Summary of information on the leak in the y arm at the LIGO Livingston site

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A leak of about 2.5 x 10^{-4} torr liters/sec on the yarm opened in October 2008. It was not noticed until May 2012 when the pumping configuration was changed to allow for installation of Advanced LIGO components. At the Livingston site there was no vacuum gauge in the middle of the tube. The pressure gauges at the tube ends did show a small increase but were only taken seriously in retrospect.

In 2007 the entire tube was inspected inside the concrete enclosure. Water leaks in the caulking were found (**Table 1**) and in several places water in significant quantities had collected between the tube and the insulation. The water was sent for chemical analysis to determine the chlorine concentration, none was detected to the limit of the measurement (unfortunately do not know the limiting value).

Table 1 2007 summary of leaks and lightning strikes on the beamtube enclosure

beamtube module	caulking leaks	longitudinal cracks	lightning strikes
x1	26	7	0
x2	3	33	2
y1	112	37	2
y2	78	179	2

Between July through August 2012 attempts were made to localize the leak by gas dynamics on the assumption that there was only one leak. The solution obtained was 2070 +-40 meters from the LVEA beamtube termination. The noise in the measurement was not Gaussian and the various measurements implied that temperature gradients along the tube were an uncontrolled and unmeasured parameter.

A leak of approximately the estimated value was found with helium at 2258 meters. The leak was on a stiffener ring fillet weld near the top of the tube (**Figure 1** and **Figure 2**). The region around the leak including an adjacent spiral tube weld was found to be contaminated with mouse urine and feces. X ray photoelectron spectroscopy was done on rags that had wiped the tube surface and compared with clean rags (**Appendix 1**). The dirty rags showed chlorine and bismuth peaks.

Near the location of the leak there is evidence of an arc-gouge and a manually repaired section of the spiral weld.

The leak was repaired initially with epoxy but this was not as successful as using a lower viscosity silicone leak repair called “Vacseal”. Once the “Vacseal” was applied the pressure in the tube began to decrease. Once the region had been cleaned there was no obvious place which could be seen to indicate the exact location of the leak. Within several hours after cleaning and the application of heat by a heat lamp to cure the “Vacseal” , a second leak three times large than the original one opened

along the same weld seam. This time a plastic sheet was stretched across the region and the space between the sheet and the beamtube was evacuated. The pressure again decreased. A day later when the sheet was removed the pressure did not rise again implying that the second leak had been sealed or was a virtual leak due to a void that had pumped out. Helium was applied to the region again and a small leak between 1/100 to 1/20 of the initial leak was discovered on the adjacent rodent contaminated spiral weld.

The leaking section of spiral weld was cleaned and "Vacseal" was applied. Helium testing showed that the region was now leak tight to 10^{-6} torr liters/sec or smaller.

An accumulation was carried which showed that there is still an air leak of 5.5×10^{-5} torr liters/sec in the tube at an estimated location 1850 +- 30 meters, assuming only a single leak remains.

The insulation has been removed from the beamtube between the ports at 1657 to 2283 meters from the LVEA to allow helium leak search and to provide a larger fraction of the tube for visual inspection.

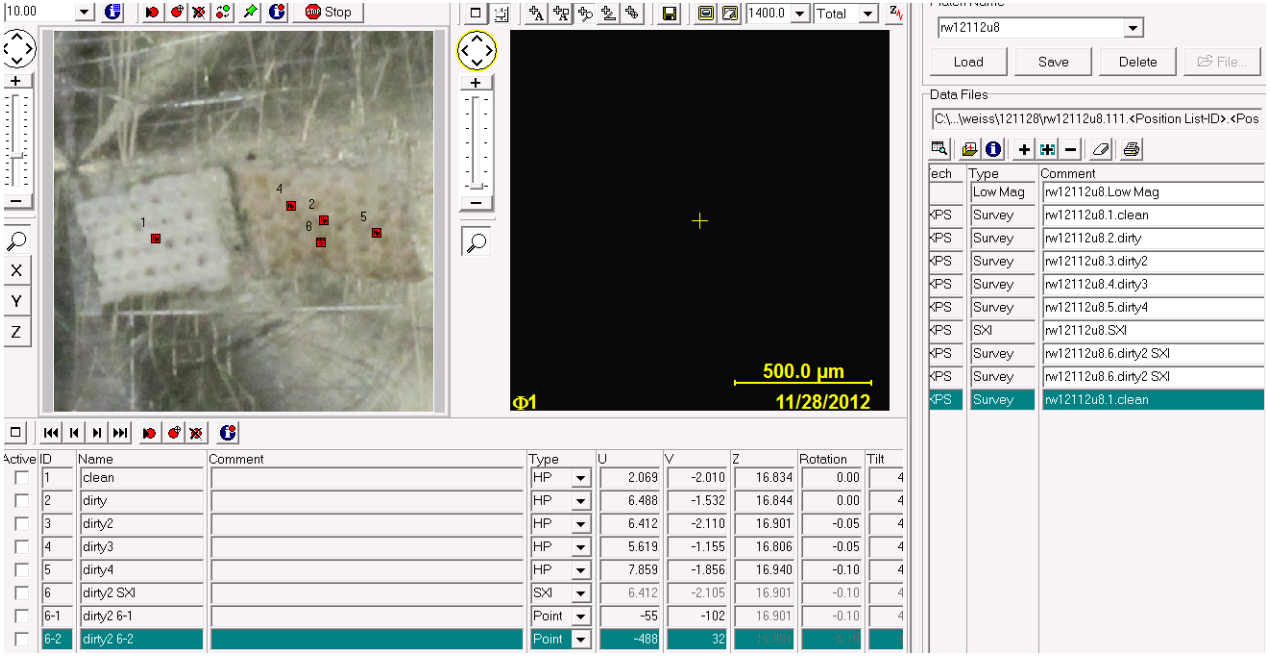
Up to today (January 28, 2013) there has been no region of the tube found as heavily infested by rodents as the location of the original leaks. The part of the beamtube exposed is the place of the heaviest concentration of caulking leaks There is evidence of rodents around the tube supports many of which have rodent droppings at their base.

Figure 1: The location of the arrow is a likely place for the original leak on the continuous weld between the stiffening ring and the tube. The brown discolorations are assumed to be due to mouse urine.

Figure 2: A larger view showing the stiffening ring and the spiral weld. The spiral weld is covered with mouse feces which comes off easily. The mouse urine has discolored the tube in patches between the spiral weld and the stiffening ring. The background brown color of the tube is due to the air heating of the tube material before fabrication to reduce the dissolved hydrogen in the steel.

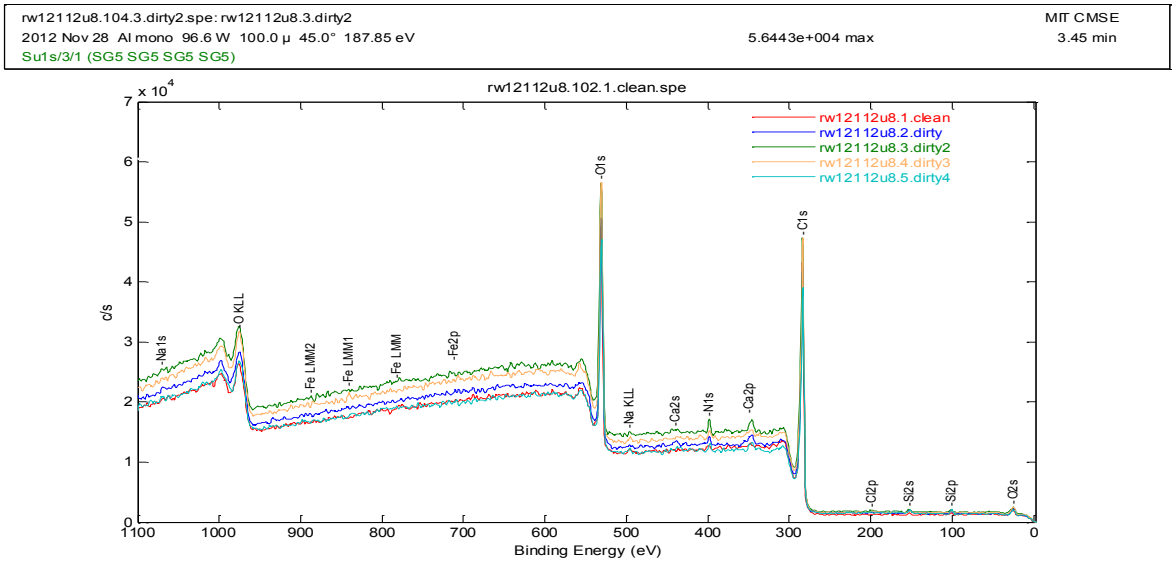
Appendix 1: XPS measurements made by Libby Shaw at the MIT Center for Material Science. The rags that show the chlorine are the dirty sections in the last two scans.

Optical image and analysis points
“Clean” and dirty fabric samples
optical image size 10 mm x 10 mm

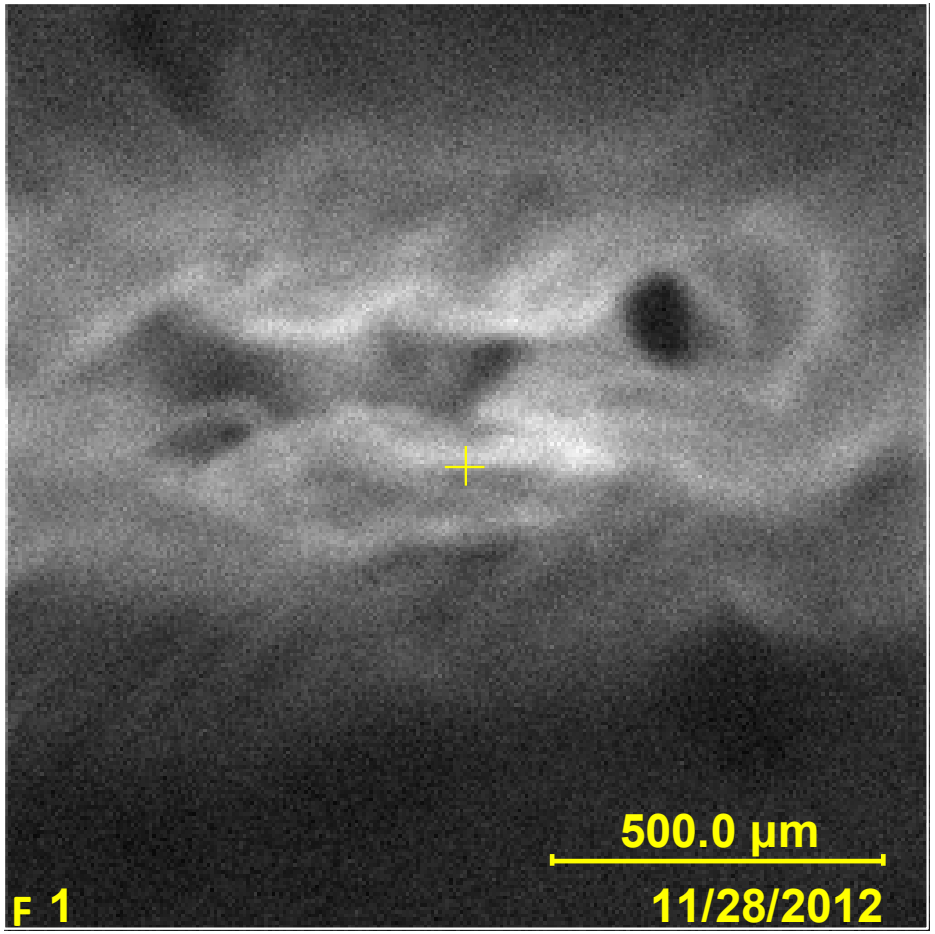


Survey spectra
“Clean” and dirty fabric (four areas on dirty fabric)
analysis areas 100 um x 1400 um

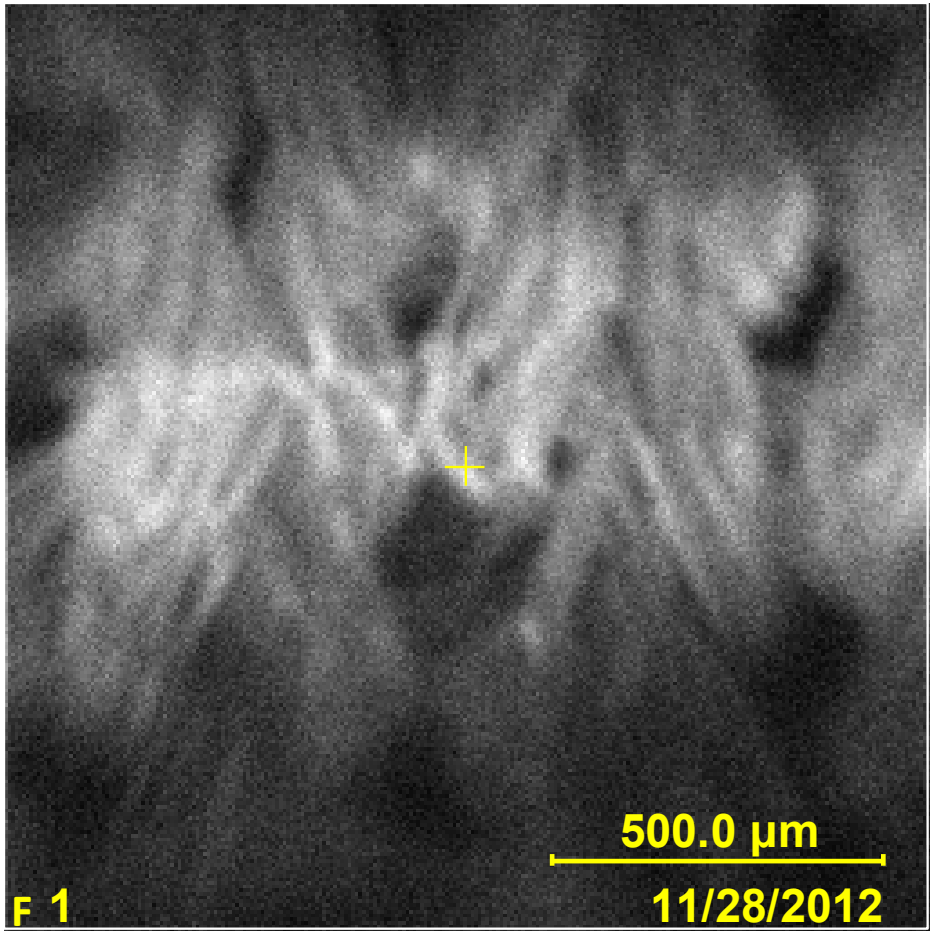
C and O major components, Ca, Na, and Si very minor components
Fe and Cl were not detected in these 3.5 minute survey scans



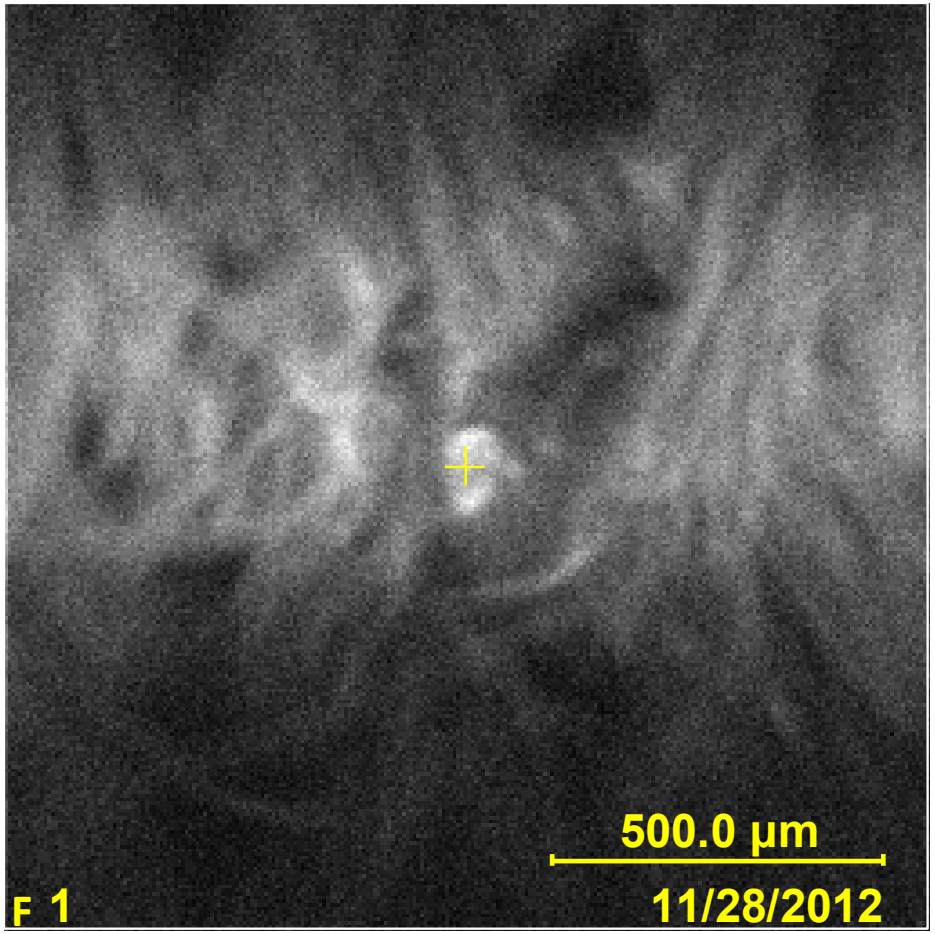
SXI image of “clean” sample
dark spots are holes in fabric



SXI image
sample position Dirty2
dark spots are holes in fabric



SXI image
sample position Dirty4

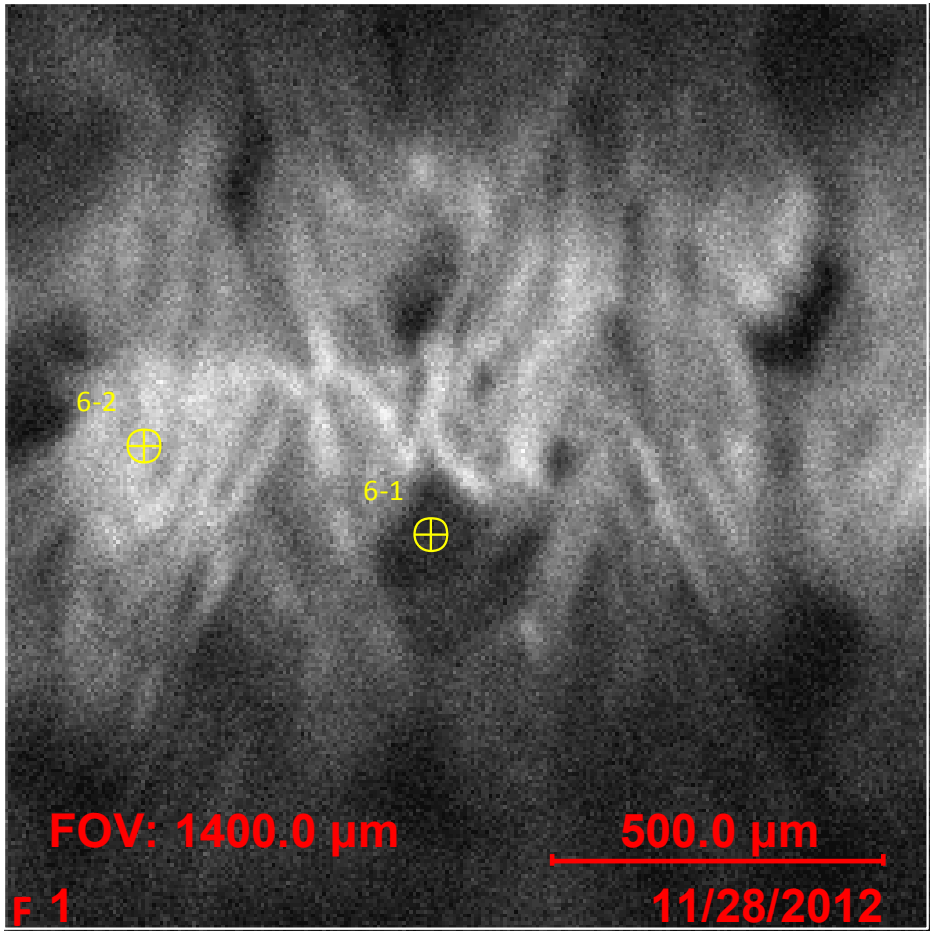


Atomic concentration ratios, initial results from survey spectra
“Clean” sample and dirty sample position Dirty2
analysis areas 100 um x 1400 um

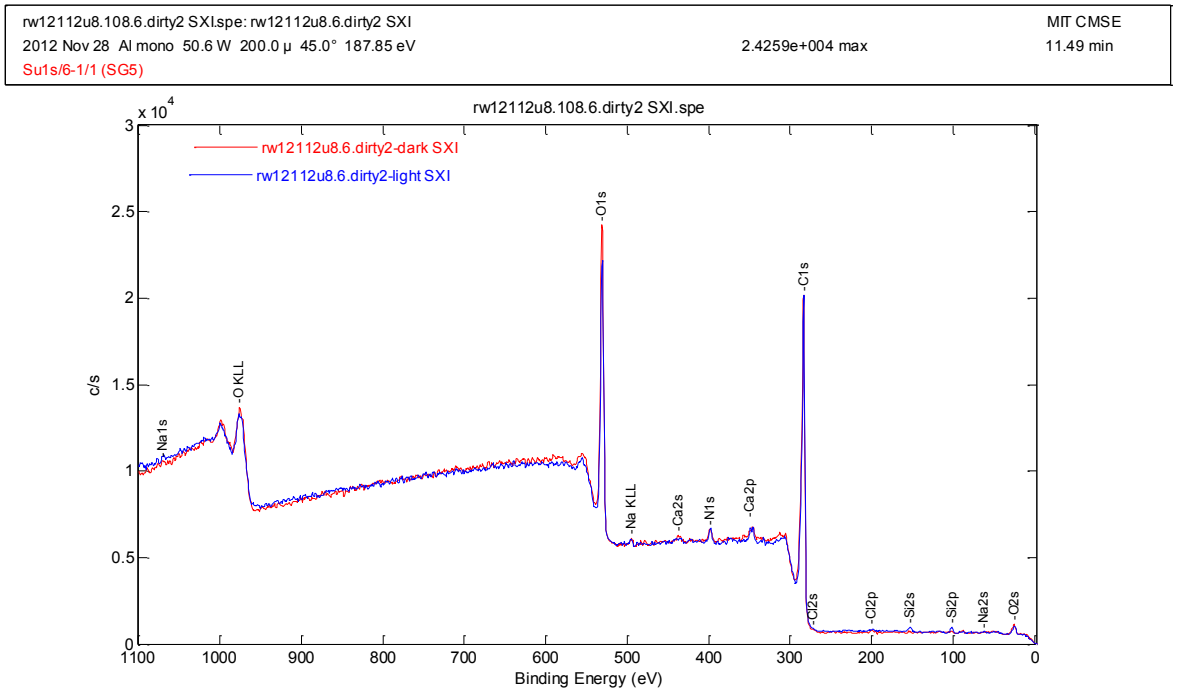
Atomic Concentration Table

C1s	N1s	O1s	Si2s	Ca2p	
0.314	0.499	0.733	0.347	1.927	RSF
58.791	93.486	137.408	64.921	400.017	CorrectedRSF
72.38	0.47	26.62	0.48	0.05	rw12112u8.1.clean
69.41	1.84	27.63	0.55	0.56	rw12112u8.3.dirty2
70.90	1.16	27.12	0.52	0.31	Mean
2.10	0.97	0.72	0.05	0.36	Standard Deviation

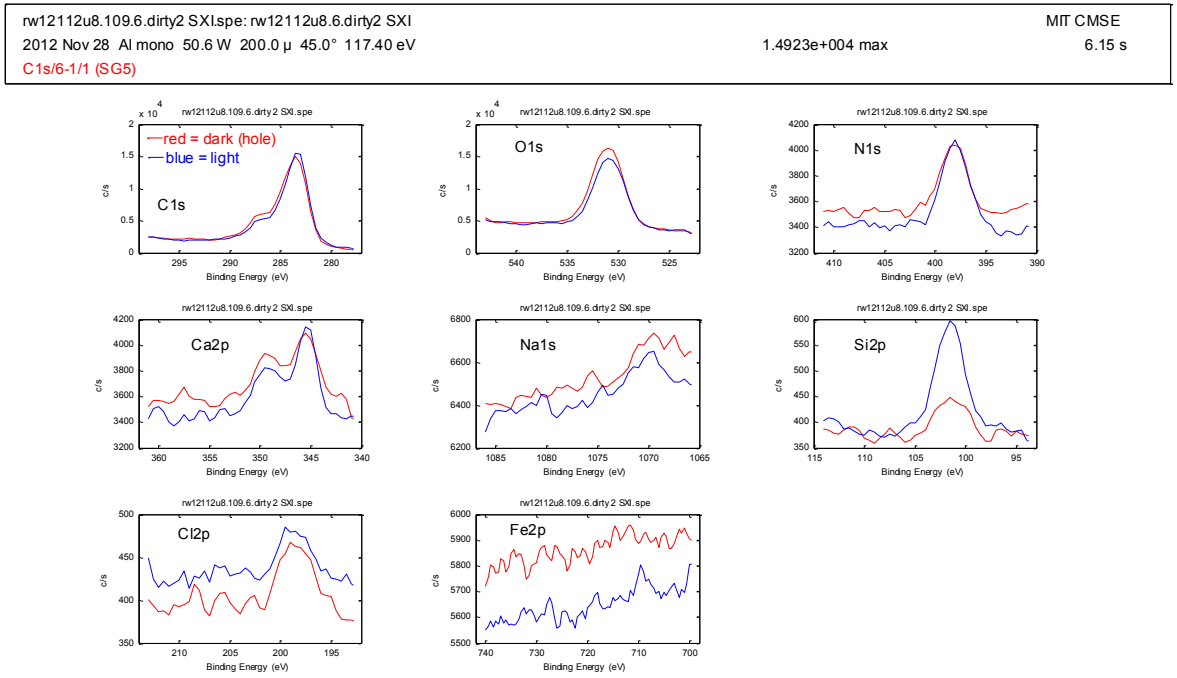
Dirty2 SXI image
showing dark (hole) and light (fibers) analysis areas selected for further analysis



Survey spectra
Dirty2 hole (dark) and Dirty2 fibers (light) analysis areas 200 um diameter

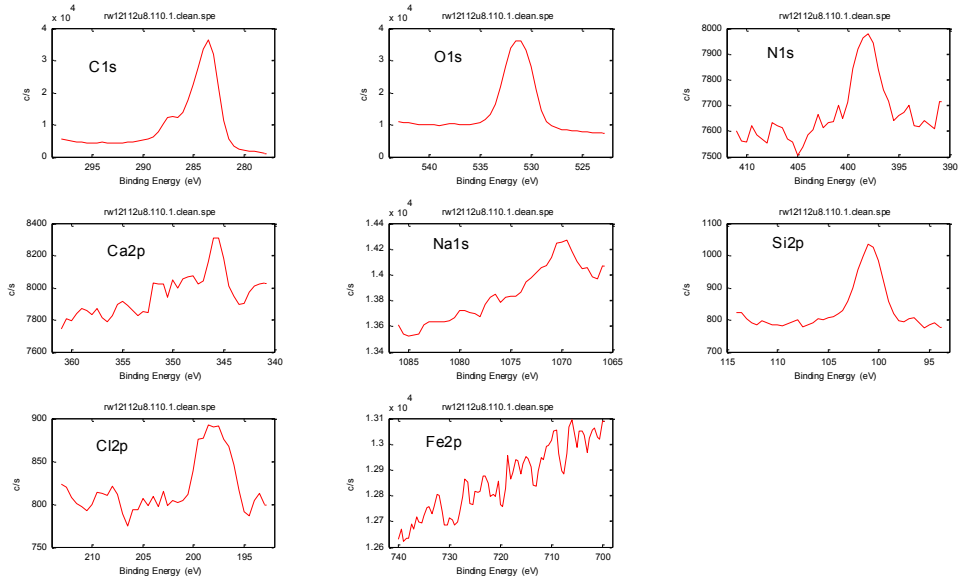


Higher S/N spectra
Dirty2 hole and fibers
60 sweeps Cl2p and Fe2p
Possible hint of iron on fibers (blue) , none on hole (red).



Higher S/N spectra
“Clean” fabric
60 sweeps Cl2p and Fe2p
no hint of iron on clean fabric

rw12112u8.110.1.clean.spe: rw12112u8.1.clean — MIT CMSE
2012 Nov 28 Al mono 96.6 W 100.0 µ 45.0° 117.40 eV — 1.3094e+004 max — 4.05 min
Fe2p/1/1 (SG5)



Atomic concentration ratios from higher S/N analyses
Dirty2 hole and fibers and “Clean” fabric
Fe quantities for dark area and “clean” sample are noise only – see spectra

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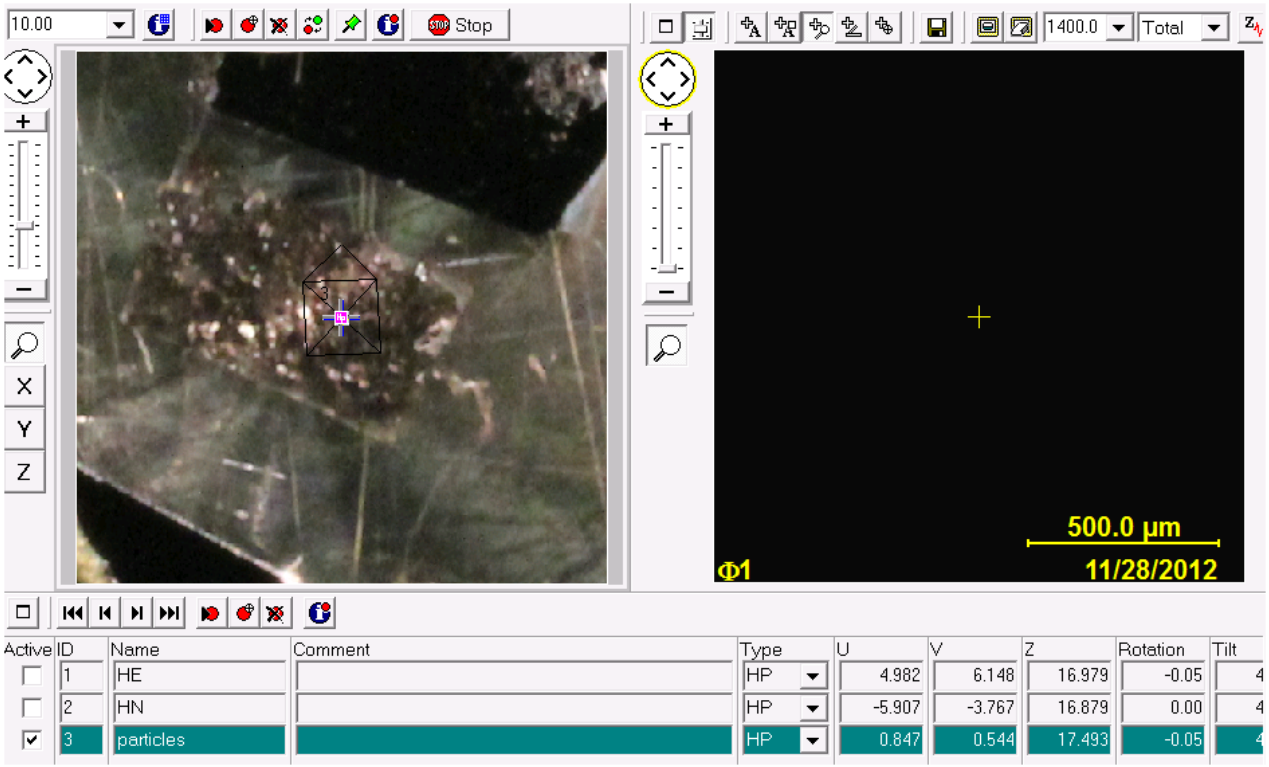
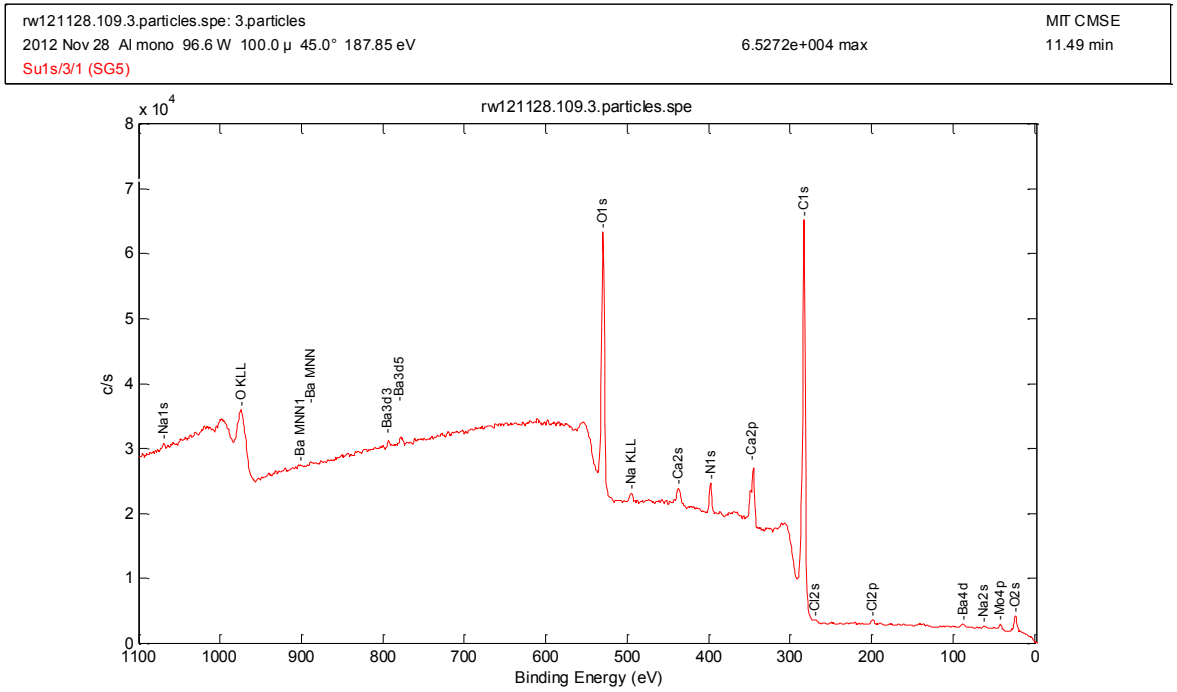
Atomic Concentration Table

C1s	N1s	O1s	Na1s	Si2p	Cl2p	Ca2p	Fe2p	
0.314	0.499	0.733	1.102	0.368	0.954	1.927	2.946	RSF
36.557	58.185	85.599	129.246	49.718	125.468	248.859	375.382	CorrectedRSF
70.08	1.35	27.35	0.21	0.28	0.12	0.59	0.02	dark area (hole)
71.49	2.10	24.75	0.18	0.70	0.08	0.63	0.07	light area
73.60	0.46	25.24	0.18	0.37	0.06	0.06	0.04	clean sample

Optical image
particles collected from fabric
image size 10 mm x 10 mm



Survey spectrum
particles collected from fabric
analysis area 100 um x 1300 um
no Fe detected, Ba unambiguously detected



Atomic concentration ratio from survey analysis particles collected from fabric

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Atomic Concentration Table

C1s	N1s	O1s	Na1s	Cl2p	Ca2p	Mo3d	Ba3d5	
0.314	0.499	0.733	1.102	0.954	1.927	3.544	7.343	RSF
58.791	93.486	137.408	206.930	201.927	400.017	753.704	1580.932	CorrectedRSF
74.98	2.96	19.65	0.23	0.25	1.87	0.02	0.05	