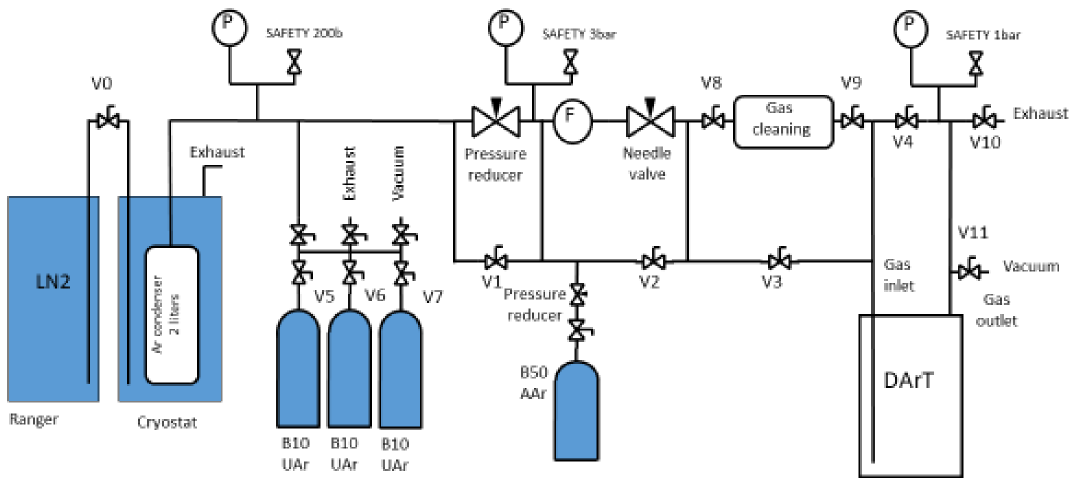
# DArT

# Modus operandi

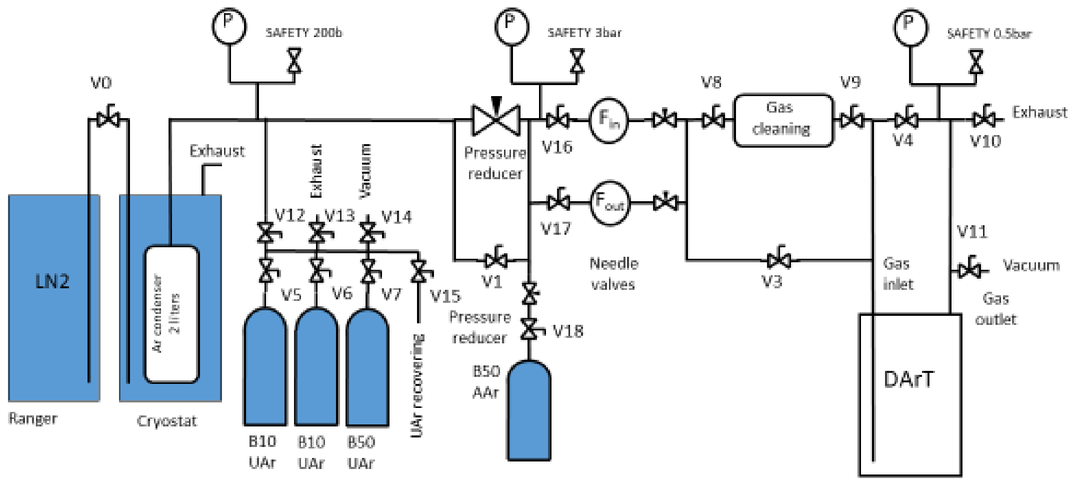
1- Current DArT gas system:




Notes:

1- V2 valve should be eliminated because is a safety issue. It allow an uncontrolled big flow of UAr into DArT vessel which may overrun the ArDM control system.
2- The DArT vessel safety bar should be reduced to 0.5 bar because legal restrictions.
3- It is needed a flow meter/controller on both senses of circulation, for filling and for emptying.
4- On/off valves should be installed in series with the needle valves.
5- A B10 bottle should be substituted for a B50 buffer bottle.
6- A recovering line of UAr should be included.

2- Proposed new DArT gas system:



3- Rest state.

Most of the time the DArT gas system is in a safe rest state. Only when filling or emptying DArT the gas system changes its default settings.

In this state all the valves are closed and all the pressures are near to atmospheric pressure.

4- Filling state.

   a. Filling considerations.

DArT is filled by condensing the gaseous argon in the walls of the vessel (5mm) and of the copper pipes (1mm). The external side of both, vessel and pipes, is maintained at a fixed temperature by the ArDM LAr bath. It is at the equilibrium temperature of LAr at atmospheric plus hydrostatic pressure. The internal side is at the equilibrium temperature at a pressure P slightly bigger that the one of ArDM. There is a temperature gradient across the walls and, consequently, a transfer of heat.

The limiting factor for filling DArT is the ability of ArDM to dissipate the condensing heat to the cryocoolers. The dissipated heat is limited to 20W.

The filling rate is stablished by the inflow meter/controller.

The heat of vaporization of LAr is 6.53KJ/mol and the molar heat capacity is 20.85 J/(mol.K), see wikipedia. Therefore to liquefy a mol of room temperature argon (40g) it is needed 4.17 + 6.53 = 10 KJ/mol. The maximum input flow of argon is 20W/(10 KJ/mol) = 0.002 mol/s = 0.04 l/s of gaseous argon at room temperature.

The LAr volume of DArT is 1,577 liters, so the LAr mass is 2,2 Kg (55 mol) and the minimum time to fill DArT is 7,6 hours.

During the filling process, the pressure inside DArT is automatically set in such a way that the transfer of heat across the walls equals the condensing heat rate. This pressure reaches its maximum value when the wall surface exposed to the UAr gas is minimum. This happen when DArT is full, then only the top copper pipes are exposed to gas, totalizing 180 $cm^2$ with a wall thickness of 1 mm. Then the temperature gradient needed to extract 20W through the walls is given by:

The thermal conductivity of copper is:

## Curve of equilibrium gas/liquid in argon.

- https://encyclopedia.airliquide.com/argon


The temperature difference of 2,7 mK correspond to a differential pressure of roughly 0,3 mbar that is negligible.

b. Filling procedure

Let assume that initially all the valves are closed, both DArT and ArDM systems are in stable conditions, the LN2 supply (V0) is shut and the argon condenser is warm. All pressures are near atmospheric.

1- Installation of a fresh UAr bottle.
   a. Install the bottle in V5.
   b. Check that V12 is closed.
   c. Open V5 and then close it to pressurize the line.
   d. Open V13 and then close it to purge the line
   e. Repeat steps c and d several times to clean the line from oxygen.
   f. Leave V5 open and V12 closed.
2- Gas system purge of old gas.
   a. Set vacuum pump on.
   b. Open valves V11, V4, V3, V16, V17 and V1.
   c. Set inflow controller at maximum.
   d. Wait until pressure drops.
   e. Close V11, V4, V3, V16, V17 and V1.
   f. Set inflow controller at zero.
   g. Set vacuum pump off.
3- Pressurize the high pressure section.
   a. Check that V1 is closed and V5 open.
   b. Open V12.
   c. Check high pressure.
   d. Check medium pressure.
   e. Adjust pressure reducer setting if needed.

4- Proceed to fill.
    a. Check that V3, V4, V10 and V11 are closed.
    b. Open V8, V9 and V16.
    c. Set the inflow controller to working value of 160 l/hour.
    d. Check the value of the inflow meter.
5- Filling.
    a. Check continuously the top level sensors while DArT is not full.
6- Stop filling.
    a. Set the inflow controller to zero.
    b. Close V8, V9 and V16.
    c. Close V12 and V5.
7- Restore rest state
    a. Check that V15 is closed
    b. Open V13 if needed.
    c. Close V12.

5- UAr emptying
    a. UAr emptying considerations.

To empty DArT we force the evaporation of liquid UAr and its condensation it a refrigerated volume away from DArT. In a second step we will transfer the gaseous UAr to a storage reservoir.

The evaporation of the DArT UAr cannot be done by applying only vacuum, since the evaporation would be carried out on the free surface of the liquid argon which is thermally isolated from the walls of DArT, due to the low conductivity of the LAr. Therefore, in addition to applying vacuum, it is necessary to inject the necessary heat for the evaporation of the UAr. This is done by means of platinum resistors (RPT) located in the bottom of the DArT vessel.

An external condensing deposit is immersed in a Dewar filled of liquid nitrogen (77K). At this temperature the vapor pressure of the solid argon is 260 mbar. It is not desirable to directly apply this low vacuum to DArT, since, being below the pressure of its triple point (687 mbar), the argon would be frozen in DArT, preventing its extraction. Controlling the flow of gaseous argon from DArT to the condenser allows to maintain the DArT pressure above the argon triple point. The slow control should keep this pressure in the middle of the triple point pressure and the ArDM equilibrium pressure.

A RPT driver circuit is used that prevent the RPT to overcome its maximum temperature when the DArT liquid argon is exhausted. There are 4 RPTs which dissipates 3.5 W each. So the total 14 W evaporates the 55 mol of DArT in:

The flow being transferred from DArT to the condenser is 173 l/hour.

It should be noted that only the molar vaporization heat have been considered. That is because the gas being extracted from DArT is still cold. It should be heated along its way through the pipes connecting DArT and the gas system. If needed, a heating resistive strap can wrap the connecting pipe.

b. Emptying procedure

Let assume that initially the system is at rest state.

2- Start the system for emptying
    a. Open valves V0, V1, V17, V3 and V4.
    b. Start heating RPT drives.
    c. Start slow control procedure for emptying.
3- Wait for DArT empty.
    a. Check the DArT pressure while is over the triple point pressure.
4- Set the system for recover.
    a. Check that the RPT are inactive.
    b. Close V0, V1, V17, V3 and V4.
    c. Open V12 and V15.
5- Recover the UAr.
    a. Let the condensing deposit to warm.
    b. Close V15
6- Restore DArT pressure.
    a. Open V1, V16 and V3
    b. Check the pressure of DArT
    c. Close V1, V16 and V3.
7- Restore rest state
    a. Check that V15 is closed
    b. Open V13 if needed.
    c. Close V12.

6- Slow control specific procedures.

To enhance the safety some of the abovementioned steps should be done in semiautomatic mode, with the slow control program assuring the correct state of some critical valves.

7- Safety considerations

During the life of DArT, accidents can always occur, either due to operating errors or due to a break in a component. Given that DArT is a relatively simple system, it is possible to enumerate the cases in which the parameters of DArT change in a dangerous way and to discuss both if such cases are possible and how to prevent them.

There are two levels of accident prevention. The hardware level provides ultimate protection embedded in the system. At the same time slow control acts on the system providing protection at a lower level.

The design should take care of the interaction of DArT with ArDM. This is a critical aspect of the safety design due to the large mass of LAr stored in ArDM. ArDM and DArT are physically separated by the DArT wall. The only way in which they can interact is the transfer of heat through the copper wall. According to ArDM experts, the maximum amount of power that ArDM can safely dissipate is limited to 20 W. This should be understand as an operational value. In case of exceptional dysfunction, this maximum dissipated power has been taken to be 30 W.

The gas system has been divided into three sections, high, medium and low pressure, to undertake the study of its safety.

a- High pressure section.

This section of the gas system is made of elements suitable for high pressure. Safety is subject to the appropriate industrial regulations for this type of installation. The weakest point is the condensation reservoir, it is limited to a working pressure of 125 bar.

The only parameter to worry about is the gas pressure. This section is protected with two rupture valves recommended by the condensation tank manufacturer. These rupture valves are set to a breaking pressure of 170 to 200 bar. In addition, the slow control should be triggered at a pressure of 140 bars to allow the release of exceeding pressure through valves V12 and V13.

In case of a catastrophic failure, the amount of suffocating argon gas released to the cavern is limited to 70 liters at 200 bars. This is 14 $m^3$ of room temperature gas that is diluted in the 7200 $m^3$ volume of the cavern. The resulting decrement in the oxygen concentration (0.2%) is not a safety concern.

b- Medium pressure section

This section of the gas system establishes the gas flow that enters the DArT and, in turn, determines the power supplied to ArDM through the cooling and condensation of the UAr. As shown before, the flow corresponding to 30 W is 0.06 liters / s equivalent to 216 liters / hour, which is the maximum allowable flow.

This maximum flow is imposed by:

1- A strangulation (needle valve) in the entry line of UAr.
2- Limiting the pressure on the entry line of UAr
3- A non-return valve on the UAr output line.

Test should be done to set the trigger value of the safety pressure valve and the setting of the needle valve. Provisions should be made in order to prevent any change in this settings.

Outgoing gas flow when emptying DArT has no safety impact.

c- Low pressure section

This section is over pressure protected with 2 hardware rupture valves with a setting point of 0.5 bar above atmospheric pressure. Additionally a resort valve limit the overpressure to 0.3 bars. The slow control also limit the overpressure to 0.2 bar by opening valve V10.

A possible safety worry is the amount of heat injected into DArT when emptying. This heat is limited by a slow blow in the output of the 24v RPT power supply. Current is limited to 1.2 amperes and power to 28.8 watt.