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HELIUM DISCHARGE AND DISPERSION IN THE LHC ACCELERATOR TUNNEL IN CASE OF CRYOGENIC FAILURE

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Abstract

The Large Hadron Collider (LHC), presently under construction at CERN, will contain about 100 tonnes of helium, mostly located in the underground tunnel and caverns [1]. Potential failure modes of the accelerator, which may be followed by helium discharge to the tunnel, have been identified and the corresponding helium flows calculated. The paper presents the analysis of the helium discharge in the worst case of conditions, as well as the corresponding helium dispersion along the tunnel. The variation of oxygen concentration has been calculated and the oxygen deficiency hazard (ODH) analysed. The preventive means of protection, namely location and sizing of safety valves are also discussed.

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Helium Discharge and Dispersion in the LHC Accelerator Tunnel in case of Cryogenic Failure

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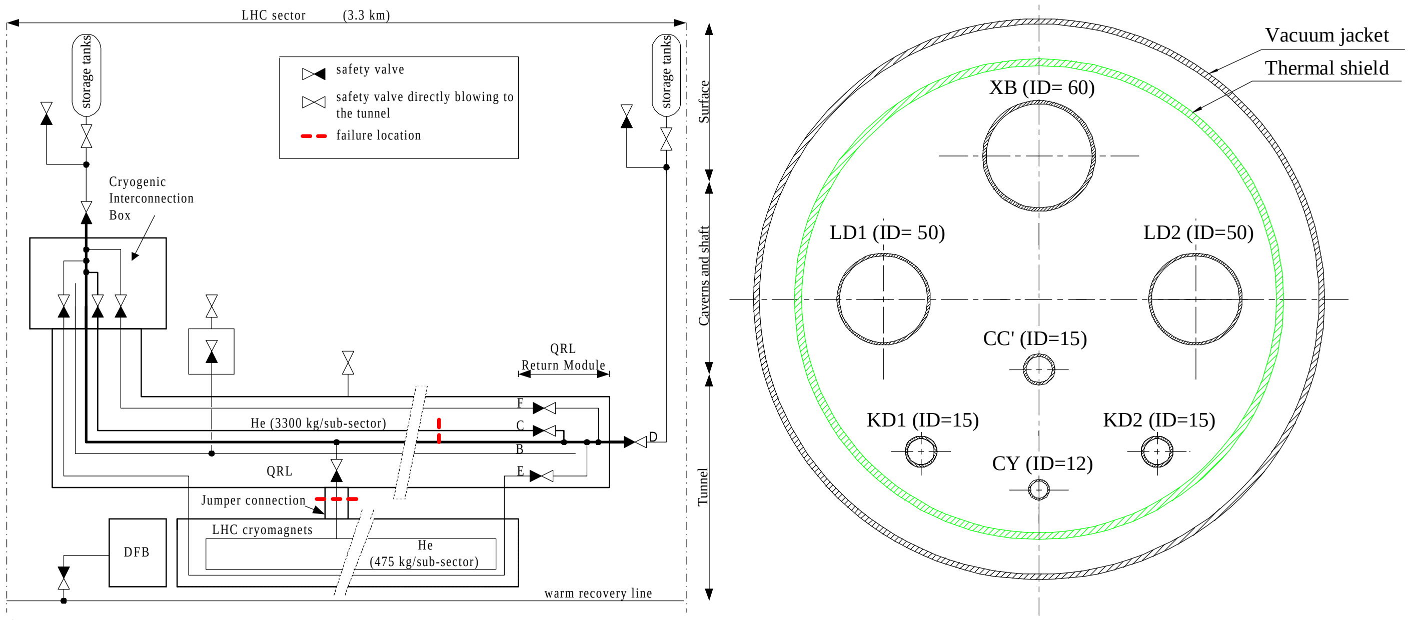
The Large Hadron Collider (LHC), presently under construction at CERN, will contain about 100 tonnes of helium, mostly located in the underground tunnel and caverns [1]. Potential failure modes of the accelerator, which may be followed by helium discharge to the tunnel, have been identified and the corresponding helium flows calculated. The paper presents the analysis of the helium discharge in the worst case of conditions, as well as the corresponding helium dispersion along the tunnel. The variation of oxygen concentration has been calculated and the oxygen deficiency hazard (ODH) analysed. The preventive means of protection, namely location and sizing of safety valves are also discussed.

1 INTRODUCTION

The LHC cryogenic system is based on a five-point scheme with eight refrigeration plants serving the eight sectors of the accelerator. Helium is supplied to the LHC cryomagnets from the Cryogenic Distribution Line (QRL) via so-called jumper connections. The simplified flow-scheme of a LHC sector is shown in Figure 1. The highest amount of helium is located in the magnet cold mass (1.9 K, 0.13 MPa) and in the QRL header C (4.6 K, 0.36 MPa). Two failure modes leading to the worst case scenario with respect to the helium discharge into the tunnel have been identified [2]. They are listed in Table 1, where their probability of occurrence is also given as well as the sequence of events. The failure mode evolution is schematically shown in Figure 2.

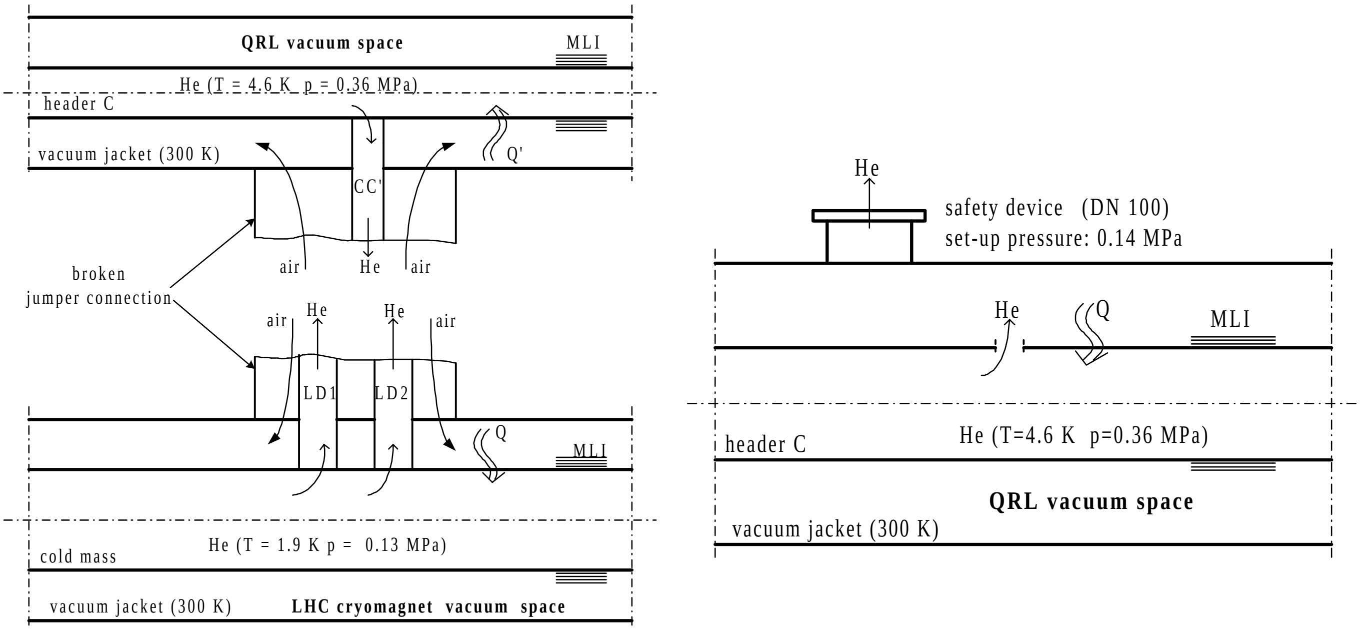
Failure	Probability [2]	Sequence of events
Break of jumper connection (see Figure 2a)	E (improbable: probability of occurrence cannot be distinguished from zero)	- air flows to the insulation vacuum space - heat flows to the helium in cold mass and header C - helium discharges to the tunnel through pipes LD1 and LD2 from cold mass, and through pipe CC' from header C (maximum amount of helium relieved 4250 kg)
Break of header C (see Figure 2b)	D (remote: unlikely to occur in life-cycle, but possible)	- helium flows to the insulation vacuum - heat flows to the helium in header C - pressure builds up in QRL vacuum space - safety device opens at 0.14 MPa and helium flows into the tunnel (max. total amount of helium relieved 3300 kg)

Table 1 Worst case scenario of helium discharge into the LHC tunnel



a) b)

Figure 1 Simplified flow-scheme of a LHC sector (a) and typical jumper connection cross-section (b)



a) b)

Figure 2 Conceptual scheme of a jumper connection (a) and header C (b) rupture

2 HELIUM DISCHARGE INTO THE TUNNEL

For the purpose of this analysis, the spatial variations of helium pressure and temperature in helium enclosure have been neglected and the lumped parameter approach has been applied. As a consequence, the energy balance (eq. 1) and the equation of state [3] are sufficient to describe the helium discharge to the tunnel:

$$dU = dQ - pdV + \sum_i h_i dM \qquad (1)$$

where: U is the internal energy [J], Q the heat input into the system [J], p the helium pressure [Pa], V the volume of helium enclosure [m^3], h the enthalpy [J/kg] and M the mass of helium [kg].

The heat flux to the helium, following the degradation of the insulation vacuum due to air, is about 0.5 W/cm^2 [4]. For a temperature of the header below 80 K, liquefaction (and eventually solidification) of the air occurs. For the header wall temperature above 80 K, the heat flux drops to 0.03 W/cm^2. For the degradation of the insulation vacuum by helium, no change of phase occurs and a heat flux of 0.03 W/cm^2 is assumed. These assumptions are conservative and, as a consequence, the estimation of the helium discharge into the tunnel represents an upper limit for the real discharge. The boundary conditions of helium for the failures, named in Table 1, are given in Table 2. The calculated helium discharges to the tunnel are shown in Figure 3. Considering break of a jumper connection, the initial discharge from the magnet cold mass is responsible for the peak of about 28 kg/s. After 0.5 min, the helium still remaining in high quantity in header C discharges at an almost constant rate of approximately 2 kg/s. In case the header C breaks, the pressure in the QRL vacuum space will first build up to open the safety device and after about 2.4 min helium starts to discharge to the tunnel. The safety device protecting the QRL vacuum jacket has been sized to discharge a peak mass flow-rate of 3 kg/s. To keep the longitudinal pressure drop within acceptable values (5 kPa), at least one safety device has to be implemented in between two jumper connections (106.9 m).

PARAMETER	Cold mass	Header C	QRL vacuum jacket
Pressure [MPa]	0.13	0.36	10^{-10}
Temperature [K]	1.9	4.6	---
Helium sub-sectorization [m]	214	3300	---
Vacuum sub-sectorization [m]	214	428	428
Helium mass per sub-sector [kg]	475	3300	---
Volume per sub-sector [m^3]	3.21	26	88.04
Diameter [m]	0.58	0.1	0.61
Area of heat transfer [m^2]	389.93	134.46	820.20

Table 2 Boundary conditions for the estimation of helium discharge into the tunnel

3 OXYGEN DEFICIENCY HAZARD

The helium discharge into the tunnel can cause an oxygen deficiency hazard. Considering the helium discharge, following the break of jumper connection or the break of header C, and the flow-rate of ventilated air (22500 m^3/h), the oxygen concentrations in the tunnel near the place of incident (see figure 4a) have been estimated. Because of turbulent flow of gases, an ideal mixing process and a homogenous composition in the whole tunnel cross-section was assumed. Helium discharge from the system can also be dangerous due to its low temperature. The mixing temperature of air and helium near helium discharge has been calculated from the energy balance:

$$M_{air} \cdot C_{p,air} \cdot (T_{air} - T_{mix}) - M_{He} \cdot C_{p,He} \cdot (T_{mix} - T_{He}) + M_{air} \cdot L \cdot x = 0 \tag{2}$$

where: T is the temperature [K], Cp the specific heat [J/kg*K], M the mass [kg], L the latent heat of vaporisation [J/kg] and x a multiplication factor due to air condensation.

Taking into account the helium discharges into the tunnel, as shown in Figure 3, the corresponding temperature evolutions near the helium discharge point were also estimated (Figure 4b). One can notice that due to the very low temperature of helium, the mixing temperature decreases rapidly and air condensation is possible. Heat is exchanged between the concrete tunnel wall and the air at about 80 K, which causes the condensed air to re-evaporise. The factor x in equation 2 takes into account this phenomenon. For mixing temperatures above 80 K, x results to be equal to zero and condensation does not occur.

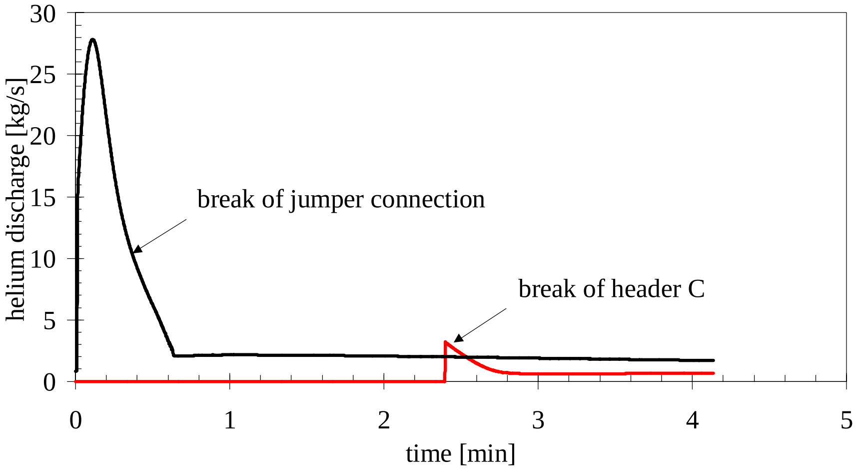
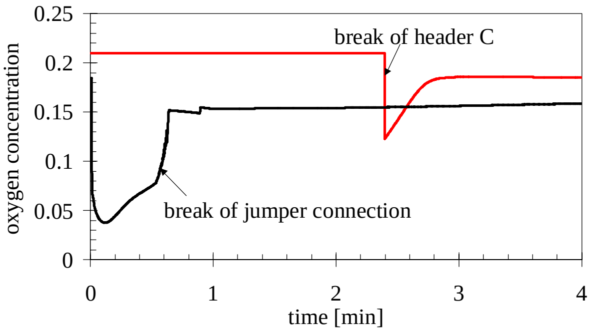
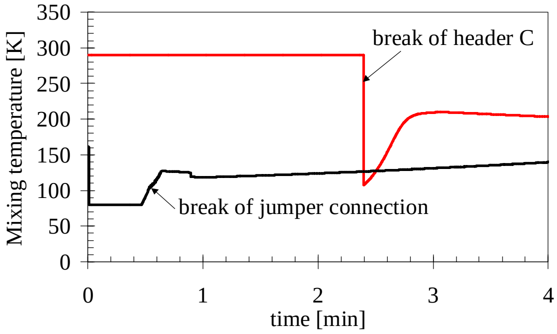


Figure 3 Helium discharge into the tunnel following break of jumper connection and header C



a)



b)

4 CONCLUSIONS

Two failure modes of the LHC cryogenic system, followed by the highest amount of helium discharged into the tunnel, have been analysed: full break of a jumper connection and break of header C. While the probability of a break of jumper connection cannot be distinguished from zero, that for break of header C is remote (unlikely to occur, but possible). In case of break of header C, the peak mass flow-rate will be about 3 kg/s. Taking into account an ideal mixing process, the oxygen content in the LHC tunnel atmosphere could drop below 19 %, and consequently cause asphyxiation hazards. The installation of oxygen deficiency meters and respirators in the LHC tunnel is therefore recommended. To verify the analytical calculations of helium dispersion in the tunnel and to provide a background for the specification of oxygen deficiency monitoring and a protecting system in the LHC tunnel, an experimental verification is proposed.

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