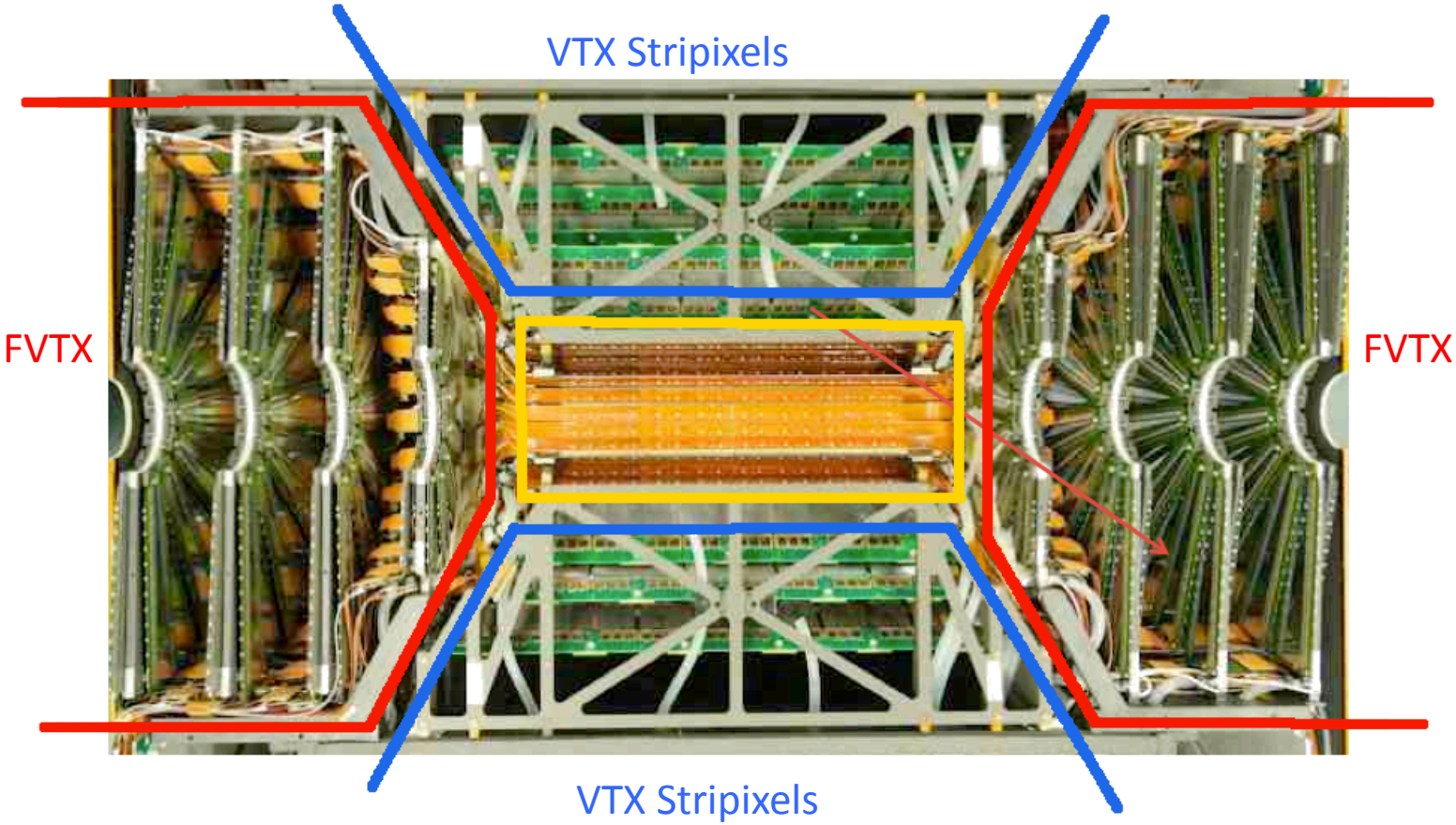
VTX leak issue

Hubert van Hecke

The full archive of the investigation can be found at
http://www.phenix.bnl.gov/WWW/fvtx/Mechanics/Cooling/vtx/vtx_leaks.html

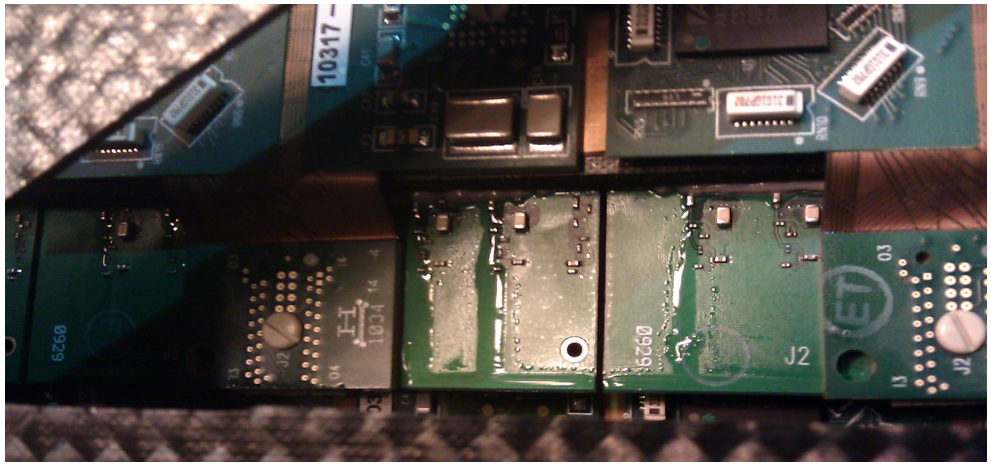
The device



FVTX: 2x4 layers of silicon strips
VTX pixels: 2 barrels of silicon pixels (barrels 1 and 2)
VTX stripixels: 2 barrels of silicon stripixels (barrels 3 and 4)

The problem

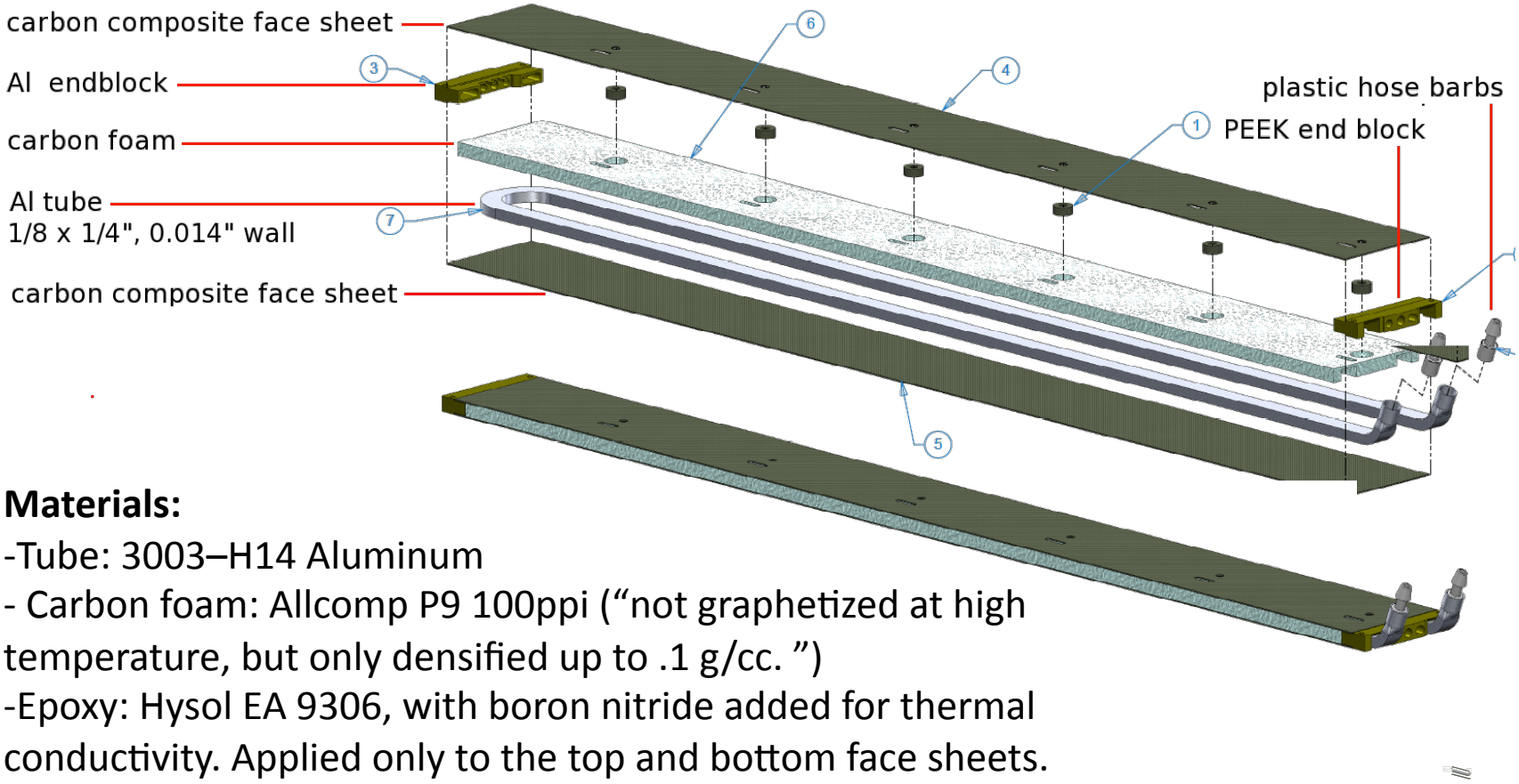
- At the start of operations (Dec 17), massive leaks were observed (~2 gals/day), only in layer 4 (outermost) of the stripixels



Pressure tests were done to establish that the leaks were not coming from the pixels, or from the VTX pixel barrels 1 or 2, or from the FVTX.

Cooling stave

There are xx staves that make up stripixel barrel 4. Silicon stripixel assemblies are mounted onto these cooling staves (not shown).



Materials:

-Tube: 3003–H14 Aluminum

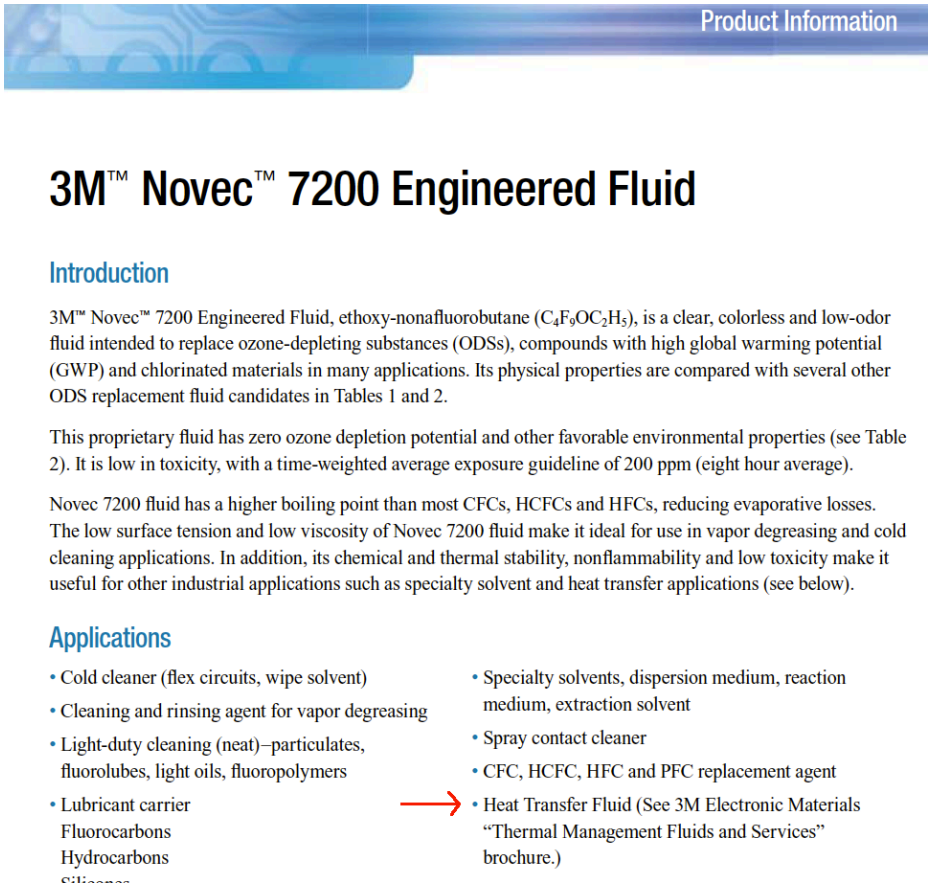
- Carbon foam: Allcomp P9 100ppi (“not graphetized at high temperature, but only densified up to .1 g/cc. ”)

-Epoxy: Hysol EA 9306, with boron nitride added for thermal conductivity. Applied only to the top and bottom face sheets.

-PEEK is a radhard plastic

Cooling liquid

- Novec 7200, made by 3M
- This is a non-conductive, non-corrosive liquid
- Density 1.5, shear viscosity ½ of water.
- Environmentally benign



Product Information

3M™ Novec™ 7200 Engineered Fluid

Introduction

3M™ Novec™ 7200 Engineered Fluid, ethoxy-nonafluorobutane ($C_4F_9OC_2H_5$), is a clear, colorless and low-odor fluid intended to replace ozone-depleting substances (ODSs), compounds with high global warming potential (GWP) and chlorinated materials in many applications. Its physical properties are compared with several other ODS replacement fluid candidates in Tables 1 and 2.

This proprietary fluid has zero ozone depletion potential and other favorable environmental properties (see Table 2). It is low in toxicity, with a time-weighted average exposure guideline of 200 ppm (eight hour average).

Novec 7200 fluid has a higher boiling point than most CFCs, HCFCs and HFCs, reducing evaporative losses. The low surface tension and low viscosity of Novec 7200 fluid make it ideal for use in vapor degreasing and cold cleaning applications. In addition, its chemical and thermal stability, nonflammability and low toxicity make it useful for other industrial applications such as specialty solvent and heat transfer applications (see below).

Applications

- Cold cleaner (flex circuits, wipe solvent)
- Cleaning and rinsing agent for vapor degreasing
- Light-duty cleaning (neat)–particulates, fluorolubes, light oils, fluoropolymers
- Lubricant carrier
  Fluorocarbons
  Hydrocarbons
  Silicones
- Specialty solvents, dispersion medium, reaction medium, extraction solvent
- Spray contact cleaner
- CFC, HCFC, HFC and PFC replacement agent
- Heat Transfer Fluid (See 3M Electronic Materials "Thermal Management Fluids and Services" brochure.)

Observations

- No large leaks were observed in the first 2 years of operation
  - Evidence of small leaks was seen in the form of deposits, most near the hose barbs, but some were seen along some stave edges.
- Leaks appear to be in the middle of the staves, not the ends
- The staves were manufactured in the LBNL composite shop which also made staves of a very similar design for ATLAS.
- When the leaks were noticed, a crackling sound (~Rice Krispies) was heard
- The exterior of the detector (fiberglass, plastic) was electrically charged
  - Discharges had been seen in the past from non-grounded cooling circuit components. Friction and a non-conductive fluid transports charge.
- Small modifications had been made to the plumbing
  - Lowered the back pressure by 1-2 psi
- The cooling channels of the VTX pixels are different (bonded carbon composite sheets)
- The cooling channels of the FVTX consist of carbon composite sheets top and bottom, and PEEK sidewalls.

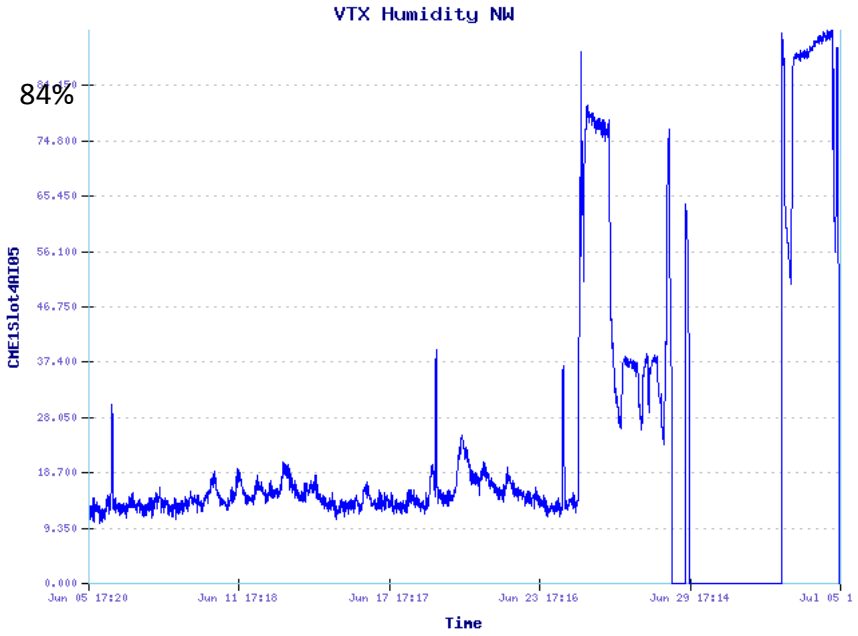
Hypotheses (1)

- Pressure spike
  - But pressures and temperatures were all normal. Tubes were tested to 125 psi before assembly, and none had failed. Operating pressure is 24 psi max. There is a 38 psi relief valve. Recorded temperatures of the coolant were normal
- Abrasion due to foreign material in the coolant
  - Analysis of samples showed no foreign content
- Contamination of the coolant, difference in coolant from last year
  - Analysis (IR spectra) of samples taken from around the cooling system showed all were pure Novec
- Static discharge damage
  - But to form a large enough spark, there needs to be a big enough gap. The carbon foam that surrounds the Al tubes is a decent conductor, and they are touching. Resistance measurements show ~few Ohms.
- Cavitation
  - Cavitation can do a lot of damage. Novec has a high vapor pressure. A crackling sound was heard. This sound was not heard last year.
  - However, the flow speed is low (1/2m/s), and the dimensionless number that indicates cavitation probability shows we are far from the cavitation regime.
  - Cavitation damage should be on the inside, near bends, not in the middle of the staves

Hypotheses (2)

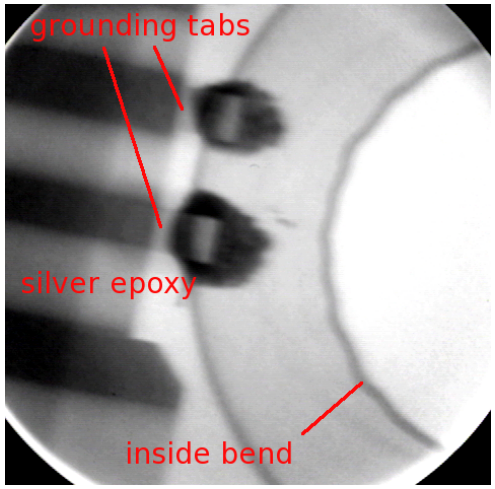
- Corrosion – internal
  - Water diffused into the Novec
  - Wates solubility in Novec is low (few ppm?), and falls with temperature. Thus water is forced out of solution in the coldest part of the loop (the chiller)
  - No water was seen in the analyzed samples
- Corrosion – external: Carbon + Aluminum + water
  - Where is the water from?

Our logs show that at the end of run 12, after electronics tests were done, the cooling was left running, with the detector in a state that did not provide a good seal to outside air.
For a few days, the humidity inside the detector reached 100%

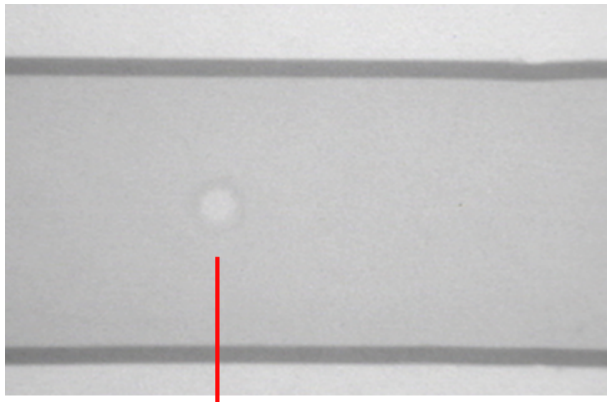


Non-destructive tests – 1: X-rays

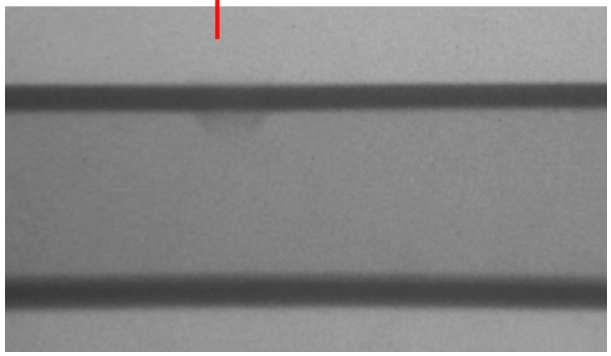
- X-ray of a tube. This was to establish whether or now we would be able to see a small hole
- A spare tube was prepared with a small hole punctured in it



Top view



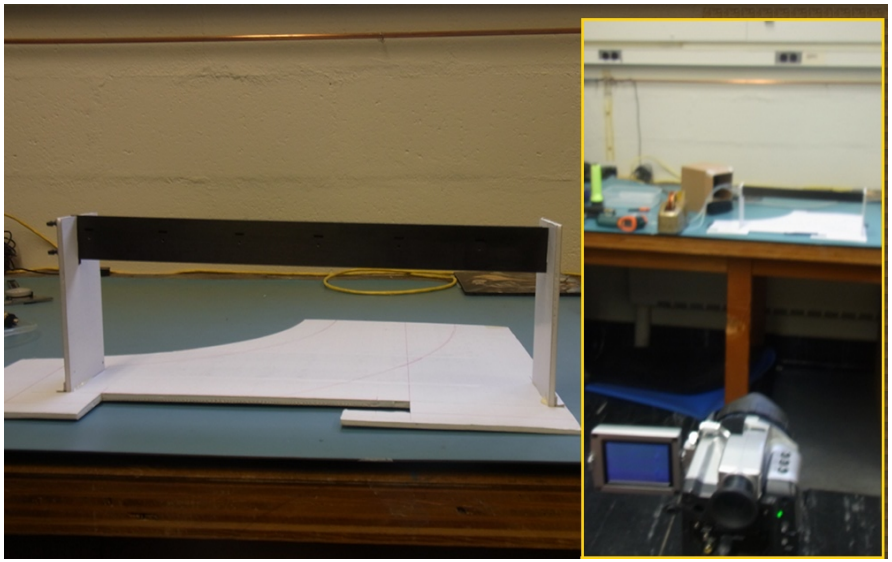
Side view



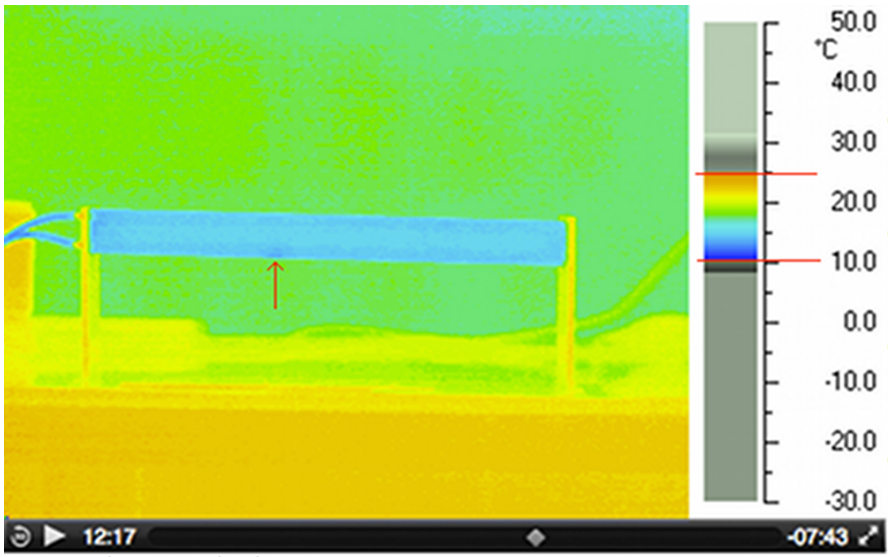
A small hole would be undetectable with this technique

2: Thermal imaging

We set up one of the known leaking staves, and hooked it up to a cooling system

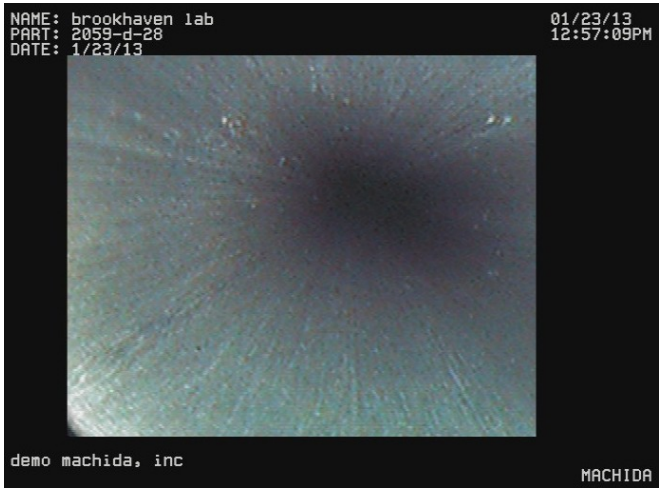


We cycled the coolant, and observed a cold spot during the warm-up phase, as leaked coolant evaporated. This allowed us to pinpoint the leak location



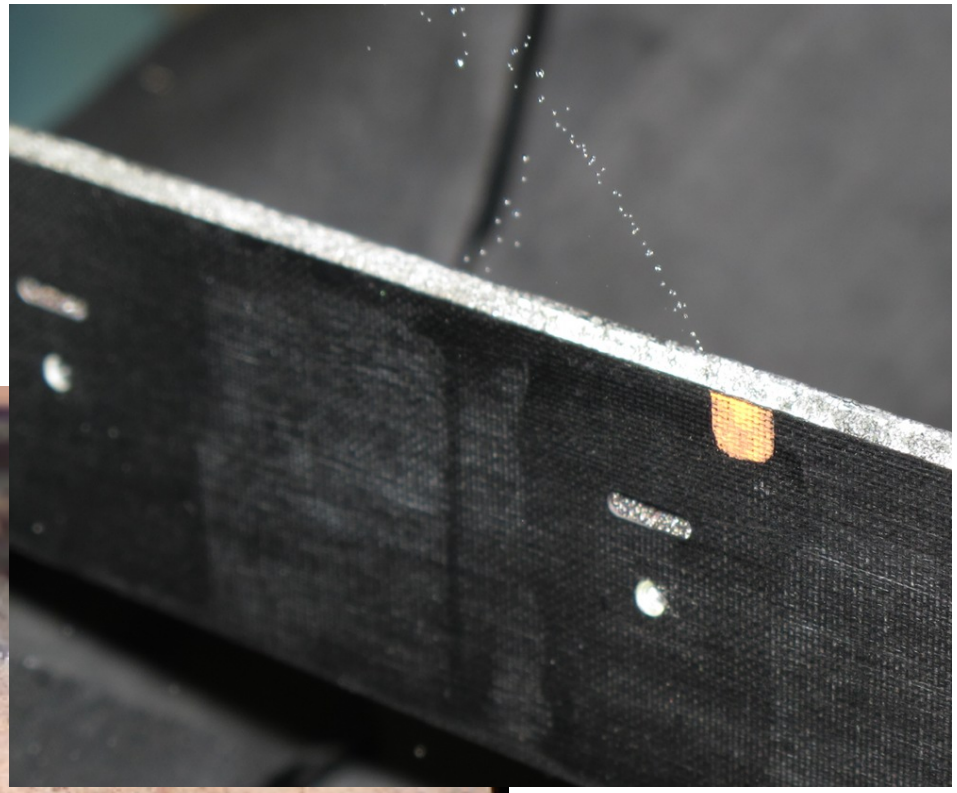
3: Borescope imaging

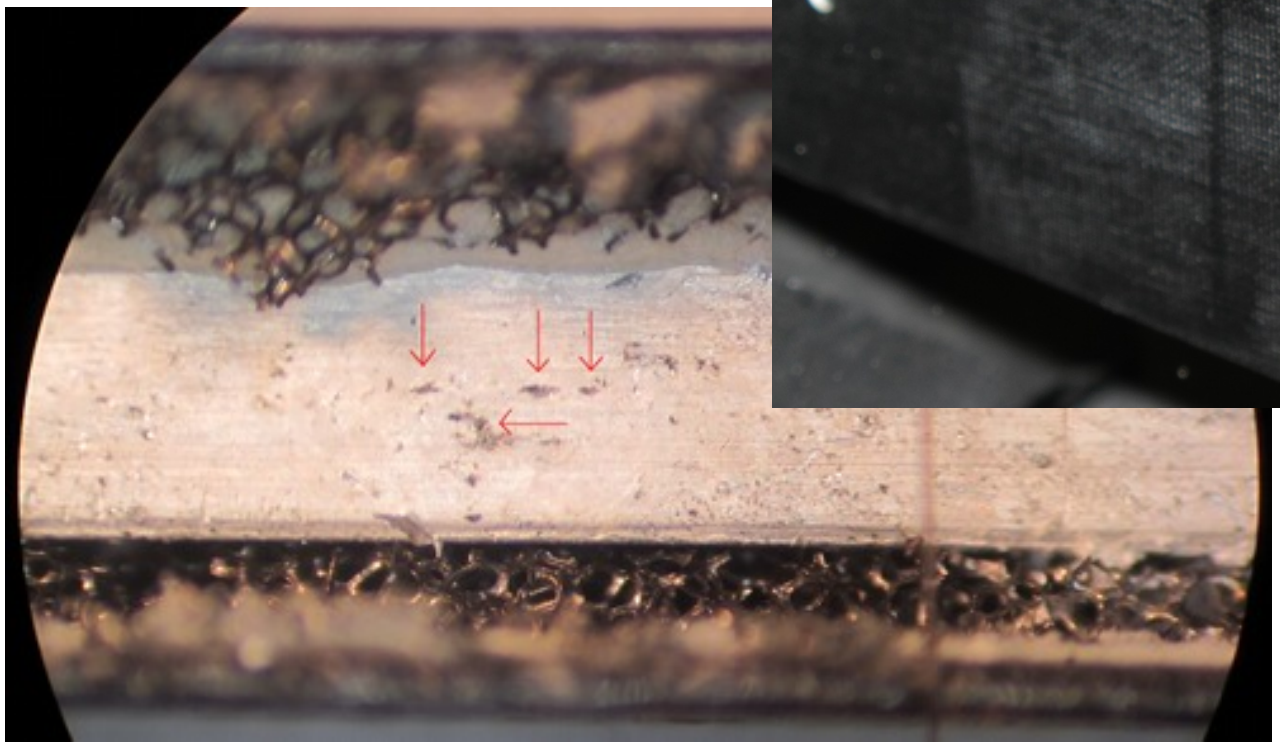
- Machida has a flexible borescope with a 2mm-high camera, 1024x640 px. This is just small enough to slide into the tube.
- An unvisited section is pristine
- The camera itself scratches the soft Aluminum
- In a few places, we saw unusual features.



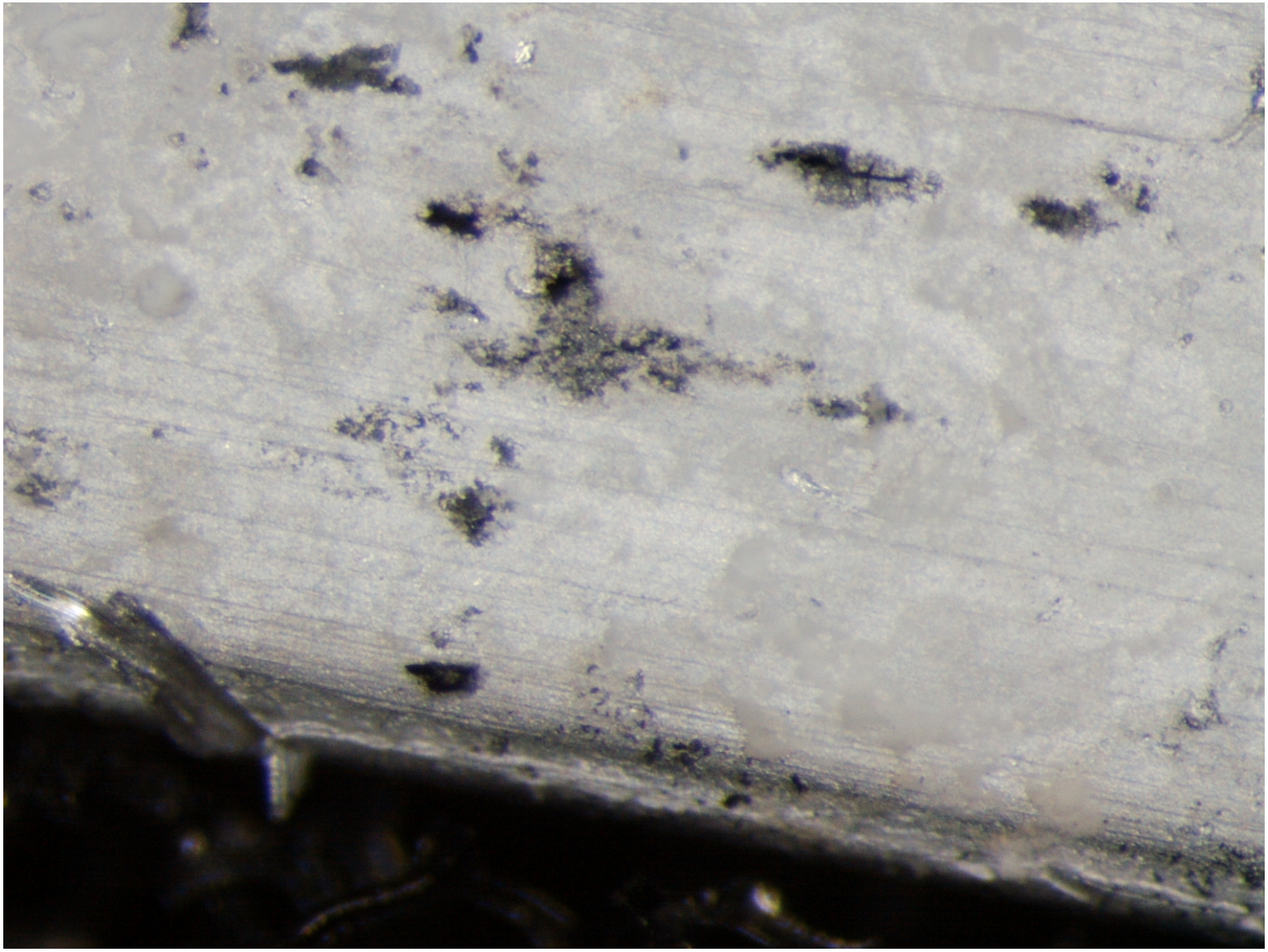
Observation of the leak

With the leak location identified, we removed the outside carbon foam, and saw the leak.
Small craters could be seen



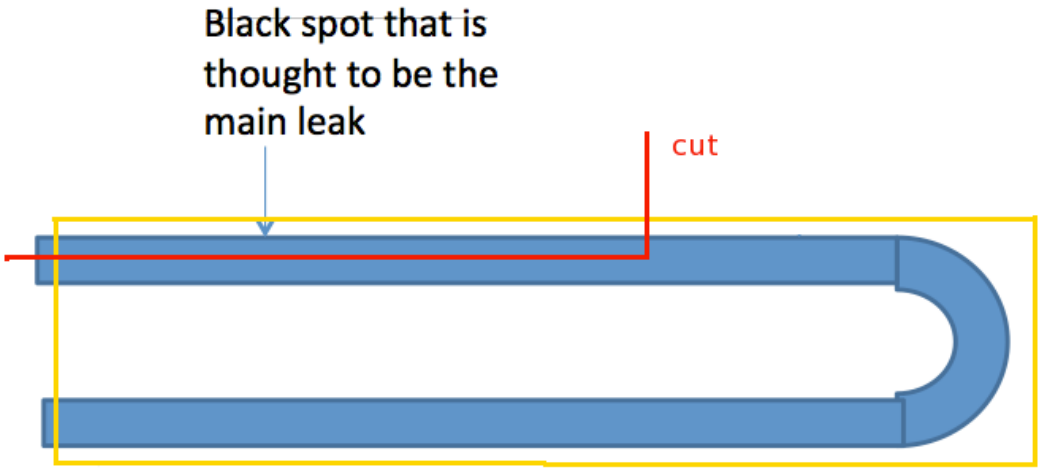


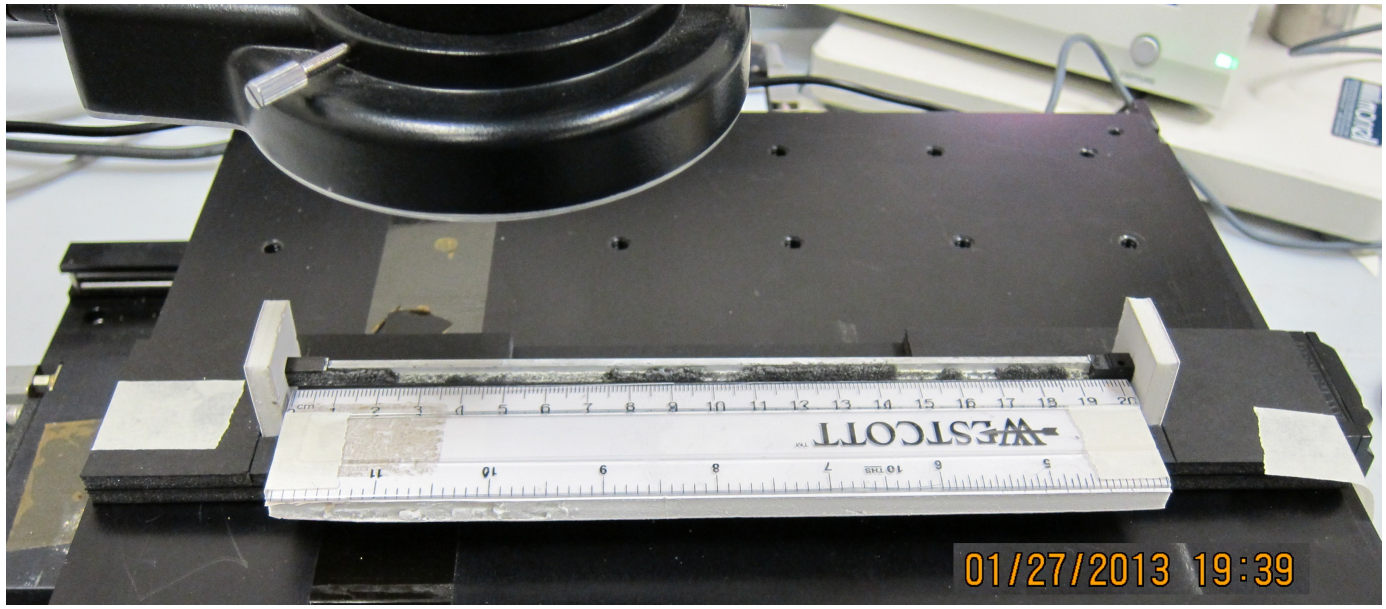
Closeup



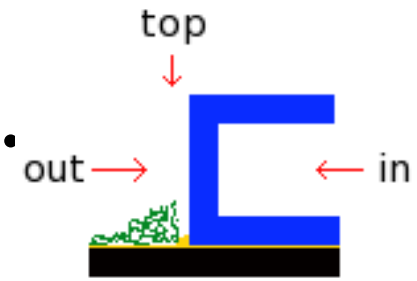
Cutting the tube open

A jig allows a scan of the cut section in 1 cm steps, and registration of front/back/top images



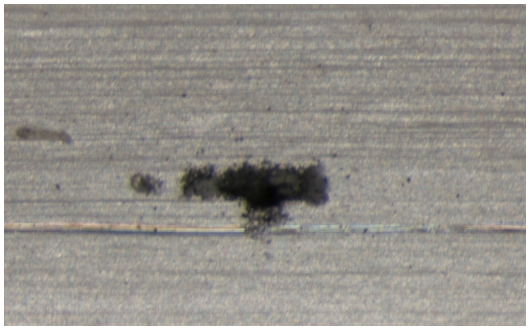


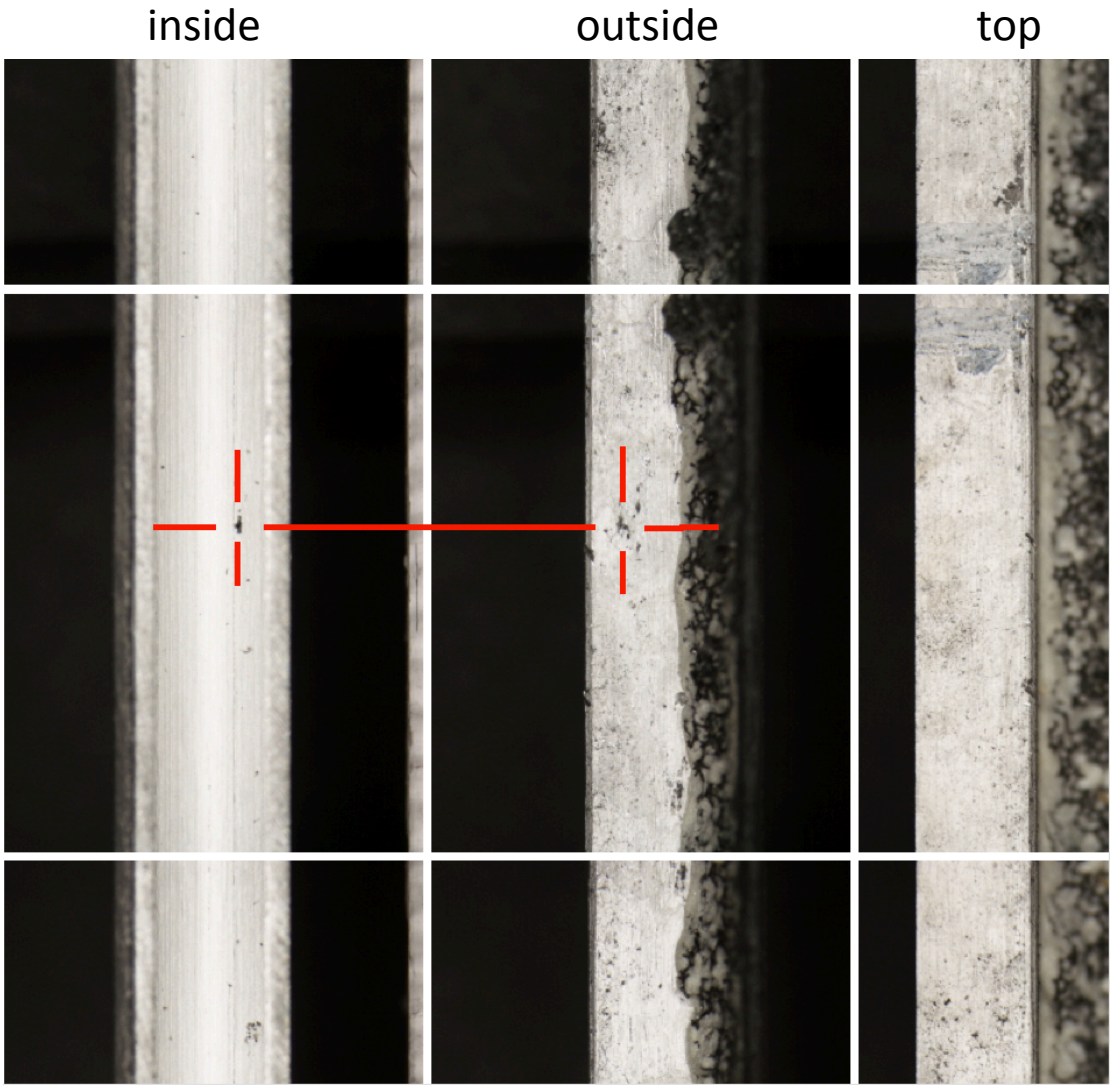
Inside/outside/top views



The inside of the tube is very clean, the outside shows signs of corrosion

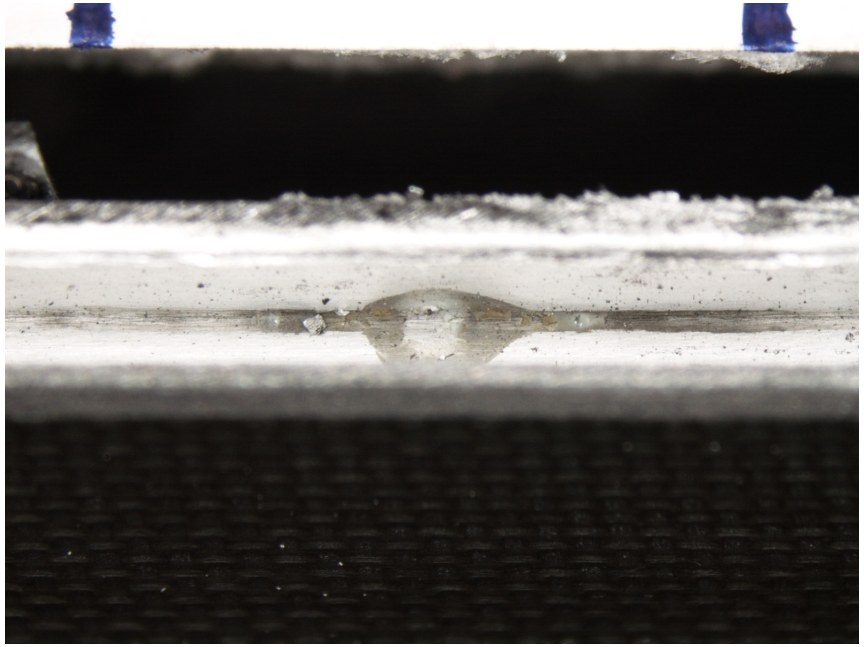
The leak can be found on the inside of the tube

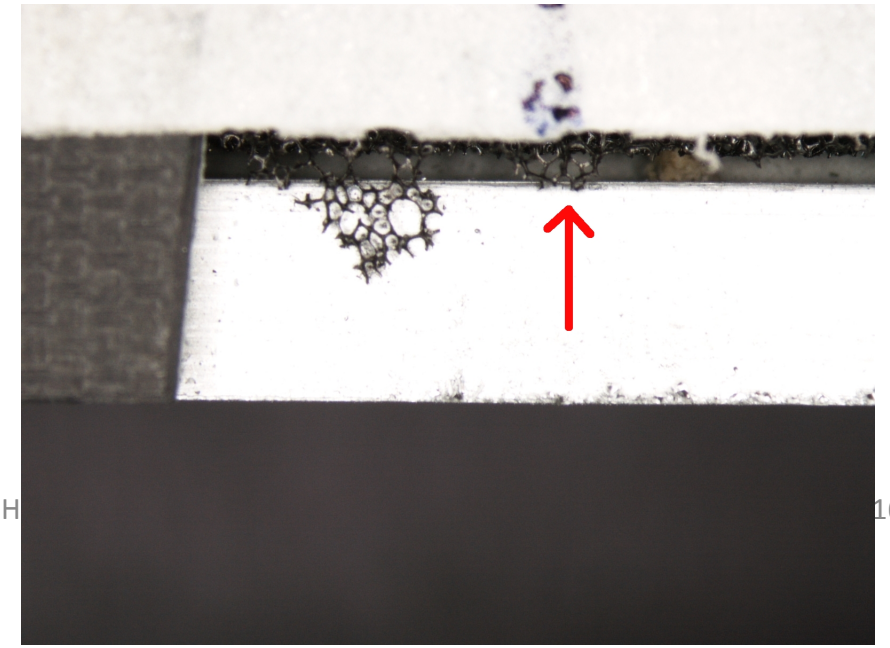




Inside/outside features

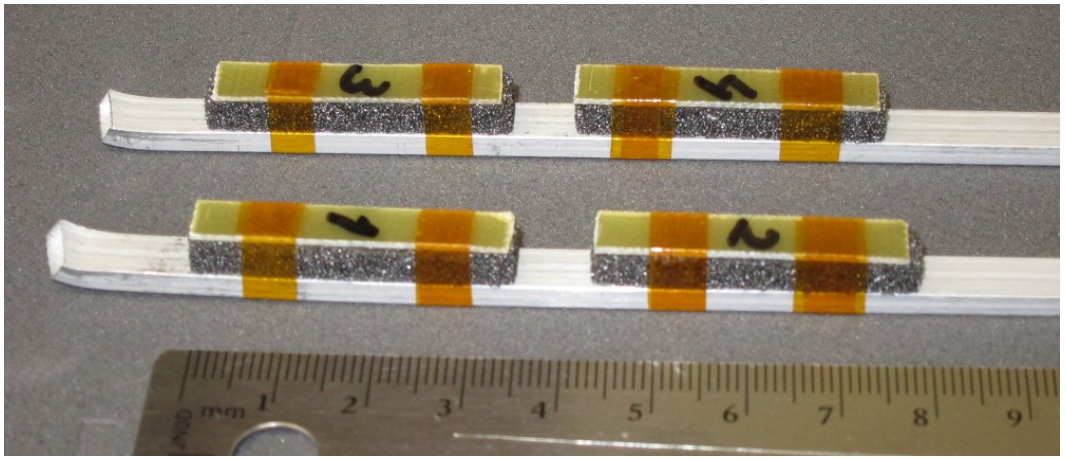
- Feature seen on the inside corresponds to a location where carbon foam remained attached to the outside



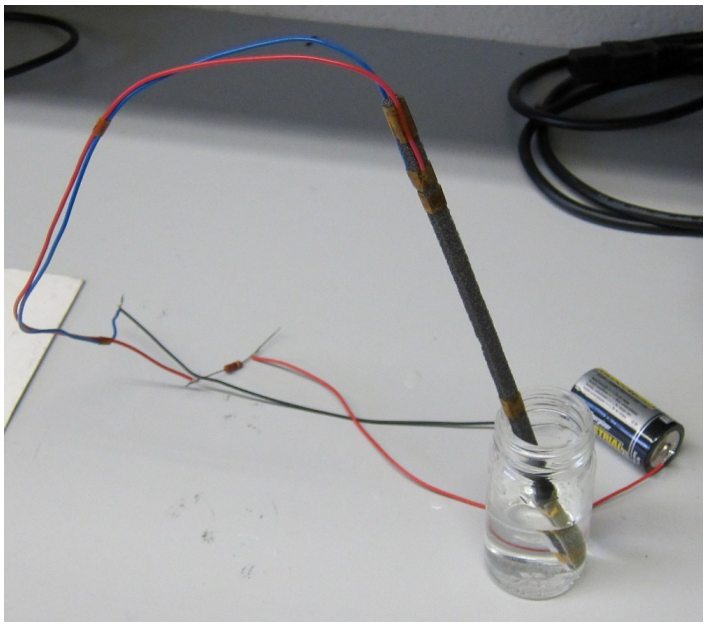


Active corrosion tests - 1

Four carbon foam/Aluminum sandwiches, immersed in tap water



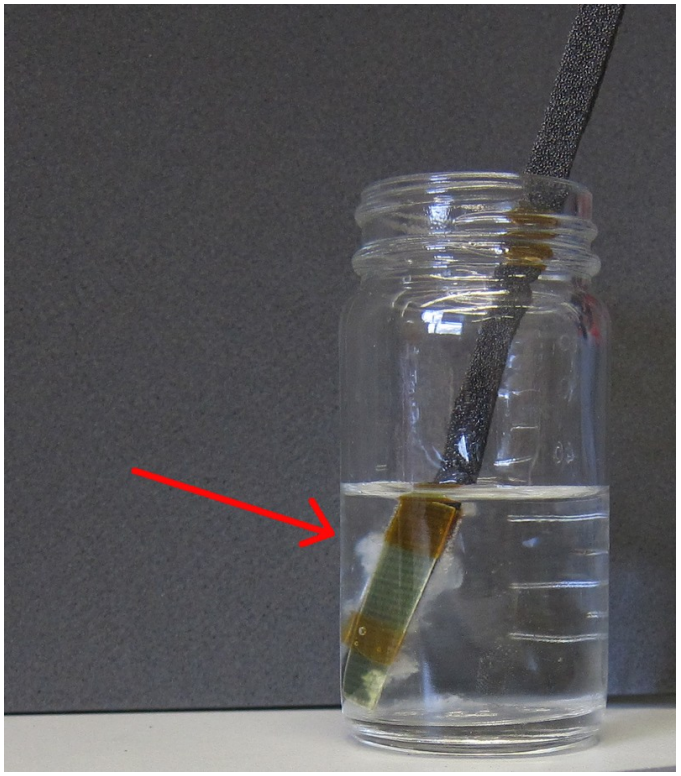
Aluminum/carbon foam sandwich, immersed in tap water, and assisted by ~30 mA of current



Active corrosion tests - 2

Within a few days, a whitish, very low density material formed at the interface between the Al and C.

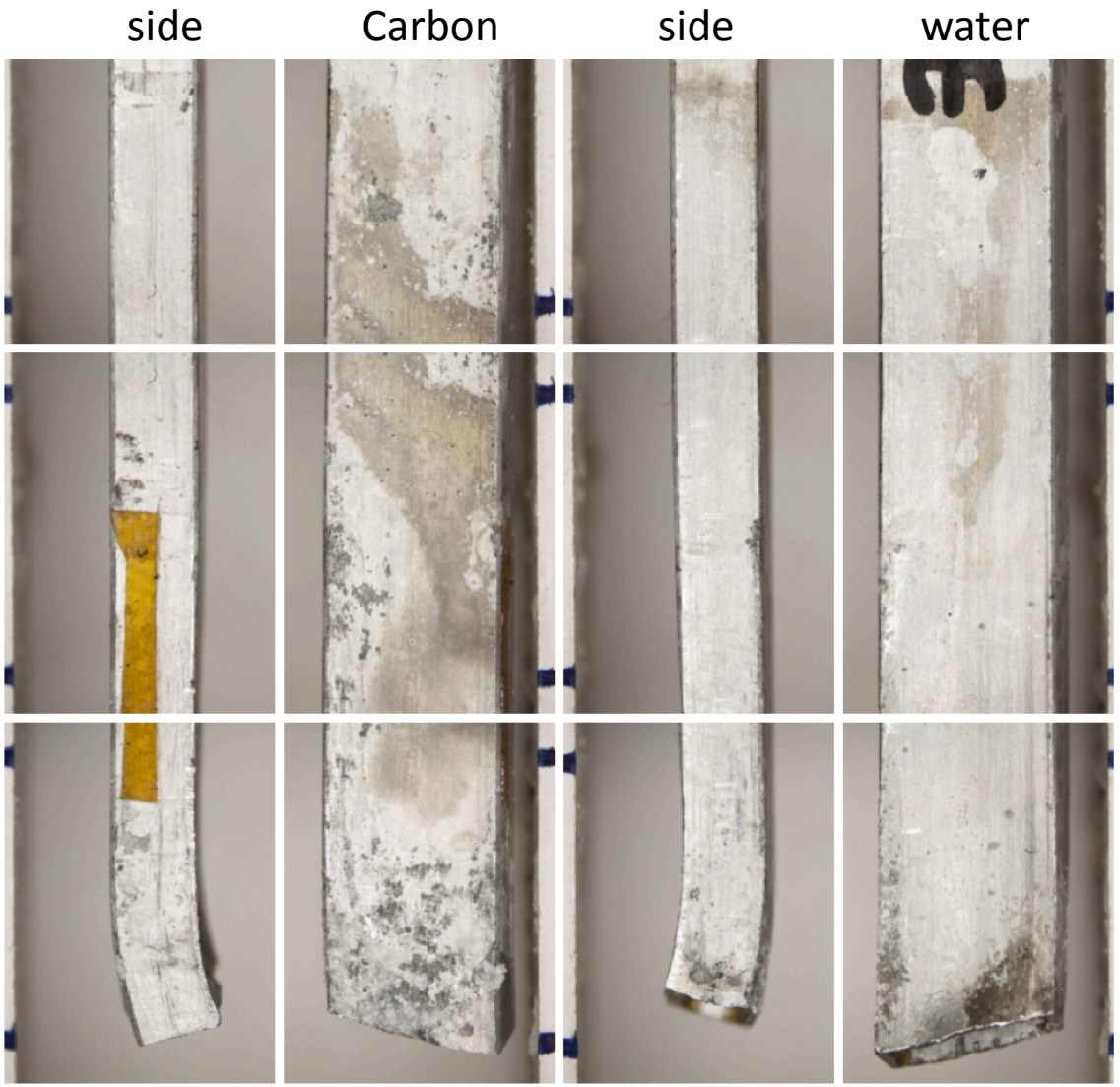
I have collected some of this, and it is currently drying so we can send it for analysis.



Active corrosion tests - 3

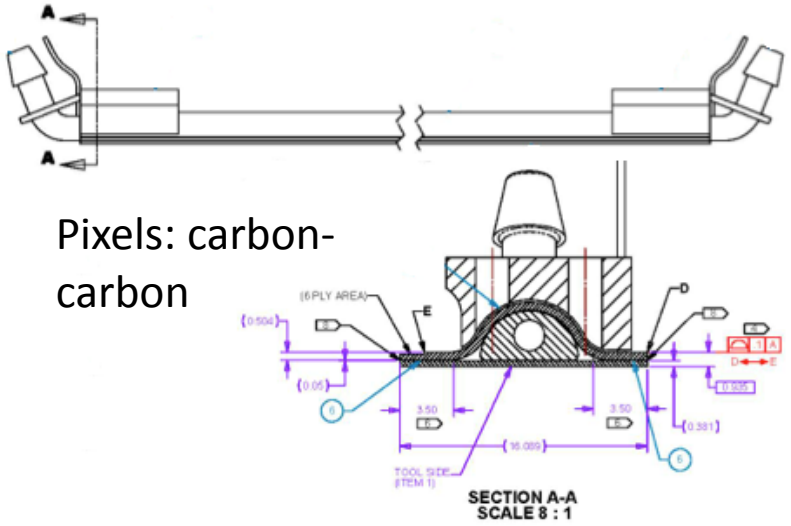
After 9 days I removed the samples from the water. The side facing the carbon shows the same discoloration and pitting as seen on the detector staves.

The side facing the water remained relatively clean

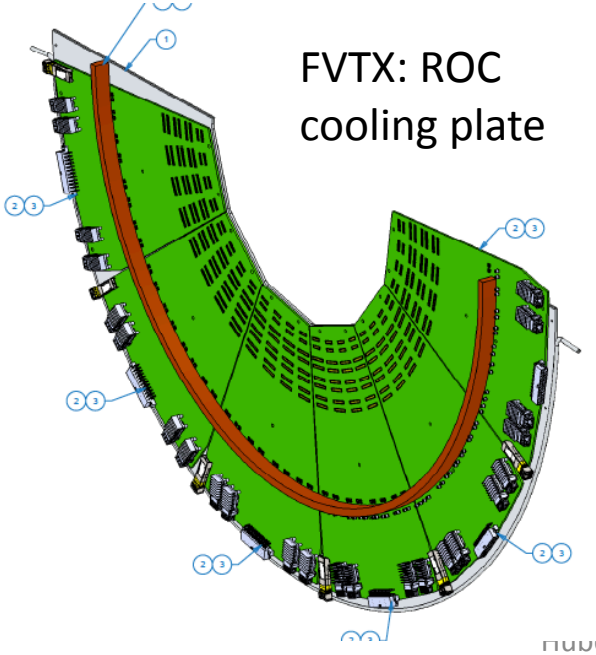


FVTX, VTX pixel cooling

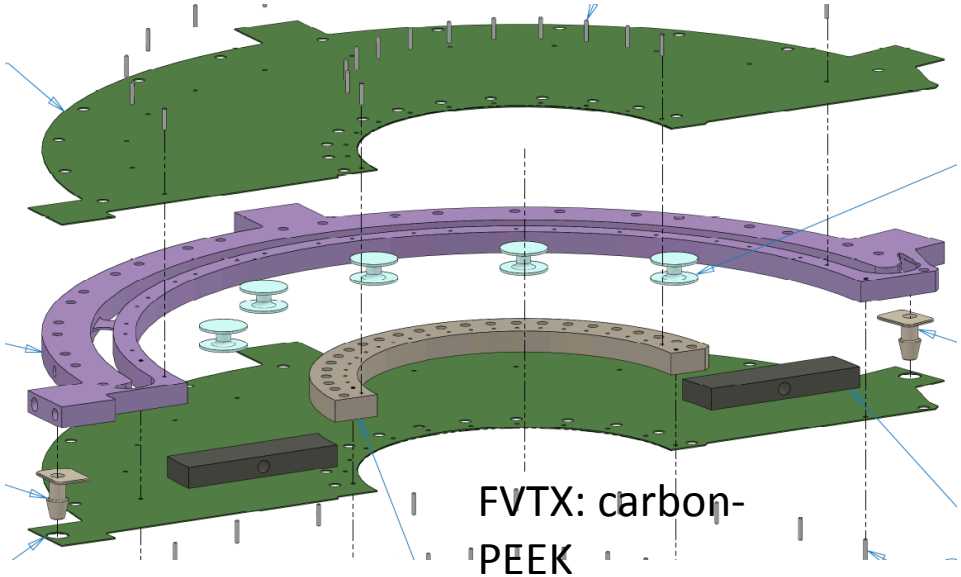
- Systems were leak-tested in the IR before removal in January
- Tested again in the lab
- Tested again after re-installation



Pixels: carbon-carbon



FVTX: ROC cooling plate



FVTX: carbon-PEEK

To be done

- Analyze the whitish stuff produced in the sample tests
  - This is assumed to be Aluminum oxide
- Do the SEM/atom probe on the known leak site
  - Identify the black material on the inside of the craters
- Analyze other residues found
  - These are thought to date back to run-12, when plasticized leached out of the cooling system tubing.
- Inspect barrel 3
- More?

Unanswered questions

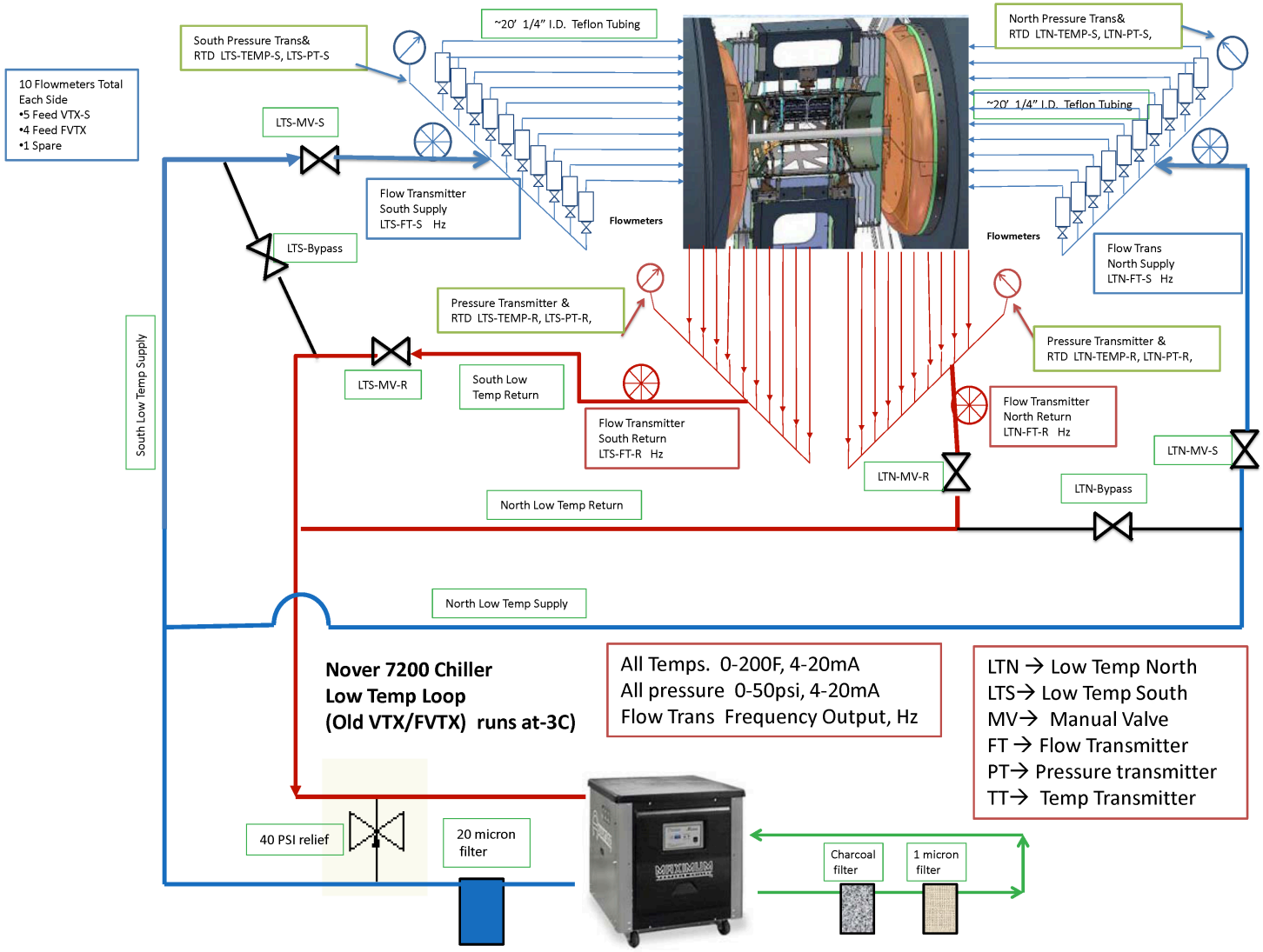
- Why was only layer 4 affected, and layer 3 showed no massive leaks?
  - dry N2 was blown in from 2 small hoses near the center of the detector. Was barrel 4 too far away?
- More?

Conclusions

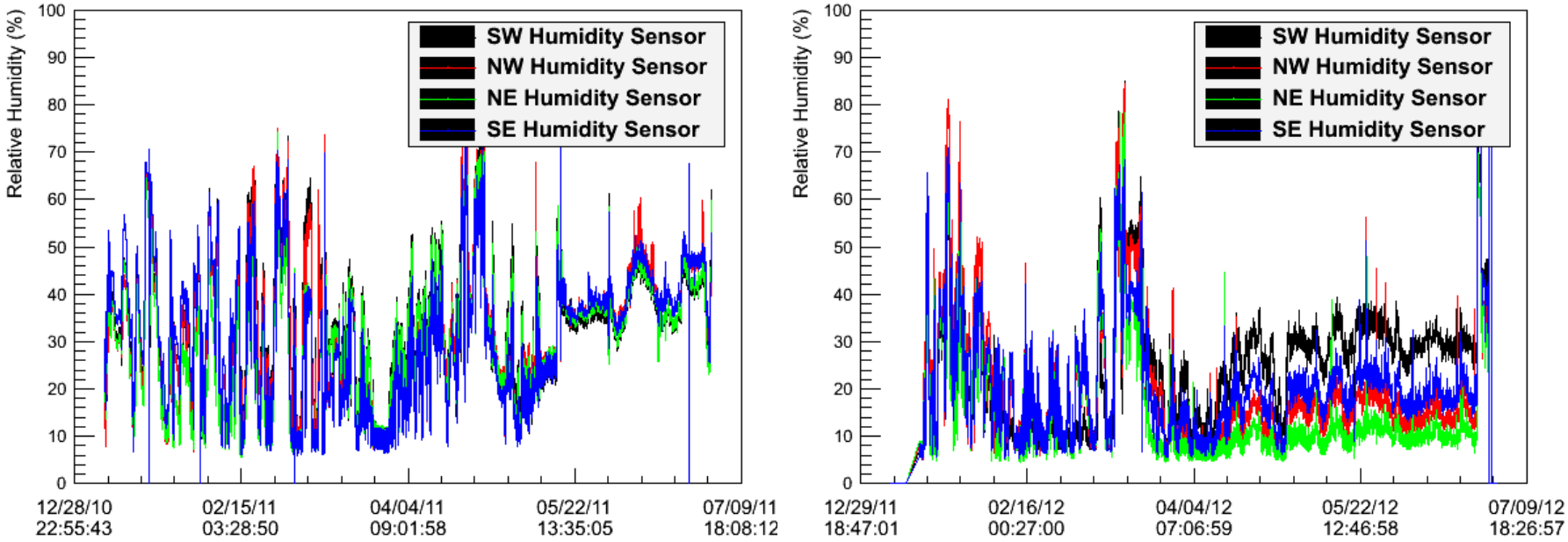
- The leaks were caused by galvanic corrosion between the Aluminum and the carbon foam
- No evidence that Novec played a role in the corrosion
- Water was introduced to the interface by condensation. Some of this may have already occurred in the first two years, but the events at the end of run-12 caused the sudden massive leaks seen in December
- The VTX pixel staves and the FVTX cooling channels are not affected by this effect, and these systems can be safely operated.

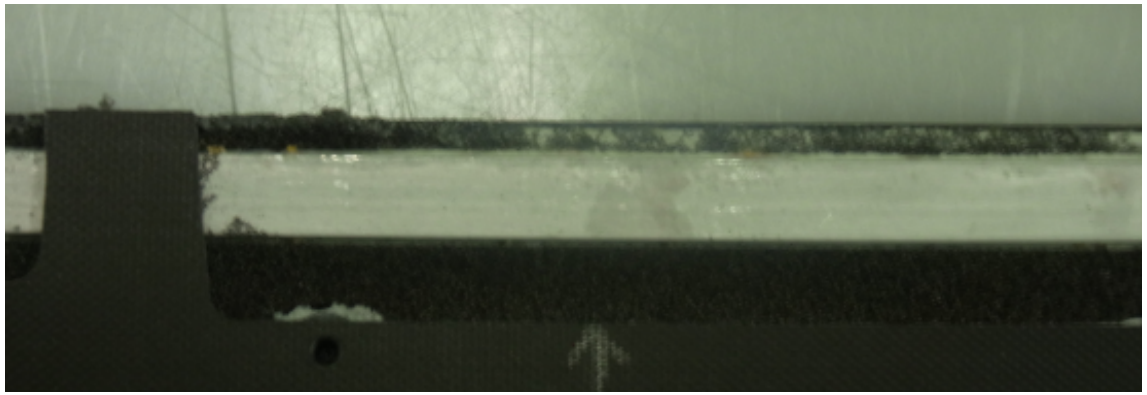
Backup

Chiller loops 2013

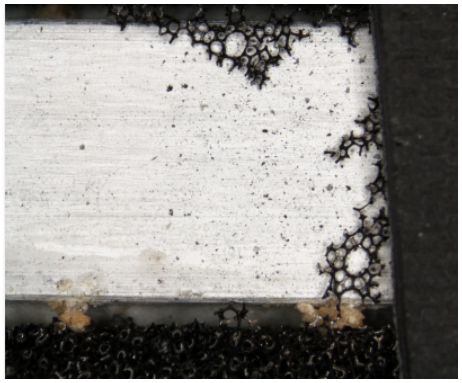


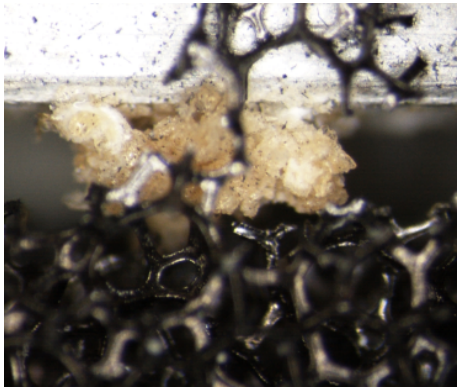
Relative humidity 2010-2012

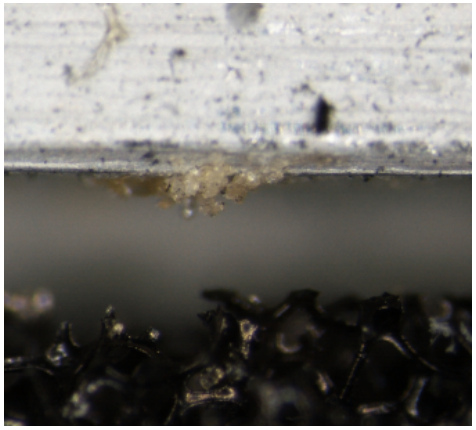


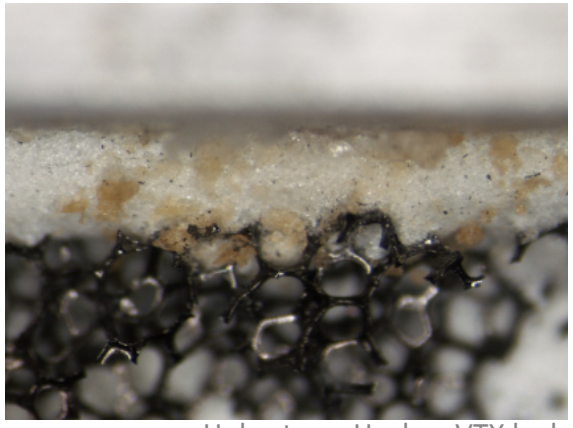


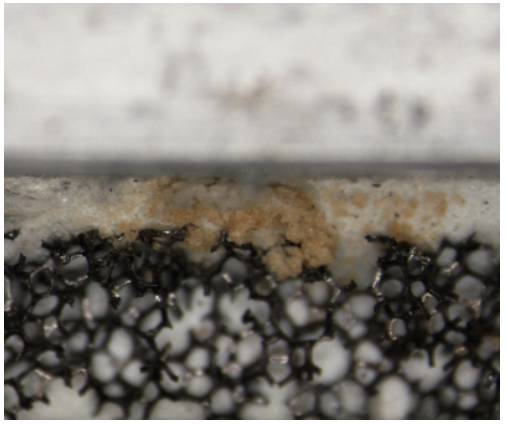
Other deposits











Leak discovery

From Eric:

….. we pressurized the system the system the afternoon of Dec 17 and did not observe any visual leaks. The system was pressurized over night and in the morning of Dec 18, we noticed an ~2gal drop in the coolant level. By the end of the day (12/18/2012) we isolated the problem to one cooling loop on B3 West but there was no indication of a leak in the east detector. The B3 West loop was closed off and the balance of the system was pressurized with Novec for the night. On Dec 19, it was discovered that there was a leak in the east strip loops. Jimmy, Mike and Rob of course are the experts on this.

Backup material

- (more pictures)

Backup material

- (more pictures)