Underground Cryogenic Systems in SARGRAV Laboratory

P. Rapagnani

Overview:

- **Archimedes Experiment Cryogenic System**

- **Safety issues in underground cryogenics**

- **A Safety Scheme for Archimedes Cryostat in SARGRAV Lab**

- **Path to full specs design for SARGRAV Lab**

The Archimedes Cryostat design guidelines:

- **Low seismic and vibration noise: cryogenic fluids to be preferred to cryocoolers**

- **High temperature stability**

- **Long time duty cycle**

- ***Underground operation***

Archimedes – The Cryostat

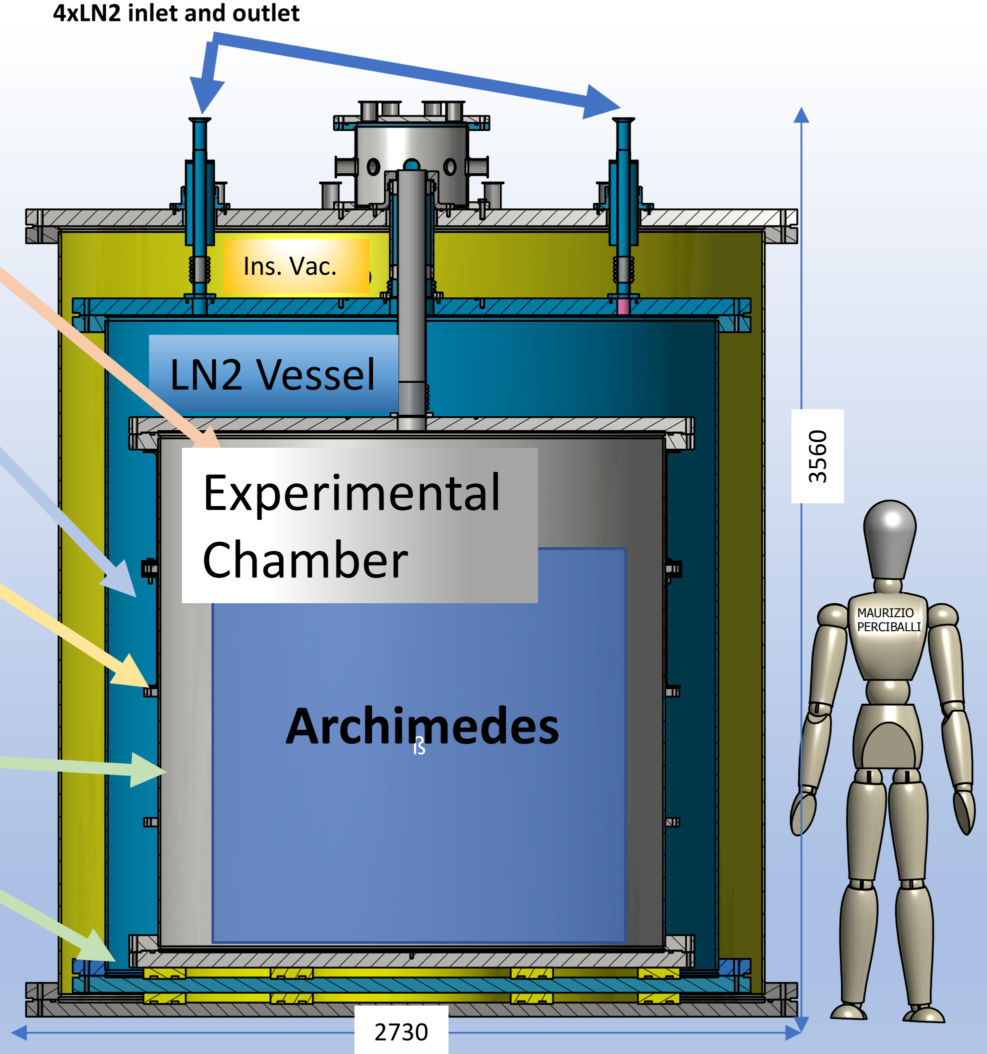
Experimental chamber can be completely covered with LN2 *(thermal stability)*

The vessel contains ~ 4000 l of LN2. With a typical thermal input of 2W/m², the evaporation time will be about 5 months. *(long duty cycle)*

Even with LN2 level below the top, temperature uniformity is assured by an aluminum shield clamped on the ss experimental chamber. (thermal stability)

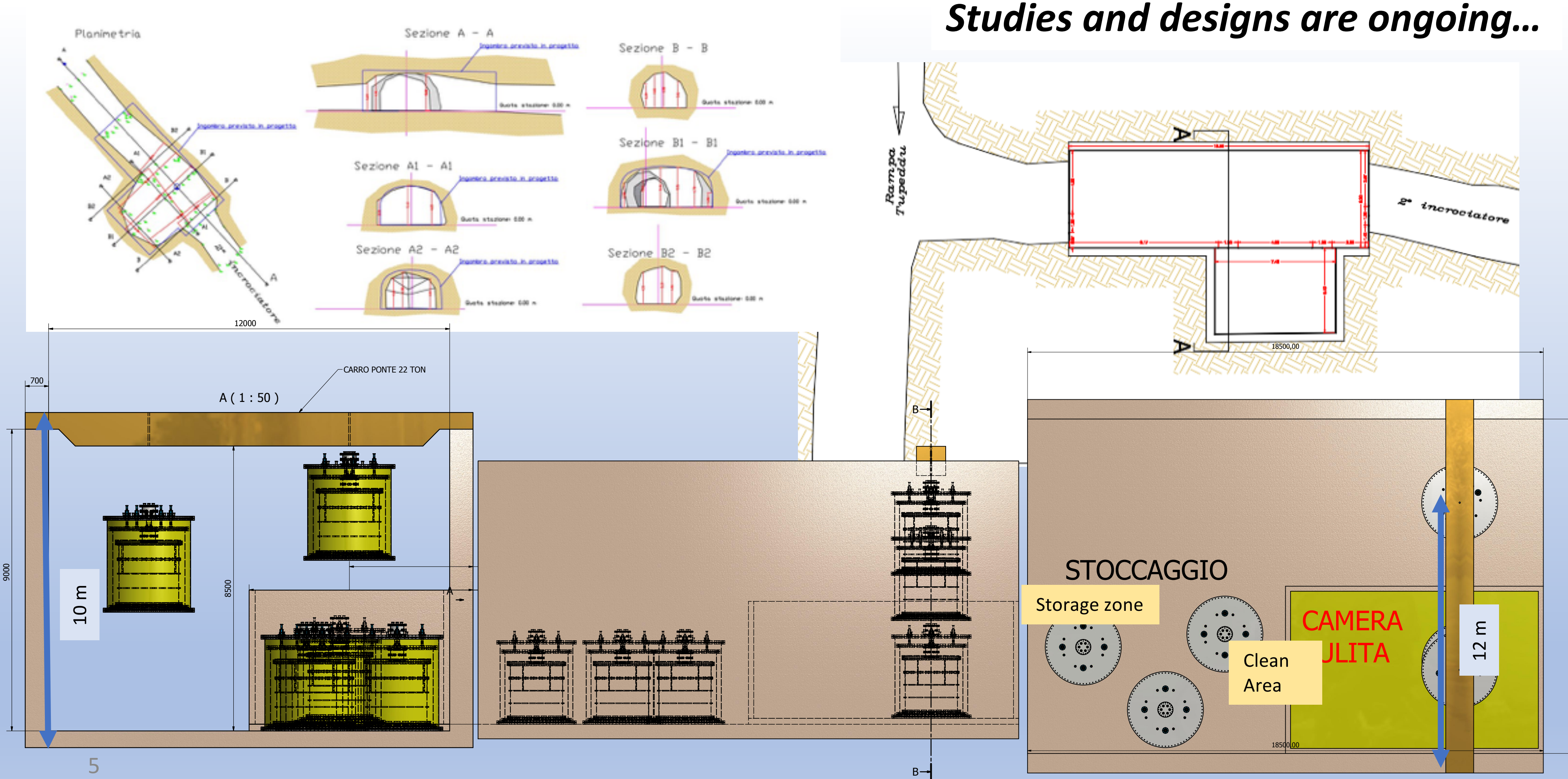
The cryostat is equipped with a level gauge, several thermometers and a heating resistance on the bottom, to reduce warm up time of the experiment, if necessary.

If LN2 boiling off disturbs the experiment, solid LN2 could give a quiter environment, while keeping the long operation time.



Archimedes Cryostat will be hosted in the new SARGRAV Lab

Studies and designs are ongoing…



One of the <u>main issues</u> in the installation of Archimedes Cryostat in SARGRAV, will be the use of cryogenic liquids in a confined environment.

However, on this topic, a vast expertise, also inside INFN, is available, e.g:

- **CERN with LHC**
- **INFN with the Cryogenic Dark Matter Detectors at LNGS, ARIA facility in Sardinia**
- **LAGUNA Underground Laboratory Studies**

Cryogenic Hazardous Events

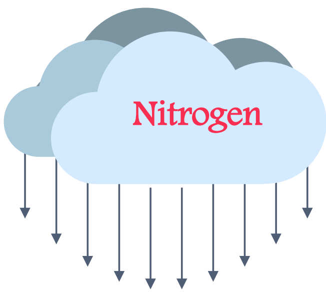
Thermo-physical properties

Fluid	^4He	N_2	Ar	H_2	O_2	Kr	Ne	Air	*Water*
Boiling temperature (Tb) in (K) at 1.013 bar	4.2	77.3	87.3	20.3	90.2	119.8	27.1	78.8	*373*
Latent heat of evaporation at (Tb) in kJ/kg	21	199.1	163.2	448	213.1	107.7	87.2	205.2	*2260*
Ratio volume gas (273 K) /liquid	709	652	795	798	808	653	1356	685	***.....***
Specific mass of liquid (at Tb) in kg/m3	125	804	1400	71	1140	2413	1204	874	*960*

1 l of cryogenic fluid expands to about 700 l (0.7 m^3) of gas when warmed to ambient temperature (at constant pressure)

		
Helium **He** Neon **Ne** Nitrogen **H_2** Argon **Ar** Krypton **Kr**	Hydrogen **H_2**	Oxygen **O_2**

Cryogenic Hazardous Events
Cryogens - discharge



Safer location at the top

- Argon and nitrogen fall downwards when discharged, forming clouds
- Avoid confined spaces in pits underground channels etc.

Demonstration: Balloons air and helium

Cryogenic Hazardous Events
Physiological - Asphyxiation

Gradual asphyxiation

Human behaviour depending on the oxygen level

LEVEL OF OXYGEN IN THE ATMOSPHERE		
21% O_2		Normal level of oxygen in the atmosphere (at sea level)
19% - 15% O_2	**18 %**	Oxygen deficiency alarm level
	17 %	Night vision reduced, Increased breathing volume, Accelerated heartbeat
	16 %	Dizziness, Reaction time for new tasks is doubled
	15 %	Poor judgment, Poor coordination, Loss of muscle control
15% - 0% O_2	**12-10%**	Very faulty judgment, Very poor muscular coordination Loss of consciousness
	< 8%	Nausea, Vomiting, Coma
	< 5%	Permanent brain damage
0% O_2	**0%**	Spasmodic breathing, Convulsive movements, Death in 5-8 minutes

Cryogenic Hazardous Events
Technical risks

Build-up of pressure

- Pressure can be released when thermal loads are beyond normal operation dur to:
  - Fire
  - Loss of insulation vacuum
  - SC magnet resistive transition (quench)
  - Return line blocked

- Release of cryo-pumped gases during warm-up (air leaks)

Use pressure-relief devices to protect both the fluid volume **and** vacuum vessel against overpressure **is mandatory.**

Demonstration: Table tennis ball, film box

Cryogenic Hazardous Events
Technical risks

Embrittlement

- Some materials become brittle at low temperature and rupture when subjected to loads

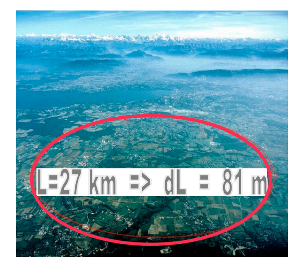
- Protect surrounding equipment/structures from crogens discharge.

Thermal contraction (293 K to 80 K)

- Stainless steel: 3 mm/m

- Aluminium: 4 mm/m

- Polymers: 10 mm/m



Cryogenic Hazardous Events
Technical risks

Combustion / Fire

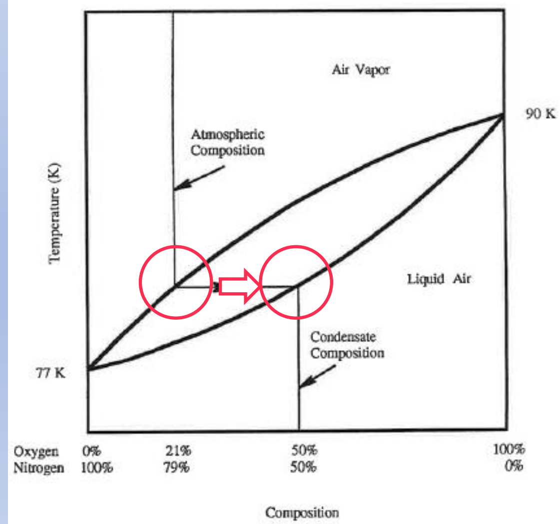
- Use of flammable cryogens (e.g. Hydrogen).
- Liquid oxygen can cause spontaneous combustion. Adheres to clothing and presents an acute fire hazard.

Condensation of atmospheric gases

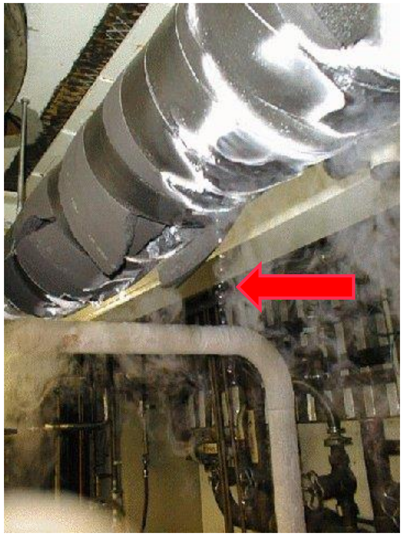
- Innappropriate insulation or discharge of cryogens can lead to oxygen enrichment
- Mainly observed at tranfer lines and during filling operations

(liquid air → **50% O_2** instead of 21% in atmospheric air)

Cryogenic Hazardous Events
Condensation of atmospheric gases – Oxygen enrichment



From: F. Edeskuty, Safety in the Handling of Cryogenic Fluids



Cryogenic Hazardous Events
Oxygen Deficiency Hazard (ODH)

Actions

- Vent discharged cryogenic fluids to safe locations outdoors (use of relief lines)
- Equipment/system leak tightness
- Ventilation/extraction systems
- Oxygen deficiency hazard monitoring (ODH detectors)
- Emergency procedures & evacuation plan
- Use self-rescuing mask (PPE for long exposure to lack of oxygen – LHC tunnel) :
  Special HSE training required!

Keep evacuation paths free

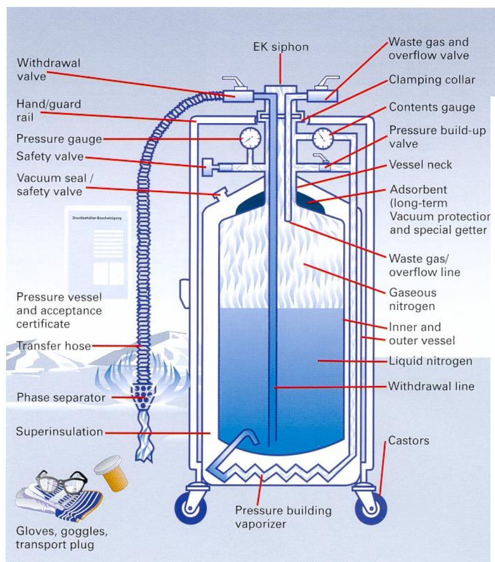
Follow evacuation / exit panels

Keeping in mind the movement of cols gas clouds

Accident Scenarios

Frozen or blocked Dewar

Risks:
- Pressure rise in the Dewar
- Bursting of outer or inner shell



In case of a blocked Dewar

Evacuate the zone and contact:

- **CERN Fire brigade: (+41 2276) 74444**
- **Helium liqu. (Bldg. 165): 160041**

Spills and Disposal

Minor release (V<1 liter):

- Allow liquid to evaporate, ensuring adequate ventilation

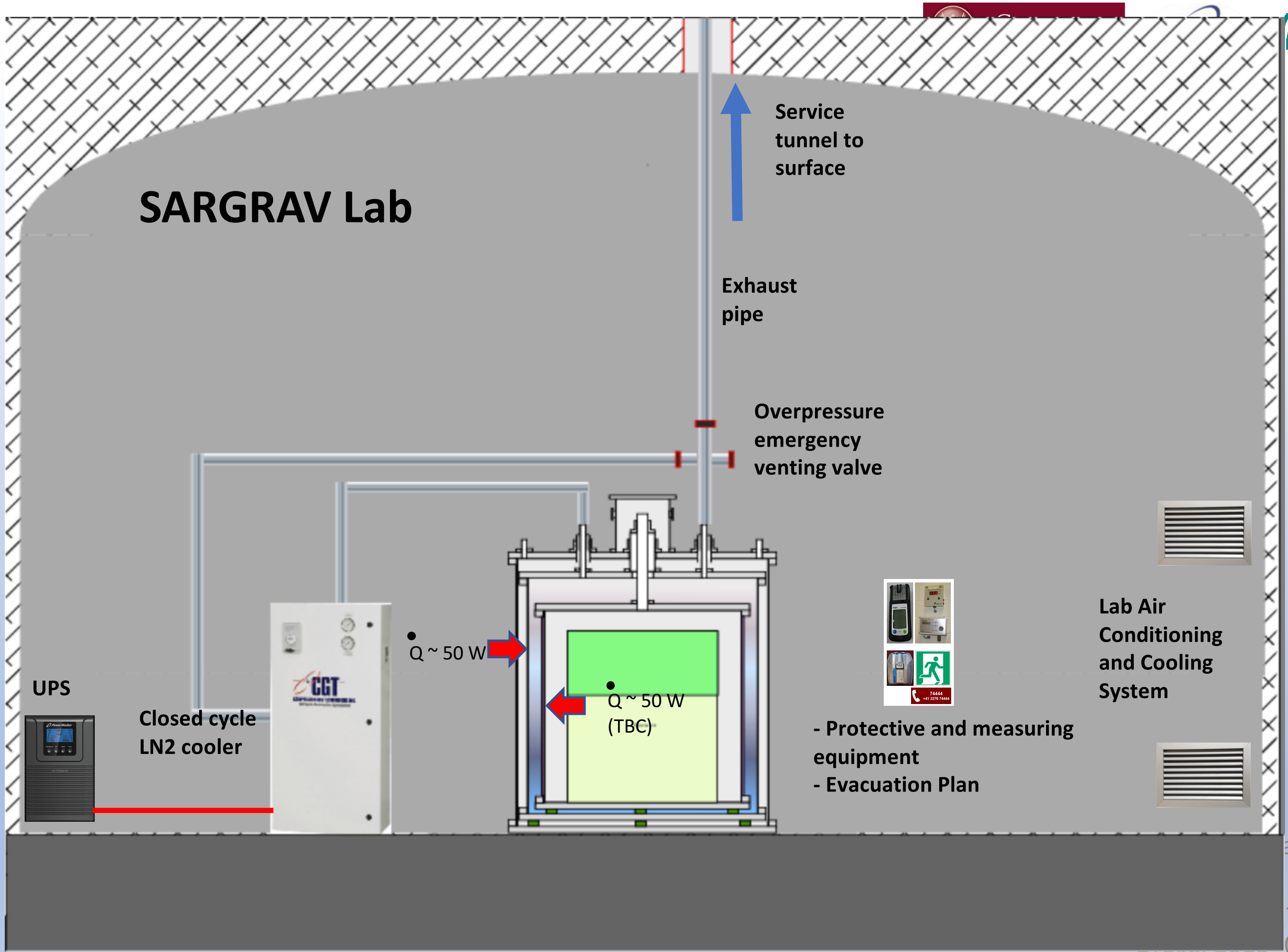
Major release (V>1 liter):

- Shut off all sources of ignition (whenever present)
- Evacuate area of all personnel
- Contact CERN fire brigade
- **DO NOT** return to the area until it has been declared safe by CERN fire brigade

Disposal:

DO NOT pour cryogenic liquids down the sink - they will crack waste pipes .
DO NOT store cryogenic fluids or allow them to vaporize in **enclosed areas**
→ including cars, sealed rooms and basements.

DO ensure that the area in which the cryogenic liquid is left to vaporize is well ventilated or that is located outdoors.



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It is more difficult to avoid these risks in an underground lab.

We can follow for instance the guidelines for Liquid Argon Dark Matter Detectors:

Safety analysis and quantitative risk assessment of a deep underground large scale cryogenic installation

Effie Marcoulaki* and Ioannis Papazoglou
National Centre for Scientific Research "Demokritos", Athens, Greece

Abstract: This work considers the safety analysis and quantitative risk assessment of a deep underground cryogenic installation intended for neutrino physics. The neutrino detector equipment will be submerged in 50ktons fiducial mass of purified liquid argon, stored in a specially designed heat insulated tank located inside a deep underground cavern. The conditions inside the tank and the cavern, and the purity of argon will be maintained using appropriate systems for cooling, heating, pressurization and filtration. Smaller adjacent caverns will host the process unit equipment (process unit caverns). The caverns for the tank and the process units are planned to be excavated inside a mine at about 1400 meters underground. The quantitative results presented here provide incentives for improvements on the current process design of the installation that can reduce significantly the expected frequencies of accidental argon release due to tank overpressure.

Keywords: safety assessment, cryogenic argon, loss of containment, underground installation, tank overpressure, neutrino detectors

PSAM 12: Probabilistic Safety Assessment and Management,
Hawaii, USA 2014

Following Markoulaki & Papazoglou 2014:

Main risk in Underground Cryogenics: Loss of Containment (LOC)

LN2 is released from its containment, evaporate, and:

- **reach concentrations in a particular confined space that can expel oxygen from the air** → **ODH (Oxygen Deficiency Hazard)**

- **result to extremely low temperatures in the confined space**

All containment failures may be divided in:

Structural Failures
They occur if the stress employed on the containment by the various operating conditions is larger than the stress of the containment.

Containment Bypassing
It occurs whenever an engineered opening in the containment (like a valve) opens inadvertently when it is supposed to be closed. Such failures are mainly caused by human actions either during normal operation or during test and maintenance activities ***(not treated here)***

Overpressure and Related Safety Measures

Increase of the internal pressure can cause an increase of the stress on the containment exceeding its design limits and resulting in LOC.

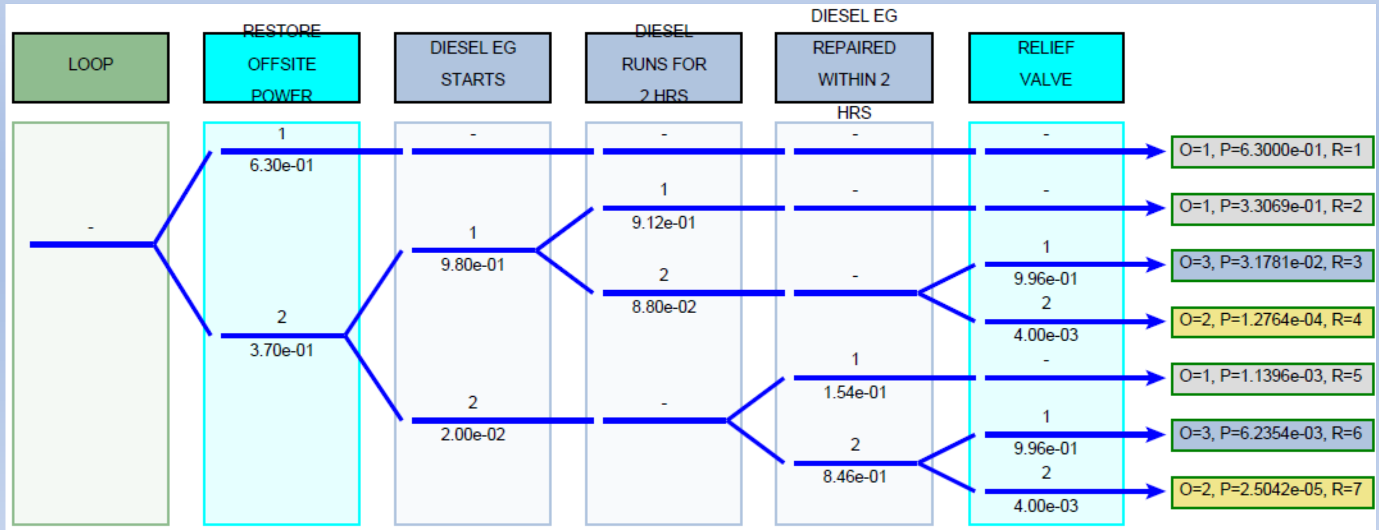
Accident sequences *are sequences of events* (either hardware failures and/or human actions) *that lead to LOC and hence to LN2 release.*

Example: Loss of Offsite Power

Mean Time To Repair

EVENT	PROBABILITY
Loss of offsite Power	10^{-5}/hr (Frequency) [4]
Mission Duration	2.2 hours
Failure to recover Offsite Power within 2.2 hours (MTTR=2hours)	0.37
Emergency Diesel Generator starts on Demand	0.98
Emergency Diesel Generator is repaired within 2.2 hours	1.54×10^{-1}
Given that Emergency Diesel Generator starts, mean availability over 2.2 hours	9.11×10^{-1}
Pressure Relief System failure (on demand)	4×10^{-3}

Mission Duration = = "grace period": Time before overpressure becomes dangerous



Loss of Service Water Cooling System

EVENT	PROBABILITY
Loss of the operating fan	$3.1x10^{-4}$/hr (Frequency)
Loss of the Heat exchanger (ventilator)	$3.6x10^{-5}$/hr (Frequency)
Failure to recover pump within 2 hours (MTTR=12hours)	0.85
Failure to recover pump within 2.2 hours (MTTR=12hours)	0.83
Failure to recover Heat Exchanger within 2 hours (MTTR=36hours)	0.95
Failure to recover Heat Exchanger within 2.2 hours (MTTR=36hours)	0.94
Failure to switch Instrumentation OFF	0.1

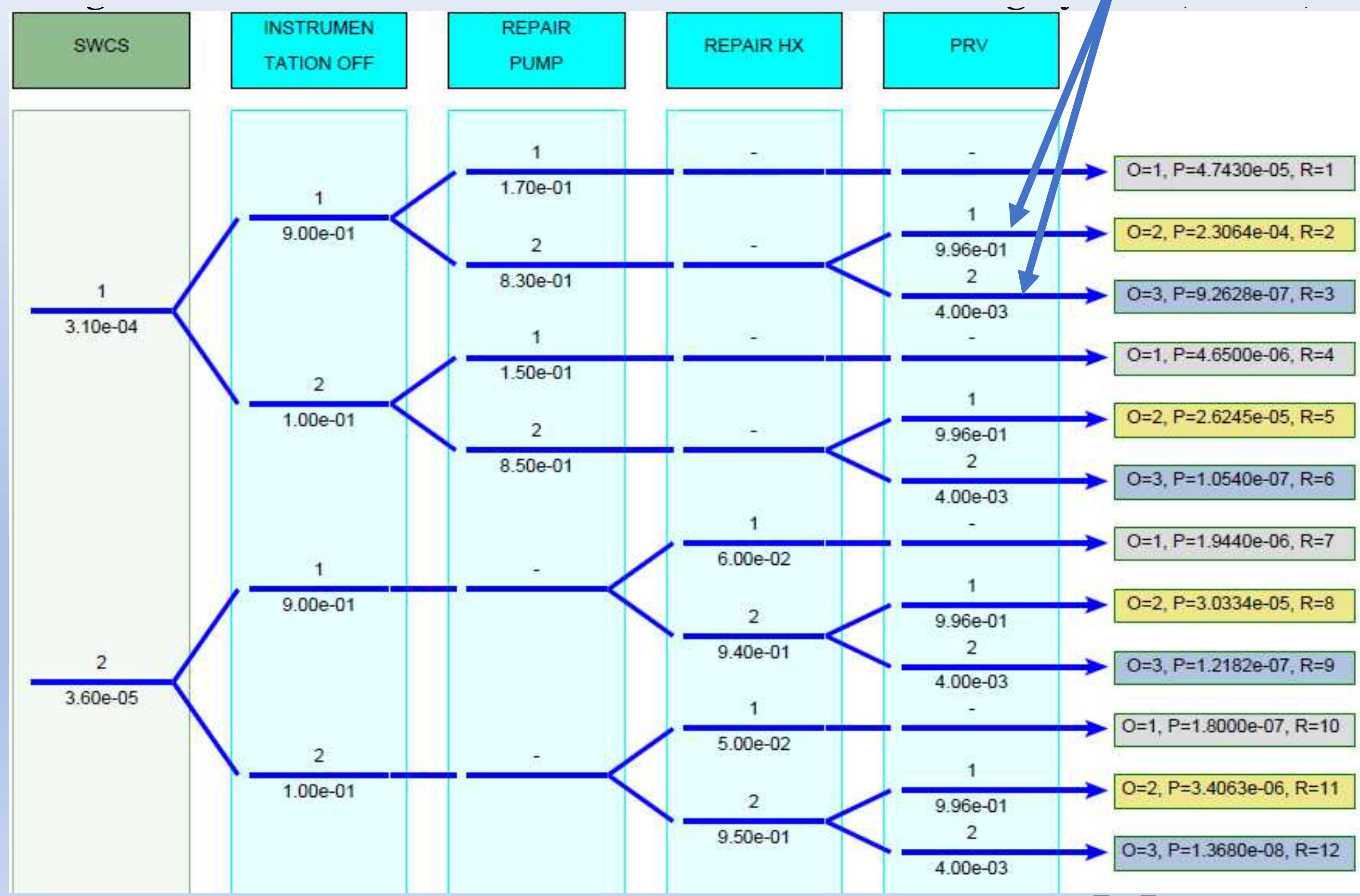
LN2 released in cavern

Initiating events:
(a) loss of a pump
(b) loss of a Heat exchanger (HX).

Logic: Success if the failed component is repaired within 2.2 hours (if instrumentation is turned off) and in 2 hours (if instrumentation is not turned off).

If the failed component is not repaired within the available grace period the sequences result in failure due to overpressure.

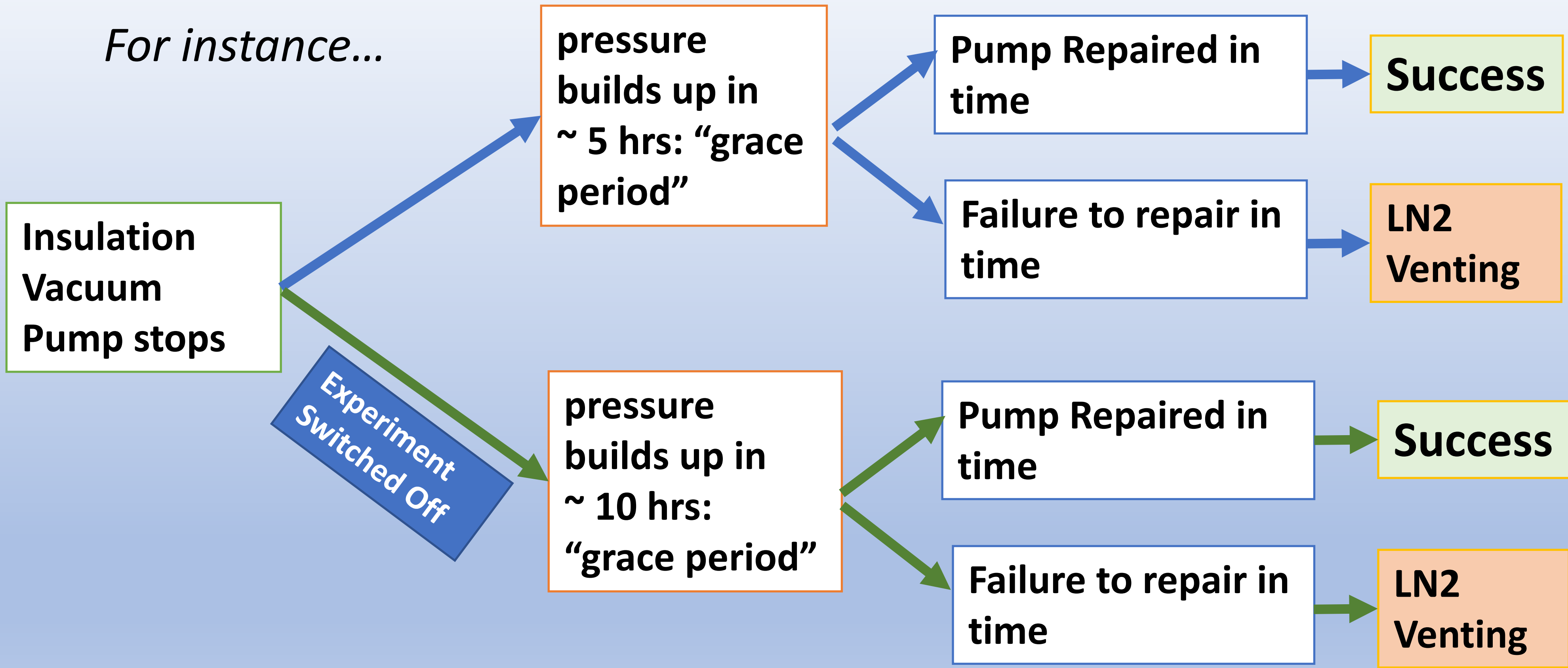
e.g.: Sequences #2 & #5 are accident sequences, as they involve failure of the SWCS pump with failure to recover it within the available time. Sequences #3 & #6 involve Ar release in the tank cavern since PS6 has failed. Similar accident sequences #8 & #11 and #9 & #12 are calculated for shorter grace period since the Instrumentation is left ON.



These are just examples of the kind of analysis to be done...

Of course, for Archimedes Cryostat, the worst accidents are due to a loss of insulation vacuum.

For instance...



Of course, the grace period can vary from days (e.g. pumps stop with solid N2 inside) to minutes, if a gasket fails.

These cases, with the relevant weak points, must be considered, and the related fault trees identified

In this way, we can introduce redundancies and additional safety systems, where required.

In any case, release of LN2 in the cavern must be avoided as much as possible: the venting tunnel is necessary

Even in case of release of LN2 in the closed environment, an emergency status of the air conditioning system can be implemented, to mitigate its effects.

For instance, in the ICARUS experiment at LNGS, air conditioning was designed to pump eventual LAr spills through the floor *(2015 JINST 10 P12004)*

Some experience:

Explorer was in operation from 1983 to 2010: 27 years

It contained ~ 600 l of LN2, refilled manually once every 14 days

In that period, we had only some minor emergencies, due to:

- Pumping system failures
- Electrical power cuts
- o’rings freezing during refill

which were contained with only minor damages

Conclusions

Underground cryogenics safety is challenging, but there is a wide expertise available, e.g., both at CERN and in INFN, that can be accessed.

Excluding really catastrophic (and unlikely) events, the time to reach overpressure could be of minutes, or even hours (to be determined with symulations and a thermodynamical analysis)

A careful analysis of several accident scenarios must be performed, in order to increase reliability and minimize damage and down time.

A venting tunnel to the surface is necessary

END