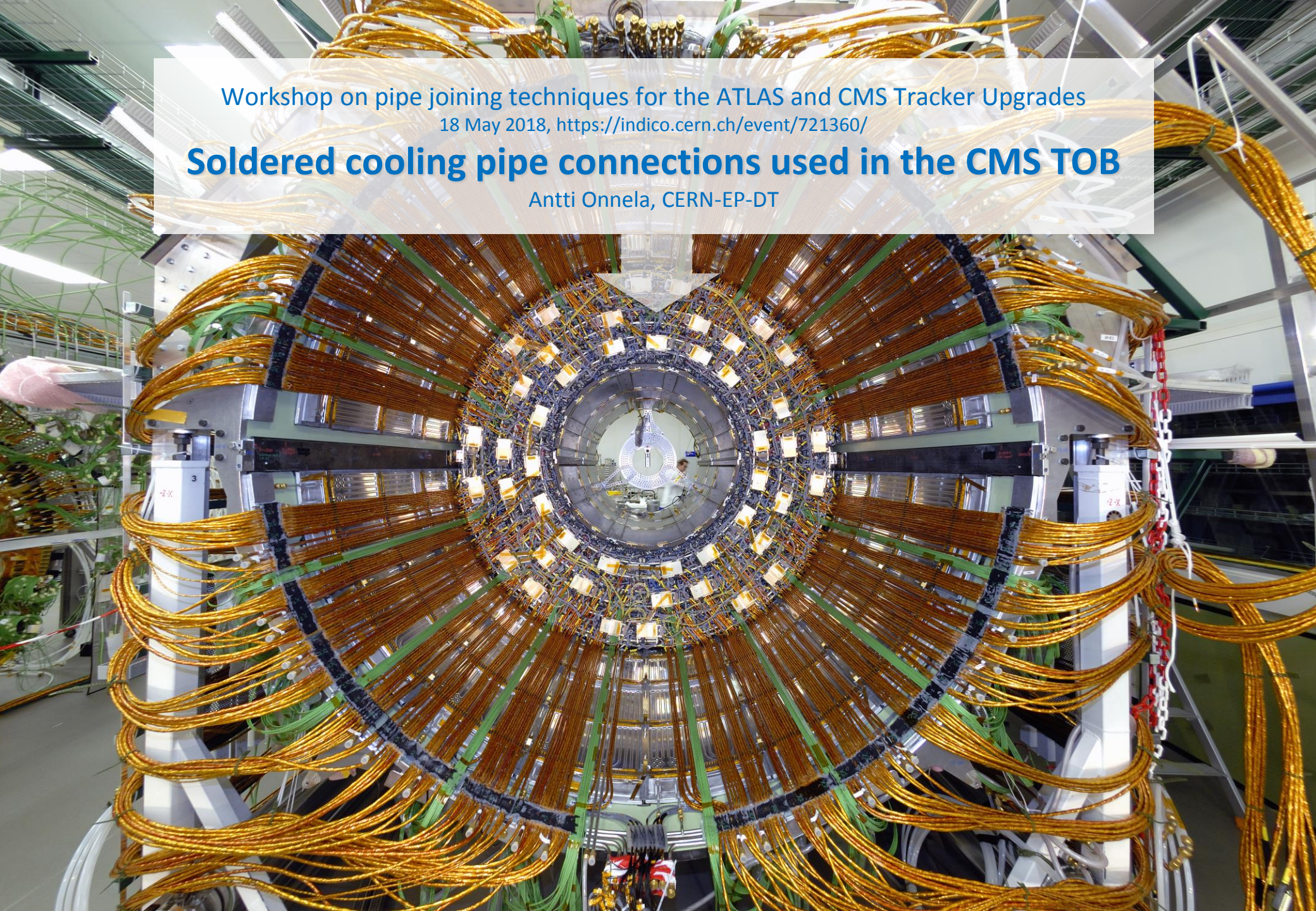


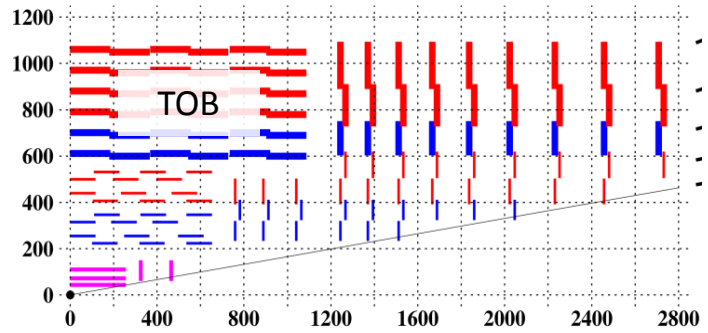
Workshop on pipe joining techniques for the ATLAS and CMS Tracker Upgrades

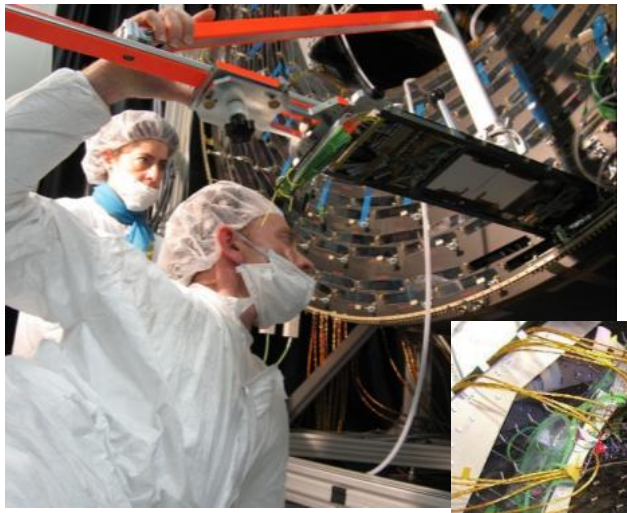
18 May 2018, https://indico.cern.ch/event/721360/

Soldered cooling pipe connections used in the CMS TOB

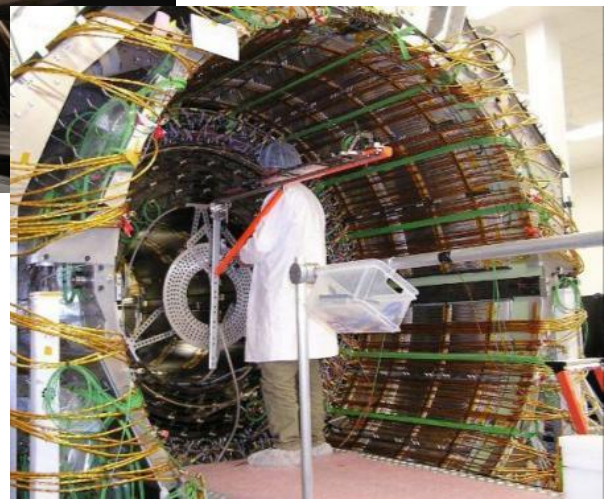
Antti Onnela, CERN-EP-DT

Tracker Outer Barrel (TOB)





Rods of layers
6 and 5 installed
when outside TST



Rods of layers
4 to 1 installed
when inside TST

TOB, ~1/3 (15 kW) of the CMS silicon strip tracker

- 5208 detector modules (20 cm x 10 cm)
- on 688 “Rods” (1.2 m x 15 cm, ~20 W)
- on 6 layers in 1 Support Wheel (L 2.4 m, OD 2.3 m)
- in the middle of Tracker Support Tube, TST (L 6 m, D 2.5 m)

A ‘copy’, TB2S, now being designed for the Phase 2 upgrade.

CMS Tracker Cooling

- Remove ~50 kW, maintain sensors at -10 °C
- Liquid-phase C_6F_{14}
  - Fluid temperature: +10 °C … -20 °C
  - Fluid pressure: Max 6 bar (max 2 bar for the first Pixel detector)
  - Cooling plants on balconies of CMS Experimental cavern
- Since 2017 also two-phase CO_2 cooling, for new Phase 1 upgrade Pixel detector.

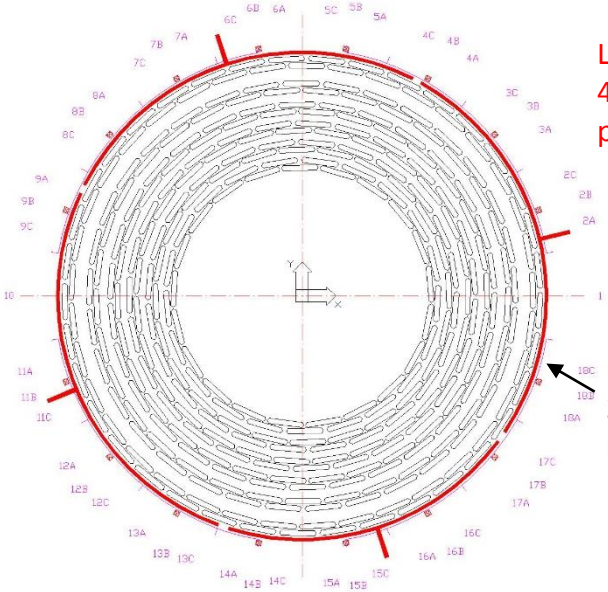
- Materials used in the C_6F_{14} cooling pipework (a lot of history…):
  - Supply and return pipes: soft copper
    - Brazed and soldered connections, double O-ring fittings at Tracker ends
  - Thermal screen: Cold panels and connection pipes in aluminium
    - Welded joints, compression fittings
  - TOB: Copper-nickel pipes
    - Brazed and soft soldered joints with connection pieces in brass

    This presentation
  - TIB/TID: Aluminum pipes
    - welded joints, compression fittings
  - TEC: Titanium pipes in petals, manifolds in stainless steel
    - welded joints, compression fittings

TOB cooling circuitry

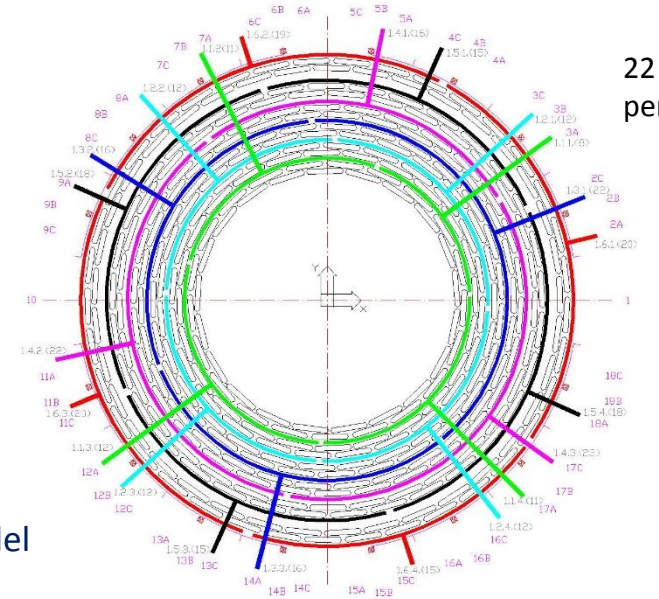
688 Rods

- U-shape cooling pipe
- in 44 cooling segments with 11 to 22 Rods in parallel



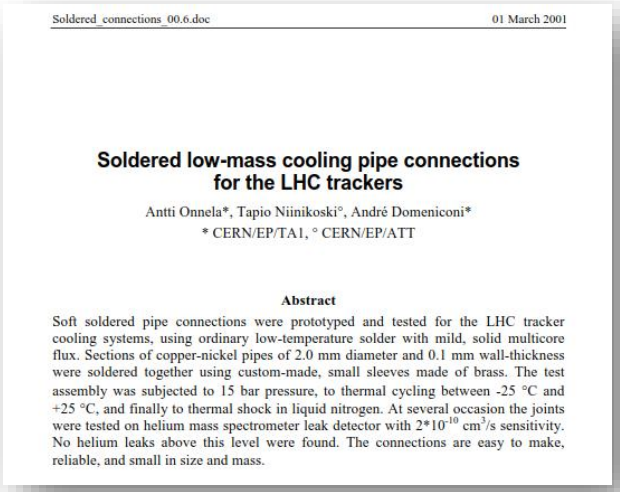
Layer 6:
4 cooling segments per end

2 pipes: Inlet and outlet manifolds side by side



22 cooling segments per end, 44 in total

The TOB Rod to manifold connection


Soldered_connections_00.6.doc 01 March 2001

Soldered low-mass cooling pipe connections for the LHC trackers

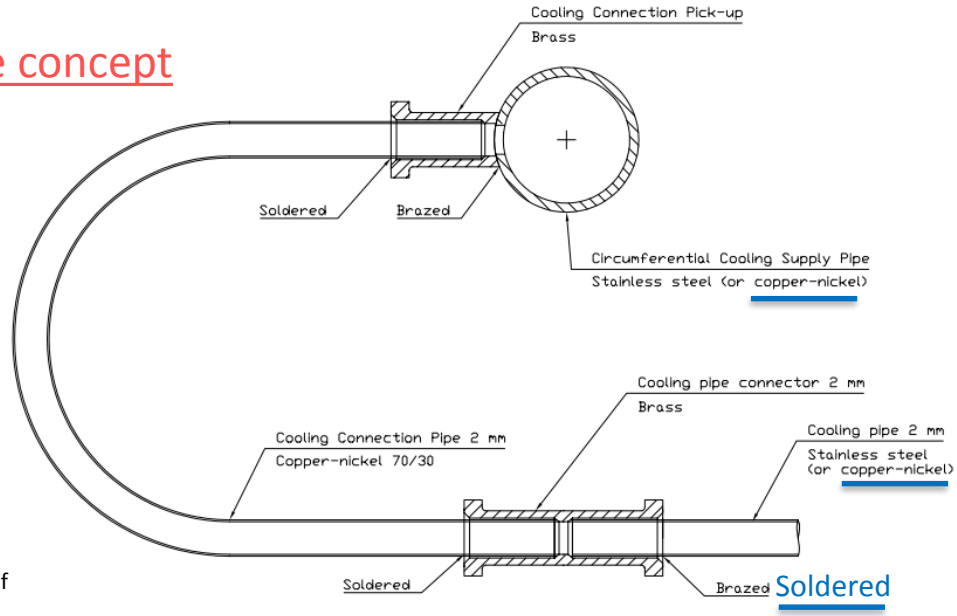
Antti Onnela*, Tapio Niinikoski°, André Domeniconi*
* CERN/EP/TA1, ° CERN/EP/ATT

Abstract

Soft soldered pipe connections were prototyped and tested for the LHC tracker cooling systems, using ordinary low-temperature solder with mild, solid multicore flux. Sections of copper-nickel pipes of 2.0 mm diameter and 0.1 mm wall-thickness were soldered together using custom-made, small sleeves made of brass. The test assembly was subjected to 15 bar pressure, to thermal cycling between -25 °C and +25 °C, and finally to thermal shock in liquid nitrogen. At several occasion the joints were tested on helium mass spectrometer leak detector with $2*10^{-10}$ cm^3/s sensitivity. No helium leaks above this level were found. The connections are easy to make, reliable, and small in size and mass.

http://cms-ul-tmb.web.cern.ch/CMS_TMB/PERSONAL/vanhala/Notes/TOB-00-6.pdf

The concept



Final TOB components	Material, dimensions	Manufacturer / Reference
Rod cooling pipes	CuNi 70/30, seamless, drawn, ½ hard; Diam. 2.2/2.0 and 2.5/2.3 mm	High Tech Tubes, UK
Connection pipes	CuNi 70/30; Diam. 2.5/2.0 mm	High Tech Tubes, UK
Manifold pipes	CuNi 70/30; Diam. 6.0/5.6 mm	High Tech Tubes, UK
Supply/return pipes	Cu DHP, soft, EN 12449 CW 024A; Diam 10.0/9.0 mm	
Connectors	Brass, ISO 1637, CuZn39Pb3-HB	Mansner, FI
Soft solder (+180 °C)	Multicore SnPbAg 62/36/2 with core flux: ERSIN 362	CERN SCEM: 29.20.01.F
Brazing solder (+600 °C)	Fontargent A306, CuZnAgCd 19/19/41/20 Flux: AGX UTP	CERN SCEM: 29.20.20.110.1 CERN SCEM 29.30.10.100.1

“TOB” solder in CERN stores (image: 16.5.2018)

CERN Stores Catalogue

SCEM Code: Search Keyword(s):

29.20.01.E Group: 29.20 29.20.01.FA

29.20.01.F - TIN-LEAD-SILVER WIRE OF WELDING - FOR ELECTRONICS

For any further technical information additional - click here

```
Maker           : MULTICORE
Type            : Sn 62 (LMP) - ERSIN 362
Composition     : Sn 62% - Pb 36 - Ag 2% with 5 cores of pickling compound
Characteristics : Melting temperature : 179°C
                : Traction resistance : 90 MPa
Pickling flux   : Included in the wire, 5 cores of 362 pickling compound (3%)

WARNING         : Incompletely removed flux residues may be corrosive in certain conditions.
Application(s) recommended by the supplier :
For printed circuits, ceramics, silver, electronic equipment.
Example of CERN application(s)
In brazing non-ferrous metals the risk of corrosion through flux residues is small.

Remark : Purity of product not checked. Unsuitable for vacuum applications.
```

Safety Guideline C-5 :Safety Guideline C-5 : Guidelines for the safe use and handling of lead and its compounds at CERN cf. : EDMS 1050102(v.3)

Pickling flux 362 is classed F-SW 26 in standard DIN 8511-2.
It is of the same hazard class as CASTOLIN 197C.

For use, refer to : Data sheet 29.30.30.102

Material Safety Data Sheet (MSDS)
Material Safety Data Sheet (MSDS)

Buy	SCEM Code	Unit	Unit Price	Stock	Expected Delivery	Direct Delivery	Ø WIRE mm	REMARKS	PACKAGE
	29.20.01.349.6	PC	27.0	4	17.05.2018	>=8	1.0	with stripper	0,500 kg coil
	29.20.01.362.9	PC	30.5	18	17.05.2018	>=11	1,2	with stripper	0,500 kg coil
	29.20.01.372.7	PC	52.5	0	09.05.2018	>=8	1,6	with stripper	0,500 kg coil
	29.20.01.385.2	BB	49.5	2	17.05.2018	>=7	1	without stripper	1 kg coil

Eutectic alloy tin-lead for reduced risk of embrittlement.

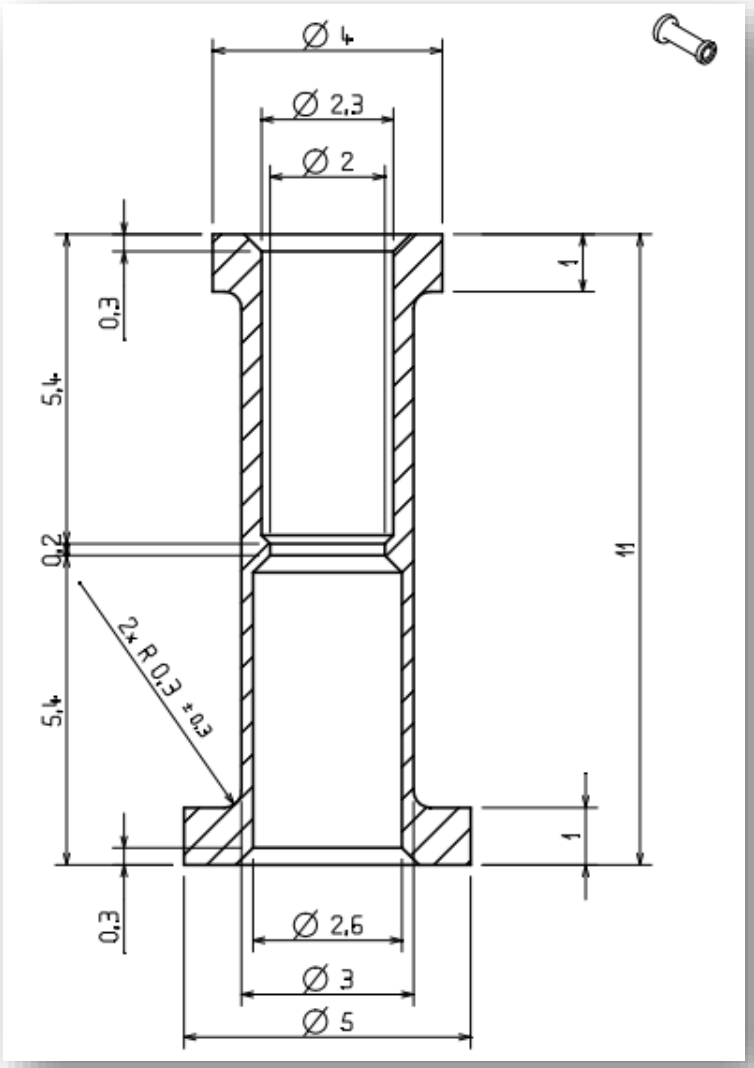
Silver added for strength (~ factor 2 increase).

With tensile strength 90 MPa in TOB-type soldered connections and with 2 mm pipes expect to resist ~500 bar pressures.
Such CuNi pipe with 0.1 mm wall resists ~380 bar.

Ersin Multicore
5-Core Solder

“362” is a rosin activated flux
Data sheet in the spare slides.

TOB solder joint sleeve in brass



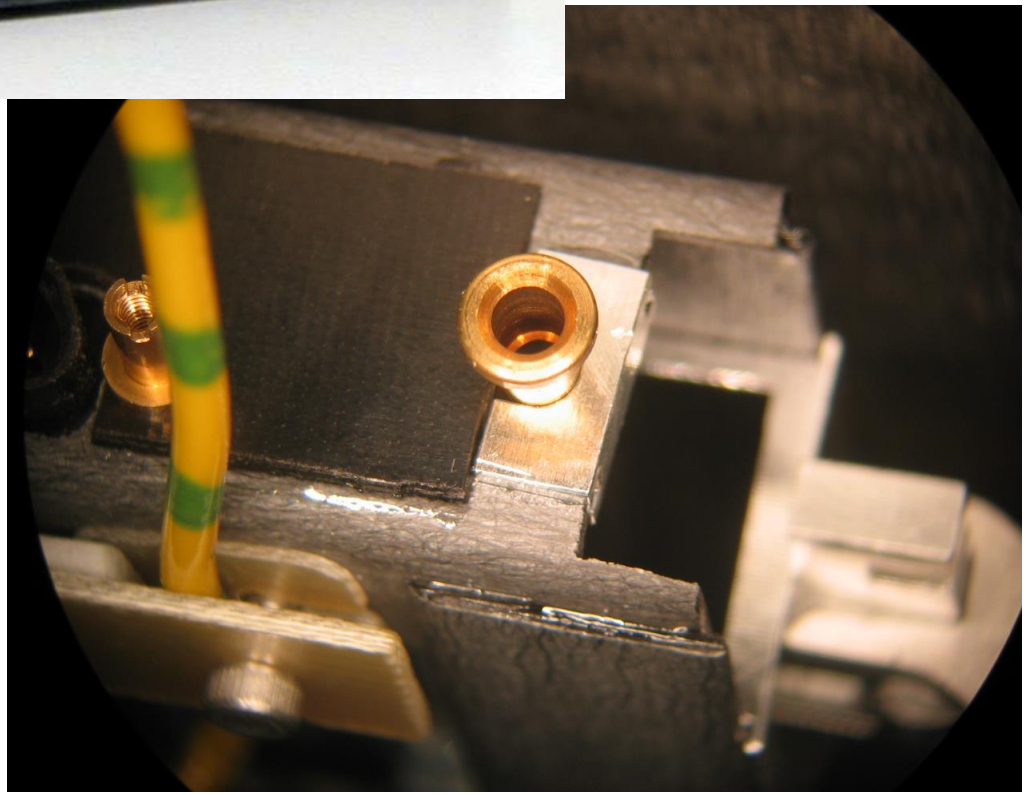
Here a version for joining Ø 2.2 mm and Ø 2.5 mm pipes

- 0.05 mm nominal gap between pipe and sleeve
- Pipe stop in the middle
- End collars have multiple uses
  - Provide contact surface and guide for soldering iron
  - Improve heat distribution around the sleeve, without need to move soldering iron
  - Provide surface area to apply solder
  - Allow surface for a solder fillet to form
  - Allow temporary connections to be made.

Soldering connection pieces to Rod cooling pipes

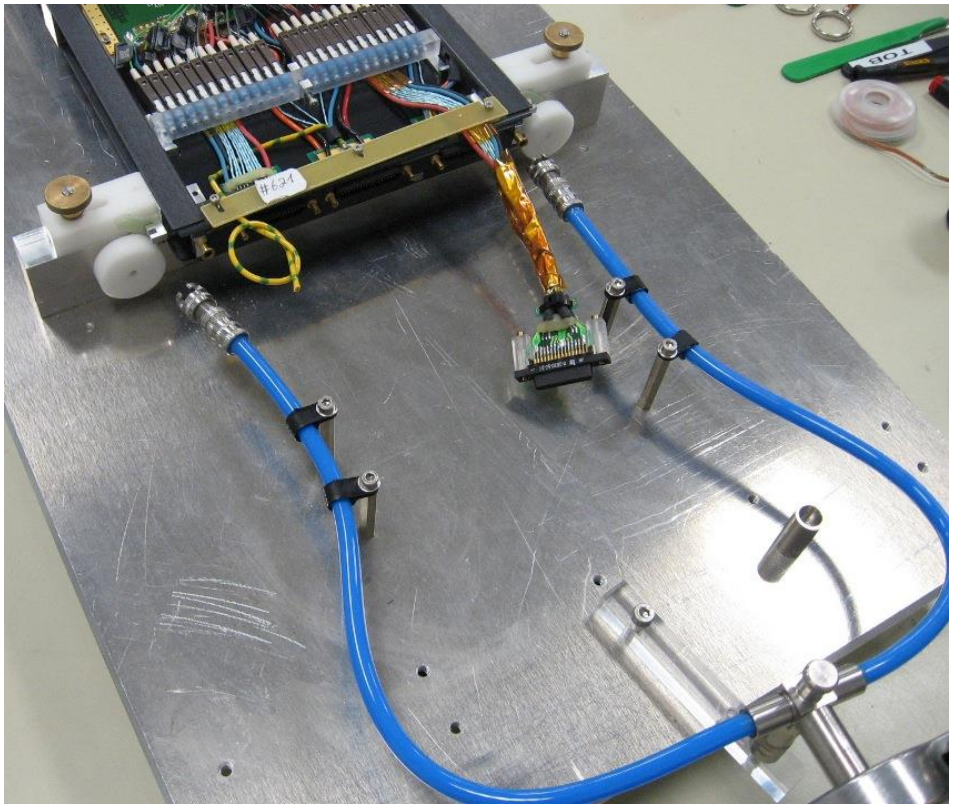
Tip of the soldering iron machined to a concave shape for increased thermal contact area to the pipe and the brass piece

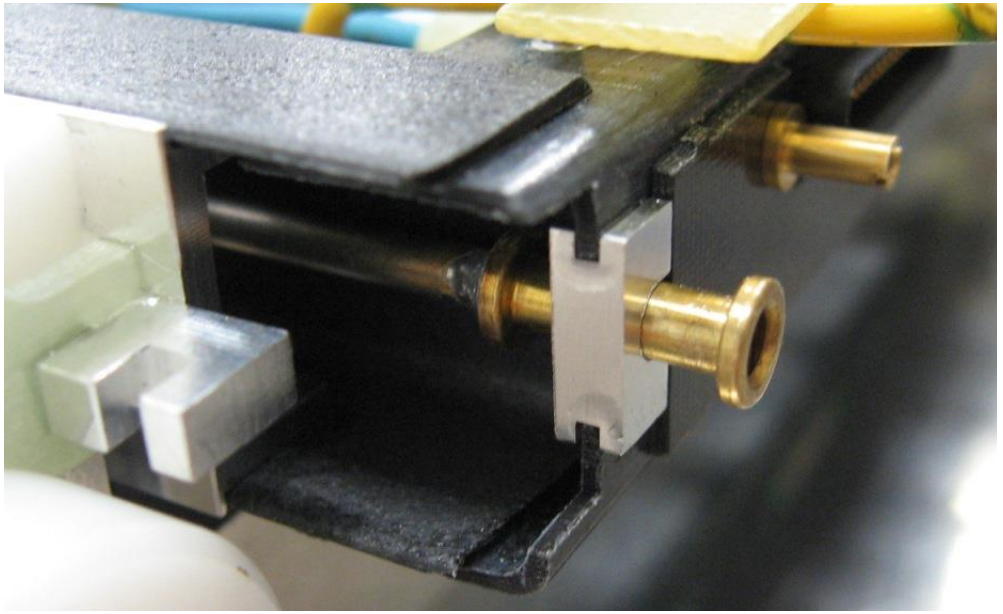
Cooling pipe in the Rod structure



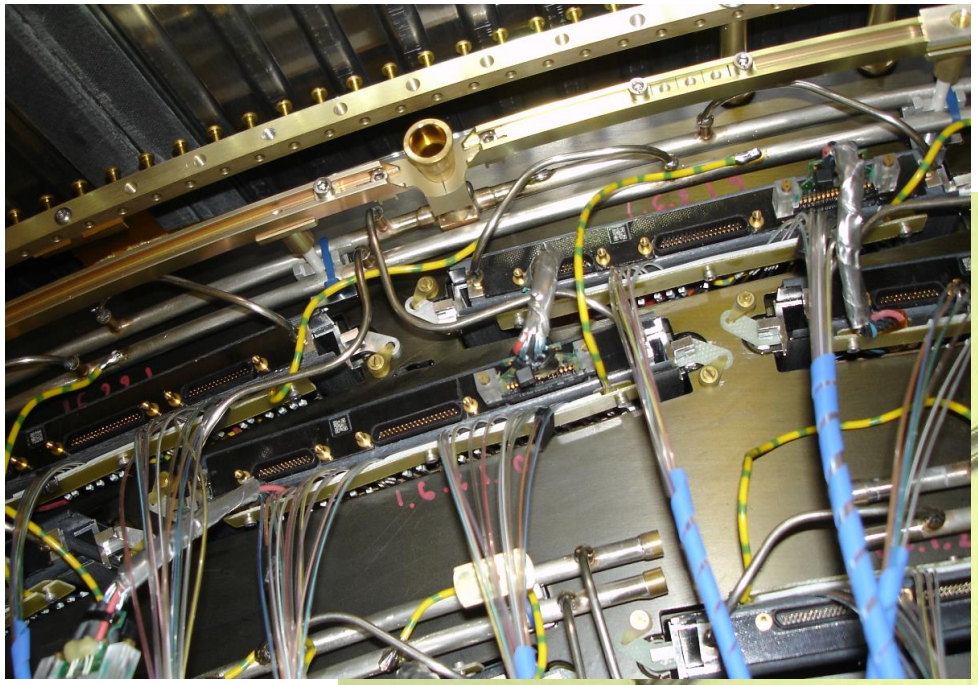
Test phase connections WITHOUT soldering

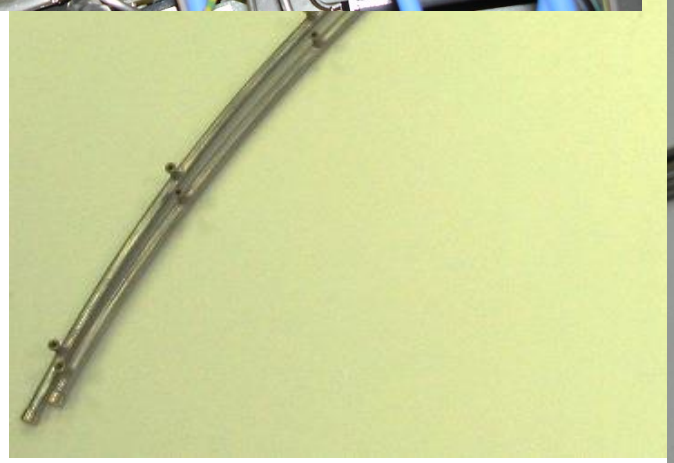
Custom-made **quick-connects**

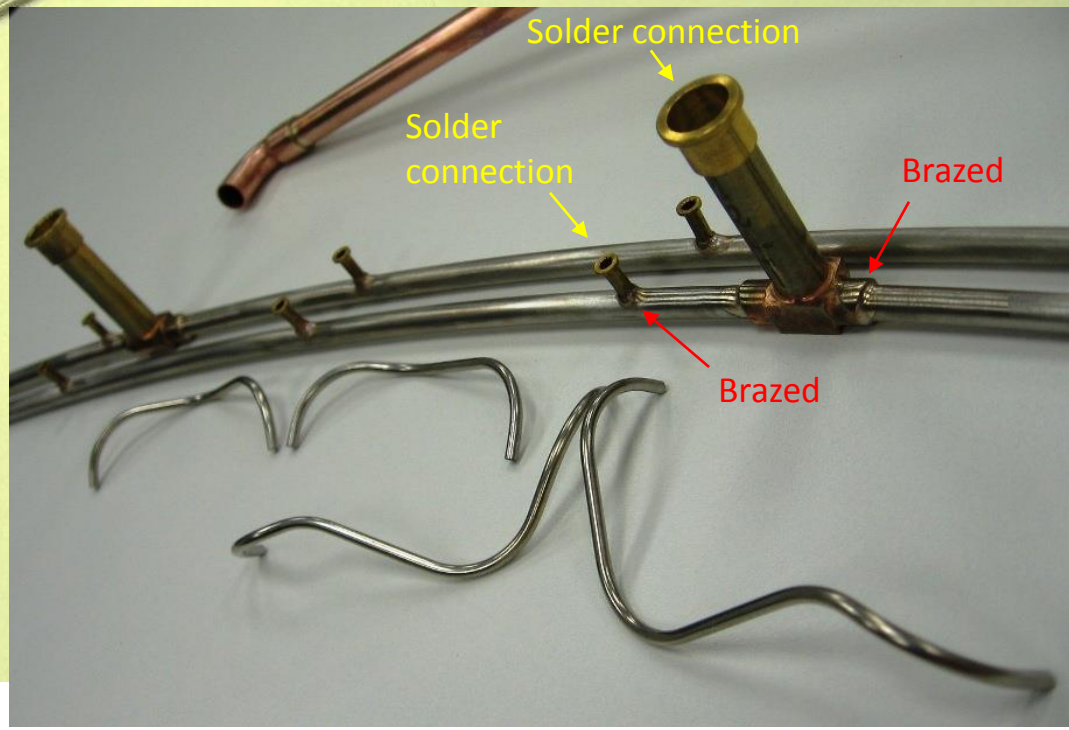




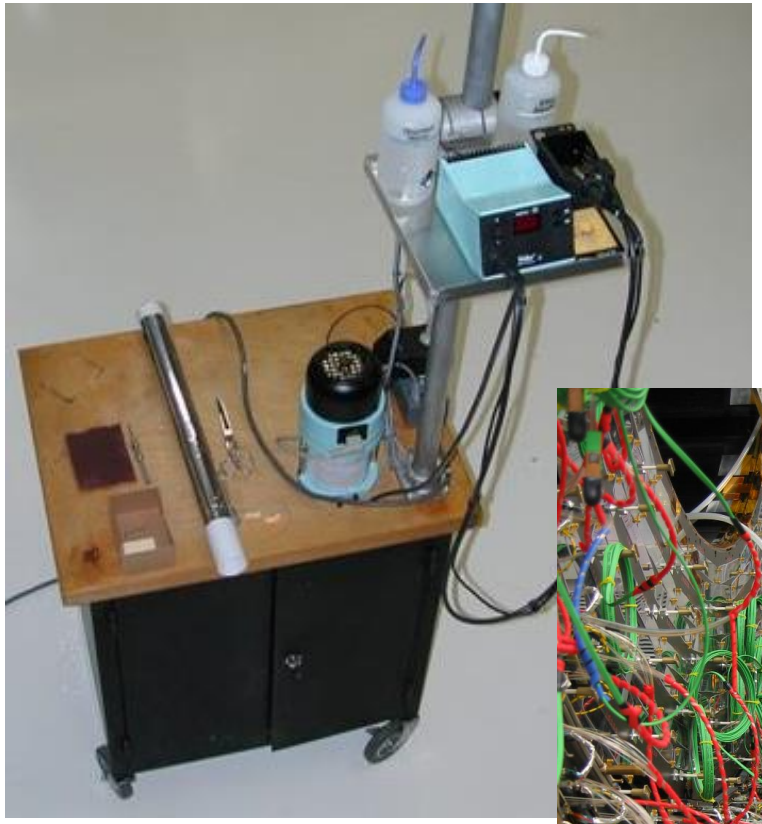
Manifolds and connection pipes

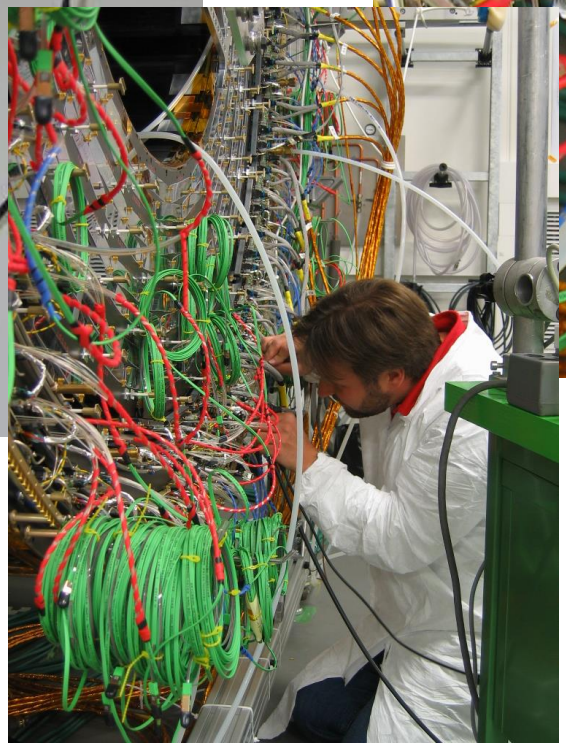


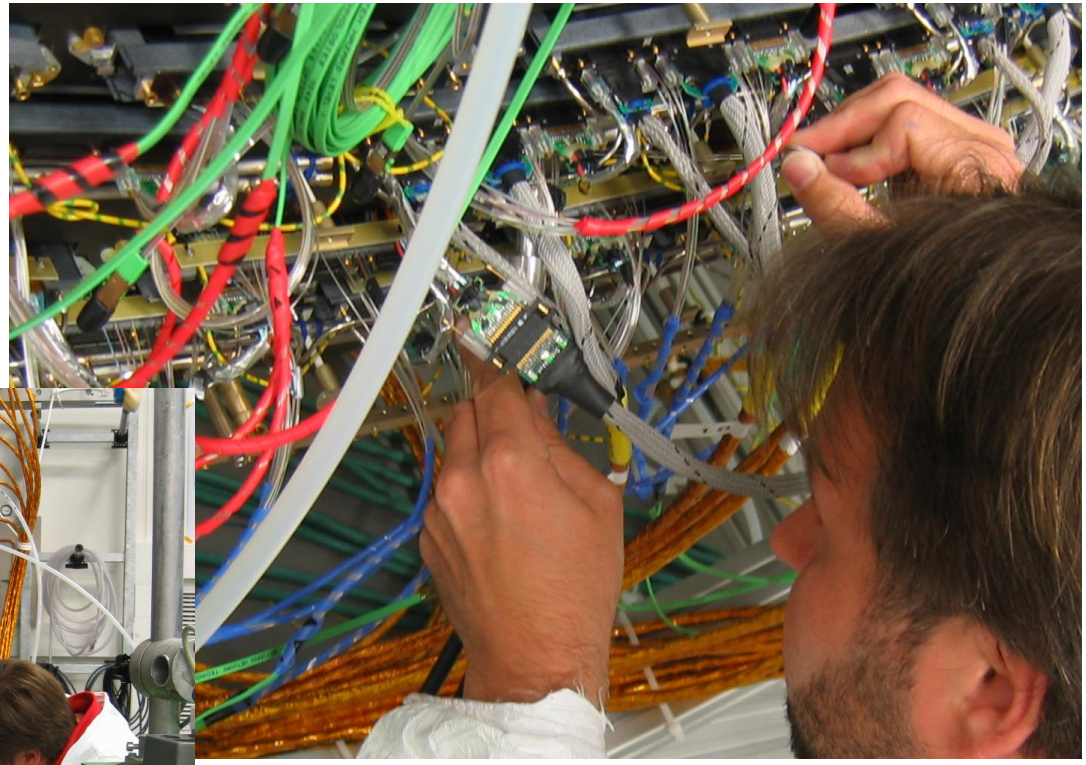




Soldering the final connections







Soldering iron with fume extraction tip

Soldering the final connections

In total 4216 soft solder connections

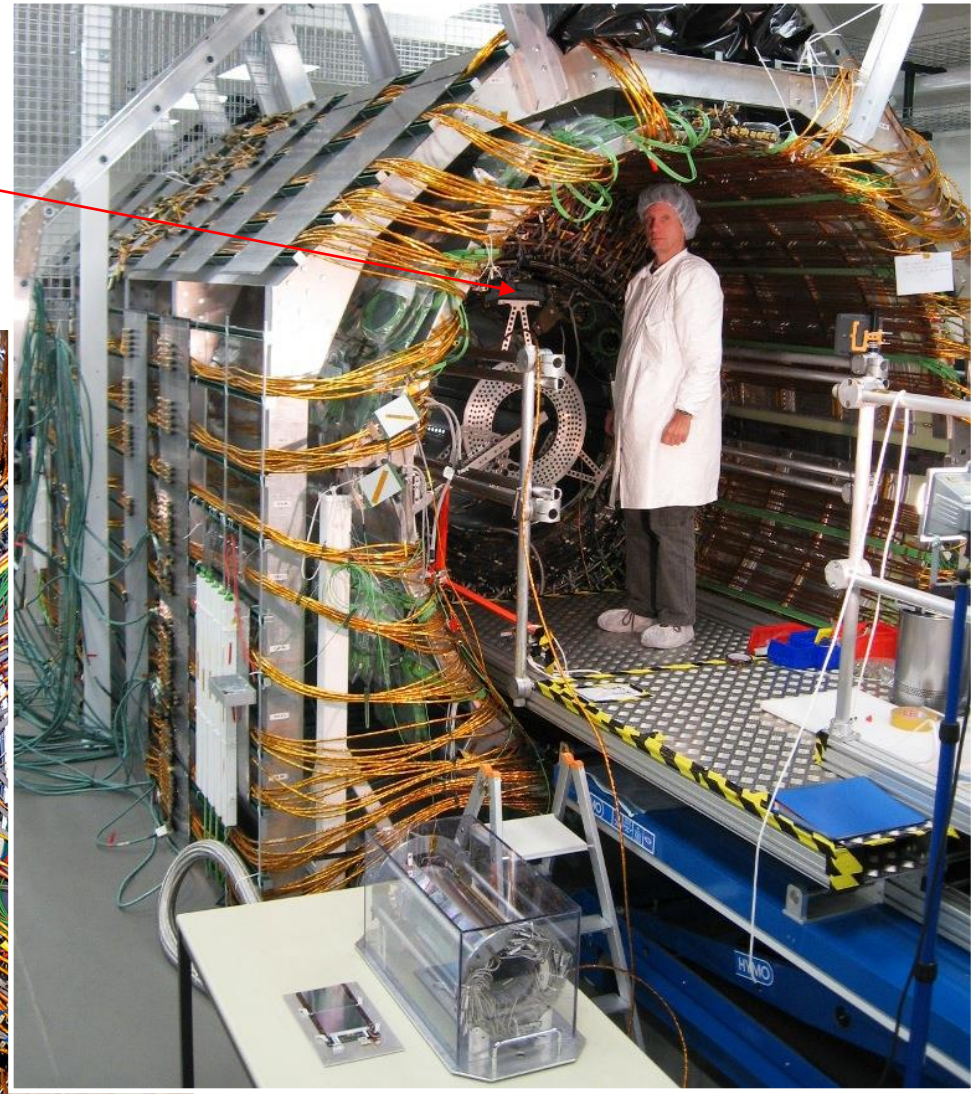
In pipe production:

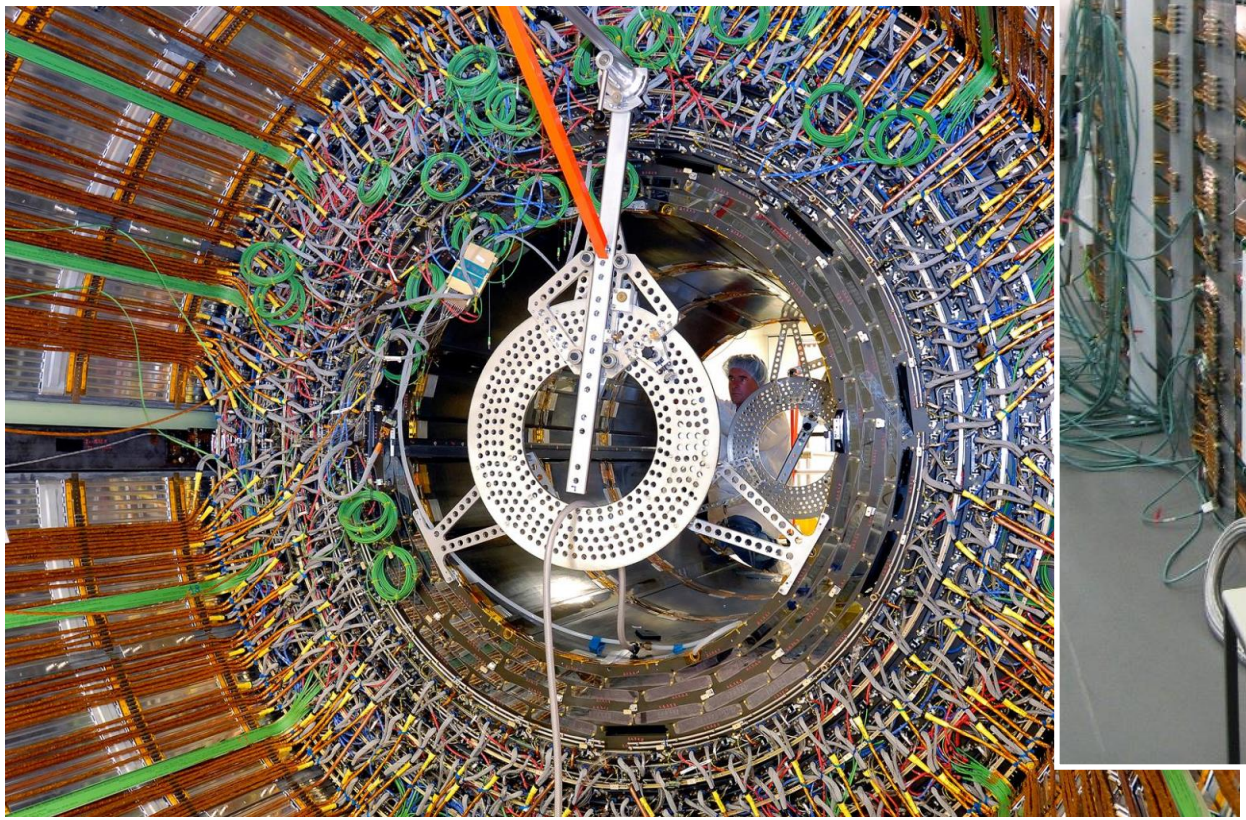
- 688 Rods x 2 connection pieces

In final detector assembly:

- 688 Rods x 2 connection pipes x 2 solder connections
- 44 supply + 44 return feed pipes

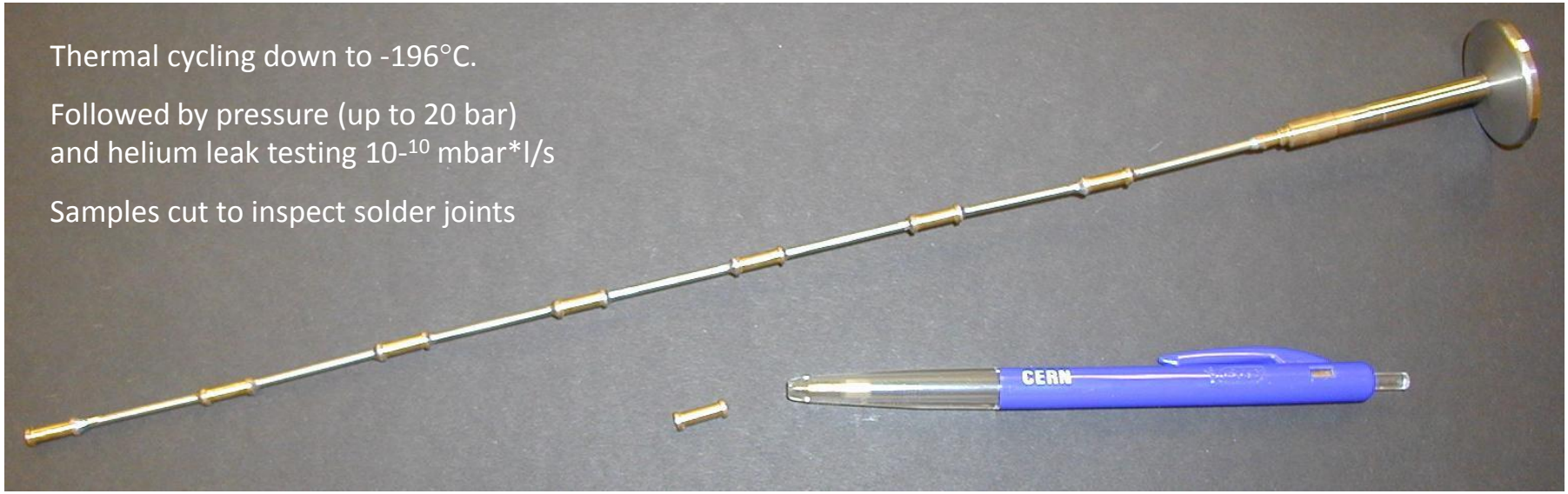
~50% of the solder connections was done there



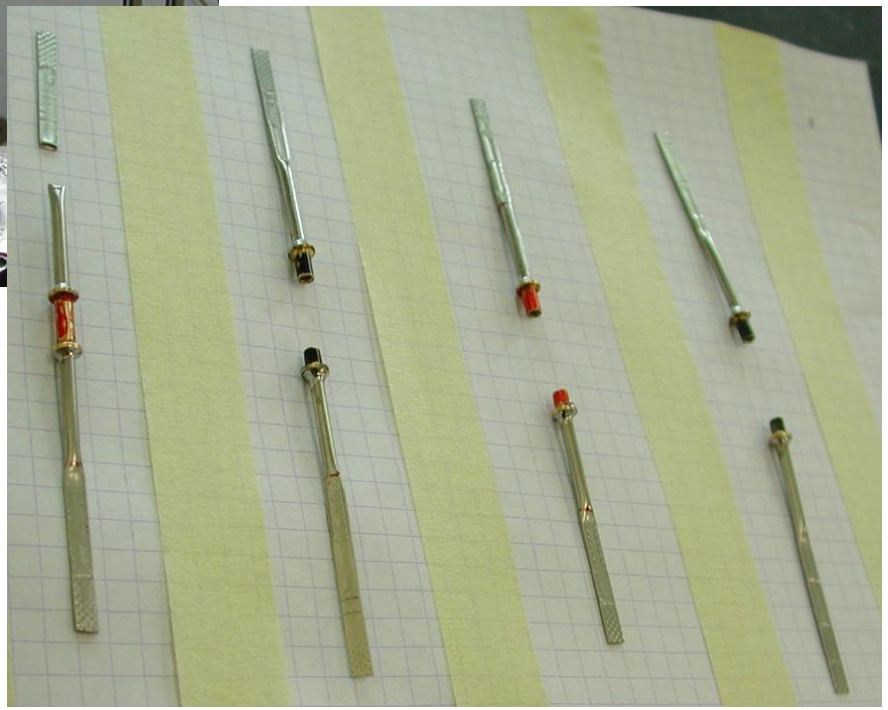


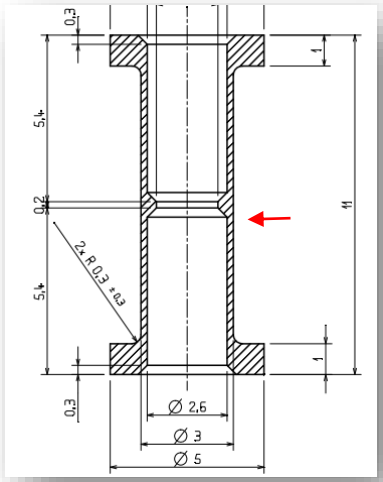
Testing

Some early-on proto tests



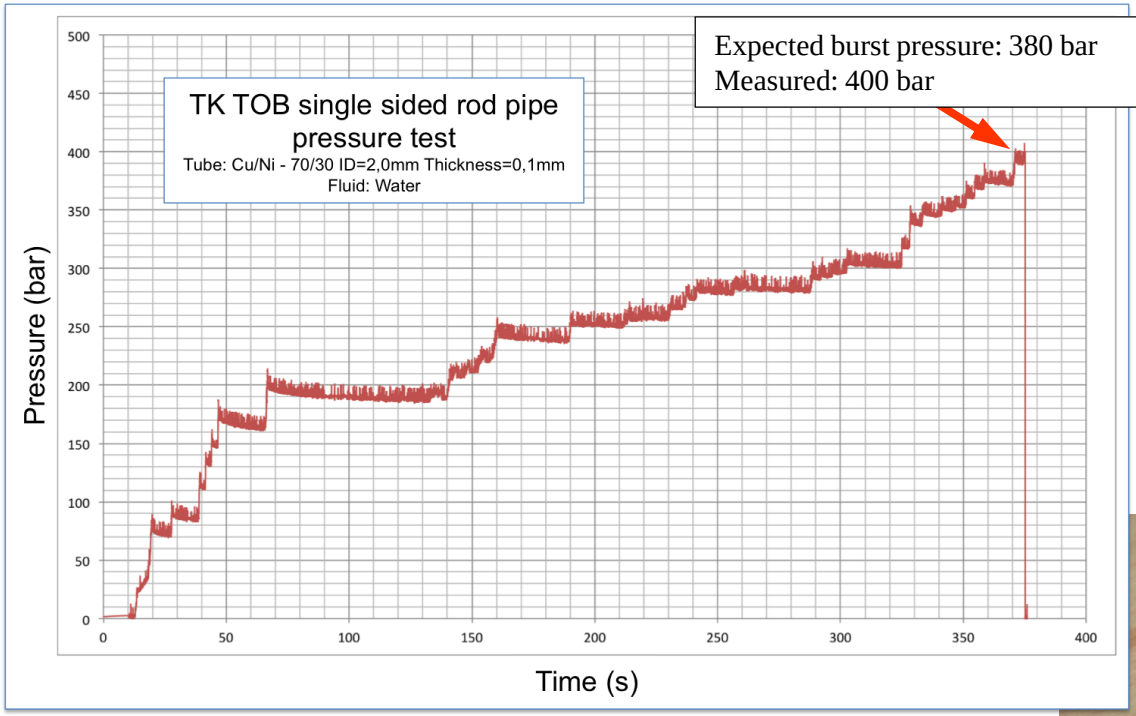
Some early-on proto tests



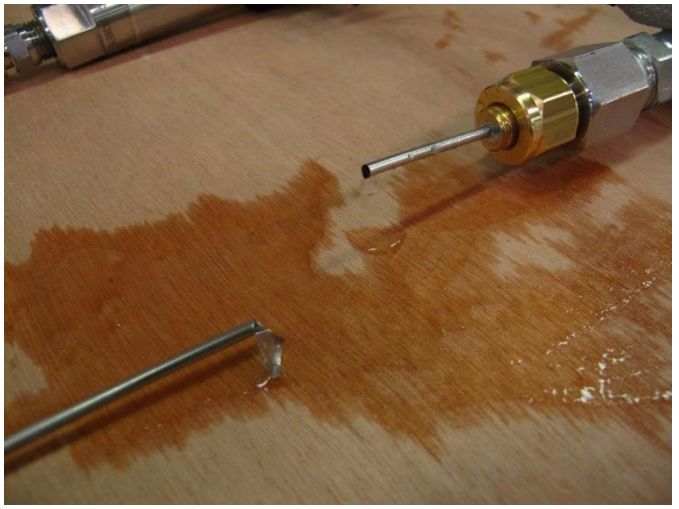


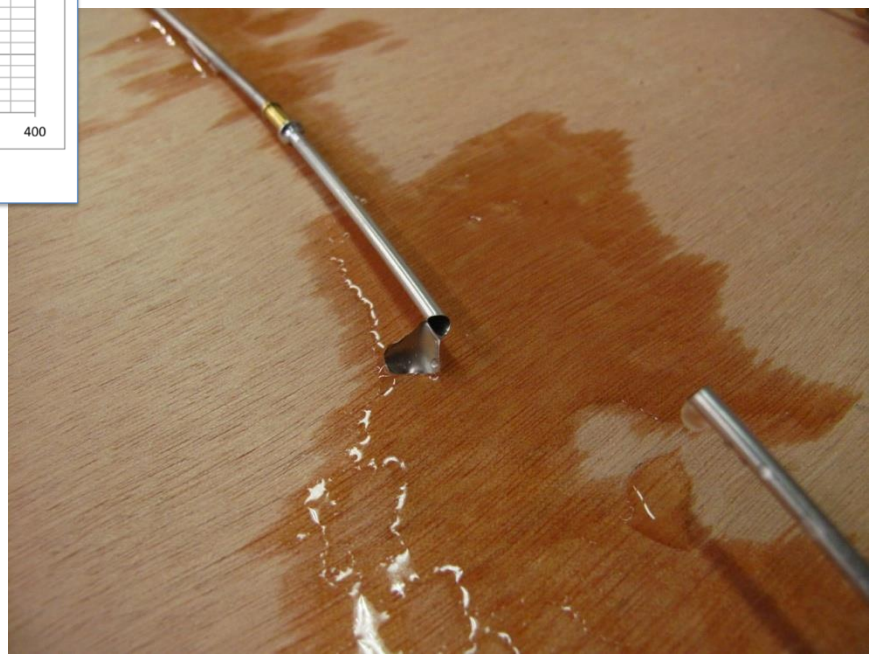
- 3 broken in the brass connector at wall-thickness discontinuity and where no pipe / no solder
- 1 broken in the pipe in pre-deformed flat-round transition
- None broken in the solder itself

High-pressure tests much later (in view of possible CO_2 use)



Jérôme DAGUIN, CERN

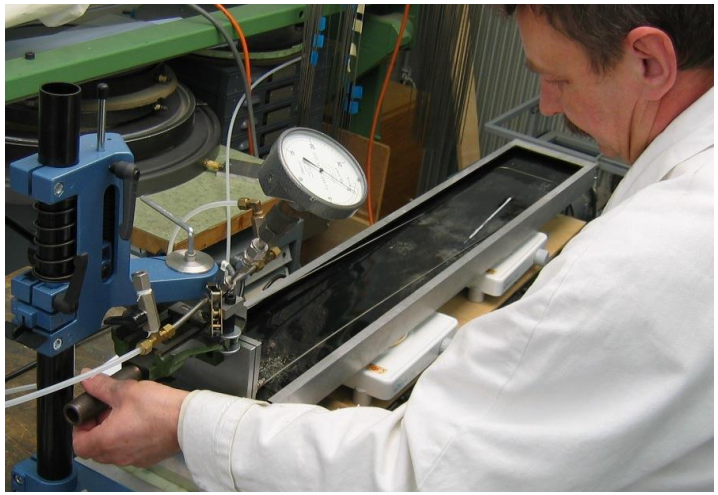




- OD 2.2 mm, ID 2.0 mm CuNi pipe broken at 400 bar
- No leaks or visible damage in solder joints

Testing during series production

1. Water bath test with 20 bar air pressure in the cooling pipe
2. Vacuum test with He at various stages of Rod assembly and after installed + soldered to the final manifolds.
3. Before final vacuum-He test the completed TOB cooling segment was pressurised to 15 bar. No pressure decay measurement, but a ‘stress-test’ followed by the He leak test.



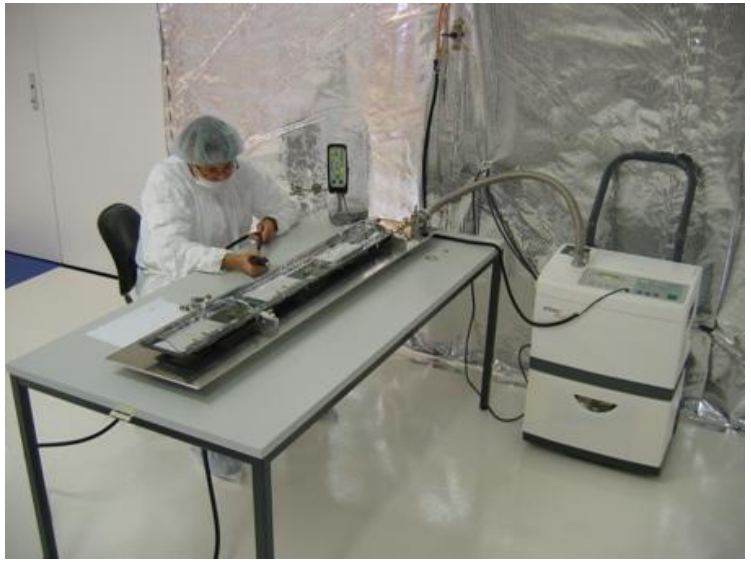
THE problem (with the pipes not with the solder)

"Bubble test" of bent and soldered rod pipes with water and 20 bar air
→ **850 pipes tested, 10% of them leaked !**

Leaks never in the pipe bends or in the solder joints…!?

- The straight pipes were supposed to be pressure tested at the factory. Did they really test them and how (we should have checked!)
- If we would have known earlier would have taken action, but we learned this only gradually during the pipe production and finally the 90% yield was ok as we had enough of spare material.
- The probably cause of the leaks was analysed by Atlas people (studying use of 70 um wall CuNi pipes) to be the grain size of the pipe wall material that created in the thin wall a local "hole". If the metal lattice grains are of the size of the pipe wall-thickness, such grain may get removed, creating a hole. The positions of the holes were in our case completely random, and none of them were in the few bends (the bends represent about 5% of the total pipe length).
- Heat-treatment, to reduce the grain size, may solve this problem.

The problem reappearing



During later production steps He leak-detection, test in vacuum mode.

Alarm limit set at 10^{-8} mbarl/s (bubble-test at best ~10^{-5} mbarl/s).

Fortunately, only ~ 1% of pipes found now leaking, again always in the pipe wall, even if now with tighter test and after Rods gone through all production chain, thermal cycling, transports, etc.

These leaks were repaired by soldering, to be He leak-tight.

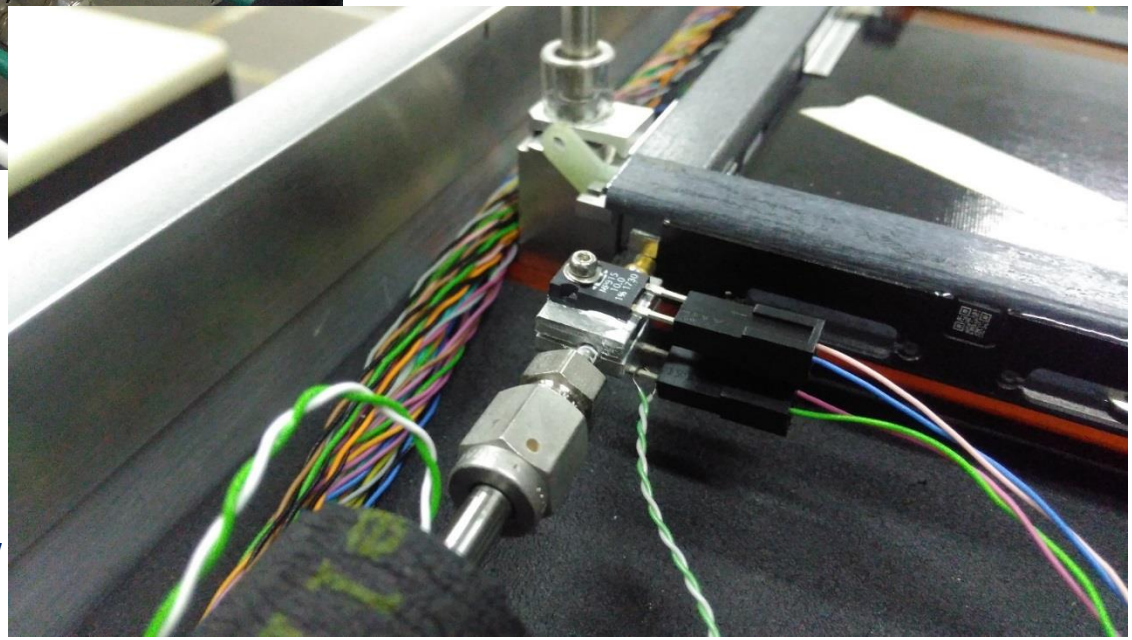
Experiences from the TOB

- Now 10 years of reliable operation, with about half of the time at -20 C coolant temperature.
- Copper-nickel + brass + soldered joints:
  - Soldering, even in-situ in difficult conditions, works ok
  - Need appropriate tools, methods and trained persons. Surfaces must be correctly prepared !
  - Easy soldering yields also possibility to repair, and to make electrical connections (grounding)
  - We had one real problem: quality of thin-wall CuNi pipes. Should be solvable, but remains to be proven (to me). Lesson: Watch the micro-structure and quality of the pipes (e.g. scratches in 0.1 mm wall could be a problem), not only the connections!
  - Another worry: activation of silver (in solder). But in TOB only 5 g, much less than in the silver-plated aluminum cables
- Leak-testing
  - Absolutely necessary, and must be thought and tried in advance before production
  - Bubble-test ok for coarse QC, but rather slow and operator dependent
  - Happy with He –leak testing, in particular in vacuum mode:
    simple to use, high-precision (spot very small leak-sizes and precisely localize them)

- Is there future for soft solder also with higher pressures, with CO_2?
  - Strength for small (~2 mm pipes) is enough
  - Creep data for many solders exists, but need to be further investigated under relevant load conditions
  - To be further developed and studied if using other pipe materials (e.g. stainless steel or titanium).

CO_2 cooling tests on-going, using original TOB Rods

Thomas French, CERN



Adaptor soldered to Rod pipe to allow use of dismountable VCR coupling

Spares

Multicore ERSIN 362 flux

Technical Data Sheet

Multicore® Solder Cored Wire Flux 362 & 366

June 2004

ROSIN BASED CORED SOLDER WIRE FLUXES

Properties of Multicore 362 and 366 solid fluxes for cored solder wire:

- **Good wetting on most common surfaces**
- **Two activity levels: Multicore 362 for general work and Multicore 366 for more difficult surfaces**
- **Non-corrosive**
- **Fast soldering**
- **Rosin based**
- **Halide activated**

PRODUCT RANGE

Multicore 362 and 366 cored wires are manufactured with a range of flux contents. Although users will normally be using products with a nominal flux content of 3%.
Multicore 362 and 366 cored wires are available in a variety of alloys conforming to J-STD-006 and EN 29453 or alloys conforming to similar national or international standards. For details refer to document "Properties of Alloys used in Cored Solder Wires". A wide range of wire diameters is available. Alternative flux contents and alloys may be manufactured to special order.

TECHNICAL SPECIFICATION

A full description of test methods and detailed test results are available on request.

Alloys: The alloys used for Multicore flux cored solder wires conform to the purity requirements of the common national and international standards. A wide range of wire diameters is available manufactured to close dimensional tolerances. For details refer to document "Properties of Alloys used in Cored Solder Wires ".

Flux: Multicore 362 and 366 solid flux leave dry and non-sticky residues. In use its odour is typically that of rosin fluxes.

TYPICAL FLUX PROPERTIES		
Test	362	366
Acid value	170mgKOH/g	158mgKOH/g
Halide content	<0.5%	1.0%
SIR Test (without cleaning) J-STD-004	Pass	Pass
Classification J-STD-004 EN29451-1	ROL1 1.1.2	ROM1 1.1.2

SPECIAL PROPERTIES

Surface Insulation Resistance: Multicore 362 and 366 flux pass the J-STD-004 SIR test and other elements of J-STD-004 test protocols associated with the flux classification ROL1 for 362 and ROM1 for 366.

Electromigration Test: Multicore 362 and 366 pass the Bellcore GR-78-CORE Electromigration tes

RECOMMENDED OPERATING CONDITIONS

Soldering iron: Good results should be obtained using a range of tip temperatures. However, the optimum tip temperature and heat capacity required for a hand soldering process is a function of both soldering iron design and the nature of the task and care should be exercised to avoid unnecessarily high tip temperatures for excessive times. A high tip temperature will increase any tendency to flux spitting and it may produce some residue darkening.

The soldering iron tip should be properly tinned and this may be achieved using Multicore cored wire. Severely contaminated soldering iron tips should first be cleaned and pre-tinned using Multicore Tip Tinner/Cleaner TTC1, then wiped on a clean, damp sponge before re-tinning with Multicore cored wire.

Soldering process: Multicore cored wires contain a careful balance of resins and activators to provide clear residues, maximum activity and high residue reliability, without cleaning in most situations. To achieve the best results from Multicore solder wires, recommended working practices for hand soldering should be observed as follows:

- Apply the soldering iron tip to the work surface, ensuring that it simultaneously contacts the base material and the cmponent termination to heat both surfaces adequately. This process should only take a fraction of a second.
- Apply Multicore flux cored solder wire to a part of the joint surface away from the soldering iron and allow to flow sufficiently to form a sound joint fillet – this should be virtually instantaneous. Do not apply excessive solder or heat to the joint as this may result in dull, gritty fillets and excessive or darkened flux residues.
- Remove solder wire from the work piece and then remove the iron tip.

The total process will be very rapid, depending upon thermal mass, tip temperature and configuration and the solderability of the surfaces to be joined.

Henkel Technologies

Multicore flux cored solder wires provide fast soldering on copper and brass surfaces as well as solder coated materials. Activity of the halide activated versions on nickel is also good depending on the state of oxidation of the nickel finish. The good thermal stability of Multicore fluxes means they are also well suited to soldering applications requiring high melting temperature alloys.

Cleaning: Multicore 362 and 366 cored solder wires have been formulated to leave pale flux residues and to resist spilling and fuming.
Cleaning will not be required in most situations but if necessary this is best achieved using Multicore MCF800 Cleaner (see separate technical data sheet). Other proprietary solvent or semi-aqueous processes may be suitable. Saponification may be viable but customers must ensure that the desired level of cleanliness can be achieved by their chosen system.

HEALTH AND SAFETY

Warning: The following information is for guidance only and users must refer to the Material Safety Data Sheets relevant to specific Multicore 362 and 366 products before use.

Health Hazards and Precautions: Inhalation of the flux fumes given off during soldering should be avoided. The fumes are irritating to the throat and respiratory system. Prolonged or repeated exposure to rosin or modified rosin based flux fumes may lead to the development of respiratory sensitisation and occupational asthma.
Multicore solder wires must always be used with suitable fume extraction equipment to remove fumes from the breathing zone of operators and the general work environment.
Solder alloys containing lead give off negligible fume at normal soldering temperatures up to 500°C.
Normal handling of lead alloy wires will not cause lead to be absorbed through the skin. The most likely route of entry is through ingestion but this will not be significant if a good standard of personal hygiene is maintained. Eating, drinking and smoking should not be permitted in the working area. Hands should be washed with soap and warm water after handling solder wire.

Waste disposal: Wherever possible, waste solder wire should be recycled for recovery of metal. Otherwise it should be disposed of according to local or national regulations.

Note
The data contained herein are furnished for information only and are believed to be reliable. We cannot assume responsibility for the results obtained by others over whose methods we have no control. It is the user's responsibility to determine suitability for the user's purpose of any production methods mentioned herein and to adopt such precautions as may be advisable for the protection of property and of persons against any hazards that may be involved in the handling and use thereof. In light of the foregoing, **Henkel Corporation specifically disclaims all warranties expressed or implied, including warranties of merchantability or fitness for a particular purpose, arising from sale or use of Henkel Corporation's products. Henkel Corporation specifically disclaims any liability for consequential or incidental damages of any kind, including lost profits.** The discussion herein of various processes or compositions is not to be interpreted as representation that they are free from domination of patents owned by others or as a license under any Henkel Corporation patents that may cover such processes or compositions. We recommend that each prospective user test his proposed application before repetitive use, using this data as a guide. This product may be covered by one or more United States or foreign patents or patent applications.

NOT FOR PRODUCT SPECIFICATIONS
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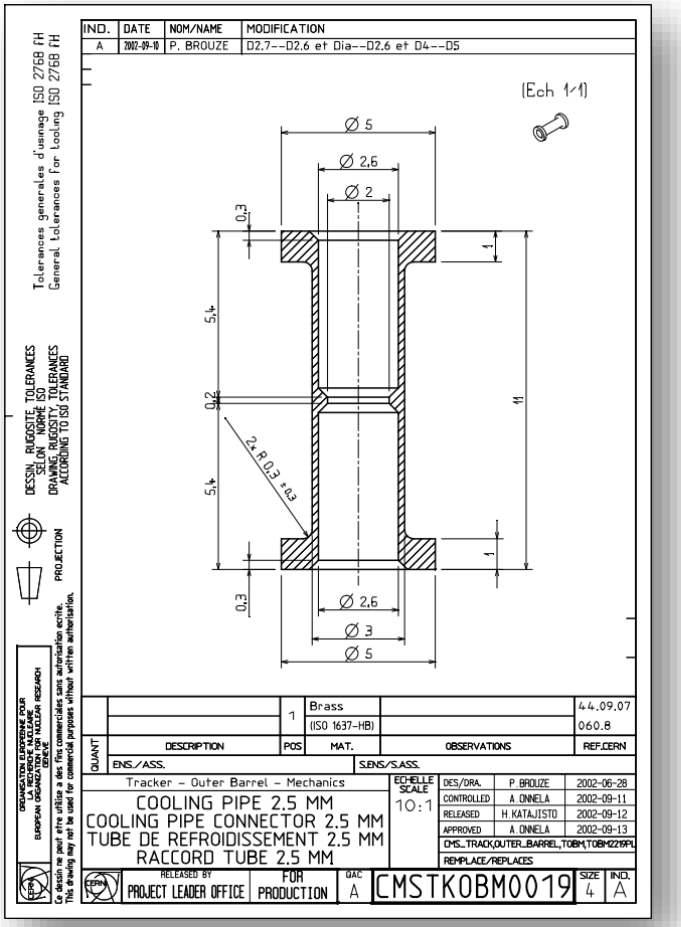
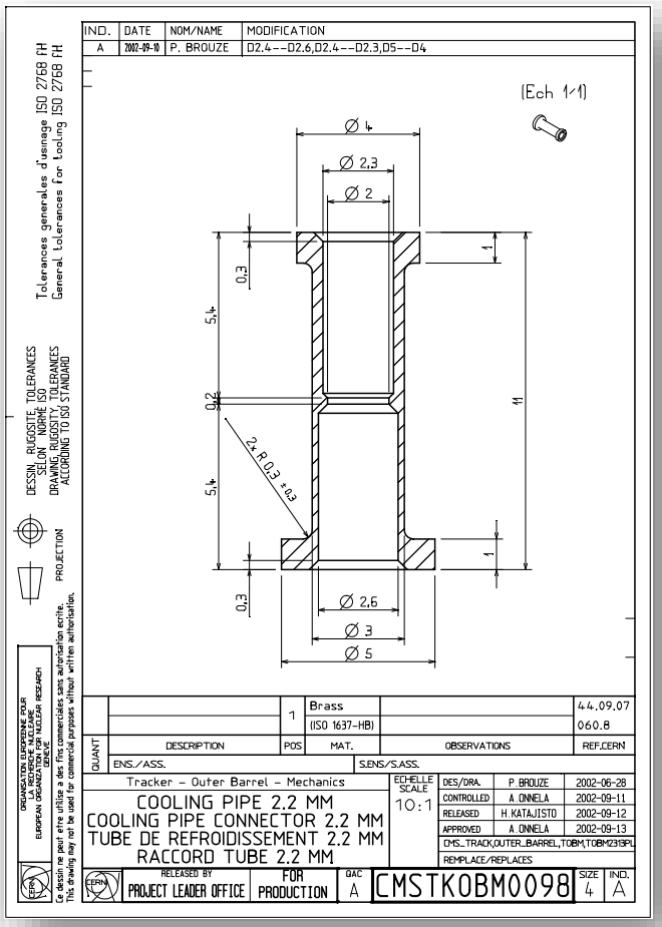
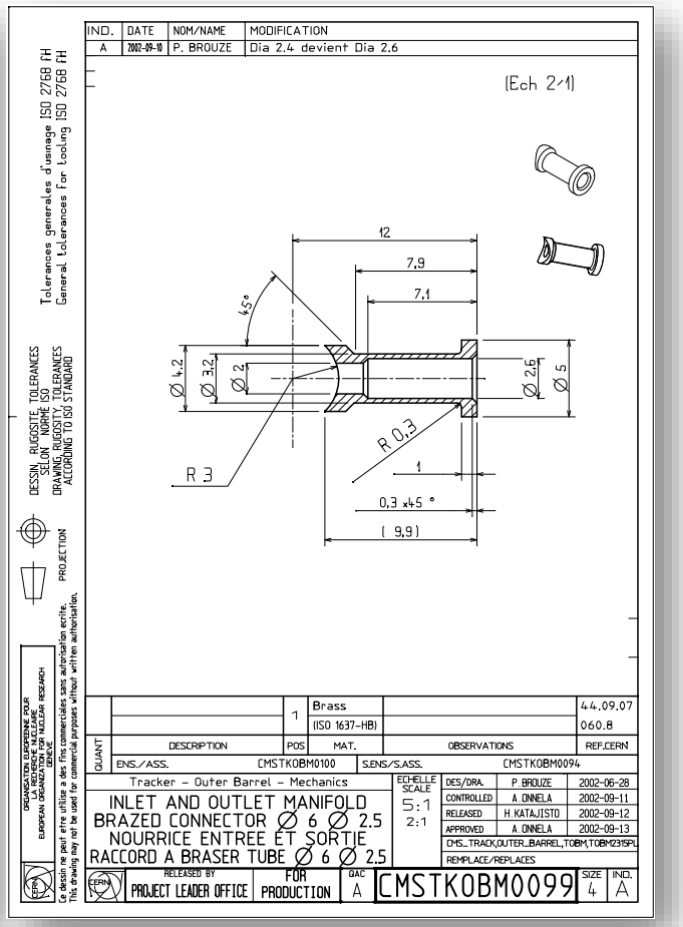
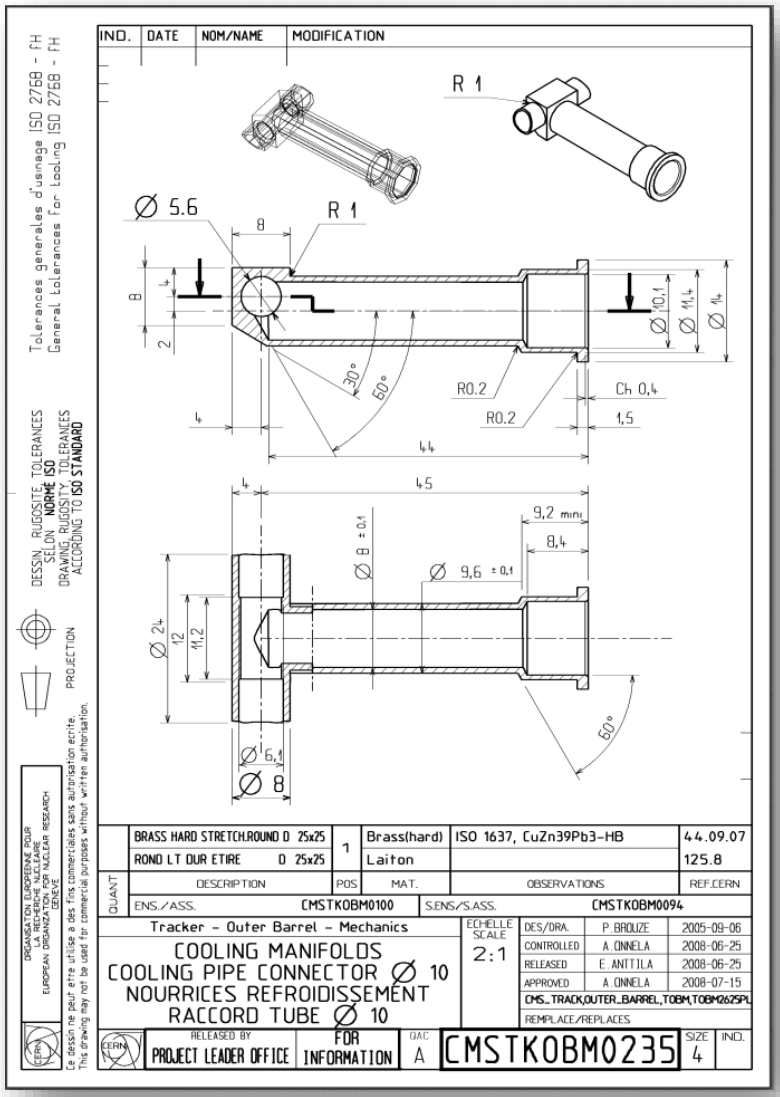
Brass connectors



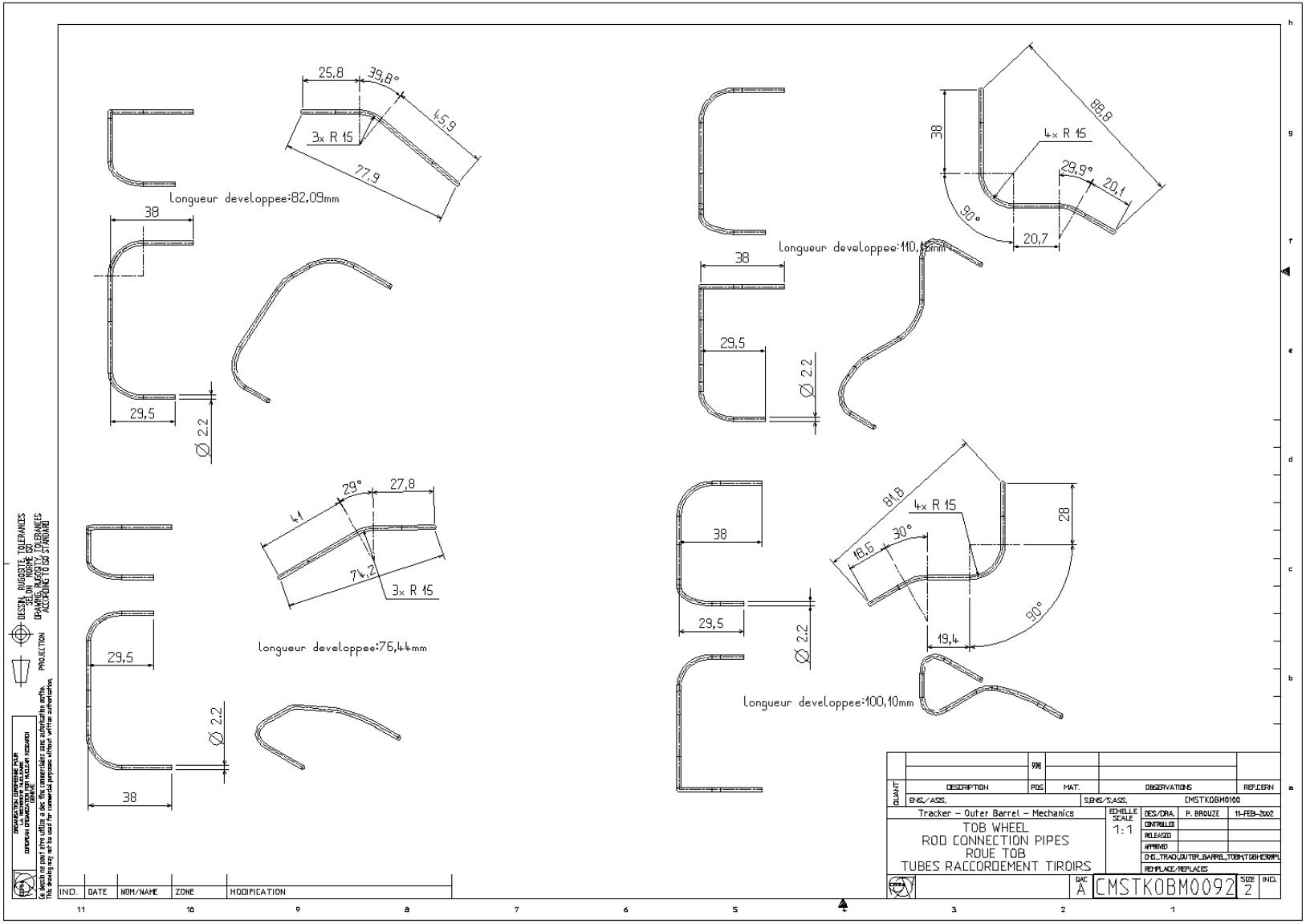




Manifold connector

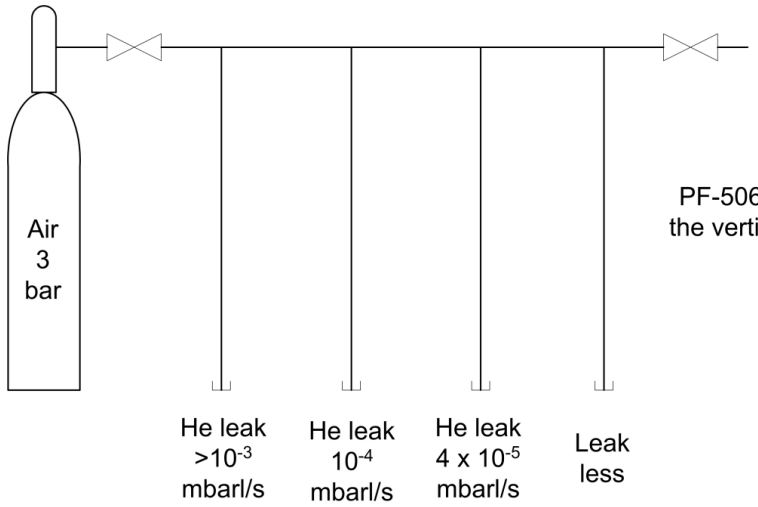


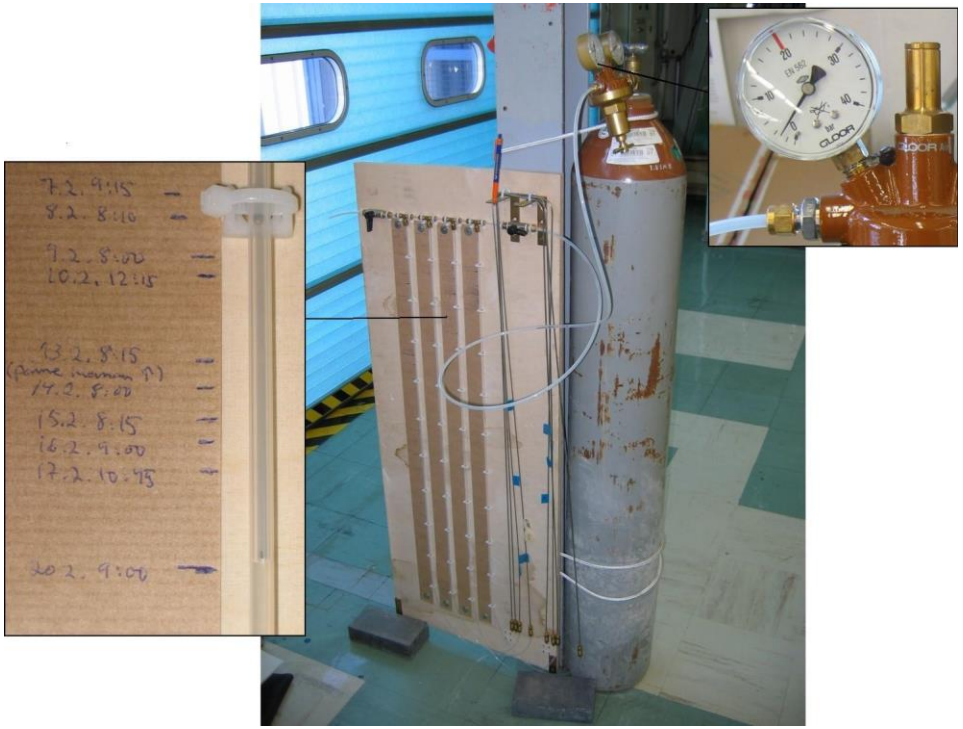
Connection pipes



Relevance of leaks?

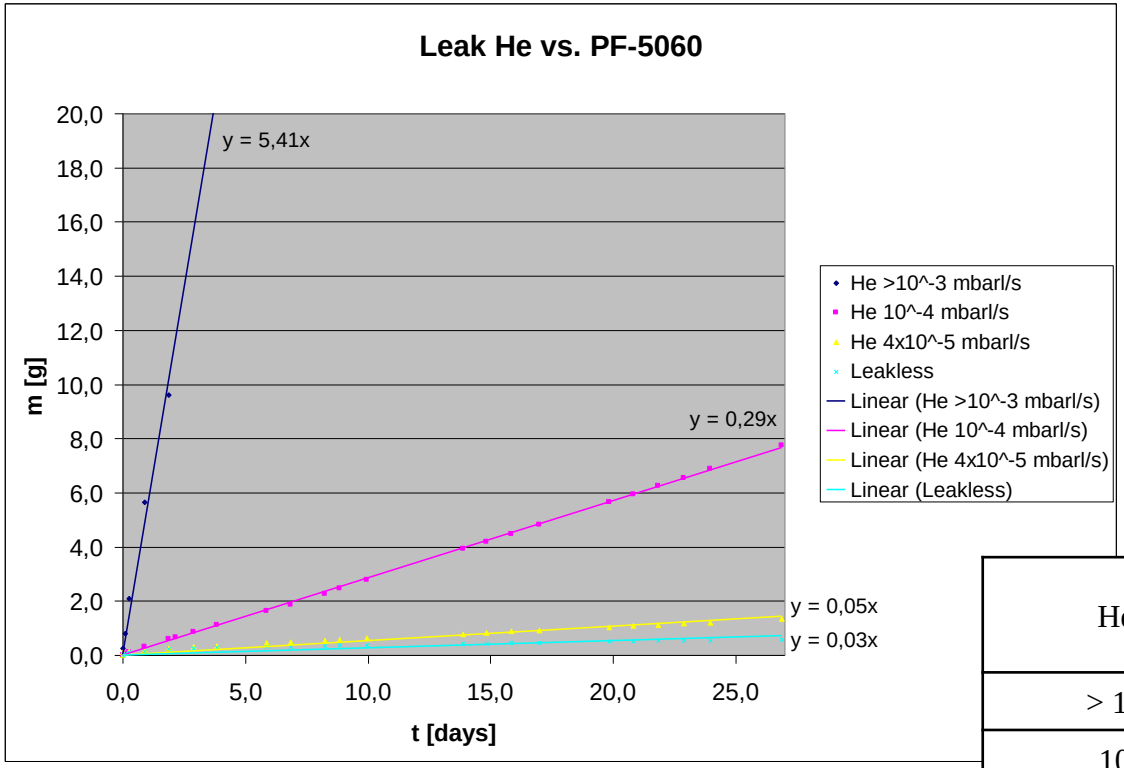
- Losses of final cooling fluid C_6F_{14} (PF-5060) are relevant both financially (~100 CHF/kg) and environmentally (global warming potential of about 7400 times higher than CO_2).
- Correspondence between Helium leak and the leaks of the final cooling fluid studied using final type rod pipes with varying levels of measured leaks.





Erkki ANTTILA, Helsinki Institute of Physics

Relevance of leaks?



He leak size	Loss of PF-5060	
	[g/a]	[ml/a]
> 10^{-3} mbarl/s	1870	1113
10^{-4} mbarl/s	105	63
4 x 10^{-5} mbarl/s	18	11
< 10^{-10} mbarl/s	8	5

Bubble-test can spot leaks down to 10^{-5} mbarl/s of He, i.e. to ~10 g/a of the final fluid PF-5060.

With He testing (1000-100'000x more sensitive) drop to insignificant leak levels for fluid loss.

But, even tiny leaks are signs of weak-spots, which can become problems in long-term operation.