Safety in Cryogenic Systems

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Plan of Presentation

- Brief introduction to Cryogenics & its applications
- Sources of accidents in Cryogenic systems
- Properties of Cryogenic fluids / Cryogens
- Risks in handling Cryogens
- Conclusion

Brief introduction to Cryogenics

CRYOGENICS

‘Cryos’ – Icy cold
‘*Genes’* – generation / production

Cryogenics deals with production, utilization and maintenance of low temperatures.

As per National Bureau of Standards, Colorado:

Cryogenics deals with temperatures below -150 ºC (123 K)

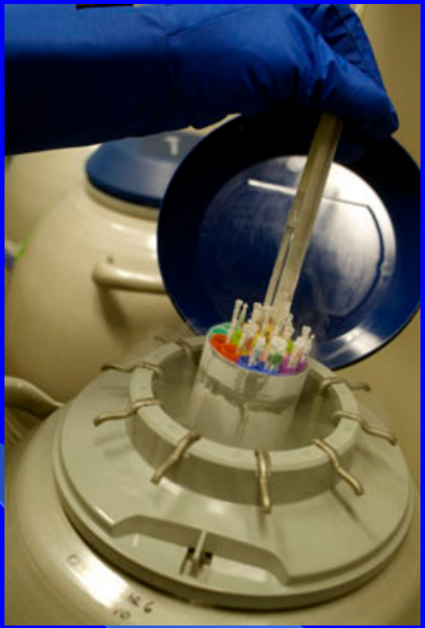
Below this temperature (< 123 K):

- The so called "PERMANENT GASES" namely N_2, O_2, Ar, H_2 and He are liquefied

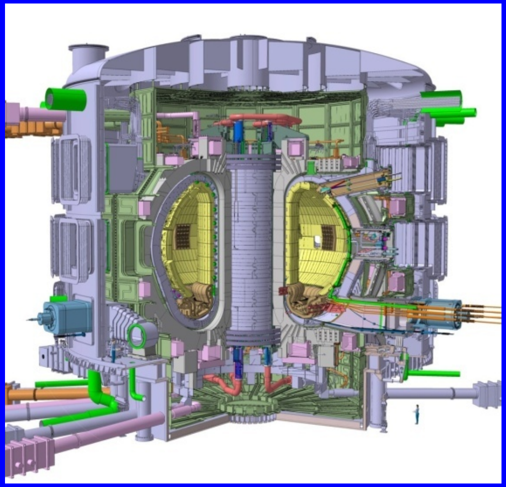
In this realm of temperatures:

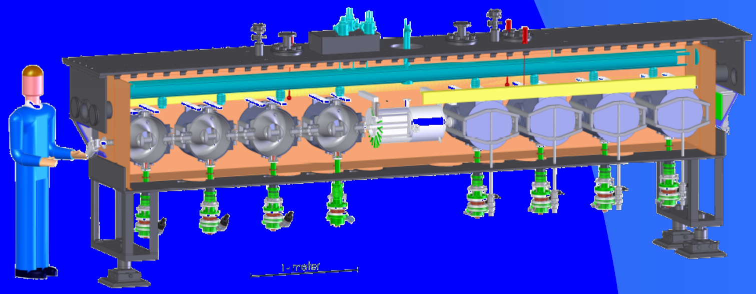
- Rubber becomes as brittle as glass
- Metals & alloy change their properties to become Superconducting (R=0)
- Living cells pass a state of suspended animation

APPLICATIONS OF CRYOGENICS



Cryogenics is a multibillion dollar industry with applications ranging from the very small to very large systems





Safety in cryogenic system design & operation is vital

Sources of Accidents in Cryogenic Systems

- Sources of accidents in Cryogenic Systems are mainly due to:

1. Properties of Structure Materials

2. Properties of Cryogens

3. Handling of Cryogens

4. Improper knowledge on operation of Cryosystems

Properties of Structure Materials

Properties of Structure Materials

- Equipment like vessel, container, transfer line may **Fracture** with consequence of sudden release of the cold cryogen

Causes may be due to:

- Design of vessel / material selection not according to requirements
- Standards and regulation for pressure vessel design not respected
- Thermal stresses due to contraction / expansion at large temperature differences
- Change of material properties at low temperatures (in particular embrittlement of the material)

Fractured pipe / elbow due to embrittlement at cryogenic environment

Properties of Cryogenic Fluids

Properties of Common Cryogenic Fluids

Cryogen	Boiling point (K)	Freezing point (K)	Latent heat (kJ/kg)	Density (kg/m3)
Oxygen	90.2	54.4	213	1141
Argon	87.3	83.8	161.9	1394
Nitrogen	77.3	63.2	199.3	807
Neon	27.1	24.5	85.9	1206
Hydrogen	20.3	13.9	443	70
Helium	4.2	---	20.9	125

- **Latent heat of vaporization for cryogenic fluids are very less**

  For the same amount of heat,1 litre of

  - Liquid Argon vapourises 10 times faster than water
  - Liquid nitrogen vapourises 14 times faster than water
  - Liquid helium vapourises 100 times faster than water

- **Expansion ratios of cryogenic fluids are very high (at 300 K & 1 atm)**

Cryogen	Vgas / V liquid
Oxygen	797
Argon	779
Nitrogen	646
Neon	1341
Hydrogen	788
Helium	701

Thumb Rule:

1 liter of a liquid cryogen expands to 700 liters (0.7 m3) of gas when warmed to ambient temperature (Except Neon)

- **Such behaviors are of concern** as rapid vaporization and large expansion may lead to rapid pressure building….must be taken into consideration in the cryosystems design and safety measures

Liquid Nitrogen Pressurized Container

Liquid Oxygen Pressurized Container

Risks in Handling Cryogens

Cryogenic Handling Mistake…with deadly consequences

Deadly Experiment at minus 220 Degree

Göttingen (AP) A 24-year-old student has died after an accident in a laboratory of the physical Institute of Göttingen University. As the police reports, the young man wanted to prepare an experiment for the next day together with a 25-year-old fellow-student. The students worked in different rooms. After some time the 25-year-old student wanted to look for the younger fellow-student and found him stiff-frozen on the floor of the nitrogen room. The valve of the nitrogen line was still open and all floor frozen.

The re-animation attempt by a doctor was without success. Liquid nitrogen is stored in dewars at minus 220 degrees according to the police.

Newspaper article
Courtesy G. Perinic, CERN

Three workers — aged 31, 34 and 52 — were killed on Nov. 15, 2018 at Millennium Cryogenic Technologies, Canada an oilfield supply company in the Leduc Business Park. Leduc Mayor Bob Young said the men were killed in a “gas accident.” OHS is leading the investigation and to determine what happened. Fatalities involving liquid nitrogen, the key component used in cryogenic processes, are rare, said Glenn Johnston, president of the National Cryogenics Corporation, which operates out of Edmonton and Texas.

“We’ve been in the industry since 2007. And these are the only fatalities we’ve heard of, “Johnston said in an interview Tuesday with CBC Radio’s Edmonton AM. In a lab or workplace setting, cryogenics uses liquid nitrogen to freeze a space or a piece of equipment.

In Alberta, the technology is often used to treat mechanical gears or tools used in the oilfield industry to make them more durable. It’s extremely unlikely the men would have been killed by nitrogen exposure, said Johnston. If they did die from exposure, it would likely have been due to inert gas asphyxiation, he said.

Risks involved in handling cryogens are:

Physiological risks

1. Cold damage to living tissue
2. Asphyxiation (lack of oxygen)
3. Hypothermia
4. Toxicity

Other risks

5. Impaired vision
6. Flammability

• Cold damage to living tissues generally occur by direct contact with cryogens during Transfer / Spill of cryogens !!

Transfer of LN2 from mobile tanker to storage Dewar

Spill of LN2 while transferring to storage Dewar

Spill of LN2 from storage Dewar

• 4 out of 6 Risks are already present (except toxicity and flammability) with a simple nitrogen release or spill

• Cold damage to living tissue
• Asphyxiation
• Hypothermia
• Impaired vision

1. Cold damage to living tissue

The low temperature of cryogens can cause serious damage to living Organisms

a) Immediate injury by direct contact with cryogen or cold surface
b) Physical harm with hypothermia due to extended time exposure to a cold atmosphere

Freezing of Tissue:

- Cellular changes can already start to occur to tissues at about 15 ºC
- Formation of ice crystals at temperatures of - 3 ºC (= freezing point of human tissue)

(Effect: ice crystals are formed outside the cell membranes. Water is then transferred from inside the cell resulting in cell dehydration and cell damage. This effect is similar to burns from heat)

Therefore the tissue damage caused by freezing is frequently referred to as "Cold burns", "Cryogenic burns", "Frostbites"

Freezing of tissue

- Ice crystals damage the cells, blood flow decreases or is interrupted can result into
  - Necrosis (= cell death)
  - Gangrene

    Gangrene is a serious and potentially life threatening condition which arises when a considerable body tissue dies due necrosis

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A terrible risk when touching a cold and uninsulated surface lies in the fact that the skin freezes (like gluing !) onto the cold surface and it is difficult to remove the hand and the heat transfer is very rapid

Cold burn

Necrosis / Gangrene due to severe Cold burn

Safety needs

- Use of PPE (Personal Protective Equipment) is must in Cryogenic labs
  - Apron for body protection
  - Goggles / mask for eye protection
  - Cryogenic gloves which are well insulating, non combustible, non permeable for cryogens and easily removable
  - High, tight-fitting closed shoes (no sandals..)
  - Long trousers which overlap shoes
- In case of Cryogen trap in Shoes, remove the shoes immediately

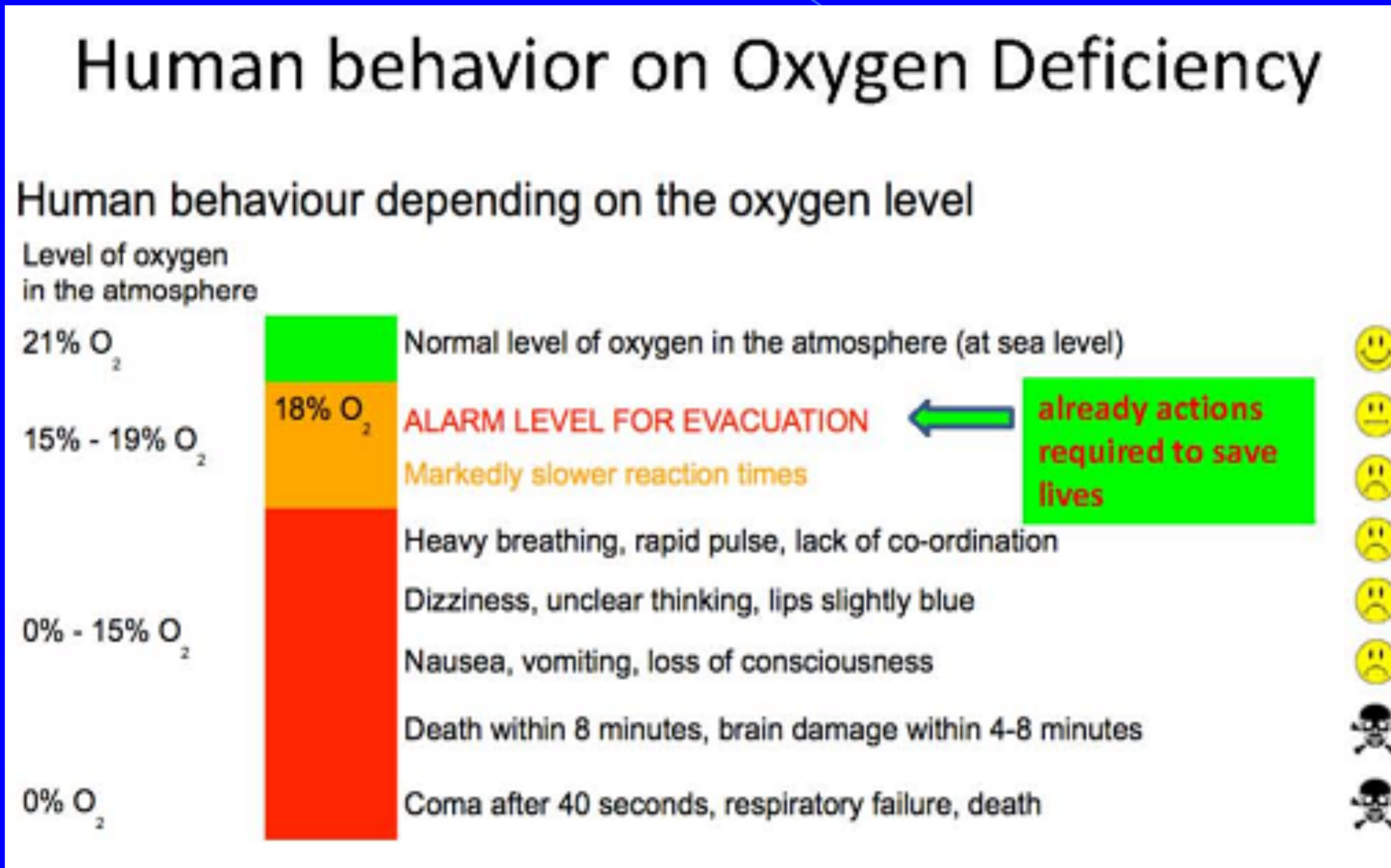
Safety Goggles

Cryogenic Gloves

Person with full PPE in a Cryogenic Lab

2. Asphyxiation

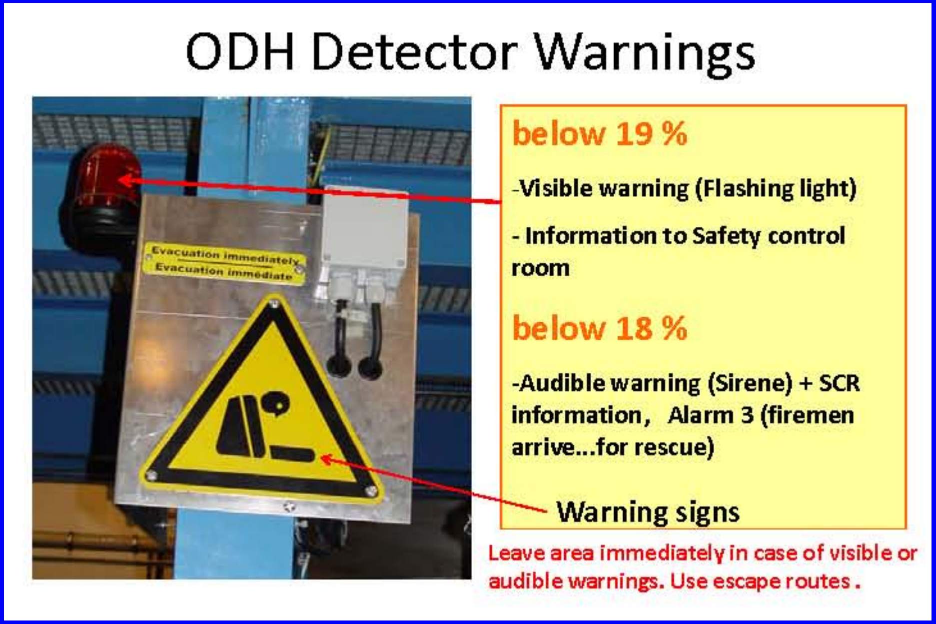
(Asphyxiation - risk of damage to body and brain or death due to lack of oxygen)



Volume % Oxygen (at sea level)	Effect
17	Night vision reduced Increased breathing volume Accelerated heartbeat
16	Dizziness Reaction time for novel tasks doubled
15	Impaired attention Impaired judgment Impaired coordination Intermittent breathing Rapid fatigue Loss of muscle control
12	Very faulty judgment Very poor muscular coordination Loss of consciousness Permanent brain damage
10	Inability to move Nausea Vomiting
6	Spasmodic breathing Convulsive movements Death in 5-8 minutes

Safety needs for Asphyxiation

- Lab / room should be large enough having well ventilation with fresh air
- Installation of ODH (Oxygen Deficiency Hazard) Detectors with visible and audible (Siren) warnings
- Sign boards for escape routes and "Escape Training" to all users.



ODH warning system

Warning and Escape routes sign boards

3. Hypothermia

- An extended time exposure to a cold atmosphere can lead to physical harm in form of **Hypothermia (body temperature decreases)** due to

  - Cold environments (freezers)
  - Spills in laboratories and underground with difficult escape routes

(a cold atmosphere may slow the mobility of persons down with risk of hypothermia and subsequent risks)

4. Toxicity

- Some fluids stored or used at cryogenic temperatures and exhibiting cryogenic risks in addition are toxic.

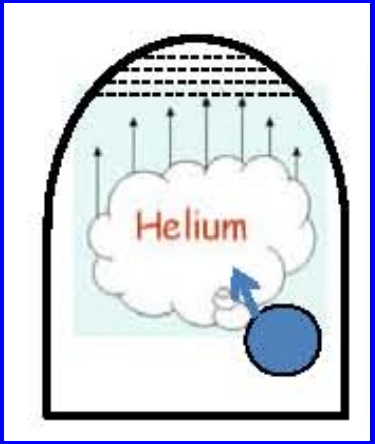
Poisonous substances like

- Carbon monoxide (CO)
- Fluorine (F2)
- Ozone (O3)

- Risks mainly found in chemical industry and industry using industrial gases

5. Impaired Vision

- Spills of cryogens can lead to air moisture formation, clouds resulting in reduced visibility
- Very dangerous in closed areas (buildings, underground caverns)



Helium leak / spill

In underground or closed areas, Helium (or other cryogen) leak or spill from equipment can lead to impaired vision

Persons, apart from being exposed to cold environment, may loose orientation and miss escape route !!

6. Flammability

- The two main cryogens which are highly flammable due to their chemical nature are

  1. Hydrogen (H_2) (stored in liquid form at approximately 20 K)
  2. Liquid Natural Gas (LNG)

- LNG is composed of 90 % of methane (CH_4) with ethane, propane, butane…etc and stored in liquid form at 110 K
- Chemicals reacts with oxygen (pure or air oxygen) and burns with flames of temperatures above 2000 degrees Celsius

- Combustion properties of Hydrogen and Methane

Property	Hydrogen	Methane
Flammability limits (vol %)	4 – 75 %	5 – 15 %
Detonation limits (vol %)	18 – 60 %	6 – 14 %
Minimum Ignition Energy (mJ)	0.02	0.29
Autoignition temperature (K)	790 - 1020	900 - 1490
Flame temperature	2320	2150

Improper Knowledge on Operation of Cryosystems

Problems in Operation of Cryogenic Systems / Plants

- Engineering Mistakes (e.g. systems design, flow scheme)
- Engineering mistakes in instrumentation (not appropriate)
- No redundancy in instrumentation for important parameters
- Not all hazardous situations investigated
- Active safety measures not fully exploited
- Passive safety measures not sufficient
- Engineers / technicians not sufficiently trained
- Lack of or improper maintenance of the cryosystem

Conclusion

Cryogenic hazards are manageable!

- Always conduct a safety analysis of a cryogenic system - no matter how small the system
- Consider safety from the beginning of the design
  - Retrofitting can be very expensive
- Consider both normal and all possible abnormal operating conditions
- Have safety calculations and designs reviewed either internally or externally
- Build redundancy into safety systems – no single point failure should cause a hazard
- Ensure personnel are aware of hazards and properly trained
- Think of the (minimum) two-person rule when you go to confined areas
- Oxygen deficiency hazard (ODH) is a serious hazard and can be managed by awareness and analysis of risk
- Take advantage of previous work and outside resources
  - Codes, Regulations, National Labs, CGA
- Always wear Personal Protective Equipment (PPE) and in the event of an alarm or other indication of a hazard immediately leave the area

Thank You