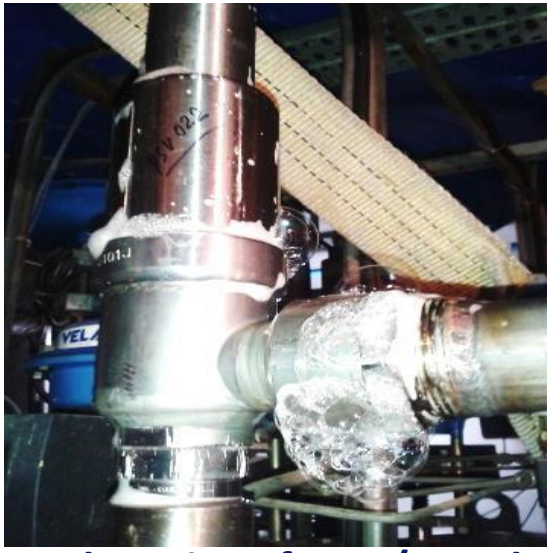
High pressure cryo grade thread sealant used in Helium connectors, Rupture disc coupler

80 K NRV sealing **Vacuum evacuation and puppet v/v sealing** **Vacuum barrier joint**

[5] Installation and Performance Tests of Safety Valves with NRV in the Recovery Line of Pressure Vessel

- As per safety guidelines the outlet pressure should not be > 1.0 bar
- 1/2” and G1” size safety valves (i) Soap bubble test 10 bar (g) (ii) Helium leak rate: < 2.5 x 10^{-6} mbar- l/s at 14 bar (Sniffer mode)
- Safety valve test and sealing standards API 257 and API 527
- NRV (2-3000 psi) installed to prevent the helium leakages.



Leakage in safety v/v outlet

Testing of safety valve

Safety valve with NRV in system

Periodic Hydrostatic Pressurization Test of High Pressure Helium Gas Storage Vessels

- SMPV (U) Rule 19 as a part of CCOE norms in every 5 years to renew the operational license.
- Assurance of moisture level < 2 ppm
- The stored energy are considered to be high hazard as per the OSP/ 19 of SMPV rules (U) (i) Stored Energy > 100 KJ (ii) P X V > 25 atmospheric * Cu. ft. (P=test pressure, V: test volume)

Hydro Test Pressure bar (g)	Vessels HP/MP HP Volume: 25 m^3 MP Volume: 68 m^3	*Stored energy (Helium gas) Kilo-Joule	Stored Energy (Water) Kilo-joule	Equivalent mass in TNT 1 Kg TNT= 4.2 x 10^3 kJ energy release	
				Helium gas	Water
203	High Pressure Vessel	26400	6850	6.36	1.5
23	Medium Pressure	2181	0.874	1.56	2.39E-4

Periodic Hydrostatic Testing, Inspection and Certification of Helium Gas Cylinders

- As per Gas Cylinder Rules 2004 in every 5 years CCOE norms, PESO
- **Procedure for testing, acceptance and rejection of gas cylinders :**

  (i) Non corrosive gas cylinders of < 20 liters : 10% of the total stretch during the test (ii) > 20 liters (water capacity): 10% of the total elongation during the test or 1/5000th of the original volume of the cylinder, whichever is less.
- IS-5844 Stretch Testing of Compressed Gas Cylinders
- IS-4379 Material Identification of Industrial Gas Cylinders
- IS-8451 Periodic Inspection and Testing of High Pressure Gas Cylinders
- IS-8868 Periodic Inspection Intervals of Gas Cylinders in Use
- Rule 11 & 12 - Repair of cylinder
- Rule 36 - Destruction of cylinder after making it unusable

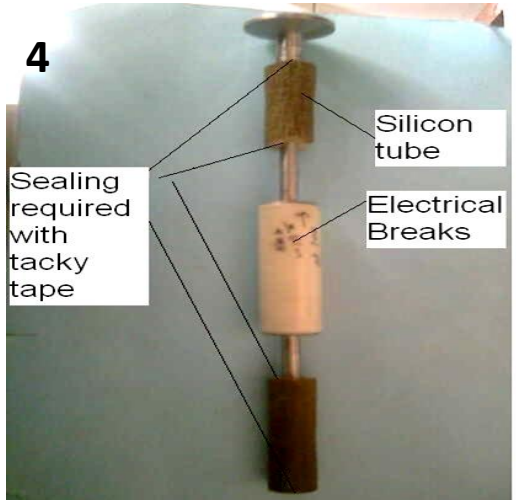
Hydro test pressure Kgf/cm2	Volume of gas cylinder (Liters)	*Stored energy (Helium gas) Kilo-Joule	Stored Energy (Water) Kilo-joule	Equivalent mass in TNT 1 Kg TNT= 4.2 x 10^3 kJ energy release	
				Helium gas	Water
250	46.7	1559	10	372 Gram	2.6 Gram

Safety Measures of High Pressure Testing of Gas Vessels & Compressed Gas Cylinders

- Barricade the hydraulic test area and provide warning signage to prevent unauthorized entry of personnel.
- Use only calibrated pressure gauges and pressure relief valves.
- The rating of fittings, gauges, vent and valves, flanges and plates must be adequate for the test
- Air ventilation provision at the highest elevation of the vessel.
- Make sure the vessel vent open to eliminate air pockets before pressurizing.
- Raise the pressure gradually to allow time for vessels and hydraulics to strain.
- Hydro test equipment should not stand in the direction of the blind flanges to avoid injury if the flange breaks.
- Do not change the color of the cylinders
- No inflammable material should be stored in the cylinder area
- Do not subject any cylinder to heat-treatment or high temperature
- Do not tamper with safety device in valve cylinder
- Cylinders must not be dropped or allowed to collide with each other
- Construction Cylinders containing flammable gases and toxic gases should be kept separate from each others in fire resistant storage area

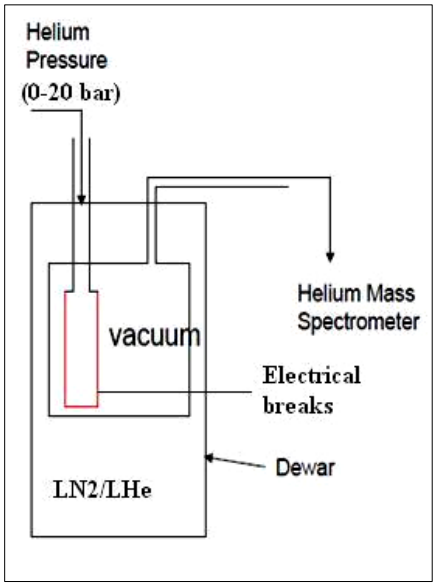
Sealing at High Pressure and Cryogenic Temperature

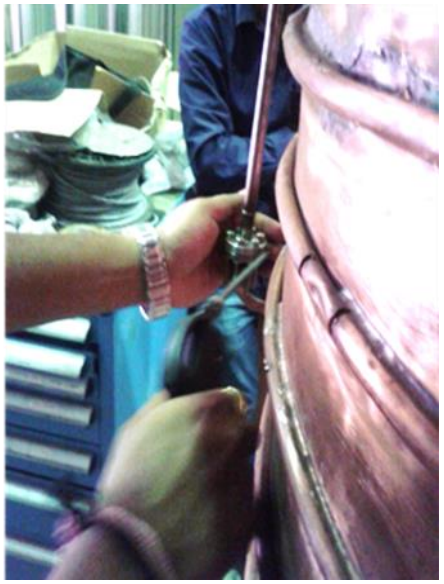
RTJ gasket, High pressure valve seal, Rupture disc and ANSI 150 Flange High pressure sealing at 150 bar, 16 bar of high pressure helium gas vessels

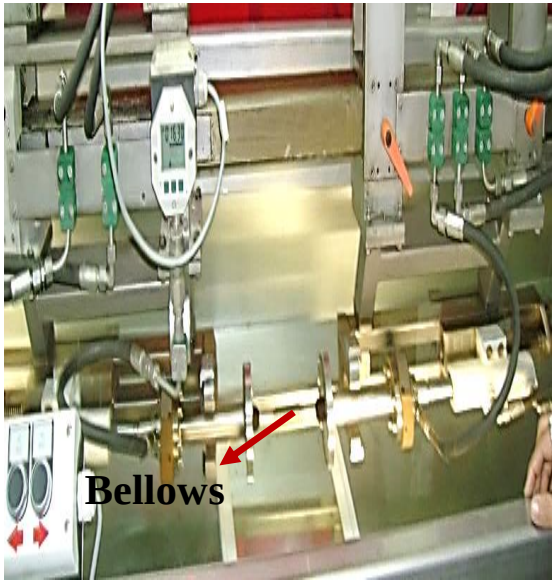


1: 4.2 K Indium seal, 2: Puppet valve seal of cryo transfer line, 3: 4.2 K Wilson seal, 4: Silicon vacuum seal & 5: Dissimilar joint testing with ferrule

He Leak Test at High Pressure and Cryogenic Temp.

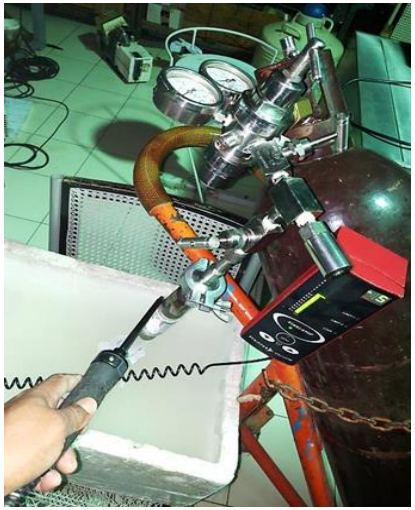






He leak test at 77K, 4.2 K, 0-20 bar of IB, Indium seal test

Hydro test of Bellows at 20 bar

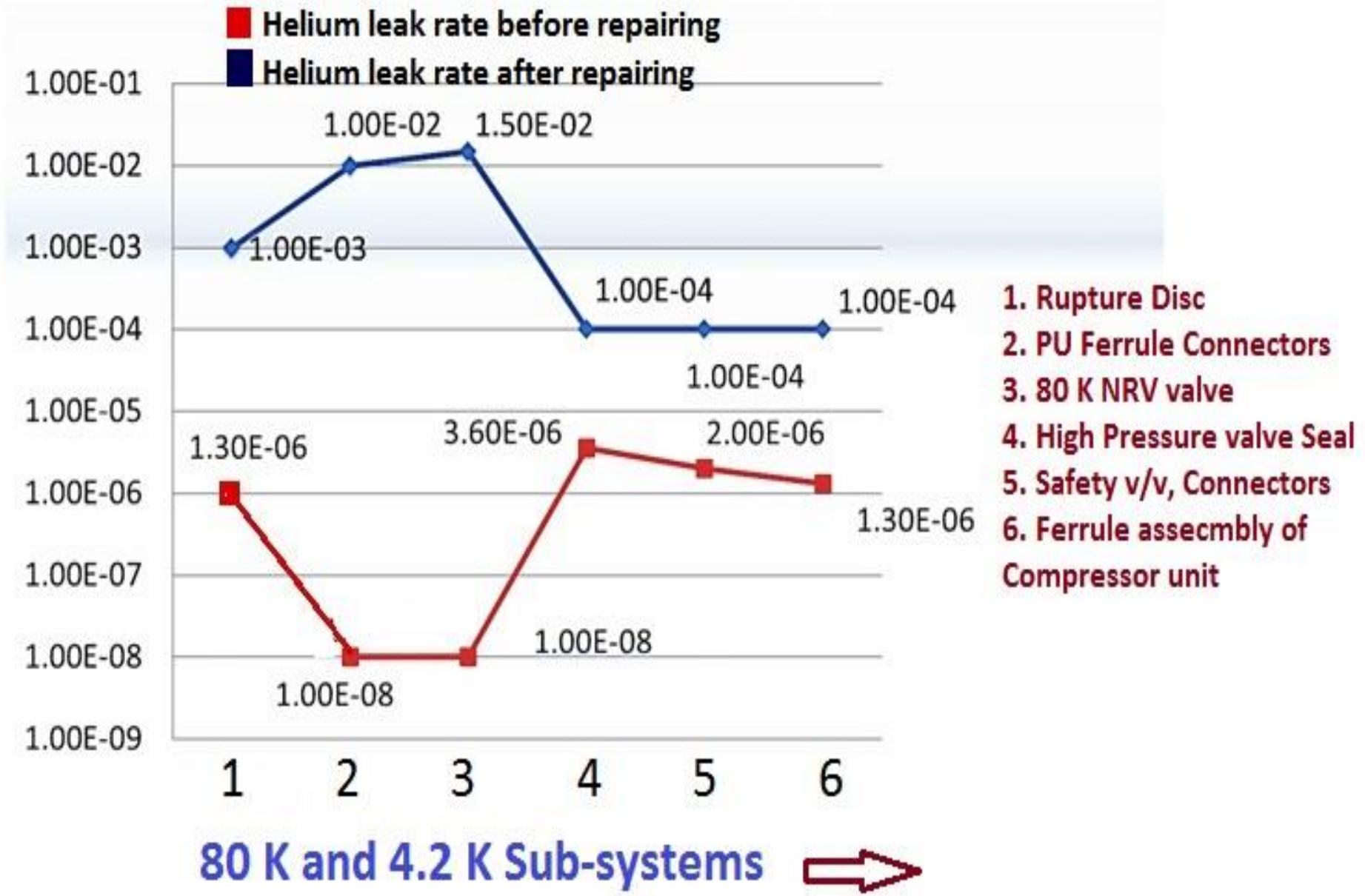


AL+SS Joint at 12 bar(g), 77 K

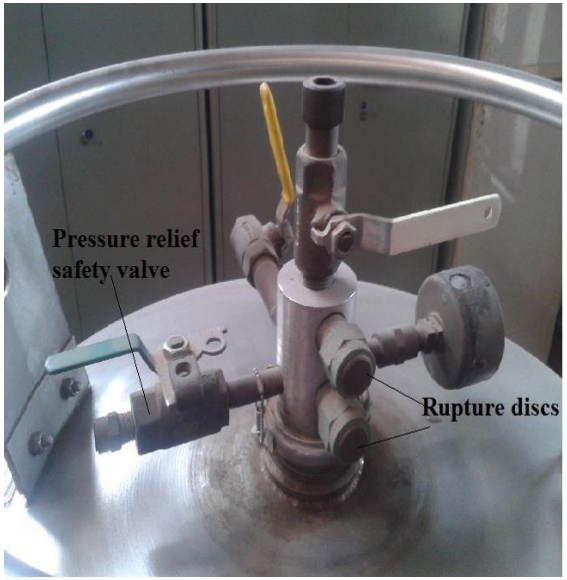
Paschen test at 77 K

Thermal shock test of Flexible Hoses & He leak test of VB at 12 bar (g), 77 K

Statistics of helium leak rate



Cryogenic safety & Personnel Protective Equipments in IPR



Pressure safety device in LHe Dewar

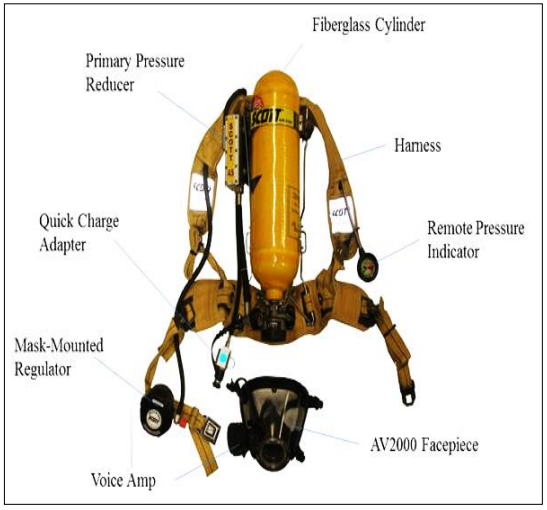
Trolley for LN_2 Dewar movement

Face shield

Cryo hand gloves

Safety goggle

Cryo Apron

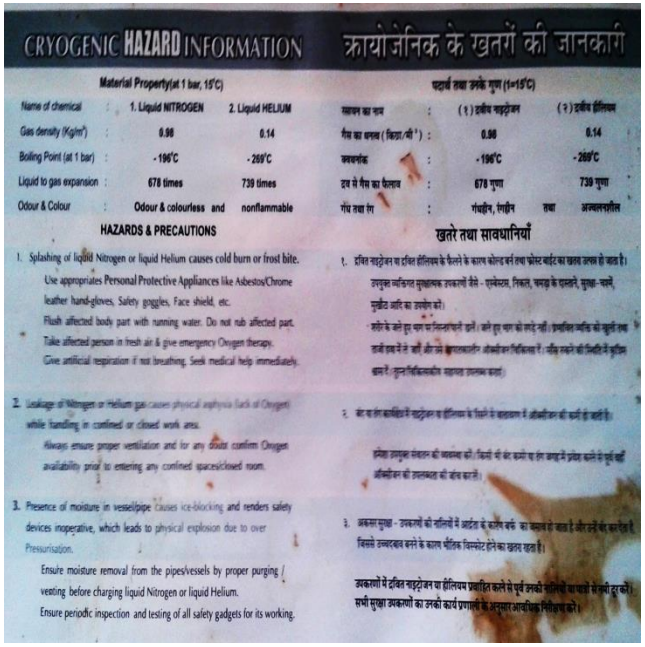


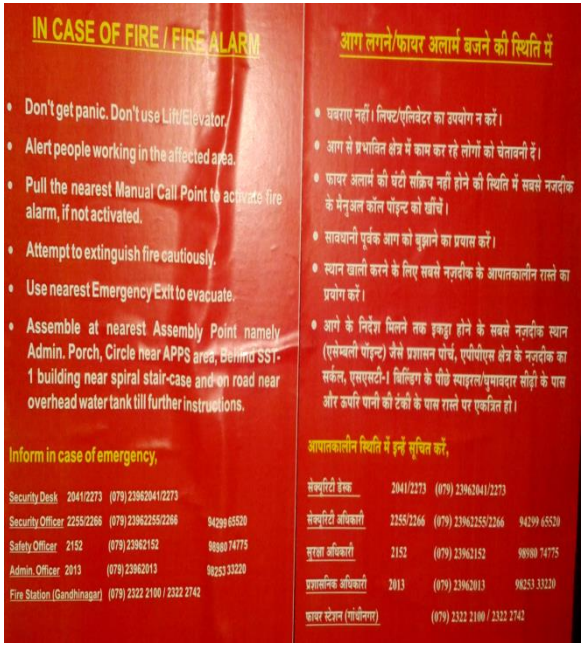
Self Contained Breathing Apparatus

Fire Alarm System

O_2 Sensor and Monitor

Emergency Shower & Breathing Set

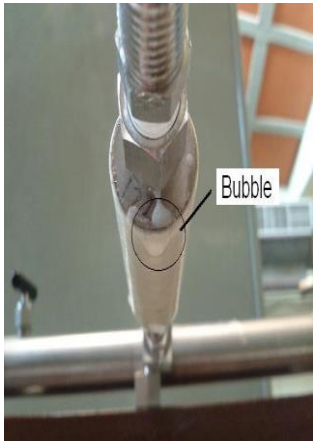




Display Information about System, Cryogenic Hazards and Fire Alarm System in IPR

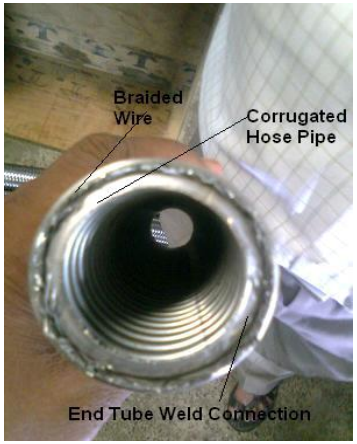
Probable Failure Reasons of Cryogenic Components

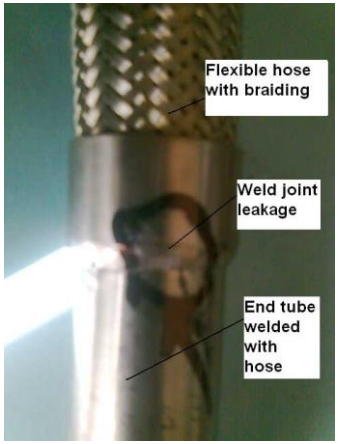
- Cohesive , Adhesive failure and Peel failure
- Adhesive failure results when the interfacial chemical bond fail
- Contamination during processes : (i) Strength is always low (ii) Short service life before disbond occurs
- Inadequate adhesive cure, degradation of interfacial bond (strength is initially high but fails off with time)
- Number of thermal cycles from 300 K -77 K -300 K
- Thermal contraction varies of different materials at 77K and 4.2 K
- Different mechanical strength and behavior at cryogenic temperatures
- Aging factor or usage limit of the component



Insulation breaks

Rupture disc





Flexible Hose

Cryogenic Bellows

Summary

- The employer should show commitment towards safety and health practice and give full priority to promote and enforce the safety culture and health rules in workplace.
- At IPR, we are adopting and following the cryogenic guidelines and established procedures.
- By applying this practice that resulted the safe long working in cryogenic environment without meeting any emergency condition.

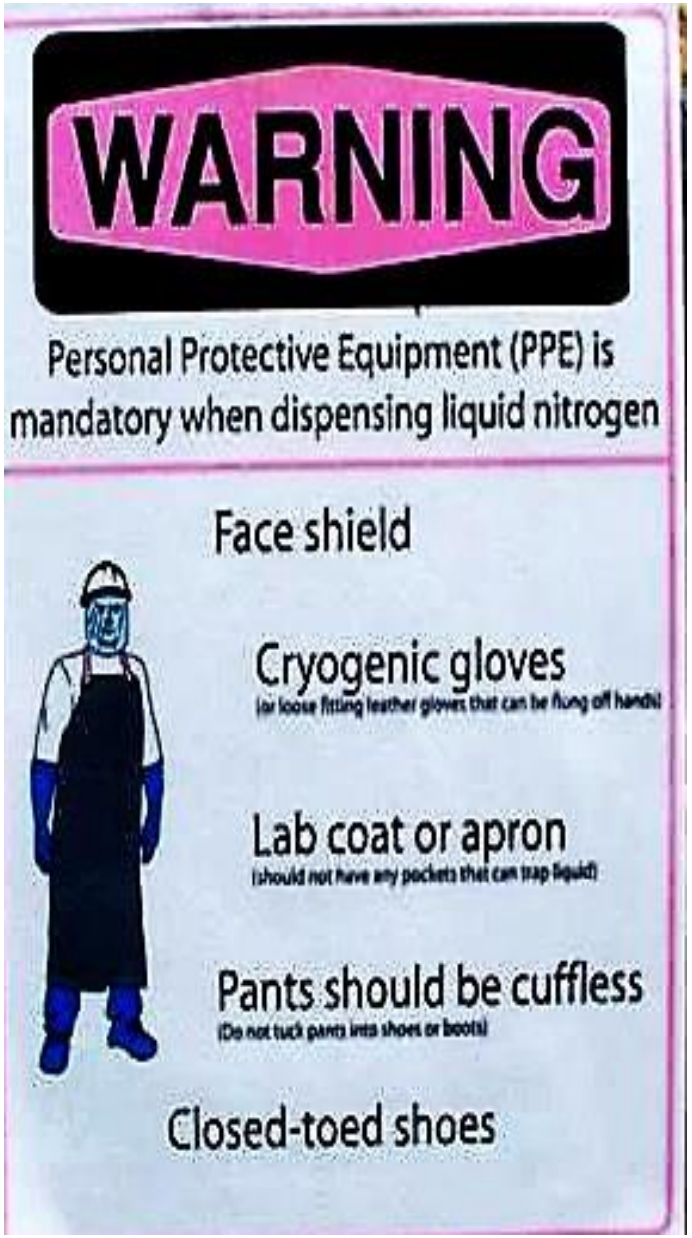
Acknowledgements:

- Team members of cryogenic division

(Mr. Pradip Panchal. Mr. Rohit Panchal, Mr. Dasarath Sonara, Mr. Rakesh Patel, Mr. Gaurang Mehsuria, Mr. Atul Garg, Mr. Nitin Bairagi, Mr. Srikanth, Mr. Dikens, Mr. Ketan Patel, Mr. Pankil Shah, Mr. Hiren Nimawat, Mr. Gaurav Purwar.)

- Institute safety officer

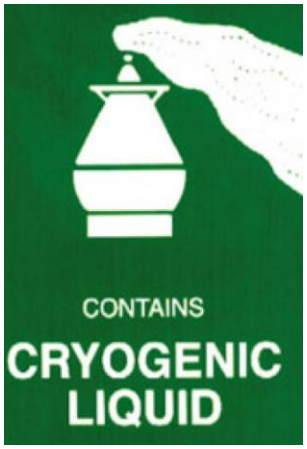
Cryogenic Safety Signs



Do not go for rescue without PPE

Low Temperature

Asphyxiation hazard



Stay safe, Stay healthy

Thank You