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Short Course on Cryogenic Safety

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Short Course Agenda

- Part 1 8:45 – 10:30AM
  - Introduction
    - Safety and Cryogenic Fluids
    - Cryogens of Interest to SLAC
  - General Safety Topics
    - Physiological Hazards
    - Materials and Construction
    - Over-pressurization, Explosive and Flammability Hazards
    - Personnel and Operational Awareness
  - Material Safety Data Sheets
- Part 2 10:45 – Noon
  - Cryogenic Design and Safety Equipment
    - Design Considerations
    - Cryogenic Relief Valves
    - Burst Discs
    - Venting of Facilities and Systems
    - System Monitoring
  - Problems of Interest
  - Summary

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Short Course on Cryogenic Safety
Part 1. – Introduction

- Safety and Cryogenic Fluids
- Cryogens of Interest to SLAC

Cryogenic Storage and Cooling Systems

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- Cryogens require specialized storage containers to maintain any kind of shelf life (system boil-off time > minutes)
  - Commonly known as “Dewars”!
  - **Storage containers range in size from 1 Liter to 42,000,000 gallons**
  - **Cooling systems, such as the ones in use at SLAC (LN_2, LHe)**
- Economics and Safety determine best system design
  - Rate Loss (Heat leak)
  - Weight
  - Materials of Construction (System Compatibility)
  - Insulation System (Dependent upon life requirements)
  - Specialized Requirements (dynamic environments, etc.)
- SLACs use of the nitrogen, carbon dioxide and helium also brings in the need for some amount of knowledge on oxygen and its unique requirements
- In this course we will not deal a lot with carbon dioxide, most everything that relates to cryogenic nitrogen will cover $C0_2$
  - Freezing point at about 216 K somewhat the conventional number of 188K, not considered a cryogenic fluid

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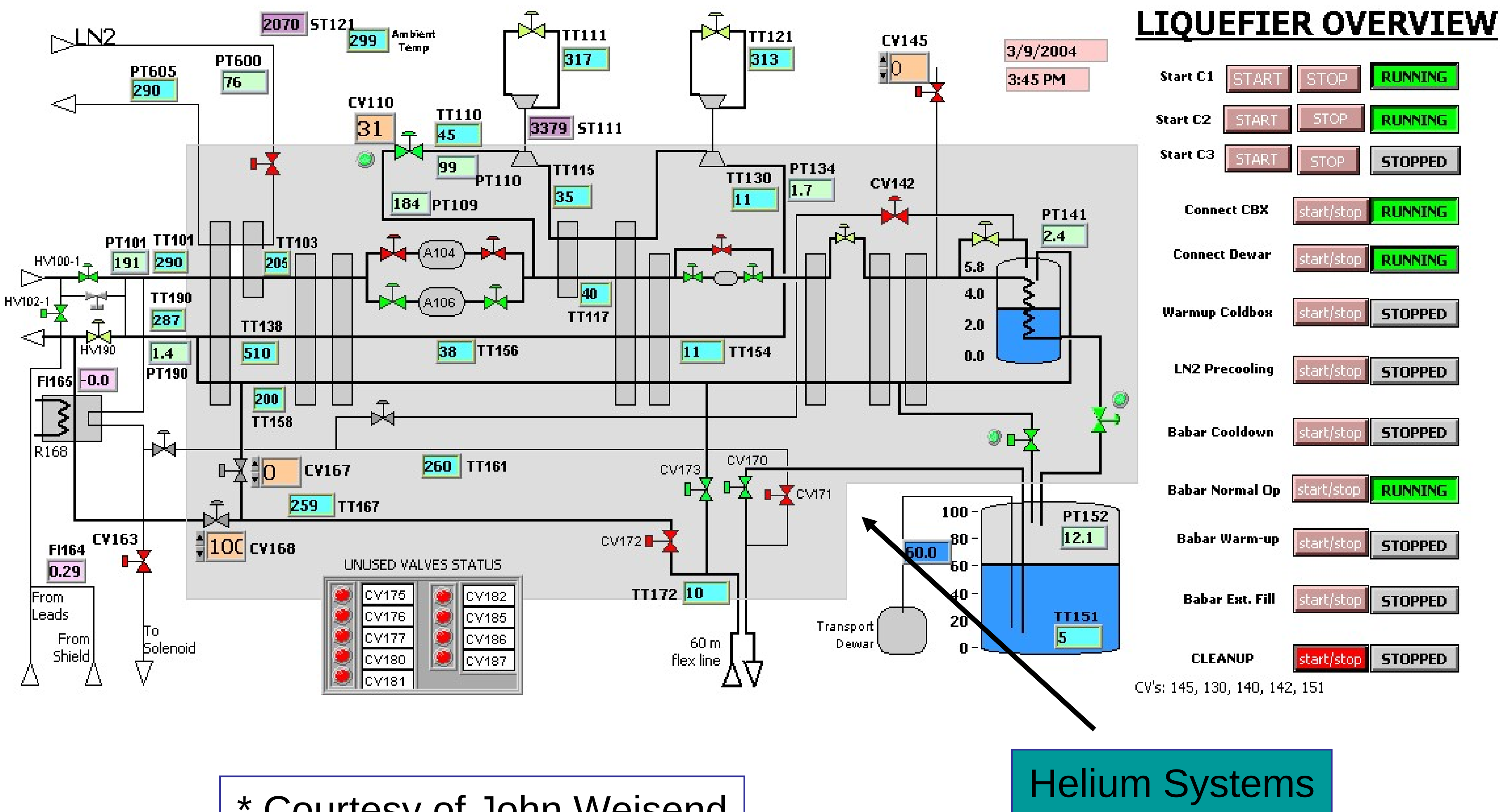
BaBar Refrigerator & Solenoid



* Courtesy of John Weisend

Cryogenic Storage and Cooling Systems

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- Many standard designs are available through a variety of suppliers and manufacturers; established international codes and regulations have worked out.
- ASME Boiler and Pressure Vessel Code, Section VIII and is mandatory for most experimental equipment design and construction
- Compressed Gas Association (CGA) has a number pamphlets published 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-1.2 Pressure Relief Device Standards Part 2 (cargo and transportable)
  - 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 (design and inspection of welded joints)
- Other regulatory documents that I recommend
  - CGA G-4.1 Cleaning Equipment for Oxygen Service
  - 29 CFR 1910.104 Oxygen (OSHA standard)

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Short Course on Cryogenic Safety
Part 1. – General Safety Topics

- Physiological Hazards
- Materials and Construction
- Over-pressurization, Explosive and Flammability Hazards
- Personnel and Operational Awareness

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Physiological Hazards

- Contact Burns/Frostbite
- Asphyxiation/Toxicity
- Hypothermia

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Contact Burns/Frost Bite: What are they?

- **<u>Contact Burn</u> – exposure of the skin to low temperatures.**
  - **Similar to heat burns; can locally freeze and tear or remove skin.**
  - **Due to decrease in feeling, can easily led to Frost Bite!**
- **<u>Frost Bite</u> – freezing of skin and body parts due to exposure of low temperatures.**
  - **Can led to permanent damage and discoloration up to loss of limb**
  - **Prolonged exposure of cold vapour or gas can damage lungs and the eyes.**
  - **Exposure time on the order of seconds, not minutes!!**
- **Due to the nature of cryogens low viscous nature, will penetrate woven and other porous clothing materials much faster than water!**

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Contact Burns/Frost Bite: How to Avoid?

- **Personnel training is critical to personnel safety**
  - **An organized well thought-out safety training program will significantly reduce personnel injuries in this area**
- **Minimize exposure to operation**
- **If you need to be there, understand where the risks are. Vent locations, cold equipment, etc.**
- **Wear proper protective clothing**
  - **Non-absorbent loose fitting gloves; eye protection, non-flammable cover-alls, proper footwear**
- **Never go alone!!**
- **Make someone aware of what you doing, who is not with you.**
- **Watch out for problems and if you don't understand; STAND DOWN!**

Contact Burns/Frost Bite: What about clothing?

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- **Not only are safety glasses or goggles required but face shields are also required for systems under pressure and handling/venting cryogens**
- **Recommend loose fitting, grease-free leather gloves**
- **Trousers should always been worn outside of boots or work shoes; no open or porous shoes are permitted**
- **All clothing should be grease free**
- **Clothing exposed to low temperature helium gas should be handled with care, potential oxygen build up in articles**

Contact Burns/Frost Bite: What to Do if Exposed?

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- **Immediate first aid**
  - Remove from area, if required
  - Flush area with copious amounts of tepid water
  - Do not apply direct heat to area
  - Notify medical and arrange transport
- **While awaiting transport**
  - Loosen restrictive clothing
  - Continue flushing with water
  - Protect frozen/burned parts with sterile dry bondages
  - Do not smoke or drink, affects blood flow
  - Do not remove frozen clothing; massage or rub frozen parts; use safety showers or eye washes; or apply ointments

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Asphyxiation/Toxicity: What is it?

- **Displacement of oxygen in the air that you breathe by the cryogenic fluid vapour/gas release or venting could be an asphyxiation risk**
  - **Confined or minimal ventilation areas are biggest risk**
  - **However, all vapour clouds should be treated very carefully**
  - **Oxygen concentrations as low as 13% can be tolerated at 1 atmosphere**
- **Toxicity (poisoning) can cause damage and death if not adequately dealt with; appears not to be a problem at SLAC since the primary cryogens are non-toxic**
  - **Mentioned for completeness**

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Asphyxiation Oxygen Limits and Physical Reactions

Sudden Asphyxia – Inhalation of a gas containing practically no oxygen; unconsciousness is immediate (two breaths and out!)

Gradual Asphyxia – See Below!

Percent Oxygen in Air	Physiological Reactions
12% - 14%	Respirations deeper, pulse up, coordination poor.
10% - 12%	Respiration fast and shallow, giddiness, poor judgment, lips blue.
8% - 10%	Nausea, vomiting, unconsciousness, ashen face.
6% - 8%	8 minutes, 100%fatal; 6 minutes, 50% fatal; 4-5 minutes, all recover with treatment.
4%	Coma in 40 seconds, convulsions, respiration ceases, death.
0%	Immediate unconsciousness without warning; may fall as if struck by a blow on the head. Death in 2-3 minutes if not resuscitated.

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Asphyxiation/Toxicity: What is it avoided?

- **Best option is to have a well ventilated area which sweeps and exchanges the air in the area of concern**
  - **HVAC design requirement, 1 – 2 volumes per minute**
- **Personnel training in confined space operations, use the Job Safety Analysis (JSA) approach!**
- **Use harnesses to allow you to be extracted**
- **Use air packs or lines until the environment is verified safe**
- **Allow work in teams with at least one member outside the confined space or area of concern to be the safety valve!**
  - **Communications within the entire team is critical to a safe operation**
- **Monitor environment for air composition**
  - **Portable and/or permanent oxygen monitors should be used**

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Asphyxiation/Toxicity: What to do if?

- **Make sure that you are prepared**
  - **Safety extraction equipment is available and ready to use**
  - **Personnel are trained and certified for tasks**
  - **Have a plan (checklist) and use it!**
- **Remove any victim as quickly as practical to a normal atmosphere**
- **If not breathing, start artificial respiration immediately**
  - **Time is the killer here!**
- **Get into medical facility as soon as possible.**

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Hypothermia: What is it?

- **Occurs when the body is not capable of maintaining its normal temperature.**
  - **Do you think in long duration operations with cryogenic fluids that this might be a problem?**
  - **Condition does affect personnel reaction time and mental awareness**
- **Precautions**
  - **Similar approach to Frost Bite however may add a layer or two of clothing to keep warm**
  - **Rotate crew members to keep from long term exposure**
- **What to do?**
  - **Get warm and do not re-engage until rested for at least 8 hours, if possible**

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Part 1. – General Safety Topics

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What materials are suitable for cryogenic systems and reduce the safety risks?

- **Materials should remain ductile at the temperature of the cryogen used**
  - **Avoid bcc metals such as carbon steel of soft solder**
- **This are always trade-offs in material selection**
  - **Thermal expansion or contraction**
  - **Strength, yield and ultimate**
  - **Ductility, shock strength, fatigue life**
  - **Heat capacity**
  - **Thermal conductivity**
  - **Magnetic properties, etc**
- **Of particular interest in the safety arena are when and how might the material become unsafe?**

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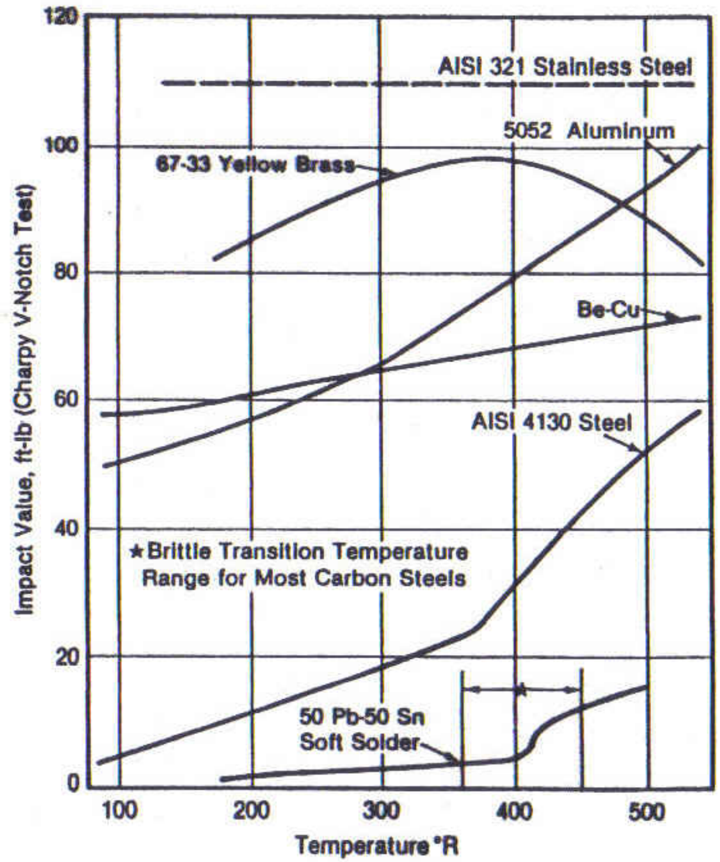
Materials Can be Used to Your Advantage! Such As Ductile-Brittle Transitions

- Ductility of most metals decreases at low temperatures. Some undergo a rapid change over a narrow band.
- Transition temperature between ductile and brittle behavior is called NDT (Nil Ductility Transition) and is measurable.
- Charpy impact test is one of these tests
- NDT data is available for most materials but varies with specimen size, shape and test threshold.



Impact Resistance of Various Metals

-360	-260	-160	-60	40	⁰F
-218	-162	-107	-51	4	⁰C
55	111	166	222	277	K

Thermal Stresses in Cryogenic Service Must be Accounted for in Design

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- All materials contract when cooled from room temperature to cryogenic temperatures
- The expansion (and contraction) coefficient is a function of temperature but is typically 3 to 5 mm/m for common structural materials between room temperature and 77K
  - Little additional change occurs below 77K
- Joints and supports must be able to handle induced stresses and transitions between various materials, eg aluminum and stainless steel must be accounted for in the design
- An uneven cooldown will create large thermal stresses within a vessel
  - Pipeline example: 30 m stainless steel pipeline would contract 8.4 cm on cooldown to 77K

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Is SLAC at risk for an explosion?

- **An explosion results from a sudden release of energy dissipated by air chock waves (and acceleration of shrapnel, thermal radiation, etc.) and causes a temporary over-pressurization**
- **Definitions of interest for explosions**
  - **A bursting explosion releases stored pressure energy without a chemical reaction – most likely risk at SLAC**
  - **A deflagration is a combustive explosion with a subsonic flame speed – least likely but possible at SLAC**
  - **A detonation is a combustvie explosion with a supersonic flame speed**
  - **An enclosed space may turn deflagration into a detonation**
- **Mitigation is a usually a combination of design and appropriate safety devices to keep system from exploding**

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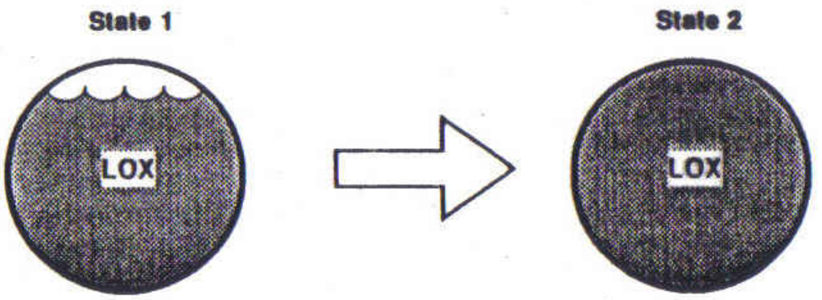
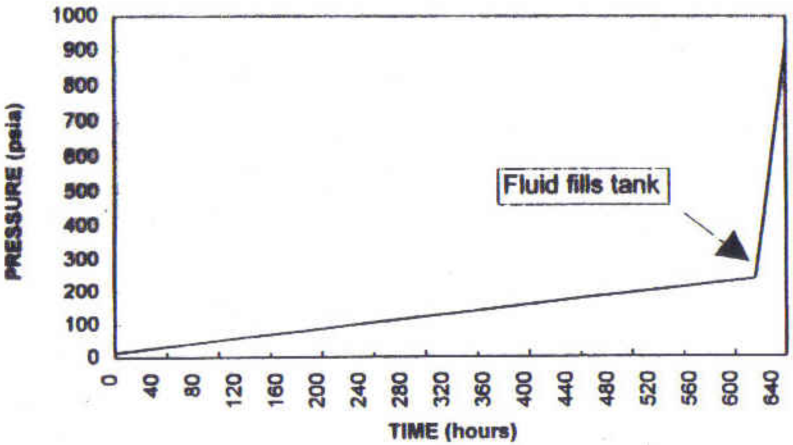
Over-pressurization needs to be addressed for all operations

- Example case for tank lock up
  - 1000 gal storage dewar
  - 1 percent per day boil off
  - Storage dewar is 70% full





- **Parasitic heat expands liquid in tank**
- **Pressure rises at 0.36 psi/hour**
- **Once lquid fills ullage, pressure rises rapidly, 21 psi/hour**

Quenching a large magnet with all its energy into a cryogenic cooling medium in the matter of milliseconds has the same effect only incredibly faster!

Overpressurization Relationship to Blast Wave Dissipation Helps Make Point

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Blast Overpressure or Shrapnel Momentum	Structural or Biological Response to Blast Effects
0.5 to 1 psig	Glass windows shatter
1 to 2 psig	Corrugated steel or aluminum paneling buckles
2 to 3 psig	Non-reinforced concrete or cinder-block walls shatter
5 psig	Eardrums rupture
7 to 8 psig	Non-reinforced brick walls shear and fall
15 psig	Lung damage
115 ft/sec for a 0.35-oz glass projectile or 10 ft/sec for a 10-lb masonry projectile	Projectile penetrates abdomen
10 ft/sec for a 160-lb man	Skull fracture from impact

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Ok, but what does that mean to me?

Distance (feet)	Overpressure (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 is the blast wave arrival time
t2 is the time required for the overpressure to decay back to zero

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Is fire a risk at SLAC due to cryogens?

- **Obvious with gases such as hydrogen, oxygen, LNG and acetylene; but not used in normal operations at SLAC**
- **However, liquefied inert gases such as nitrogen and helium may condense oxygen out of the atmosphere, causing oxygen enrichment or entrapment in unsuspected places**
- **At temperatures < 82 K, metal surfaces will condense oxygen and form enriched air (50% O_2 and 50% N_2) to drip and pool on surfaces**
  - **Uninsulated pipelines provide this surface**
  - **Air boils at 78 K (at 1 atm of pressure) in a 6% O_2-94% N_2 vapor mixture, enriching the O_2 content**

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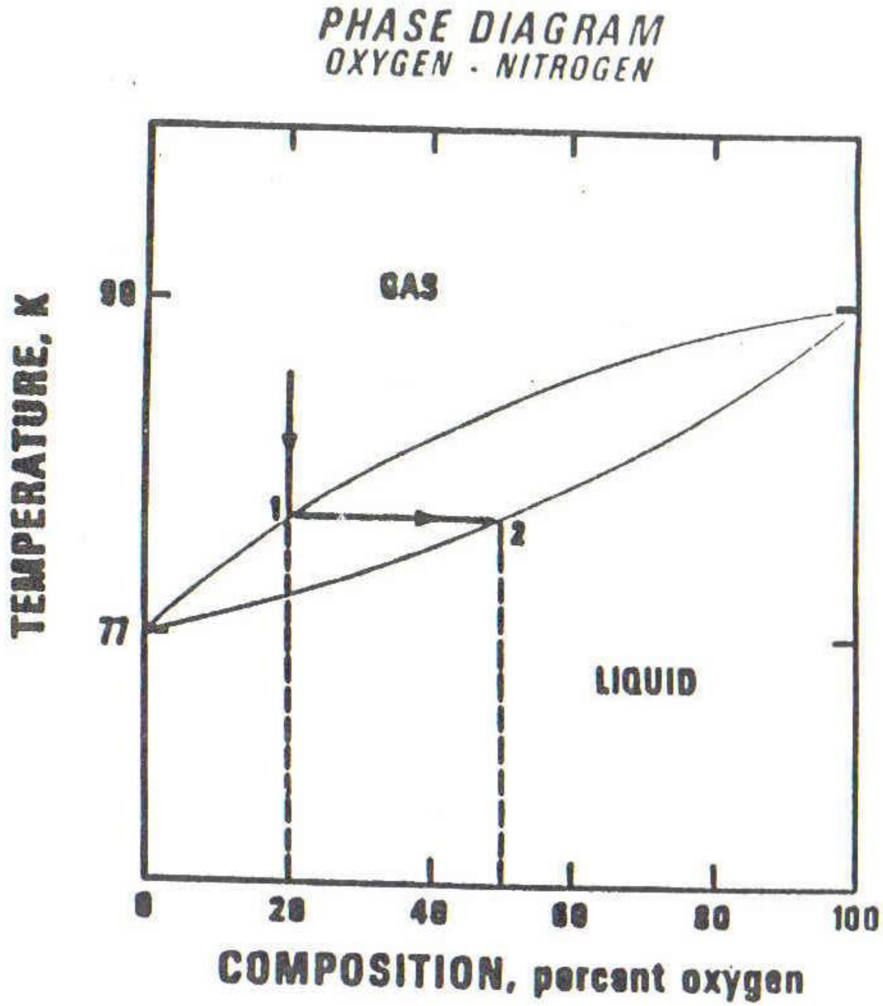
This is how enrichment works!

- **Air condenses from an exposed LN_2 or cold GHe pipe is enriched to 50% O2 (see chart)**
- **Falls/drips to ground and may flash off leaving O_2 rich local atmosphere; pool is ground gets cold enough; or drip onto flammable material**
- **Avoid this condition if at all possible**
- **If not, use drip pans to control where enriched air can go**



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Ok, so how do we prevent the possibility of fires in your cryogenic operations?

- As in all fire risks, you control the fire triangle you control the risk of fire
- In the case of SLAC, reduce the presence of the oxidizers to the minimum possible
  - Insulate exposed cryogenic transfer lines
  - Maintain good ventilation
- Eliminate all combustible materials
  - Good housekeeping is essential
  - Oxygen makes most everything burn so be careful
- Attempt to eliminate all ignition sources
  - Always assume they are present
  - No smoking, open flames, thermal ignition sources
  - Proper electrical techniques, lightning protection, static discharge controls

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Operational Hazards to Cryogenic Operations at SLAC

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- **Storage and tank failures – overpressurization**
  - **Must have relief devices and set at appropriate pressures**
  - **Tanks should be sized and spaced appropriately**
  - **Calibration and periodic maintenance is required!**
- **Process and procedures for spills, leakage and disposal**
  - **Venting paths established and verified open**
  - **Emergency equipment staged**
- **Transportation and transfer**
  - **Paths in and out are clear**
  - **Procedures established and dry-runs completed**
- **All venting should be controlled**
  - **Free venting of any cryogen should be eliminated or tightly controlled.**

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General Safety Check List

- Personnel training is critical in all aspects of cryogenic safety
- Always be safety conscious
- Be sure that all equipment is in good working order, including safety equipment
- Understand hazards to be faced in doing job
- 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
- Know emergency steps and appendices

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Contamination is Nothing to Mess With!

- **Practice these essential elements of contamination control:**
  - **Initial system component disassembly and inspection**
  - **Cleaning of individual parts (I recommend all cryogenic parts be cleaning to a level equal to oxygen cleanliness as a minimum)**
  - **Visually inspect**
  - **Store and label components**
  - **Pressure and leak test systems**
  - **Verification of cleanliness by sampling**

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Short Course on Cryogenic Safety
Part 1. – Material Safety Data Sheets

- Nitrogen
- Helium

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Nitrogen

Acrobat Document

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Helium

P4600g.pdf