Summary of session 3:

Optimise Interventions and Recovery from Collateral Damages on Cold Sectors

Prepared by Caroline Fabre & Pierre Strubin

Based on presentations by:

Vincent Baglin	Can we optimise the cleanup process further?
Rob van Weelderen	What is the MCI in case of a “beam driven” failure of a magnet enclosure?
José Miguel Jimenez	Means to limit the colateral damages in the beam vacuum chamber
Paul Cruikshank	What repair activity can be done today on a locally warmed-up sub-sector?
Serge Claudet	Can we change a magnet without warming-up a full arc?
Gérard Ferlin	Decoupling of adjacent cryogenic sectors

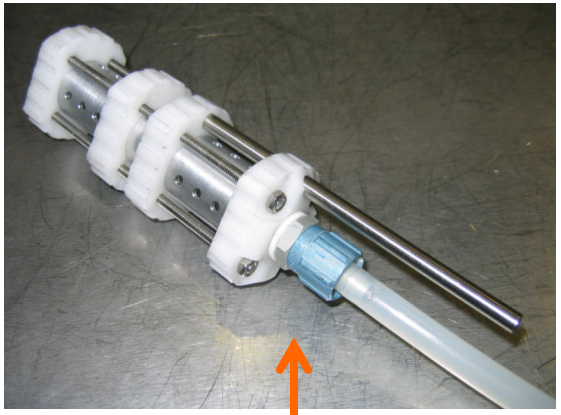
Can we optimise the cleanup process further?

Vincent Baglin

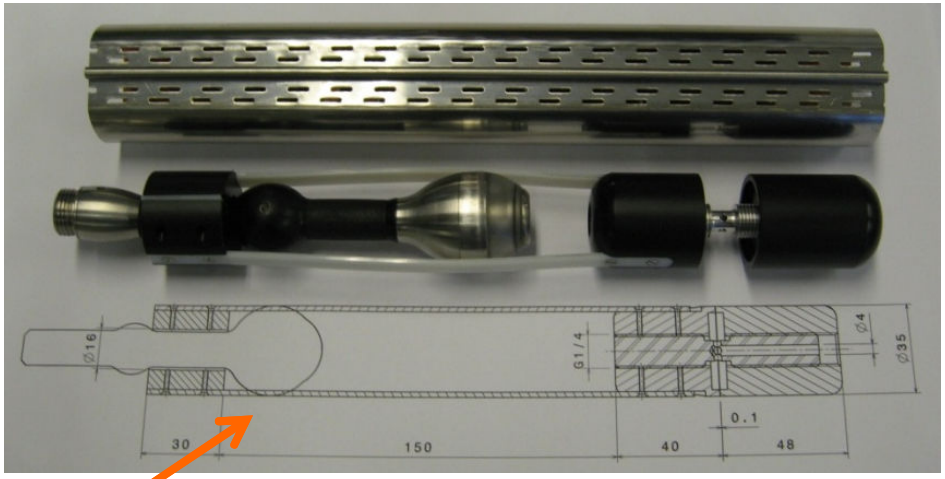
- Inspection and documentation
  - After sector 3-4 incident: 4.8 km of beam lines and 212 interconnections have been inspected by endoscope and documented

	V1	V2	V1	V2	Total
Ok	54	39	26 %	18 %	22 %
MLI	124	129	58 %	61 %	59 %
Soot	35	45	16 %	21 %	19 %
Total	213	213	100 %	100 %	100 %

- Special tooling was developed



Initial version of “vacuum cleaner”

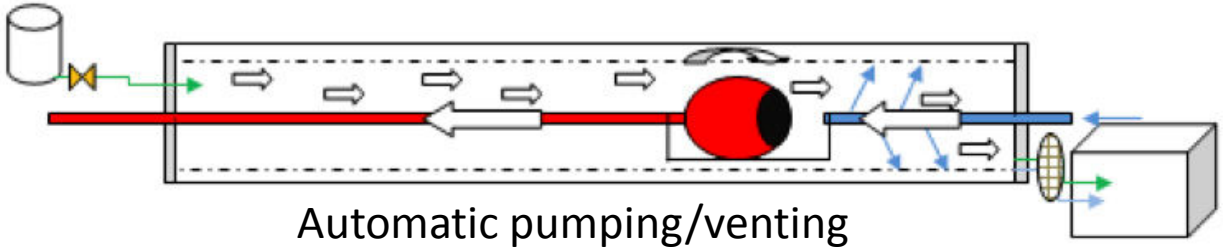


Improved with the attachment of an endoscope

Can we optimise the cleanup process further?

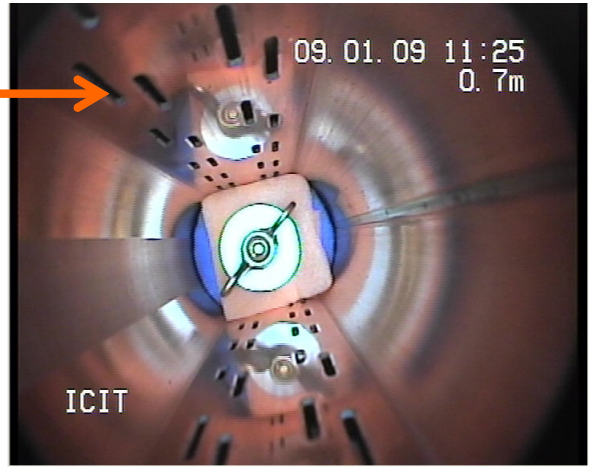
Vincent Baglin

- Use a combination of “blowing” and “sucking” to clean MLI debris



Automatic pumping/venting
based on RF ball technology

- More special tooling
  - “Chimney” sweeping tool to remove soot

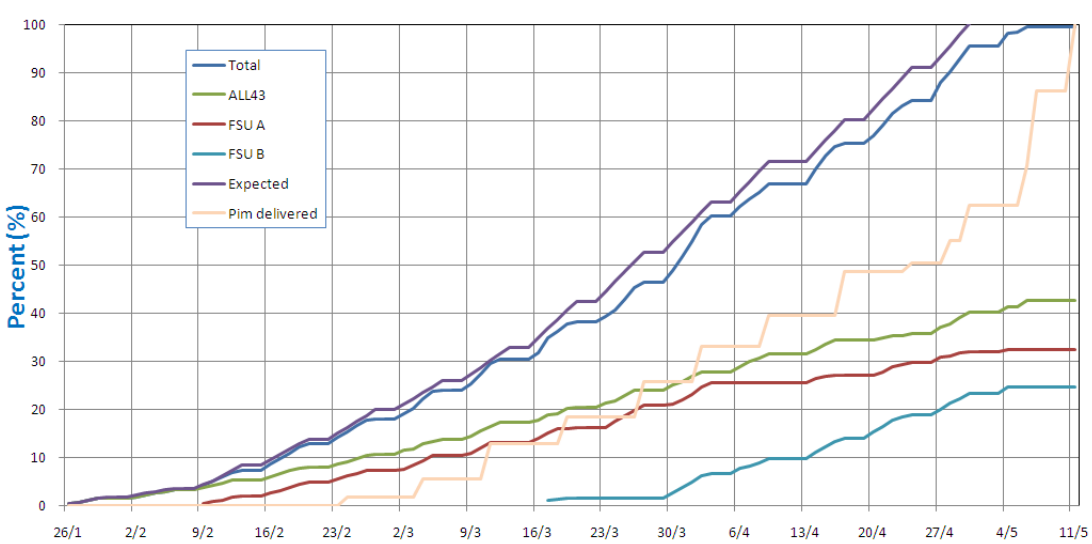


- Definition of acceptable cleanliness
  - 1 fibre per half-cell
    - 82 half-cells to clean
  - 2 debris (MLI or other less than 1 mm2) per magnet
    - 304 beam tube magnets to clean

Can we optimise the cleanup process further?

Vincent Baglin

- What was achieved
  - ~ 3 months were required to set up the process
  - ~ 3 months were required to cleanup the sector
    - Cleaning rate: ~ 50 m / day / team, of which 3h 15 min for PIMs!
- Many difficulties to overcome
  - Completely new situation
    - Did not know what would be found
  - Debugging of tools
  - Many co-activities



6 sets of tooling now "on the shelf"
Could now be done in less than 3 months, but we hope we will never have to redo it…

What is the MCI in case of a "beam driven" failure of a magnet enclosure

Rob van Weelderen

- Assumptions
  - Beam driven hole between beam pipe and cold mass
  - Flow rate estimated by sound velocity limit of the escaping helium through the slits formed by the magnet laminations
    - Slit area is 3.23 cm2/m (0.2 mm gap per 6.2 mm length, 10 mm hole width)
  - ~ 161 slits per meter length
  - The specific discharge values will be determined by the state of the helium at the hole location and thus by the physical process taking place in the cold masses

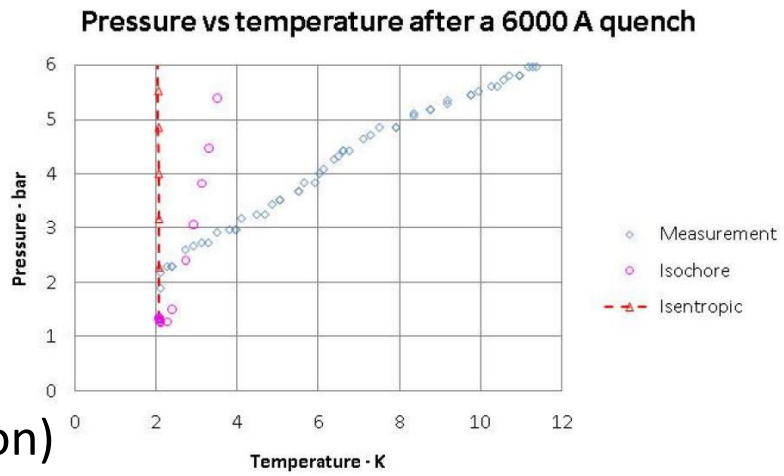
	Specific (kg/s cm^2)	Per slit (kg/s)	Per meter of collar nose (kg/s.m)
Pool boiling vapour phase	0.22	0.004	0.71
Pool boiling liquid phase	2.0	0.039	6.3
Isochoric	3.9	0.078	12.6
adiabatic	4.3	0.085	13.7
reality	?	?	?

→ From the discussion: mass flow could be larger if the beam punches the magnet end

What is the MCI in case of a "beam driven" failure of a magnet enclosure

Rob van Weelderen

- Observations after a quench
  - At about (3-4 bar, 3 K) one leaves the adiabatic/isochoric phase area, i.e. after about 15 s
  - For this first 15 seconds we will see a high specific discharge rate (~4 kg/s cm^2 / ~10 kg/s m of lamination)
  - After that the rate will decrease by an order of magnitude (~0.7 kg/s cm^2 / ~1.7 kg/s m of lamination)



→ When neighbour magnets are quenched, average long term discharge is significantly more gentle than first few seconds.

In view of this wide range of possible mass flows, specific cases of reasonable beam damage will now have to be defined in order to evaluate the beam pipe pressure rise effect

Means to limit the collateral damages in the beam vacuum chamber

José Miguel Jimenez

- Vacuum system designed to cope with *small* leaks
  - Welds, seals, feedthroughs, holes in beam screen capillaries, etc.
  - Based on risk analysis of cryogenic system (LHC-project note 177)
  - Similar incident in the string did unfortunately not "*ring the bell*"
- Initially foreseen protections of beam vacuum
  - *Arc*
    - Rupture disks (30 mm aperture) at each arc extremity (~ 3 km)
    - No vacuum sectorisation !
  - *Standalone magnets (SAM)*
    - Rupture disks (30 mm aperture) available at extremity of each SAM
    - Vacuum sector valves at each extremities (isolate from the warm vacuum sector)
  - *Long straight sections room temperature vacuum sectors*
    - Vacuum sector valves (sectors at RT can always be isolated from SAM)
  - *Experimental areas*
    - Vacuum sector valves at Q1 (each side) and to isolate the central beam pipes
    - Pressure relief valve (only in LHCb Velo)

Means to limit the collateral damages in the beam vacuum chamber

José Miguel Jimenez

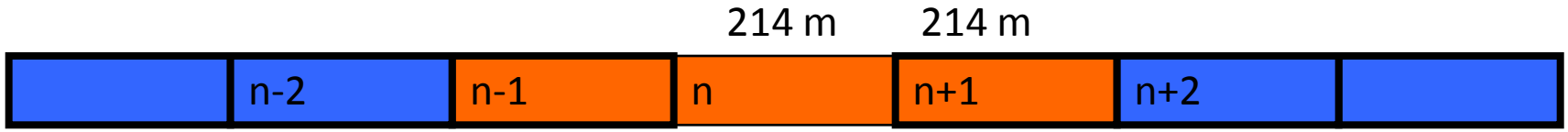
- Protecting bellows against over-pressure
  - Add more rupture disks
  - Add 2 half-shells in Vetronite or equivalent around the bellows
    - Increase resistance to plasma discharge (high temperature resistance)
    - Avoid damages induced by the projections of melted metal
    - Also helps limiting the injection of MLI in the beam vacuum
- Protecting against pressure front and debris
  - Fast-closing valves
    - Shall not be necessarily leak tight
    - Shall close within 20-50 ms
    - Use a low-Z material for the sealing plate
    - Requires reliable interlock signals
      - Beam loss monitors
      - Pressure gauges or nQPS in the absence of circulating beams

New development, needs thorough risk analysis, validation and tests

What repair activity can be done today on a locally warmed-up sub-sector?

Paul Cruikshank

- Local warm-up was foreseen in the baseline
  - For repairs at interconnects on cold mass volume (diode, busbar, splice, helium leak, IFS, line N) or instrumentation
  - *BUT NOT*
  - For repairs on beam vacuum or circuits without valves (line c',k,e,x,y)



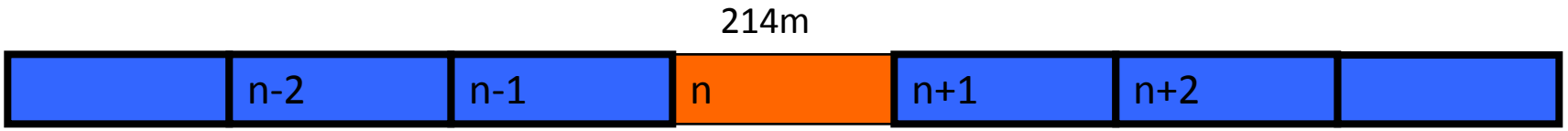
- **Scenario from LHC Project Report 60, Sept 2000**
  - **n-2….** **floating, cold, under vacuum**
  - **n-1** **thermal buffer, RT, under vacuum**
  - **n** **intervention, RT, vented, W opened** **642m (23%) at RT**
  - **n+1** **thermal buffer, RT, under vacuum**
  - **n+2….** **floating, cold, under vacuum**

- Experience gained
  - Change of flexible hoses on DFBAs in sector 4-5 in 2007

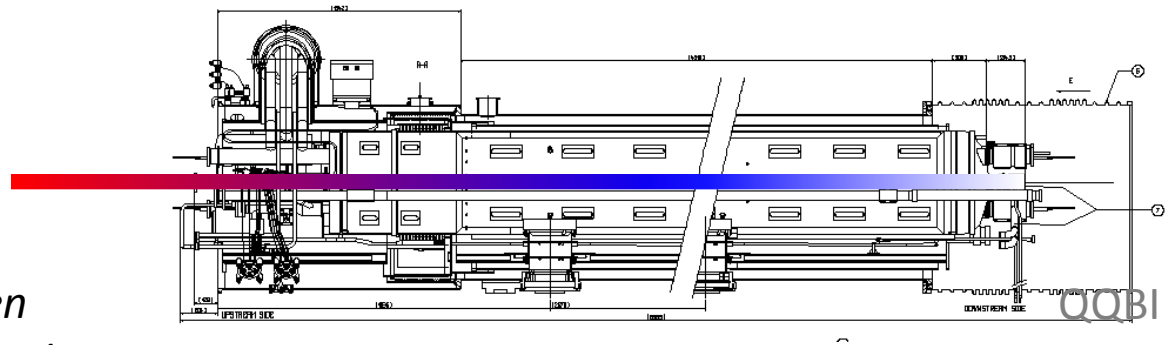
What repair activity can be done today on a locally warmed-up sub-sector?

Paul Cruikshank

- Revisited scenario
  - Goals:
    - Minimise number of PIMs which undergo thermal cycle to RT
    - Ensure access to PIMs which undergo thermal cycle to RT
    - Expect shorter intervention time w.r.t. a sector warm-up ?



  - Issues :
    - No thermal buffers - cold interfaces at sub-sector extremity ?
    - Can a failed PIM be changed with arc still cold – venting & backstreaming ?

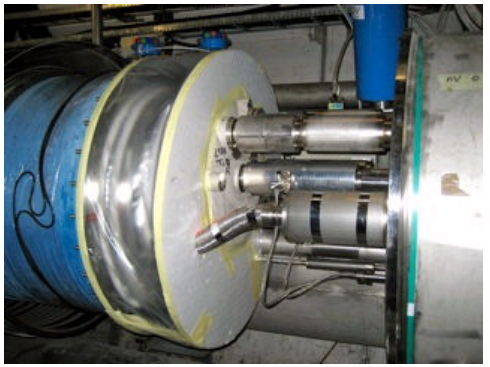


Warm-up arc to 100 K
Warm-up last SSS by circulating warm nitrogen in the beam pipe, validated in SM18 on SSS513

What repair activity can be done today on a locally warmed-up sub-sector?

Paul Cruikshank

- Protect beam vacuum against condensation
  - Flow N_2 or Ne through the beam pipe to avoid retro-diffusion
    - A flow of 5mm/s outflow is sufficient to avoid backstreaming > 0.5 m
    - PIM inspection with endoscope done under Ne flow in 2-3 and 8-1
- Protect SSS extremity against condensation and freezing
- The X-ray tomograph is here
  - Venting + endoscopy not required to check PIMs
    - …. venting only if damaged PIM

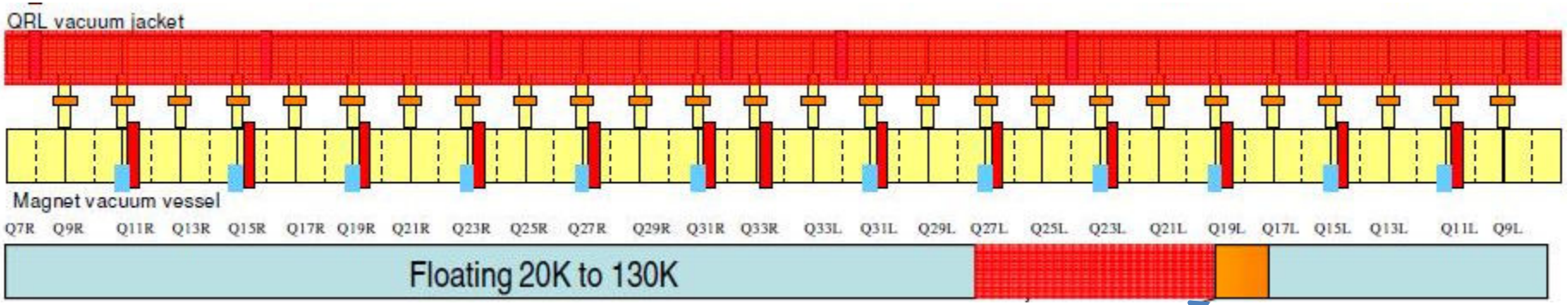


Potential gain of 2 weeks with respect to a full sector warm-up: 53 instead of 69 days
but
very delicate operation
when beam vacuum has to be opened and blown through!

Can we change a magnet without warming up a full arc?

Serge Claudet

- The LHC sub-sectorisation baseline tells you: NO !
  - Cold Mass, Line N: OK as according to baseline (sectorised)
  - Line X/Y (bayonet HX), Line C' (cooling intercept), Line E (thermal shield): Air would reach cold surfaces in the cold sub-sectors and get trapped
- However probably possible
  - Based on local warm-up methods developed to protect beam vacuum



– Warm-up of concerned sub-sector to 300K, and adjacent right to 100K (then GN2 bag against condensation)

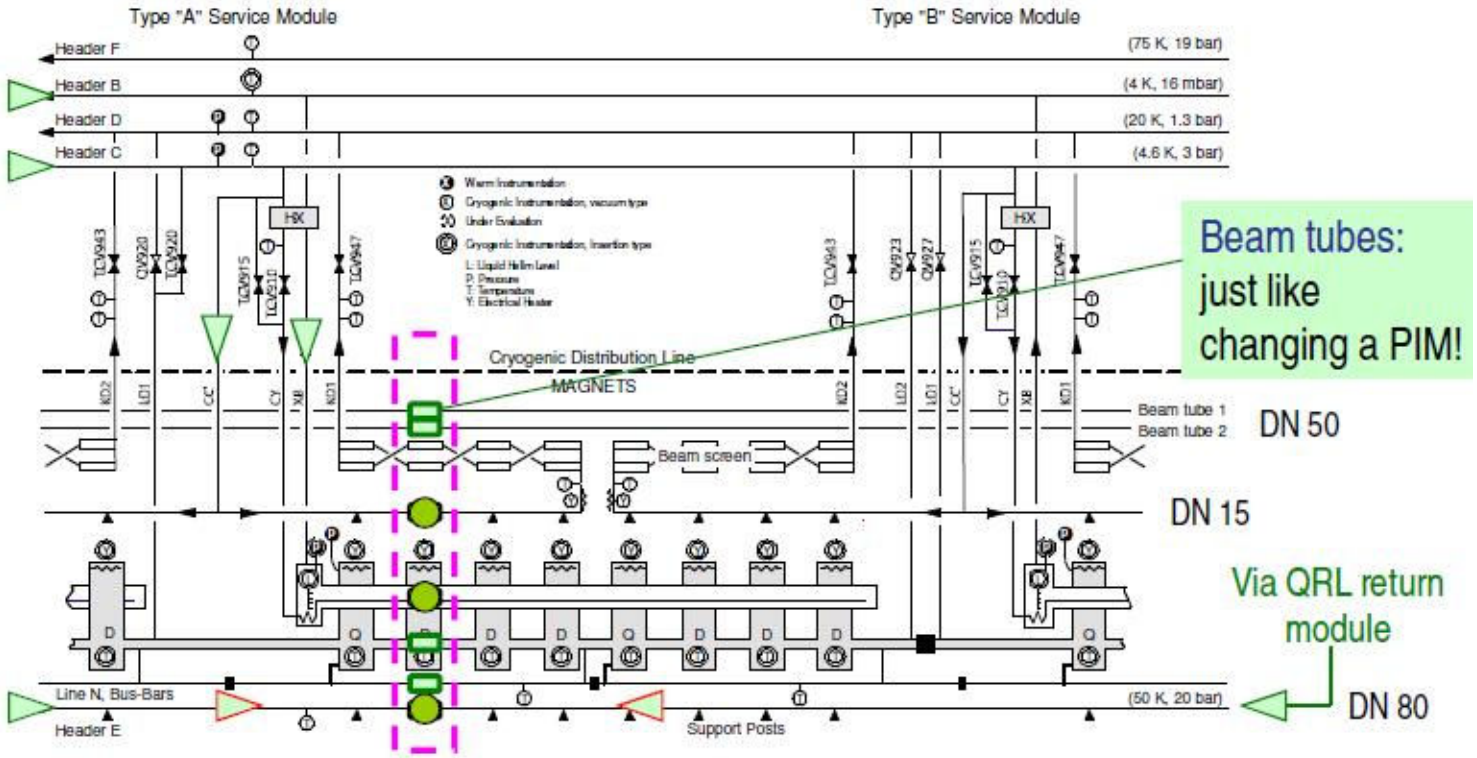
– Most likely a 2nd sub-sector to be warmed-up, as ELQA of Line N requires so far to access 4 boxes (3 x 54m)

Can we change a magnet without warming up a full arc?

Serge Claudet

- Provided that:
  - Cutting is made with little over-pressure to prevent air contamination
  - Temporary caps are placed on opened pipes
  - We can develop tools and procedures for welding sleeves without entering massively air in the pipes

QUI



Preliminary stage → worth to continue study!

Decoupling of adjacent cryogenic sectors

Gérard Ferlin

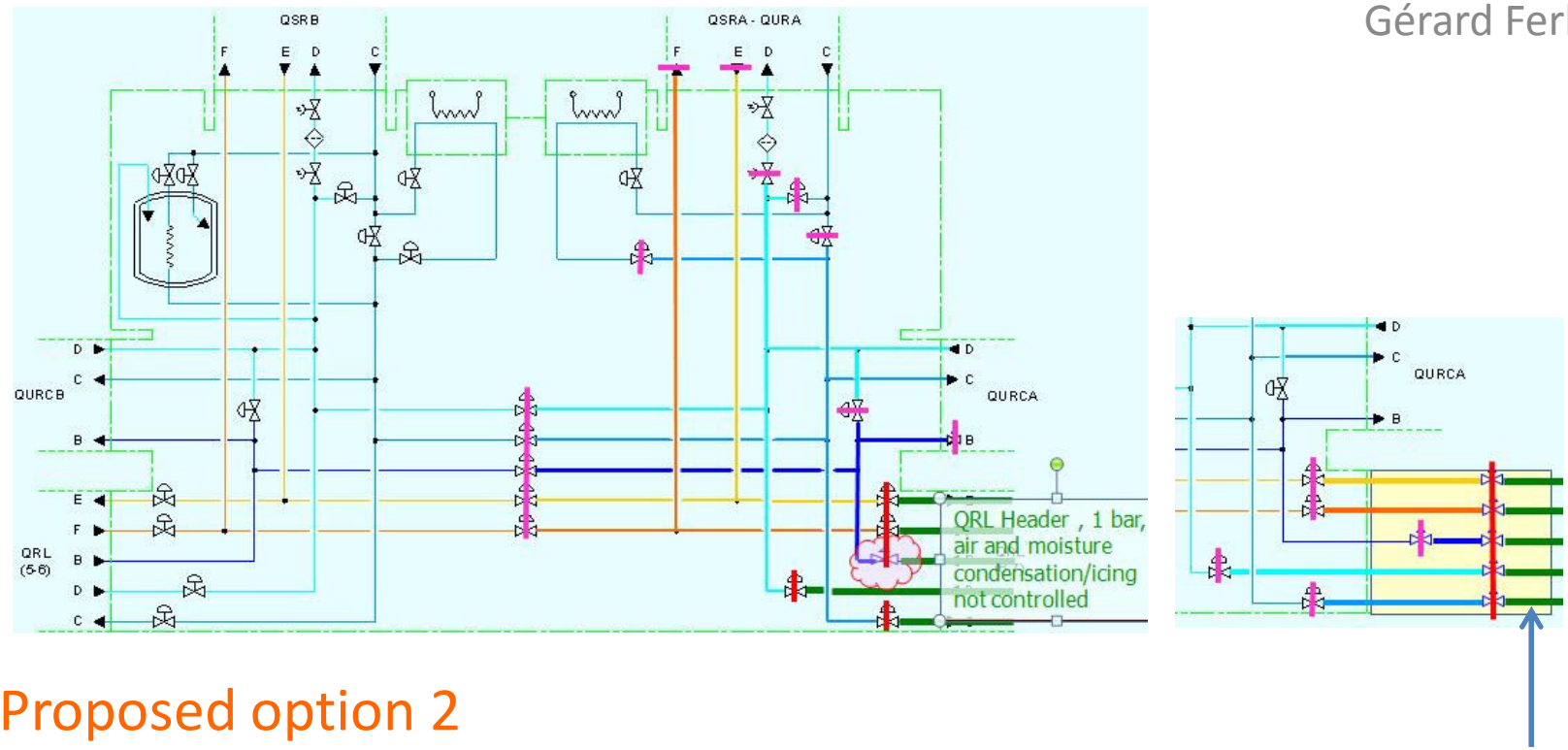
Present sectorisation does not allow exchanging a magnet or a QRL service module in a sector while keeping the adjacent sector in nominal cryogenic operation.

- Requirements for intervention on one sector:
  - Safety: sector locked-out from pressure and gas flow
  - Cryo operation: cold valves protected from air and moisture condensation
- Principle solution
  - For each circuit: 2 valves locked-out with helium gas buffer in between

  → True for all circuits except Header B (GHe pumping line, 15 mbar, 4K)
- Proposed option 1
  - Adding a DN250 valve on header B would allow safe intervention on sector while keeping the adjacent one cold
  - However the cooling plant redundancy is lost (during intervention)

Decoupling of adjacent cryogenic sectors

Gérard Ferlin



- Proposed option 2
  - Adding a new valve-box on QRL junction region would, in addition, allow to preserve cryoplant redundancy

- Both options require validation of design and integration study
- Implementation requires full warm-up of the 2 adjacent sectors

Conclusion

- Consolidation of MCI and corresponding protecting devices in case of full beam lost in a magnet

- Many efforts developed to try and find solutions while deviating from the baseline scenarios

  and risking to endanger vacuum and cryo operation availability !

- Principle solutions allowing interventions after local warm-up presented → now more detailed studies needed

- Next steps:
  - Define how far we should go in sectorization
  - Draw-up table with benefits and drawbacks