Design and integration of safety equipment and safety aspects in the LHC tunnel
(cryogenic safety only)

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DFX Detailed Design Review, CERN 20 June 2019

Contents

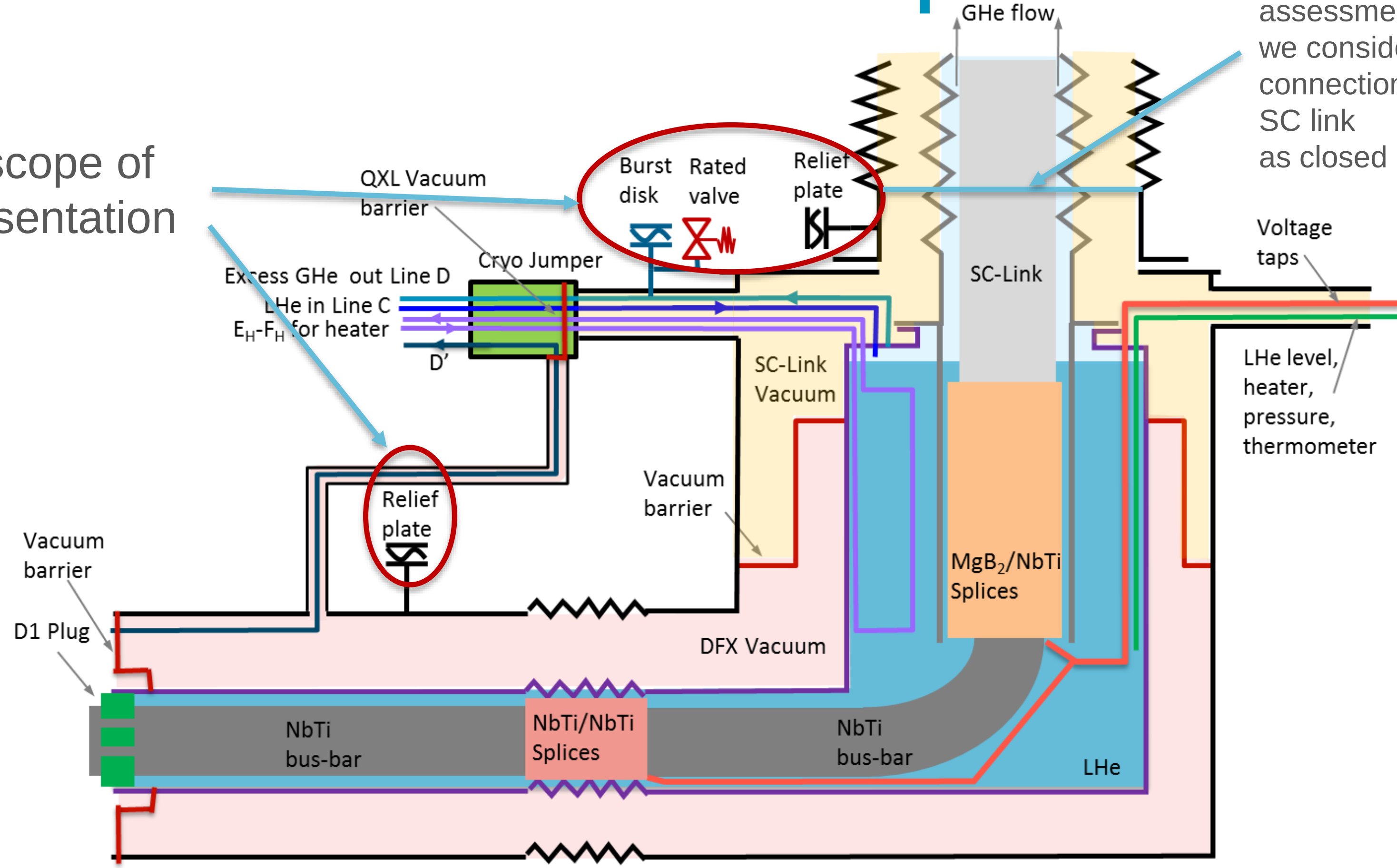
- System description
- Cryogenic safety
  - Updated figures wrt CDR
  - Risk assessment and sizing of safety
- Summary

Disclaimer: the following presents an updating of the cryogenic safety devices only. For more details on safety approach please refer to CDR presentation: https://indico.cern.ch/event/783116/

DFX schematic description

Within scope of this presentation

For the safety assessment we consider this connection to the SC link as closed



Sketch not up to date, only for illustration of volumes and safety devices

DFX Volumes and Cold Surfaces: (update wrt CDR)

Based on Model v3.5.9 (W.Bailey, SOTON)

Volumes and surface areas		Units	(CDR Values)
Horizontal Section - Cold Volume	379	Litres	568
Horizontal Section - Conductor Volume Removed	296	Litres	
Vertical Section - Cold Volume	277	Litres	212
Vertical Section - Conductor Volume Removed	223	Litres	
DFX Total Cold Volume	**656**	Litres	**780**
DFX Total Cold Volume (Conductor Volumes Removed)	519	Litres	
DFX Helium Vapour Space (nominal conditions)	75	Litres	21
DFX Annular Volume (between 2 vacuum barriers)	**637**	Litres	**1’293**
Cold Surface Area (Plug side to barrier)	**6.6**	m^2	**7.6**
Cold Surface Area (SC Link side to barrier)	**1.7**	m^2	**1.2**

- Helium inventory reduced (-16%) → OK
- Insulation vacuum reduced (-50%)
- Overall cold surfaces slightly reduced (-6%) → OK

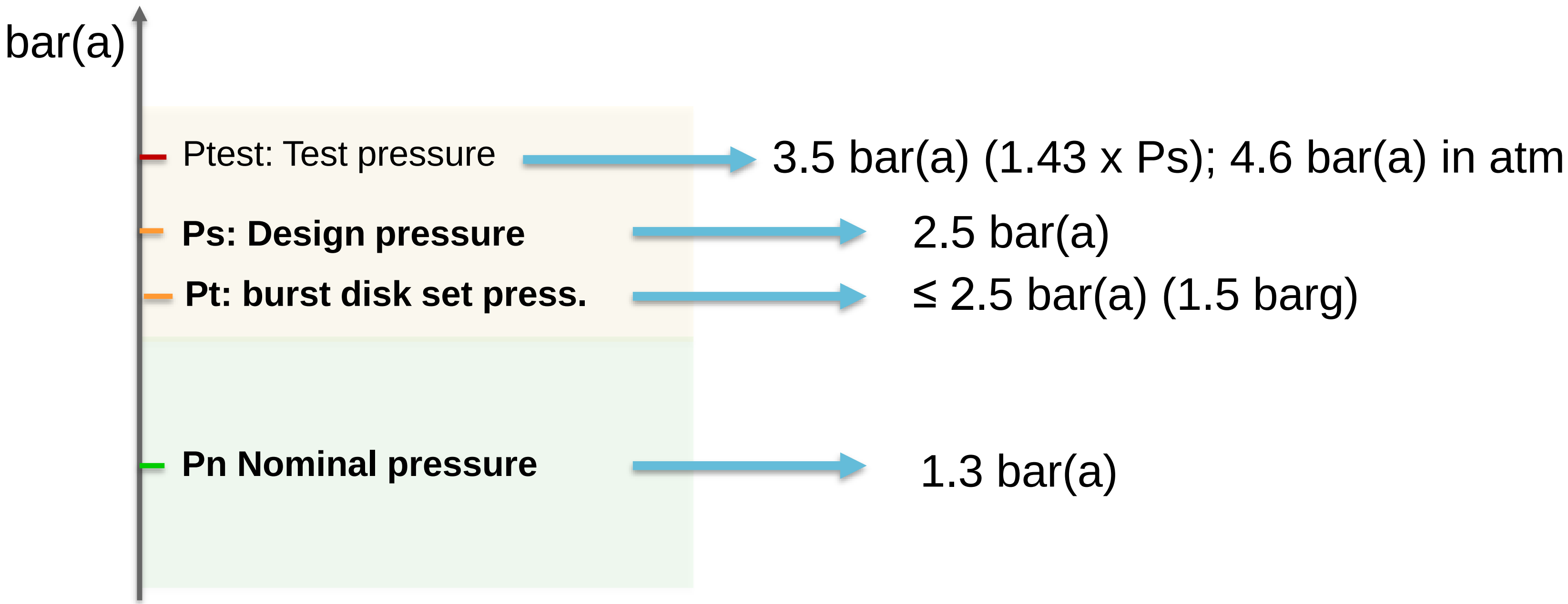
Helium envelopes (DFX specification, EDMS1905633)

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~~ 2.5 bara	[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]

- Change of Design Pressure of He vessel: <u>reduced from 3.5 to 2.5 bara (-28%) t</u>o align to the Design Pressure of SC link (an incorrect value was assumed up to the CDR!)

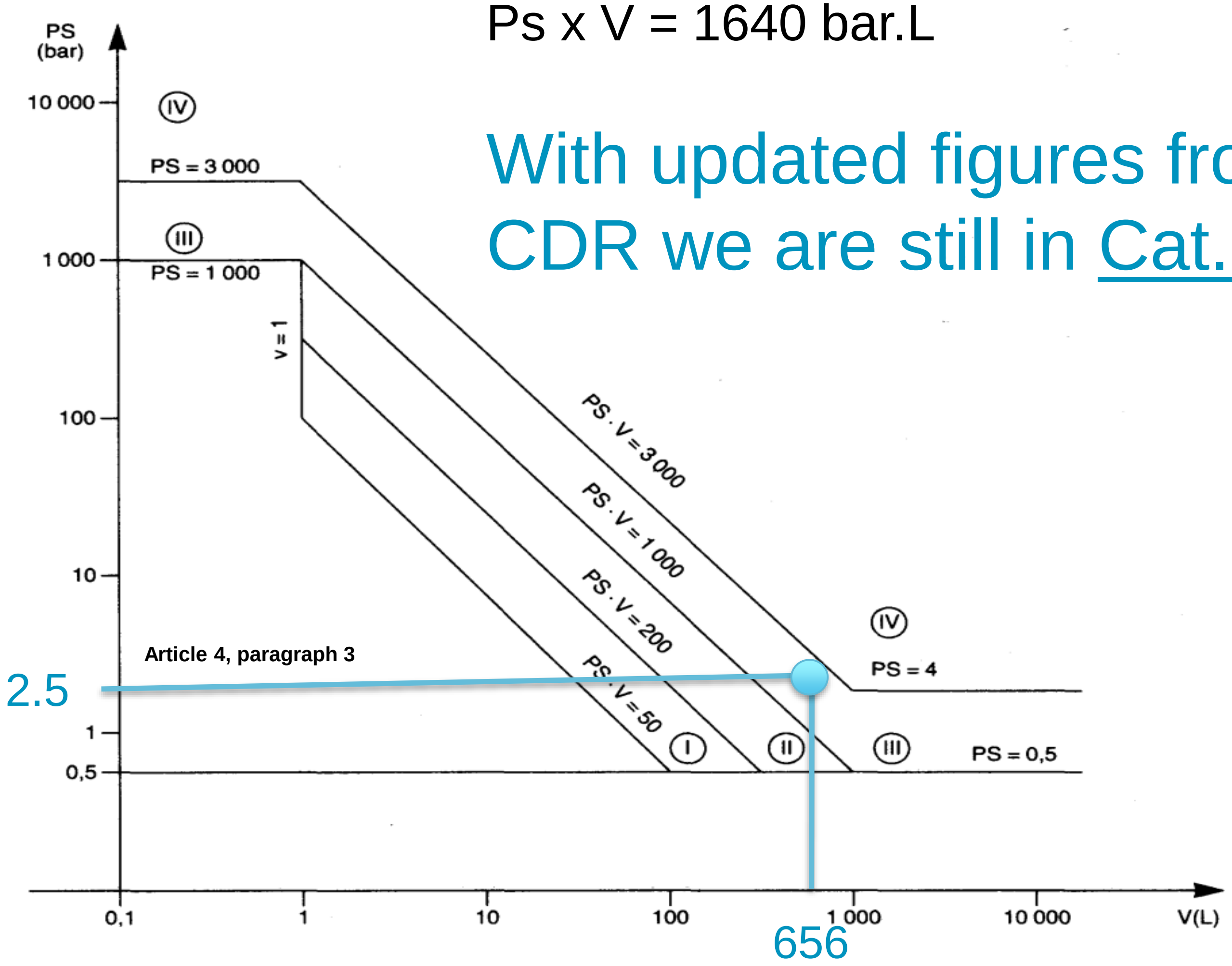
Updated Scale of pressures, helium vessel



PED category

Ps x V = 1640 bar.L

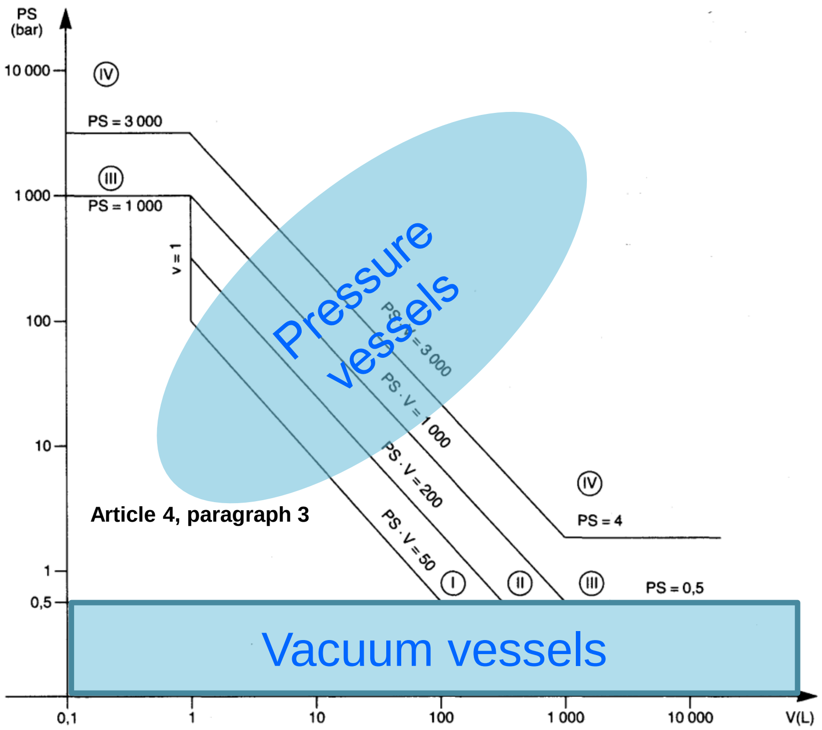
With updated figures from CDR we are still in Cat.3



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.

Risk assessment matrix (unchanged wrt CDR)

RISK MATRIX, Overpressure hazard for the DFX

	Source of overpressure	Possible cause	Consequence	LIKELIHOOD	IMPACT	Mitigation measures
A	Loss of insulation vacuum to air	External bellows failure, relief plate accidental removal	sudden air inrush and cryocondensation on cold surfaces	Possible	Major	Adequate design, manfacture & QC of bellows; protection of bellows against accidental damage; limited mechanical work in cyogenic operation.
B	Helium spill to insulation vacuum	internal bellows failure	helium spill through orifice (size?) to vacuum vessel.	Possible	Major	Adequate design, manfacture & QC of bellows; consider protection sleeves to limit spill mass flow;
C	Helium spill to insulation vacuum	dielectric failure, development of excessive resistance in splice	arc bursting helium envelope, helium pressurized at burst disk pressure, spill helium inventory to vacuum vessel.	Rare	Catastrophic	Adequate electrical insulation design, installation, and QC; online Vtap measurements acrooss all splices to monitor degradation;
D	Pressure build-up from triplets at quench	Lambda plug failure	sudden mass flow through damaged plug to DFX, providing pressure rise	Possible	Moderate	Adequate design, manfacture and QC testing of plugs;
E	Expansion of cryopumped air leaks	elastomeric ring leaks	Pressure increase at warm-up	Possible	Moderate	Leak checks of all sealed elements;
F	Pressure surge	fluid velocity change caused by e.g. starting/stopping pumps, opening/closing valves	pressure increase with limited mass flow change	Frequent	Moderate	Add rated valve to open at lower pressure than burst disk set pressure
G	Pressure build-up from EH-FH boiler line	failure of a junction (st.steel/Cu)	Pressure increase due to HP helium venting to helium reservoir	Rare	Moderate	Adequate design, manfacture and QC testing of boilers;
H	...					

(Rows A–F: Medium Risk colour; row G: Low Risk colour)

High Risk

Medium Risk

Low Risk:

Remarks:

- causes of excessive pressure are considered to be unrelated (single jeopardy theory) unless cause/effect exists

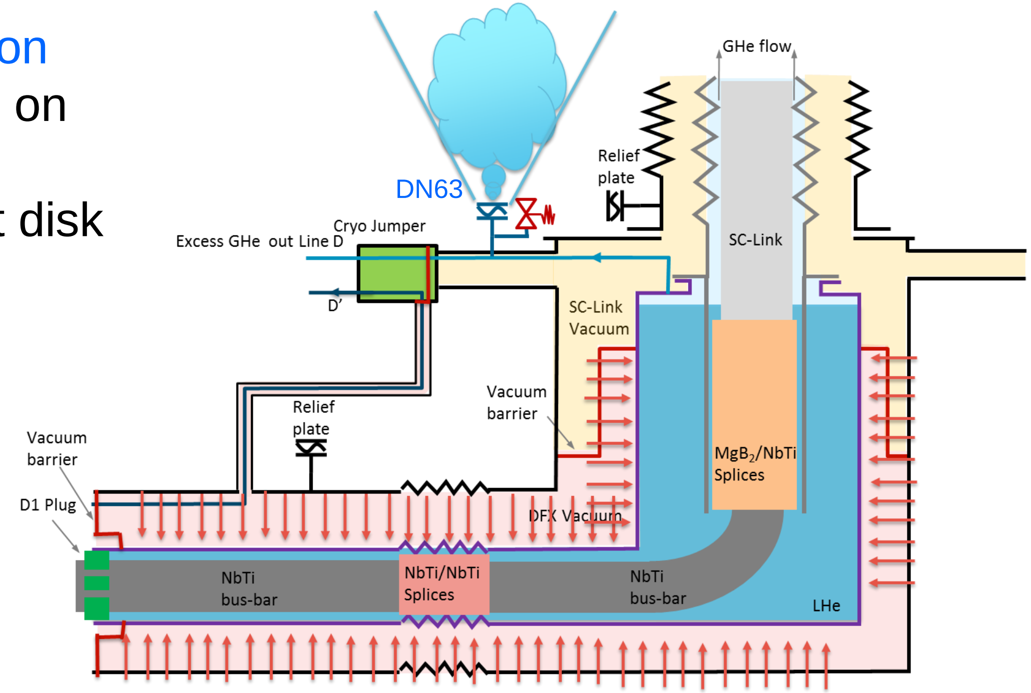
Retained pressure hazards

- A) Accidental air venting of insulation vacuum with sudden condensation on cold surfaces, helium boil-off and pressure build-up → sizing of burst disk

- C) Accidental release of cryogenic fluid from helium vessel to insulation vessel due to arc bursting helium envelope, helium pressurized at burst disk pressure, spill of helium inventory to vacuum vessel → sizing of vacuum vessel relief plate

Hazard A

A) Accidental air venting of insulation vacuum with sudden condensation on cold surfaces, helium boil-off and pressure build-up → sizing of burst disk



Preliminary sizing:

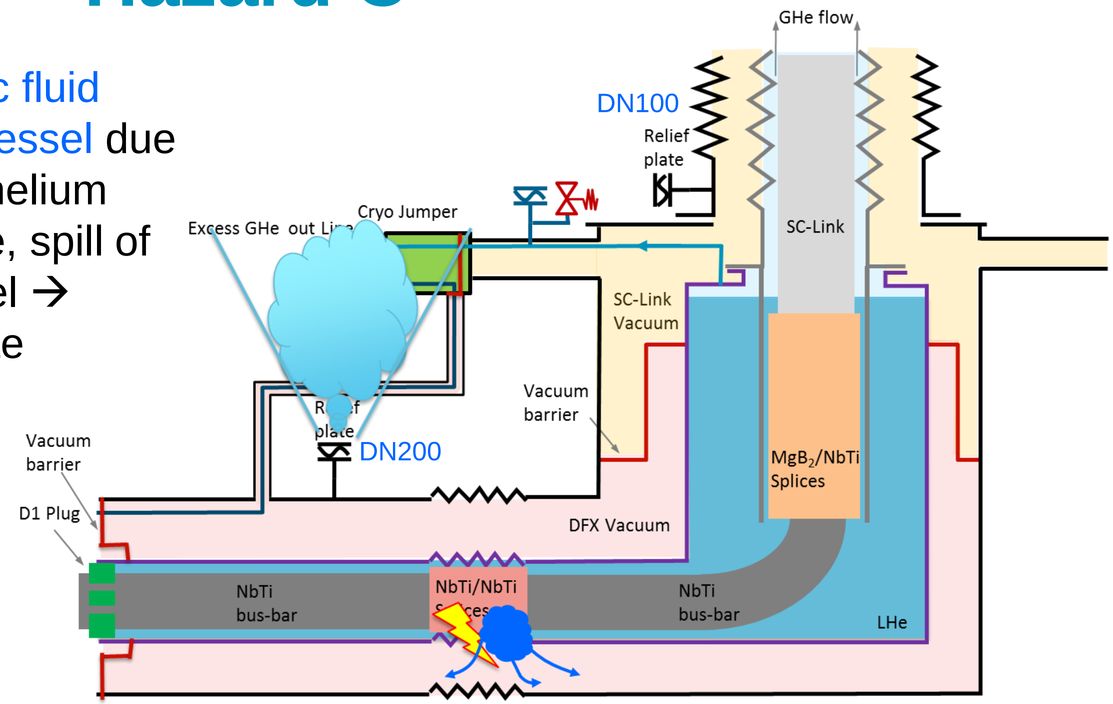
- Heat power density (10 effective MLI layers): 6.2 kW/m2
- Heat flux: 54 kW
- Bust disk rupture pressure Pt: 2.5 bara (1.5 barg)
- Safety device sizing (EN13648-3; EN4126-6 Annex C): supercritical He at ~6.2 K:
  → Qm = 3.5 kg/s
  → DN > 45 mm → DN63, and equivalent burst disk

Example of DN50-mm bust disk

Thanks to Y.Leclercq for his calculation spreadsheet!

Hazard C

C) Accidental release of cryogenic fluid from helium vessel to insulation vessel due to arc bursting helium envelope, helium pressurized at burst disk pressure, spill of helium inventory to vacuum vessel → sizing of vacuum vessel relief plate

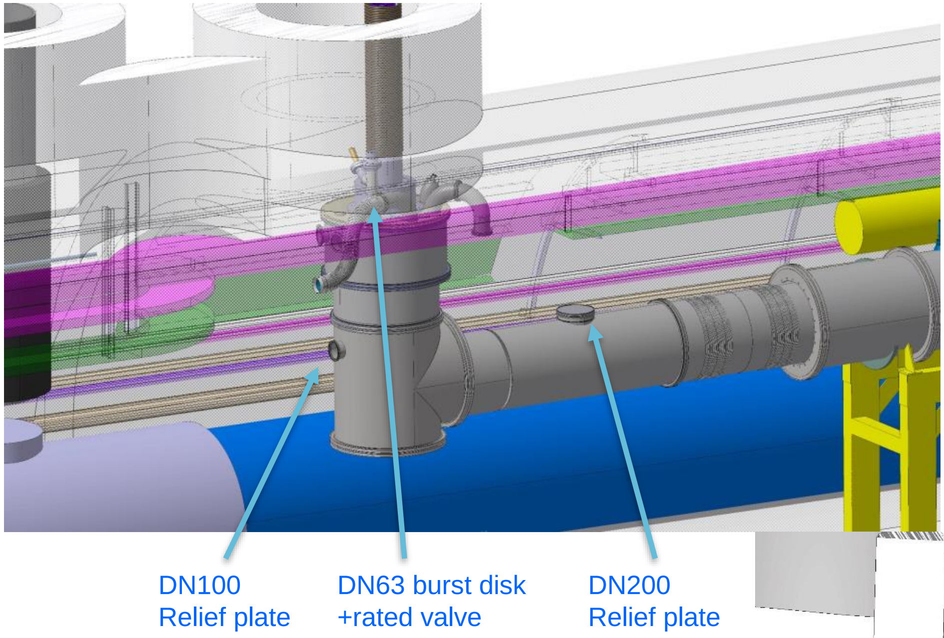


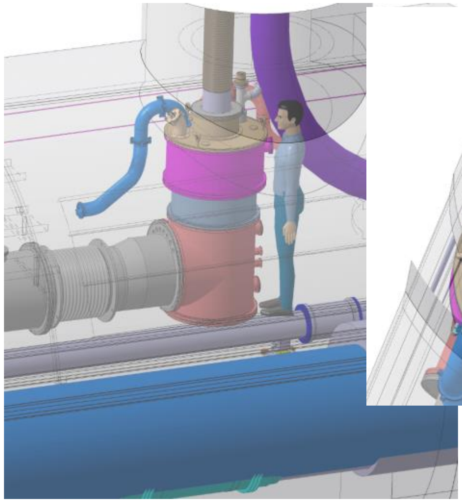
Preliminary sizing:

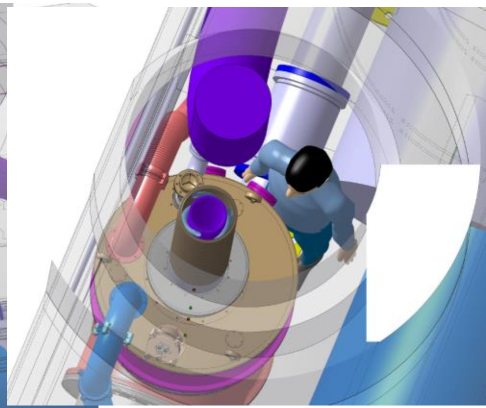
- Assume orifice: DN50
- Pt= 2.5 bara; Pb=0 bara; T_{rel}= ~5 K
  → Qm_{vessel} = ~5 kg/s to the vac.vessel
- Relief plate to limit ΔP to 0.5 barg (opens at 1.5 bara)
- Assuming continuity of mass relief (conservative): $Qm_{vessel} = Qm_{relief}$
  → ~DN100 → having space we choose DN200 for the horizontal section and DN100 for the vertical section

Example of DN200-mm relief plates,
(also exists in DN90,100, 160, 230)

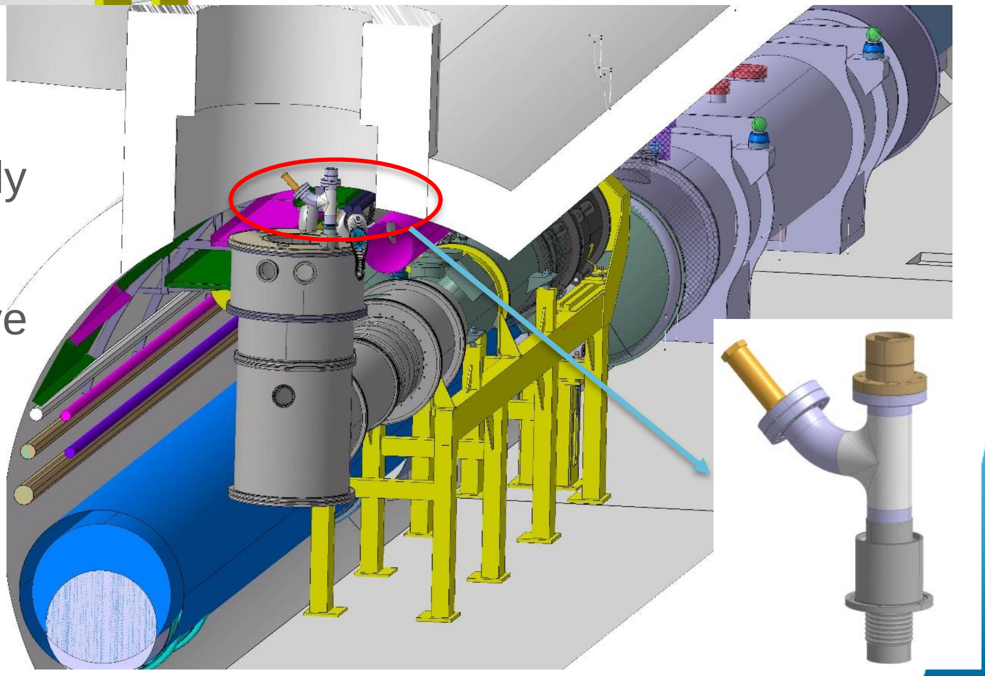
Locations of safety device



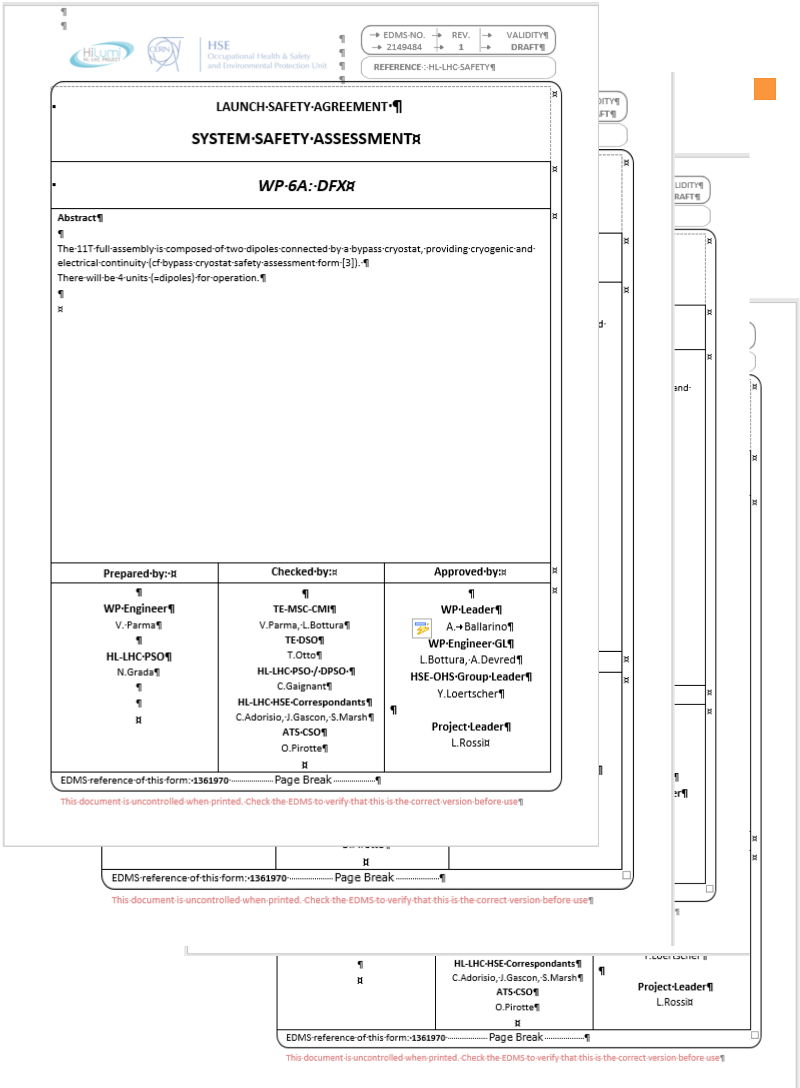




- Integration/maintainability to be carefully studied with WP15
- Need for re-routing outside of the tunnel? Additional p drop ? (but we have contingency)



Safety Assessment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REFERENCE : HL-LHC-SAFETY

HSE Occupational Health & Safety and Environmental Protection Unit

LAUNCH SAFETY AGREEMENT

SYSTEM SAFETY ASSESSMENT

WP 6A: DFX

Abstract

The 11T full assembly is composed of two dipoles connected by a bypass cryostat, providing cryogenic and electrical continuity (cf bypass cryostat safety assessment form [3]).

There will be 4 units (=dipoles) for operation.

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EDMS reference of this form: 1361970

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- Based on work breakdown structure of WP, Project Safety Officers conduct “System Safety Assessment” (SSA):
  - (Sub-)system description
  - Hazard register
  - Definition of mitigation measures
  - Risk assessment, where required
  - Safety clearance

(T.Otto, TE Dept.)

Safety Assessment – HSE Involvement

- The SSA document for all (sub-) systems are submitted to HSE for comments
- Mitigation measures agreed upon by HSE are implemented under project control
- Design, fabrication, testing and installation of equipment with "major Safety implications"(mSi) are followed closely by HSE
- Pressure vessels without CE mark are mSi
- HSE defines in a "Memorandum of Safety Checks"
  - Which controls it will make
  - Which supporting documentation it expects from the manufacturer
- When all HSE requirements met → Safety Clearance

HiLumi HL-LHC PROJECT CERN

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Summary

- Since the CDR, the evolution of the design has not brought and major change in the cryogenic safety assessment
- Even with a reduced design pressure of 2.5 bara, the safety devices can be kept to their original size
- The equipment remains under Cat.3 of the PED
- The locations of the vacuum insulation safety devices is similar to the ones of the LHC; the need for deflectors will be assessed as a result of the integration study
- The location of the burst disk/rated valve assembly is positioned in the vertical shaft and the accessibility for maintenance needs to be confirmed as part of a complete integration study
- Procedure for Safety Clearance presented

Thank you !

Q/A