DFX safety aspects in the LHC tunnel

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Event, date

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Safety at CERN (https://hse.cern/content/safety-rules)

- Electrical Safety Code C1 (EDMS 335725)
- GENERAL SAFETY INSTRUCTION GSI-M-4 – Cryogenic Equipment (EDMS 1327191)
  - "Cryogenic equipment liable to have major safety implications" because of "high-level hazard for people, the environment or other installations in the event of failure"
- Safety Guideline SG-M-4-0-1
- Requested compliance with European Directives:
  - Pressure Equipment Directive 2014/68/EU where relevant

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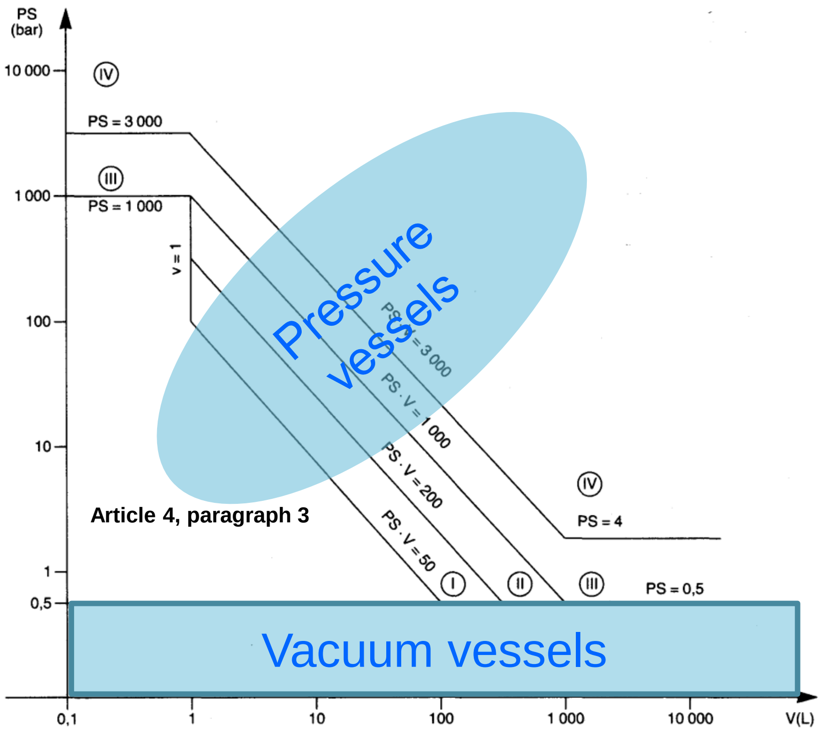
Pressure vessel codes regulations

- Pressure European Directive 2014/68/EC (PED) is a legal obligation in the EU since 2002 and CERN's Safety Unit (HSE) requests to comply with it:
  - Applies to internal pressure **≥ 0.5 bar gauge**
  - Vessels must be designed, fabricated and tested according to the requirements defined
  - Establishes the conformity assessment procedure depending on the vessel category, which depends on the stored energy, expressed as Pressure x Volume in bar.l

- → CE marking and notified body required from and above cat II



For vessels with non-dangerous gases, Group 2, (cryogenic liquids are treated as gas)

Category	Conf. assessment module	Comment
SEP	None	The equipment must be designed and manufactured in accordance with sound engineering practice. No CE marking and no involvement of notified body.
I	A	CE marking with no notified body involvement, self-certifying.
II	A1	The notified body will perform unexpected visits and monitor final assessment.
III	B1+F	The notified body is required to approve the design, examine and test the vessel.
IV	G	Even further involvement of the notified body.

Harmonised codes and standards

- Harmonised standards give presumption of conformity with the PED, within their scope. Useful codes for cryostat design and fabrication, including safety devices:

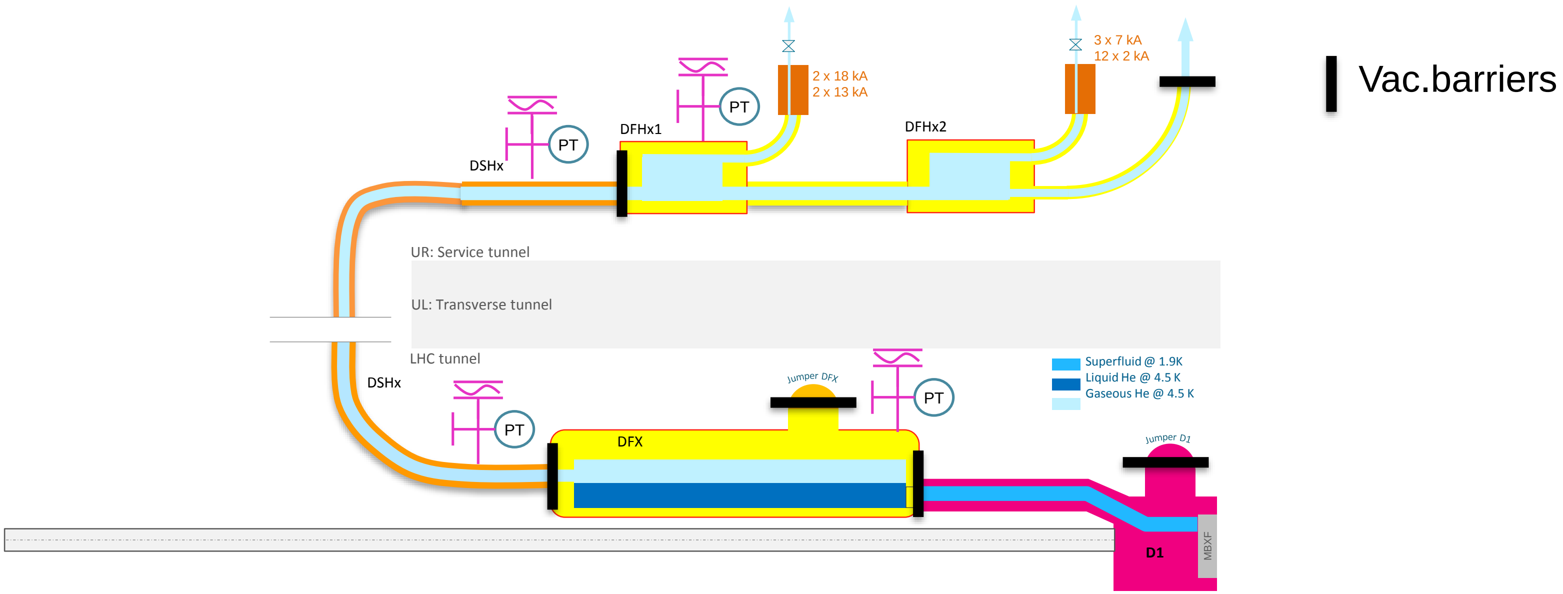
Standard	Title
EN 764-5	Pressure equipment – Part 5: compliance and inspection documentation of materials
EN 764-7	Pressure equipment – Part 7: safety systems for unfired pressure vessels
EN 1251	Cryogenic vessels – Transportable vacuum insulated vessels of not more than 1000 litres volume
EN 1252	Cryogenic vessels – Materials
EN 1626	Cryogenic vessels – Valves for cryogenic service
EN 1797	Cryogenic vessels – Gas/material compatibility
EN 12213	Cryogenic vessels – Methods for performance evaluation of thermal insulation
EN 12300	Cryogenic vessels – Cleanliness for cryogenic service
EN 12434	Cryogenic vessels – Cryogenic flexible hoses
EN 13371	Cryogenic vessels – Couplings for cryogenic service
EN 13445	Unfired pressure vessels
EN 13458	Cryogenic vessels – Static vacuum insulated vessels
EN 13480	Metallic industrial piping
EN 13530	Cryogenic vessels – Large transportable vacuum insulated vessels
EN 13648	Cryogenic vessels – Safety devices for protection against excessive pressure
EN 14197	Cryogenic vessels – Static non-vacuum insulated vessels
EN 14398	Cryogenic vessels – Large transportable non-vacuum insulated vessels
EN 14917	Metal bellows expansion joints for pressure applications
EN ISO 4126	Safety devices for protection against excessive pressure

→ Now replaced by ISO 21013-3

Very useful guidelines and design rules to be used!

Insulation vacuum volumes

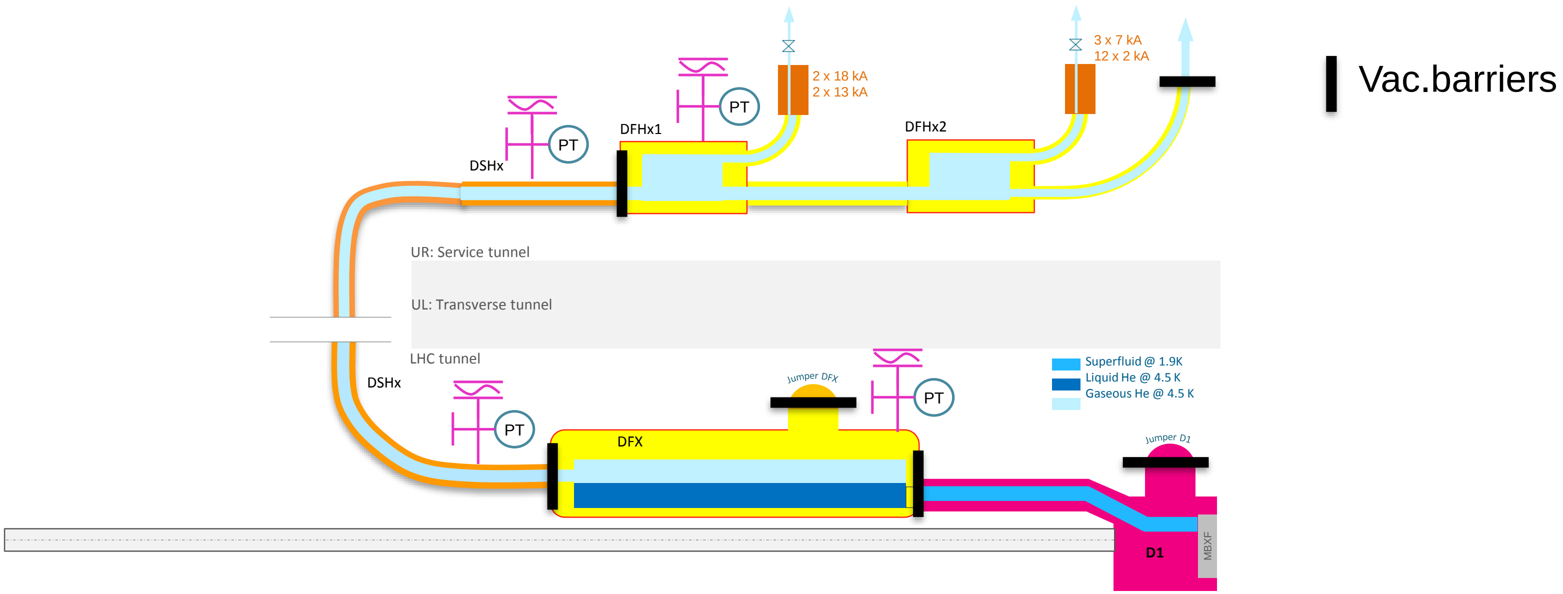
- 4 independent insulation vacuum per cold powering chain
- Each equipped with pressure gauge, pumping port (static), pressure relief plate



Item	Volume [m3]	Remark
DFX		
DSHx		
DFHx1		
DFHx2		
DFH flex.line		

Helium volumes

- 4 independent insulation vacuum per cold powering chain
- Each equipped with pressure gauge, pumping port (static), pressure relief plate



Item	Volume [m3]	Remark
DFX		
DSHx		
DFHx1		
DFHx2		
DFH flex.line		

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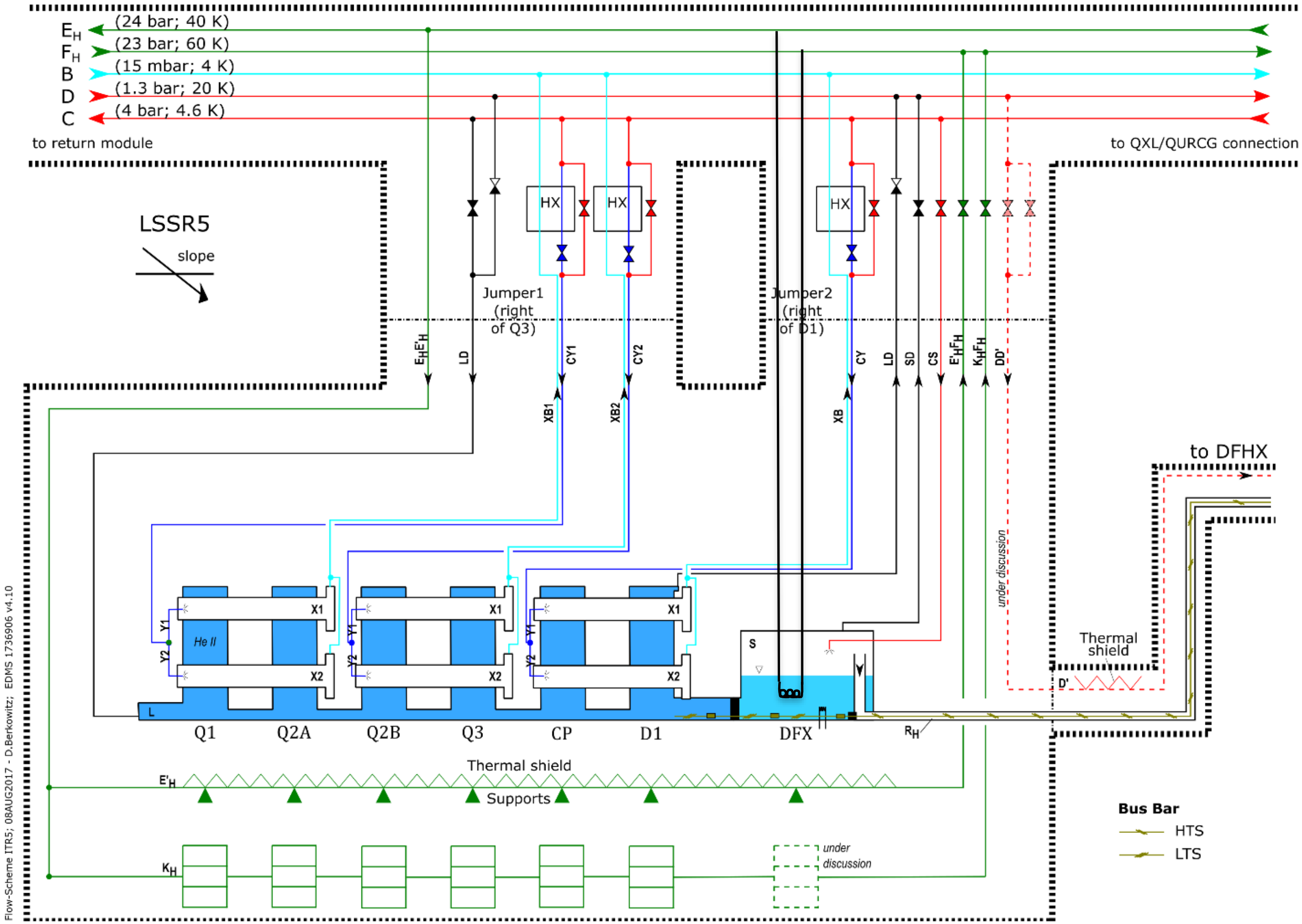
Cryogenic scheme (EDMS1736906)



Cryogenic boiler circuit not yet included (recently added)

DFX specification (EDMS1905633)

Table 2: Cryogenic parameters and equipment design pressures [9]

Description	Ref:	Inlet outlet	DN [mm]	Fluid	Nominal pressure [bara]	Design pressure [bara]	Temperature range [K]
Inlet Liquid helium	CS	From line C	DN12 TBC	Mix liquid-gas helium	1.3	3.5	[4.5;300]
Return gas helium for transient phases	SD	To line D	DN40 TBC	Gaseous helium	1.3	3.5	[4.5;300]
DFX helium volume	S	From line CS To DSHx	TBD	Saturated liquid helium bath	1.3	3.5	[4.5;300]
Outlet thermal shield	E'_HF_{H2}	From D1 side To DFX jumper	TBD	Gaseous helium	24	25	[60;300]
Inlet coil warm up	TBD	From E'_HF_H	DN4	Gaseous helium	24	25	[40;300]
Outlet coil warm up	TBD	To jumper	DN4	Gaseous helium	24	25	[40;300]

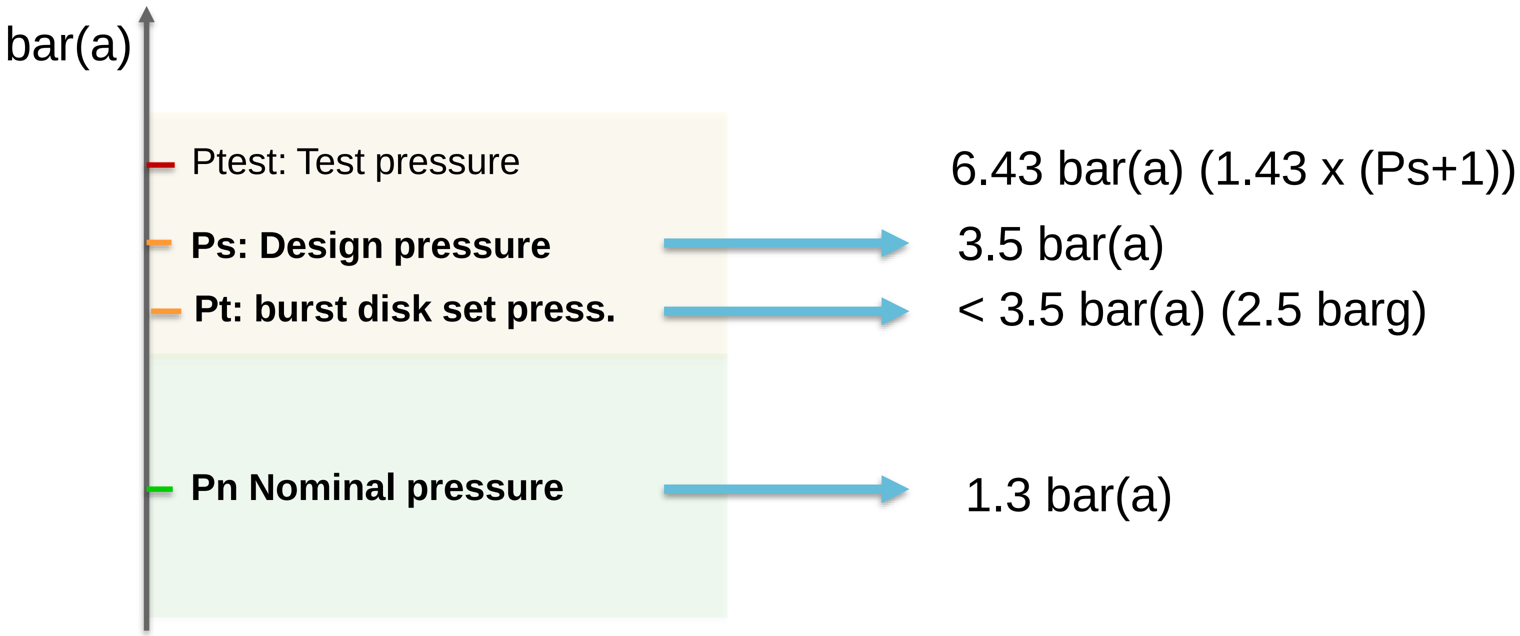
DFX Schematic

DFX volumes and cold surfaces

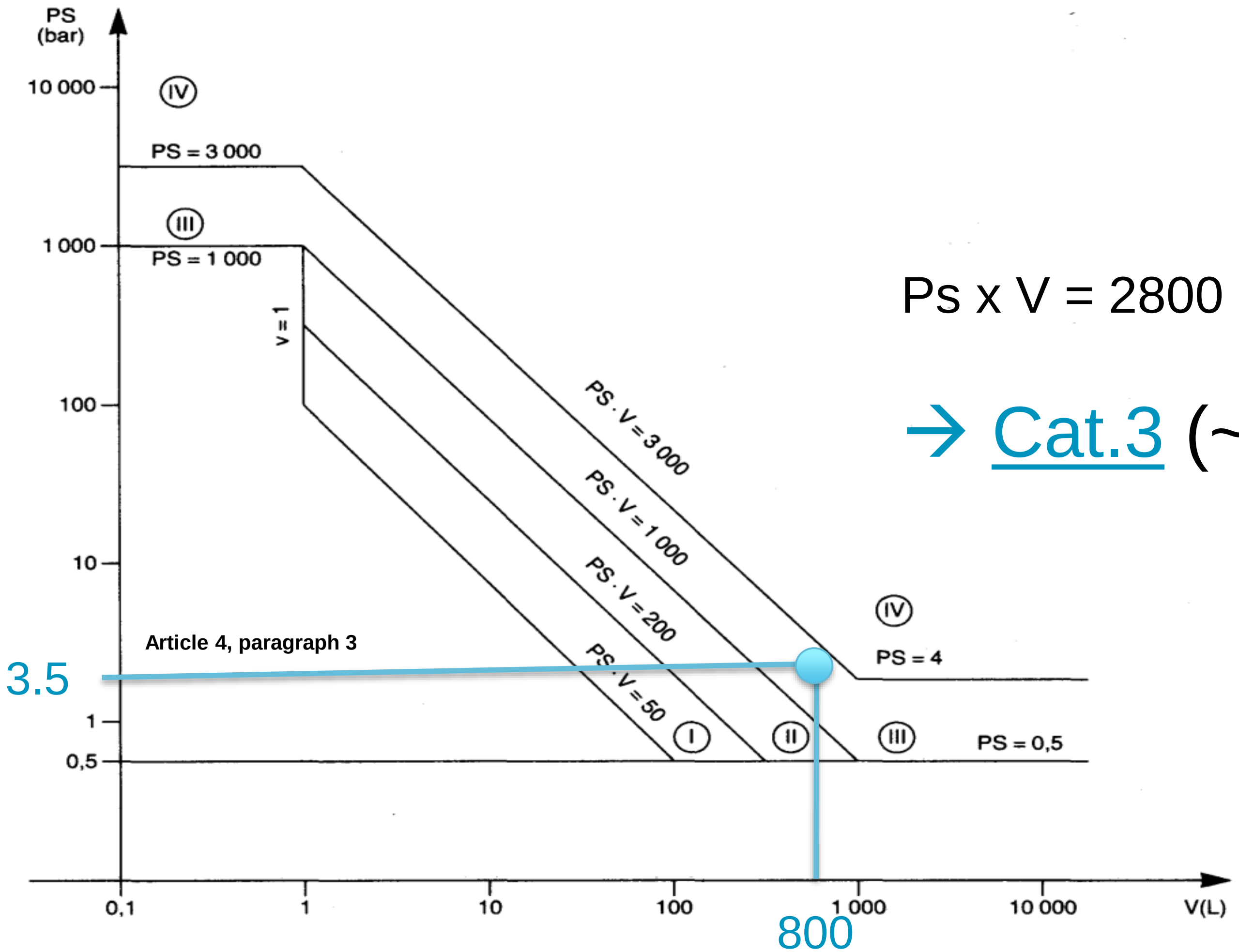
Volumes and surface areas		Units
DFX Horizontal Section	568	Litres
DFX Vertical Section	212	Litres
DFX Total Liquid Volume	**780**	Litres
DFX Vapour Helium Volume (at nominal conditions)	21	Litres
DFX Vacuum Volume (between Plug to Vacuum Break in DFX Vertical)	1292	Litres
DFX Cold Surface Area (Plug side to vacuum barrier)	7.6	m^2
DFX Cold Surface Area (SC Link side to vacuum barrier)	1.2	m^2

(W.Bailey, SOTON)

Scale of pressures



PED category



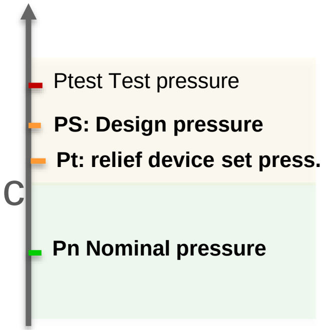
Ps x V = 2800 bar.L

→ Cat.3 (~4)

The pressure safety design process

- Identify all circuit/enclosed volume(s) for the cryostat to be protected *(as a minimum vacuum and helium vessels)*

- Build the scale of pressures. As a minimum:
  - Nominal operating pressure (Pn), related to the operation of the device
  - Design Pressure (PS), related to mechanical limits (e.g. cavity plastic limits) or to operational scenarios (e.g. magnet quench)
  - Set pressure (Pt) of the relief device < PS
  - Test pressure (Ptest) depending on the norms



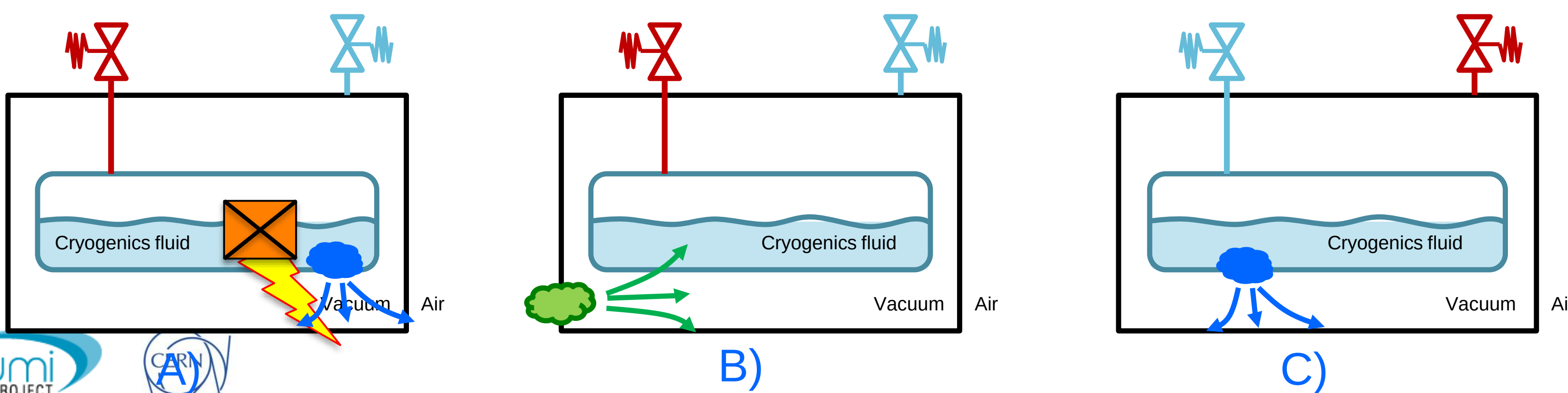
- Make risk hazard analysis & mitigation measure:
  - Risk matrix: risks, likelihood vs. severity
  - Identify mitigation measures (e.g. protections of exposed bellows)
  - Identify the credible worst-case scenario

- Design the safety relief system according to the worst-case
  - The safety relief system must be designed to keep pressure rise within the limits of the Design Pressure (PS)
  - Sizing of devices according to EN 13648-3 and ISO412

Risk assessment matrix

Retained pressure hazards

- A) Heating/vaporization of cryogens from sudden release of stored energy in SC device from arcing
- B) Accidental air venting of insulation vacuum with sudden condensation on cold surfaces, helium boil-off and pressure build-up
- C) Accidental release of cryogenic fluid to higher T surfaces (thermal shield and vacuum vessel), and consequent pressure increase and increased of conduction/convection heat loads to cold surfaces
- D) Brake of lambda plug(s)…

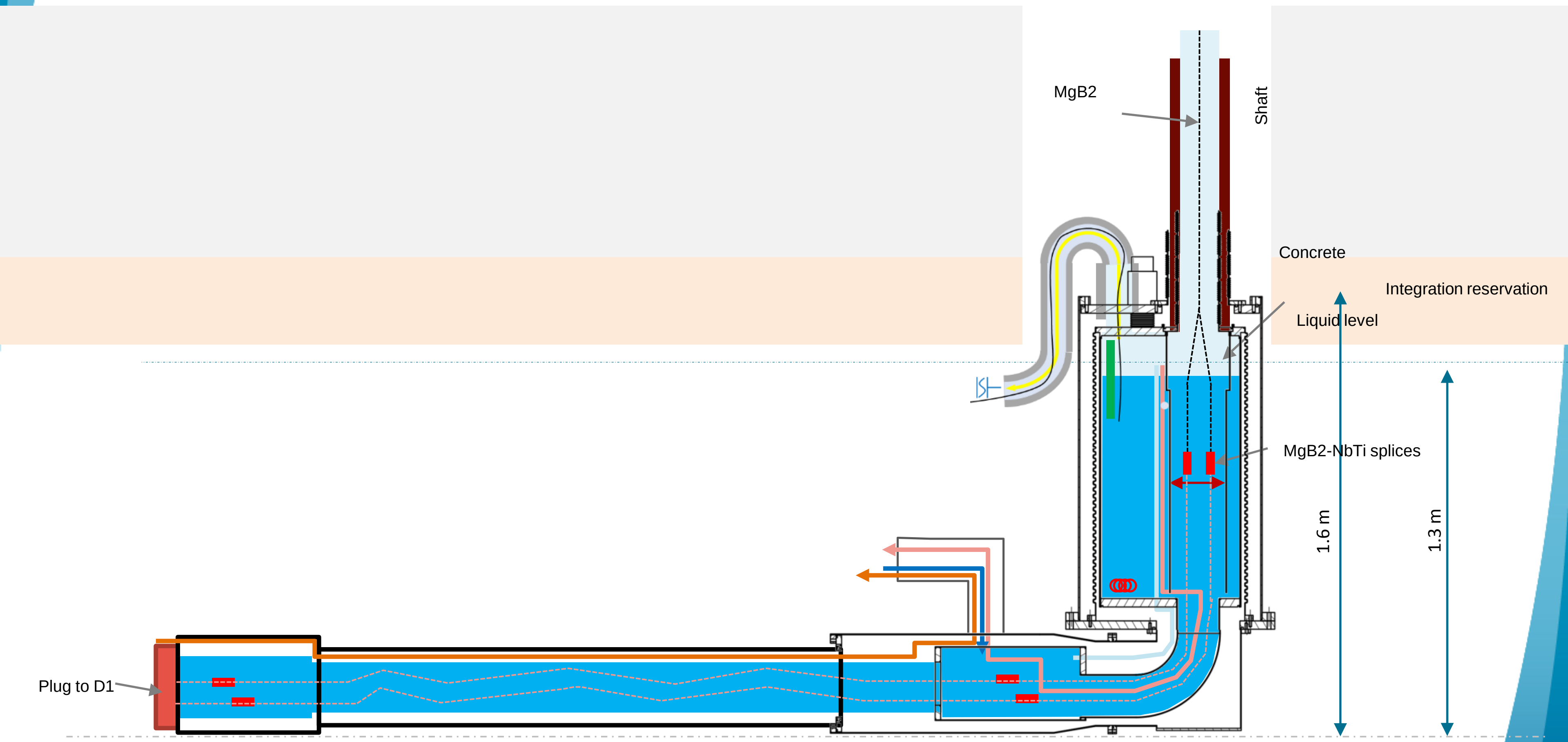


Safety devices: preliminary sizing

- Bust disc for helium reservoir
  - ~ DN ? burst disk + rated valve

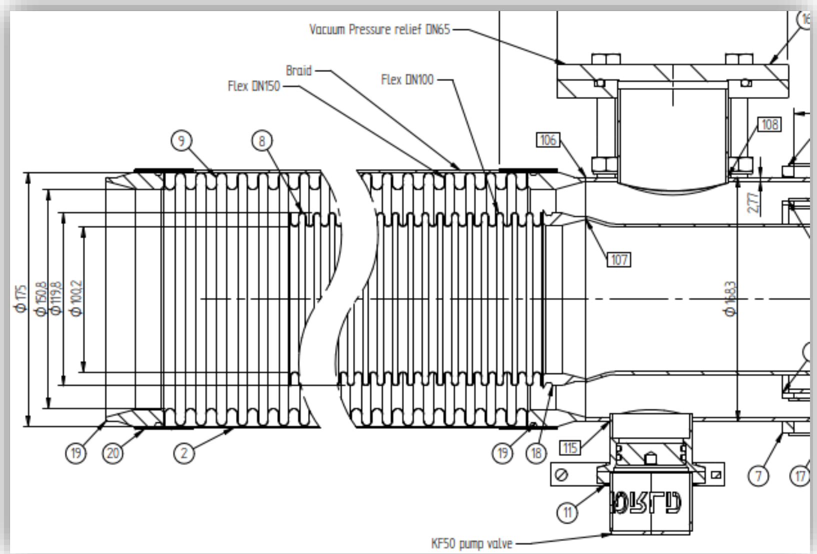
- Relief plates for vacuum vessel
  - DN 150-200 (TBC)

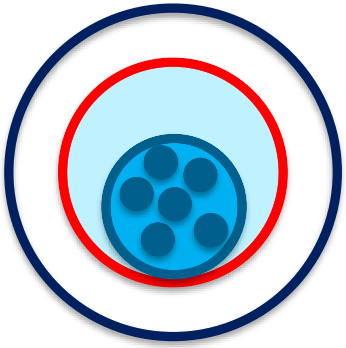
Summary

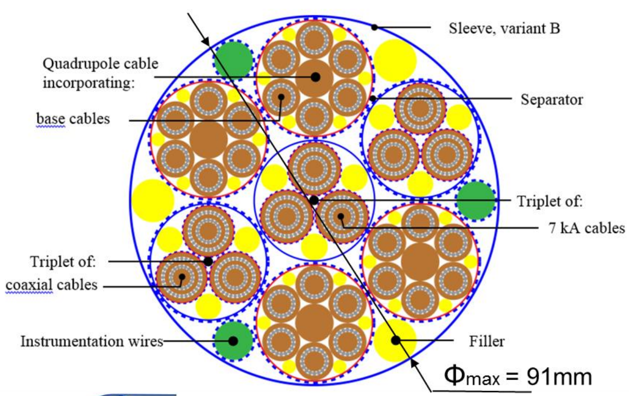


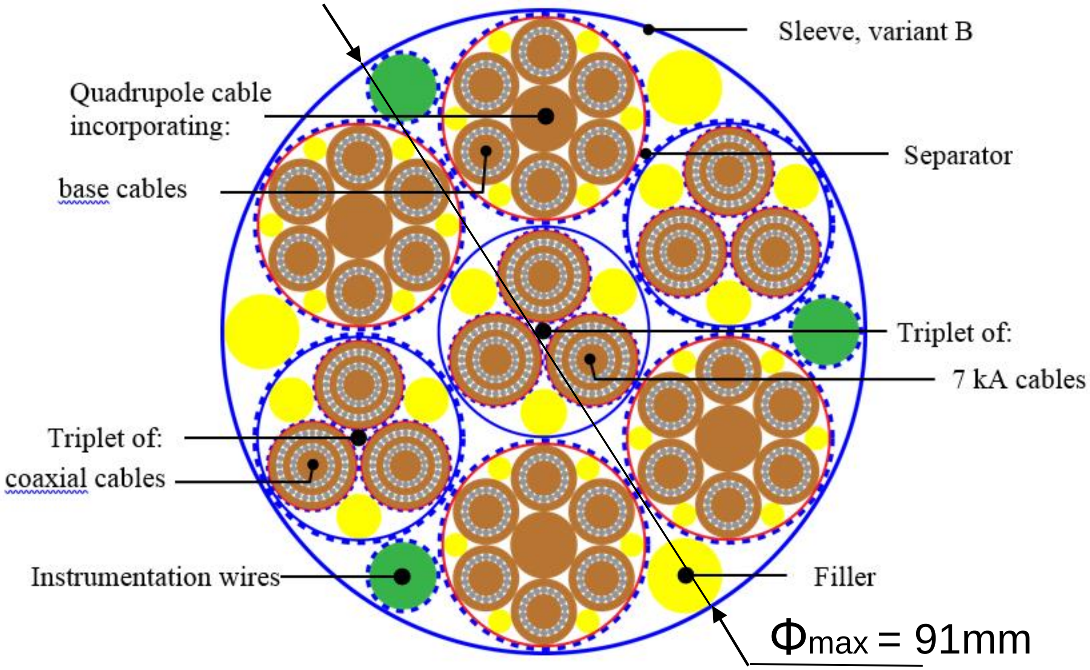
MgB2
Shaft
Concrete
Integration reservation
Liquid level
MgB2-NbTi splices
1.6 m
1.3 m
Plug to D1

DSH cross section








Sleeve, variant B
Quadrupole cable incorporating:
base cables
Separator
Triplet of:
7 kA cables
Triplet of:
coaxial cables
Instrumentation wires
Filler
Φmax = 91mm