

National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center
2101 NASA Parkway
Houston, Texas 77058-3696



November 17, 2009

Reply to Attn of: EA3-09-030

TO: AMS Records

FROM: EA3/NASA AMS Project Manager

SUBJECT: AMS Burst Disk Vent Duct Redesign and Certification

On July 9, the Alpha Magnetic Spectrometer (AMS) Collaboration Magnet design team experienced a failure of the AMS Superfluid Helium Tank Burst Disk duct system. Over the next three months, the collaboration in conjunction with the AMS Project Office at JSC went through an extensive redesign and recertification process. This letter summarizes the results of this extensive effort. This letter is an attempt to provide closeout verification documentation for Safety Data Package verification items as well as Acceptance Data Package verification items.

A design change effort began soon after the test failure. The test report from the failed test can be found in Enclosure 1 of this letter. Once a new design concept was developed, the AMS Project Office requested a meeting with the Payload Safety Review Panel (PSRP). That meeting was held on August 13. The minutes from that meeting can be found in Enclosure 2. At that meeting, a series of eight certification tests were outlined. The following is a summary of the results of those tests. Although an eight-test certification approach was accepted by the PSRP, the AMS team actually performed more than eight tests. The team learned something new in just about every test, and based on the test results, several changes were made in the final flight design as well as in the test setups and procedures. The final design is shown in the following figures :

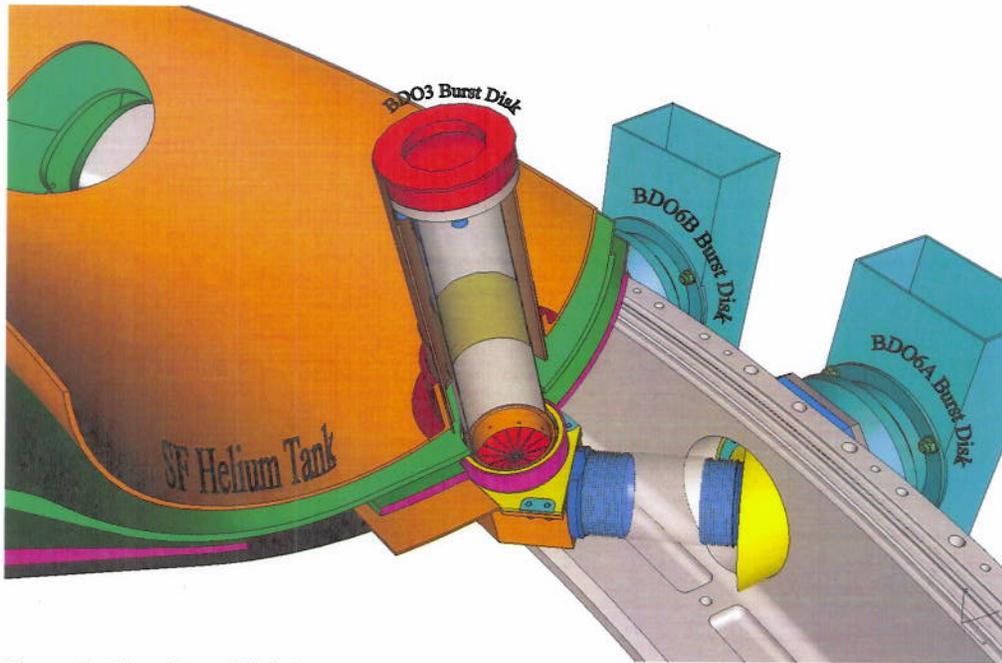


Figure 1: New Burst Disk Duct Design – Shown with Helium Tank and Vacuum Case Ring

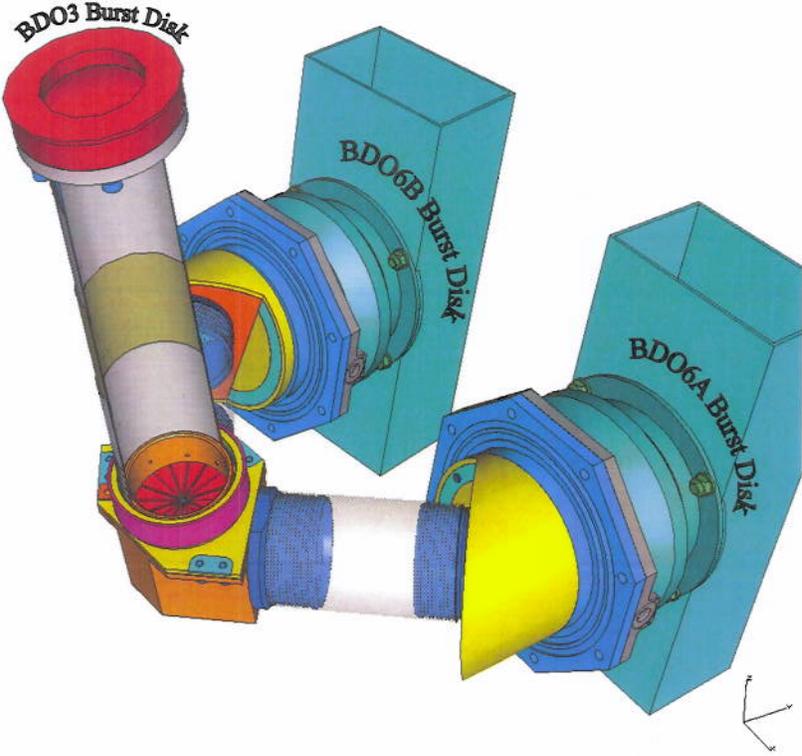


Figure 2: New Burst Disk Duct Design – Duct Only

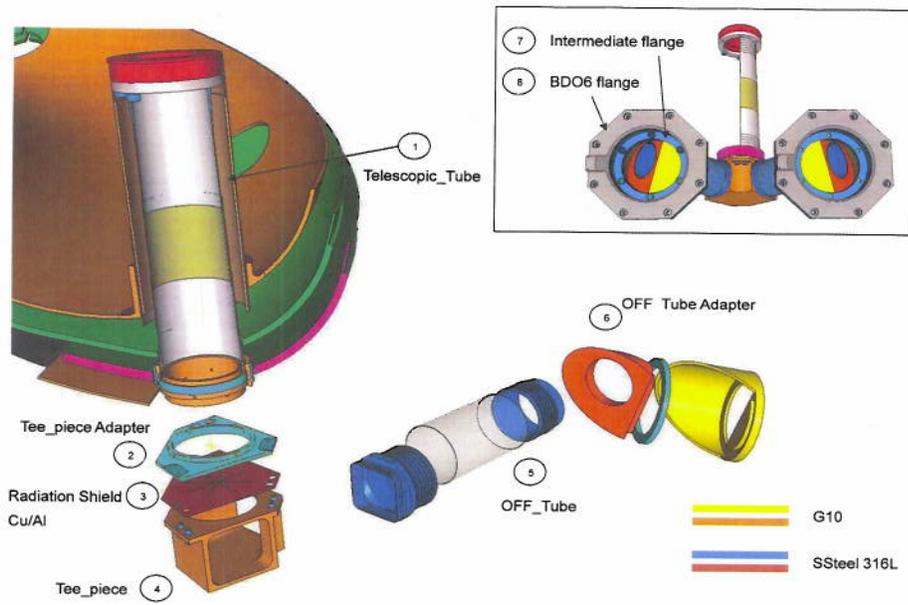


Figure 3: Cut away showing materials

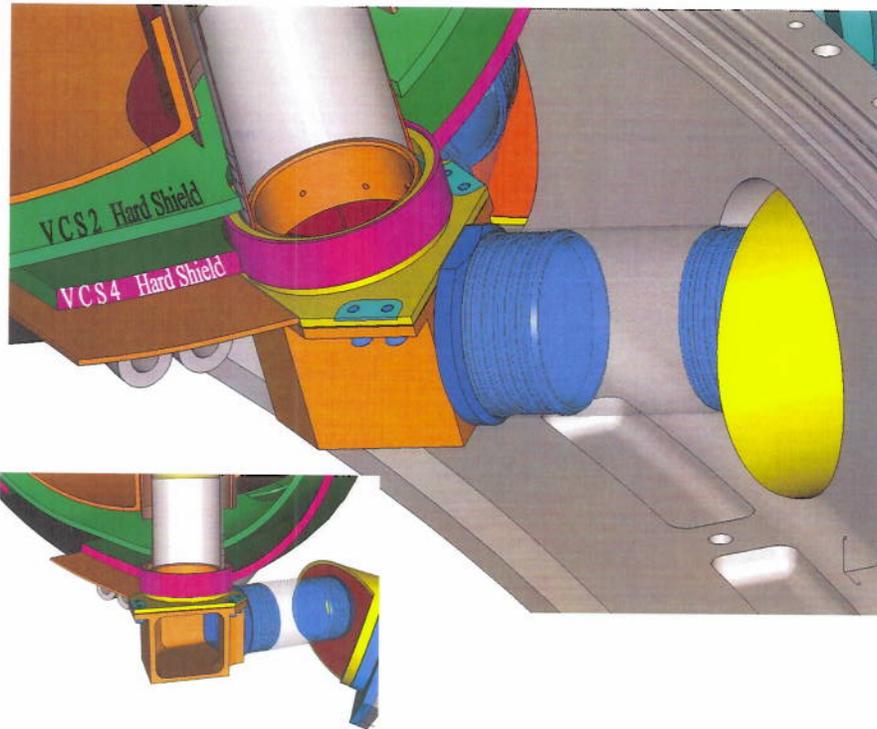


Figure 4: Close up of Tee-Box including cut-away

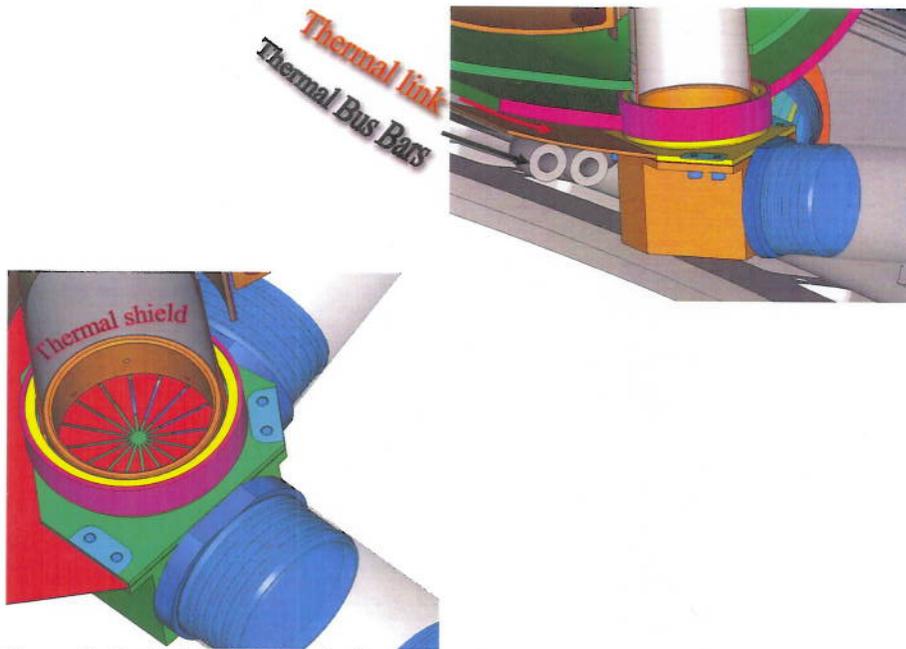


Figure 5: Radiation shield and Thermal Link to Tee-Box

1. The first tests were on the Telescoping Tube of the new design. The telescoping tube was subjected to two static tests. The first was done at room temperature and the tube held together up to 24 bar. A subsequent static test was performed with the burst disk in a liquid nitrogen bath. The tube was submerged in an LN2 Styrofoam dewar and connected to a gaseous helium supply and then pressurized. The pressure rose from 1 to 30 bar in 13 seconds. The last part of the test went from 30 bar to 36 bar in 2 seconds. At 36 bar, the end cap used for pressure testing blew off, but the tube had not failed. In fact, the tube never failed. This gave the team adequate confidence in the telescoping tube design to proceed.

2. The second major portion of the new design presented to the PSRP in August was a stainless steel bellows. The second test was done on August 12 on the 72 mm (Outside Diameter) (OD) / 52 mm Inside Diameter Stainless Steel (ID SS) Bellows in a LN2 bath. The video of the test indicates the Bellows began to yield around 3-4 bar, became unstable around 5-7 bar, and failed at 9.3 bar. The Bellows also failed in a way that it blocked the BD03 to BD06A & B flow path. The failure and its mode were not unexpected since edge-welded bellows like these are normally used in vacuum service and are not pressurized without an "anti-squirm" sleeve; typically a SS wire braid. Unfortunately, the extremely tight space and flexibility requirement in the system over a relatively short length does not allow for a sleeve. Based on this test, it became obvious that some new system would be required for this portion of the duct.

3. The team then started testing the Ortho-fabric Flexible Tube in a LN2 bath on August 14. Ortho-fabric is a Kevlar Nomex weave material used in the Space Suits. This material is very porous so it requires some sort of bladder to retain the helium gas while the Ortho-fabric provides the structural support. The third test indicated the Flexible Tube reached ~14 bar before the bladder and test fixture developed an unsustainable leak. There appeared to be no detrimental effects on the tube or its stitching which remained flexible even at ~77 K. The test setup used ~10 meters of 6 mm OD tube so there was quite a large pressure drop from the helium supply to the test article. The pressure was read from a gauge located just upstream and near the Flexible Tube. Thus, judging by the audible callouts in the video and the gauge visible in the video, the pressure in the tube was likely a bar or so lower due to the leak in the bladder. This test showed the team that the Ortho-fabric Flexible Tube configuration was extremely promising.

4. The fourth test using the same Ortho-fabric Flexible Tube was done on August 15th using a similar bladder with different assembly techniques. The bladder failed again at an indicated pressure of 19.7 bar while the Ortho-fabric remained flexible and intact.

5. The fifth test was conducted on the same Flexible Tube immediately after the bladder failed above. The flow was increased significantly in an effort to fail the Ortho-fabric Flexible Tube. The indicated pressure reached ~24 bar before the cloud caused by the rapidly dispersing LN2 obscured the view from the video cameras. The actual pressure probably only reached ~20 bar for the same reasons cited in #3 above. The Ortho-fabric *still* would not fail.

6. The team then reconfigured the setup to read the pressure directly on the tube by drilling and tapping the other end of the test fixture. This placed the local pressure gauge at the opposite end of the He supply line – and downstream of any leaks in the Flexible Tube bladder. The team utilized ~0.005” thick teflon sheet. Unfortunately, it was only enough to go around ~1½ times inside the Ortho-fabric – so the overlap was poor and the team suspected this would lead to an even larger leak. The test proved this assumption to be accurate. This created more nitrogen clouds during testing. However, the team did get some readings from brief glimpses between the clouds. Even with the much larger leak in this test, the pressure in the tube still reached ~15 bar as read on the gauge downstream of the leak when the gauge at the supply cylinder read ~30 bar. Judging from the call-outs at higher pressures while the gauge was obscured, the configuration reached in excess of ~20 bar again – still without failing the Flexible Tube. Post-test examination indicated the teflon sheet was very wrinkled at installation and was even folded under one of the test fixture hose clamps. This contributed to the excessive leakage. This test proved that a seamless tube without wrinkles and holes was clearly needed.

Based on the Ortho-fabric Flexible Tube tests, the team agreed that it appeared to have the strength to meet the pressure requirements while remaining flexible at 77 K. Even after installing it ~10 times (it took multiple attempts on some occasions), clamping it four times at each end with 9 mm wide hose clamps, thermal cycling it three times, and pressure cycling it four times, there are minimal signs of abrasion, wear, or fraying.

7. At this point, the testing shifted from Center European Research Nuclear (CERN) to Texas A&M where a large test chamber had been built and readied for the next round of full system tests. Numerous burst disks were ordered or retrieved from storage. Numerous Cryomagnet Ground Support Equipment (CGSE) burst disks were used during preliminary tests. Test #4 (Enclosure 5) was conducted with all CGSE disks at room temp and warm gas pressurization: September 6th. All three disks opened properly but the pressurization rate was well below the target. The flight pressurization rate is based on analysis of the maximum expected heat load from a complete vacuum failure driving the pressure in the Superfluid Helium Tank.

8. Test #5 (Enclosure 6) was conducted with all CGSE disks with LHe and warm gas pressurization: September 11. The CGSE BD03 disk simulator reversed at the proper pressure but did not open. The pressurization rate was still ~53% below the target of 6.2 psi/second. The test hardware reached 100+ psig because it was provided with a helium gas supply that had no means of turning it off. Then it reached 100+ psig due to self-pressurization of the liquid helium. Post test evaluation eventually determined that the most likely cause of the burst disk failure to open was a faulty burst disk.

9. Test #6 (Enclosure 7) with flight-like BD03 and one BD07A/B (B disk removed; no BD06B) and warm gas pressurization: September 18. Both disks opened properly and the pressurization rate was 6.17 psi/second – within 0.3% of the target. However, it was determined that this over-tested the hardware. This is because at the time the burst disk opens, essentially the test setup was adding pressure via the test system, and also adding pressure due to the increase of the pressure in the vacuum space. The team decided to pressurize via loss of vacuum through a 0.5” orifice. Analysis showed that a 0.5” orifice is equivalent to a complete loss of vacuum on the flight system.

10. It was determined that since the test configuration was being changed to a loss of vacuum test, the next test should be performed with CGSE burst disks instead of flight burst disks to make sure that the test setup was accurate. Test #7A (Enclosure 8) with CGSE disks with LHe and self-pressurization from loss of vacuum: September 25. All disks opened properly and testing data was much closer to expected results.

11. Once the team had proven that the test setup was correct, Test #7B (Enclosure 9) was performed with a flight-like BD03 and one BD07A/B (B disk removed), one flight-like BD06 and self-pressurization from loss of vacuum: September 29. All disks opened properly and testing data looked very good. During this test, the team intentionally sabotaged the test by putting a burst disk membrane that was torn free in the original failed test in July into the flow path. The team also made the assumption that one of the BD06 burst disks fails to open; this was accomplished by removing one of the disks and replacing it with a cover.

12. PSRP representatives were invited to the final test, which was a complete replica of the flight system from the helium tank burst disk to the zero thrust vents. Test #8 (Enclosure 10) was performed with flight-like BD03 and two flight-like BD06a and self-pressurization from a simulated complete loss of vacuum: October 5. All disks opened properly and testing data looked very good.

During the testing process, the flight duct system was built identical to the final test configuration and installed in the flight magnet. This testing should give everyone the confidence that should there be a complete loss of vacuum on the AMS magnet, the system will vent safely without over-pressurizing the AMS Superfluid Helium tank or the AMS Vacuum Case.



Trent D. Martin
NASA AMS Project Manager

- Enclosure 1: Test report from July 9, 2009 – Failure of original design
- Enclosure 2: PSRP meeting minutes from August 13, 2009
- Enclosure 3: Cryogenic Testing of the Telescoping Tube
- Enclosure 4: Final Flight Configuration of Ortho-Fabric Flexible Tube
- Enclosure 5: BD Test #4 Report
- Enclosure 6: BD Test #5 Report
- Enclosure 7: BD Test #6 Report
- Enclosure 8: BD Test #7A Report
- Enclosure 9: BD Test #7B Report
- Enclosure 10: BD Test #8 Report
- Enclosure 11: Analysis of Complete Loss of Vacuum

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EA321/TMartin:llb:11/17/09:33296

CONCUR	CODE	>	EA321/SP						
	INITIALS	>							
	DATE	>							

NASA FORM 1257A

Enclosure 1

Technical Report



Subject: AMS burst disc BD03/06A/06B test Author: S Harrison

Date: 9 July 2009

Dist: MIT, file

CC: K Bollweg, M Capell, C Tutt

1 Introduction

After the failure during testing of the AMS vacuum vessel burst discs BD07A/B/C, it was decided to test the other three-in-a-row burst disc combination - BD03/06A/06B - to check that they did not experience a similar problem (failure of the second disc to open completely).

A test rig was designed and constructed (Figure 1) which allowed the flight spare discs to be mounted at the end of a 2.7 m³ volume which could be pressurised to 3 bar or higher in order to burst the discs. Although the gas in the system was warm, heat exchange with a liquid nitrogen bath was included so that the inner disc (BD03, operates in the flight system at 1.8 K) could be cooled to a temperature close to 77 K.

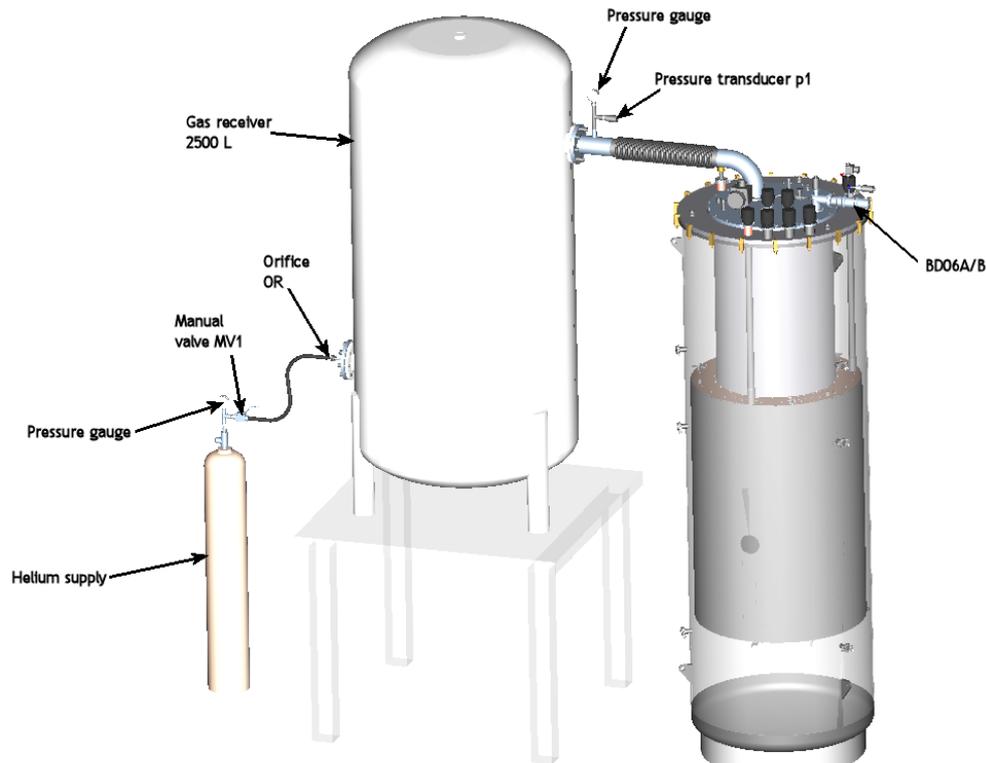


Figure 1

2 Commissioning Tests

Owing to the limited number of spare burst discs available (two), the test rig was first commissioned using relief valves. The main purpose of the preliminary tests was to establish how quickly the system could be pressurised: there was a concern that the BD07 tests had failed in part because the pressurisation was too slow. Figure 2 shows the test set-up schematically.

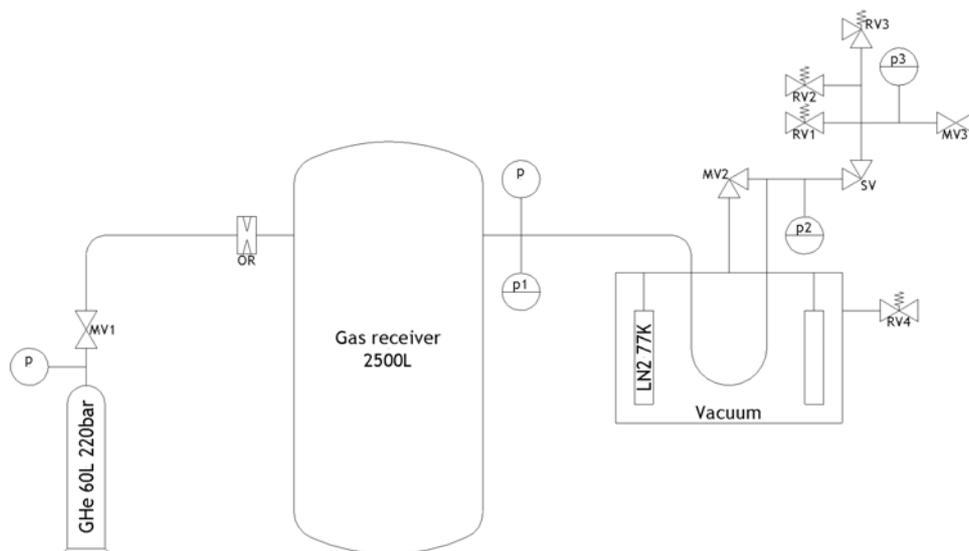


Figure 2

Helium gas from the gas cylinder is allowed to fill the gas receiver, which can be initially at any pressure between full vacuum and 3 bar. The flow rate into the receiver is limited by an orifice. From the receiver, the helium also pressurises (via a 4-inch line) a Kapton duct in the vacuum vessel. This is similar to the duct in the flight system which transports helium between BD03 (cold burst disc mounted on the helium vessel) and BD06A (the first of the warm burst discs, mounted on the vacuum vessel). When the pressure in the receiver reaches 3 bar, a fast-acting valve (SV on the diagram) opens to depressurise the system through a series of relief valves.

During the preliminary testing, it was found that a single gas bottle was not sufficient to pressurise the receiver at a rate similar to that expected in the flight system under the most severe conditions (0.44 bar/s at 3 bar). Moreover, the single bottle exhausted more completely than anticipated, so that there was little driving pressure by the time the receiver reached 3 bar. To overcome these problems, three gas bottles were connected in series, with a 5 mm orifice in the supply line to the receiver. Before the test started, the receiver was slowly pressurised to 2 bar rather than starting the test from vacuum. It was now found that the pressurisation rate was a fairly strong function of the initial bottle pressure, but was of approximately the right value.

Figure 3 shows the results from one of these runs. The receiver (including the Kapton duct) was pressurised from 2 bar to 3 bar in just over 3 seconds. The fast-acting valve then opened, and p3 (downstream of the valve) very quickly jumped to 3 bar and began to vent the helium.

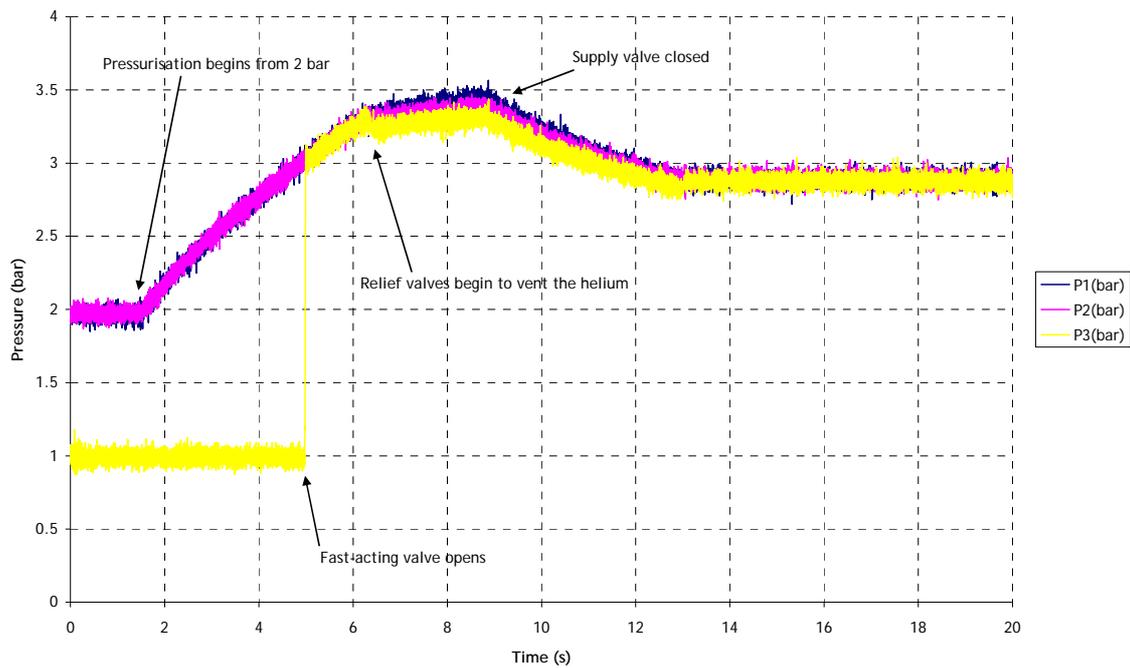


Figure 3

3 Burst Disc Test

With the commissioning tests completed, a set of spare burst discs was installed in the system. Figure 4 shows the new arrangement schematically.

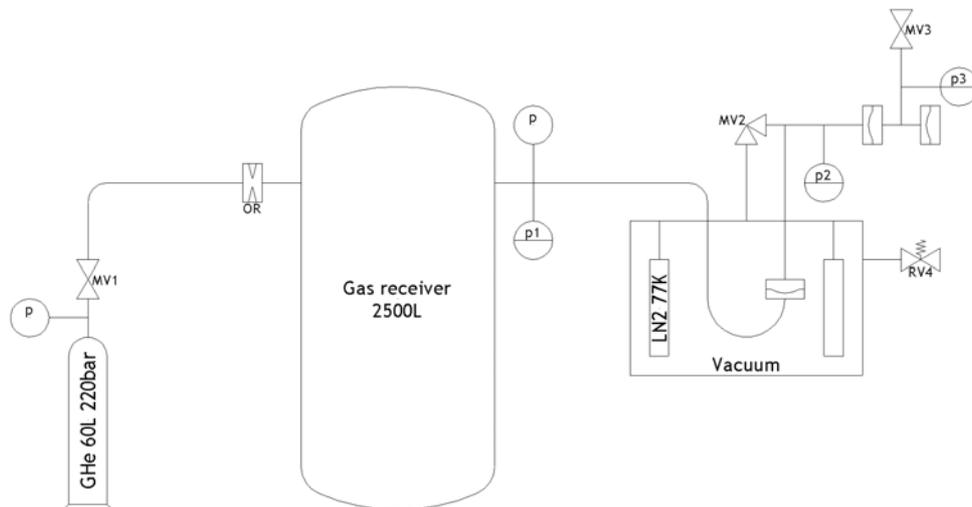


Figure 4

The 4 inch line from the gas receiver now encounters the first burst disc (BD03) inside the test chamber vacuum space. This disc is cooled by heat exchange with the liquid nitrogen. On the downstream side of BD03 is the Kapton duct, which takes vented helium - via some

stainless steel pipework - to the pair of burst discs (BD06A and BD06B) on the outside of the vacuum vessel.

The pressurisation of the receiver vessel is monitored by pressure transducer p1. The pressure in the Kapton duct and pipework is monitored by p2: this should read vacuum until BD03 bursts, when it is expected to rise very rapidly to 3 bar. On bursting the second burst disc (BD06A) the interspace between BD06A and BD06B should pressurise rapidly to 3 bar. BD06B is then expected to burst very rapidly, with the whole system then depressurising to atmospheric pressure. These final changes should be registered by pressure transducer p3.

3.1 Test Results 9 July 2009

The system was set up ready for testing on 9 July 2009, with the nitrogen vessel filled with liquid nitrogen. The interspaces between BD03 and BD06A, and between BD06A and BD06B were all evacuated.

The gas bottles were connected and the supply valve MV1 was opened. The gas receiver pressurised fairly rapidly, and a noise was heard when the first burst disc BD03 ruptured. At this point, however, instead of helium venting quickly from burst disc BD06B, gas instead began to vent from the pressure relief valve (RV4) on the test chamber vacuum space. Many pieces of shredded superinsulation (used to insulate the liquid nitrogen vessel) also came out through the relief valves. Transducer p2 continued to read vacuum, showing that BD06A had not burst. It was clear therefore that something had instead burst or split somewhere between BD03 and BD06.

The test rig was dismantled, and the following points were observed.

- (i) The Kapton duct had broken near the top (at the warm end). This was how the gas had escaped into the test chamber without bursting BD06A.
- (ii) Burst disc BD06A was intact, and had not reversed under the pressure loading. The BD06A/BD06B combination (flight spare) therefore remains intact.
- (iii) The foil disc from BD03 had opened as expected. However, instead of remaining attached to the housing at the hinge point as it is supposed to do, the disc had ripped away entirely and was later found among the superinsulation debris which had been damaged by the venting gas.

The sequence of events is also manifest in the logged data from the pressure transducers (Figure 5). At the start of the test the receiver had been pressurised to 2.0 bar, but the interspaces between the burst discs were evacuated. When the valve to the gas bottles was opened, the receiver pressurised to 2.8 bar in 1.2 s, at which point BD03 ruptured. Transducer p2 registered the opening of BD03 as a very rapid pressurisation of the interspace between BD03 and BD06.

Figure 6 shows the time between the rupture of BD03 and the failure of the Kapton duct in more detail. With sampling at 1 kHz, the data acquisition system was able to detect the rate of rise of pressure over a number of readings after BD03 burst. The plot shows that the pressure rose from zero to 2.2 bar in 4 ms: it is clear that this is the point at which the Kapton duct failed.

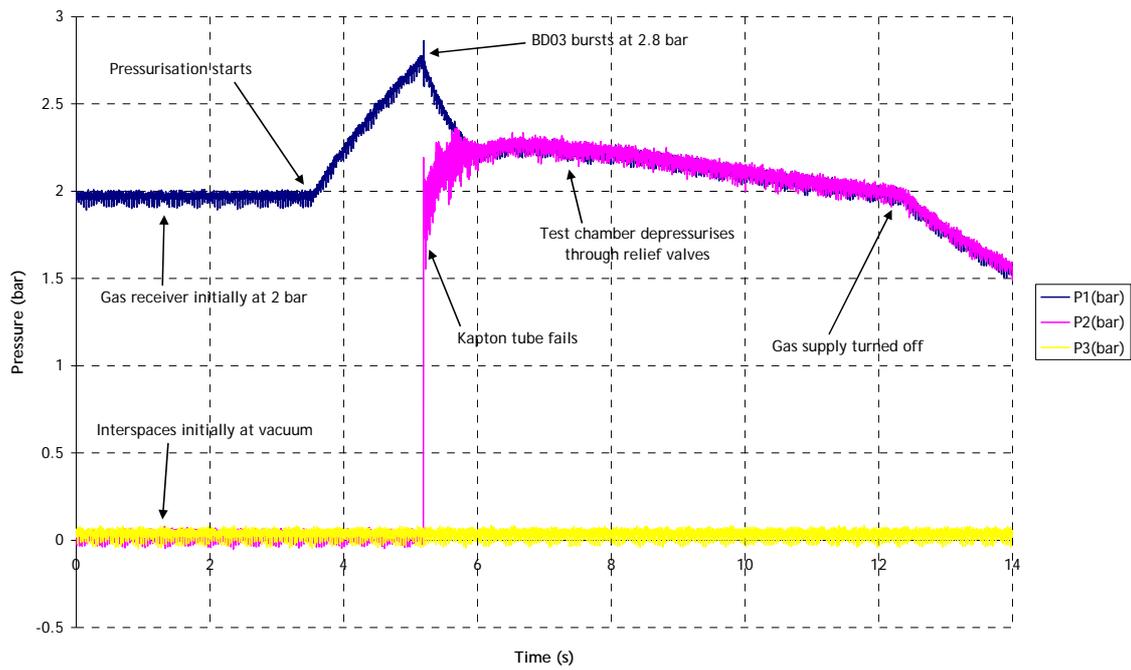


Figure 5

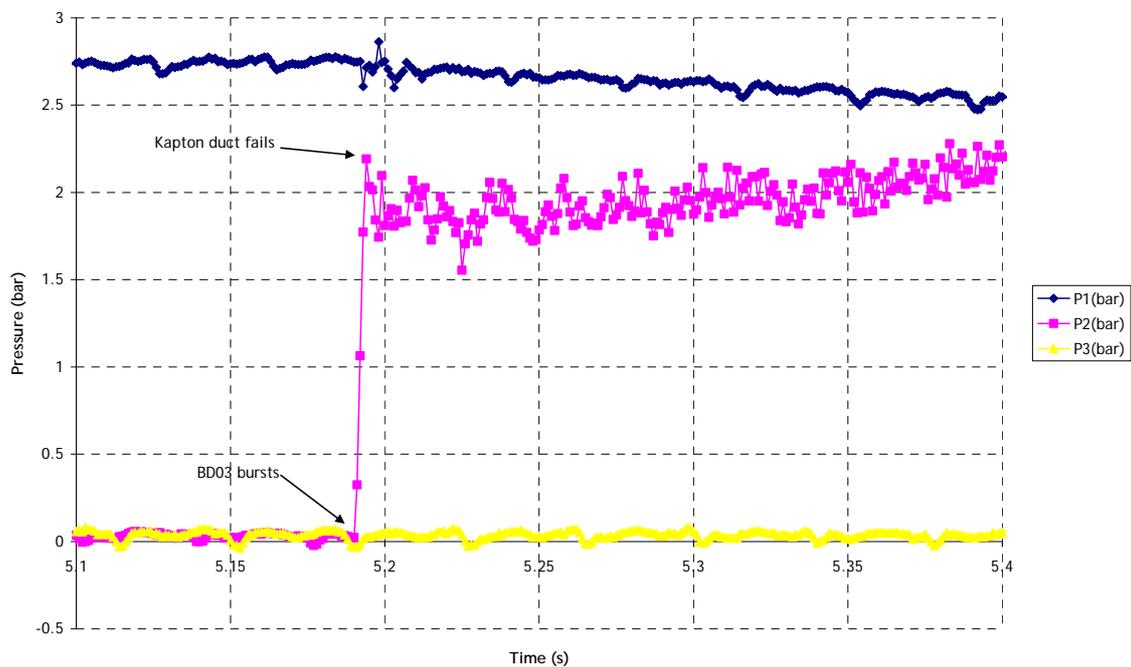


Figure 6

3.2 Discussion

It is not immediately clear why the Kapton duct failed in the burst disc test. A number of identical Kapton tubes had been tested before: although some of them had failed this was

only ever seen at very much higher pressures. It had been considered that there was sufficient margin between the observed failures and the real system pressures (determined by the burst discs) that there was no significant risk in the flight system or the burst disc test of the Kapton tube failing.

An investigation needs to be carried out urgently. This should concentrate on the known differences between the arrangements in the earlier tests of the Kapton tube, the burst disc test rig, and the flight cryostat - even though these small differences had previously been considered insignificant. They include the following.

<i>Kapton tube tests</i>	<i>Burst disc test</i>	<i>Flight cryostat</i>
Tube mounted on long GFRP spigots at both ends.	Tube mounted on a long GFRP spigot at one end, and a short stainless steel spigot at the other.	Tube mounted on long GFRP spigots at both ends.
Pressurisation rate set by opening a valve.	Pressurisation rate set by rupturing a burst disc.	Pressurisation rate set by rupturing a burst disc.
External environment atmosphere or liquid nitrogen.	External environment vacuum.	External environment vacuum.

It is notable that the failure of the Kapton tube was at the warm end, so the cooling does not seem to be significant. This is also the position of the short stainless steel spigot for mounting, which was a new feature shared neither by the previous Kapton tube tests nor by the flight system.

The failure of BD03 to retain the foil disc after bursting is also a concern, as this was not supposed to be able to happen. The disc manufacturer has been contacted to seek an explanation.

Enclosure 2

NASA JSC
Payload Safety Review Panel
Alpha Magnetic Spectrometer-02
Burst Disk
Technical Interchange Meeting

Minutes of Meeting
August 13, 2009

1.0 INTRODUCTION

1.1 **General:** The Payload Safety Review Panel (PSRP), chaired by JSC/OE/M. Surber, met on August 13, 2009, with representatives of the JSC/Alpha Magnetic Spectrometer (AMS) Project Office, the Payload Organization (PO), at the Regents Park III Conference Facility for an AMS-02 Burst Disk Technical Interchange Meeting (TIM). JSC/NA2450/R. Rehm and K. Chavez, the supporting Payload Safety Engineers (PSEs), introduced the meeting and attendees (see Attachment 1).

1.2 **Background:** The PO has coordinated the current design of the AMS-02 Dewar Burst Disks (BDs) through numerous meetings with JSC/Pressure Systems and the PSRP. The PSRP held the following meetings on AMS-02:

- Helium Venting TIM, 4/20/00
- Phase 0/I Flight Safety Review (FSR), 1/16/01
- Vacuum Jacket Leakage Special Topic Meeting, 10/11/01
- Gauss Limit Special Topic Meeting, 10/16/01
- TIM, 1/17/03
- Phase II FSR, 5/21-25/07
- Hazard Report (HR) TIM, 10/10/07
- Non-compliance Report (NCR) TIM, 12/10/08

1.3 **Scope:** This meeting focused on the PO report of BD test results. The PSRP reviewed no previous action items (AIs) associated with this payload in this meeting.

1.4 **Conclusion:** No agreements and no AIs resulted from this meeting. The PSRP reviewed no HRs. The PSRP accepted the PO's proposed resolution and redesign of the BDs for the vent lines. The PSRP urged the PO to have all verification tracking log (VTL) items that are not associated with nominal ground processing for launch closed prior to the Phase III FSR. The PO also should include the assessments of the composite-over-wrapped pressure vessels (COPVs) and the WSTF review (visual inspection) of them in the Phase III Flight Safety Review (FSR).

2.0 SIGNIFICANT SAFETY DISCUSSION

2.1 **Science Overview:** The AMS-02 experiment is a state-of-the-art particle detector that will search for antimatter and dark matter in space and study galactic cosmic rays. The experiment will advance our knowledge of the universe and its origin.

The AMS-02 experiment uses a large cryogenic superfluid helium (SFHe) superconducting magnet (Cryomagnet or Cryomag) at 2°K to produce a strong, uniform magnetic field (~0.8 Tesla). Due to the differences in electrical charge, particles of matter will curve one way when

they pass through the magnetic field, and antimatter particles will curve in the opposite direction. The mass of the particles determines the amount of curvature. Planes of detectors above, in the center of, and below the Cryomagnet record the unique particle signatures. The AMS-02 will collect data from the ISS for at least three years.

2.2 Hardware Overview: The PO conducted hardware inspections at Geneva, Switzerland, and at KSC. The Shuttle will ferry the AMS-02 experiment to the International Space Station (ISS) for installation on the external truss of the ISS. Due to limited Shuttle flights, AMS-02 will remain on the ISS indefinitely.

2.2.1 BDs: A BD is basically a highly reliable “fuse” for fluid lines. The BD design is single-fault tolerant to prevent leaking atmosphere into the helium system. BD07 protects the Dewar from venting helium into the payload bay.

2.2.2 Kapton Tube: The Kapton tube is used only for installation; it is fixed during operation. The telescoping Kapton tube is designed for thermal expansion and will withstand launch loads. Testing showed that the internal diameter (ID) of the Kapton tube was too small for the BD opening.

2.2.4 Radiation Shield: The PO will test the Radiation Shield.

2.2.5 Flange: The PO clarified that the flange that failed was a test article and not a flight unit.

2.2.6 Bellows or Fabric Sock: The PSRP inquired about the effect of air passing over the folds in the bellows at high velocity and whether this is a concern. The PO indicated that they are considering replacing the stainless steel bellows with a fabric sock for unrelated reasons.

2.3 Burst Disk Test: The PO conducted the following tests on the BDs:

- Acceptance testing on individual BDs and on assemblies, if in series
- Vibration testing on assemblies
- Leak testing on individual BDs and on assemblies

The spare BD03 membrane disengaged during the test on July 9, 2009. The failure was that the BD membrane tore loose completely, which had not occurred previously. Failure of the burst disk membrane is believed to have been caused by a design flaw in the fiberglass flange used to attach the Kapton tube to the BD03 assembly. The flange, which was supposed to be at least the same diameter as the BD opening, was actually 6.6 mm smaller in diameter than the disk opening. This caused the membrane to impale itself onto the fiberglass flange, weakening the hinge line and causing the membrane to detach. The Kapton tube failure could have been caused by the disk membrane impact or by the difference in the dynamic burst mechanism. The dynamic impact of this difference could have been enough to rupture the Kapton tube. The BD07 tests reported no leakage.

2.3.1 Anomalies during Testing/Assembly/Ground Processing: The PO found that the pressure dynamic load was much higher than expected, and any new design should attempt to accommodate this finding. This result was unusual because of the low pressure dynamic load that was seen in the testing conducted prior to this failure. Previous testing did not use Burst Disks, due to cost and availability, but rather valve opening.

2.4 Failure Scenarios:

2.4.1 BD on Launch: The PO analyzed various scenarios that might require a Trans-Atlantic Abort Landing. The PO said that it will monitor heat sources up to 9 minutes prior to launch (L-9) as a requirement for Launch Commit Criteria. The payload bay overpressurization concern is only credible between L+30 sec. and L+60 sec., not to include a launch abort scenario. The Space Shuttle Program office is aware of this and gave its approval to this assessment.

2.4.2 Variable Specific Impulse Magnetoplasma Rocket (VASIMR) Impacts: Both the AMS-02 and VASIMR payloads use large magnets. The AMS-02 PO reported that it has communicated with the VASIMR project management to determine whether VASIMR's strong magnetic flux could affect the operation and data quality of AMS-02. The PO found no hazards or mission success issues to report. VASIMR magnets are smaller than the AMS-02 Cryomagnet, and they only operate at times other than when AMS-02 will operate. Plasma concerns from VASIMR are still being evaluated to determine if they could affect AMS-02 science.

2.5 Design Changes Since the Non-compliance Report TIM (12/10/08):

2.5.1 Resolution: After the test and investigation, the AMS team developed a go-forward plan that will

- Eliminate the Kapton tube, replacing it with a more robust composite telescoping structure.
- Replace the existing internal T-Duct (Cow Horns) with a new T-Duct system that thermally isolates and provides redundant paths to new external BDs.
- Replace the BD06A/B assembly with two larger lower-burst pressure BDs in parallel. The result would be that there should be just one burst disk in each of the three vent lines. Reducing the burst pressure on the external disks should make the design safer and ensure adequate vent area. Since BD07 has already been qualified and meets these criteria, several single BD07 assemblies are on order for testing and final flight configuration. Tests show that the BDs do not leak, but additional testing is needed to demonstrate that, if they do leak, the safety system will still function. The PO plans to add a zero thrust vent to the burst disk in BD07.
- Implement an additional thermal radiation barrier made of one layer of 0.3 mm-thick pure aluminum to help improve the thermal performance of the system.
- Perform a series of tests to show that this new configuration functions properly, even under worst-case safety conditions.

2.5.2 Proposed New Testing: The PO proposed eight tests for the new configuration:

- Telescoping Tube Static Test (Rome)
- Telescoping Tube Cryogenic Static Test (Geneva)
- Stainless Steel Cryogenic Static test to failure (Geneva)
- Room Temperature Test of new Burst Disk Test Rig (BDTR) (Texas A&M University)
- Cryogenic test of BDTR (Texas A&M)
- Flight Test #1 (Texas A&M)
- Flight Test #2 (Texas A&M)
- Flight Test #3 (Texas A&M)

2.5.3 Discussion and PSRP Approval: The PO explained that JSC required it to provide three burst disks for two-fault tolerance to protect the Dewars from the hazard of backflow air leakage that might overpressurize the helium tank and cause it to leak into the payload bay. The PSRP said it believes that the original design was still single-fault tolerant. In fact, the PSRP concluded that multiple discs are actually less reliable than a single BD. In the test configuration, the PO removed one burst disc from the assembly as well as the 90-degree turn in the line that it believes caused the pressure shock that resulted in the burst disk failure. The two-BD testing configuration reduced pressure in the large tank following bursting. The PSRP concurred with the new design, which will include one BD with a single-thrust vent. The PSRP considered the design changes as meeting requirements for “failsafe.”

2.5.4 Panel Poll: The PSRP polled its members to determine whether the solution to the BD anomaly is acceptable. The panel members replied as follows:

- Shuttle Integration—Acceptable, with high confidence based on extensive previous analysis.
- Mission Operations Directorate (MOD)—Acceptable, with no issues.
- Crew Office—Acceptable.
- PSEs—Acceptable.
- Executive Officer (XO)—Acceptable.
- Chair—Acceptable.
- Engineering—Acceptable.
- Extravehicular Activity (EVA)—Acceptable.
- Payload Engineering & Integration (PE&I)—Acceptable.
- Pressure Systems—Acceptable; the test failure was fail-safe.
- Mechanical Systems Working Group (MSWG)—Acceptable.

2.6 Safety Assessment:

2.6.1 Form 1428, Fire Detection and Suppression Reporting Form: *Not applicable to this hardware.*

2.6.2 Form 622, Reflow and Series Payload Hardware Reflight Assessment Reporting Sheet: *Not applicable to this hardware.*

2.6.3 Form 1114A, Certificate of Payload Safety Compliance: *Not discussed in the meeting.*

2.7 Hazard Report Discussion: *Not discussed in the meeting.*

3.0 AGREEMENTS: The PSRP made no agreements with the PO in this meeting.

Original signed by:
JSC/NA2450/R. Rehm
Payload Safety Engineer

Original signed by:
JSC/NA2450/A. Coleman
Technical Writer

Original signed by:
JSC/NA2450/K. Chavez
Payload Safety Engineer

Status of Hazard Reports Presented
The PSRP reviewed no HRs in this meeting.

Previous Action Item Status
The PSRP reviewed/assigned no previous AIs associated with this payload in this meeting.

ATTACHMENT 1

Payload Safety Review Attendance Log

Payload: AMS-02 Burst Disk TIM

Meeting Date: August 13, 2009

Mail Code	Name	Phone 281	X
CHAIRMAN			
OE	Surber, M.	483-4626	X
SUPPORT PERSONNEL			
CB	Rickard, J.	483-3760	X
DA8/USA	Knutson, D.	483-4405	X
EA441	Henning, G.N.	483-0533	X
MO2	Kunkel, S.	483-4356	X
NE14	Guidry, R.	244-5510	X
SM	Spann, R.	483-3807	X
NT	Nobles, D.	335-2129	X
EP4/Jacobs	Manha, W.	483-6439	X
ESCG/JACOBS	Ross, S.	461-5710	X
ESCG/JACOBS	Brown, G. A.	461-5435	X
Boeing/HB3-40	Miley, R. R.	226-4968	X
NA2450/GHG	Chavez, K.	335-2374	X
NA2450/GHG	Mensingh, P.	335-2363	X
NA2450/GHG	Rehm, R.	335-2364	X
NA2450/JES	Coleman, A.P.	335-2391	X
NA2450/JES	Stauffer, P. W.	335-2402	X

Name	Mail Code	Employer	Phone Number	Technical Discipline	Internet Address
Harvey, E. K.		Barrios/ ESCG	281-461-5509 JEI SA	Systems Safety Engineer	eric.harvey@escg.jacobs.com
Martin, T.	EA	NASA	281-483-3296	AMS Project Manager	trent.d.martin@nasa.gov
Hill, L.	4E	ESCG/ Bastion	281-461-5701	Safety	leland.hill@escg.jacobs.com
Tutt, C.		ESCG	281-461-5703	Project Management	john.tutt@escg.jacobs.com
Mott, P.		ESCG	281-461-5712	AMS Chief Engineer	phillip.mott@escg.jacobs.com

Enclosure 3

BD03/06 Telescoping Tube Tests

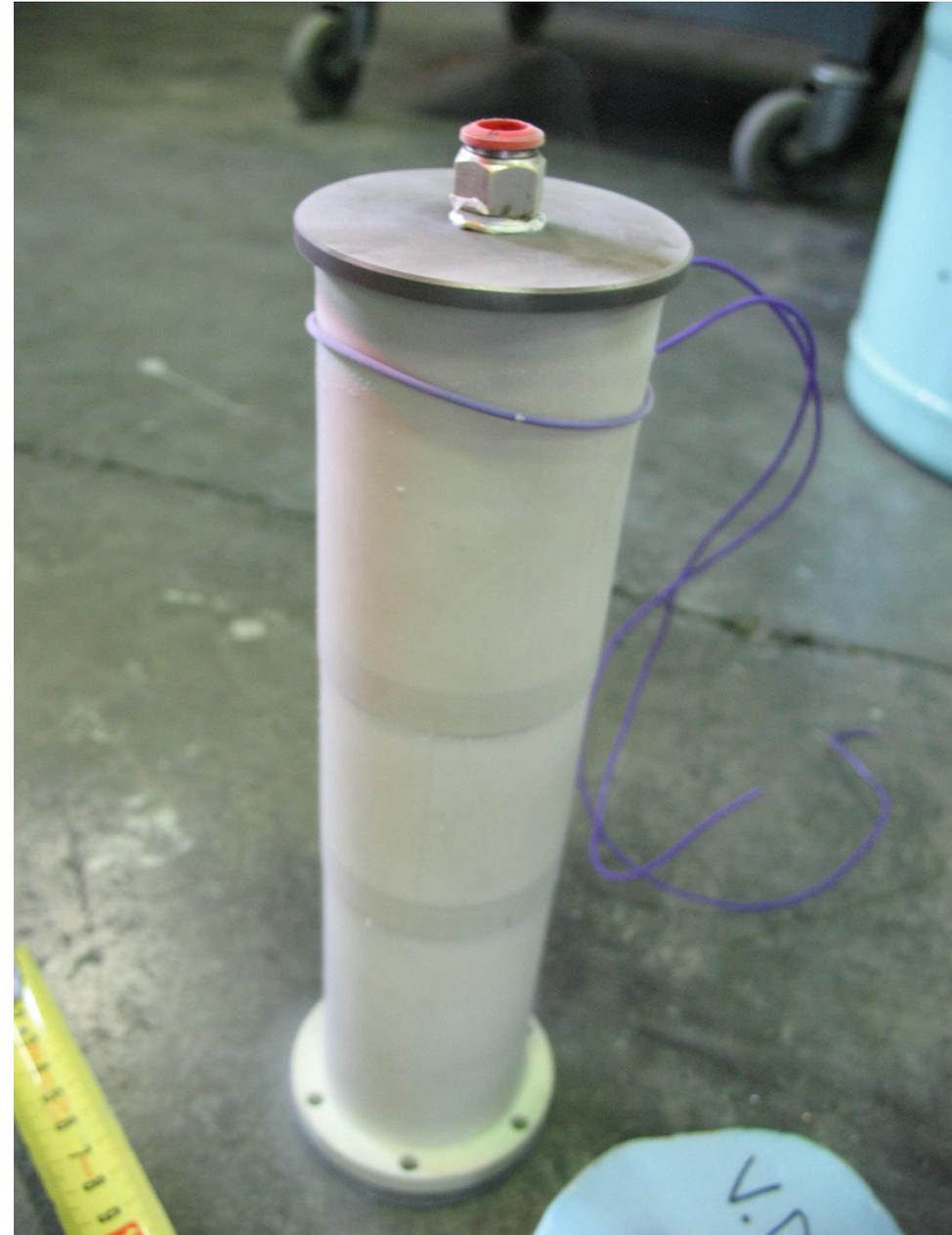
Initial thermal shock test
with LN2 and no pressure



BD03/06 Telescoping Tube Tests



No cracking, delamination of epoxied interfaces, or leakage of LN2 into the Telescoping Tube was observed



BD03/06 Telescoping Tube Tests



The cryogenic pressure test to failure was documented with 3 video cameras and carried out in an area blocked on 3 sides with large concrete blocks. Kerry volunteered Robert Becker's "Babe Magnet" to shield the fourth side.

BD03/06 Telescoping Tube Tests

The tube was then placed in a small styrofoam dewar and connected to a 0-50 bar pressure gauge



BD03/06 Telescoping Tube Tests



Then tube was pressurized to ~3 bar with helium gas and the dewar was filled with LN₂.

The tube pressure dropped to ~1 bar as it was cooled.

BD03/06 Telescoping Tube Tests



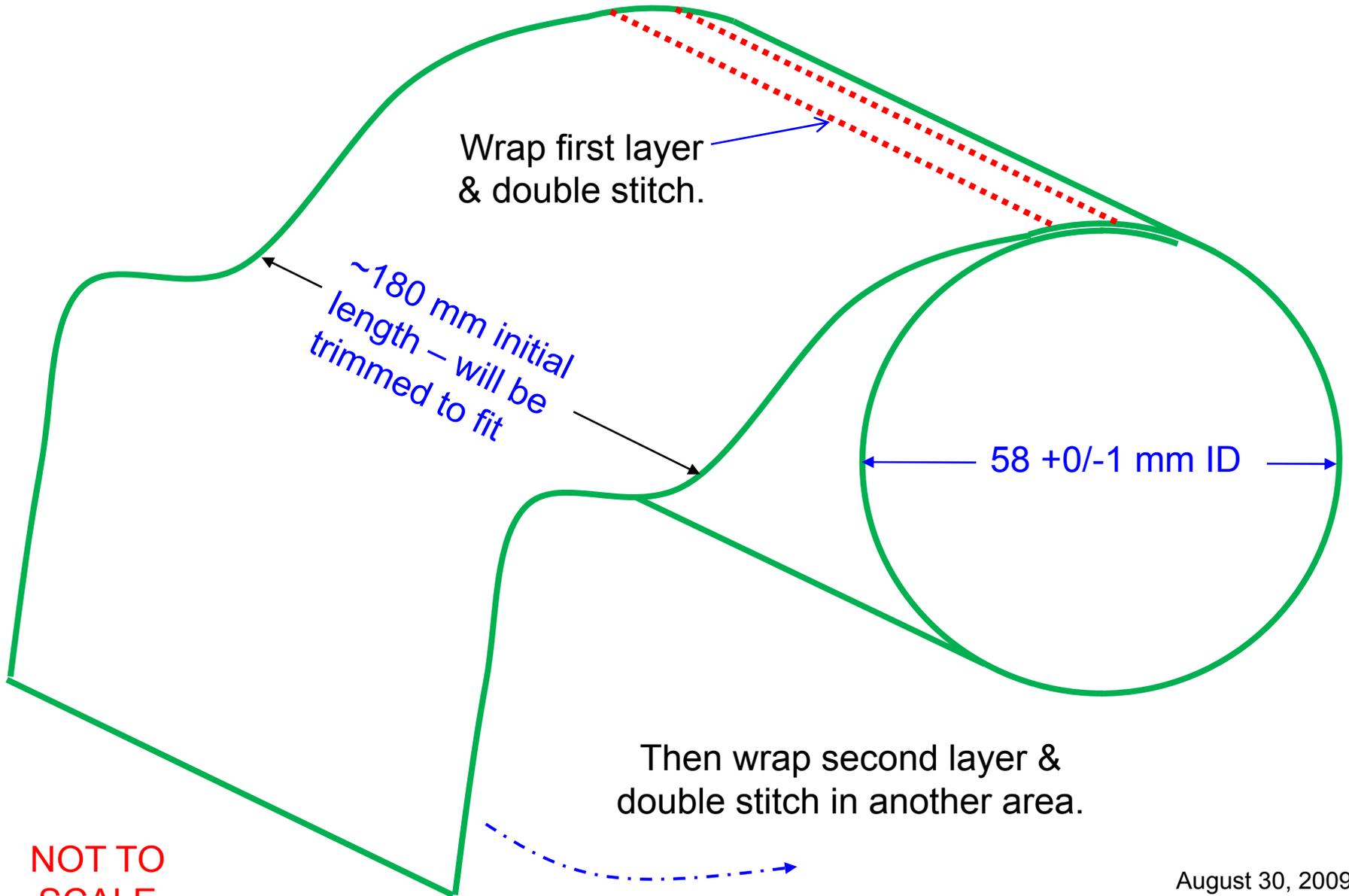
BD03/06 Telescoping Tube Tests



The glued interface to the end cap for the test failed while the tube remained intact. When this is bolted to the BD03 flange, it will be a stronger joint.

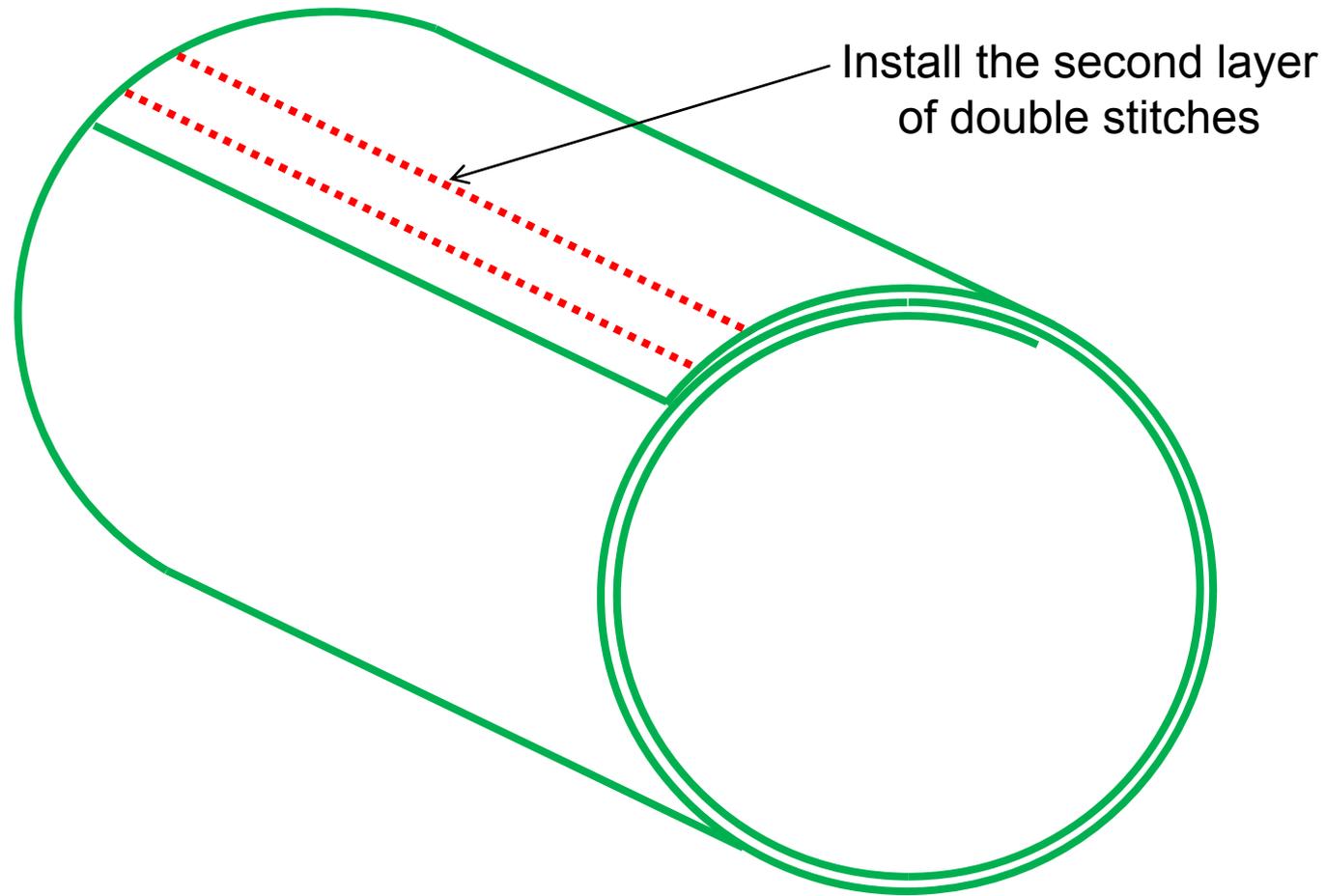
Enclosure 4

Double Layer Ortho-fabric Flexible Tube

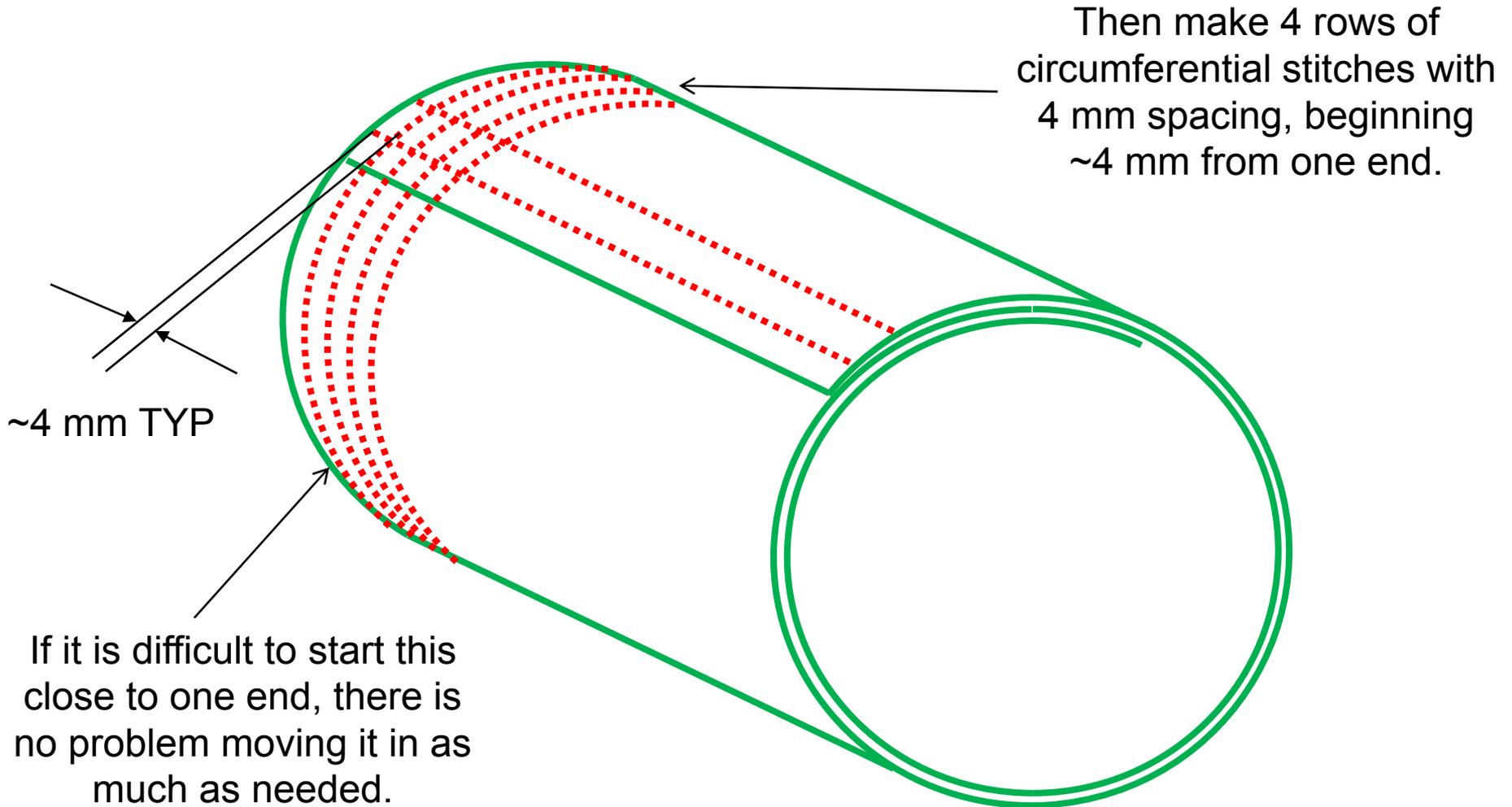


**NOT TO
SCALE**

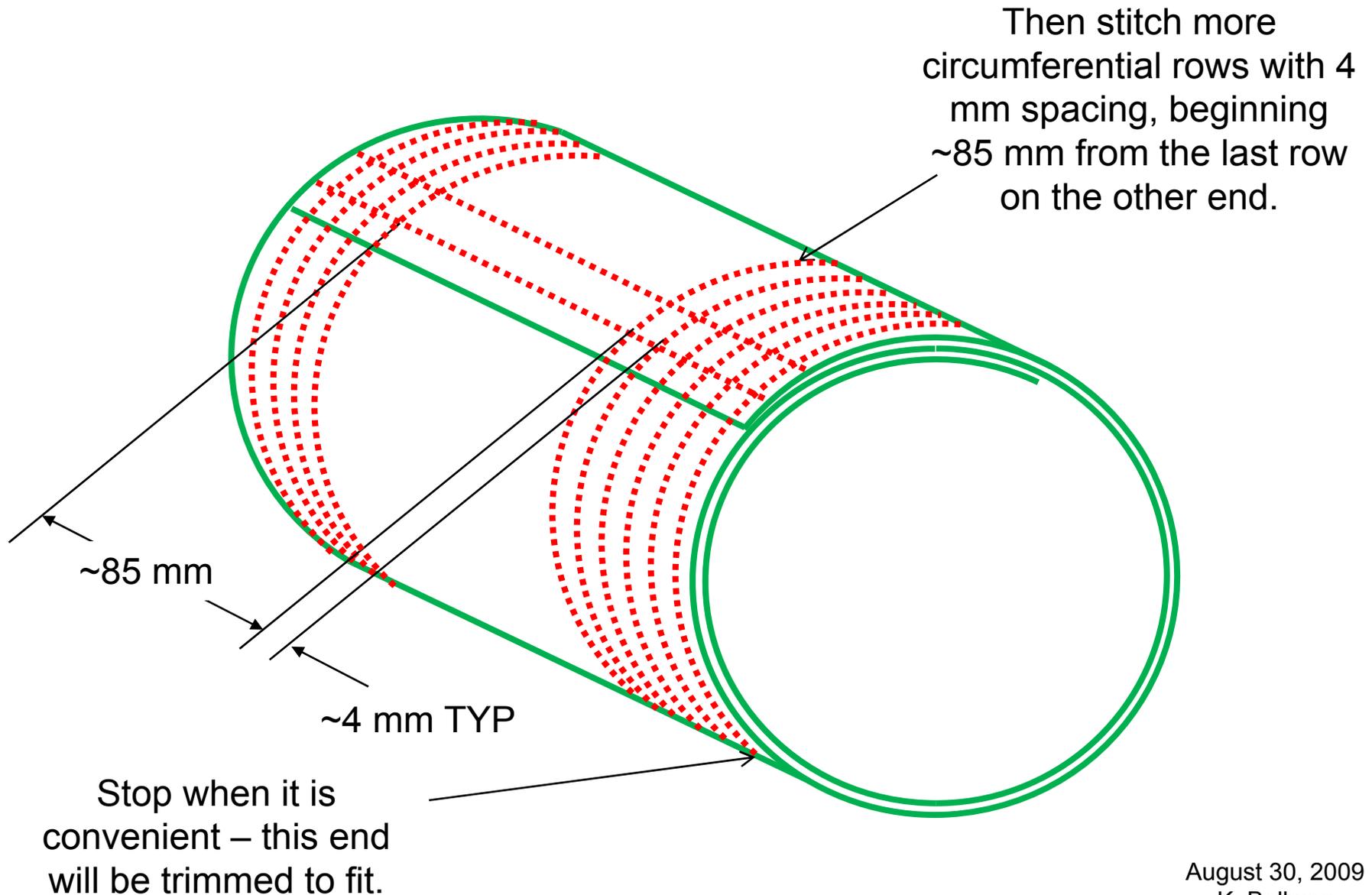
Double Layer Ortho-fabric Flexible Tube



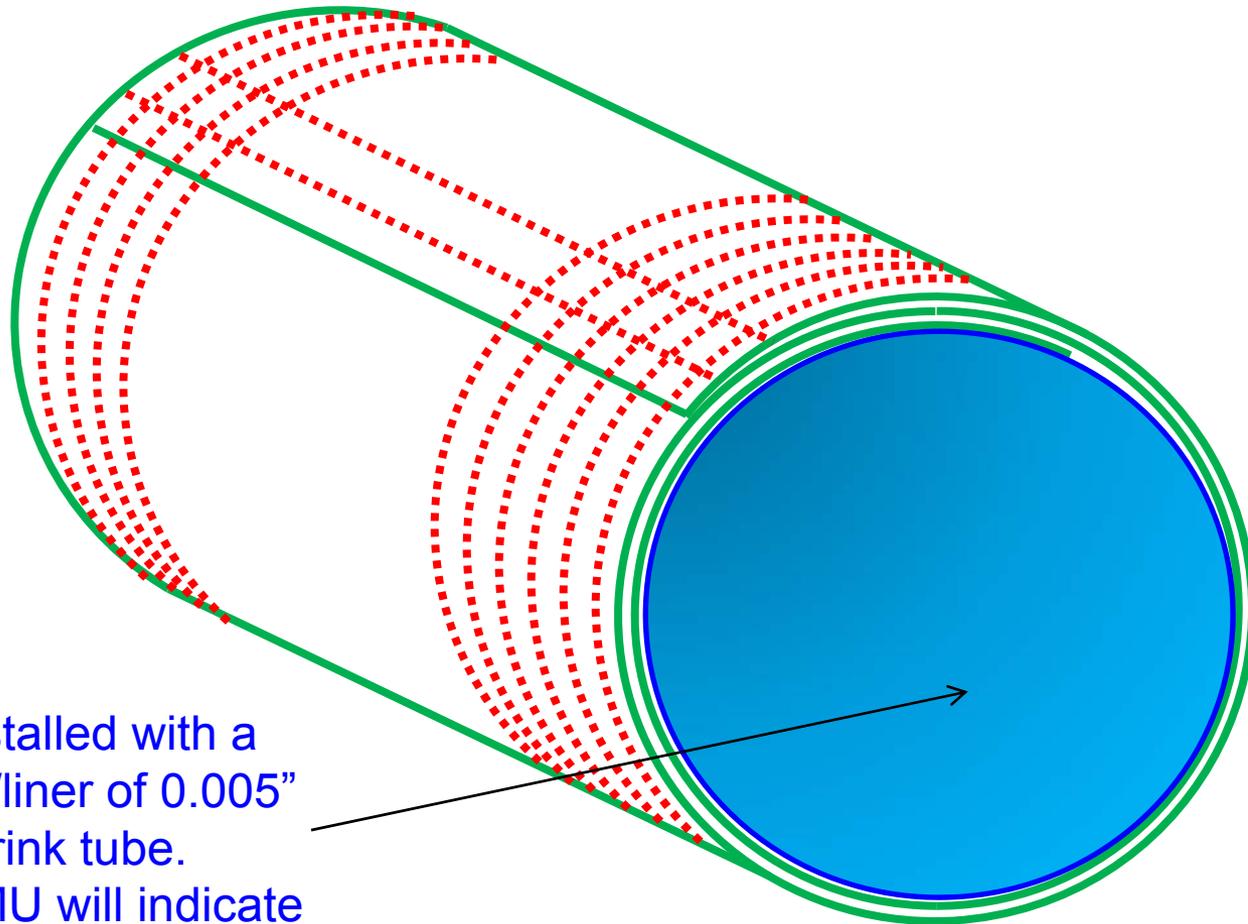
Double Layer Ortho-fabric Flexible Tube



Double Layer Ortho-fabric Flexible Tube



Double Layer Ortho-fabric Flexible Tube



This will be installed with a single bladder/liner of 0.005" thick PTFE shrink tube. Test #4 at TAMU will indicate if more layers are needed.

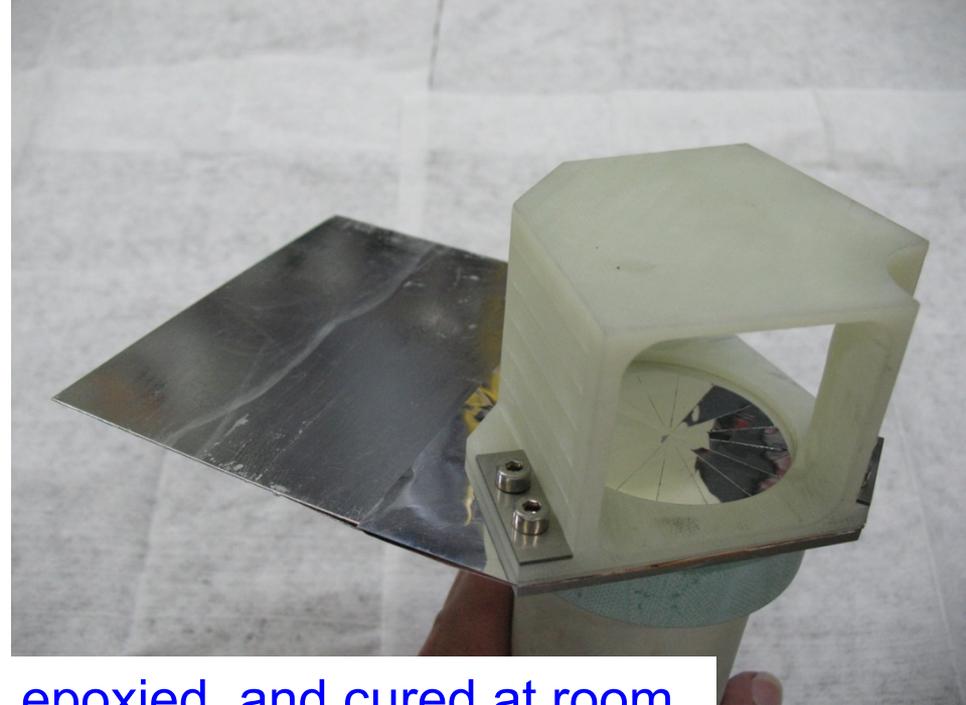
Enclosure 5

AMS Magnet Burst Discs & Ductwork Test #4 at Texas A&M

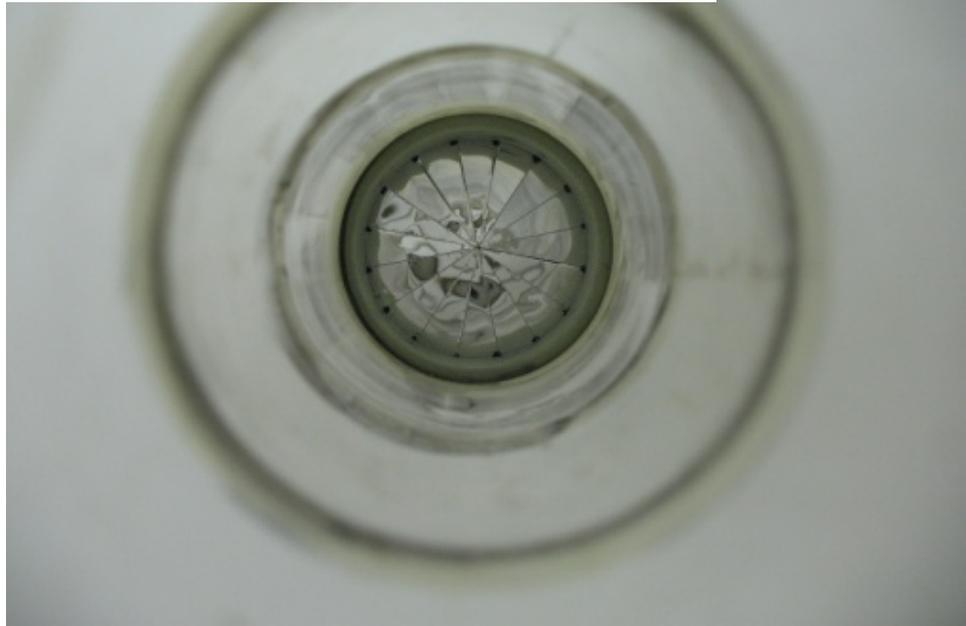
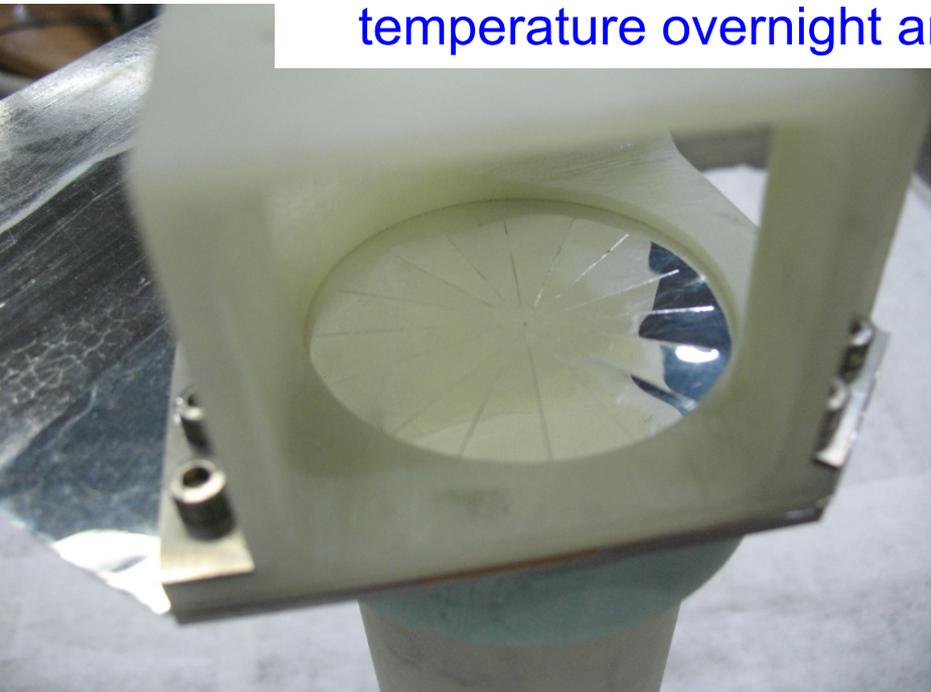
Updated September 7, 2009
K. Bollweg



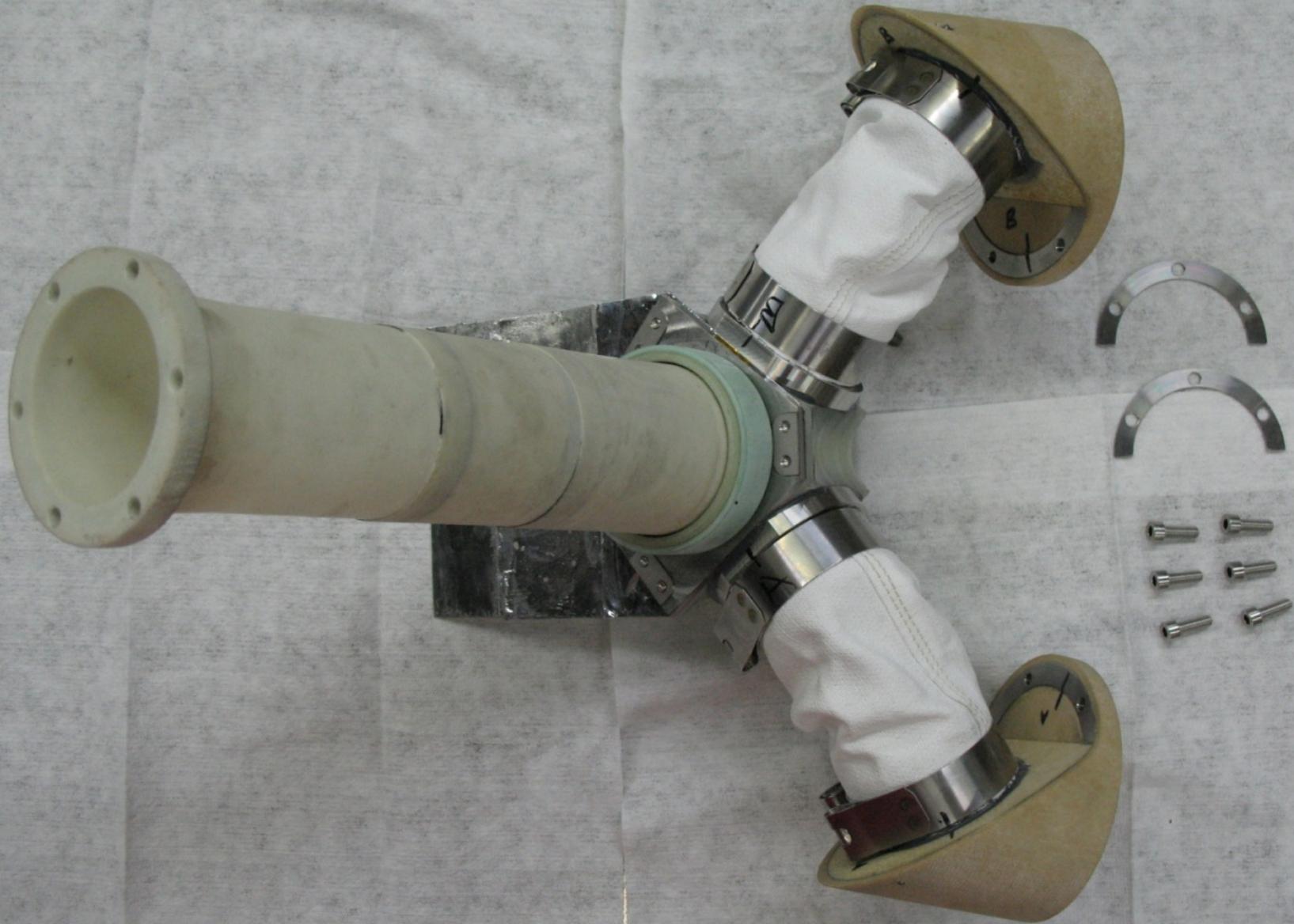
Working inside the test vessel was cramped and just a bit uncomfortable. It was done in shifts. Since Richard was the youngest & most flexible, he was inside the most.



The ducts were assembled, epoxied, and cured at room temperature overnight and then for 3 hours at 55 °C.

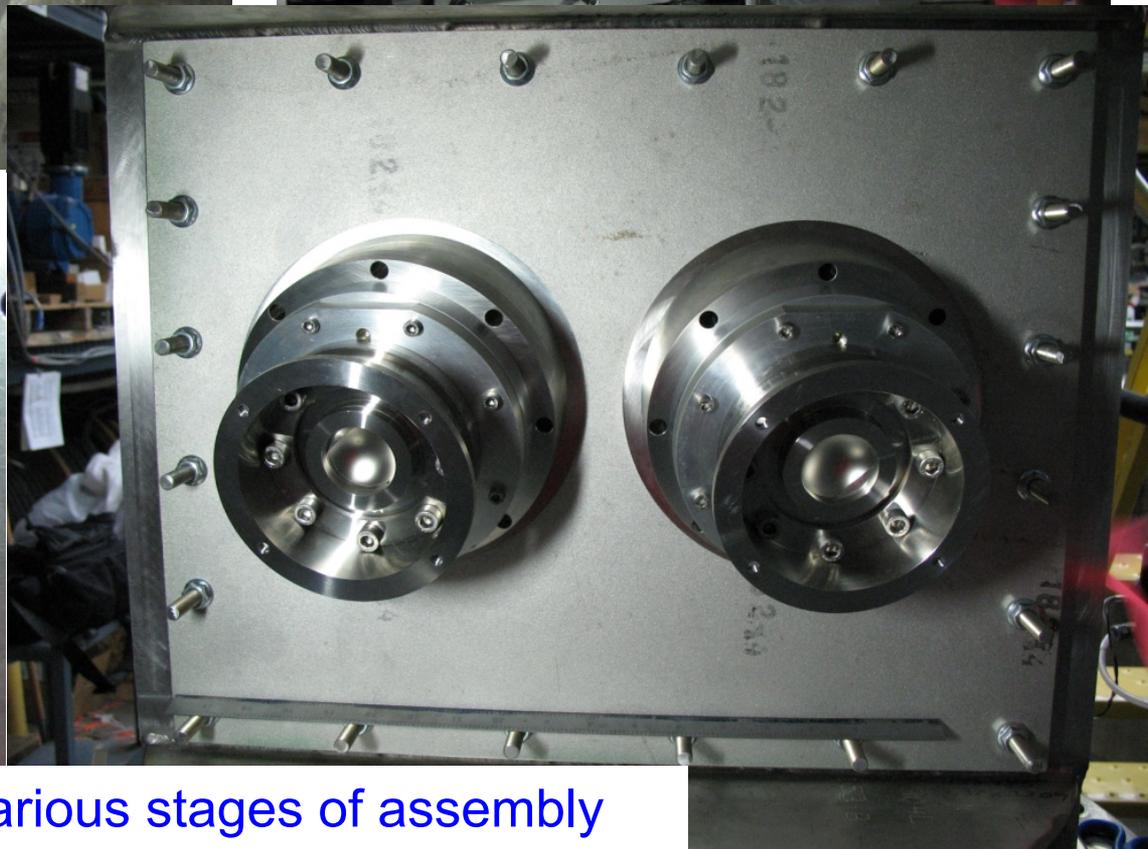
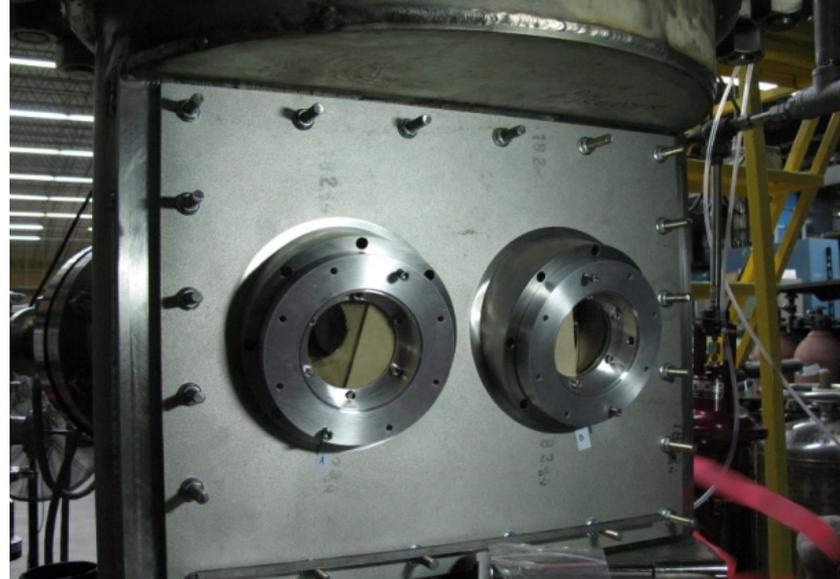


Just prior to installation in the test vessel.

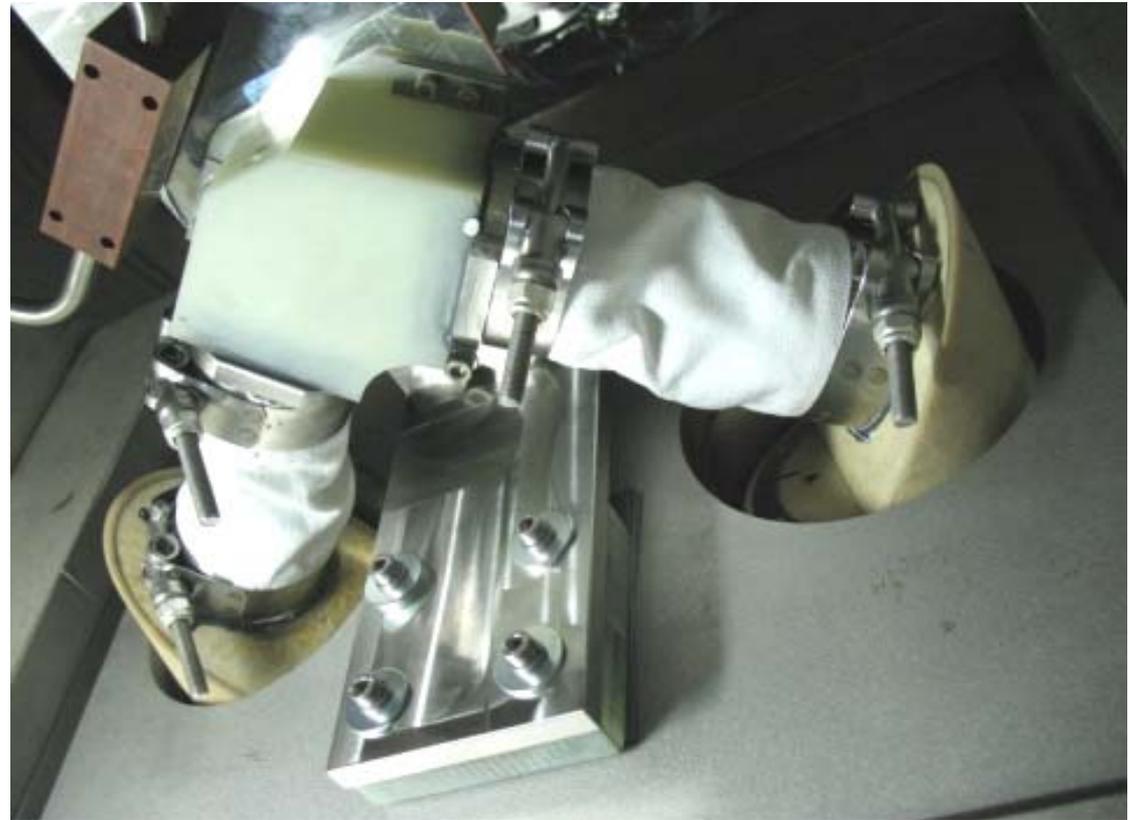
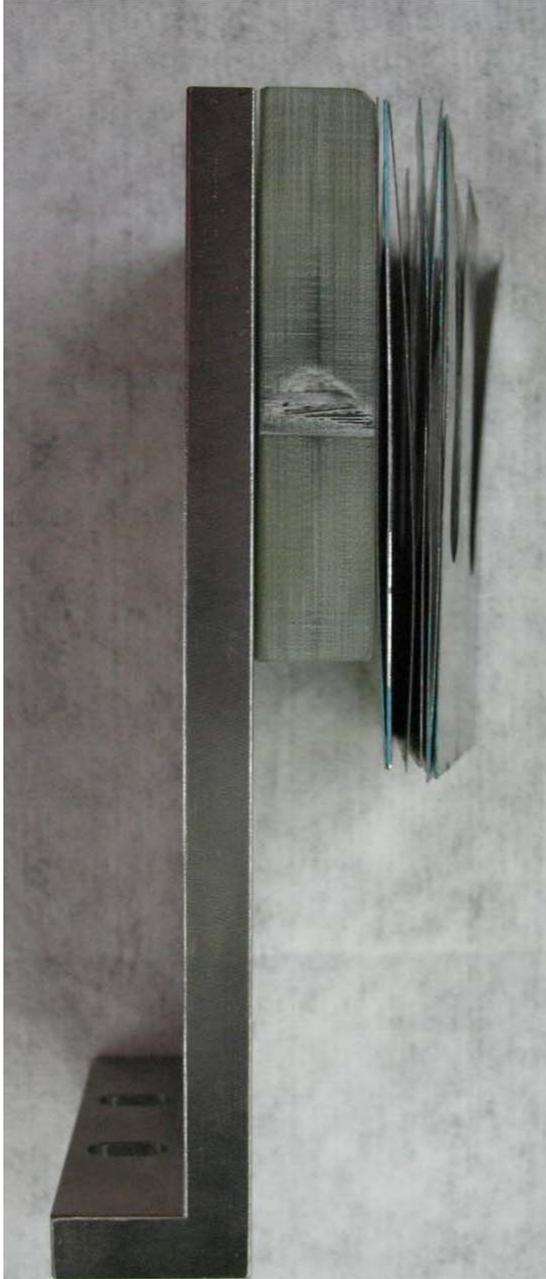


Richard felt he was in the vessel too long...so we just closed it up on him.





Various stages of assembly

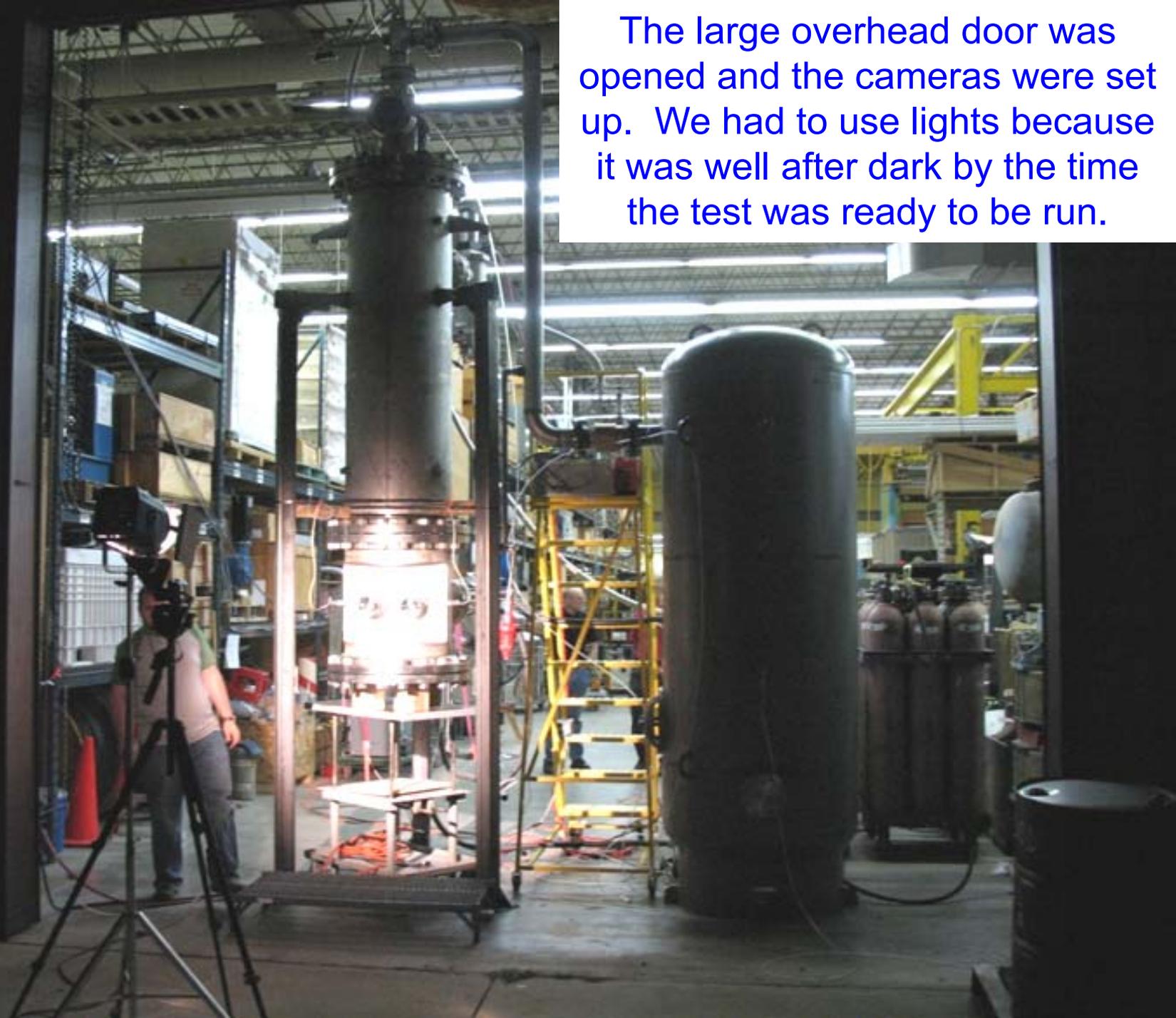


A spacer and shims were used to fill the gap between the inside of the Window Plate and the bracket that holds the Telescoping Tube in place



Eventually, the lower flange was installed, torqued, and leak testing began.

The large overhead door was opened and the cameras were set up. We had to use lights because it was well after dark by the time the test was ready to be run.

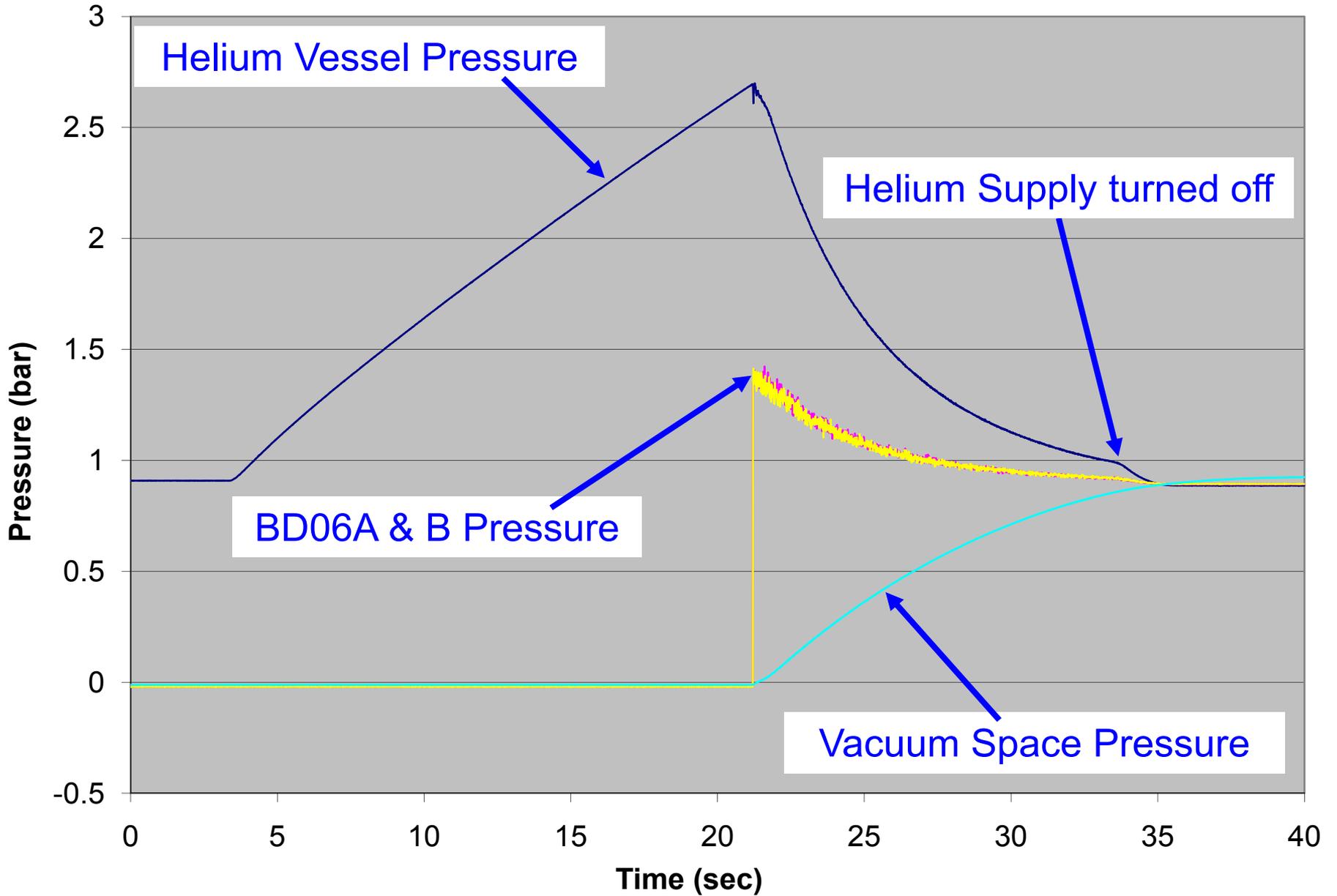




Both BD06A & B opened simultaneously. Both BD06 discs fragmented and came free of the test disc flanges. Several pie-shaped pieces of the radiation shield were found in the parking light. Disassembly and inspections will continue tomorrow.

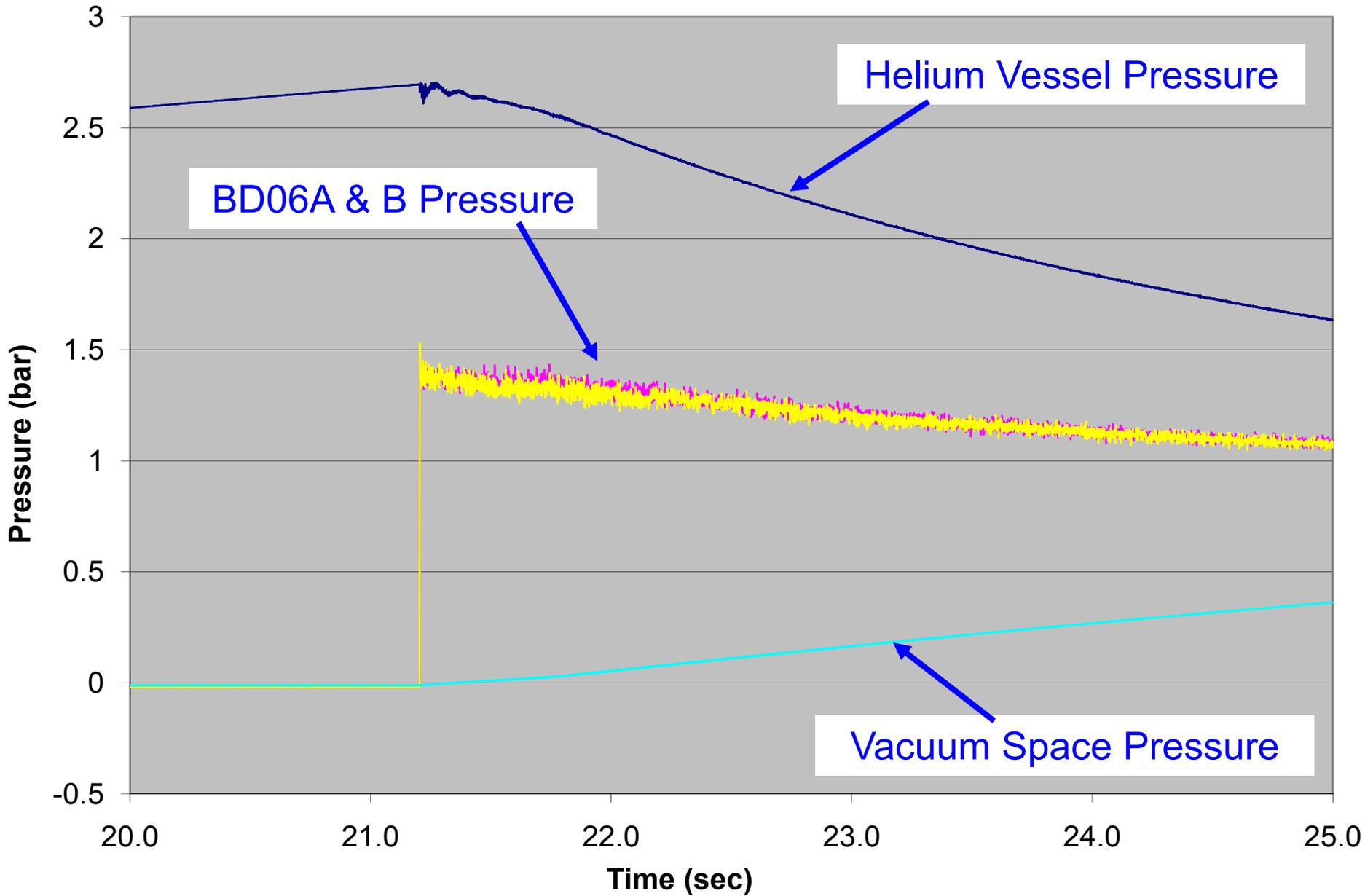
Burst Disk Test 4

Raw Data



Burst Disc Test 4

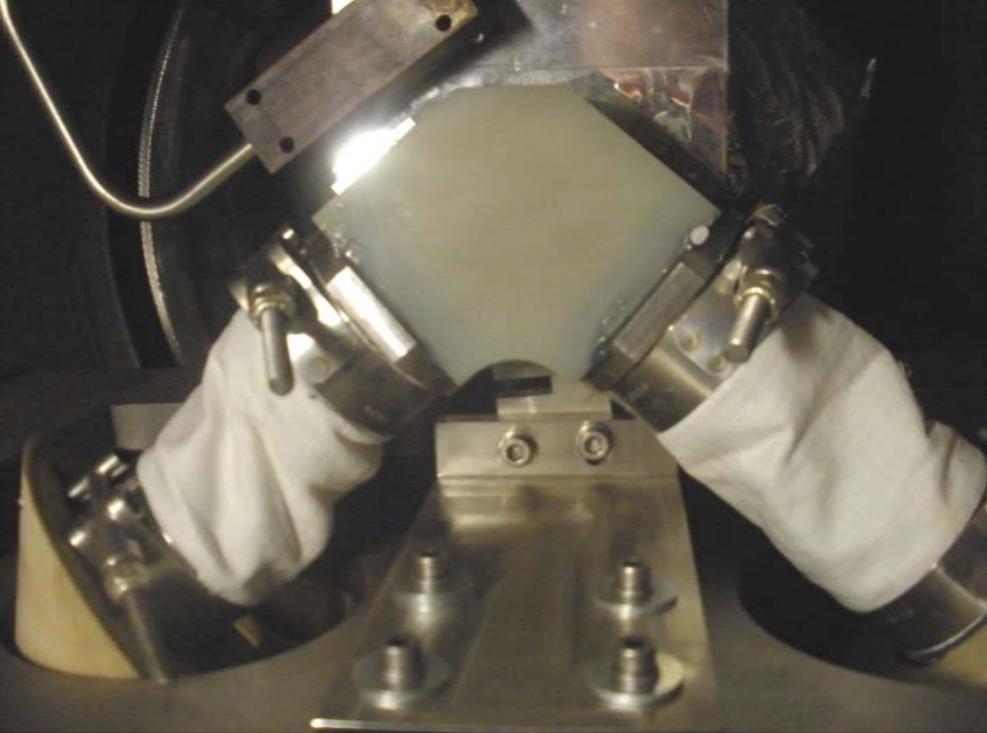
Raw Data



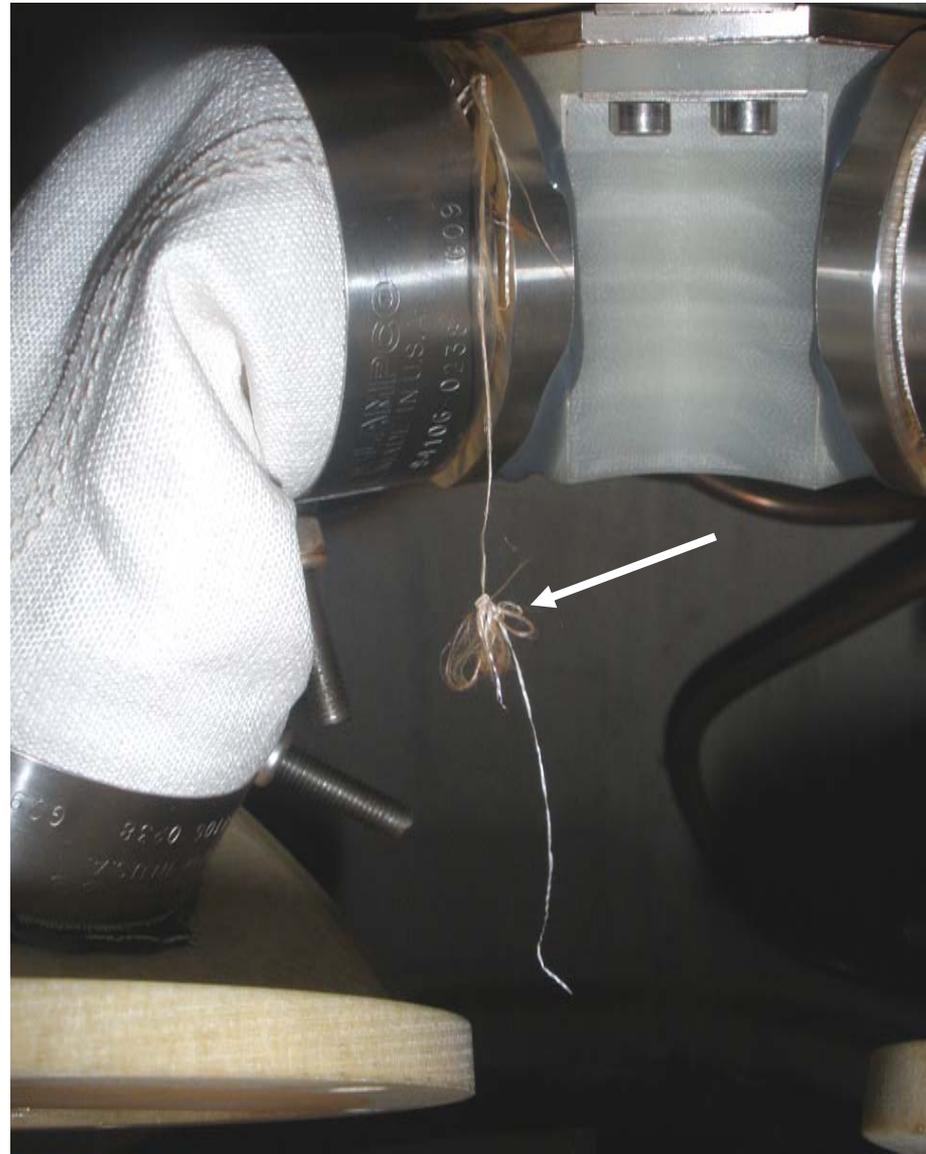
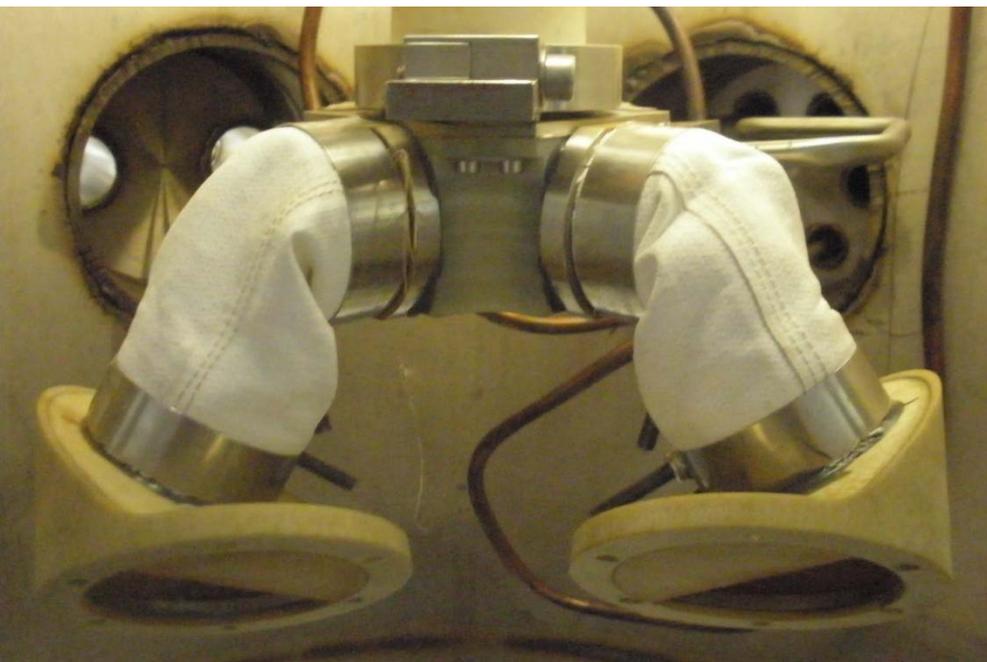


Various Stages of disassembly on 7 September



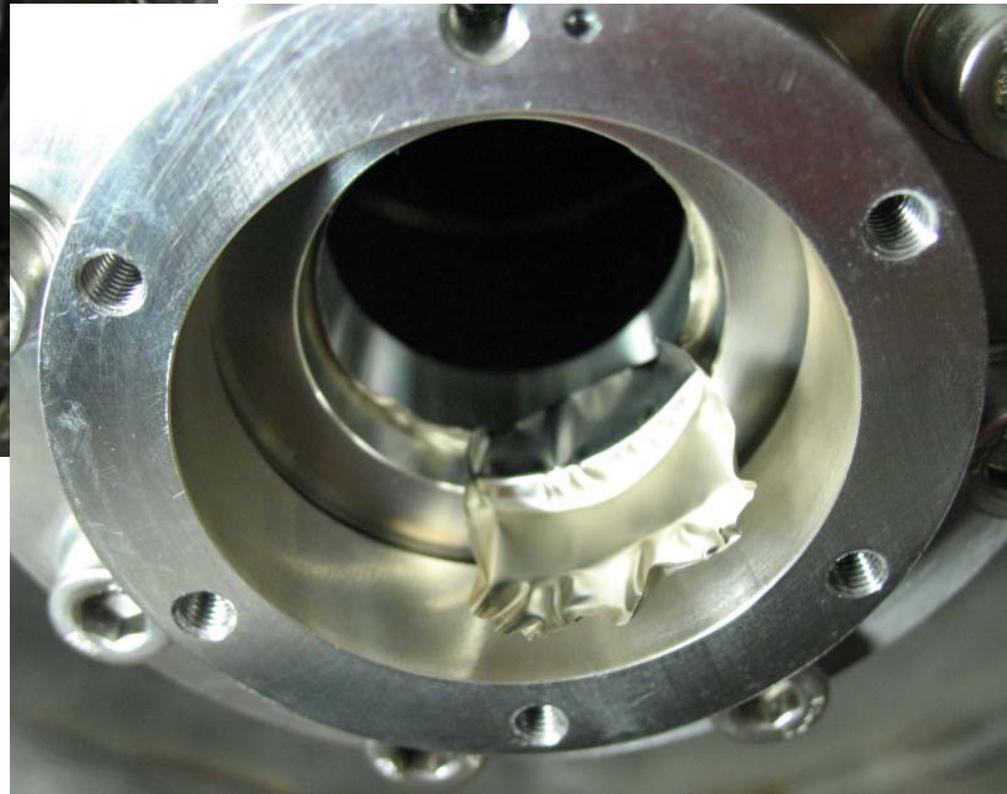


The only noticeable damage to the outside of the test article was some thread that had separated from the ortho fabric sock.





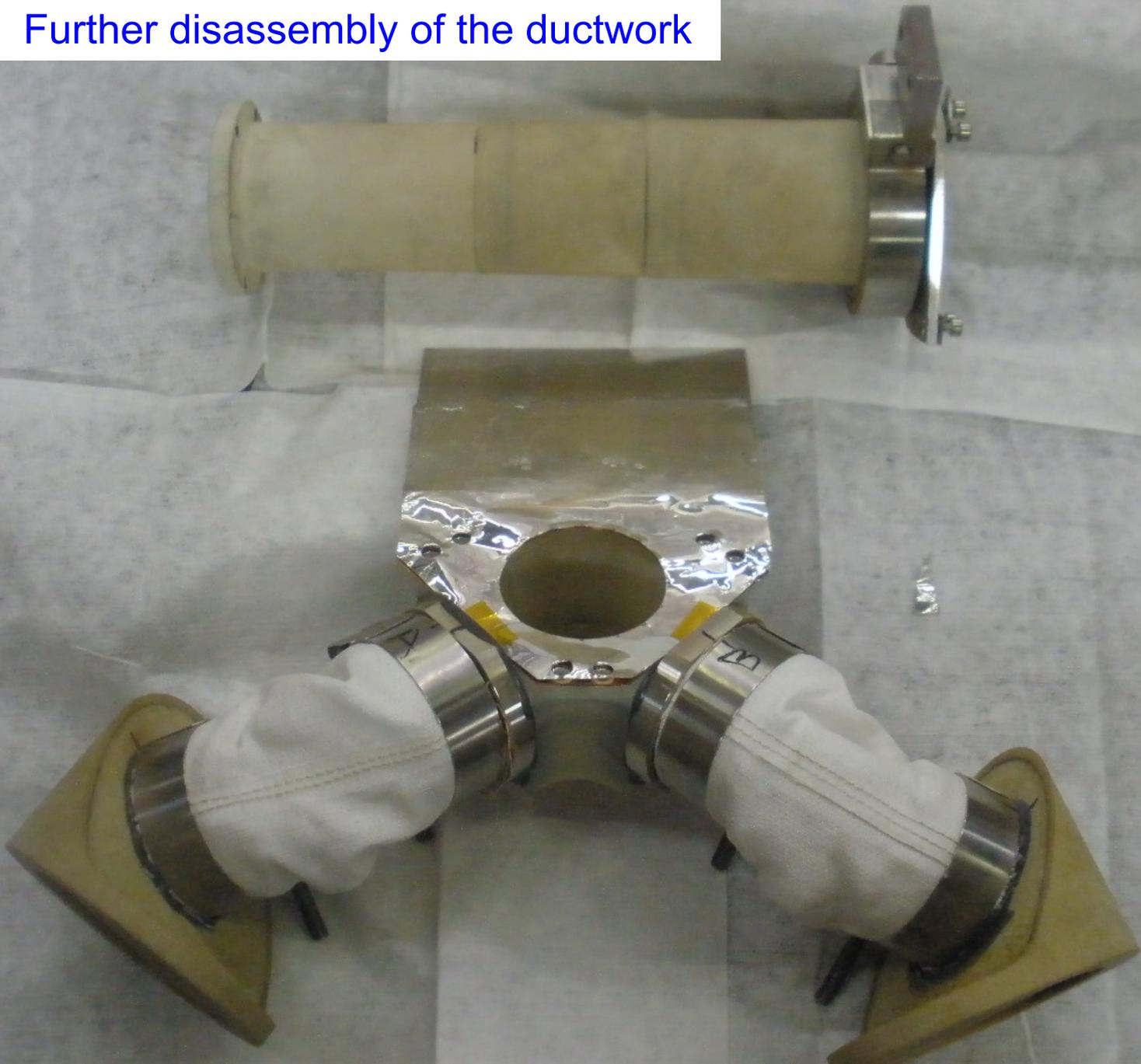
The BD03 test disc
membrane stayed
attached

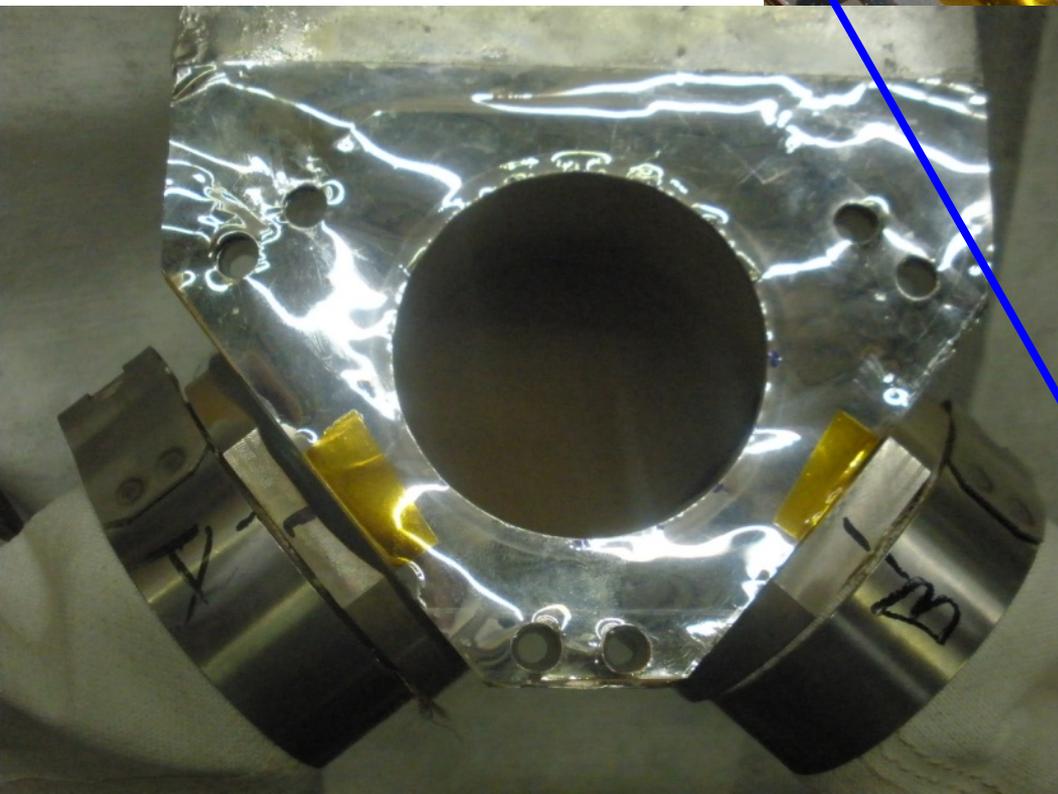
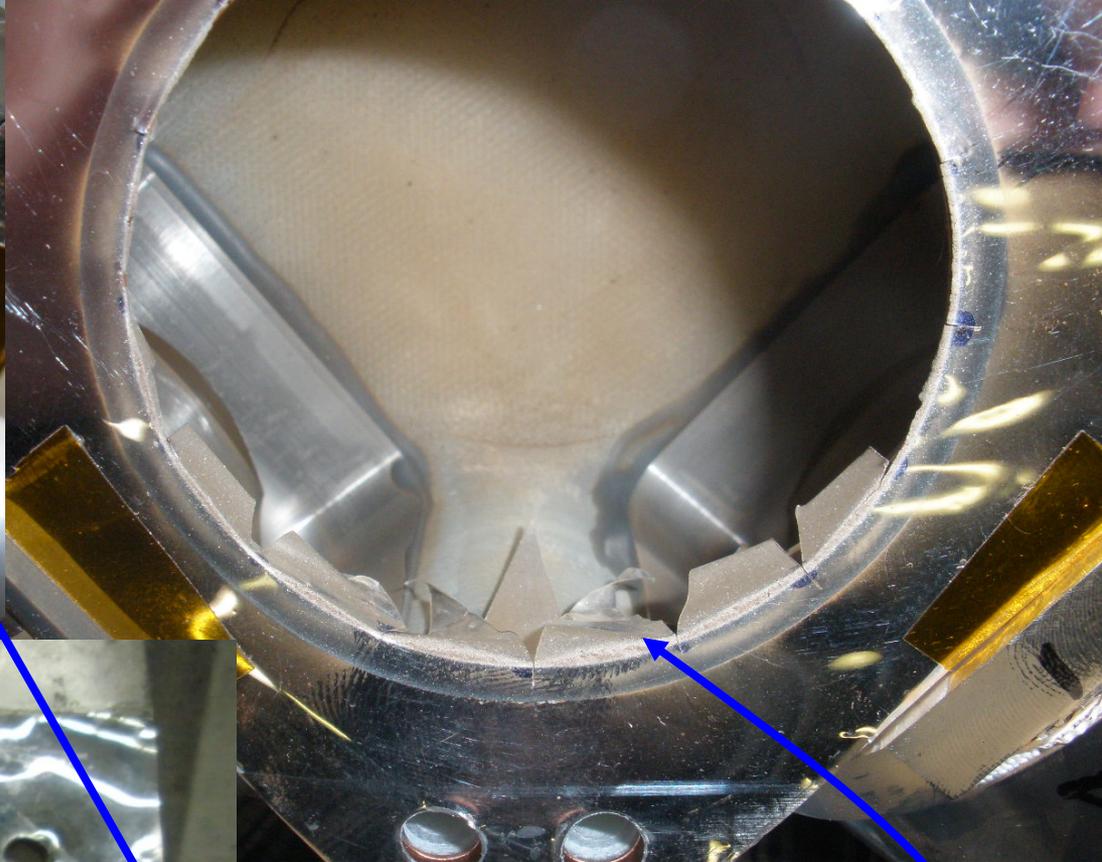




The petals of the radiation shield folded back completely or separated

Further disassembly of the ductwork

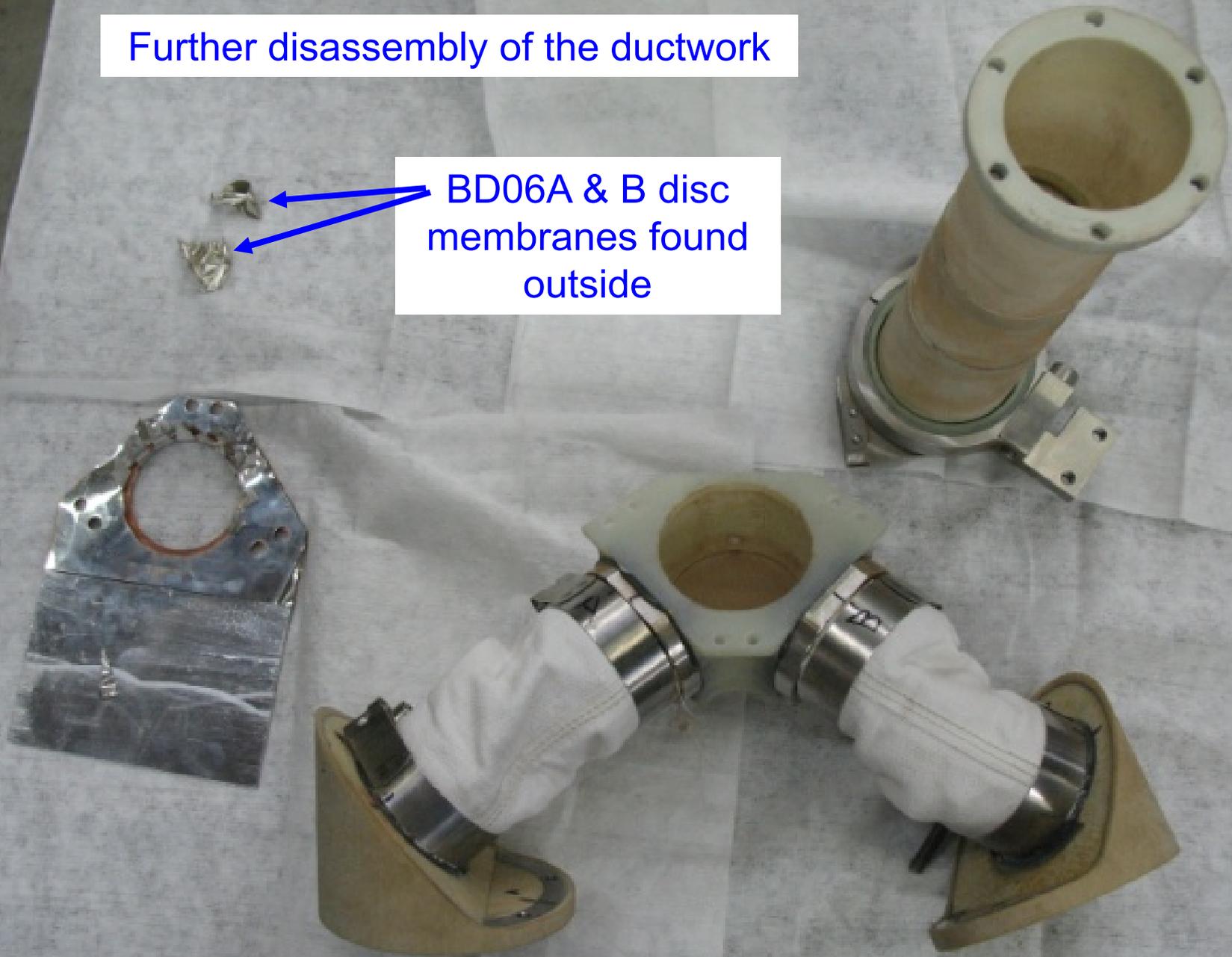




The radiation shield petals completely separated on the back side of the Tee box while the ones between the two exit ducts stayed attached.

Further disassembly of the ductwork

BD06A & B disc
membranes found
outside

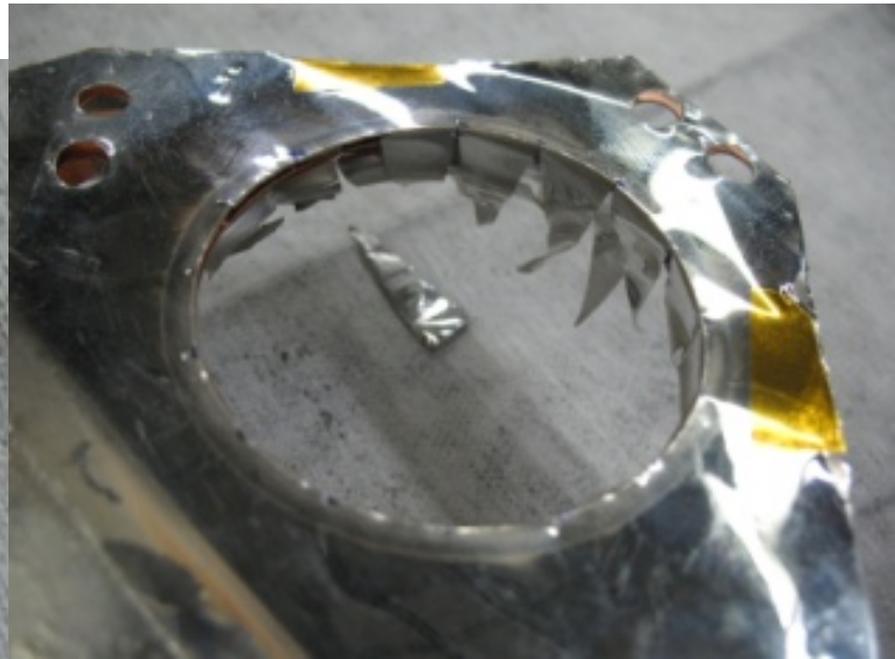


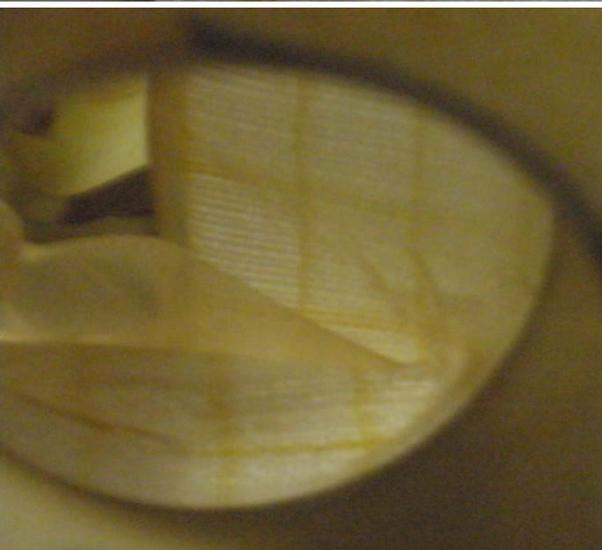
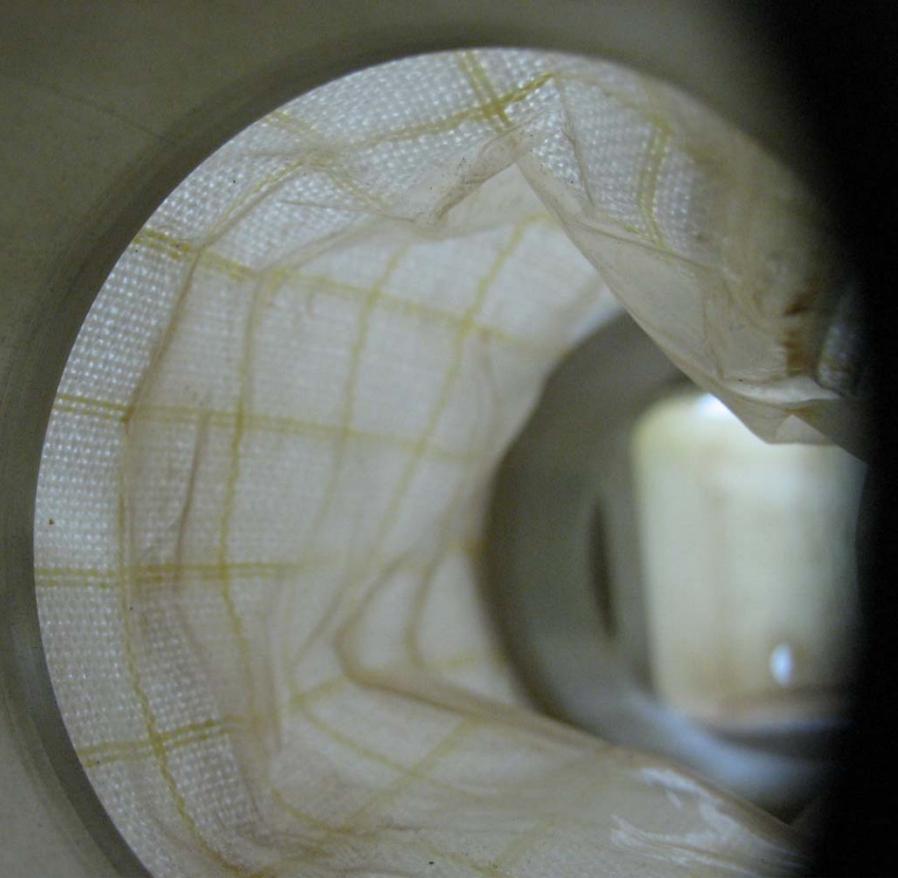


Piece of Radiation Shield found outside



BD06A & B
disc
membranes





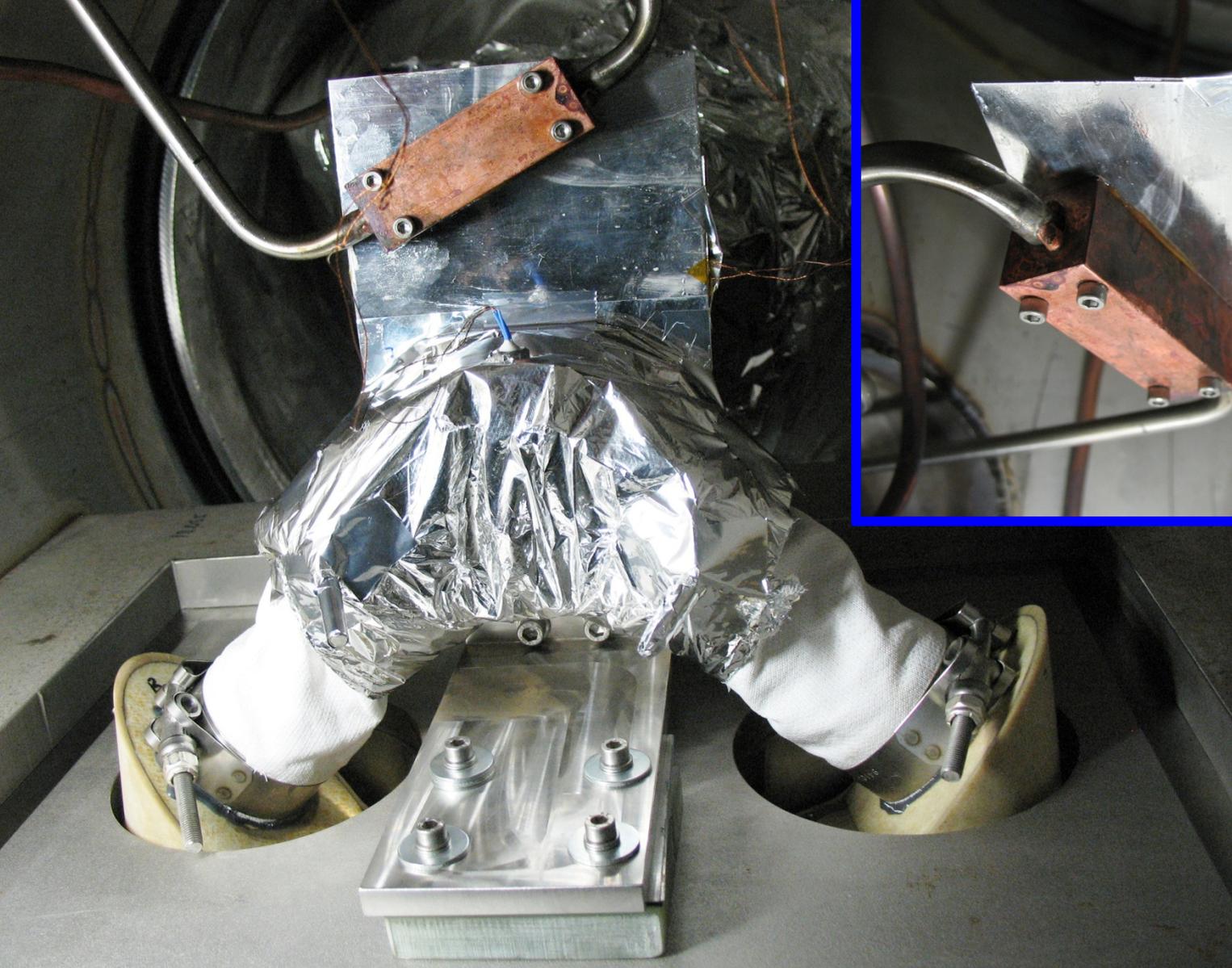
The PTFE liners inside the ortho fabric tubes appear to be intact. These will be reused for test #5.



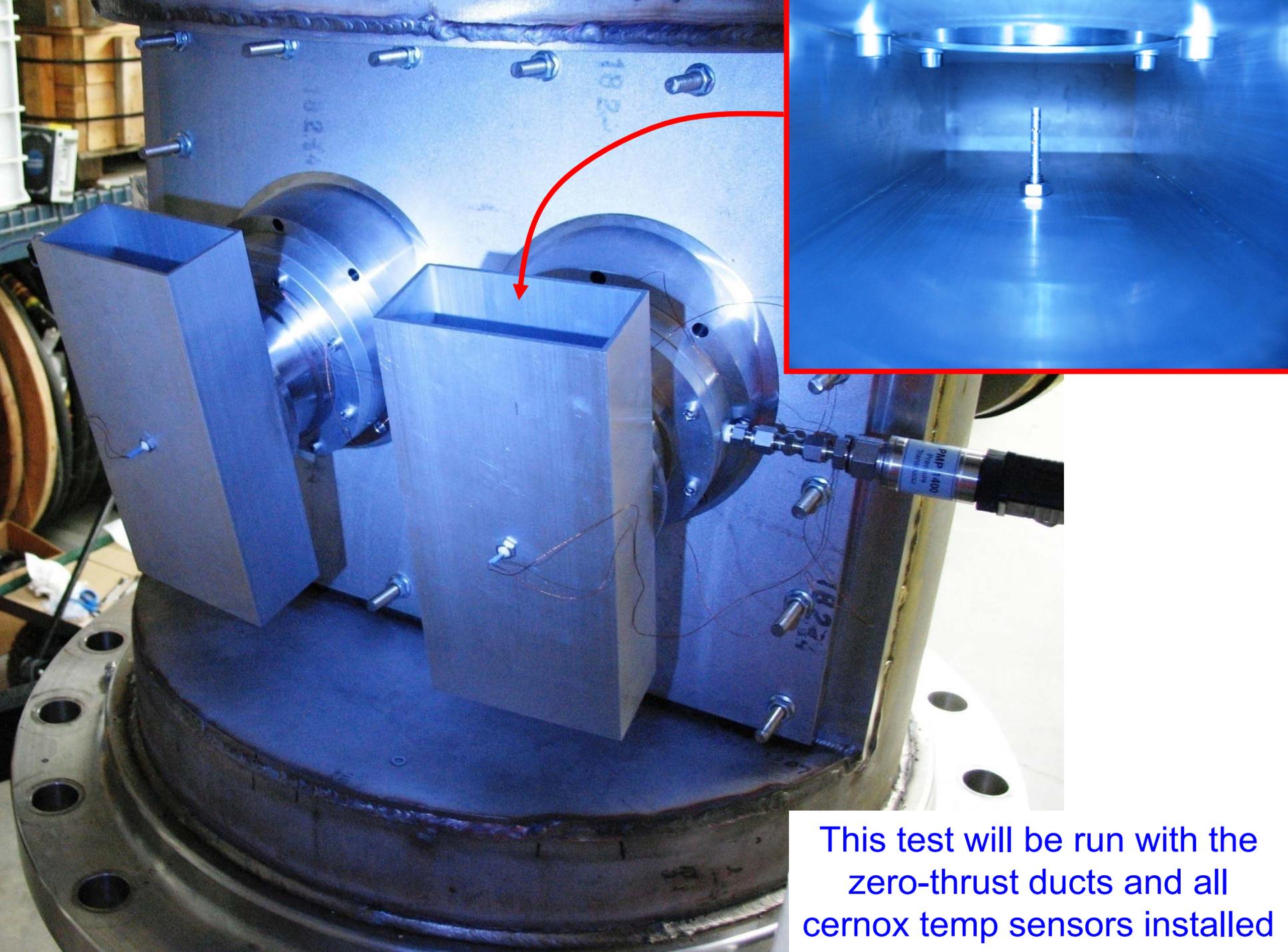
Enclosure 6

AMS Magnet Burst Discs & Ductwork Test #5 at Texas A&M

Updated September 16, 2009
K. Bollweg



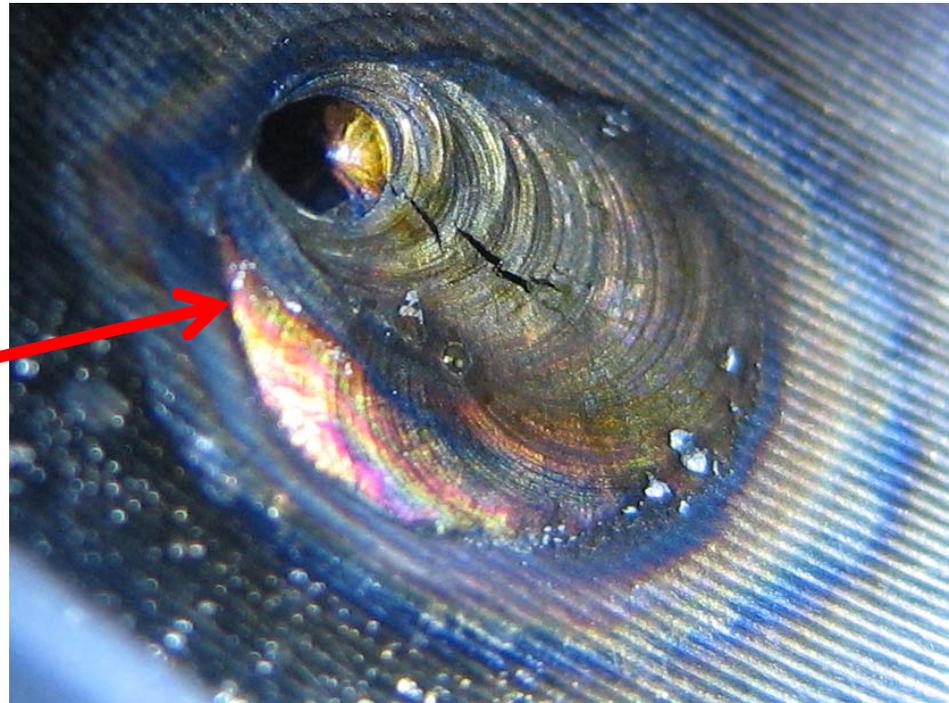
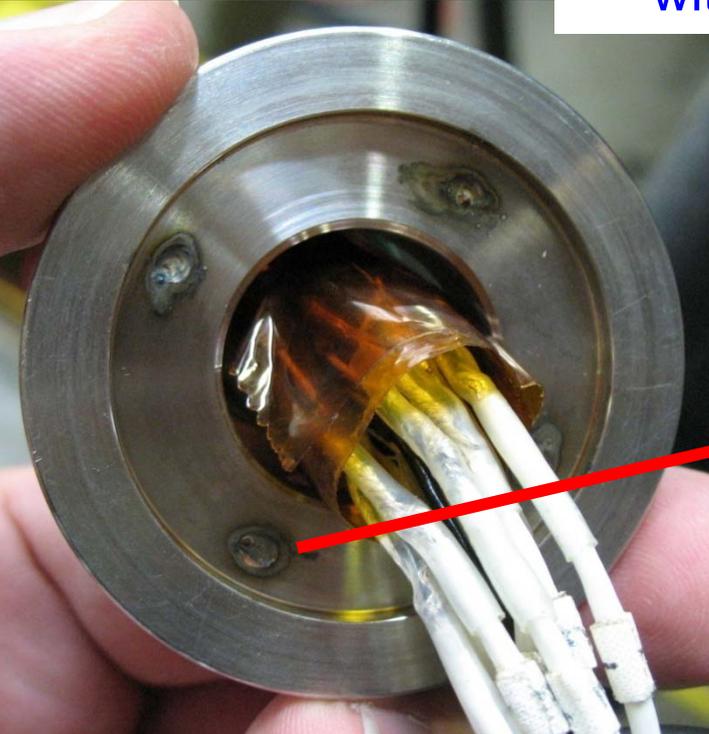
The test article was reassembled with a new set of radiation shields, installed in the test vessel and attached to the LN2 pipework and thermal block with N-grease.



This test will be run with the zero-thrust ducts and all cernox temp sensors installed

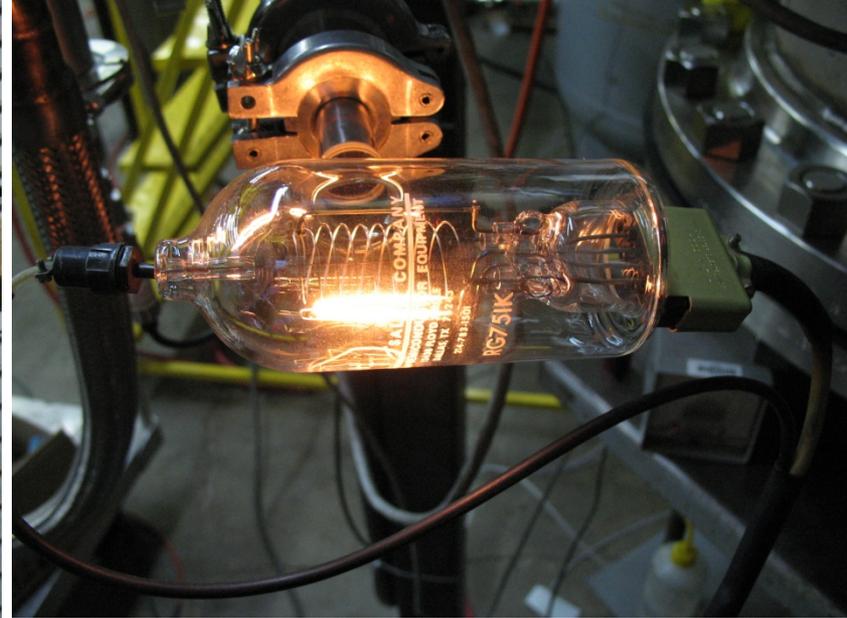
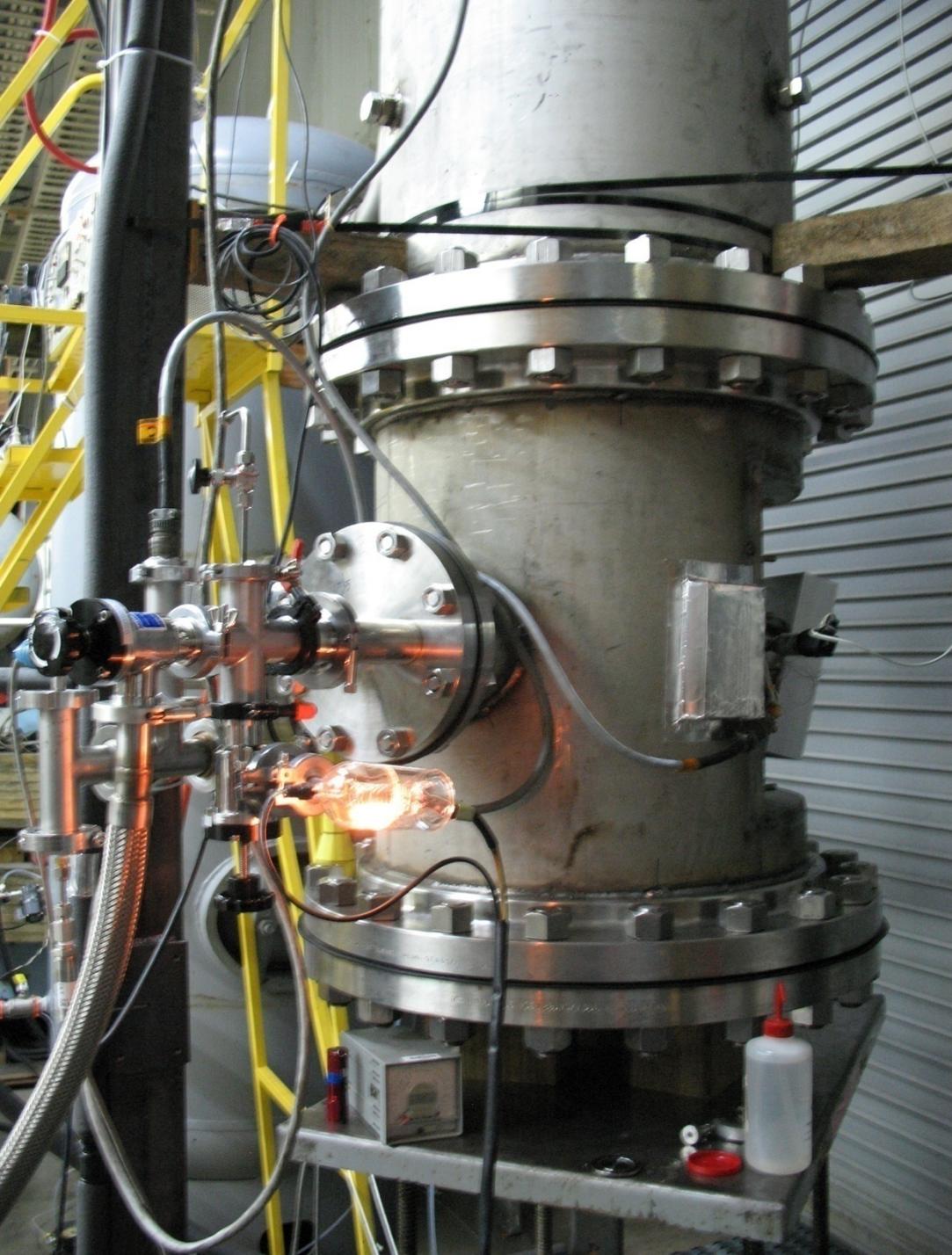


Several attempts were made to repair the leaking fitting with the cracked welds for the electrical connector

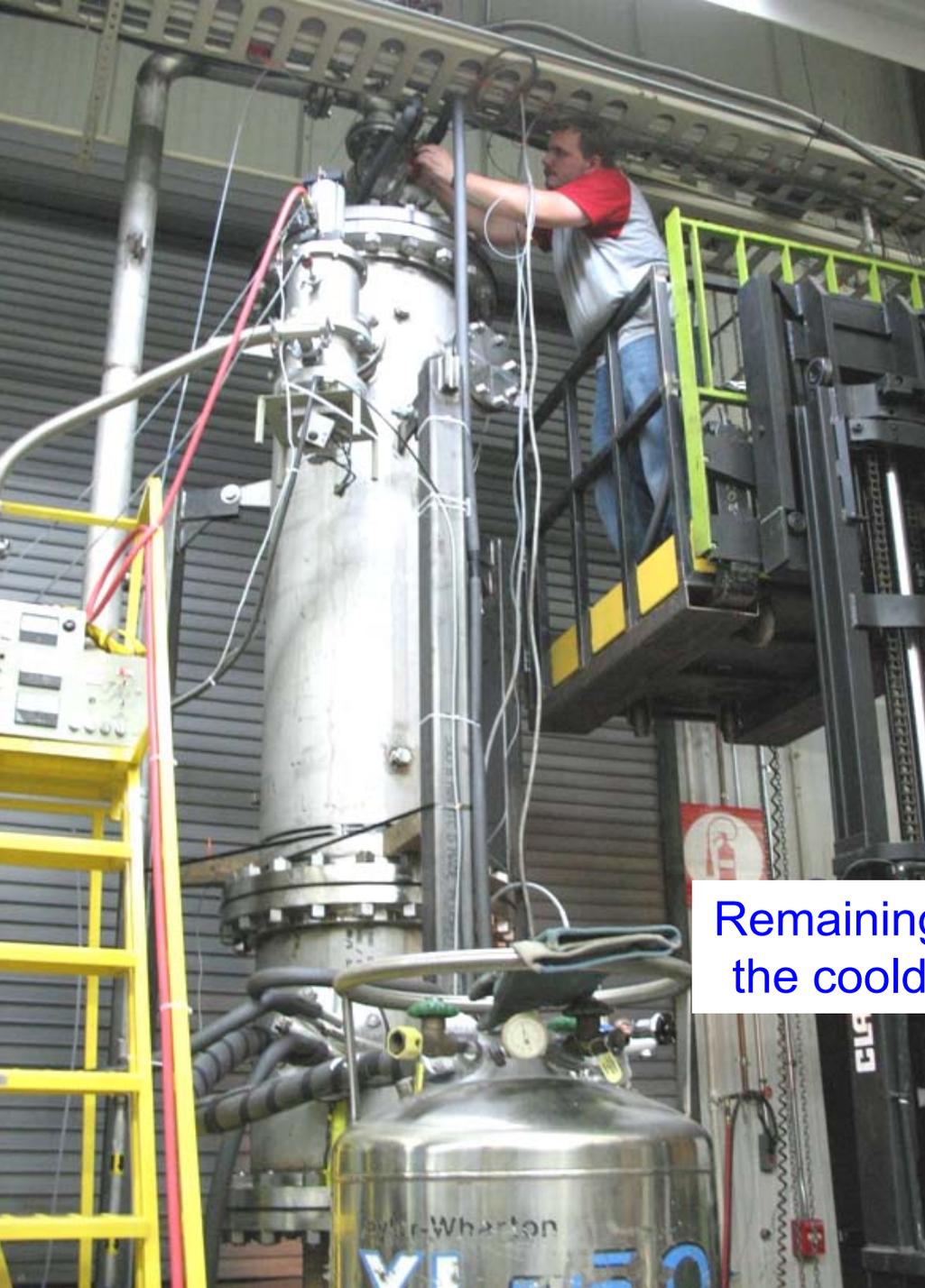




We eventually used epoxy to permanently seal the connector to the fitting



By the evening of September 9th, the vacuum had reached the 10^{-6} torr range.



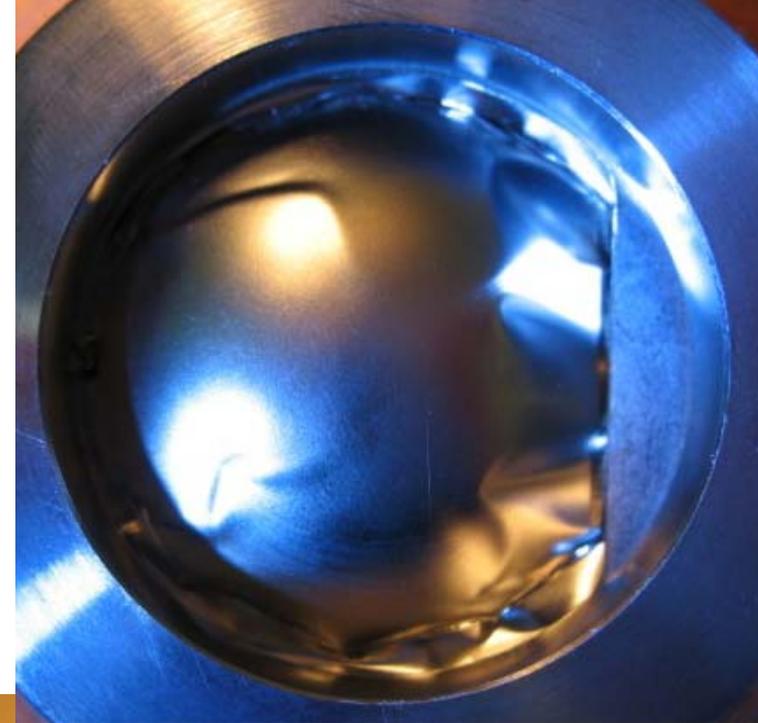
Remaining exterior insulation was installed and the cooldown with LN2 began at ~21:55 CDT.





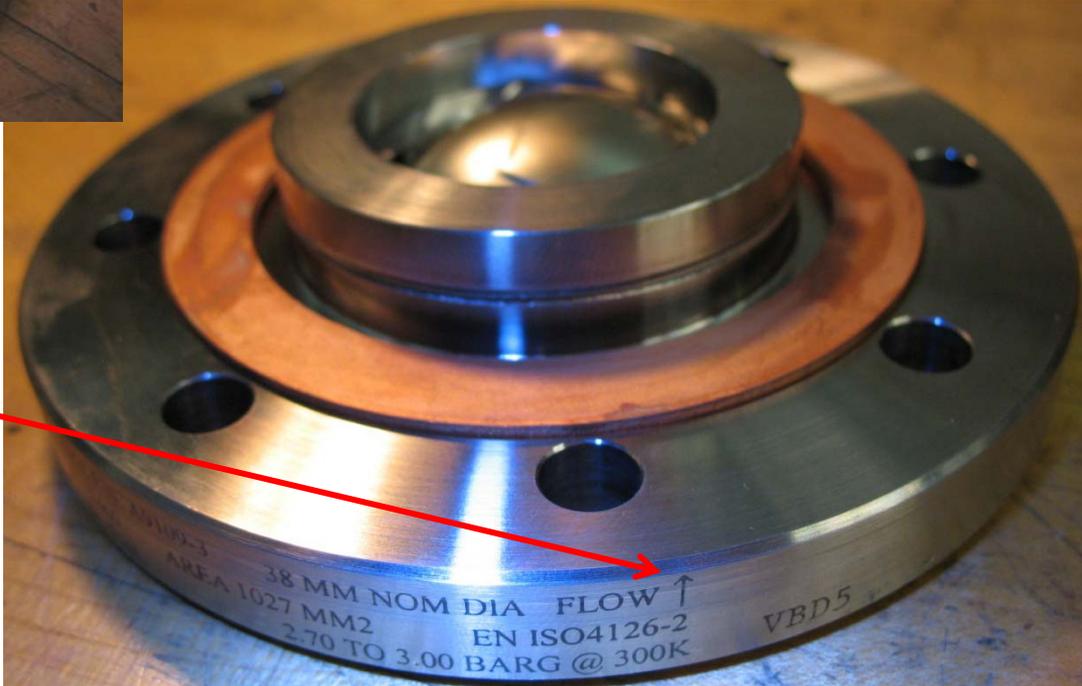
Taking turns monitoring the cooldown progress and sleeping with helium dewars...it's been a long day...

Post-test inspection of the Burst Disc Anomaly



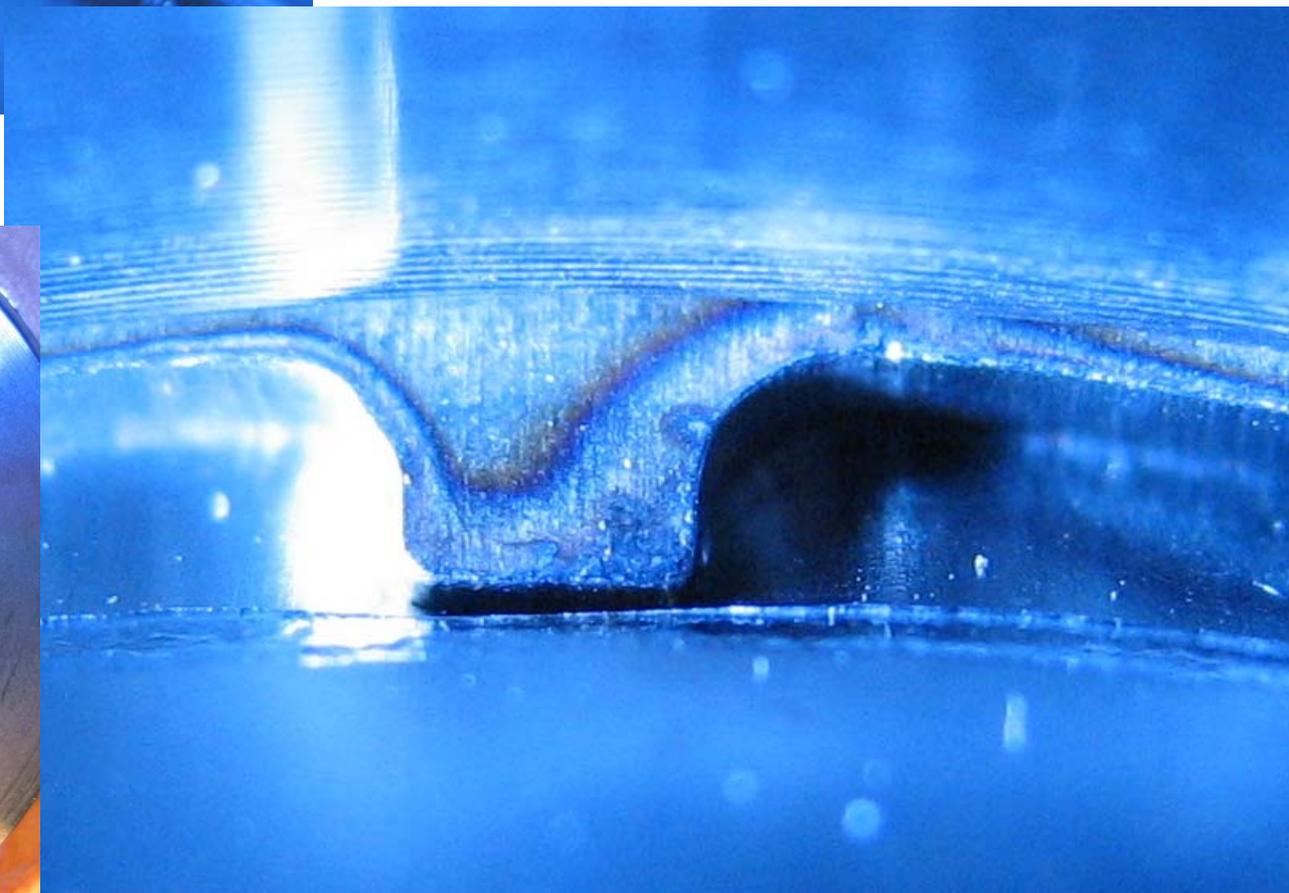
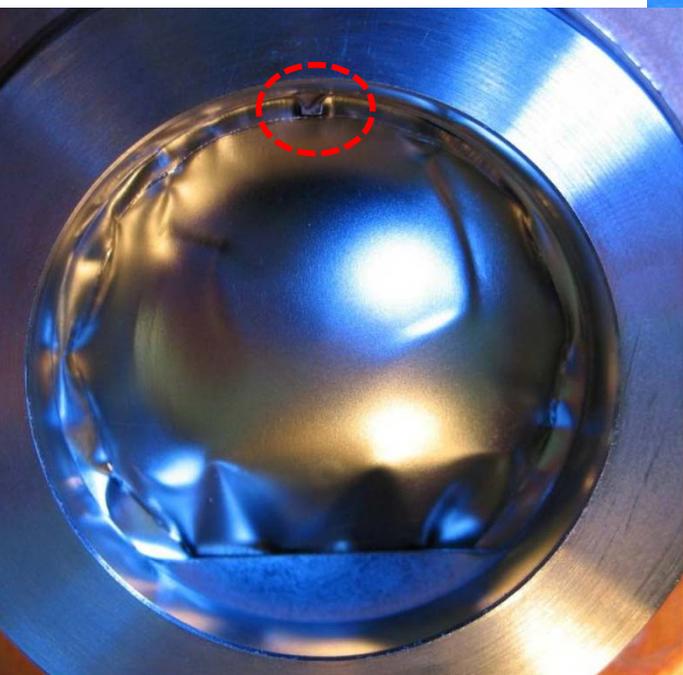
This is the downstream or low pressure side.

Note the direction of the flow arrow on the side indicating the burst disc was properly oriented.



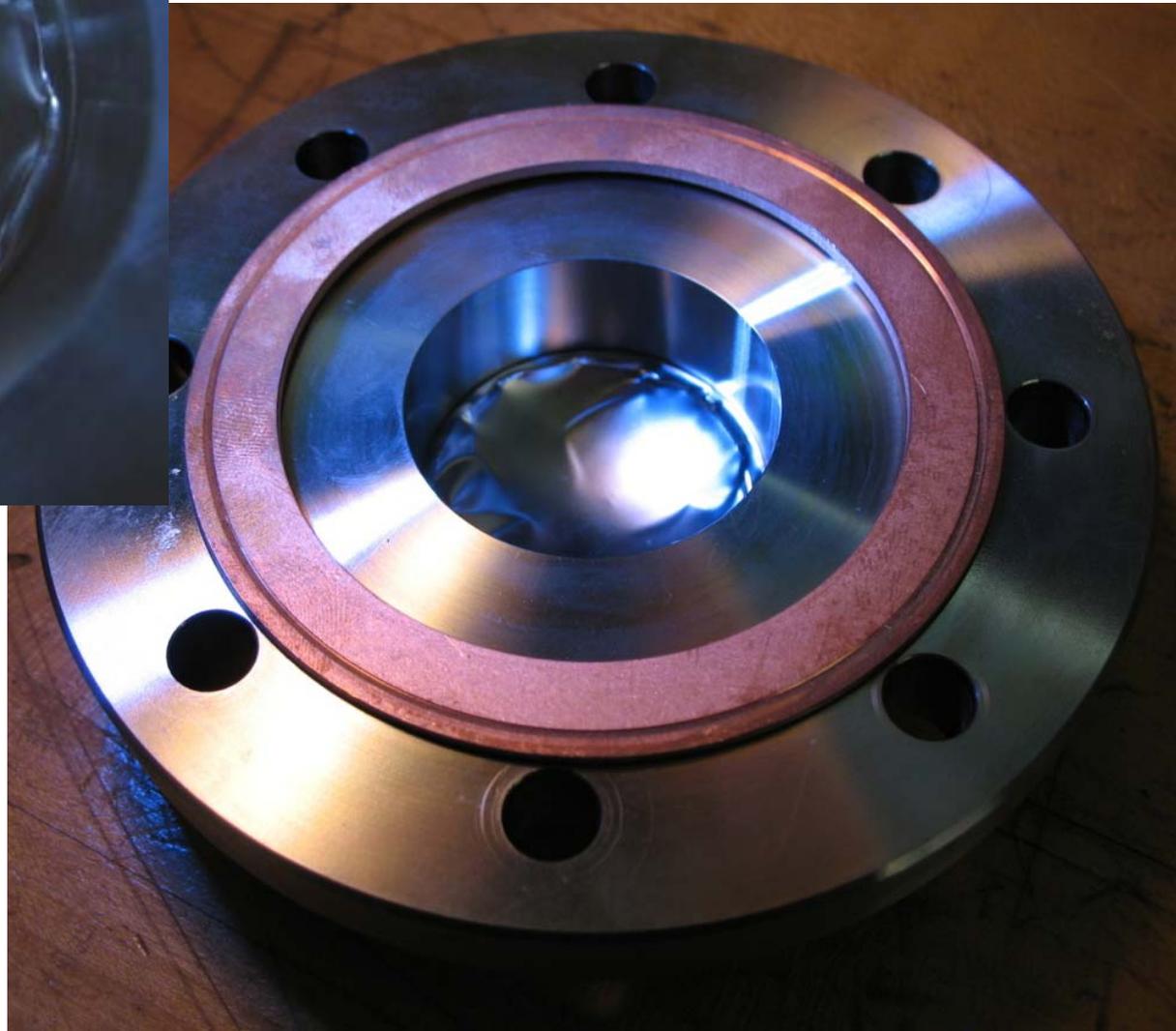


Closeups of the tooth on the downstream side.





This is the upstream or high pressure side.





Closeups of the hinge
line under different
lighting conditions.

Closeups of tooth penetration of the burst disc membrane on the upstream side. This is where helium leaked into the vacuum space after the membrane reversed.



Enclosure 7

AMS Magnet Burst Discs & Ductwork Test #6 at Texas A&M

September 23, 2009
K. Bollweg



The re-entrant tube for the flight-like BD03 was welded into the adapter made at CERN and the membrane was examined for any flaws.



The test article was assembled the same way as the flight unit with new flexible tubes made of single layers of ortho-fabric & PTFE shrink tubing.



The fabric tubes were rolled over to form a double layer at the ends.



The adapter tube was insulated with 30 layers of MLI while the Tee Box and parts of the flexible tubes were covered with 10 layers.

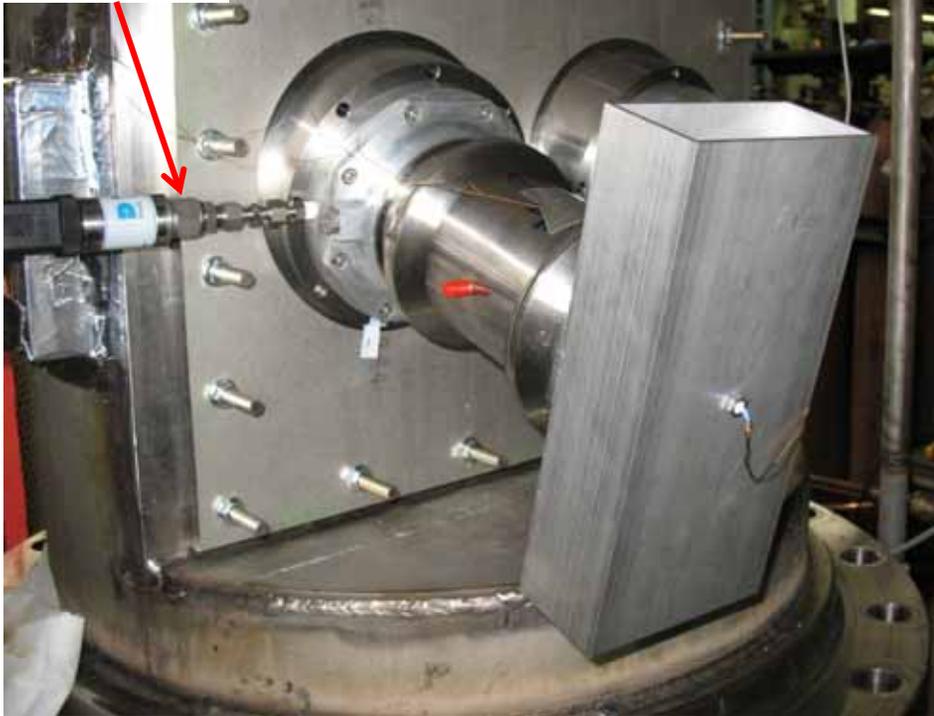




Then the assembly
was installed in the
test cryostat.



BD06A
pressure
transducer



BD06B
pressure
transducer



The window was installed along with the other hardware. Note that only a former BD07A/B assembly was used for BD06A. There was no BD06B in this test.

The BD07B disc was removed prior to installation.

The thermometry was added and the LN2 thermal block for the BD radiation shield was installed with N-grease and bolted into place.

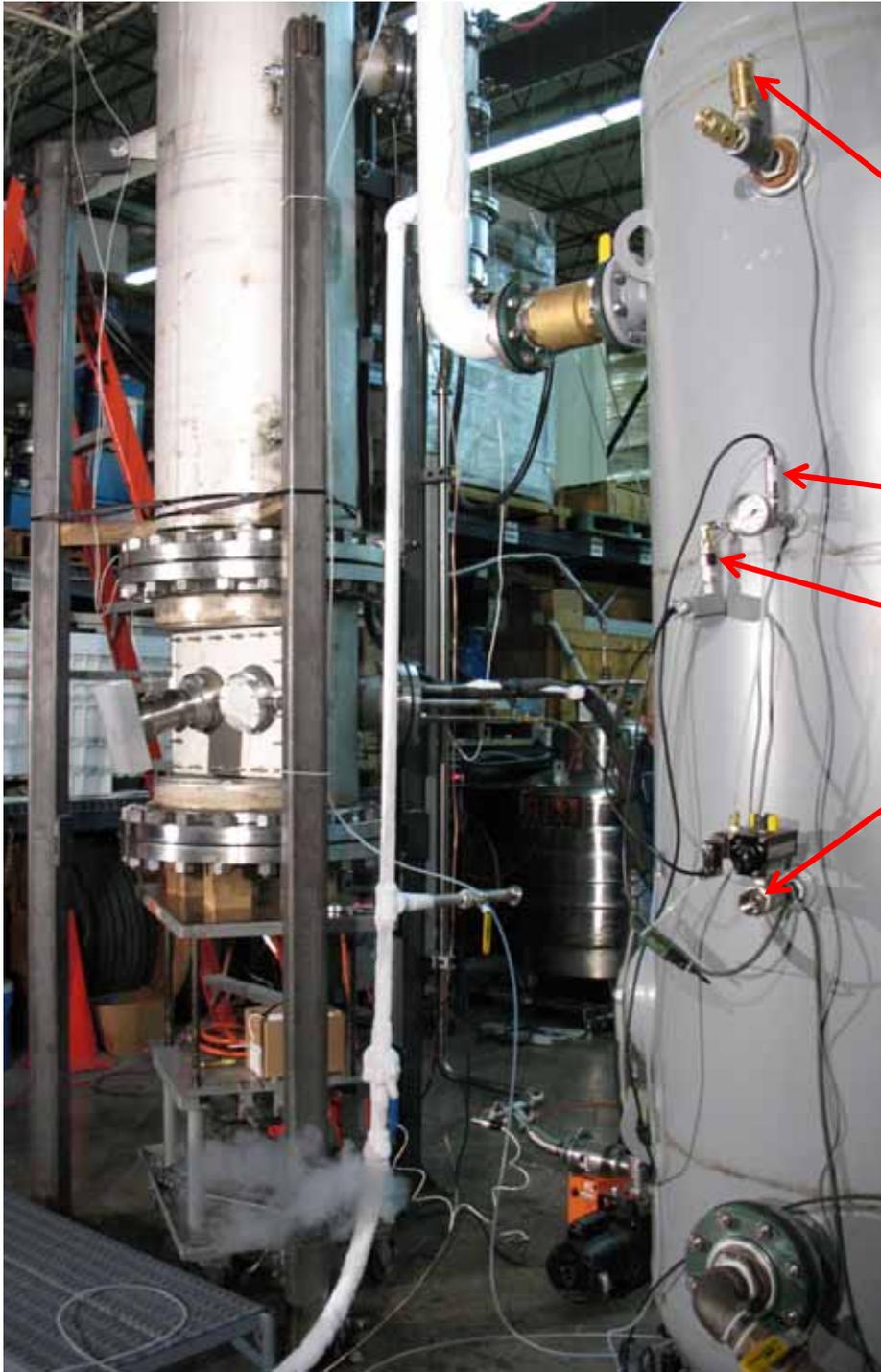


BD06B

BD06A

Calibration runs were conducted with the simplified helium gas pressurization system.





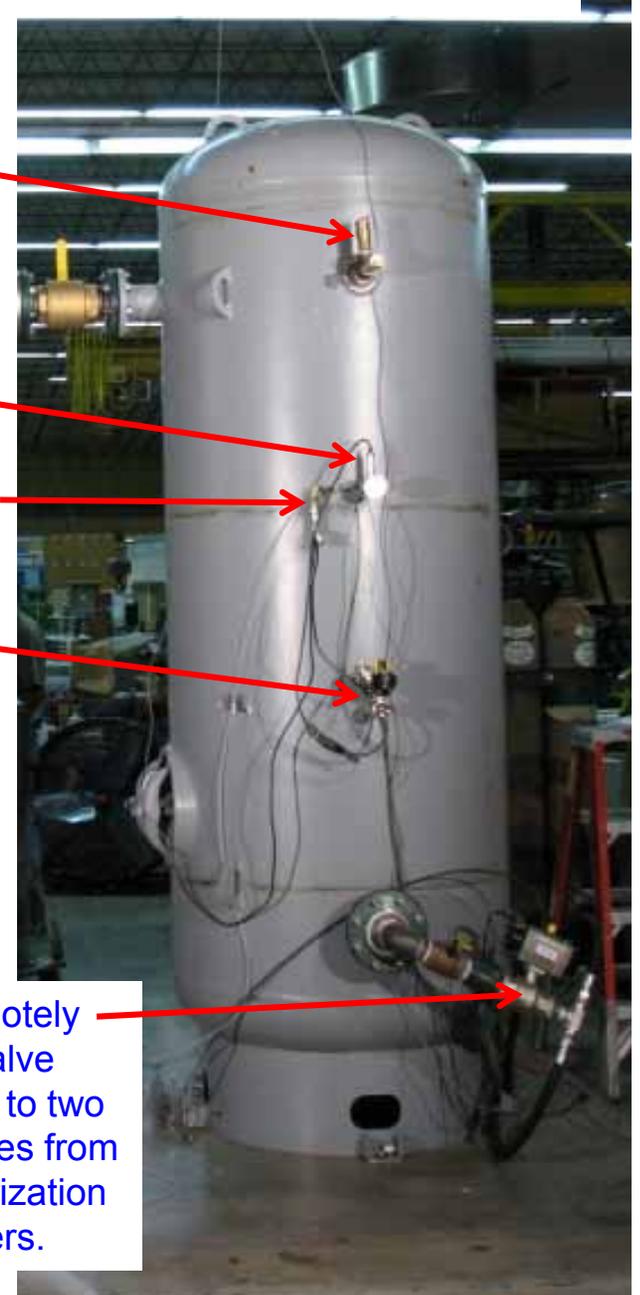
Additional safety and control features were added after test #5.

Additional relief valve

Additional pressure transducer

Additional pressure switch linked to a remotely actuated ball valve

Additional 2" remotely actuated ball valve connected directly to two large hydraulic hoses from the helium pressurization bank of cylinders.



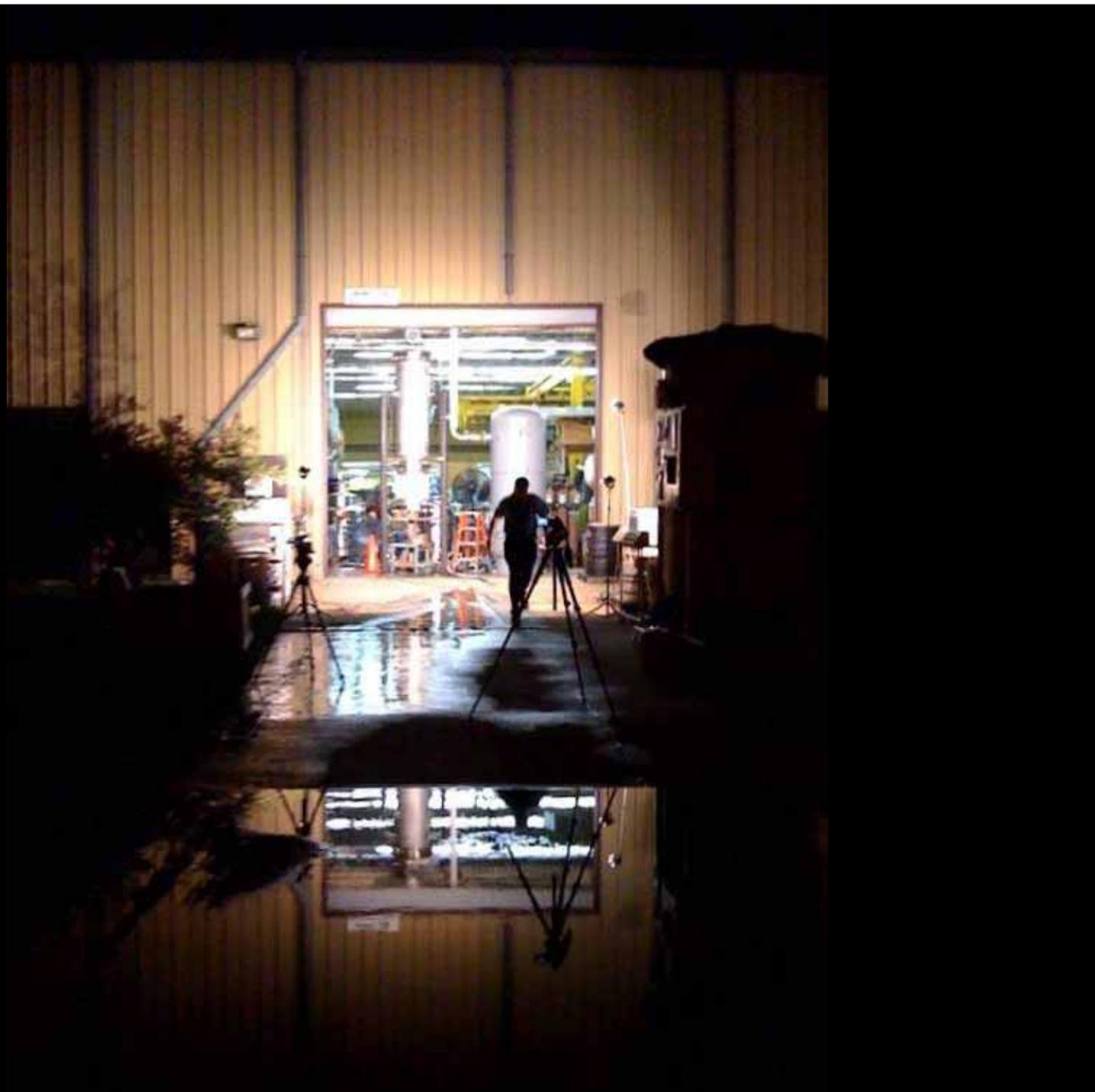
The helium vessel was pumped & purged with helium and the vacuum space was pumped & purged with dry nitrogen. It was then cooled from 300 K to 4.2 K and filled with ~200 liters of LHe in only ~24 hours.



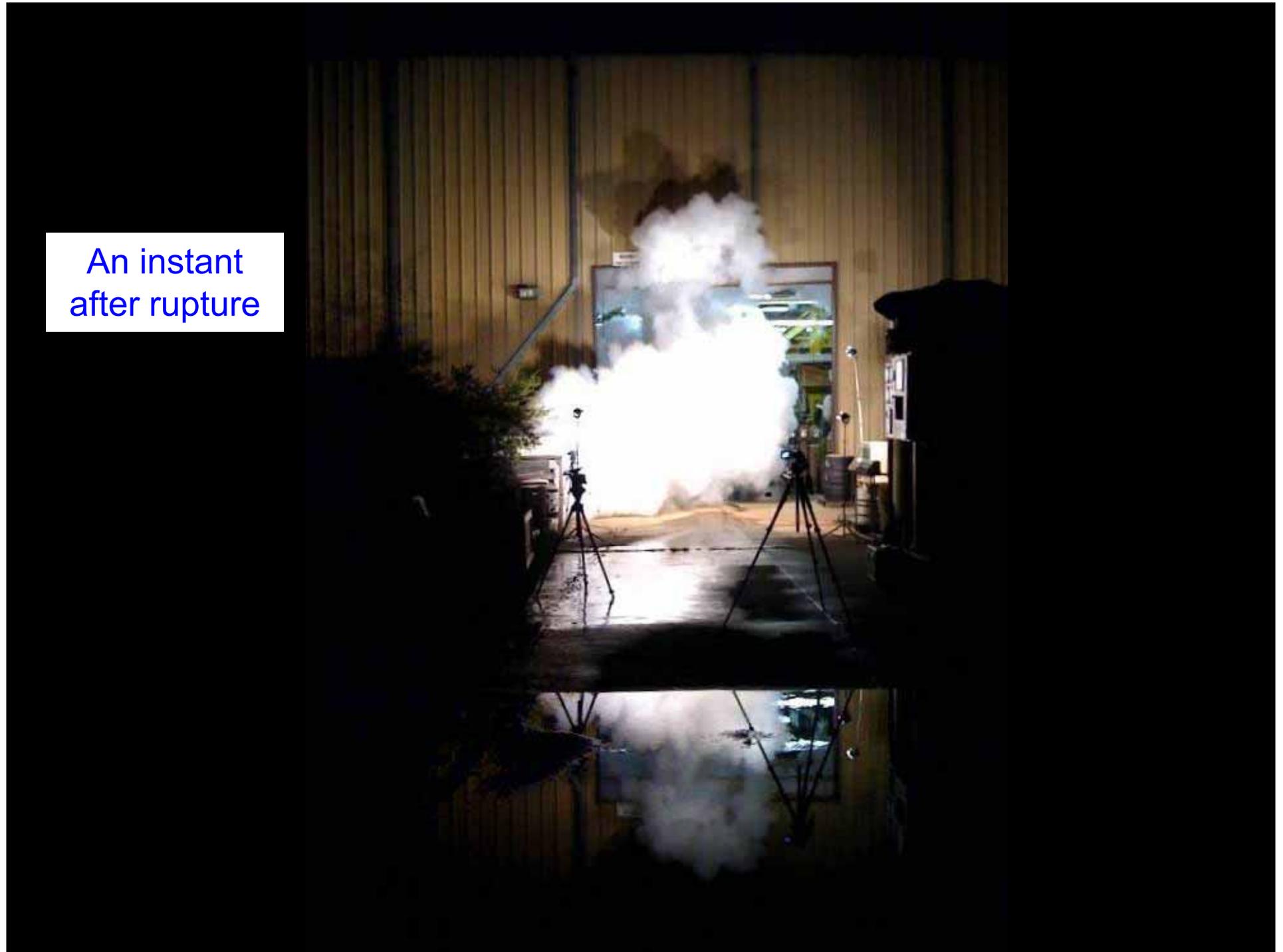


Finally, the lights and cameras were set up.

Run away!

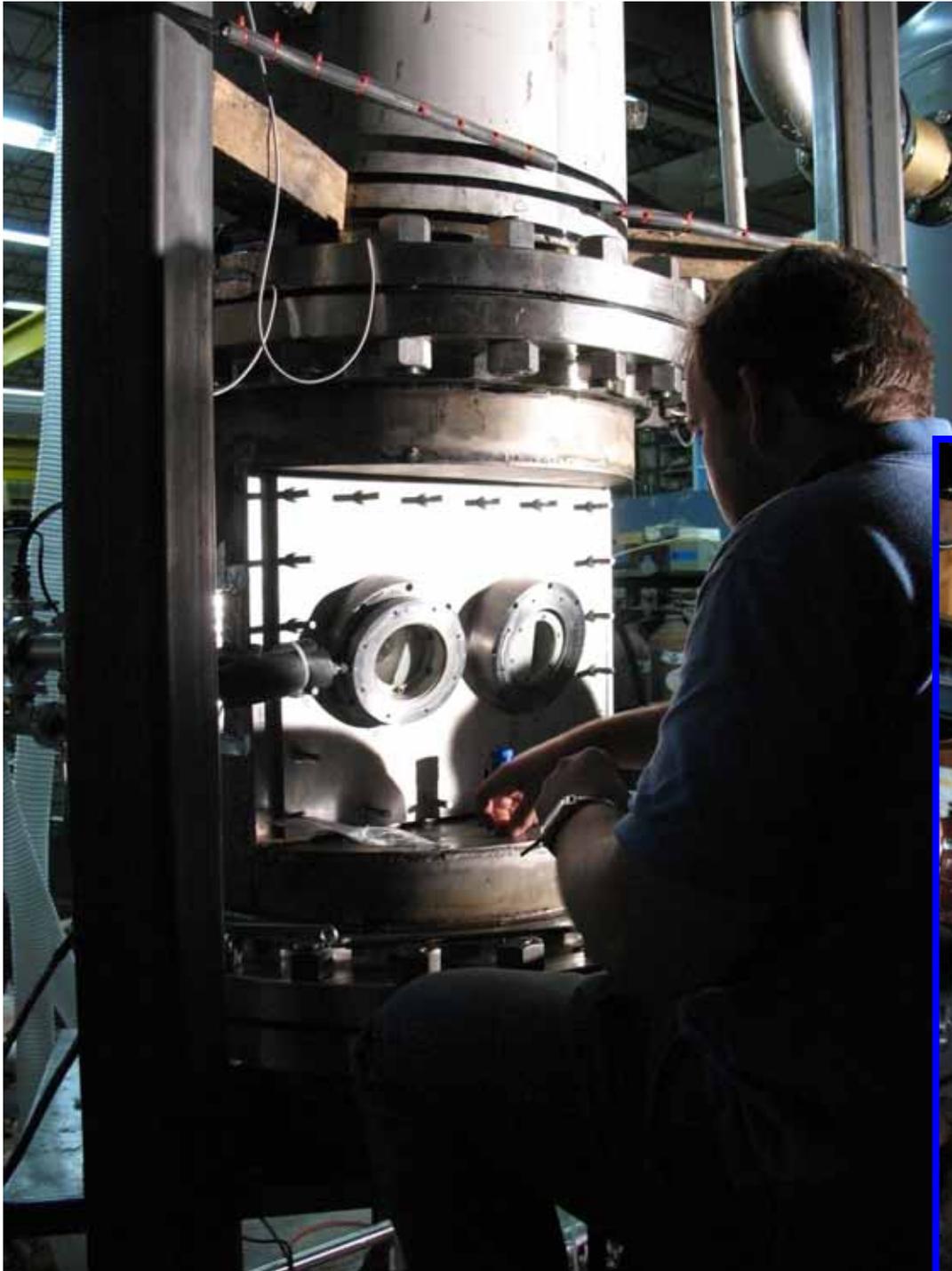


An instant
after rupture



The expanding
cloud of helium
was quite
impressive

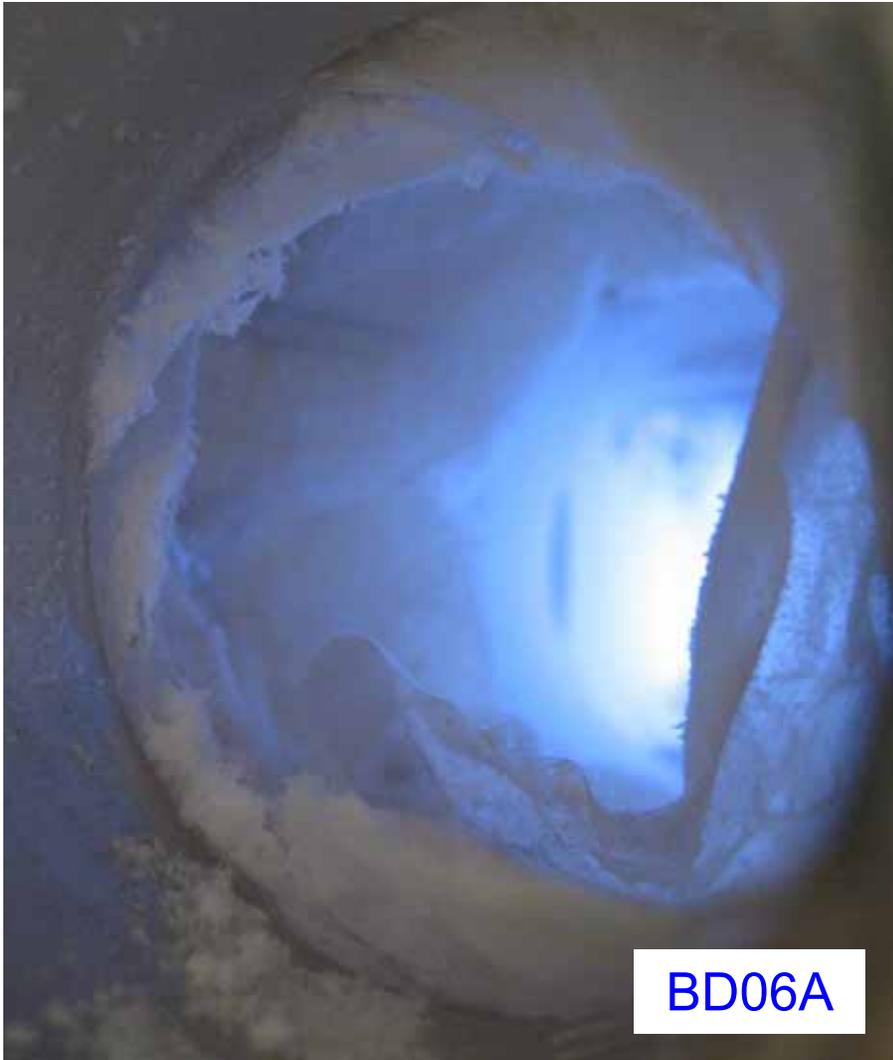




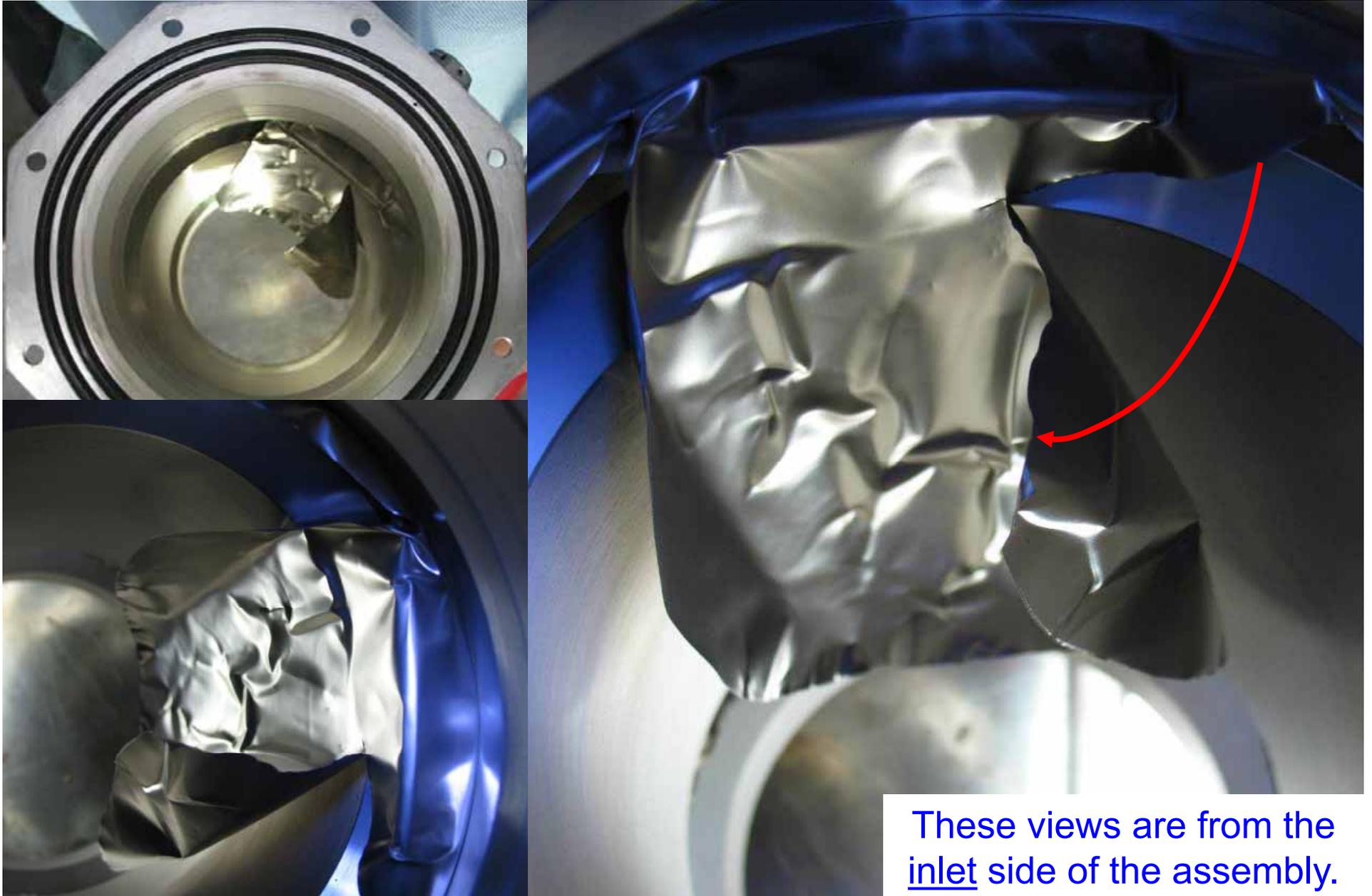
A partial disassembly was conducted shortly after the test.



Both ortho-fabric flexible tubes were intact. The PTFE liner was torn on the BD06A side that was used to exhaust all the gas. The BD06B side that was blanked off was intact. It was difficult to tell the actual conditions of the components because of frost buildup.

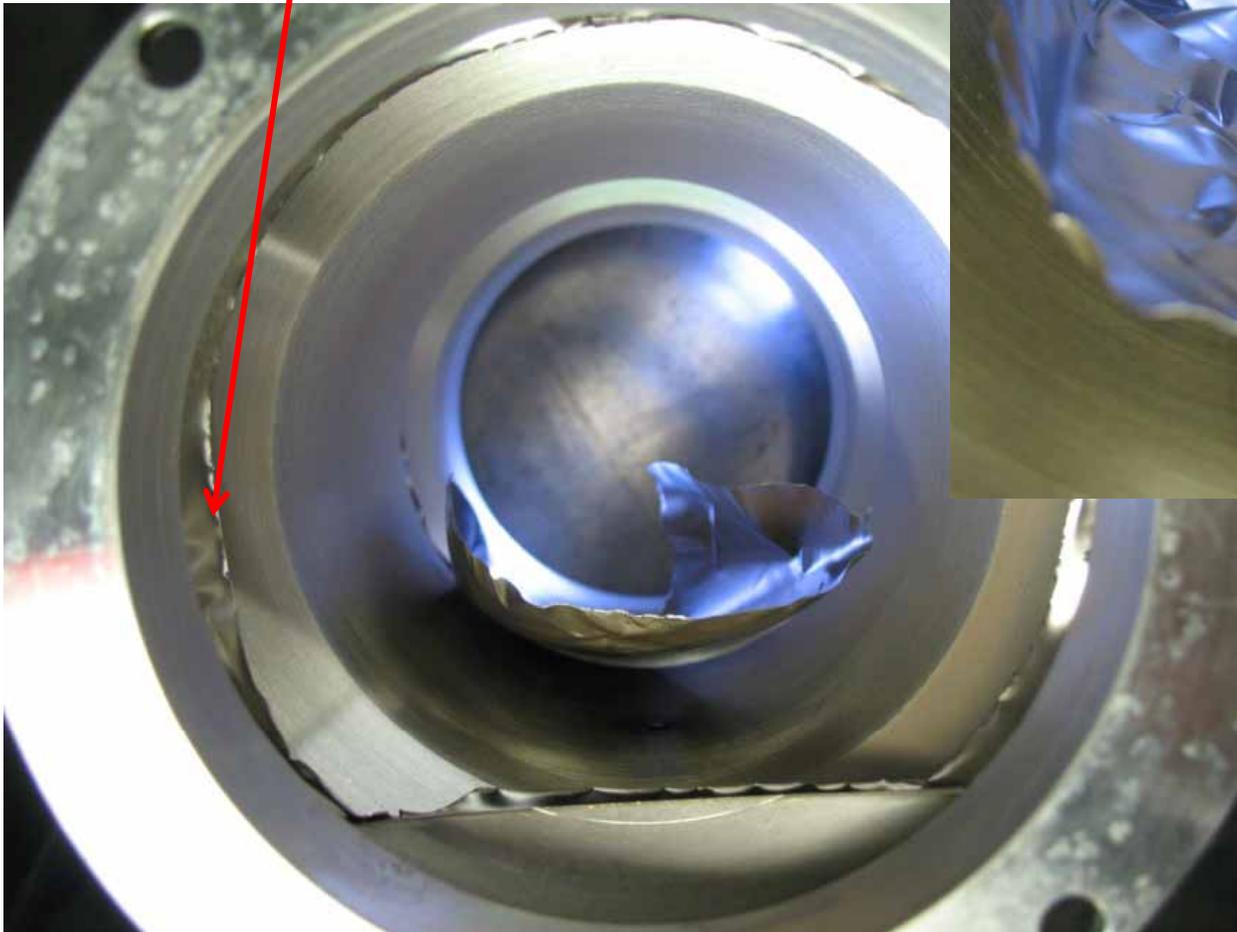
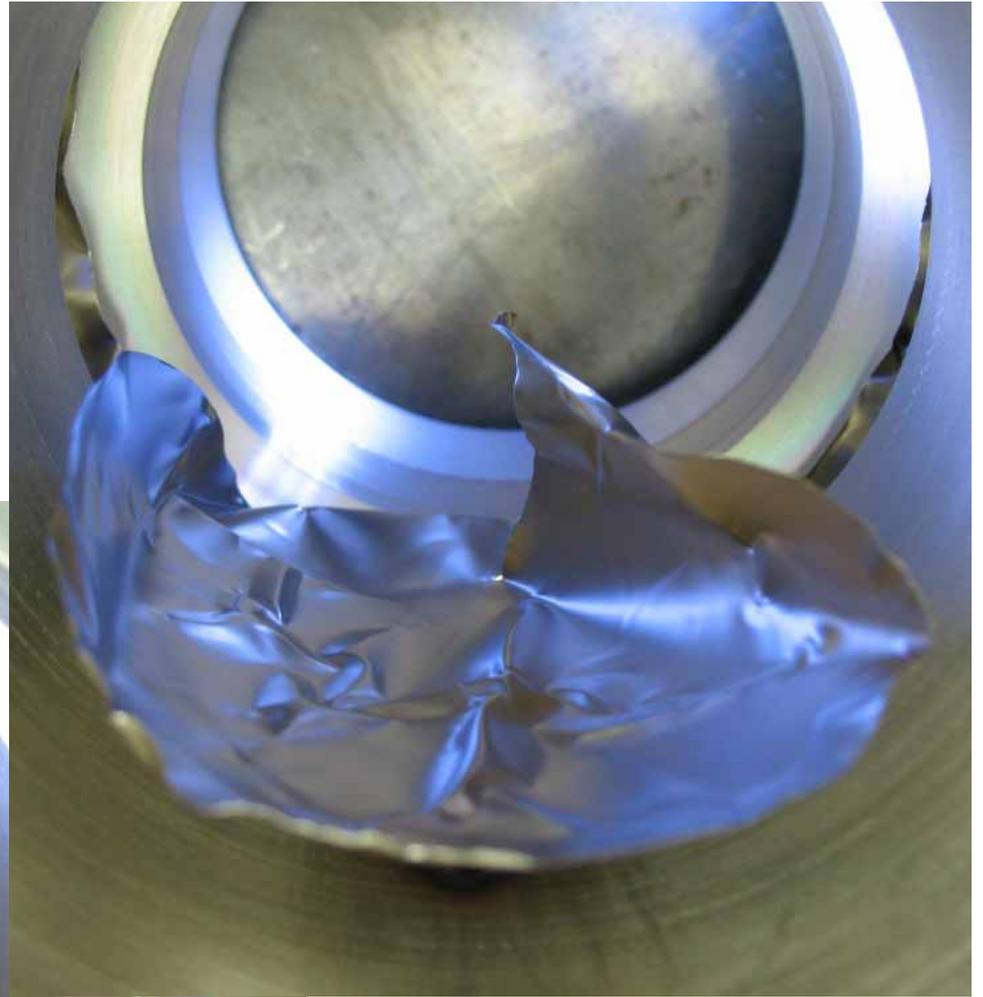


BD06A (from a flight BD07A/B) performed well. The membrane was still in the housing though it had torn along a significant portion of the hinge line.



These views are from the inlet side of the assembly.

This is the BD07B disc that was cut out with an X-acto knife prior to installation.



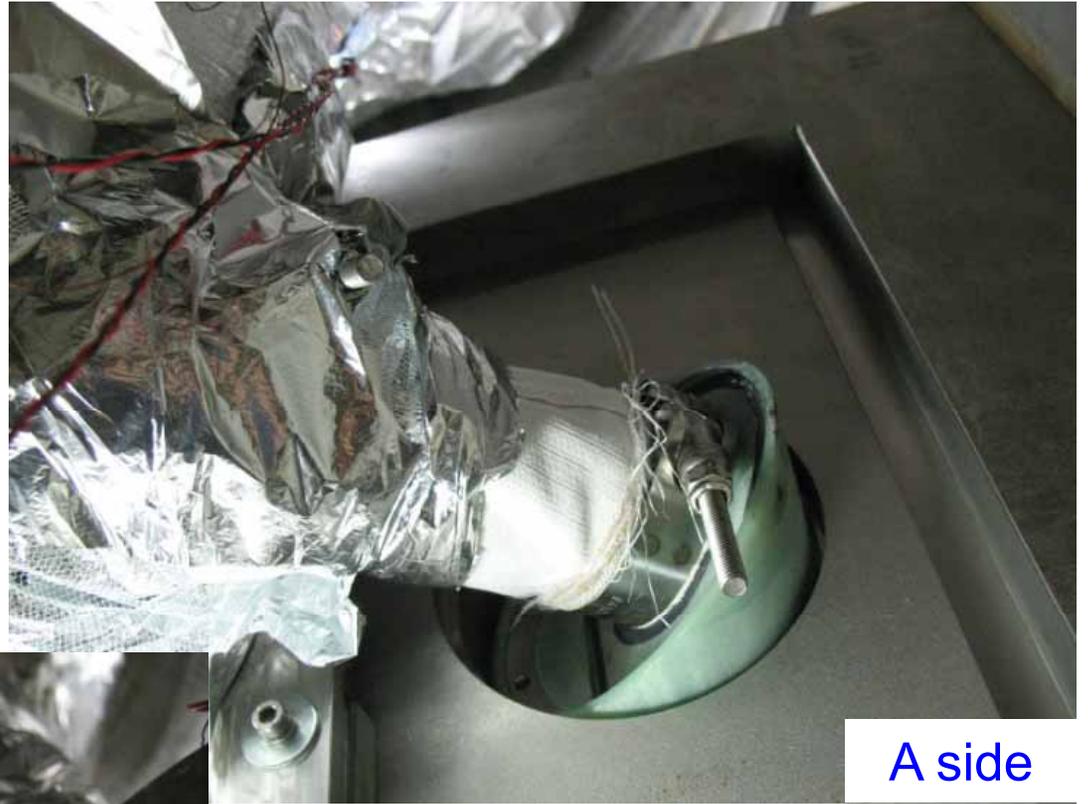
These views are from the outlet side of the BD06A assembly.



BD06B

BD06A

The cryostat was allowed to warm up over night with warm air blowing through the vacuum space. Part of one layer of MLI on the B side of the ductwork was damaged. The A side appeared relatively intact



A side

MLI damage on B side



One layer of superinsulation was missing in this area.



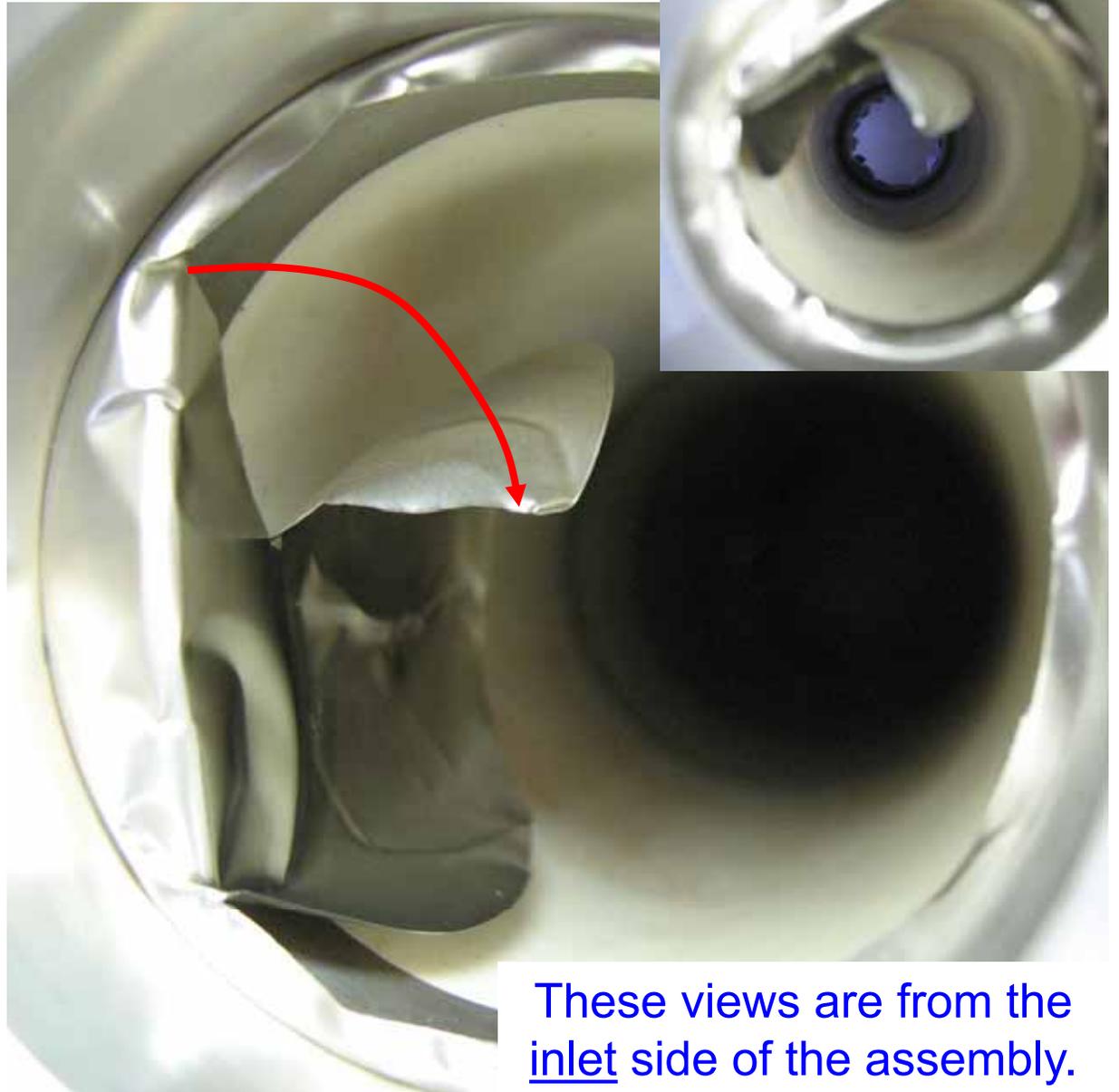
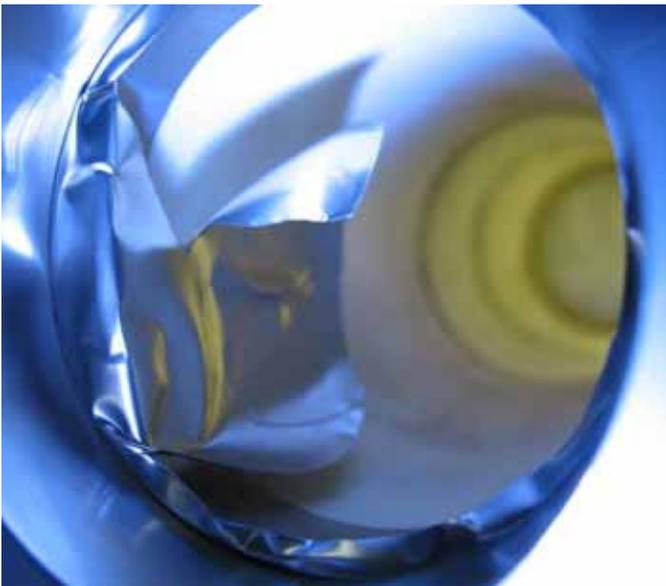
Views with window removed



Since we were working the hours of vampires, Richard graciously volunteered to climb back into his coffin to remove the test article.



The BD03 disc performed nominally. The membrane was still in the housing though it had also torn along a significant portion of the hinge line.

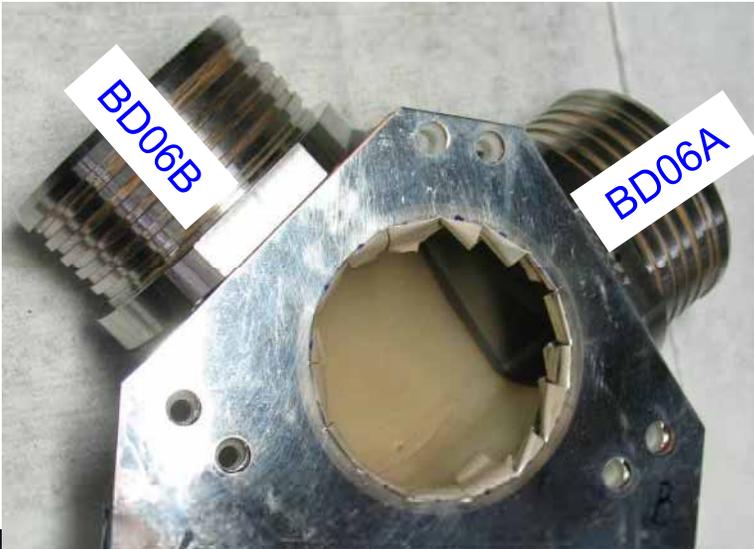


These views are from the inlet side of the assembly.

Continued disassembly revealed nothing unusual to this point.

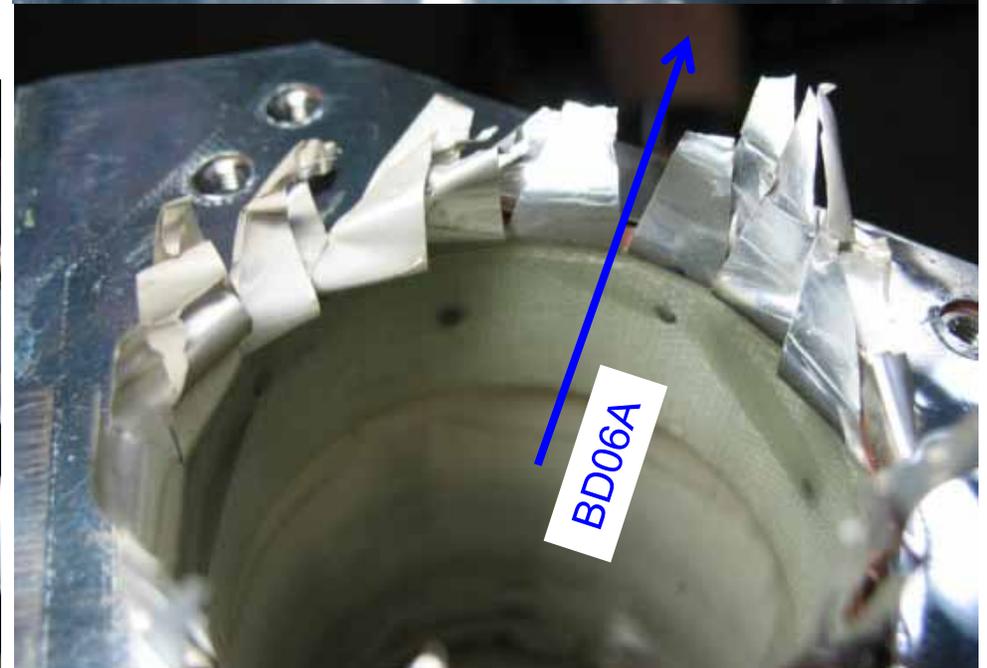
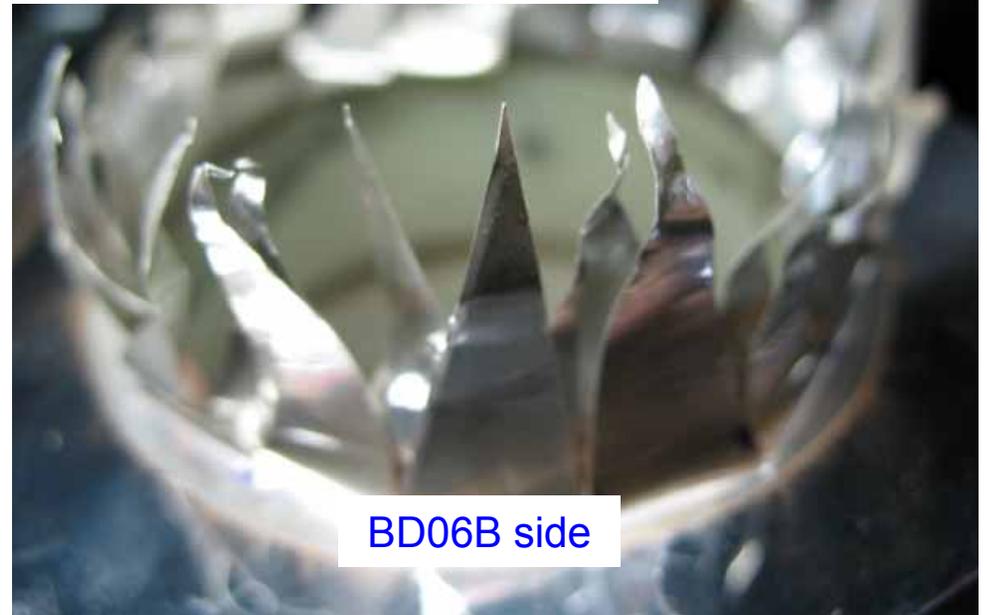
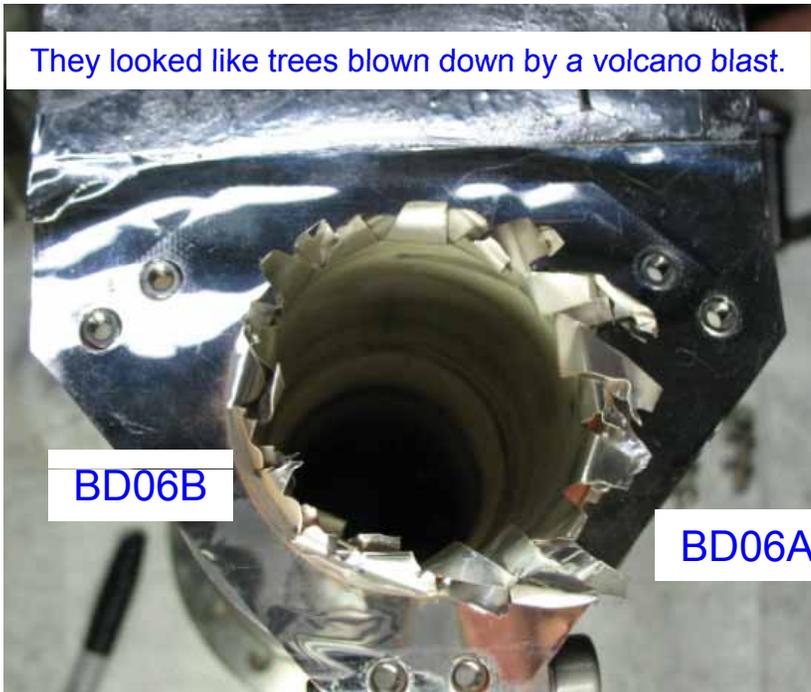


When we got to the radiation shield, it was very obvious which side the gas exited because of the rearranged shield material.



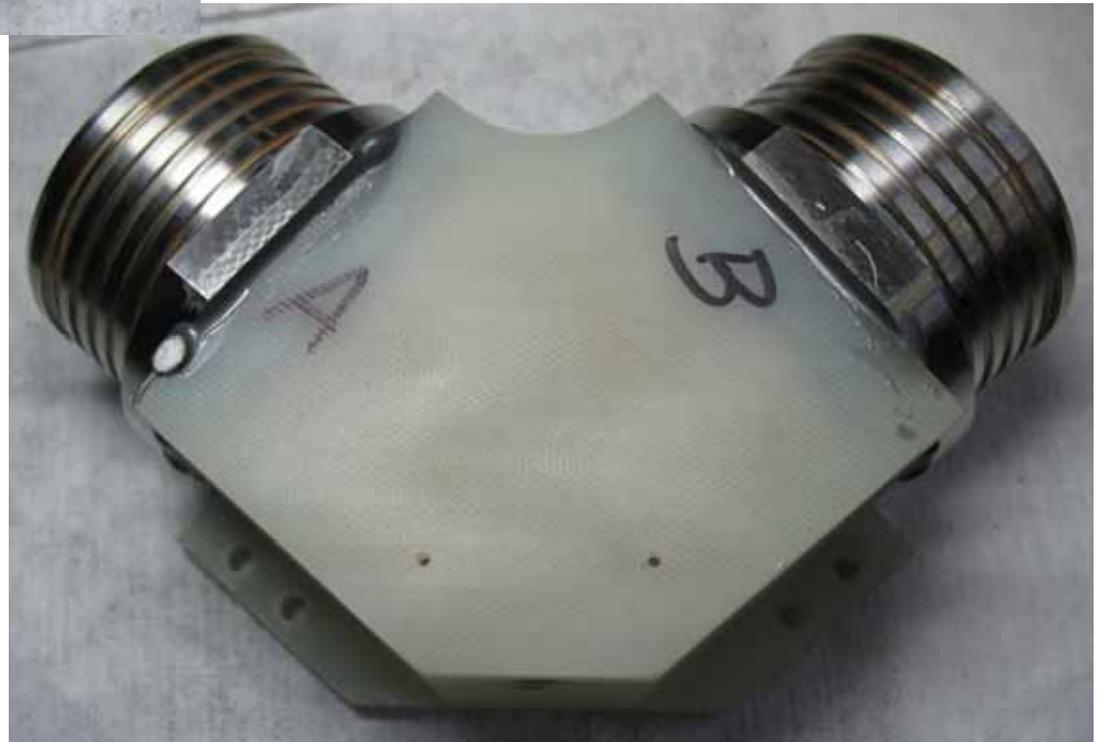
Some tips of the radiation shield near the BD06A exit were sheared off while most of the others around the circle were intact.

They looked like trees blown down by a volcano blast.





The Tee Box
appeared unaffected.



The Telescoping Tube also appeared to be unaffected.



The Collar around the telescoping tube that interfaces with the bracket on the window was cracked. This is not significant for the configuration of the flight unit and was confirmed with Corrado Gargiulo.



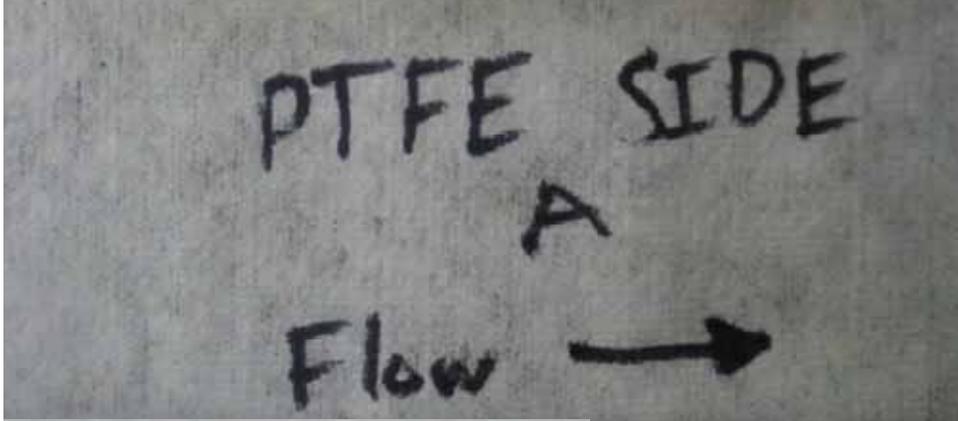
The BD06A Flexible Tube ortho-fabric looked fine. However, the PTFE had a significant tear and a large hole was apparent. This is where the majority of the helium went from the helium vessel to the vacuum space.



The hole is near the outlet of the Flexible tube.



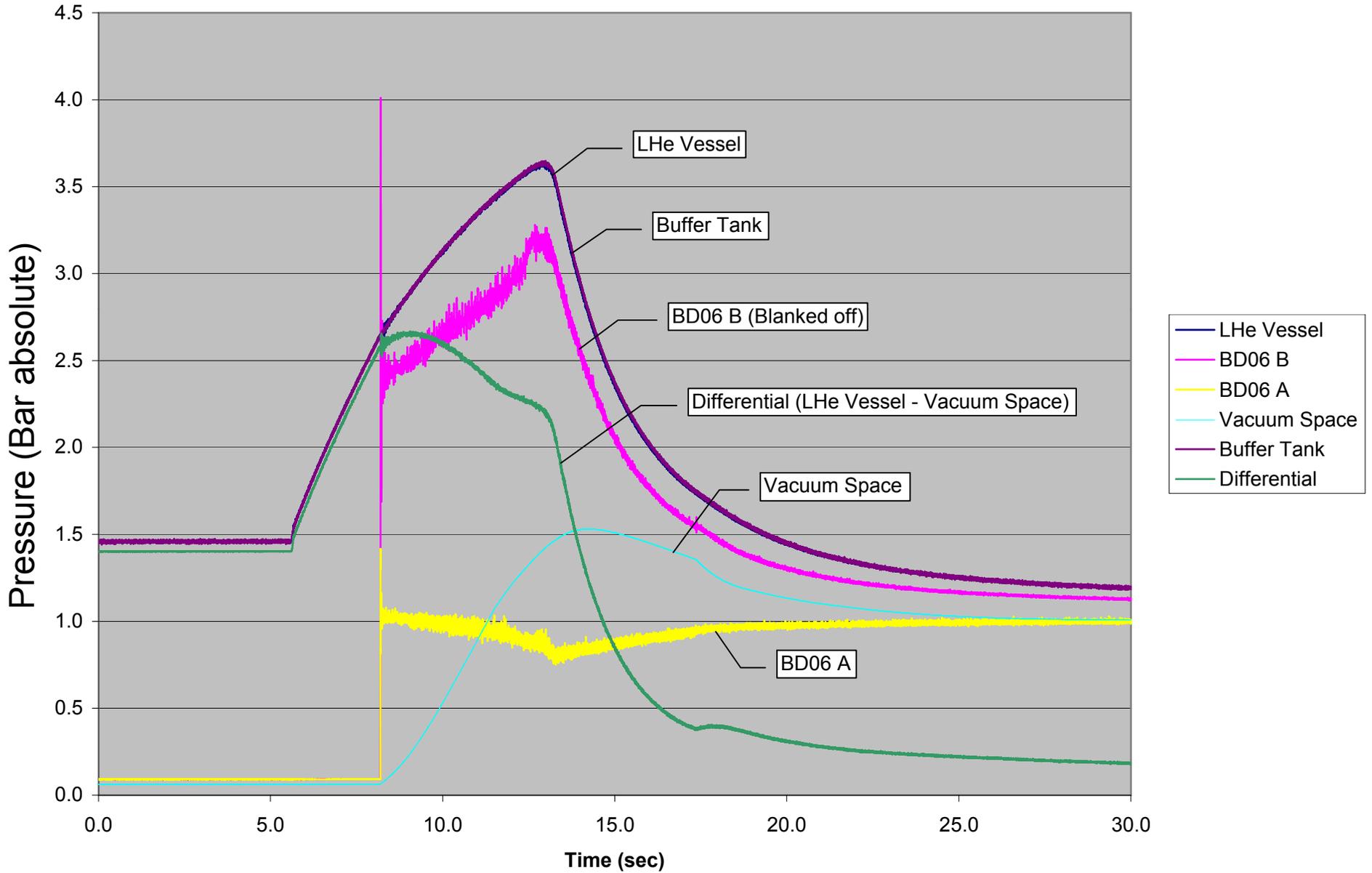
PTFE liner removed from the ortho-fabric flexible tube on side A



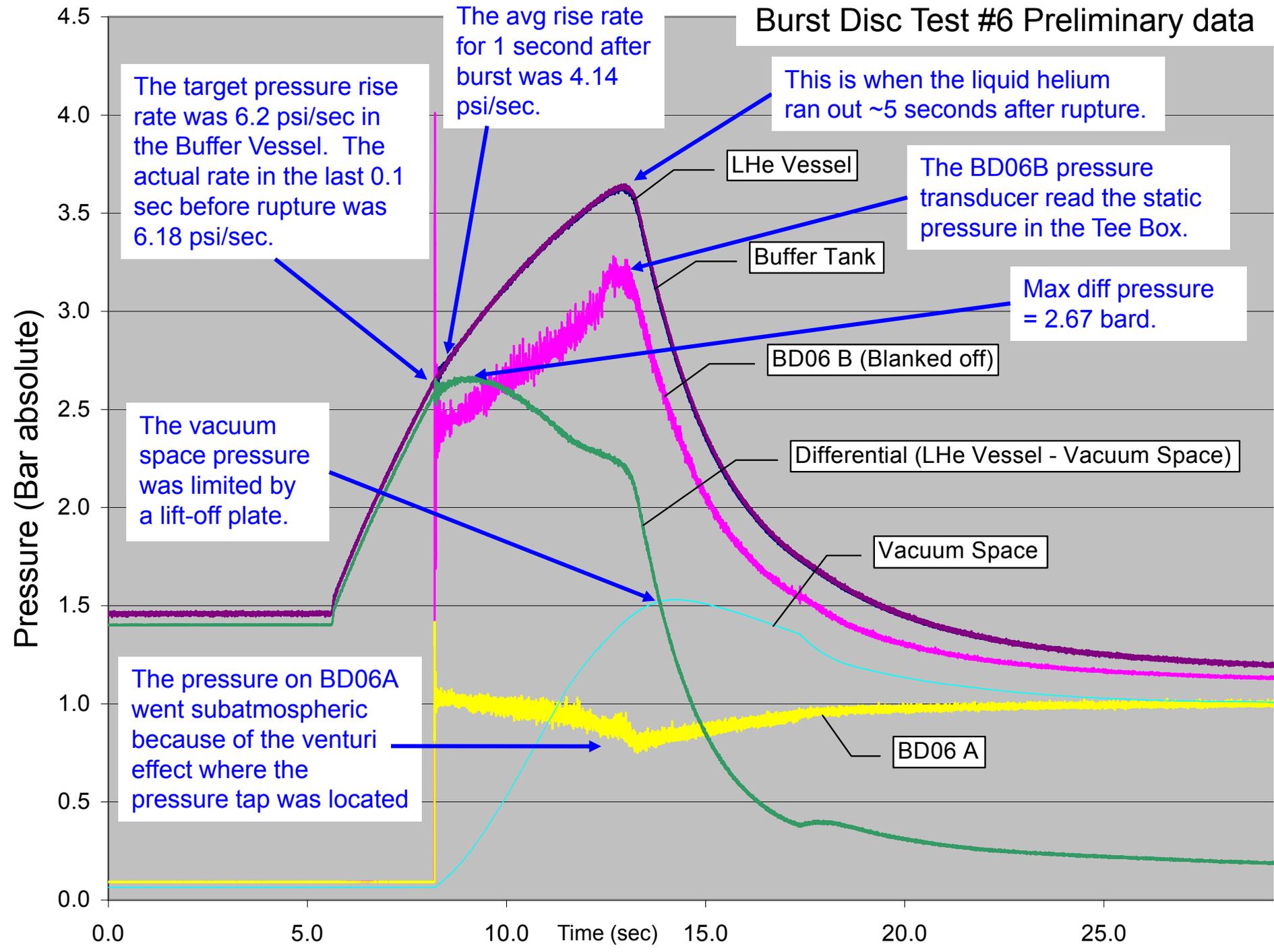
The BD06B Flexible Tube ortho-fabric also looked fine and the PTFE liner was intact.

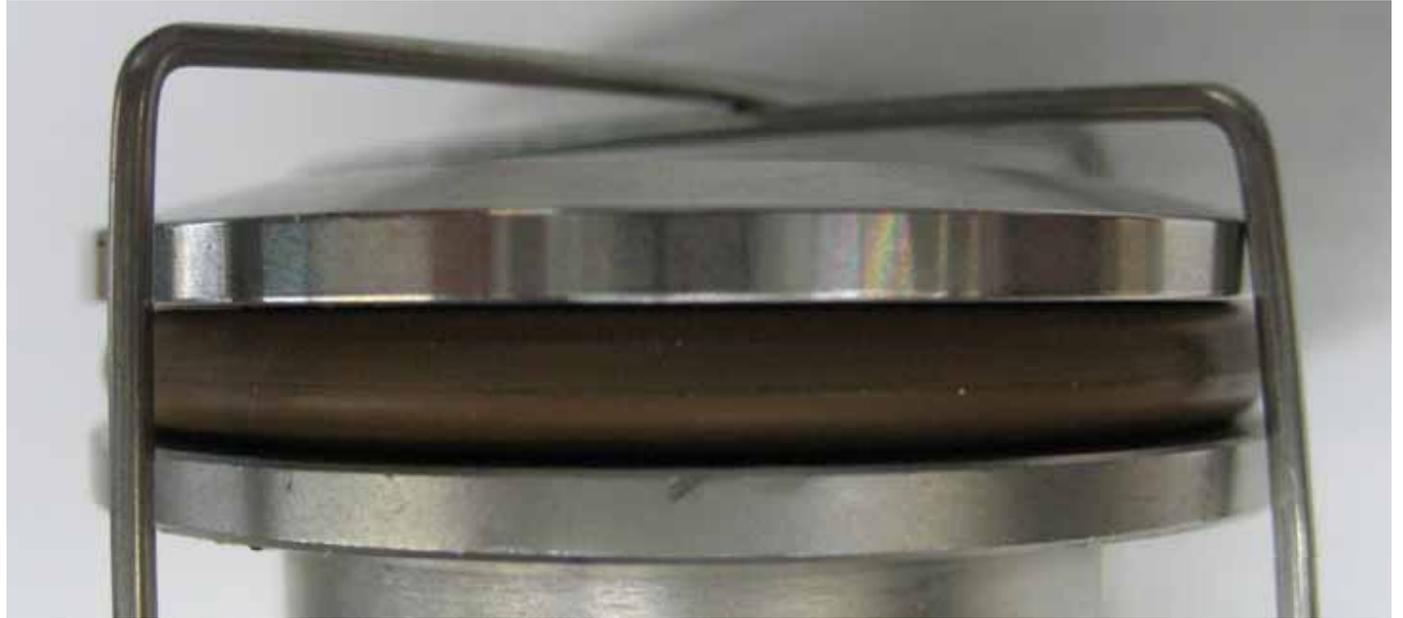


Burst Disc Test #6 Preliminary data

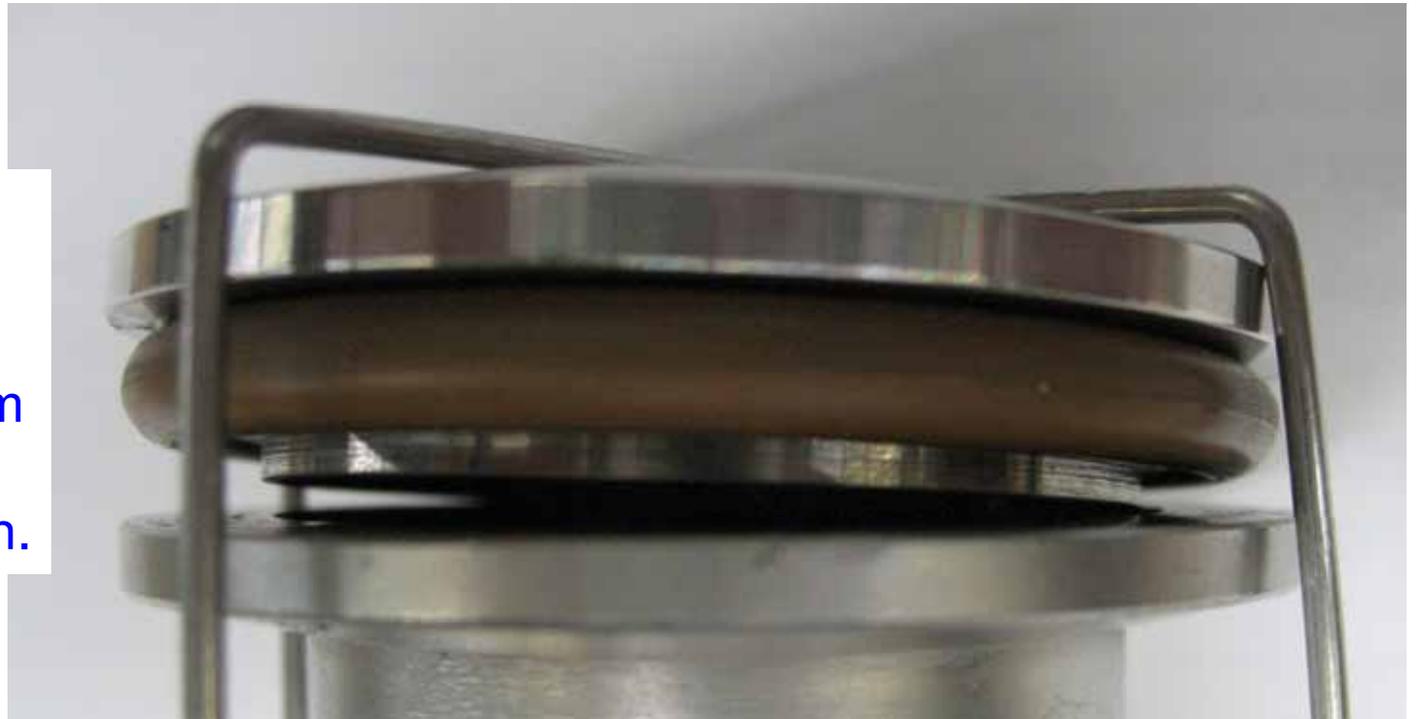


Burst Disc Test #6 Preliminary data

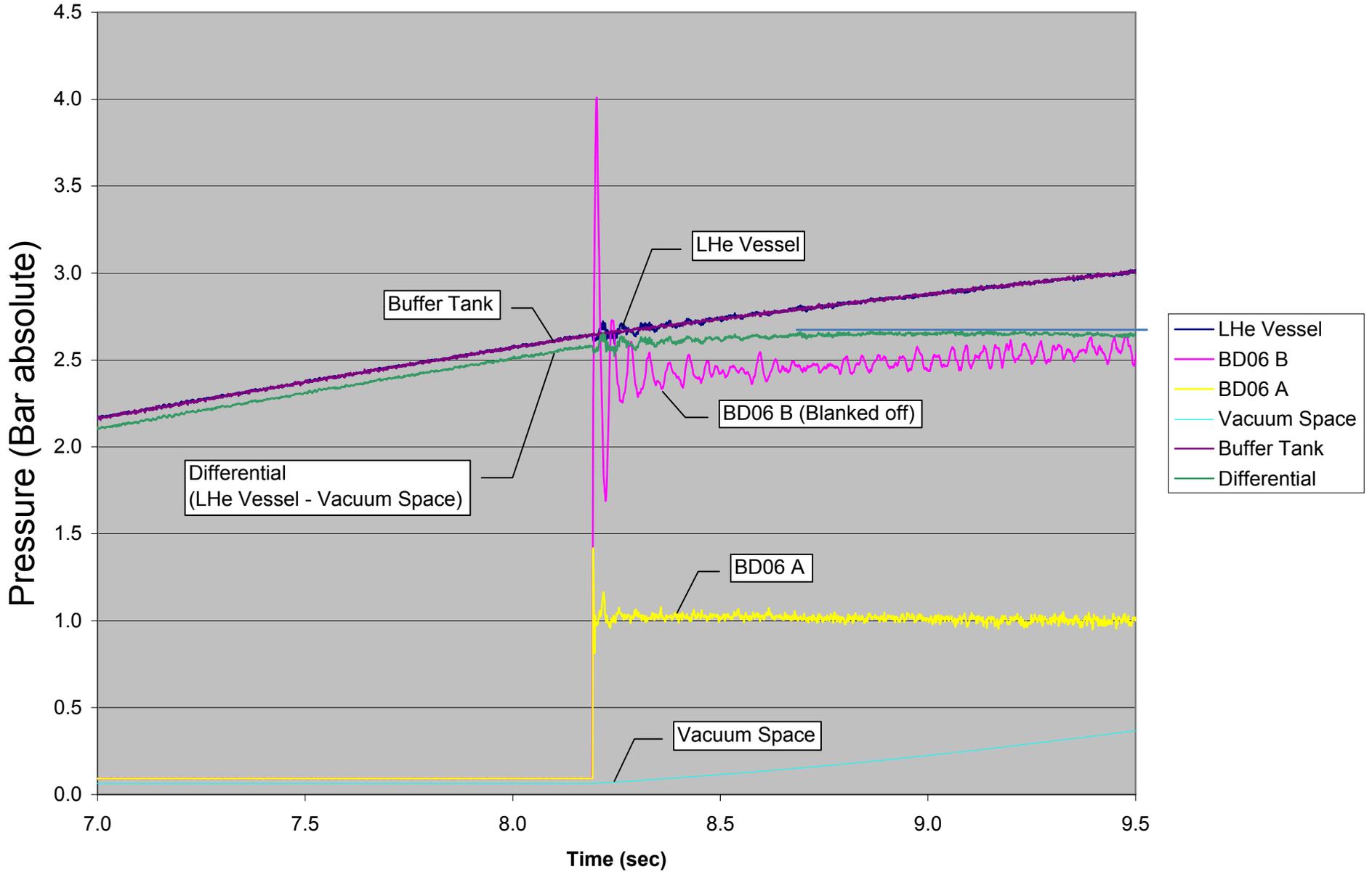




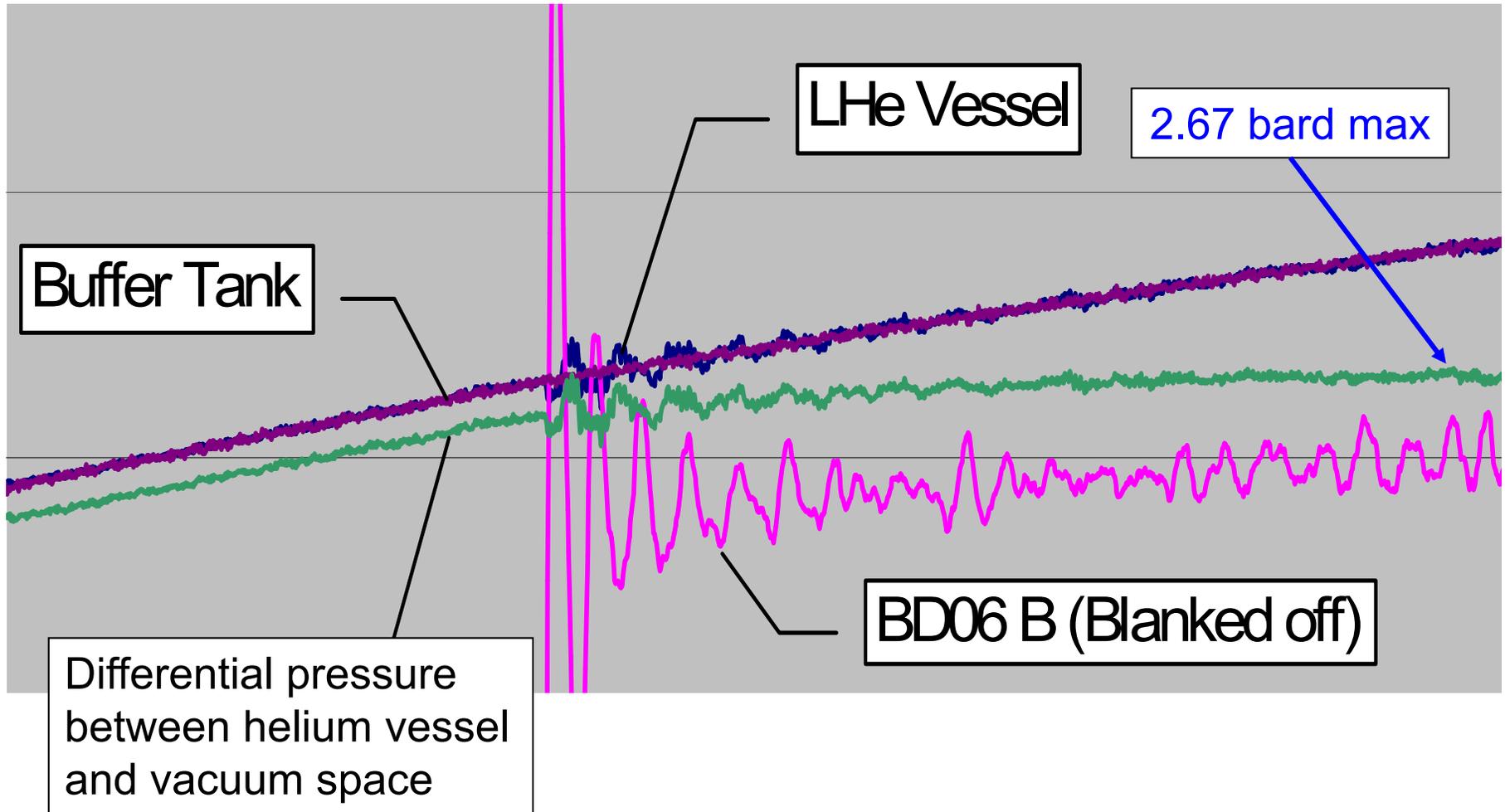
The lift-off plate installed on the vacuum space limited the maximum pressure it would have otherwise seen.



Burst Disc Test #6 Preliminary data



Burst Disc Test #6 Preliminary data – close up

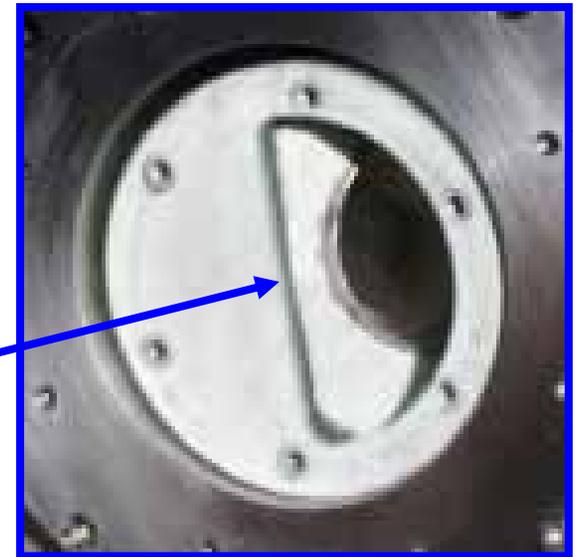


Test #6 Results & Conclusions

- The pressure rise rate of 6.2 psi/second was based on testing with a loss of vacuum due to air on a small vessel with 3 mm of cryocoat and no VCSs or superinsulation at SCL. It was calculated by S. Harrison to simulate the heat load on the AMS cryostat (with no credit for the VCSs or 120 layers of MLI) and was the rate SCL was trying to achieve when the Flexible Collapsible Kapton Tube (FCKT...) failed during the test on 9 July, 2009. This simulated heat load was allowed to continue after the burst disc rupture because the load would continue to be applied on the flight hardware. The actual rate achieved an instant before rupture in test #6 was 6.18 psi/sec. Note that no credit for the insulating effect of freezing air is considered under these conditions.
- However, the pressure continued to rise at a rate of ~4.14 psi/sec after the BD03 disc ruptured. This was due to three inputs:
 - Continued influx of helium gas simulating the heat load due to loss of vacuum as planned.
 - An unaccounted-for actual heat load from the warm helium gas rapidly being pushed into the helium vessel.
 - An actual heat load from pressurization of the insulating vacuum space with helium caused by leaking through the flexible tubes which increased when the PTFE liner ripped inside the ortho-fabric flexible tube to BD06A.

Test #6 Results & Conclusions (cont)

- In addition, this test only used one BD06A disc because of the limited number of flight-like discs available and also because we wanted to see the effect of having only one disc operational. Thus, the flow through this tube was doubled.
 - An unexpected benefit of doing this test with only one BD06 was to provide the actual static pressure in the Tee Box via the dead-end connection to pressure transducer BD06B. This pressure followed the helium tank closely which indicates the “choke” in the system is not at the BD03 burst disc or in the Tee Box. It was likely in the semi-circular exit of the angled adapter where it connects to the BD06A disc. This is warmest section with the smallest relative flow area.



Test #6 Results & Conclusions (cont)

- All things considered, it is believed the hardware was over-tested in test #6. Even so, the maximum differential pressure in the helium vessel (2.67 bard @ 0.95 sec after burst) still stayed below the design limit of 3 bard. Thus, the recommendation to proceed with the welding of the Vacuum Case at CERN.
- In an effort to test in a manner closer to actual conditions, a new test using extra CGSE test discs will be conducted (Test #7A). It will be configured much like test #5 but it will not use the helium gas pressurization system.
- Instead of simulating a heat load due to loss of vacuum with air, there will be an actual heat load due to loss of vacuum with air. The existing helium gas pressurization system will be sealed off.
- Since air will be used, the insulating effect of freezing air in the MLI will take place. However, the test will still be conservative since there are only 20 layers of superinsulation in the test cryostat.
 - A concern has been raised that this test may damage the test cryostat MLI. If this does happen, it could delay further testing by ~1 week. This has been considered and determined to be an acceptable risk to the overall test schedule.

Test #6 Results & Conclusions (cont)

- The orifice size (TBD) to be used will be estimated while considering the following factors:
 - Surface area of the AMS Cryostat at CERN vs the test cryostat at TAMU
 - Surface area to volume ratios of both cryostats
 - 130 layers of MLI on AMS vs 20 layers on the test cryostat
 - 4 vapor cooled shields on AMS vs none on the test cryostat
 - 3 mm of cryocoat on the AMS vs none on the test cryostat
- Once this new test re-establishes the operation of the test hardware using this revised pressurization method, test #7B will be conducted using the flight-like discs in a similar manner.
- Test #7A will likely result in an adjustment of the orifice size once the data is analyzed.
 - Note that since this new test will use CGSE test discs, the flow areas will be significantly different than those using the flight-like discs. The BD03 flight-like disc has a score line opening of ~47 mm diameter and BD06A has an outlet of 95.8 mm. The BD03 and BD06 CGSE test discs are only ~34 mm diameter at the score line. Thus, the new choke point in this initial test will likely be at the BD03 test disc rather than the semi-circular opening at the exit of the angled adapters.

Enclosure 8

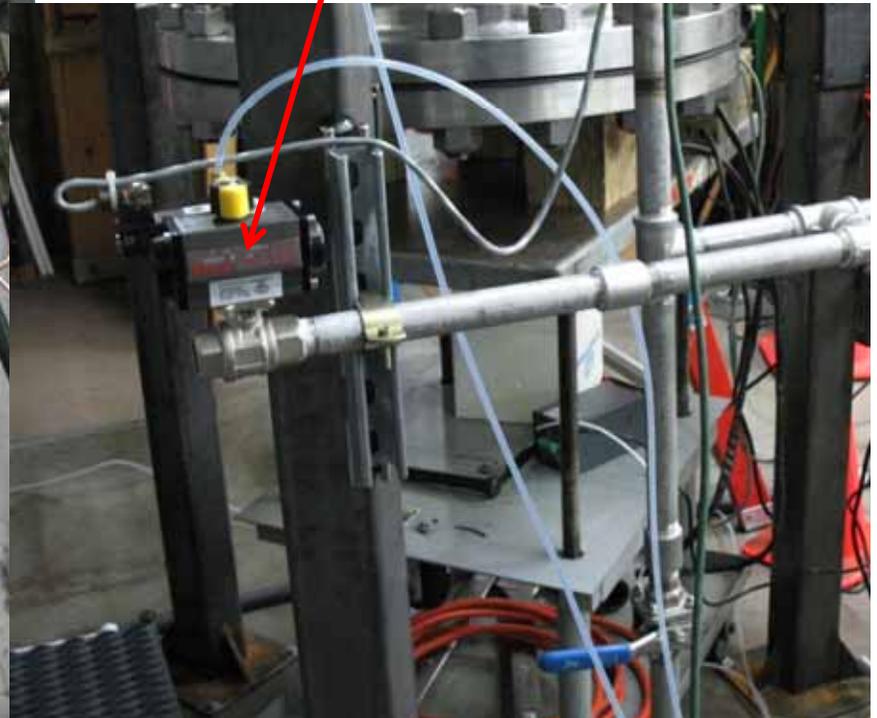
AMS Magnet Burst Discs & Ductwork Test #7A at Texas A&M

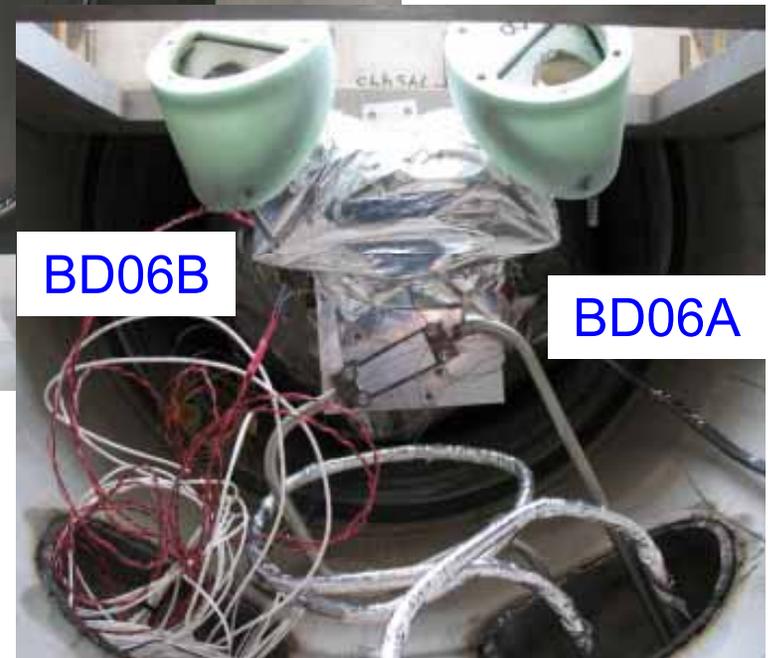
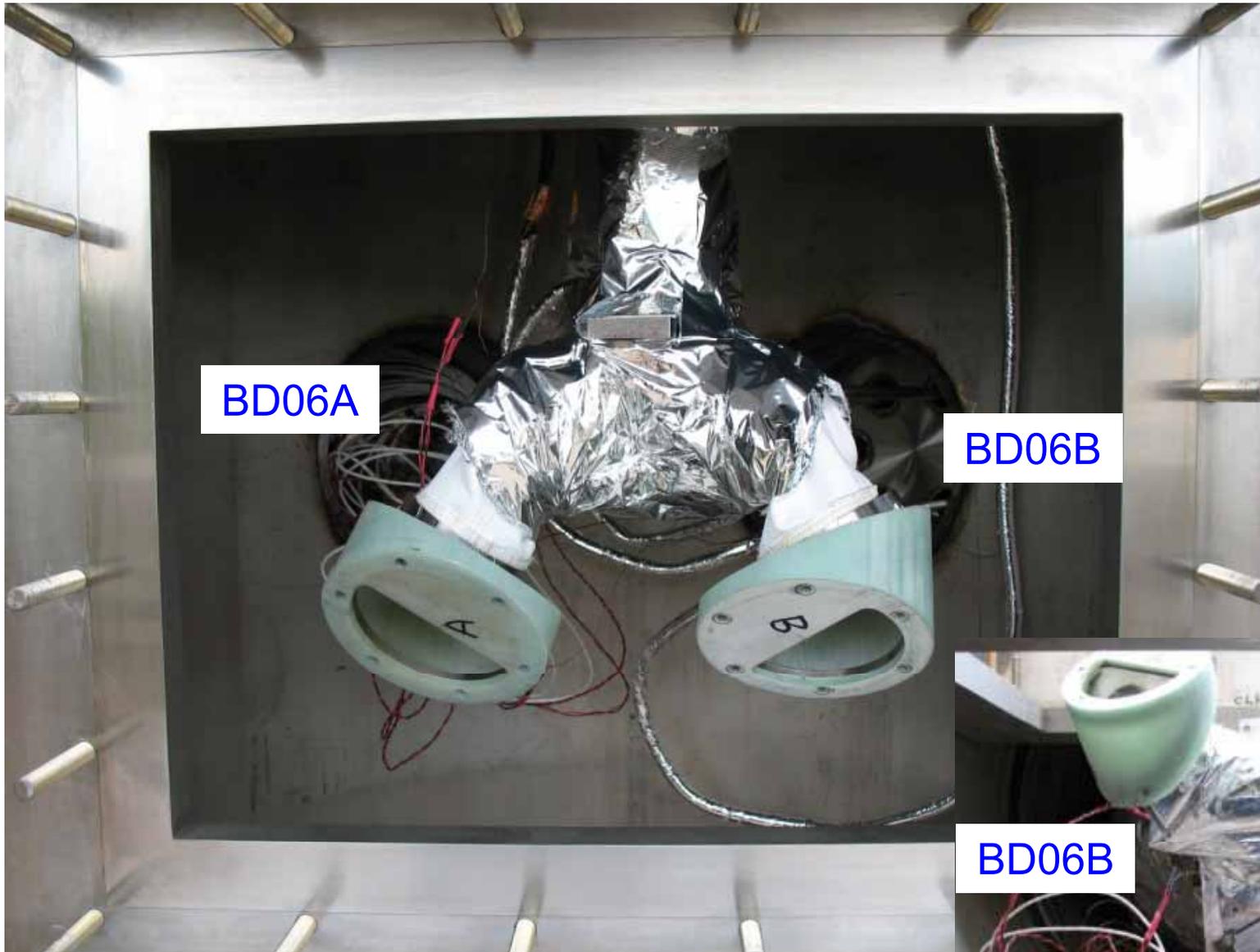
September 29, 2009
K. Bollweg

Another 4" Tee and 4" 100 psig burst disc were added to the inlet line of the helium vessel.

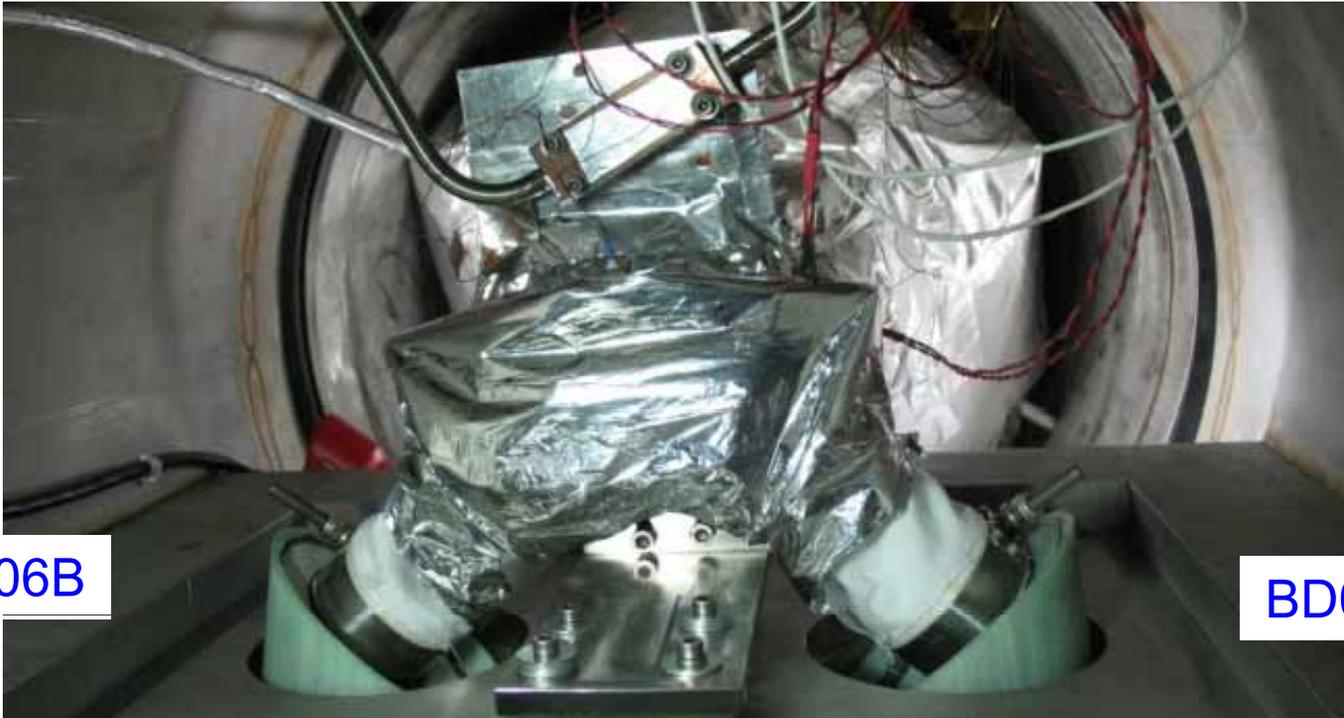


The 1" actuated ball valve and pressure switch from the large gray buffer vessel were moved to the supply line. This would open before the 4" burst disc in the event of another anomaly as seen in test #5.





The test article was assembled as before and instrumented with temperature sensors.



BD06B

BD06A



BD06B



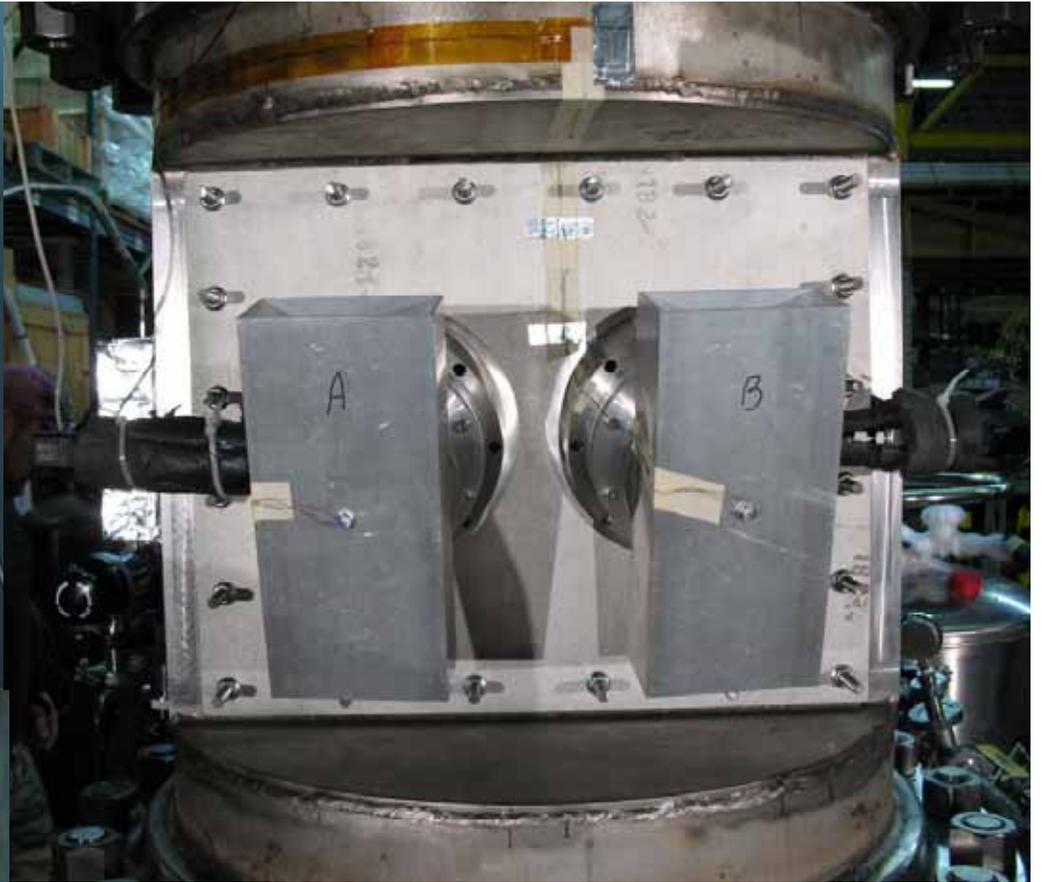
BD06A



The cryostat was assembled and leak tested. Three leaks were found which required some disassembly, cleaning & replacement of O-rings



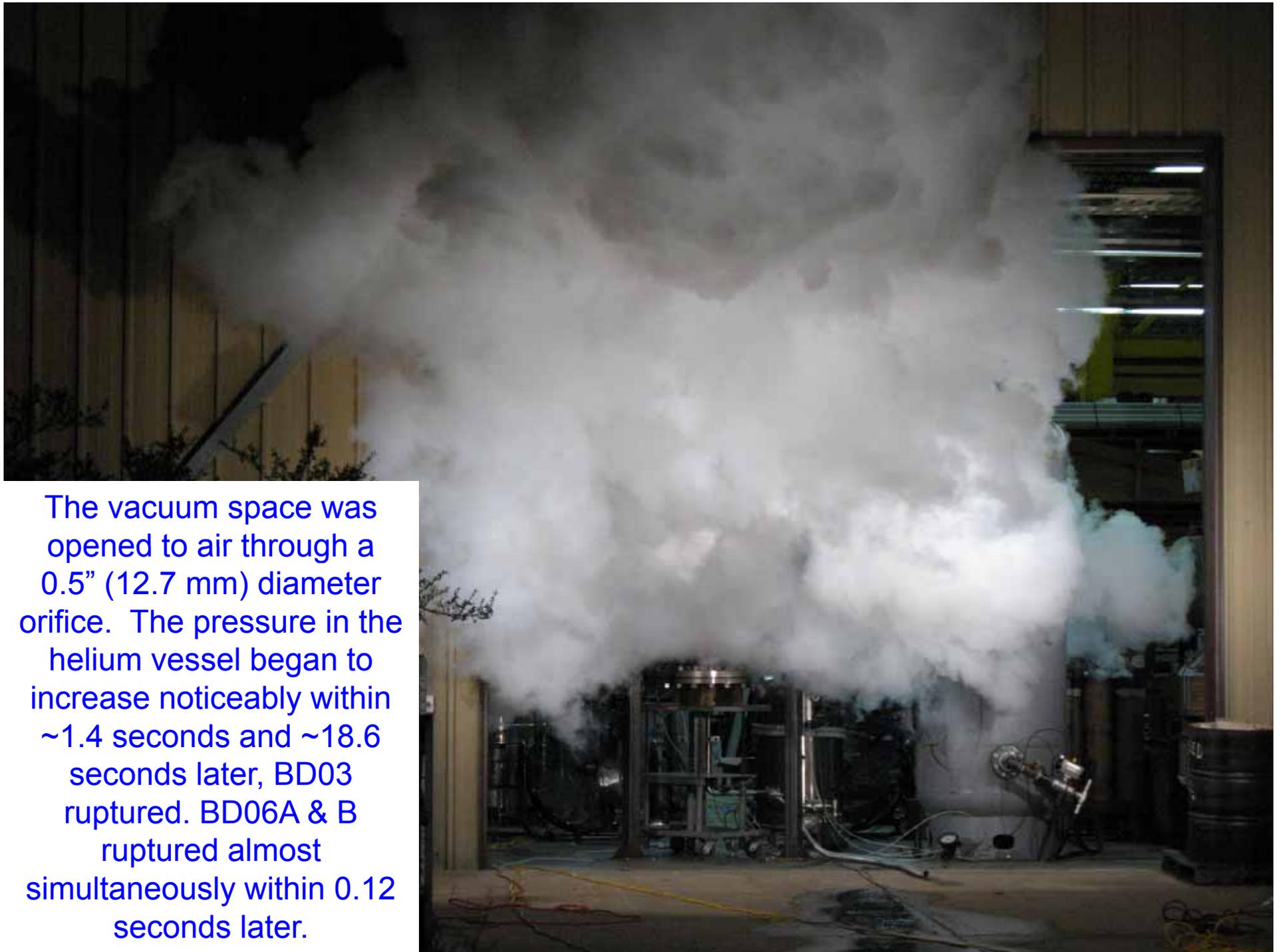
And then the spine-tingling suspense of cool-down...
along with some well-deserved shut-eye.



The system was cooled down with LN₂ beginning on 23 September. However, an operator error resulted in significant amounts of air being ingested into the vacuum space on 24 September. The entire system had to be warmed up, re-pumped & purged, and re-cooled. Another unapproved modification to the warm-up system resulted in even more moisture in the vacuum space.



The cooling took noticeably longer and the vacuum level reached was not as good as the first time around – likely due to the moisture in the insulating vacuum space. Nevertheless, ~32 hours later, we were ready to go with the helium vessel filled to ~75% (~210 liters) with LHe. The cameras and lights were set up, all the remote control functions were checked, and the data acquisition system was set to record.

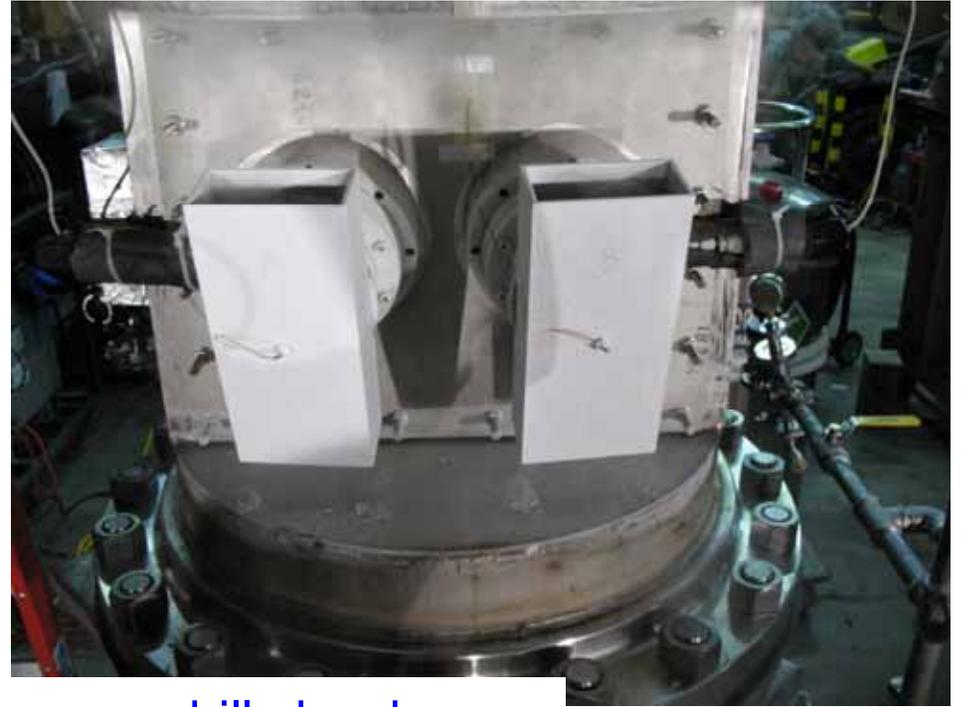


The vacuum space was opened to air through a 0.5" (12.7 mm) diameter orifice. The pressure in the helium vessel began to increase noticeably within ~1.4 seconds and ~18.6 seconds later, BD03 ruptured. BD06A & B ruptured almost simultaneously within 0.12 seconds later.



As in test #6, the cloud expanded rapidly. Within ~40 seconds, the pressure was completely relieved and the exhaust was reduced to slow venting of the remaining gaseous helium as it warmed.

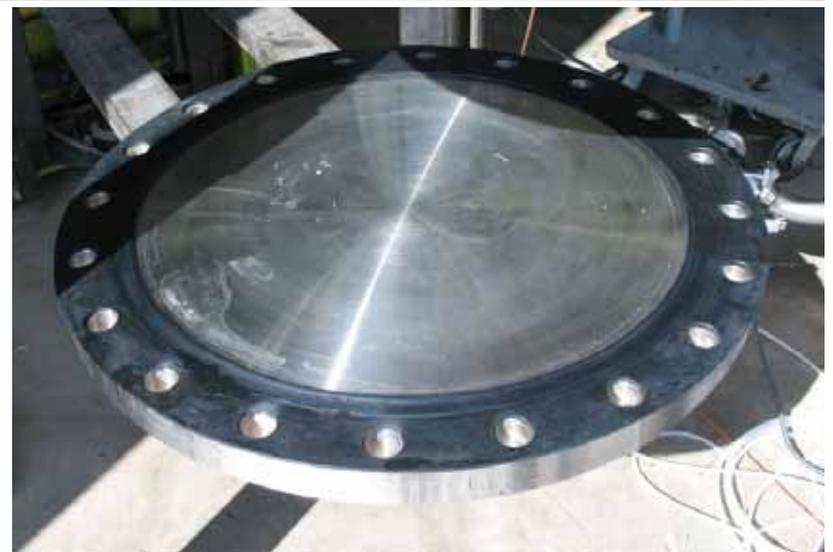


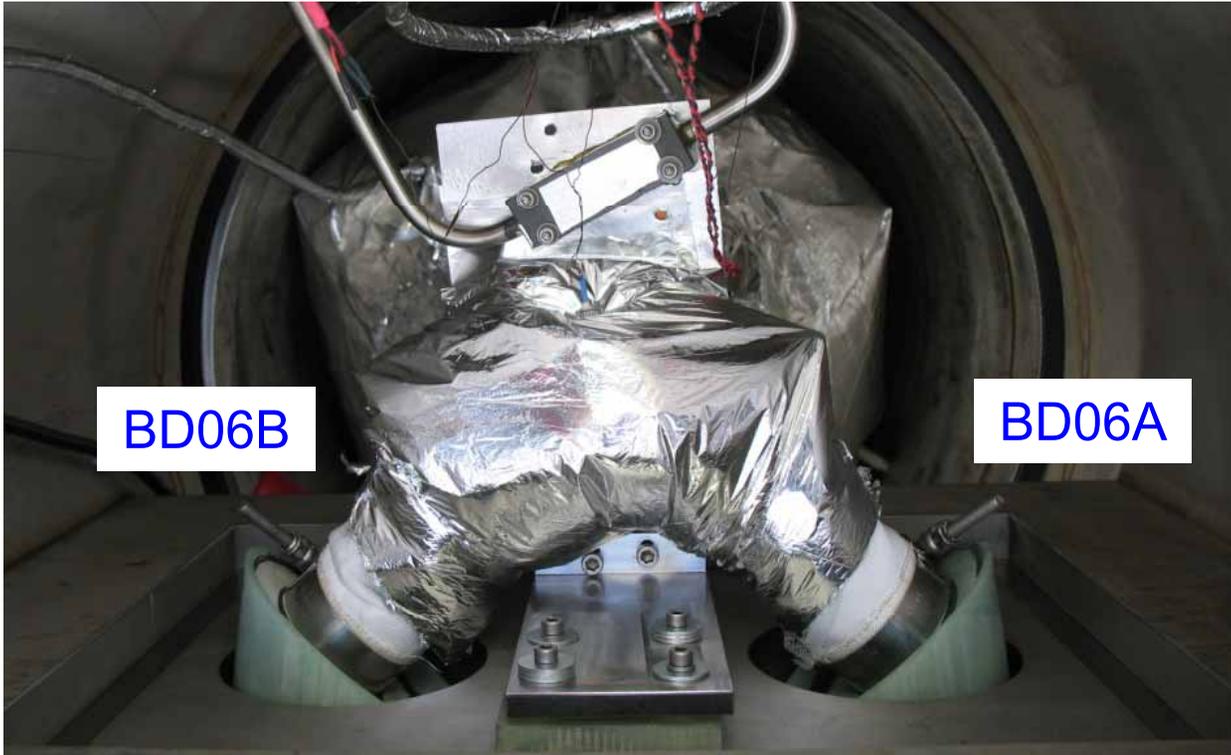


Post-test views of some very chilly hardware.



The exhaust ports were wrapped in plastic to reduce the moist air from entering the vacuum space while a heater and blower were used to dry out the hardware. The next day, considerable water was observed inside the vessel. The majority of this entered after the discs were ruptured. The same thing would happen to the AMS cryostat if the BD06A, B, or BD07 discs were to ever fail.





Post-test inspection of the hardware revealed it was still intact.





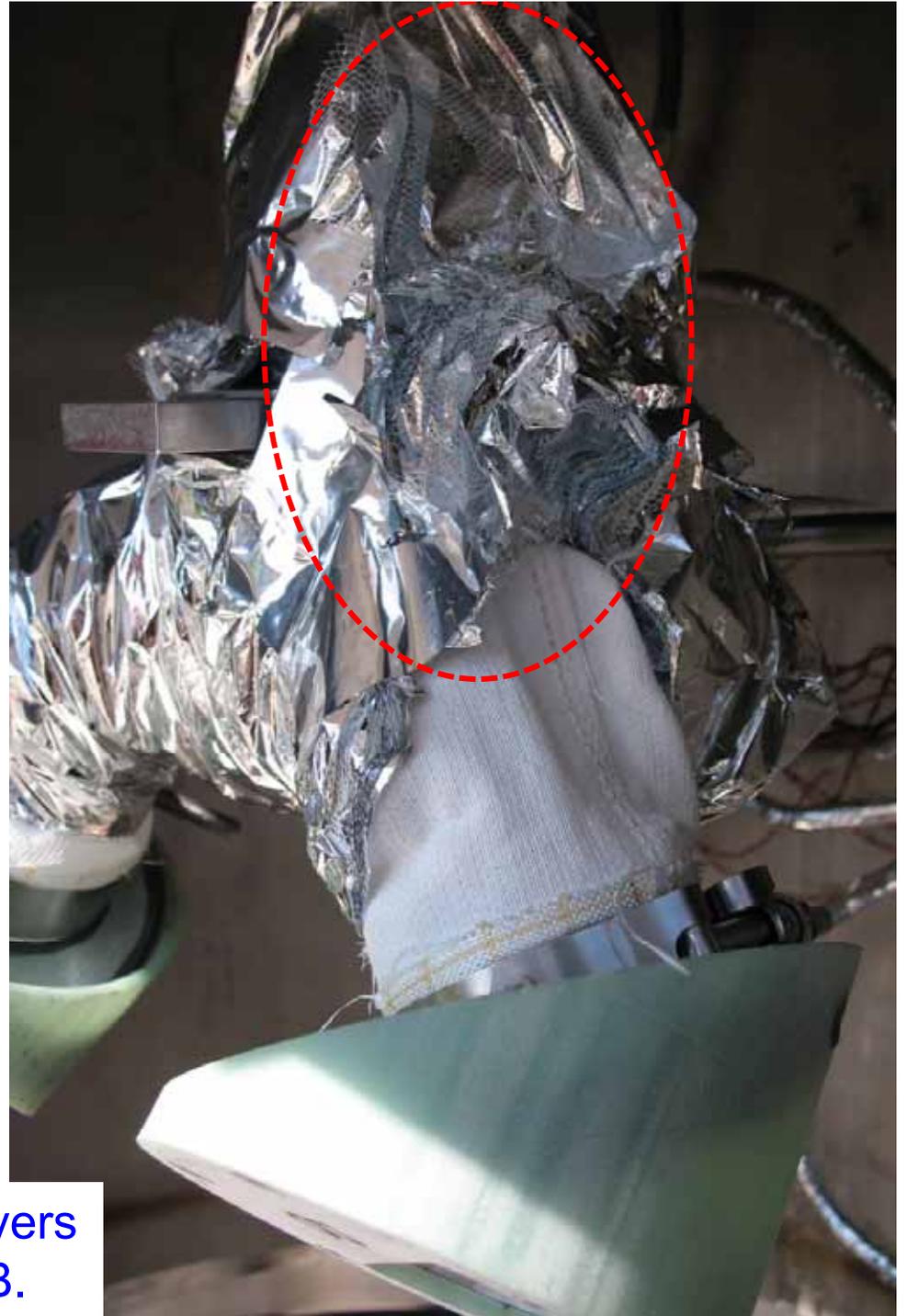
The first look at the flexible tubes and the PTFE liners were encouraging.



BD06A



BD06B



The only noticeable damage was to layers of MLI on the flexible tube for BD06B.

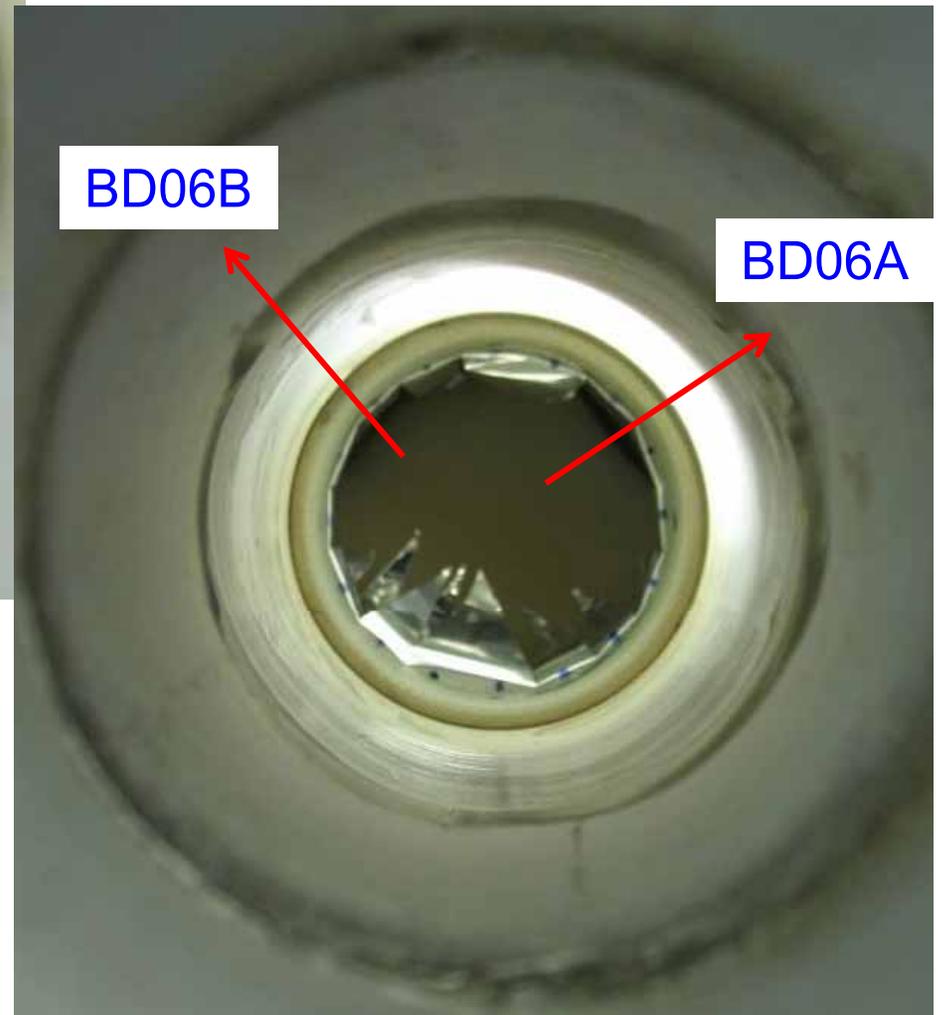
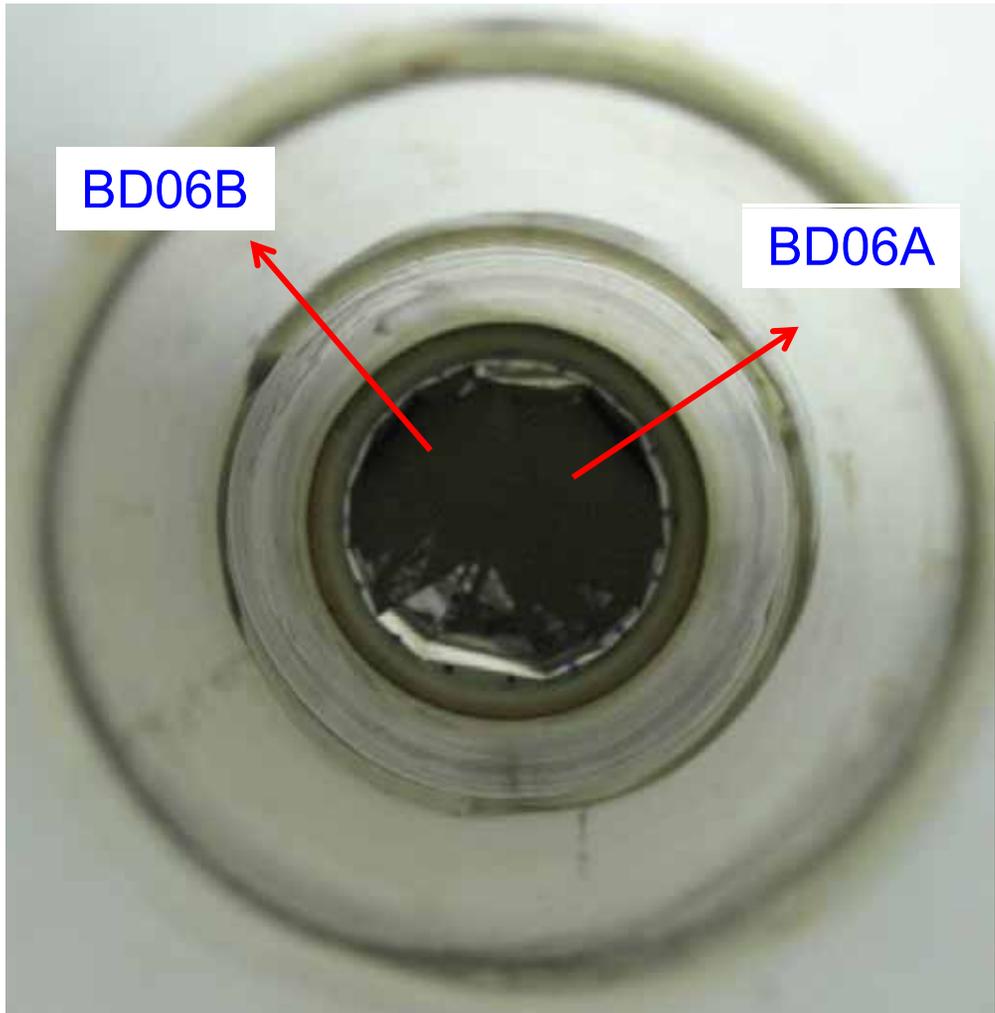
This is the bolt that had the copper tabs with the temperature sensors under it.



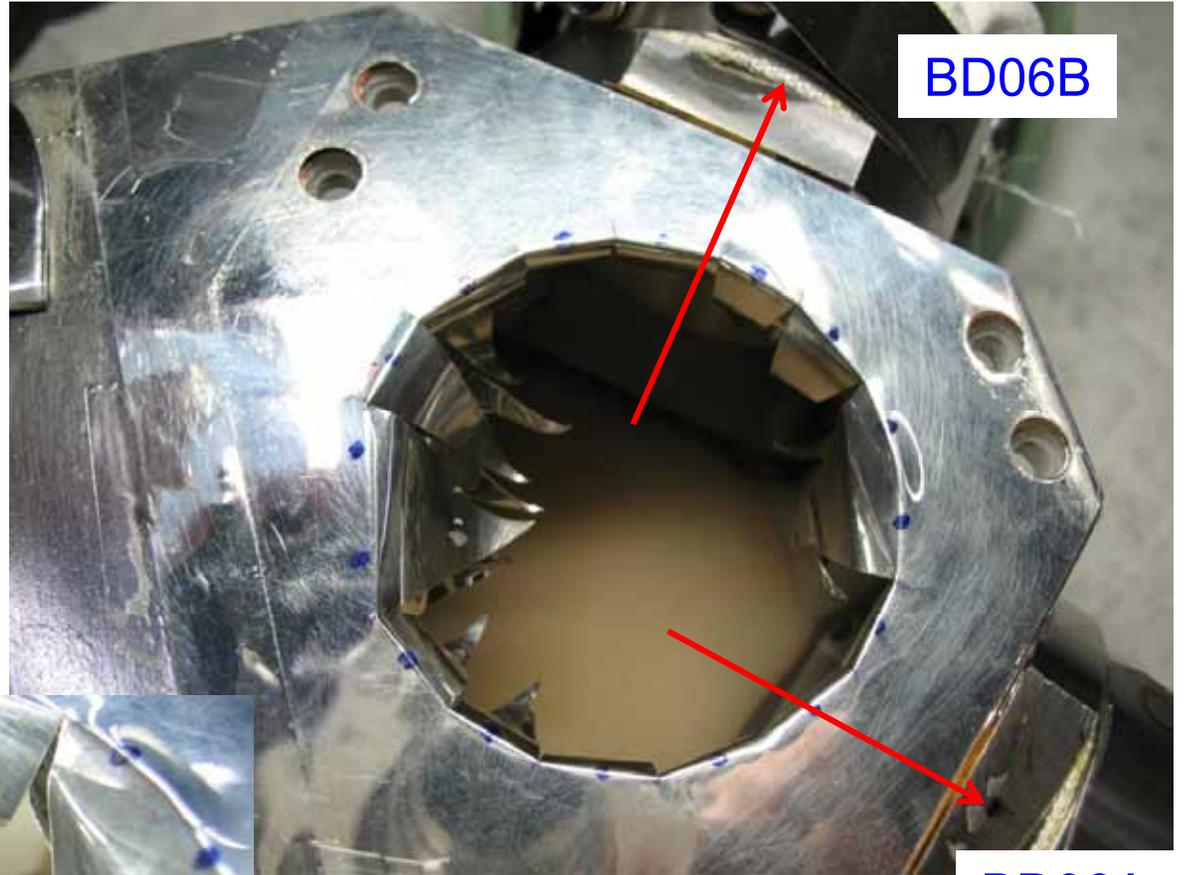
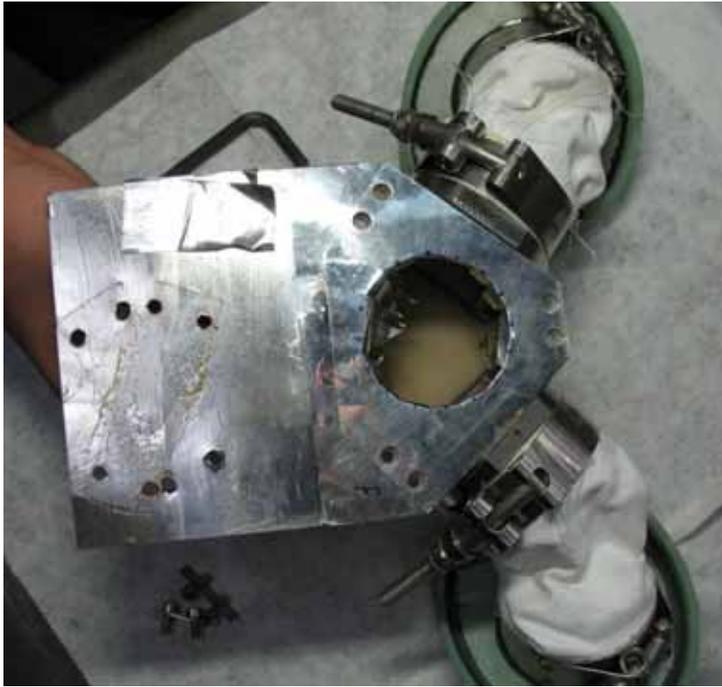
The BD03 disc was still cold, frosty, and intact after removal of the Telescoping Tube. The helium vessel MLI was unaffected.



Nothing unusual was noted
as the insulation was
removed from the assembly



The BD Radiation Shield opened nicely. The only section that wasn't fully bent back was the back side of the Tee Box which is no problem.

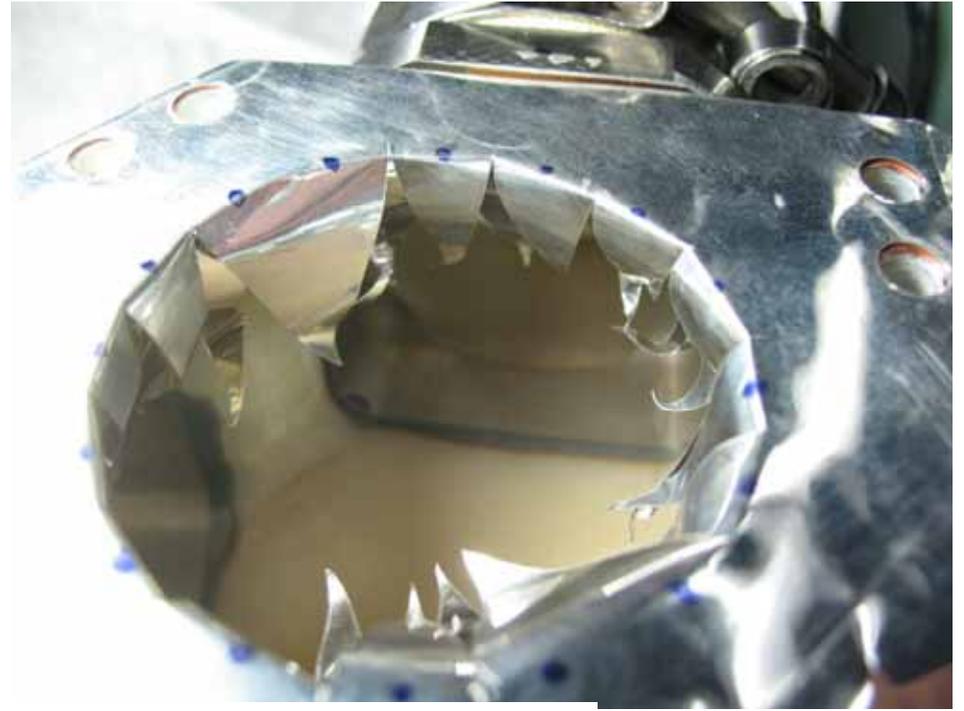


BD06B



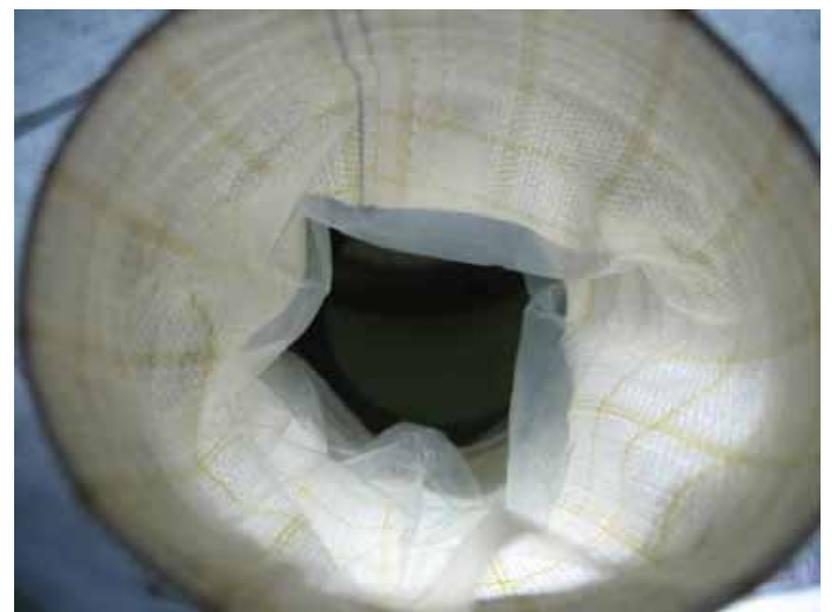
BD06A

Further disassembly and
inspection of the BD
Radiation Shield.

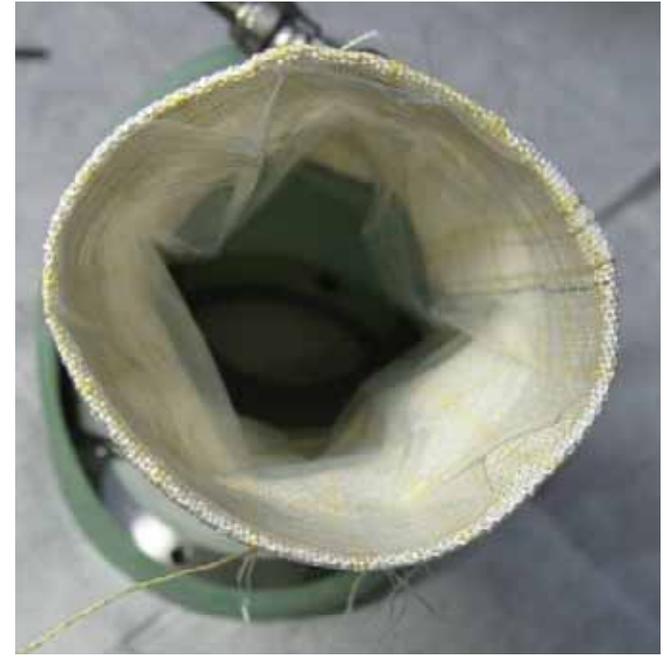


Radiation Shield removed from the Tee Box.





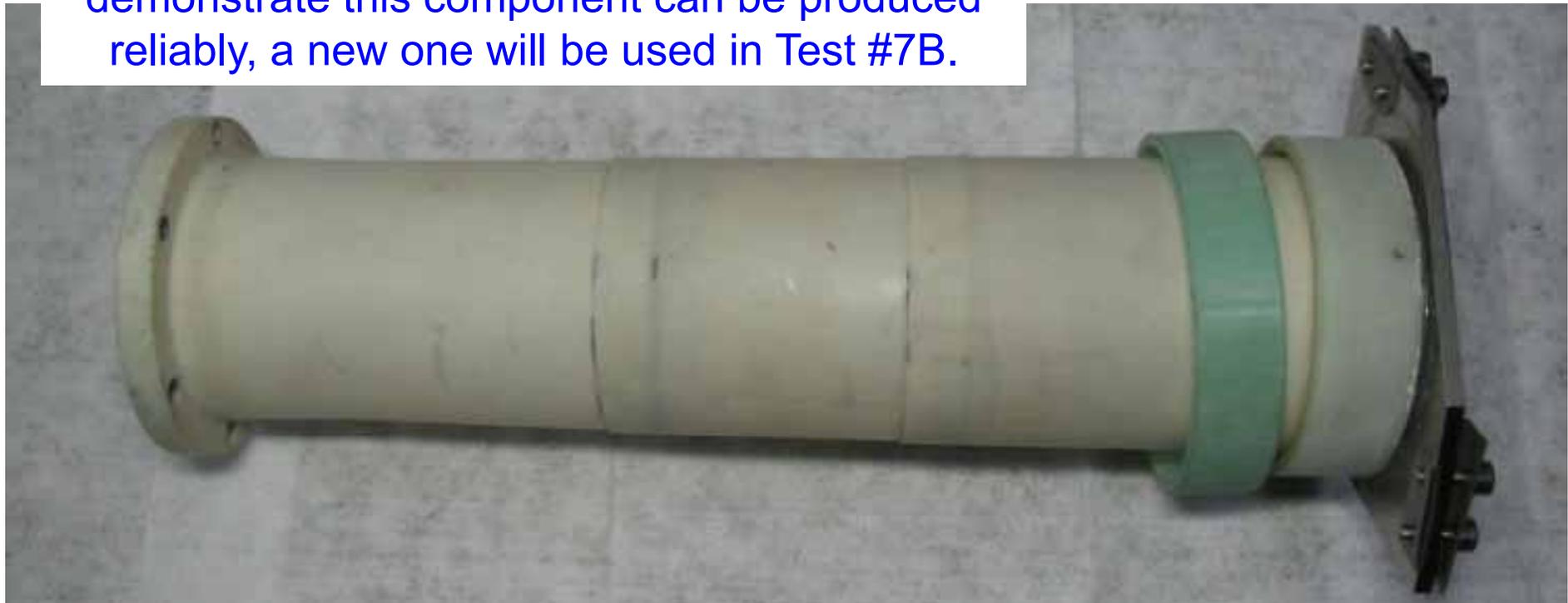
A side: The ortho-fabric flexible tube and the PTFE liner looked good.



B side: The ortho-fabric flexible tube and the PTFE liner looked good. The ortho-fabric tubes will be reused in test #7B. The PTFE liners will be replaced.

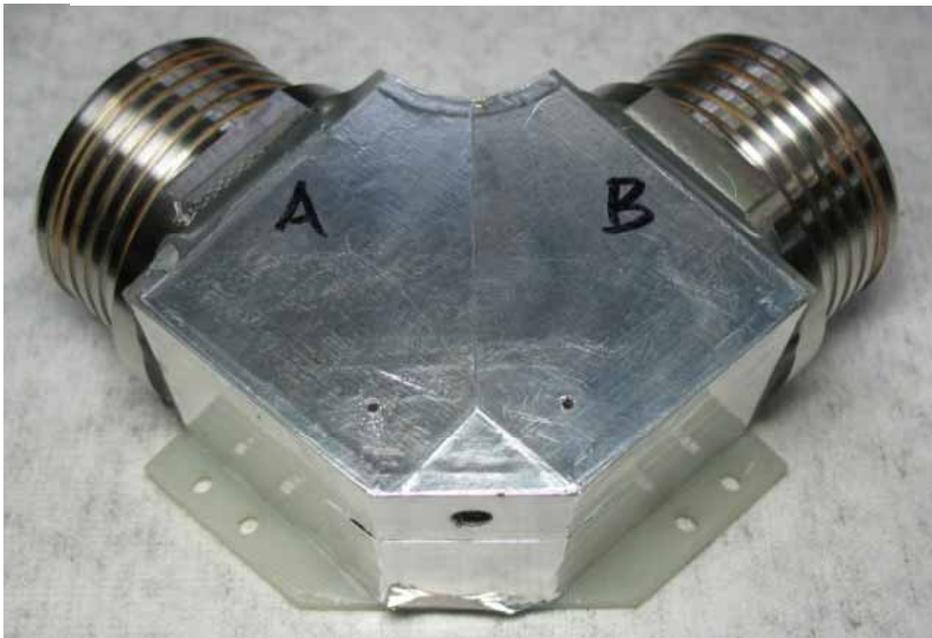


The Telescoping Tube showed no damage. To demonstrate this component can be produced reliably, a new one will be used in Test #7B.





The Tee Box was impervious to the tests. To demonstrate this component can be produced reliably, a new one will be used in Test #7B.



Close-ups of BD03
after removal.



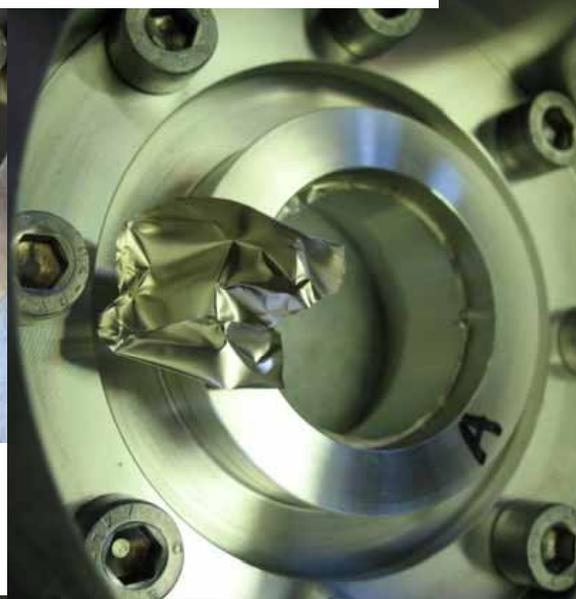
Downstream side



Upstream side



Close-ups of BD06A after removal. The membrane folded back, significantly tore away from the hinge line, but remained attached.



Downstream side



Upstream side





Downstream side



Upstream side



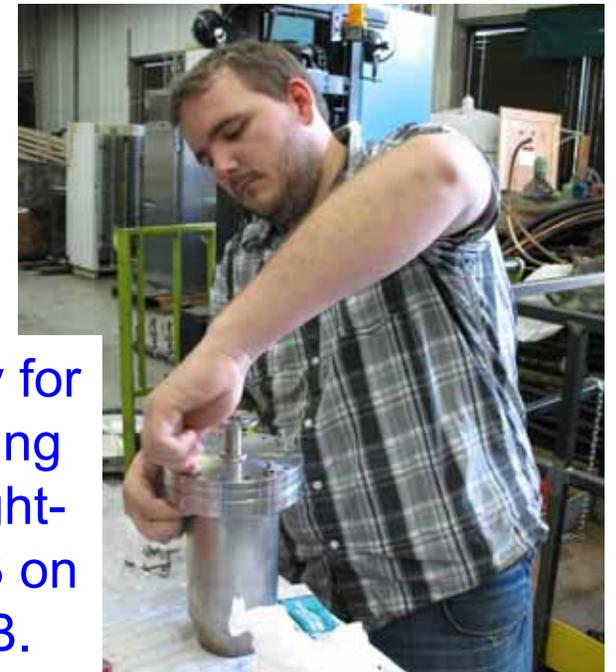
Close-ups of BD06B after removal. The membrane folded back and completely tore away near the hinge line. It was not recovered.



After the test hardware was removed, a large fan was placed under the test jig to accelerate drying.



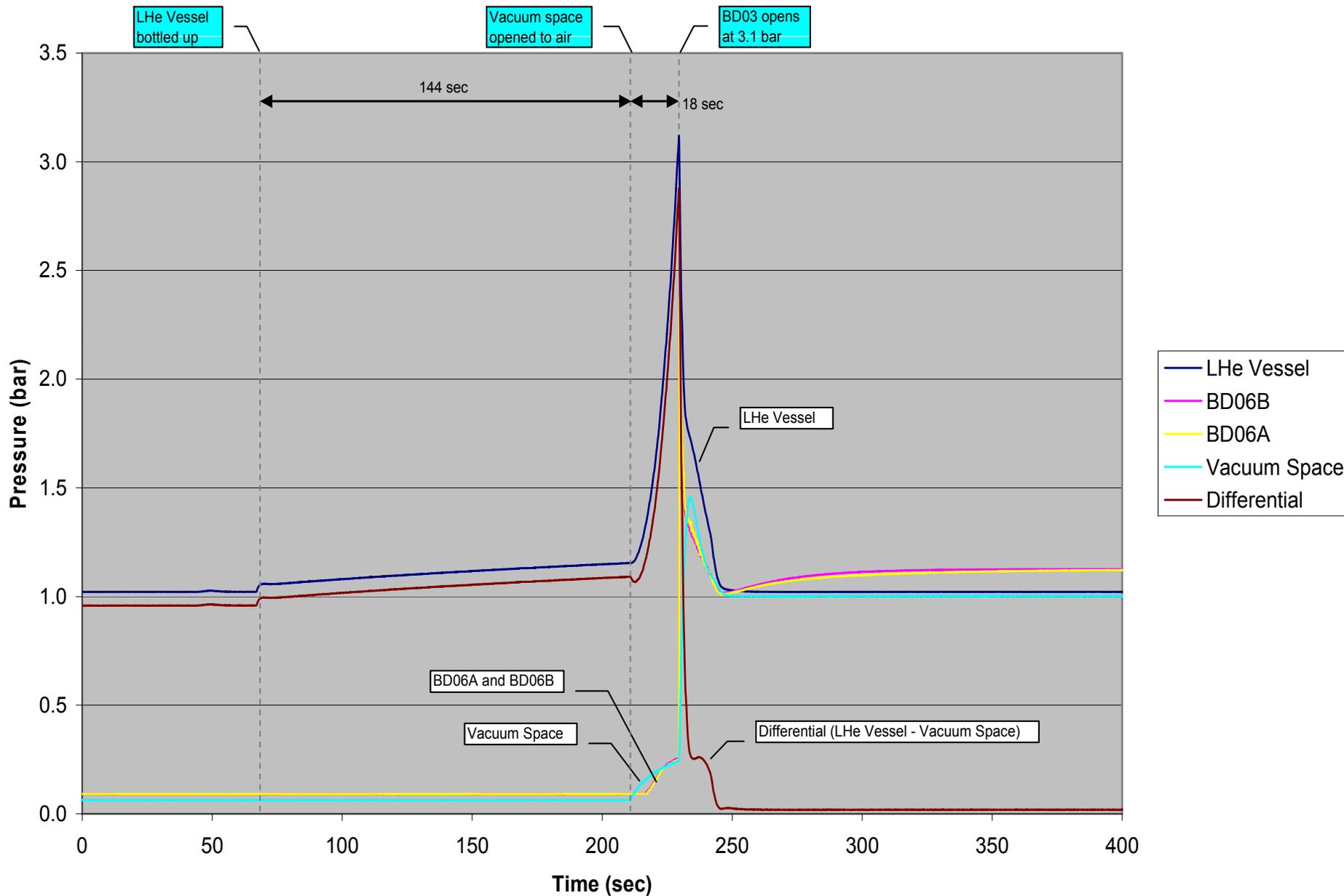
Another inspection of the helium vessel MLI revealed no problems.



Assembly for leak testing of the flight-like BD03 on test #7B.

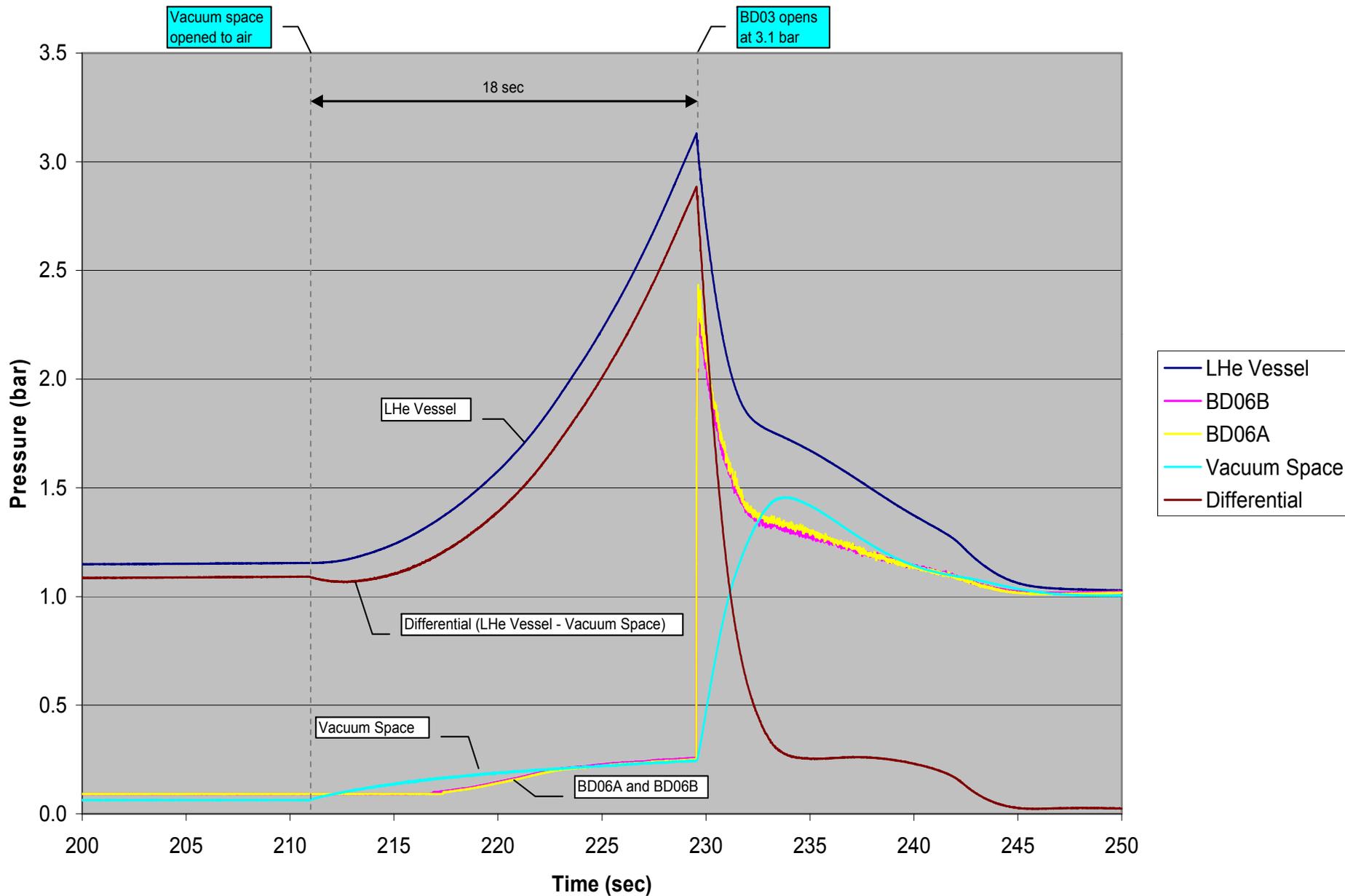
Burst Disc Test 7A

Raw Data

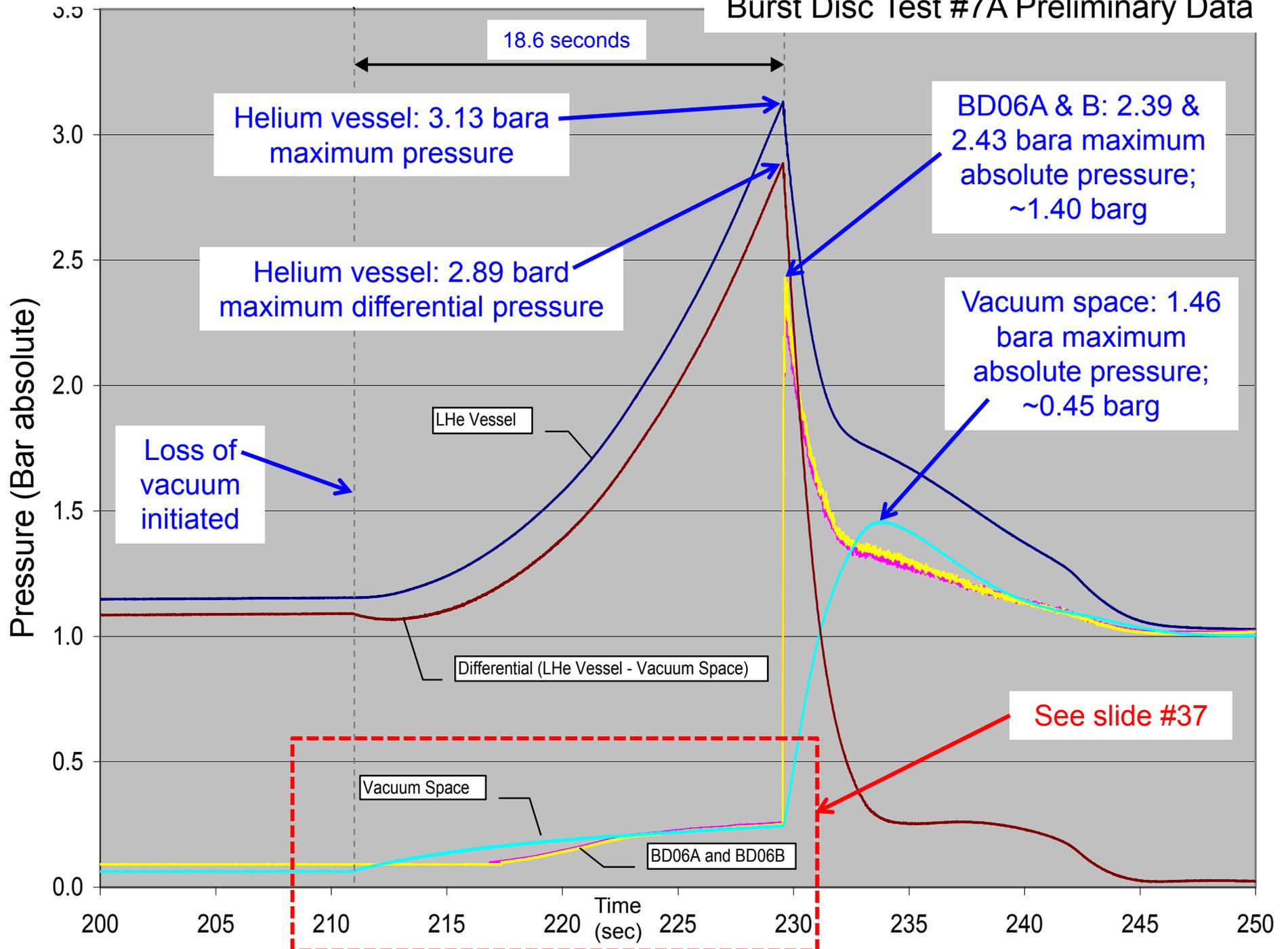


Burst Disc Test 7A

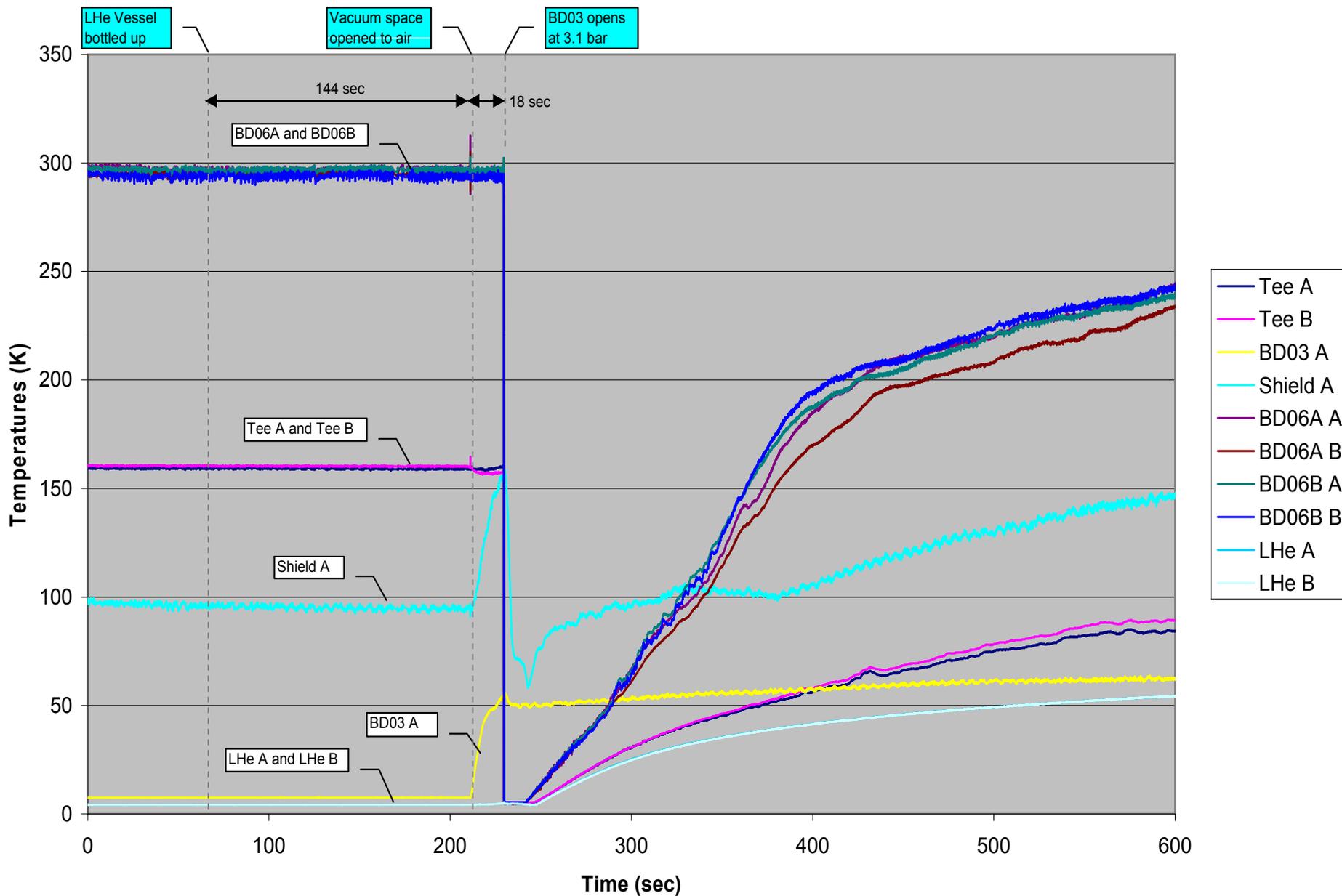
Raw Data



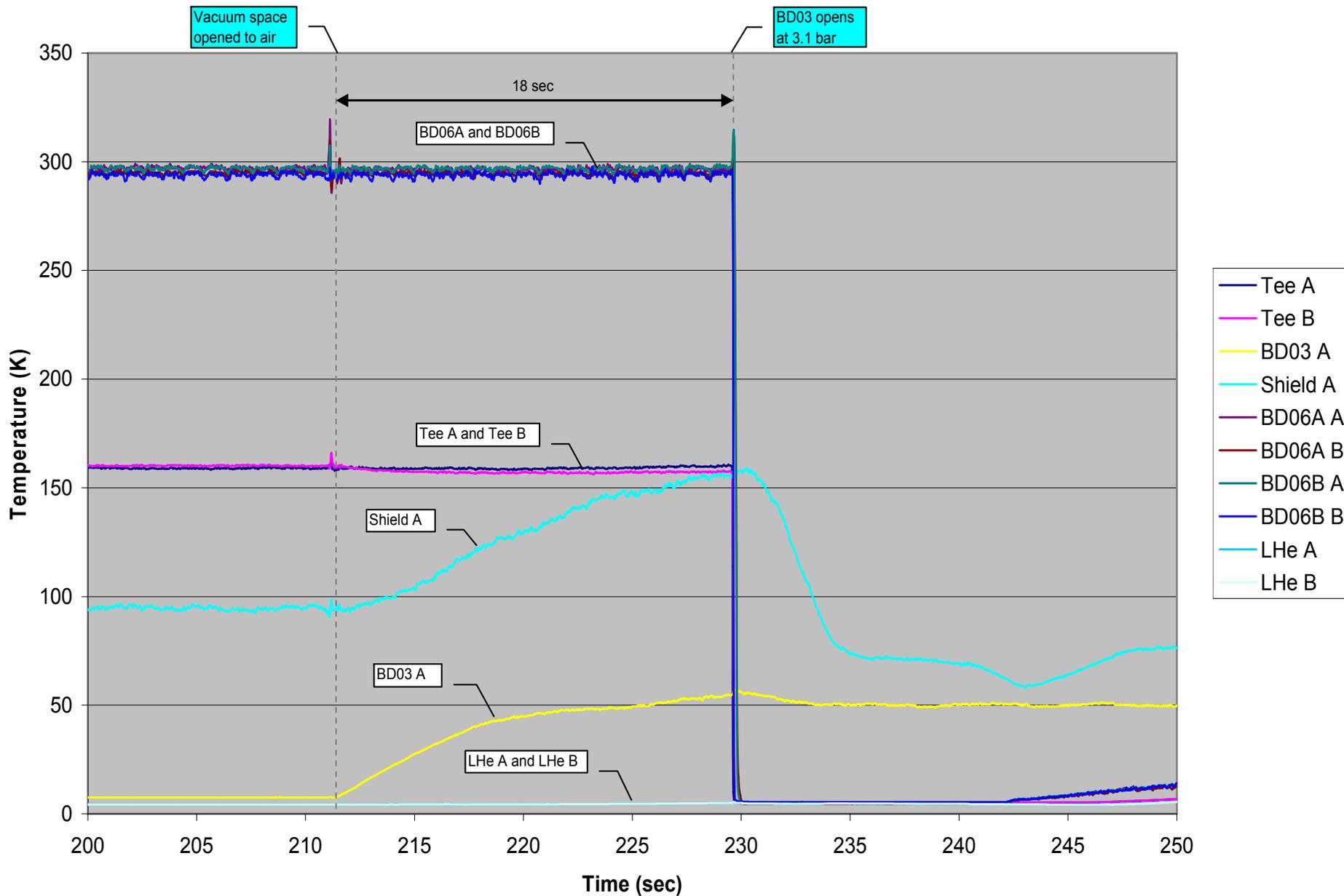
Burst Disc Test #7A Preliminary Data



Burst Disc Test 7A Raw Data



Burst Disc Test 7A Raw Data



Test #7A Results & Conclusions

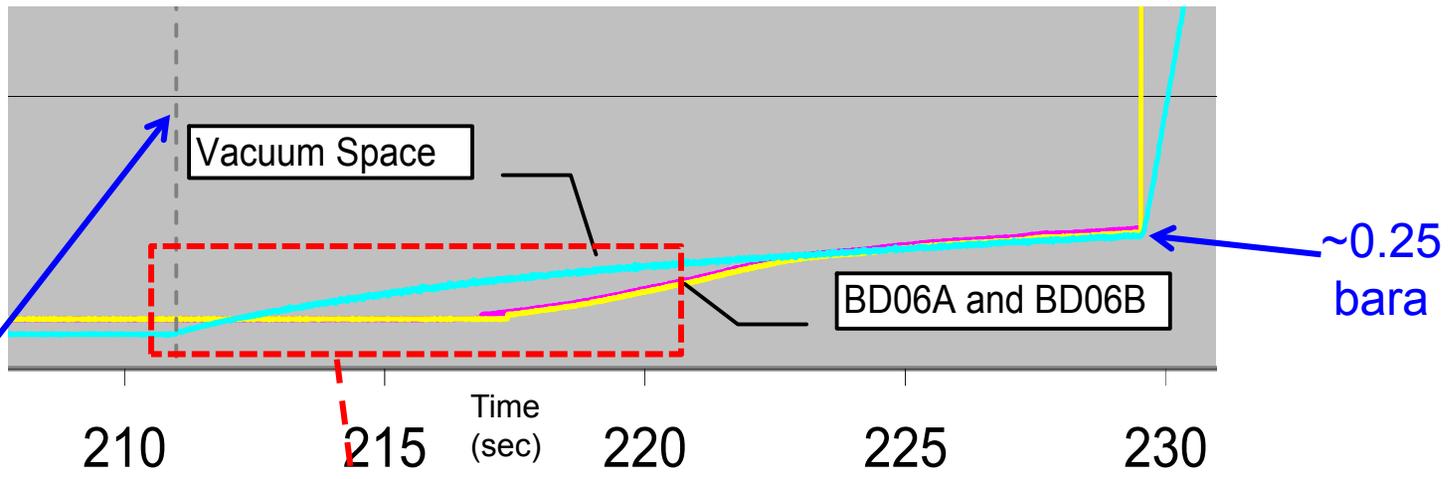
- The following factors were considered in sizing the orifice for loss of vacuum in test #7A. However, no reliable method of calculating the effects of all the differences could be agreed upon. In the end, we decided to error on the conservative side by using a 0.5" (12.7 mm) orifice. Considerations:
 - Surface area of the AMS Cryostat at CERN vs the test cryostat at TAMU
 - Surface area to volume ratios of both cryostats
 - 130 layers of MLI on AMS vs 20 layers on the test cryostat
 - 4 vapor cooled shields on AMS vs none on the test cryostat
 - 3 mm of cryocoat on the AMS Helium vessel vs none on the test cryostat
 - 4 cryocoolers on AMS vs none on the test cryostat
- The LHe vessel was bottled up and self-pressurization increased the pressure from one atmosphere to ~1.15 bara over the next ~144 seconds.
- Then a 1" ball valve was opened to the 0.5" orifice to allow humid ambient air into the vacuum space. The vacuum space pressure began to rise immediately and had reached a peak of ~0.25 bara when BD03 ruptured. This pressure would have risen much faster without the cryopumping onto the cold mass inside.
- The LHe vessel pressure rise began to accelerate ~1.4 seconds after breaking the vacuum.

Test #7A Results & Conclusions (continued)

- The BD06A/B pressures began to rise ~6.4 seconds after breaking the vacuum.
- After ~18.6 seconds, BD03 burst when the LHe vessel pressure reached 3.13 bara. The differential pressure between the LHe vessel and the vacuum space was 2.89 bard, which is less than the 3.0 bard maximum design requirement.
 - Note that original rating from Fike on this CGSE test Burst Disc was 2.7 to 3.0 barg at 300 K. Fike predicted it would burst between 2.96 to 3.24 bard under these conditions.
 - In test #5, the CGSE test Burst Disc reversed just under 3 bard but did not rupture. The excessive moisture present in test #7A further indicates that ice buildup in test #5 was not a factor in the failure of the burst disc to open after reversing.
- The pressure rise rate in the LHe vessel during the last 0.1 second prior to BD03 rupture was 0.227 bar/sec = 3.293 psi/second.
 - This compares to 4.993 psi/sec in the LHe vessel in test #6 and 6.179 psi/sec in the Buffer vessel. This supports the theory that the hardware was over-tested in test #6.
 - Thus, test #7A was still conservative when compared to the flight hardware, but as predicted, less conservative than test #6.

Test #7A Results & Conclusions (continued)

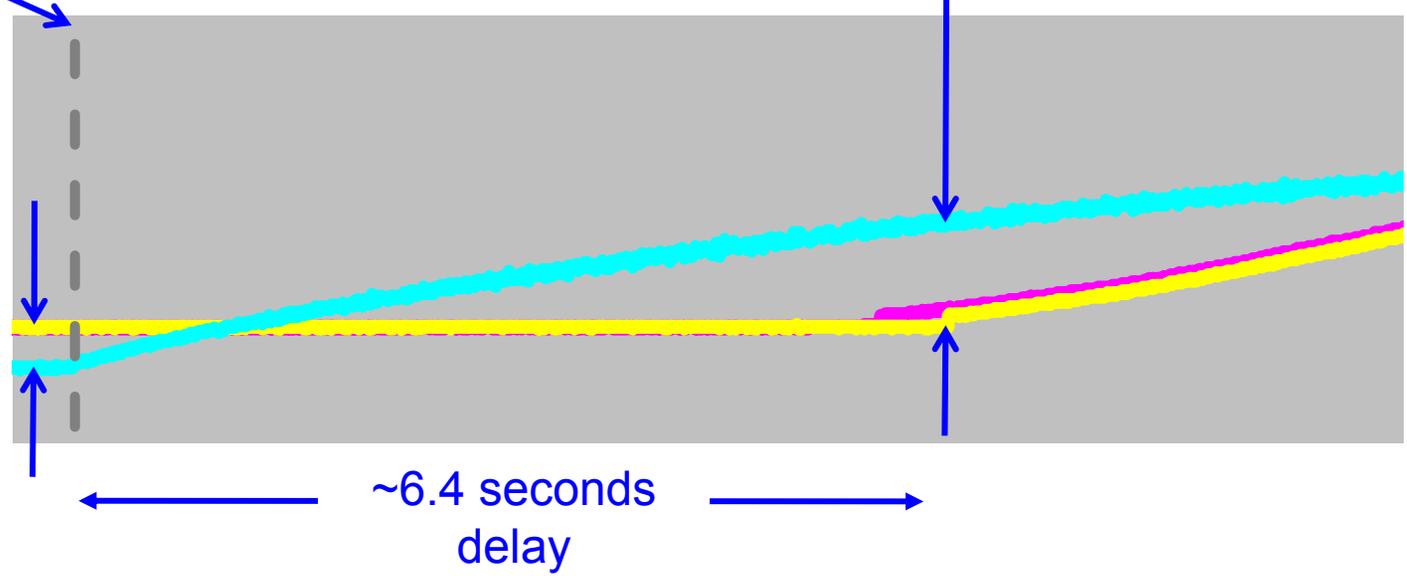
- The pressures on the BD06A & B transducers spiked at 2.39 & 2.43 bara respectively (~1.40 barg). This is due to the instantaneous pressurization of the ductwork between BD03 and BD06A & B. Within ~0.12 seconds BD06A & B ruptured almost simultaneously (~0.04 seconds apart). This was also observed in the video recording of the event.
- After the burst, the vacuum space reached a peak pressure of 1.46 bara or 0.45 barg. This compares favorably with the BD07 rating of 0.56 to 0.80 bard. Note that there was no other way of venting the vacuum space at this pressure like the lift-off plate in test #6.
- Just prior to test #7A, Bill Hungerford & Corrado Gargiulo noted that there might be a problem with negative pressurization of the PTFE liner inside the ortho-fabric flexible tubes. This is because the loss of vacuum would pressurize the volume around the tubes faster than the volume inside. This would cause the relatively weak PTFE liner to collapse inside the ortho-fabric and to bear excessively against the SS tube adapters at each end. Then it would be snapped open/instantly inflated when BD03 ruptured. They recommended doing nothing for test #7A since it was already under vacuum and being cooled.
 - The results of test #7A indicate the PTFE was negatively pressurized to 0.103 bar (~1.49 PSIG) as shown in the next slide.



Loss of vacuum initiated

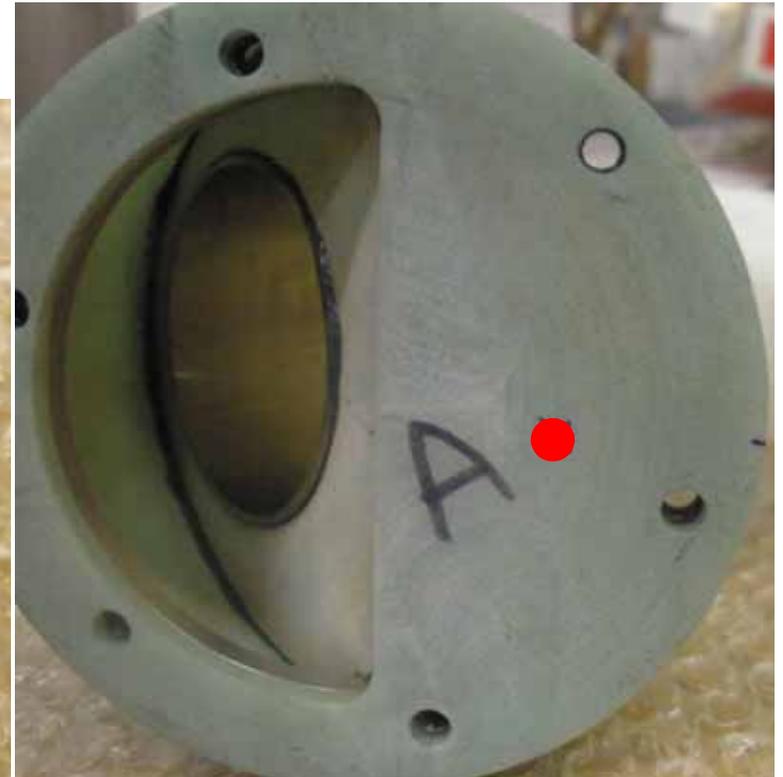
Maximum *negative* differential pressure on flexible tubes/PTFE liners: ~0.103 bar (~1.49 PSIG)

Initial offset: ~+0.028 bar (~+0.41 PSIG)



Test #7A Results & Conclusions (continued)

- As a result of the negative pressure on the PTFE liner demonstrated in test #7A, the Angled Adapters used in Test #7B will have 1/8" (3.175 mm) holes drilled in them as shown below to improve the venting.
- Another advantage of this is to improve the evacuation during the final pumpdown of the flight Vacuum Case after welding.
- These holes will be drilled when the flight BD06A & BD06B assemblies are installed after the VC is pressure tested.



Test #7A Results & Conclusions (concluded)

- Test #7B will be conducted using the flight-like discs in a similar manner as Test #7A. However, this test will also have the separated membrane from the failed flight-like disc at SCL installed on top of the BD radiation shields.
 - The purpose of this is to demonstrate a safe depressurization of the system even if the BD03 membrane separates.
- Test #7B will use the same orifice for the loss of insulating vacuum as test #7A. Two calibration runs with the cryostat warm will be done to establish a baseline for how long it takes for the vacuum space to repressurize with no cryopumping and no bursting discs.
- Test #7B will be more aggressive since the flow area of the BD03 disc is $47^2/34^2 = 1.91$ times larger. Fortunately, the flow area of the BD06s are $95.8^2/34^2 = 7.94$ times larger. Thus, the LHe vessel will empty quicker in the next test.
- However, the choke point in test #7B will likely be at the semi-circular exits of the angled adapters as it was in test #6. These are $2(52^2)/47^2 = 2.45$ times larger than the BD03 flow area but $52^2/95.8^2 = 0.29$ times smaller than the flow area of the BD06 flight-like disc assemblies.

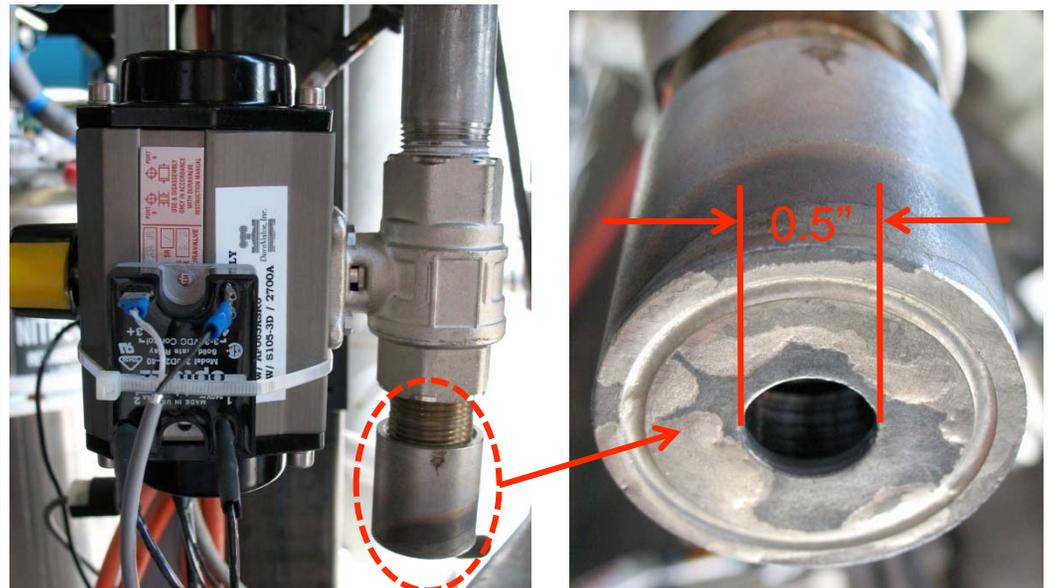
Enclosure 9

AMS Magnet Burst Discs & Ductwork Test #7B at Texas A&M

October 6, 2009
K. Bollweg

No modifications were made to the test set-up between test #7A & #7B. We considered using a larger test volume (shown at left), but then decided against it.

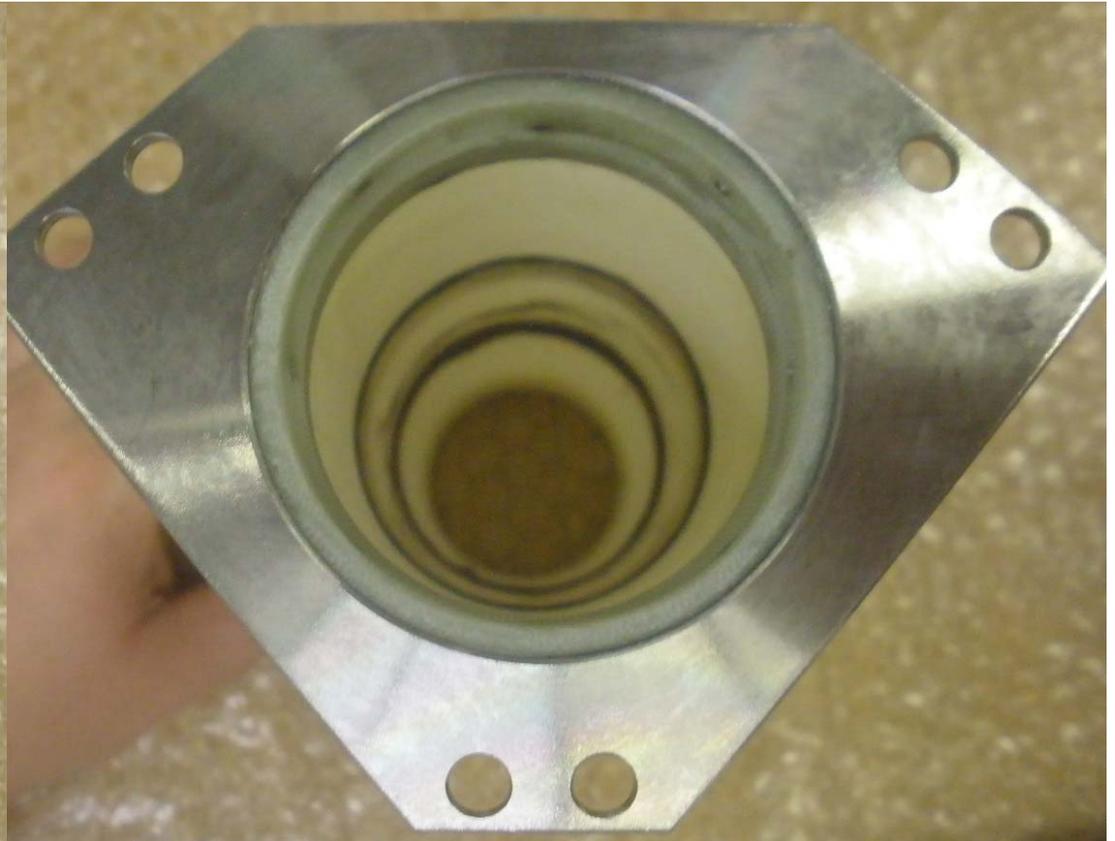
Two calibration runs were recorded to characterize the flow of air into the cryostat through the 0.5" (12.7 mm) orifice while at room temperature. The purpose was to determine the heat load onto the helium vessel in the cryostat due to cryo-pumping of the air onto the cold surfaces by comparing pressurization curves with and without LHe in the cryostat. More on that later...(slides 40 & 41).





The edge weld on the BD03 flight-like disc was leak tested at room temperature and with LN2.

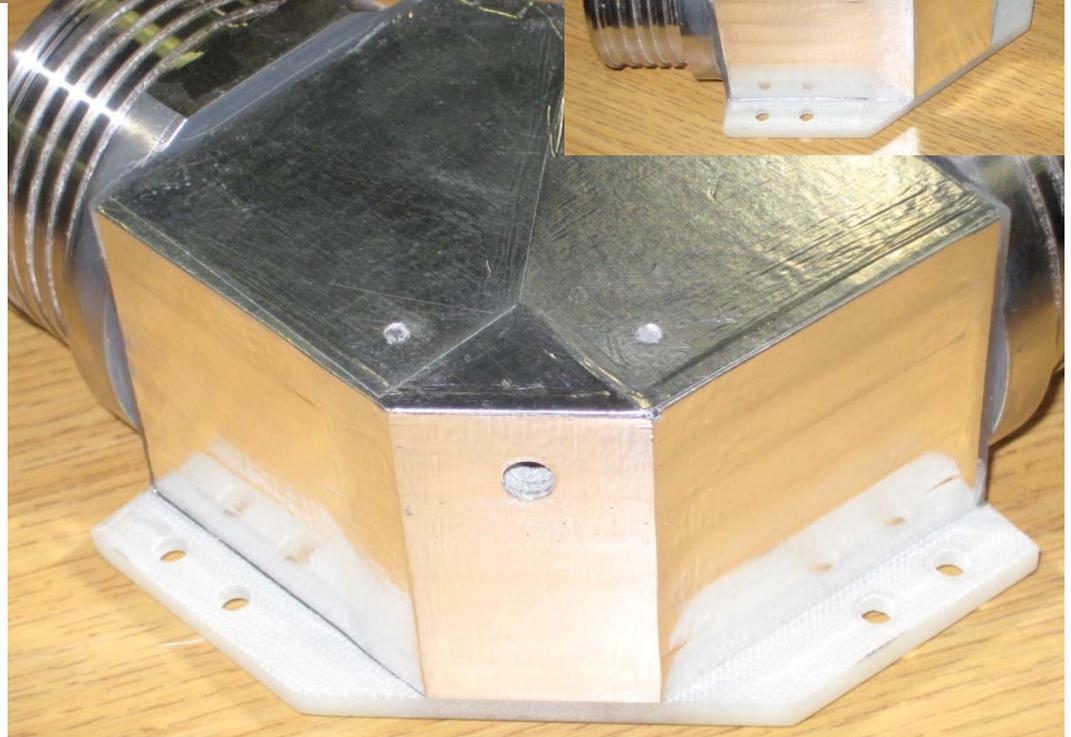
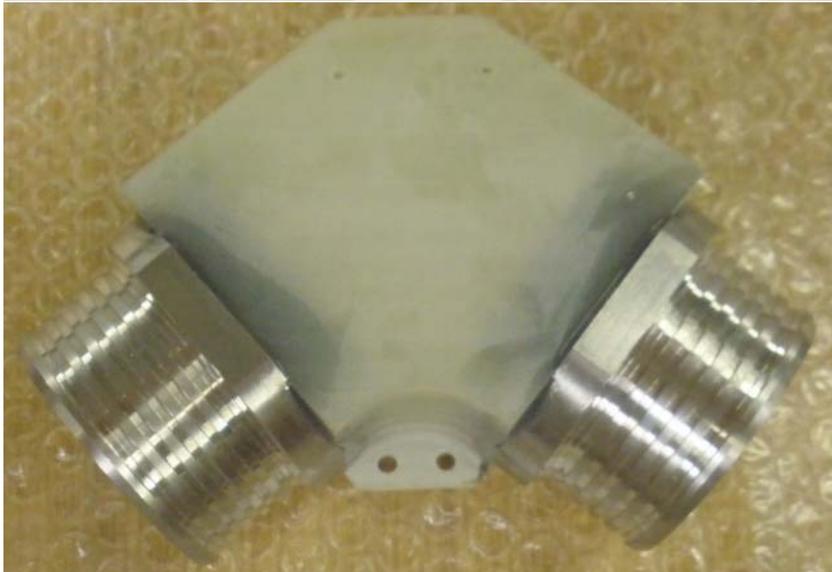
The test article was assembled as reported in previous tests. The same ortho-fabric flexible tubes from Test #7A were re-used. However, new PTFE liners were installed. A new Telescoping Tube was assembled and epoxied to a new SS Tee Box Cover.



A new Tee box with SS Adapters was assembled and covered with aluminum tape. A hole for the thermal sensors was drilled & tapped near the base.

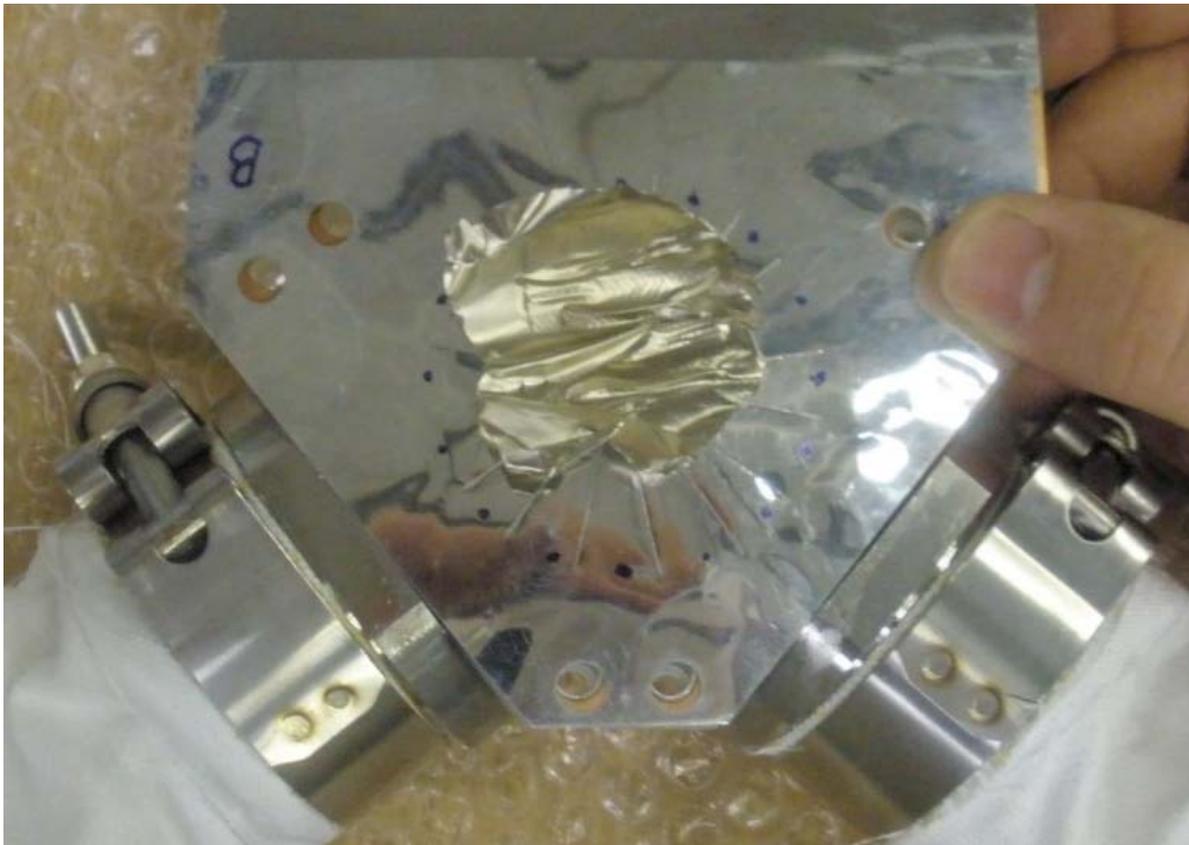


27.09.09
Tst 78





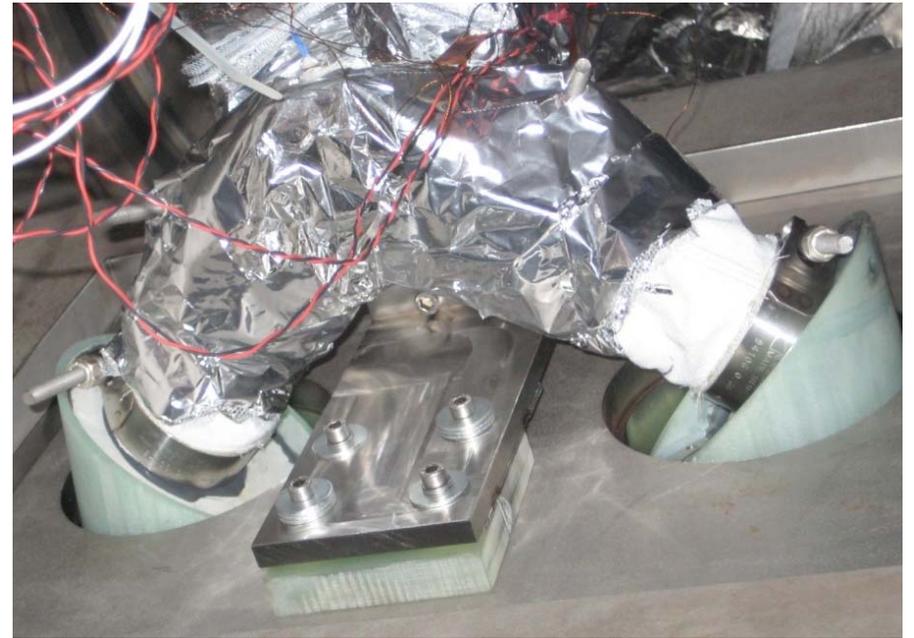
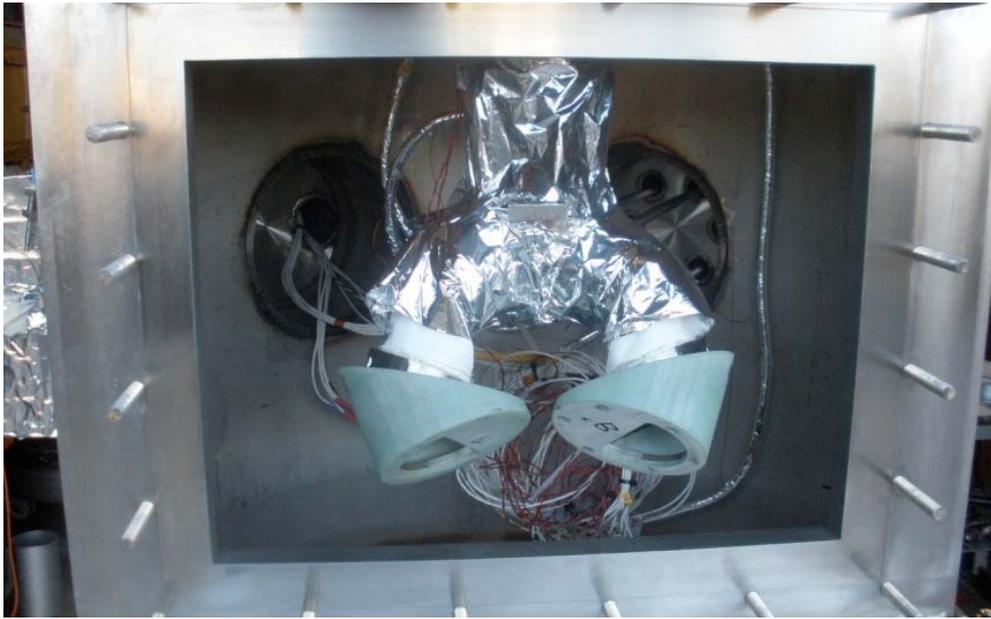
The most significant difference is that the detached membrane from the BD03 flight-like disc used at SCL/Culham was placed on top of the BD radiation shield





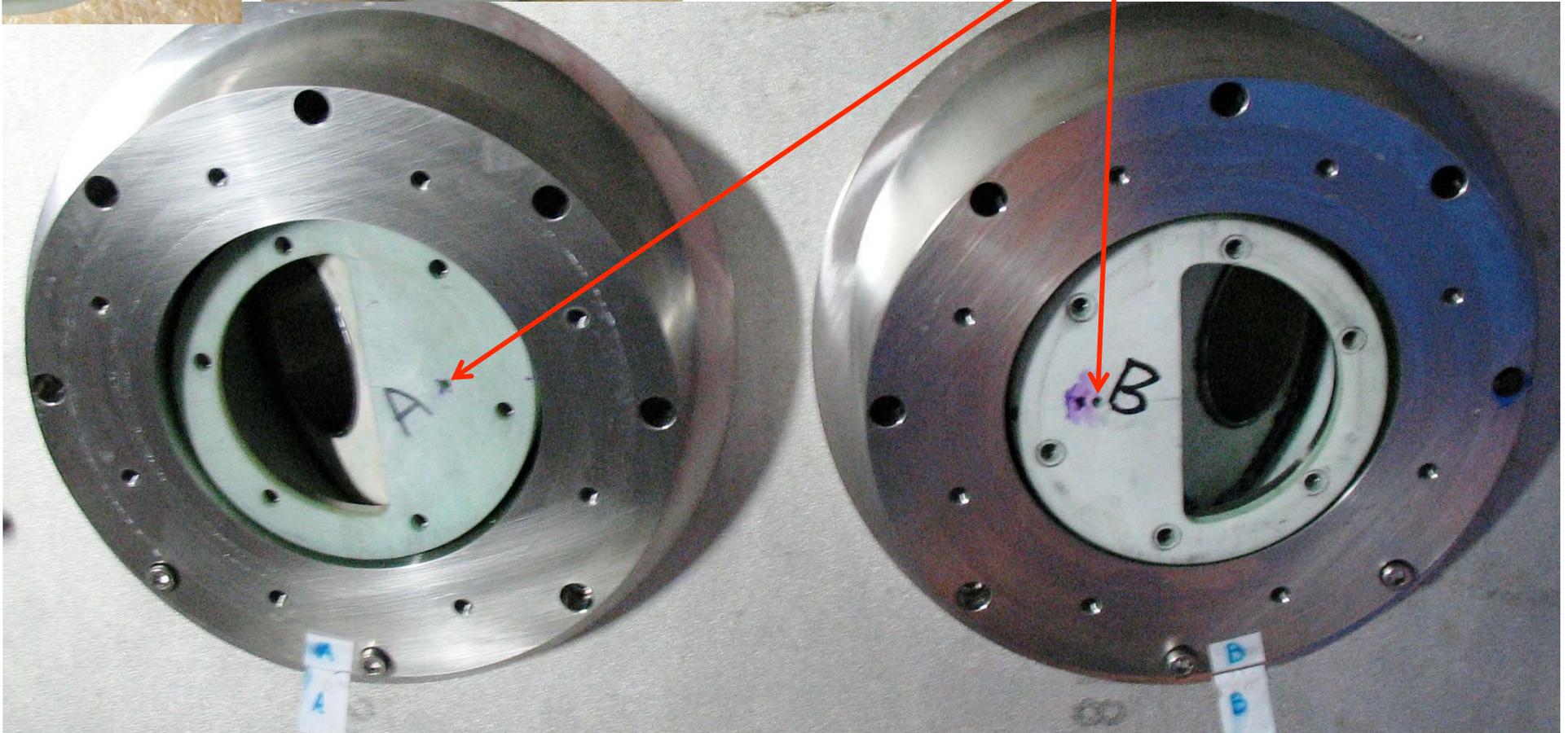
The rest of the assembly was as before.

Note: The detached BD03 membrane is resting against the Test #7B BD03 membrane in these two photos.

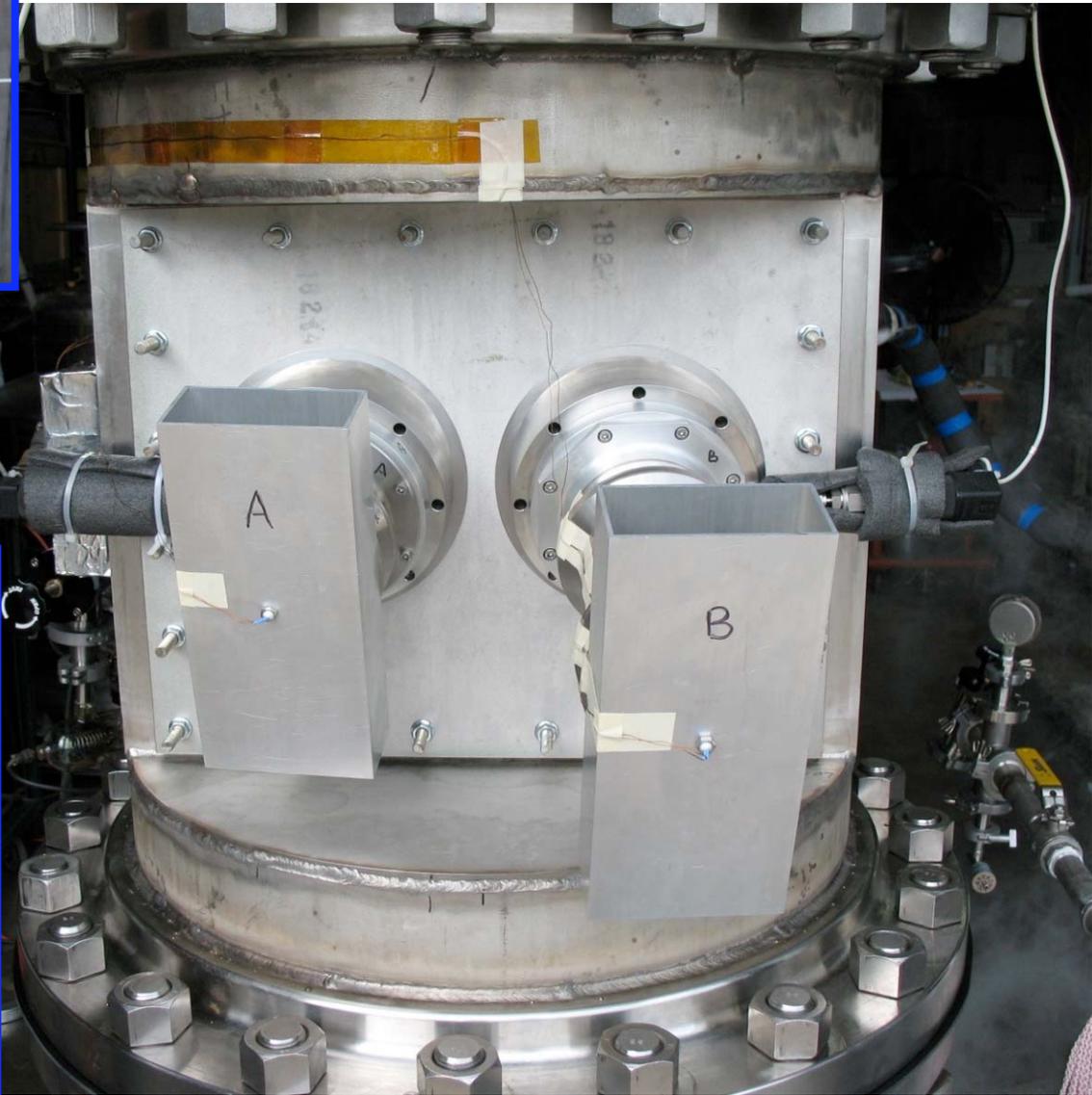
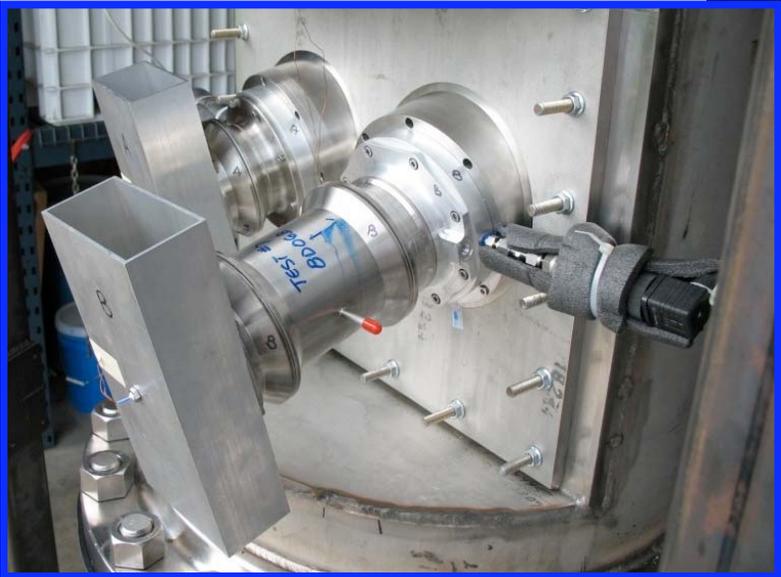
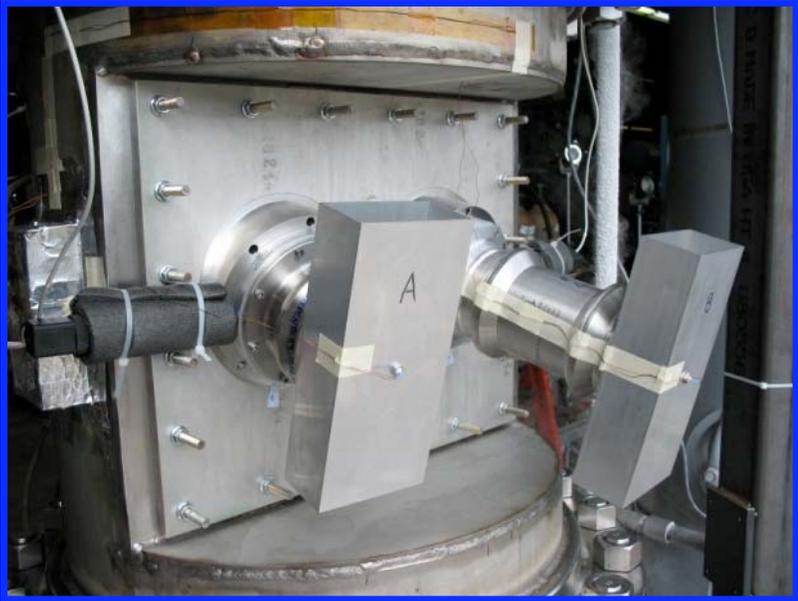


This is the first test to use a new flight-like BD06 in the "A" position. The "B" position has the remaining BD07A/B assembly with the "B" disc removed.

1/8" diameter (3.175 mm) holes were drilled in the Angled Adapters to reduce the negative differential pressure on the PTFE Liners and to improve conductance during pumpdown.



Fully assembled and ready to test.



The cool-down from
~300 to 4.2 K and fill
of the LHe vessel went
smoothly. Best of all,
it was completed in
time to run the test
during the day!

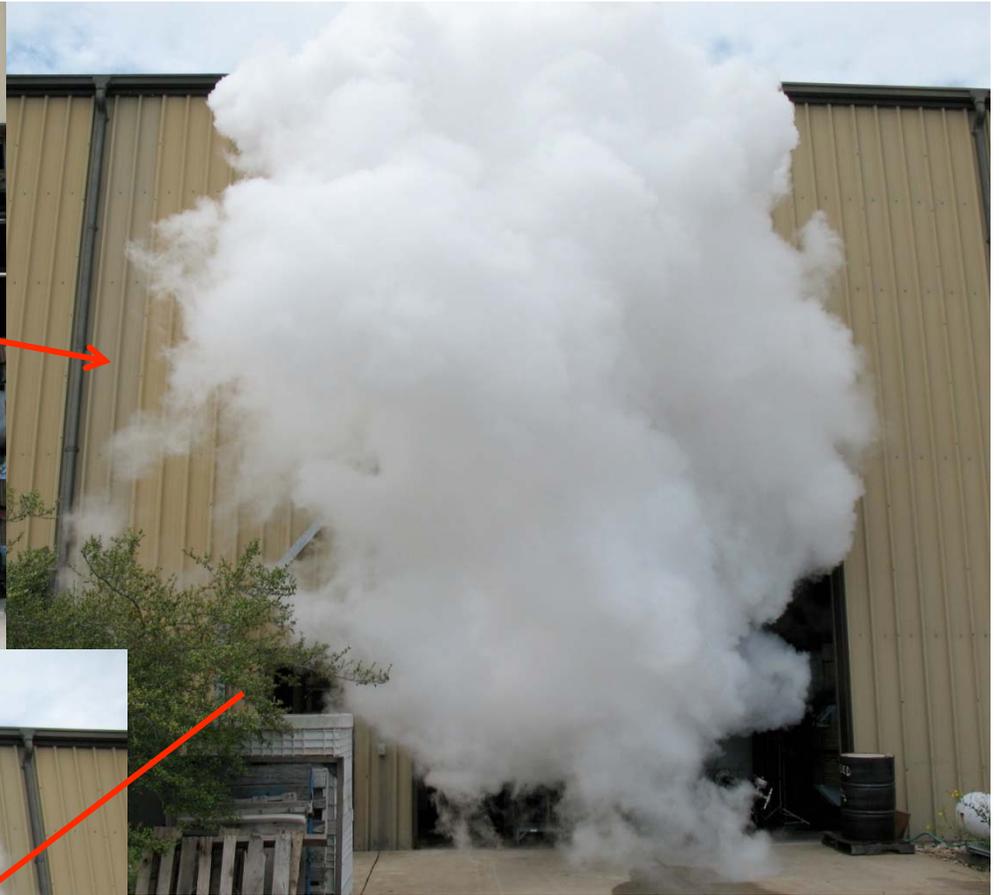
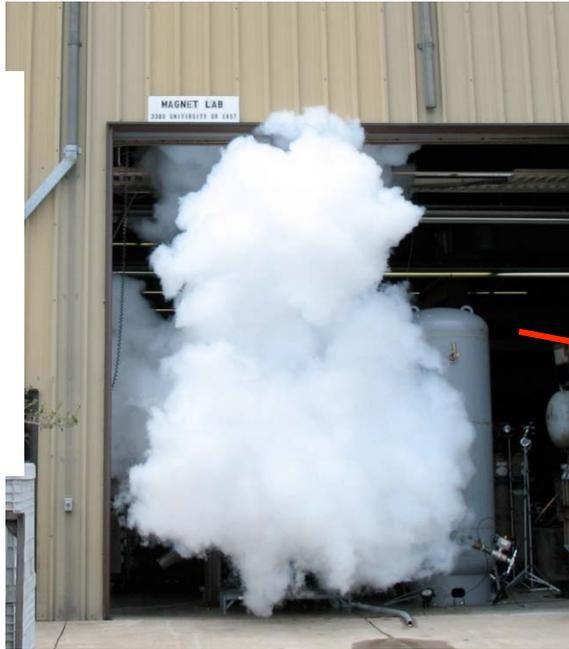


Running through the checklist
and beginning the countdown

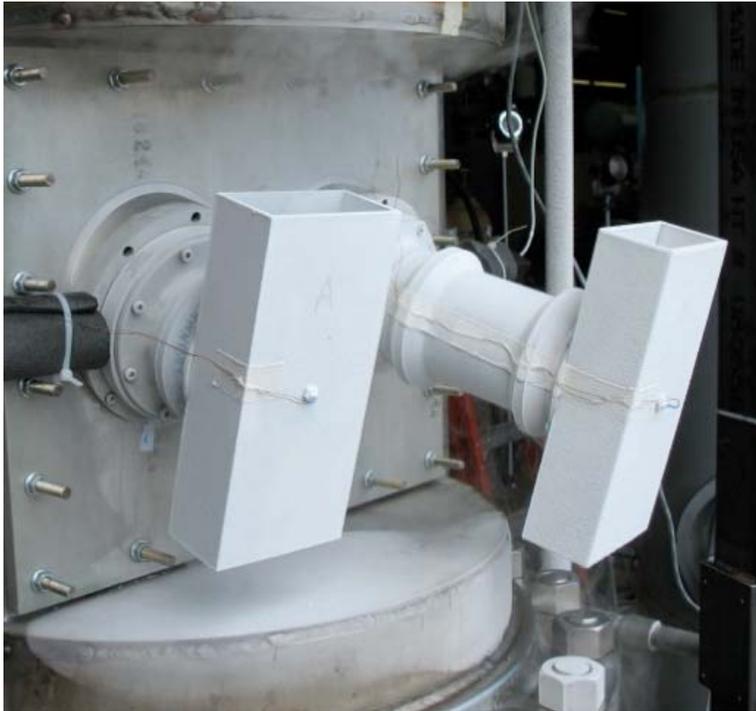
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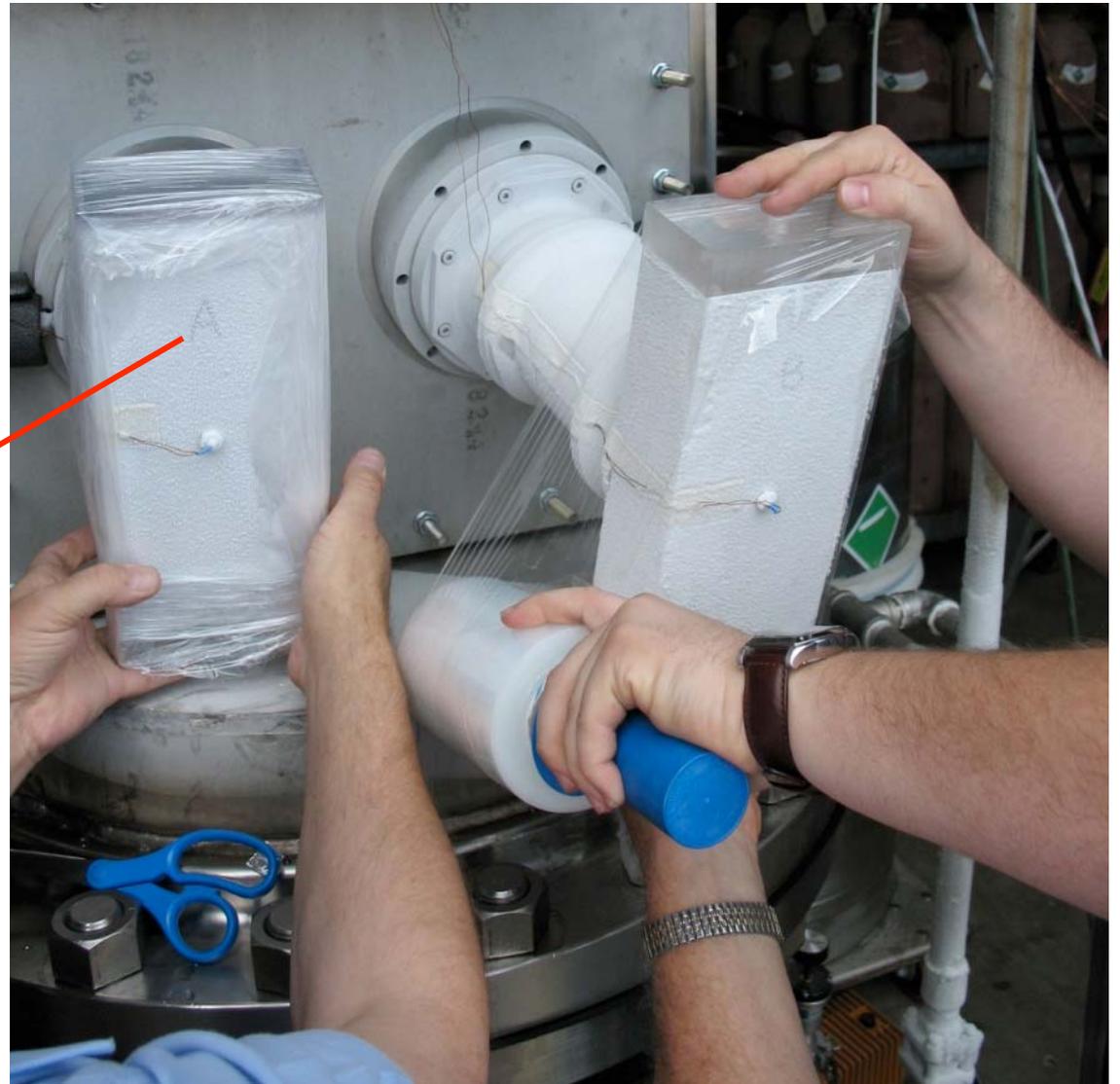
BD03 rupture occurred ~17 seconds after the loss of vacuum was initiated.

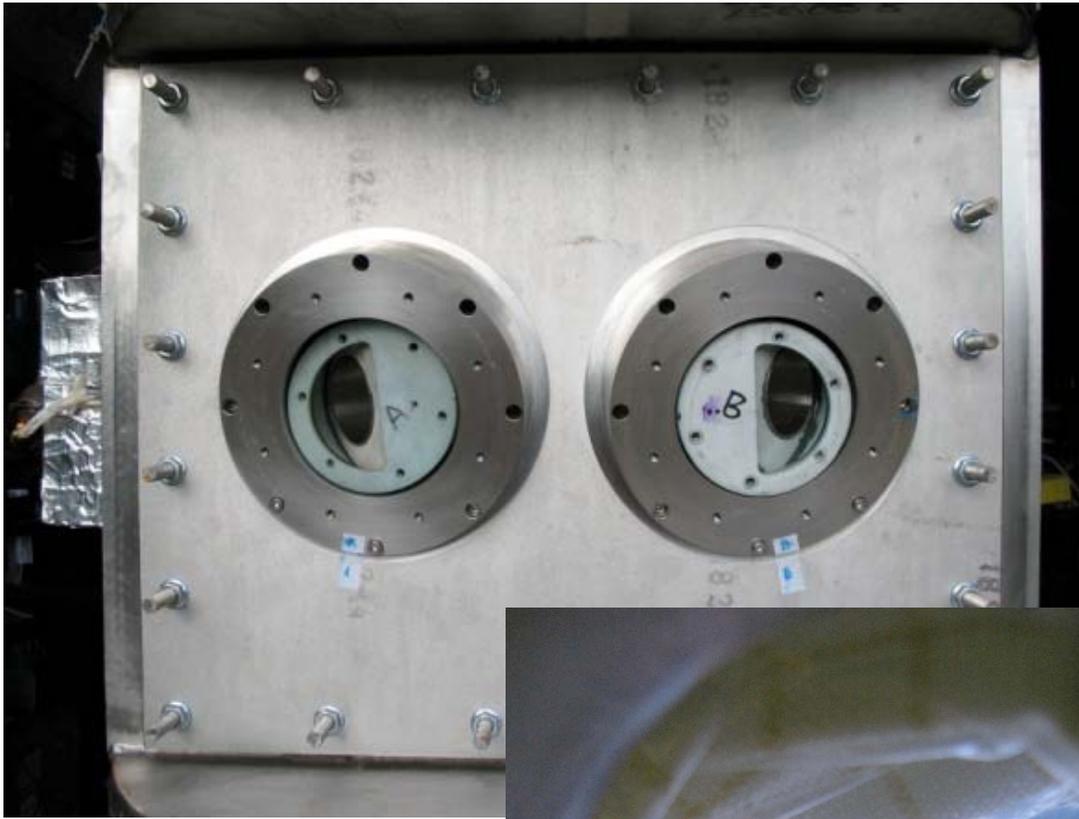


As before, the external hardware was quite frosty after the test. The exhausts were wrapped in plastic to minimize the moisture drawn in during the warmup.

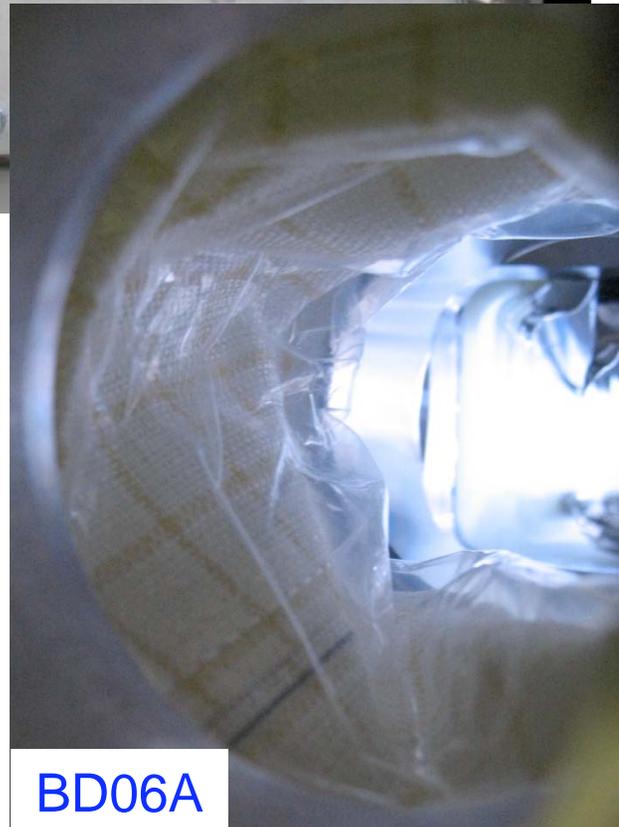


The frost became so thick, the letter "A" was almost completely obscured.





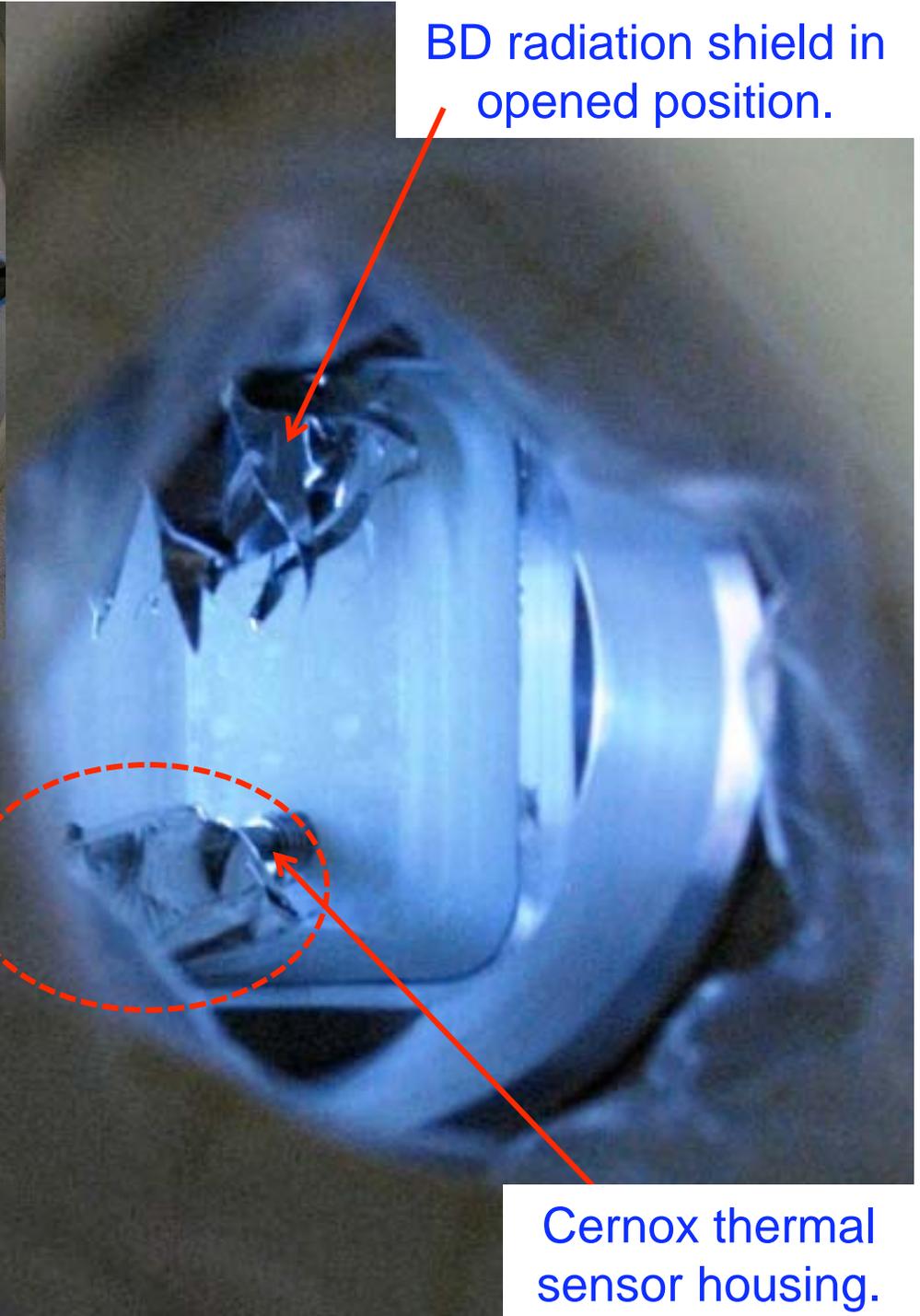
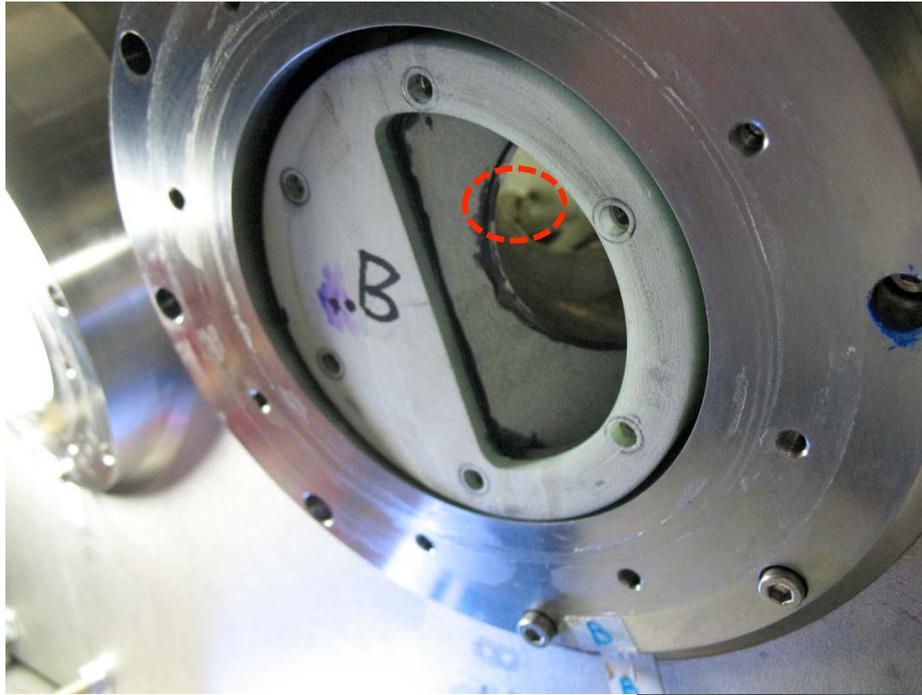
Initial inspection of the flexible tubes during disassembly indicated the PTFE was intact.



BD06A



BD06B



BD radiation shield in opened position.

Further inspection revealed the location of the BD03 disc membrane from the test at Culham that was placed on top of the BD radiation shield before this test. It had become lodged on the housing of the Cernox thermal sensor. The flight system does not have the sensor so the membrane would likely have exited the ductwork.

Cernox thermal sensor housing.

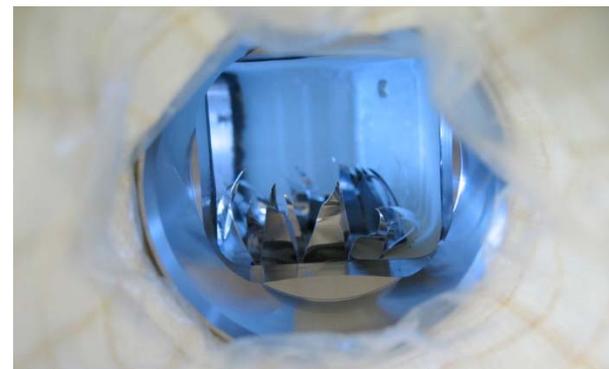
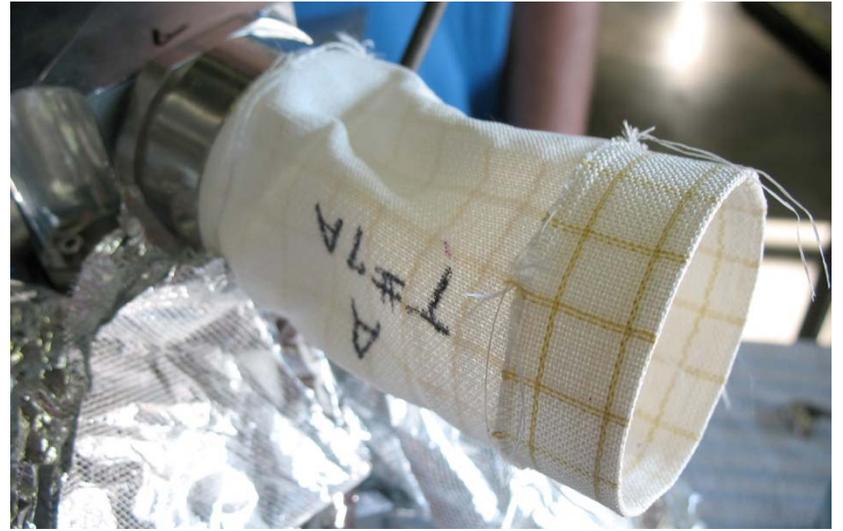


The MLI had minimal damage.
Part of one layer was torn from
the bottom of the Tee Box



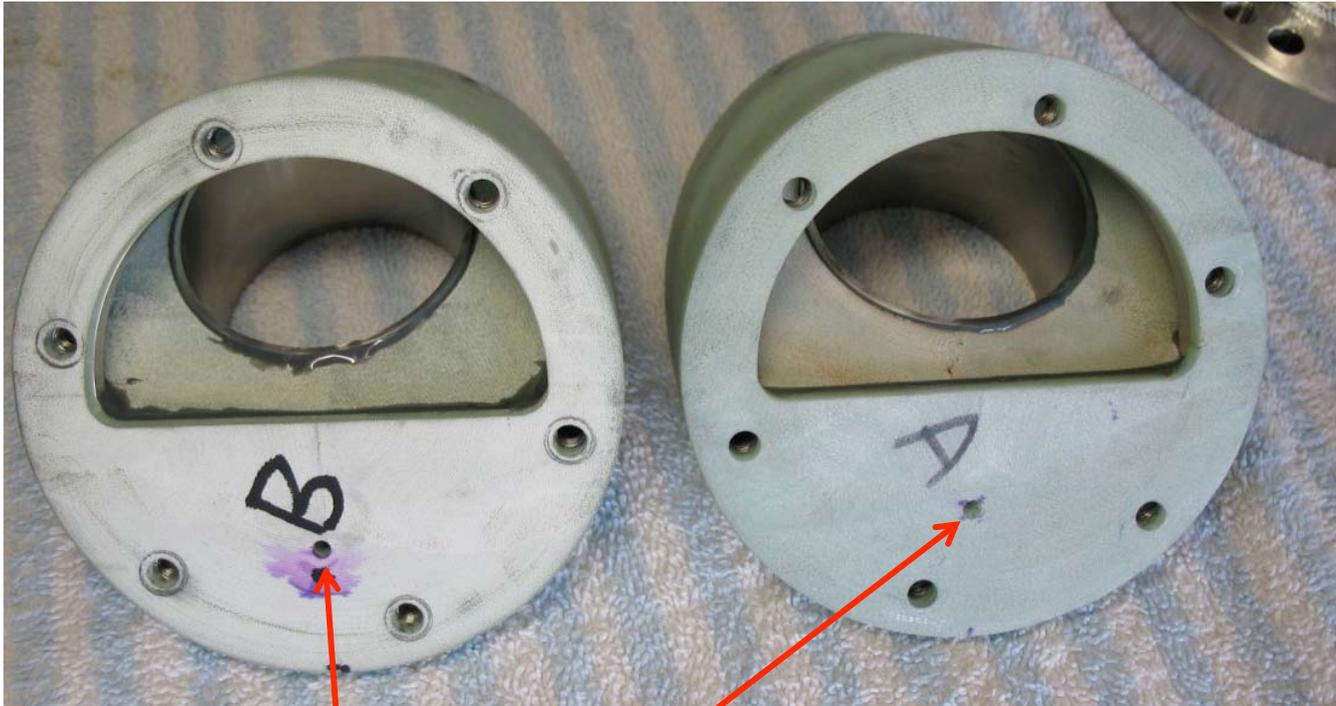


The MLI on the LHe vessel was still intact after several tests.



Continued
disassembly
revealed nothing
significant.



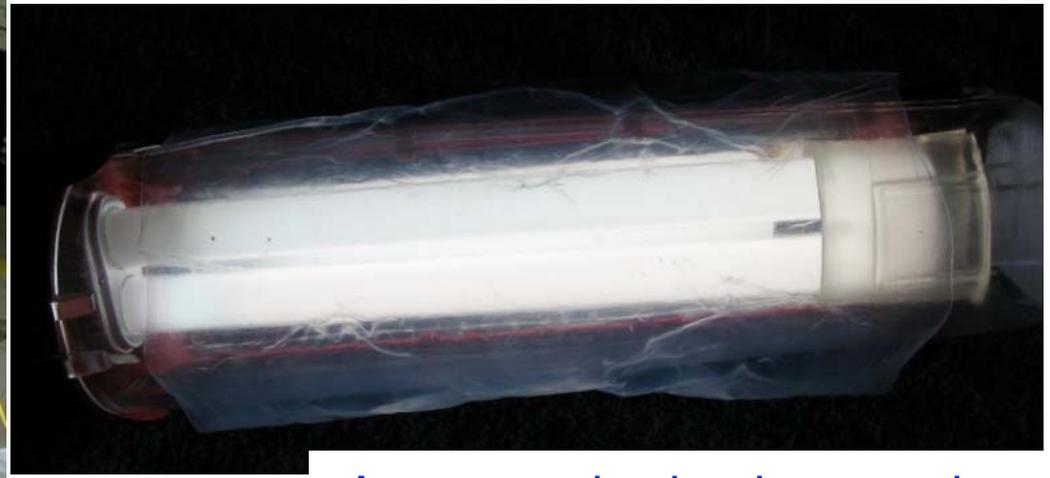


The Angled Adapter assemblies were fine.

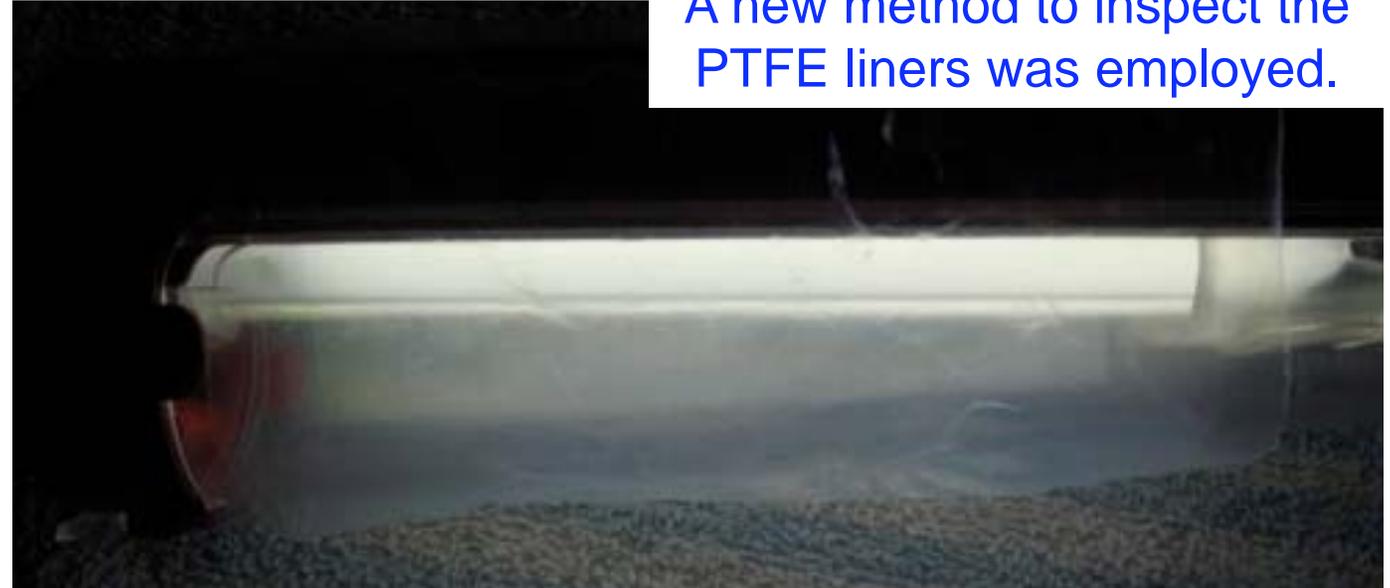
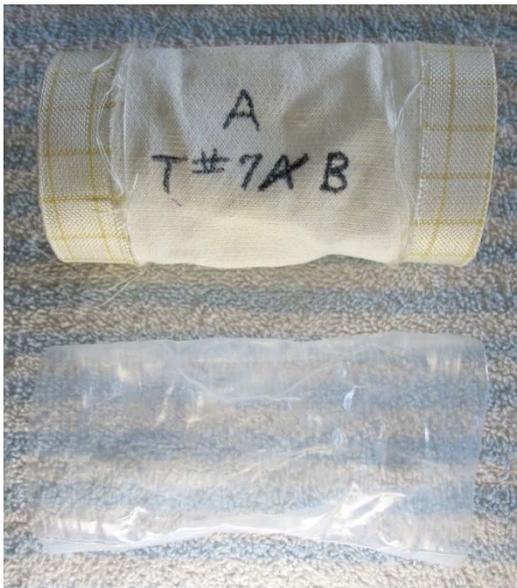
1/8" diameter vent holes.

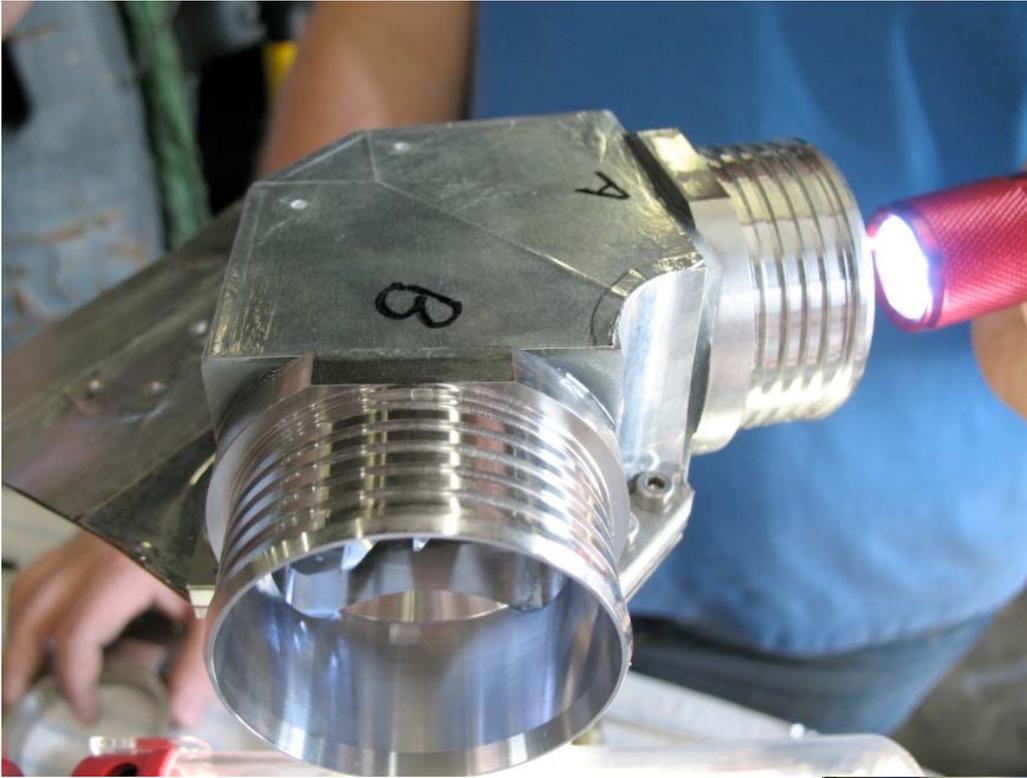


This T-shirt is from the '80s!

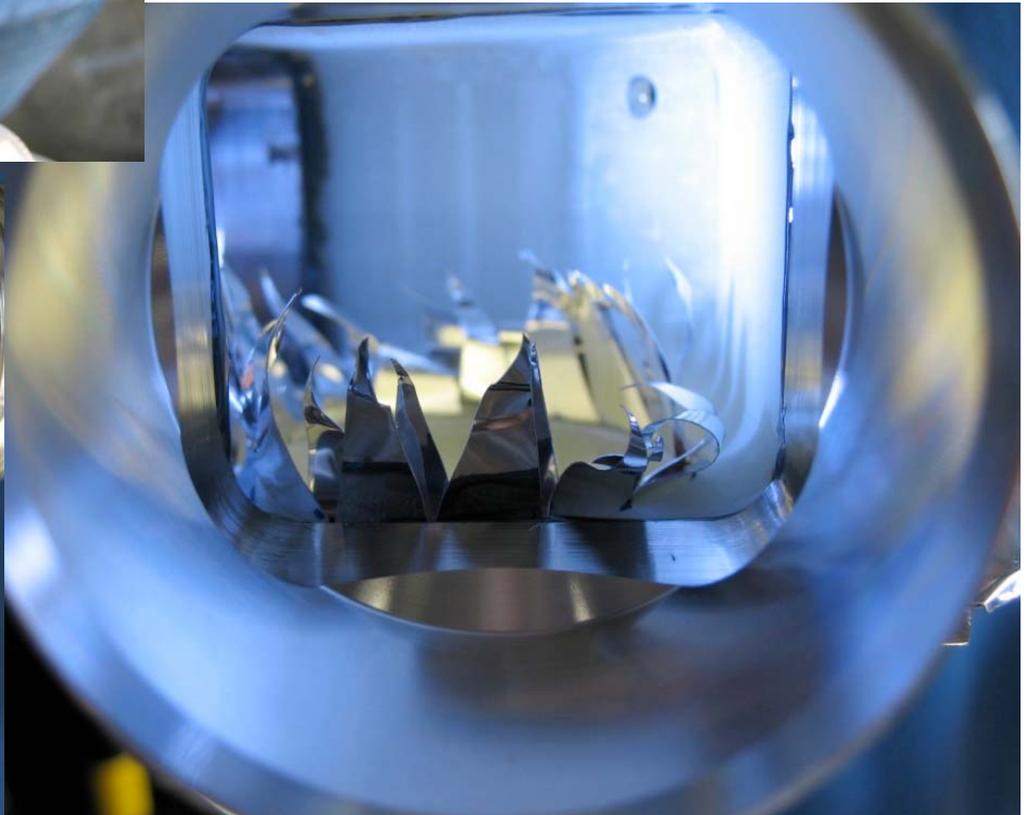


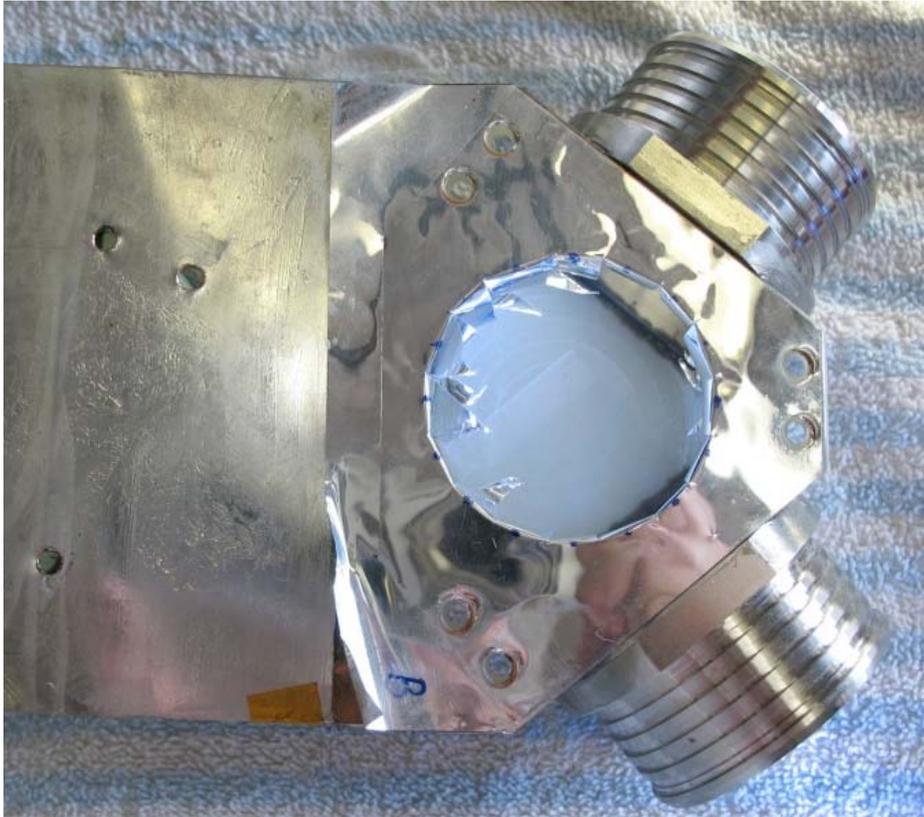
A new method to inspect the PTFE liners was employed.





The BD radiation shield opening pattern was similar to previous tests. The tips of the triangles were also intact.





It appeared that this test generated no detached debris, despite the attempt to “sabotage” it with the separated BD03 membrane.



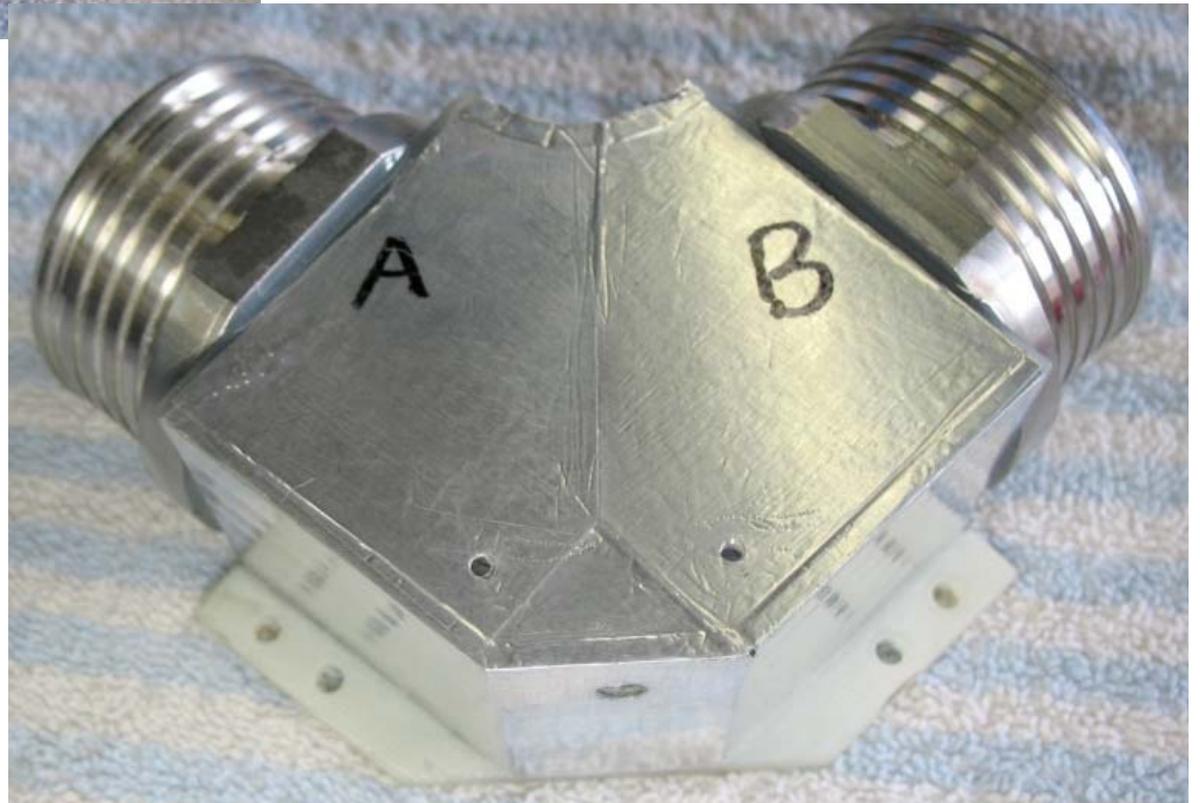


The usual opening pattern...

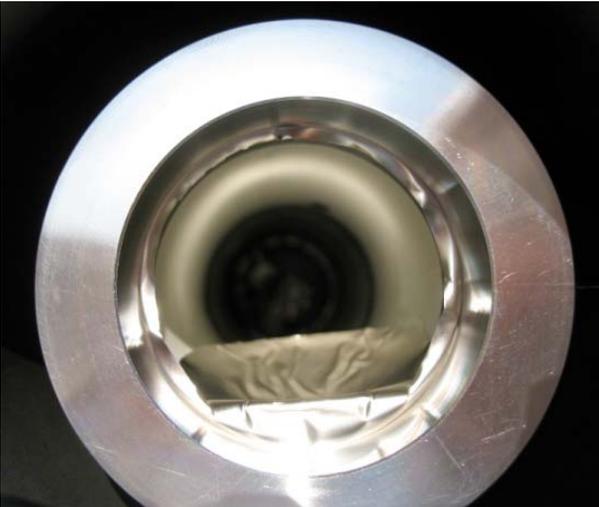
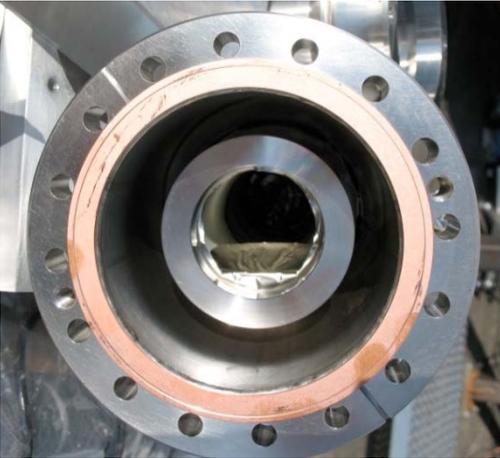




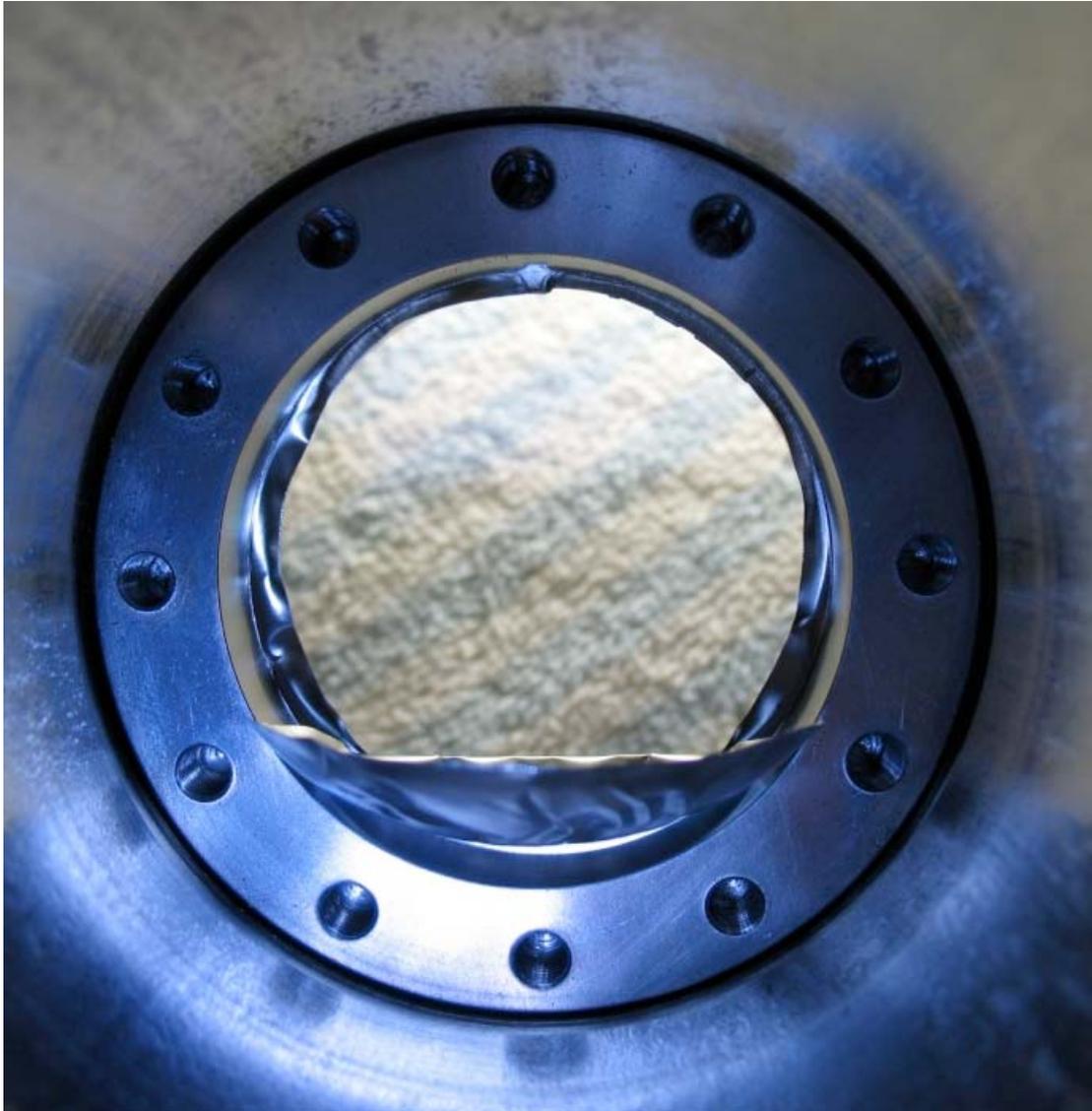
Nothing unusual with the Tee Box. It will be reused in Test #8.



Inspection of the inlet side of the BD03 flight-like assembly revealed nothing unusual. The membrane folded back nicely and remained attached.

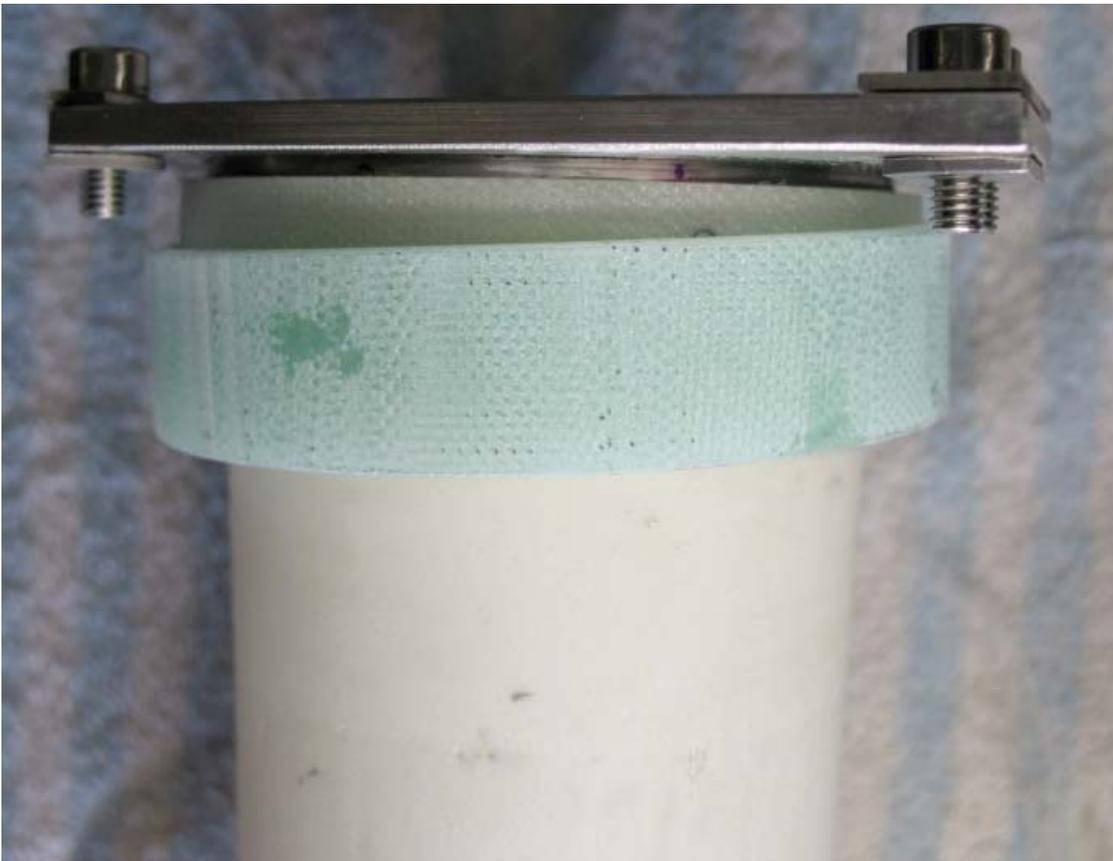


Inspection of the exhaust side of the BD03 flight-like assembly revealed nothing unusual either.





The only thing of note was that the external collar on the Telescoping Tube was found to be at an angle. This may have occurred during removal from the test set-up. It was realigned and the entire assembly will be reused in Test #8.



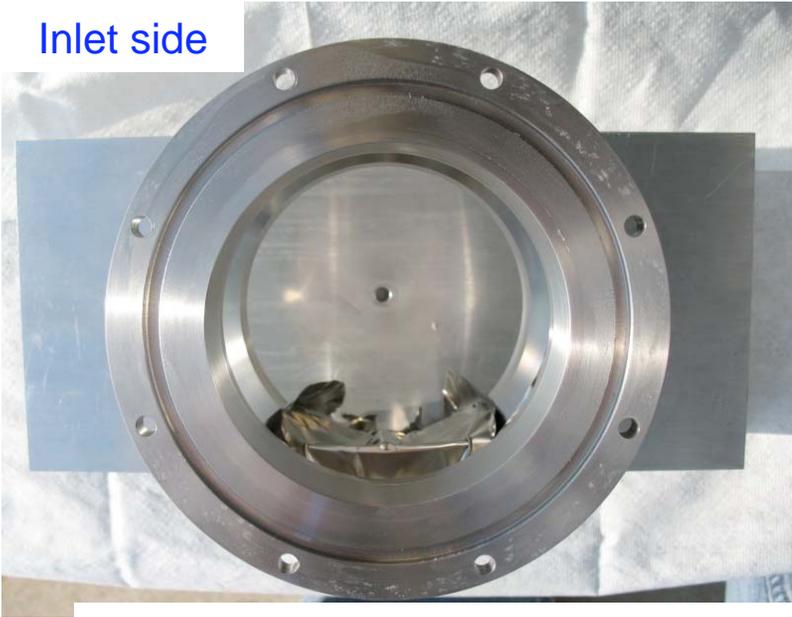


This is the detached BD03 membrane from the test at Culham installed on top of the BD radiation shield prior to the test.

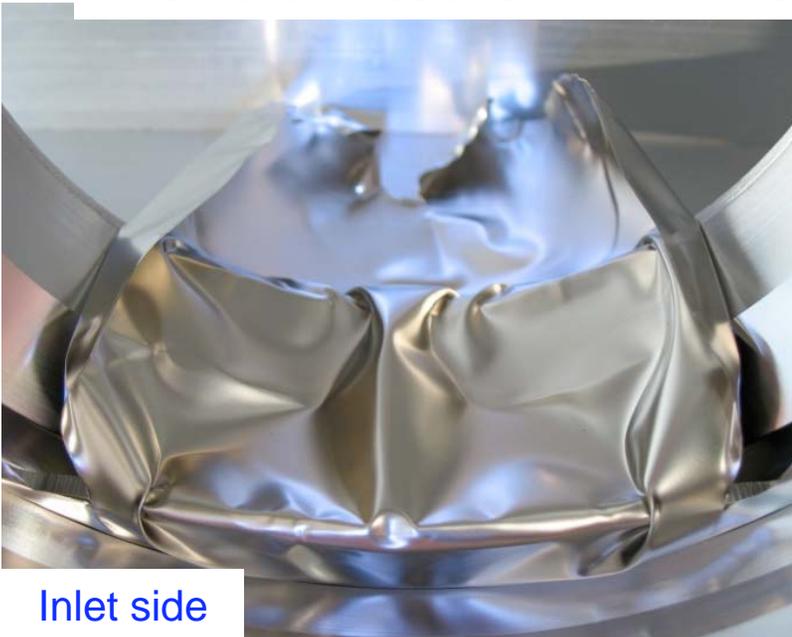
This imprint is from the Cernox temp sensor housing.



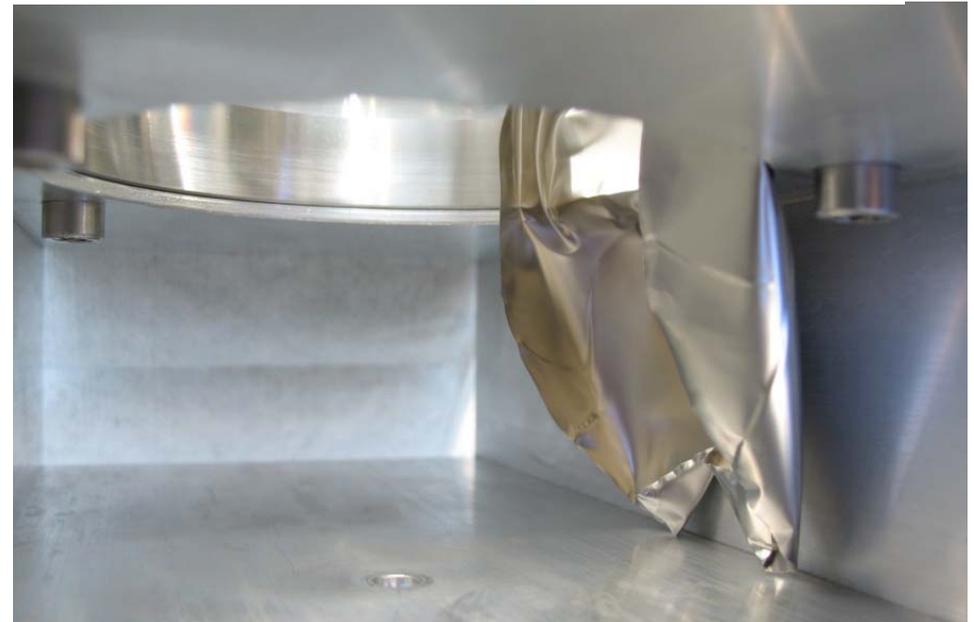
Inlet side



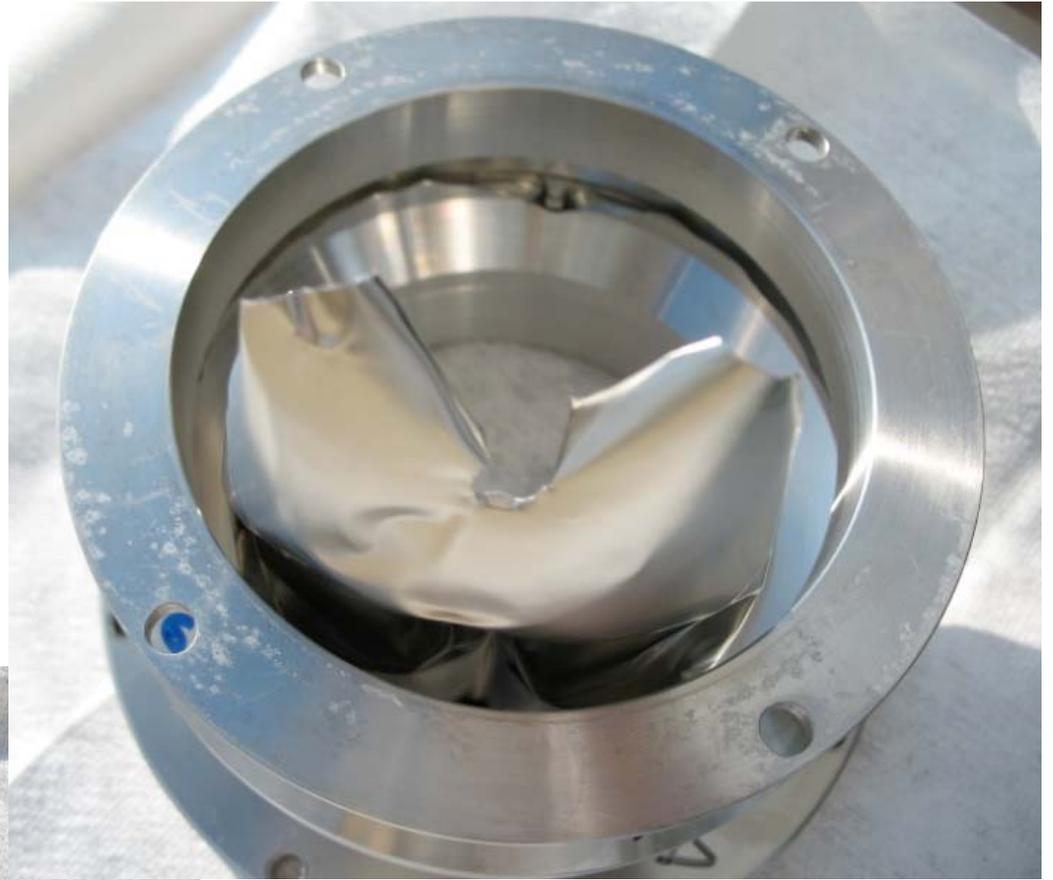
The new BD06A flight-like assembly performed as expected. The membrane folded back at the hinge line but remained attached. The membrane caused minimal obstruction to the shortened Zero-thrust Tee.



Inlet side



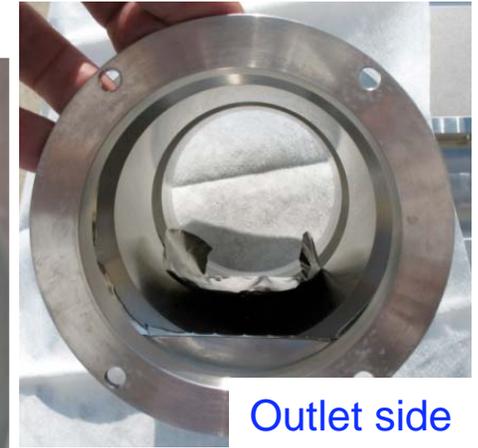
Views of the BD06A
assembly outlet side
with the Zero-Thrust
Tee removed.



Inlet side



Outlet side



Outlet side

"B" disc removed prior to test.

The BD06B assembly was a previous BD07A/B assembly with the "B" disc removed.

Outlet side



Inlet side

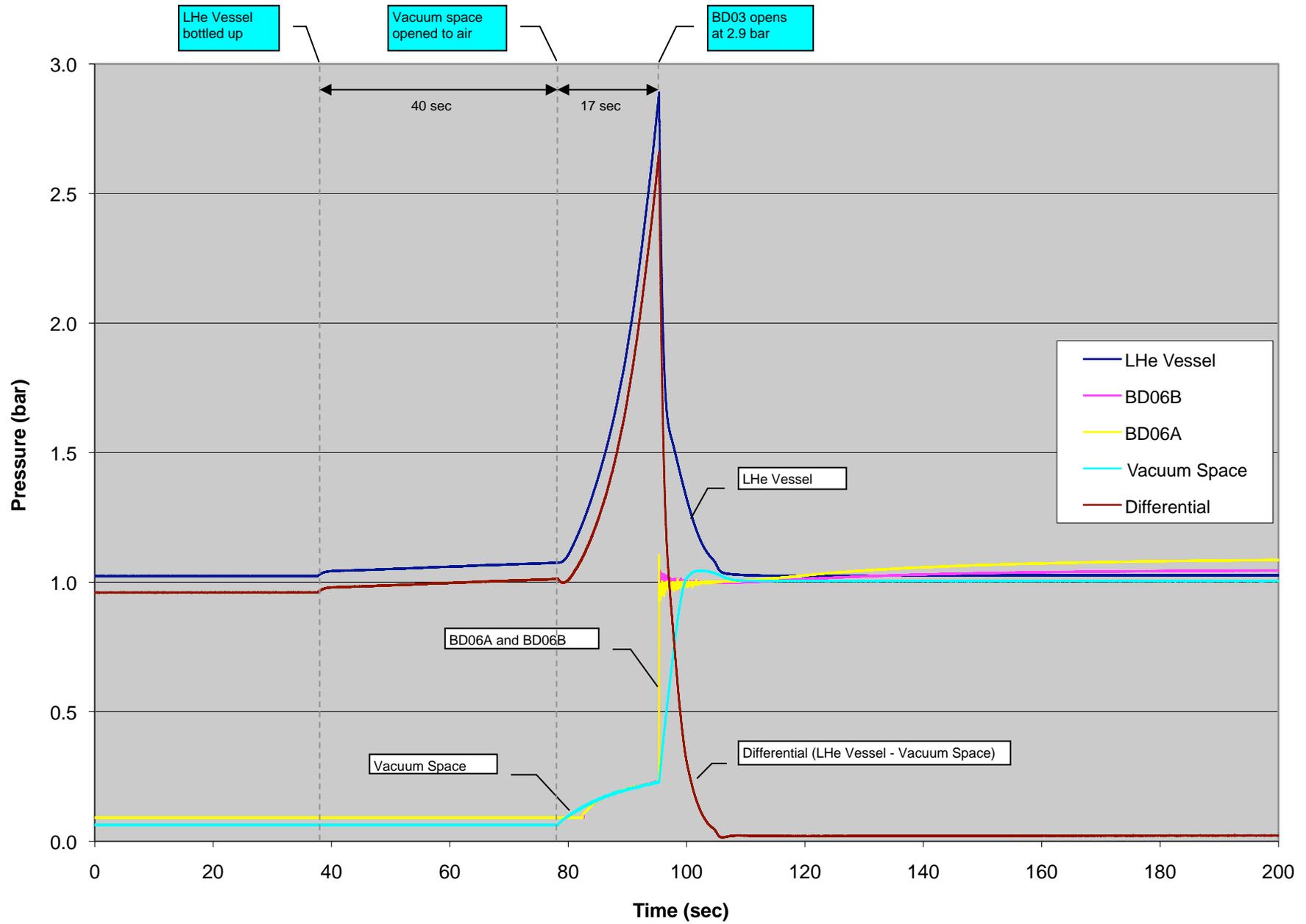




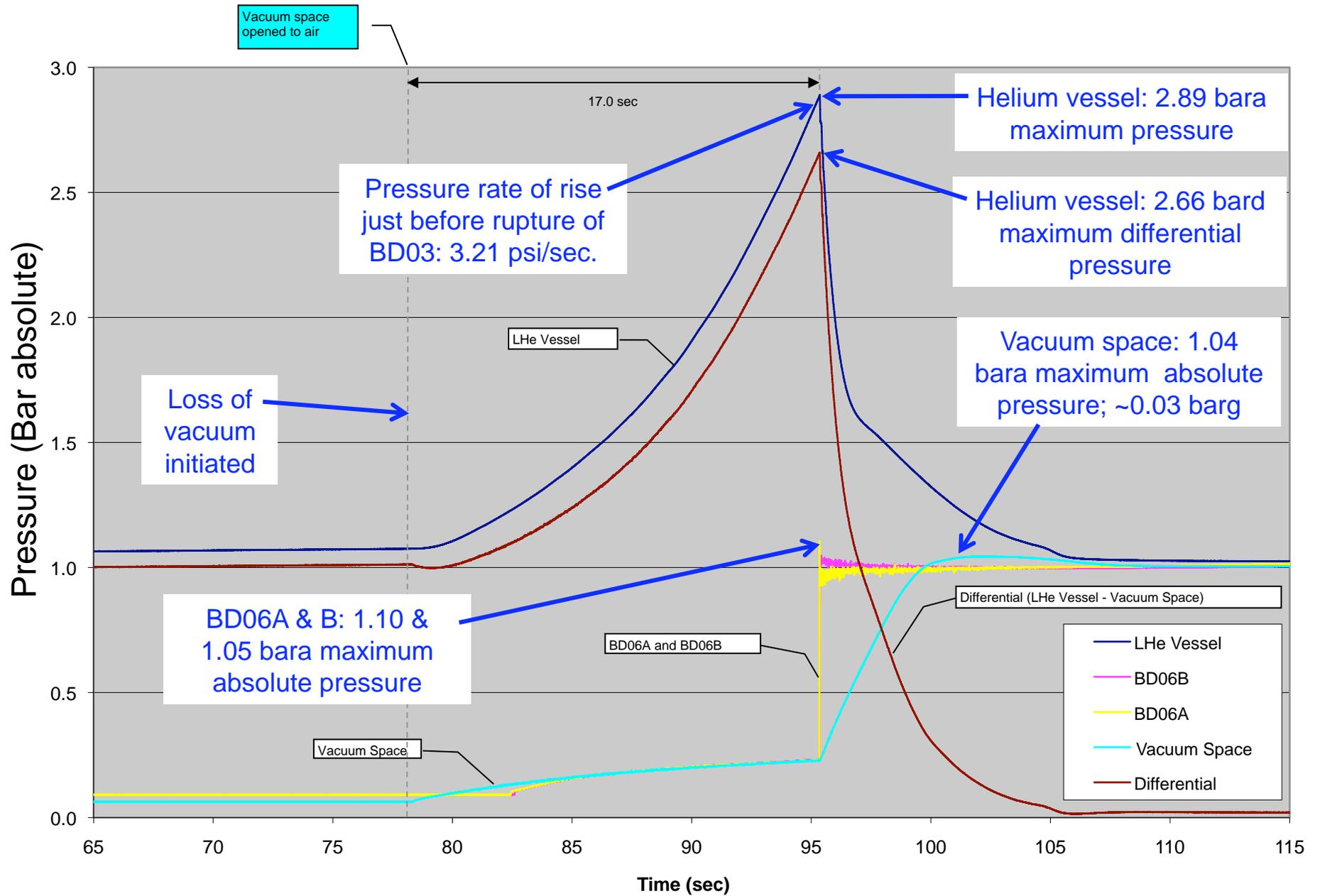
A large fan was placed under the test hardware to accelerate the drying prior to reassembly for Test #8.



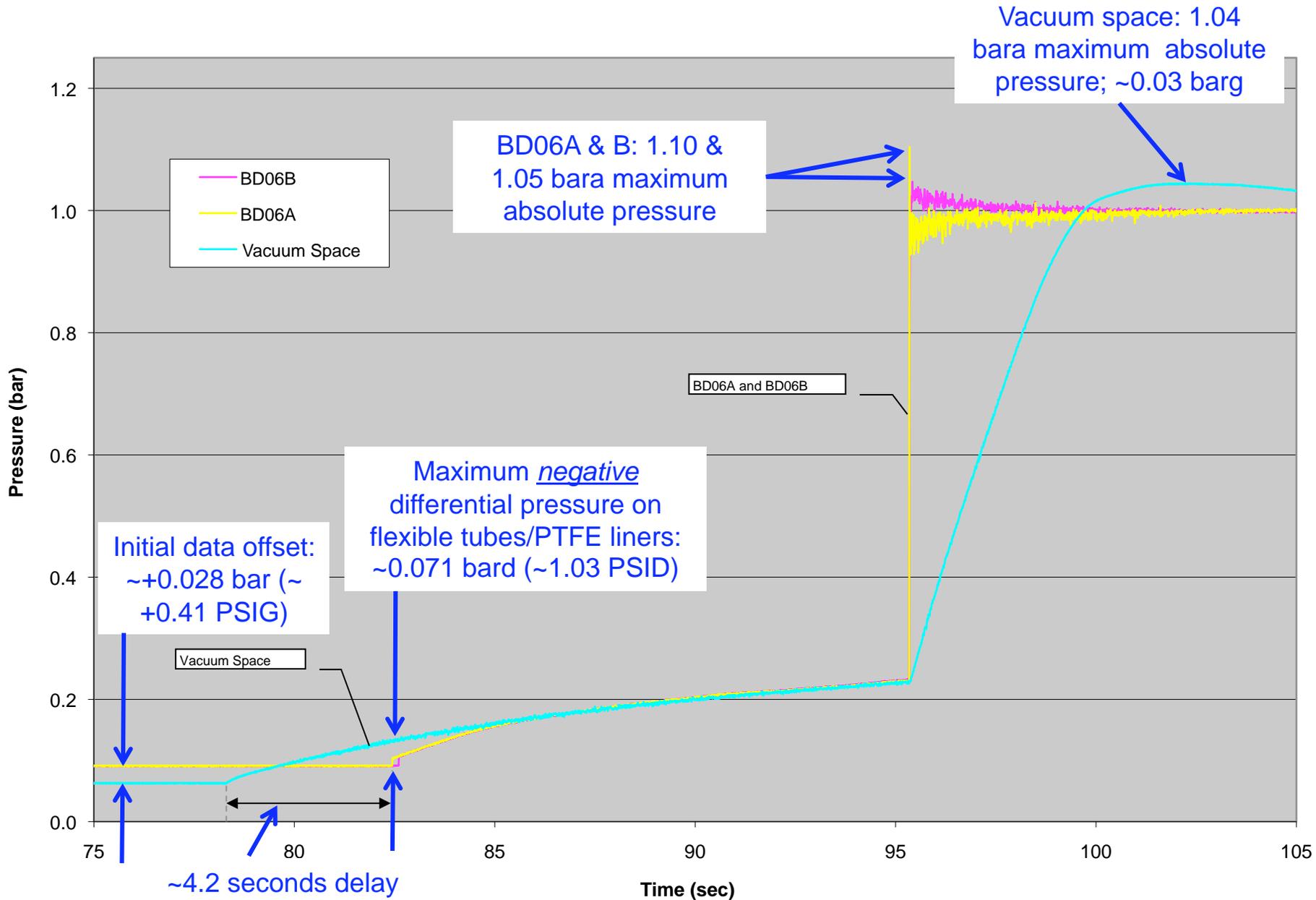
Burst Disc Test 7B Raw Data



Burst Disc Test #7B Preliminary Data



Burst Disc Test 7B
Raw Data



Test #7B Results & Conclusions

- The same 0.5" (12.7 mm) orifice used in Test #7A was used in Test #7B.
- The LHe vessel was bottled up and self-pressurization increased the pressure from one atmosphere to ~1.08 bara over the next ~40 seconds.
- Then a 1" ball valve was opened to the 0.5" orifice to allow humid ambient air into the vacuum space. The vacuum space pressure began to rise immediately and had reached a peak of ~0.23 bara when BD03 ruptured. This pressure would have risen *much* faster without the cryopumping onto the cold mass inside. (See slides 40 & 41.)
- The LHe vessel pressure rise began to accelerate ~0.7 seconds after breaking the vacuum.

Test #7B Results & Conclusions (continued)

- The BD06A/B pressures began to rise ~4.2 seconds after breaking the vacuum. This is an improvement over the ~6.4 second delay in Test #7A.
- After ~17.0 seconds, BD03 burst when the LHe vessel pressure reached 2.89 bara. The differential pressure between the LHe vessel and the vacuum space was 2.66 bard, which is less than the 3.0 bard maximum design requirement.
- The pressure rise rate in the LHe vessel during the last 0.1 second prior to BD03 rupture was 0.222 bar/sec = 3.213 psi/second.
 - This compares to 3.293 psi/sec in the LHe vessel in test #7A...which is quite consistent.
 - This also compares to 4.993 psi/sec in the LHe vessel in test #6 and 6.179 psi/sec in the Buffer vessel. This again supports the theory that the hardware was over-tested in test #6.
 - Thus, both Test #7A & #7B were still conservative when compared to the flight hardware, but as predicted, less conservative than test #6.
 - Test #8 will be run the same way as #7A & #7B.

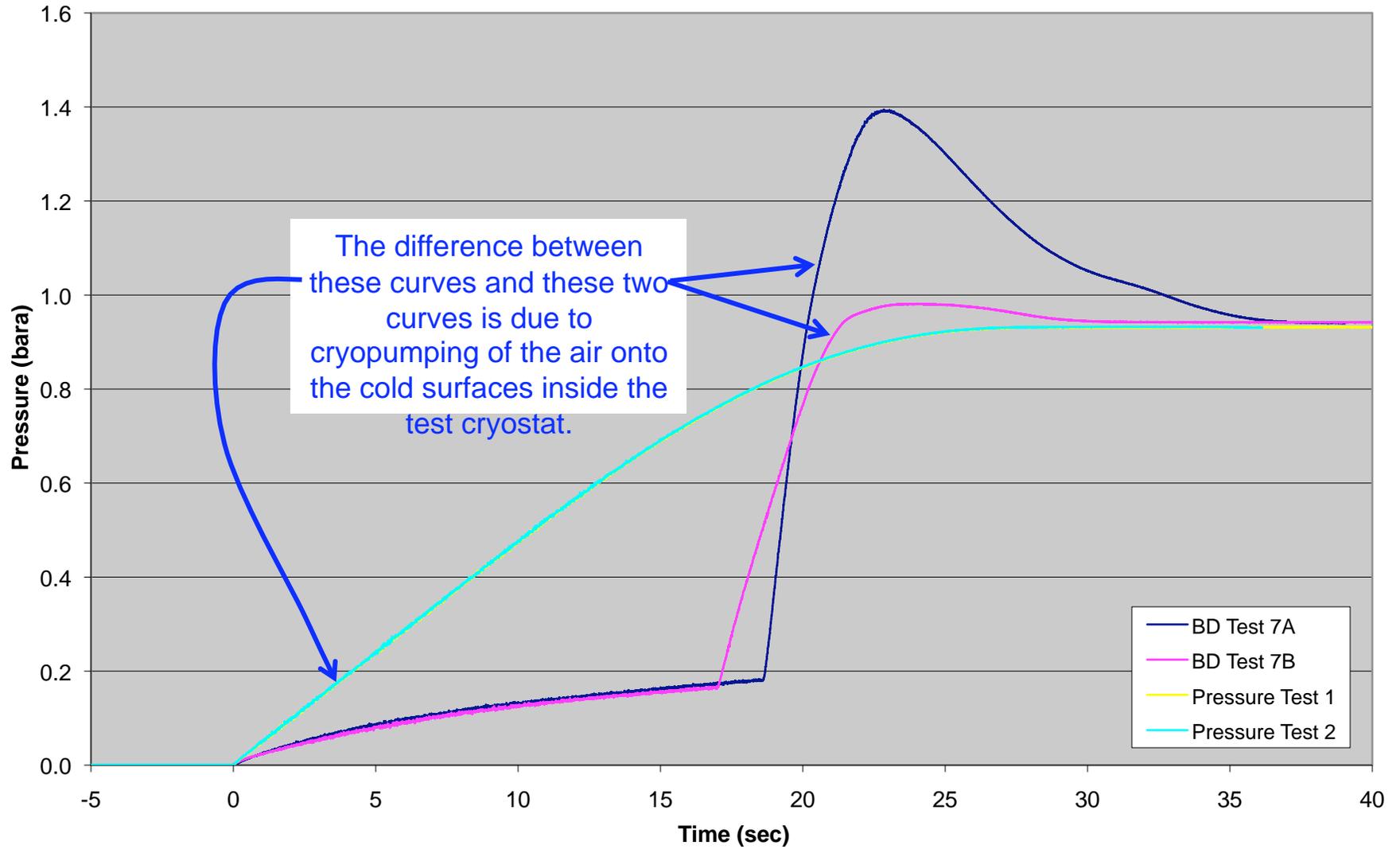
Test #7B Results & Conclusions (continued)

- The pressures on the BD06A & B transducers spiked at only 1.10 & 1.05 bara respectively (compared to 2.39 & 2.43 bara in Test #7A). This indicates the choke point is back near where it should be – at BD03. Within ~0.02 seconds BD06A & B ruptured simultaneously. This was also observed in the video recording of the event.
- After the burst, the vacuum space reached a peak pressure of only 1.04 bara or 0.03 barg. (It reached 1.46 bara in Test #7A.) This compares very favorably with the BD07 rating of 0.56 to 0.80 barg. Note that there was no other way of venting the vacuum space at this pressure like the lift-off plate in test #6.
- As agreed after Test #7A, 1/8” diameter vent holes were drilled in the Angled Adapters to reduce the negative differential pressure on the PTFE Liners inside the ortho-fabric Flexible Tubes.
 - The test results indicate the PTFE negative differential pressure was reduced from ~1.49 PSID in Test #7A to ~1.03 PSID in Test #7B.
 - The reaction time from loss of vacuum initiation was also reduced from ~6.4 seconds to ~4.2 seconds.

Test #7B Results & Conclusions (concluded)

- Test #8 will be conducted using all flight-like discs in a similar manner as Test #7A & #7B. However, this test will not have the separated membrane from the failed flight-like disc at SCL installed on top of the BD radiation shields.
- Test #8 will use the same orifice for the loss of insulating vacuum as test #7A & #7B.
- Two calibration runs with the cryostat warm were also done to establish a baseline for how long it takes for the vacuum space to repressurize with no cryopumping and no burst discs.
 - The results of these calibration runs are labeled “Pressure Test #1” & “Pressure Test #2” on the next slide. As can be seen, the two calibration runs are virtually identical.
 - The two vacuum space pressurization curves from Tests #7A & #7B are also plotted so the difference due to cryopumping onto the cold surfaces can be seen. Test #8 will also be added to these results.
 - From these test results, the heat load due to cryopumping can be calculated. V. Datskov has already begun this work.

Vacuum Space Pressurization



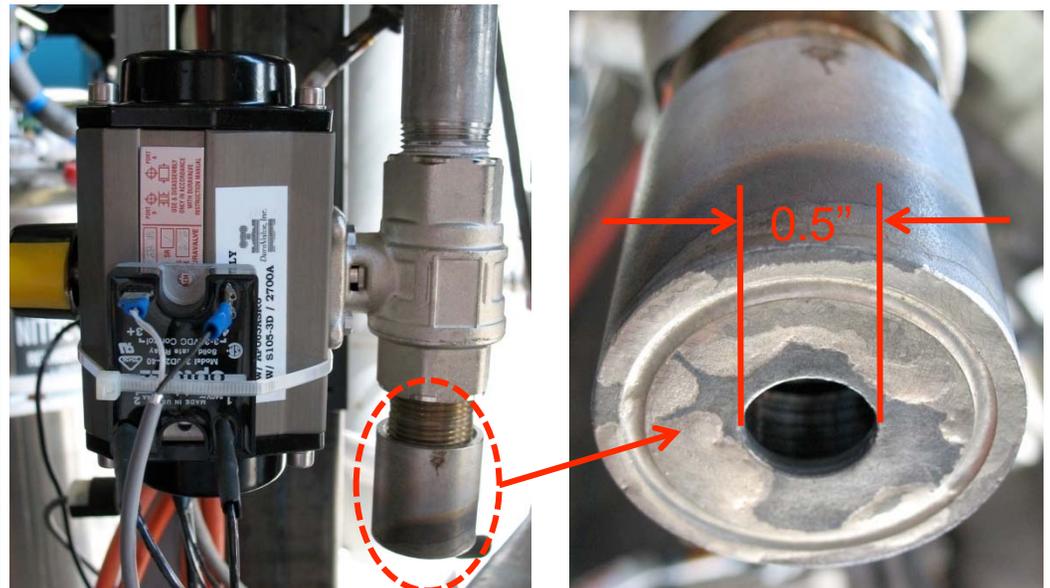
Enclosure 10

AMS Magnet Burst Discs & Ductwork Test #7B at Texas A&M

October 6, 2009
K. Bollweg

No modifications were made to the test set-up between test #7A & #7B. We considered using a larger test volume (shown at left), but then decided against it.

Two calibration runs were recorded to characterize the flow of air into the cryostat through the 0.5" (12.7 mm) orifice while at room temperature. The purpose was to determine the heat load onto the helium vessel in the cryostat due to cryo-pumping of the air onto the cold surfaces by comparing pressurization curves with and without LHe in the cryostat. More on that later...(slides 40 & 41).



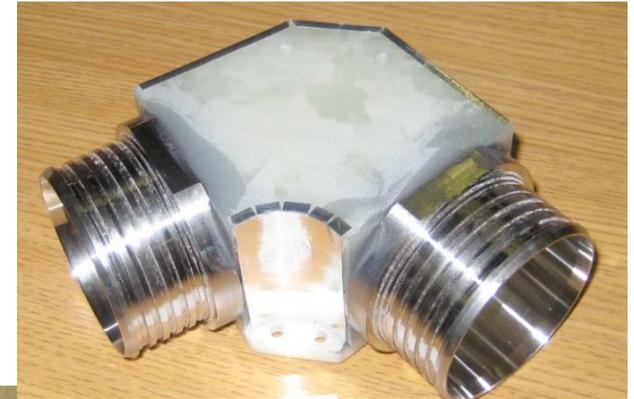
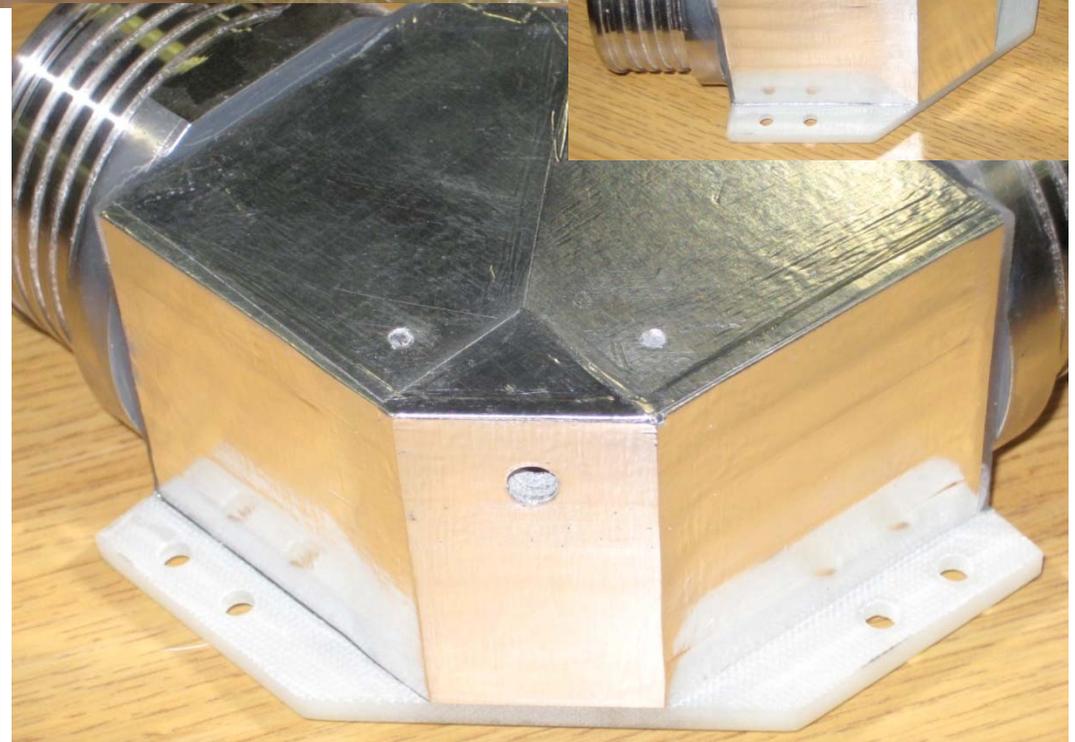
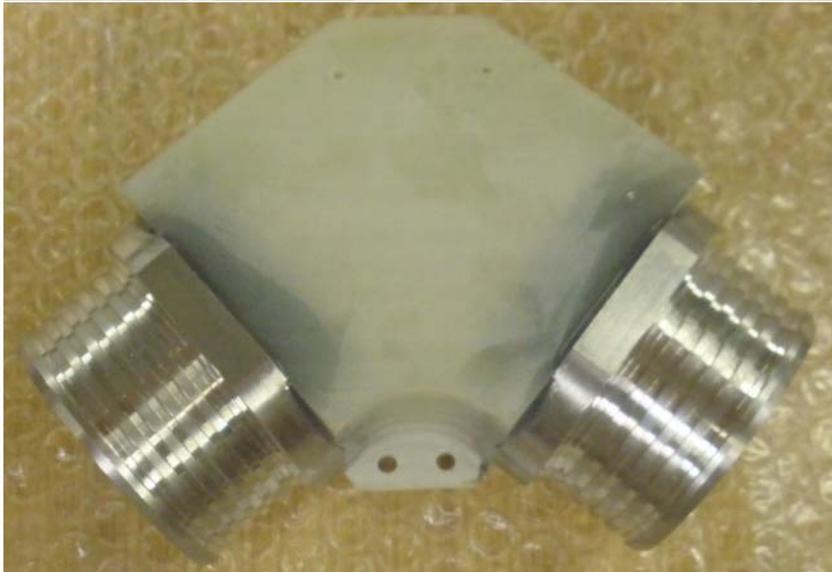


The edge weld on the BD03 flight-like disc was leak tested at room temperature and with LN2.

The test article was assembled as reported in previous tests. The same ortho-fabric flexible tubes from Test #7A were re-used. However, new PTFE liners were installed. A new Telescoping Tube was assembled and epoxied to a new SS Tee Box Cover.

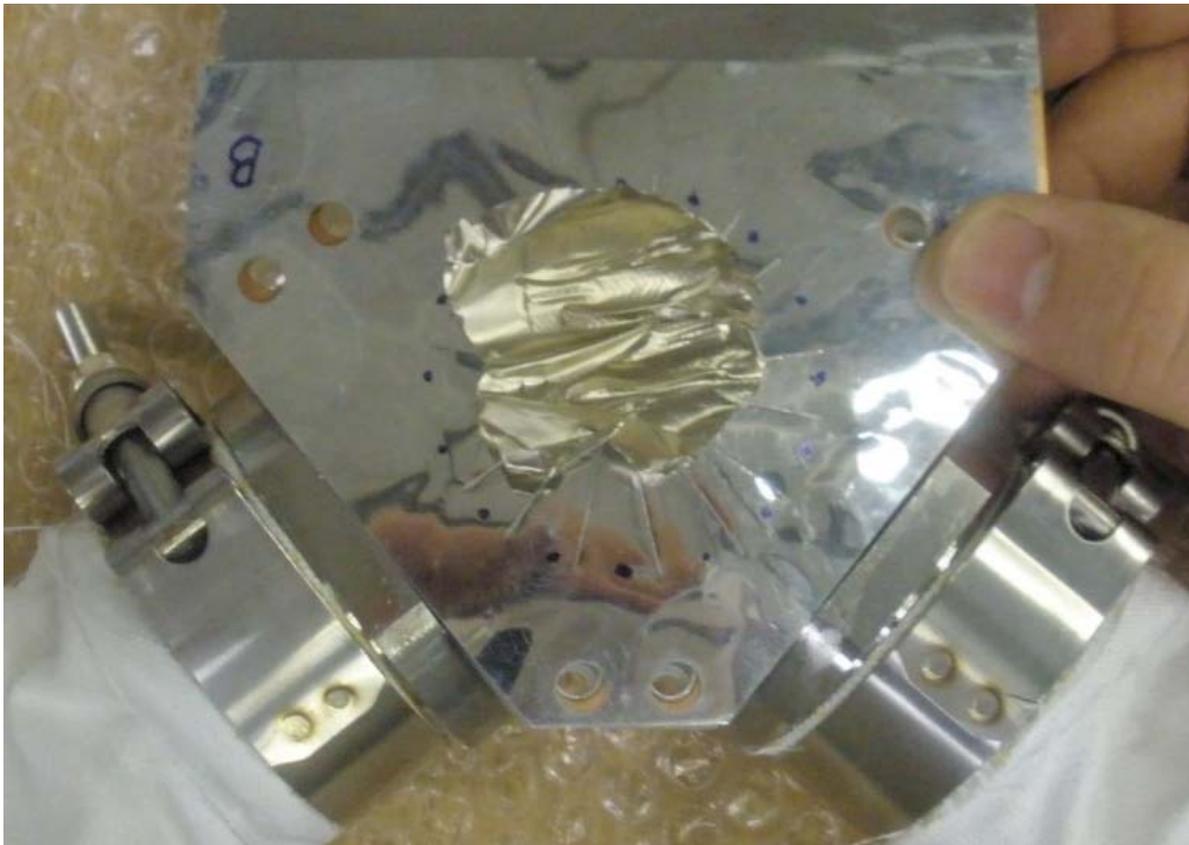


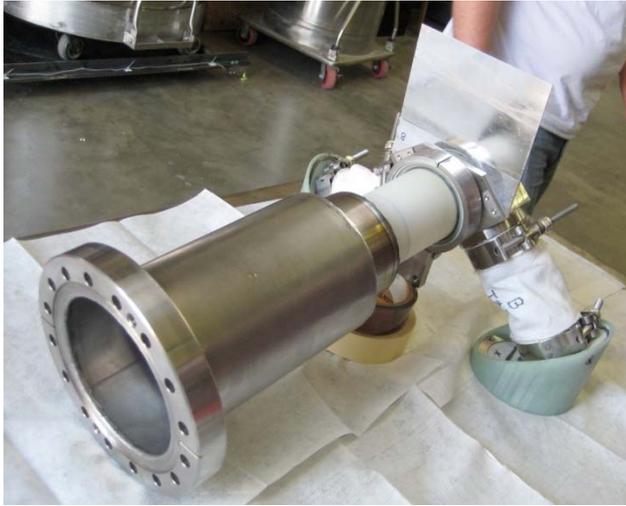
A new Tee box with SS Adapters was assembled and covered with aluminum tape. A hole for the thermal sensors was drilled & tapped near the base.





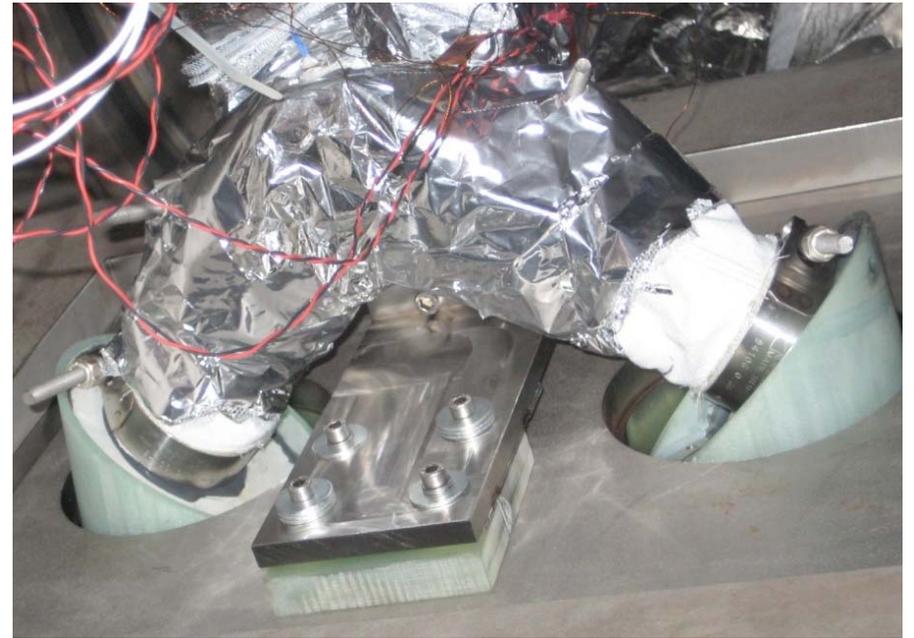
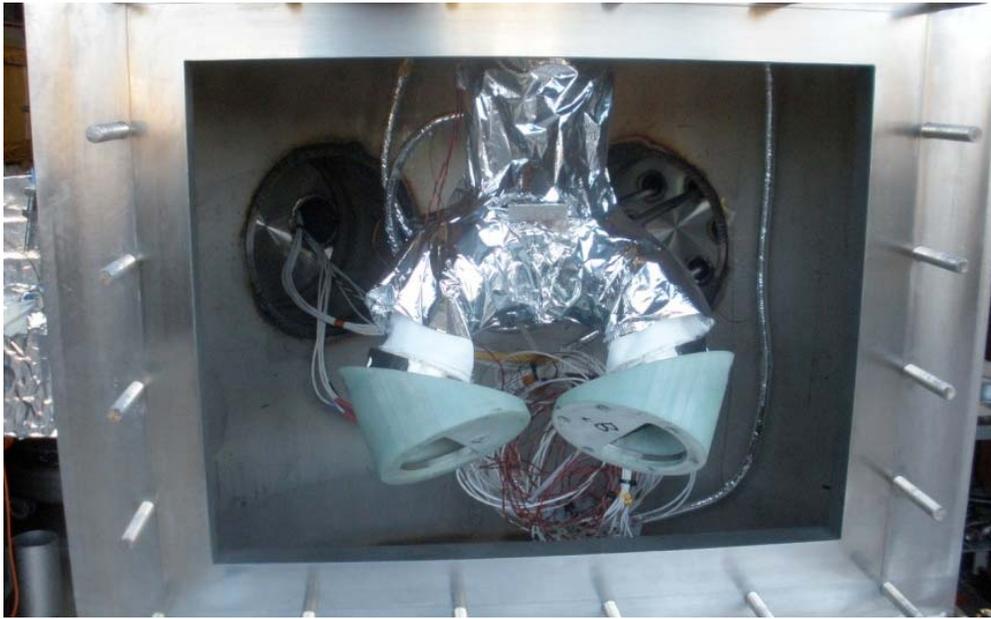
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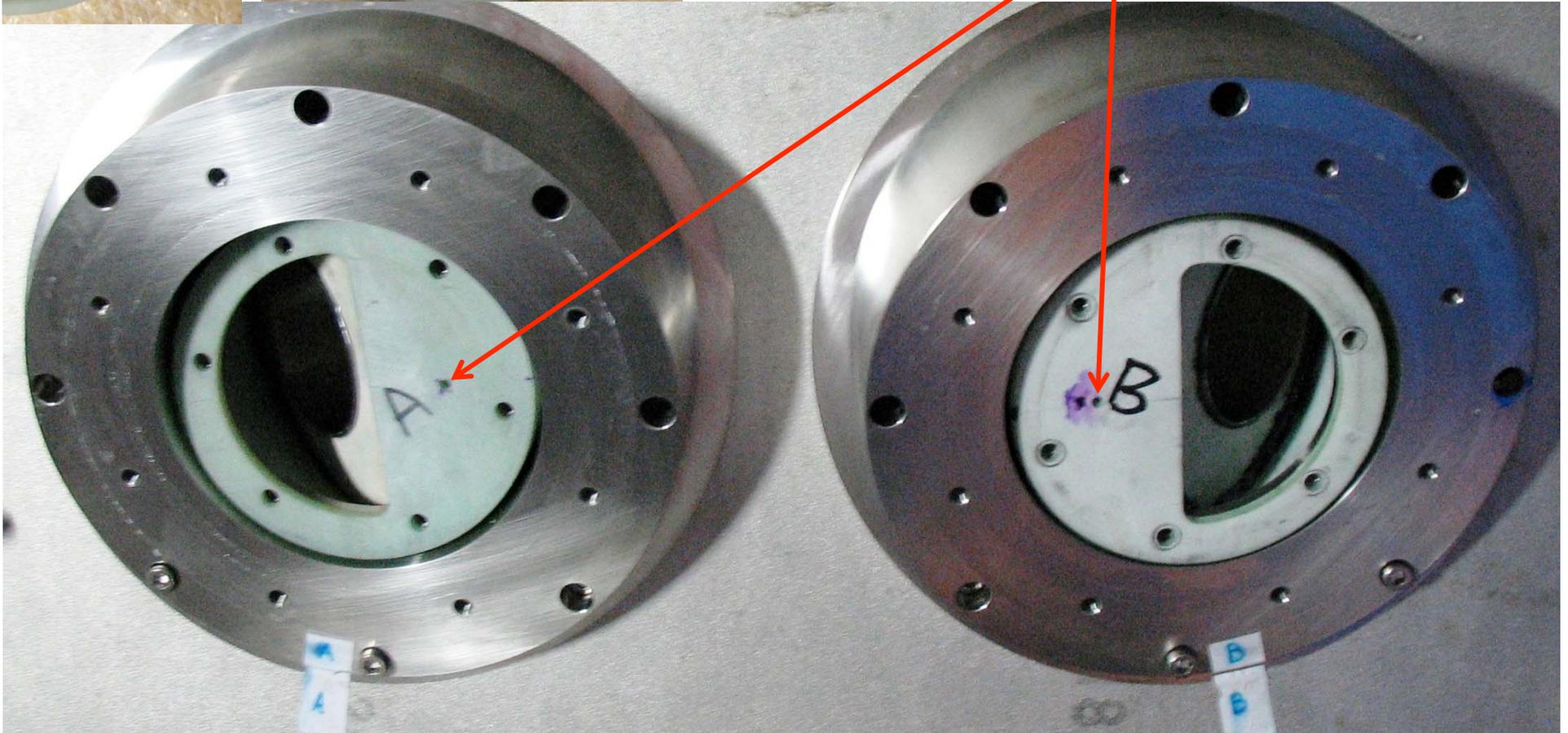
The rest of the assembly was as before.

Note: The detached BD03 membrane is resting against the Test #7B BD03 membrane in these two photos.

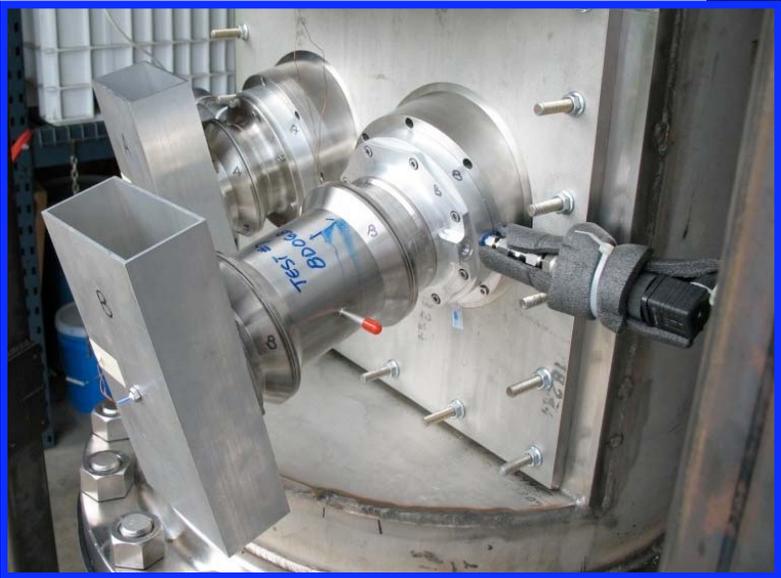
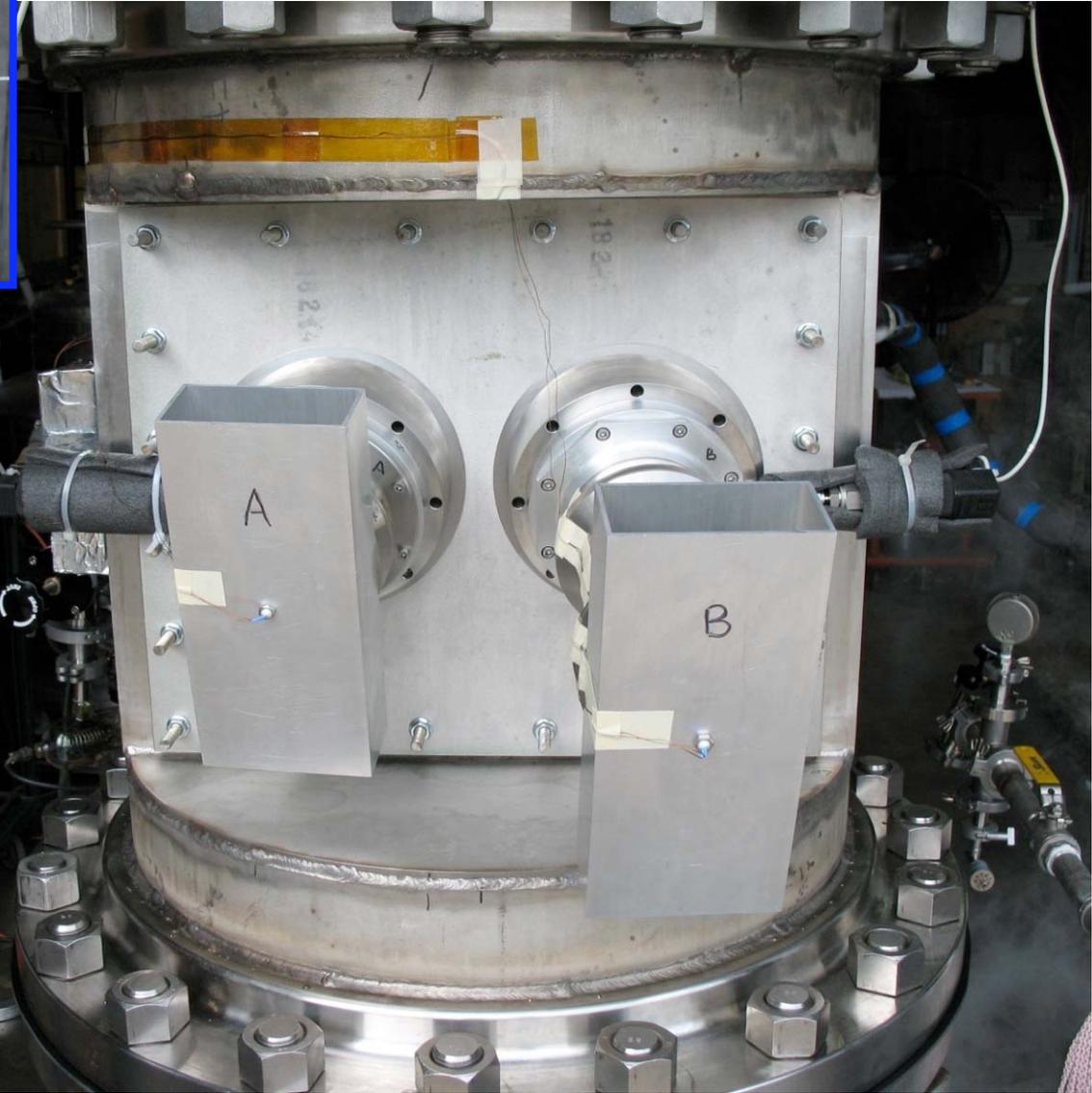
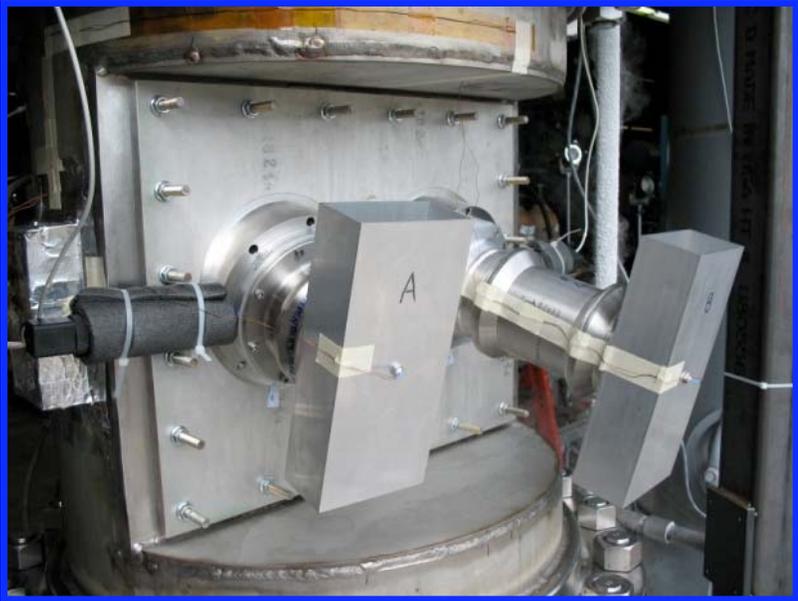


This is the first test to use a new flight-like BD06 in the "A" position. The "B" position has the remaining BD07A/B assembly with the "B" disc removed.

1/8" diameter (3.175 mm) holes were drilled in the Angled Adapters to reduce the negative differential pressure on the PTFE Liners and to improve conductance during pumpdown.



Fully assembled and ready to test.



The cool-down from
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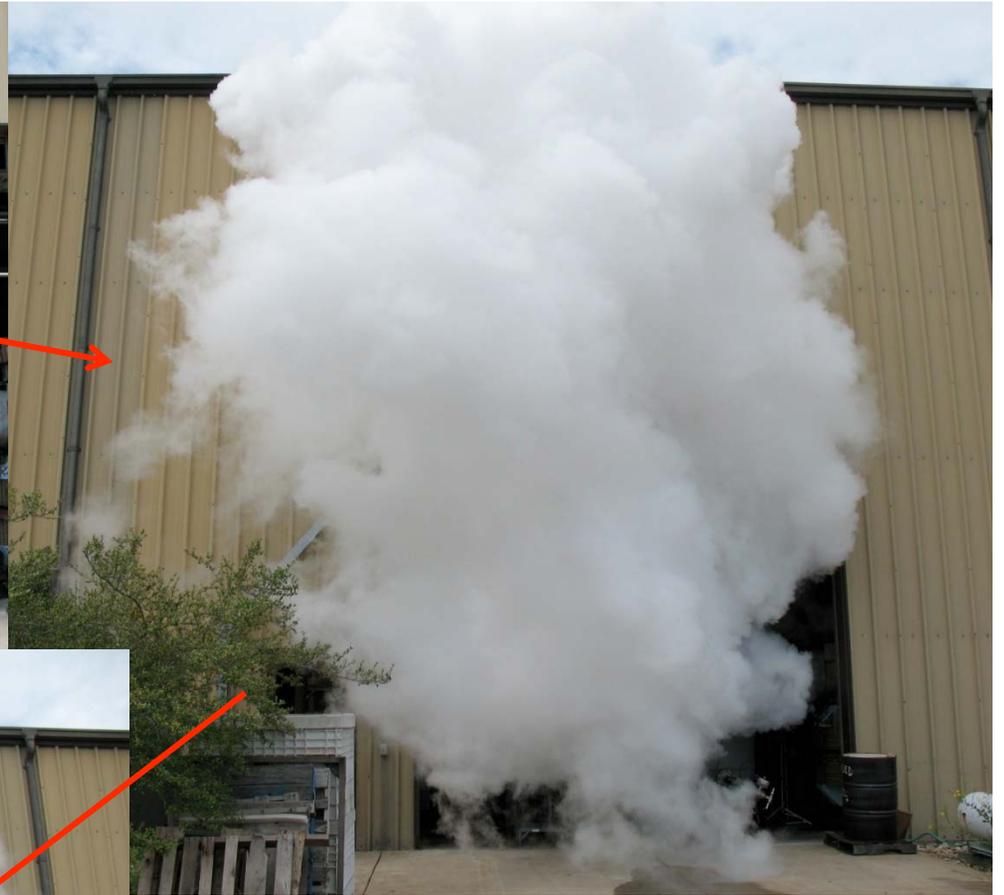
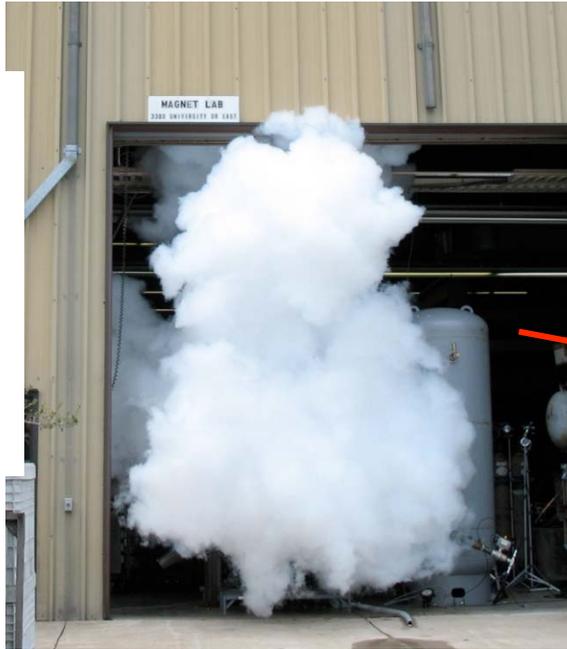


Running through the checklist
and beginning the countdown

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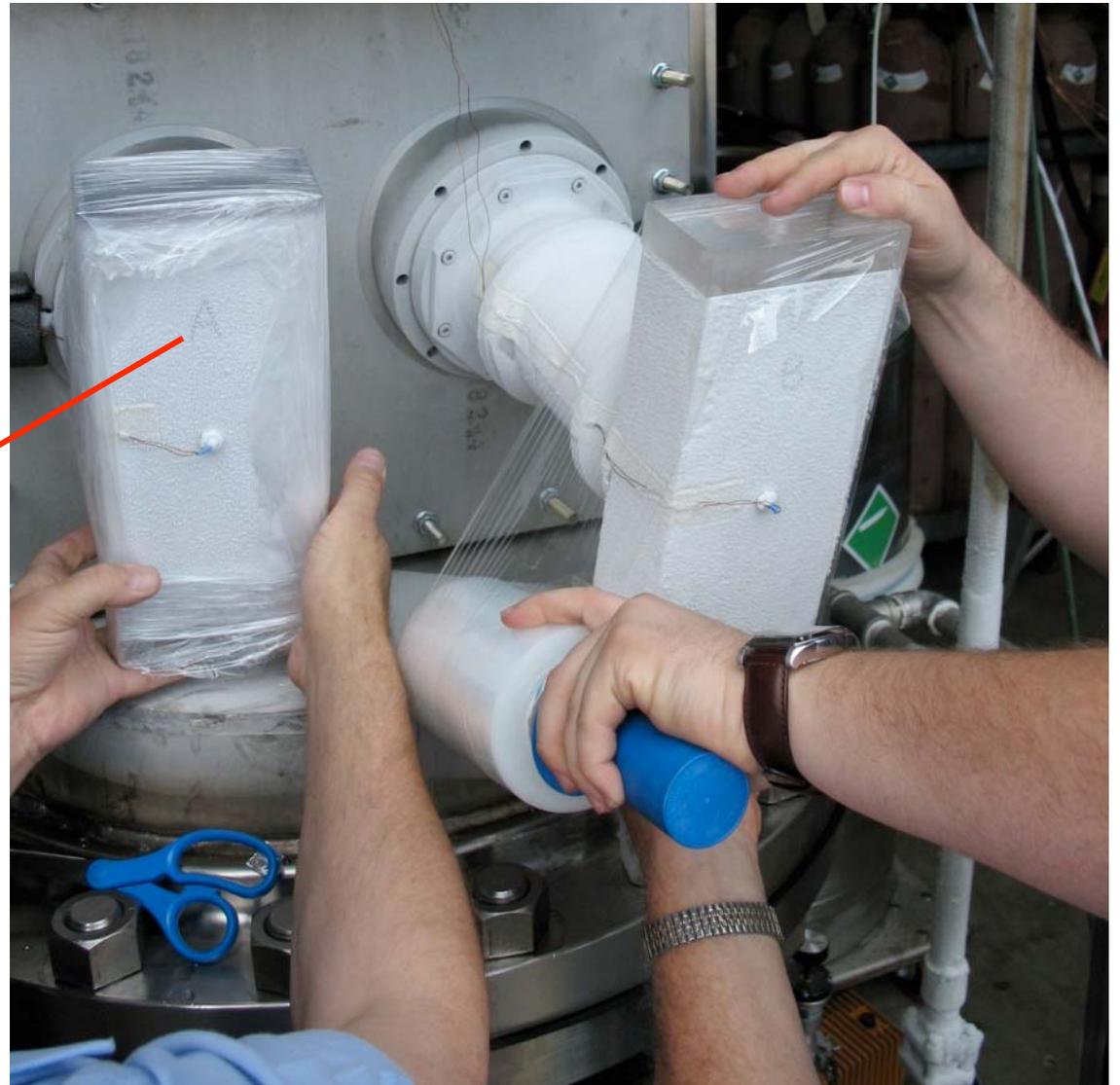
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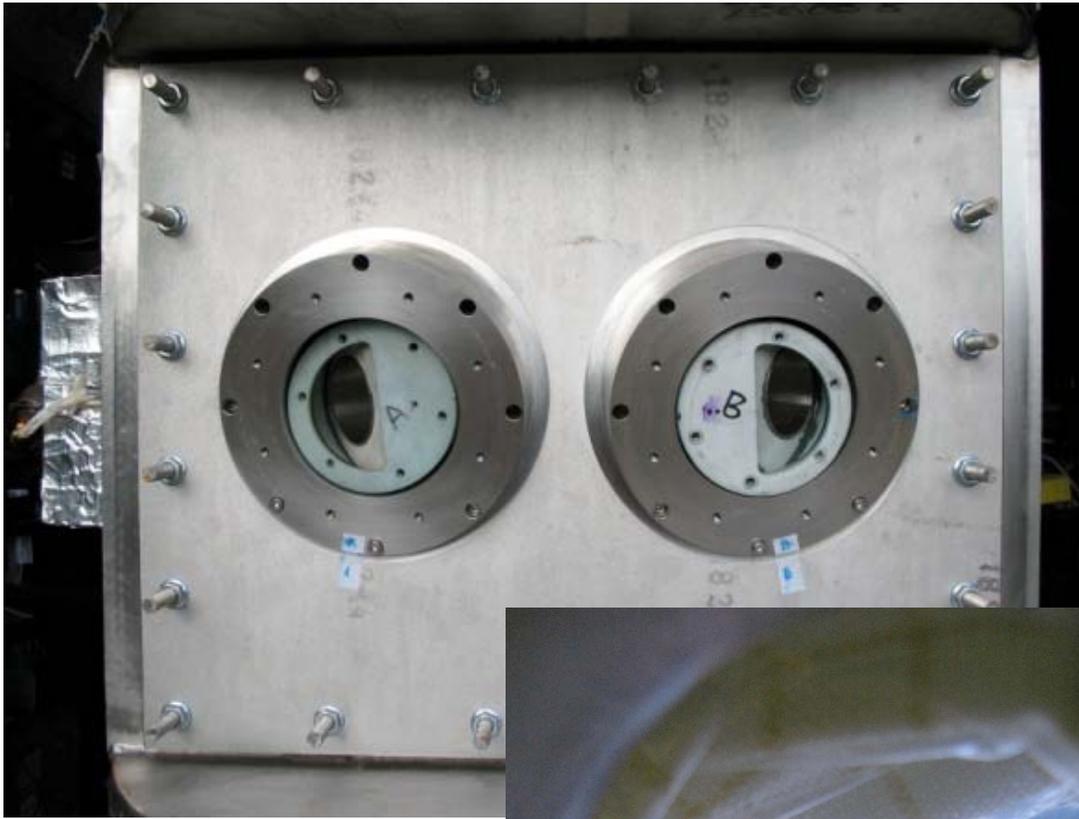


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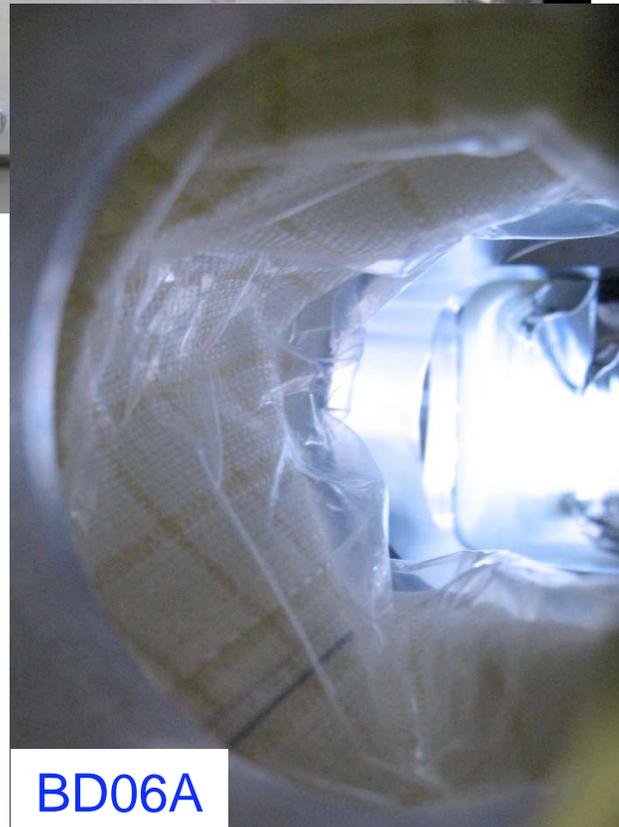


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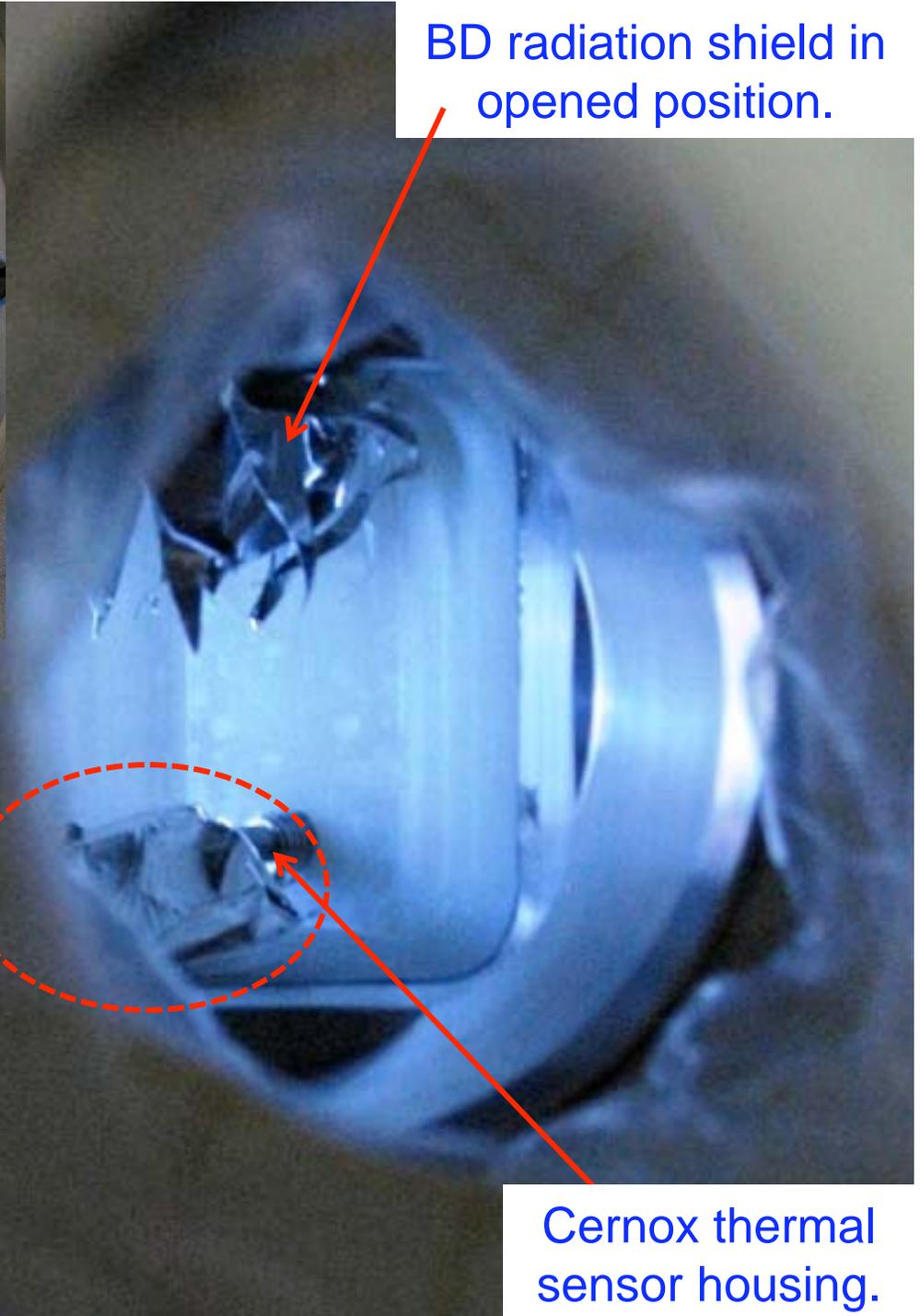
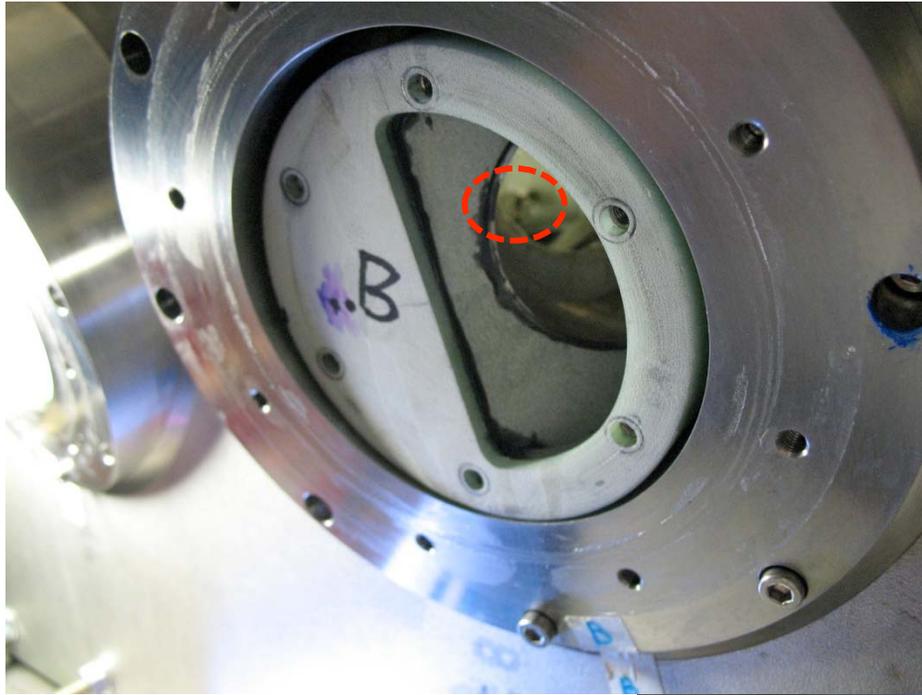
Initial inspection of the flexible tubes during disassembly indicated the PTFE was intact.



BD06A



BD06B



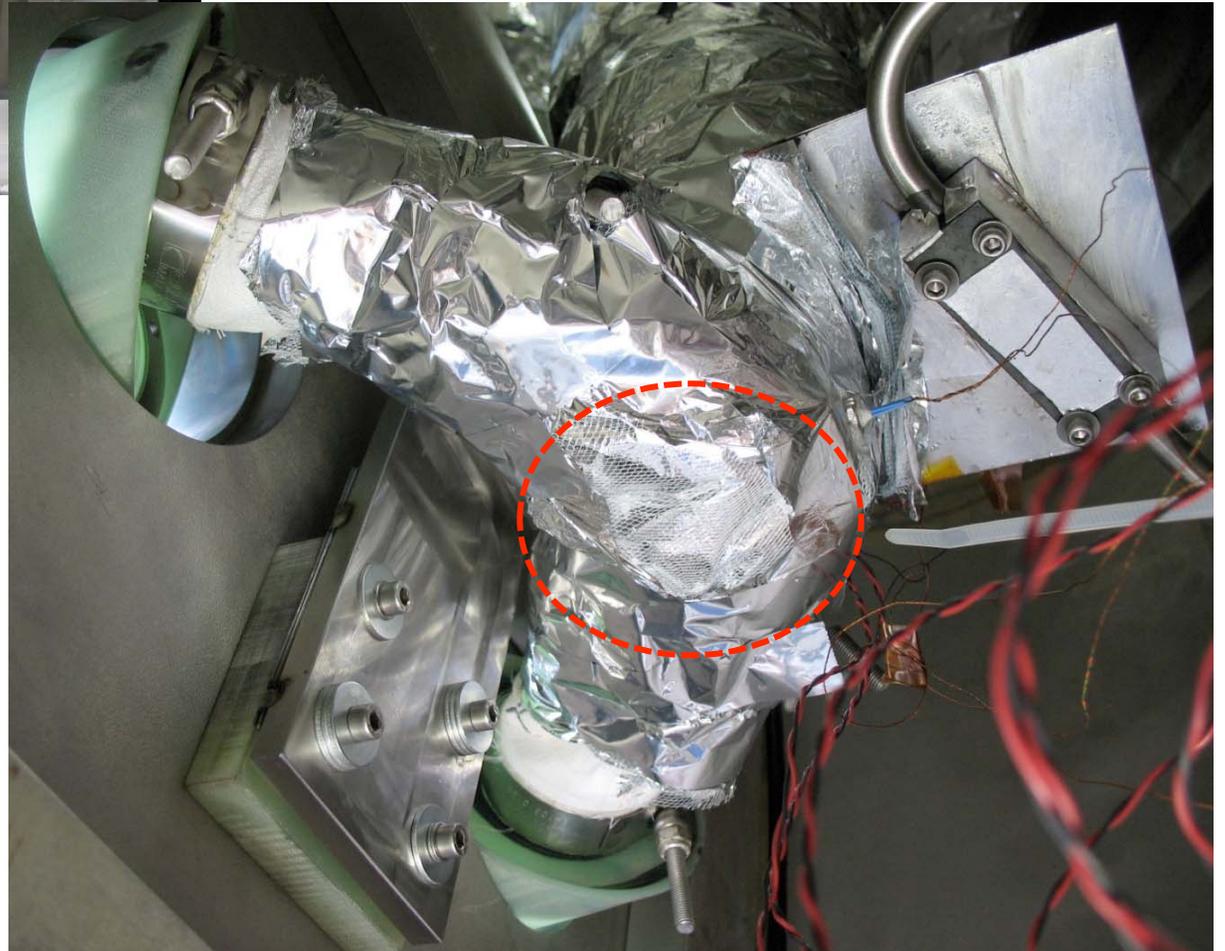
Further inspection revealed the location of the BD03 disc membrane from the test at Culham that was placed on top of the BD radiation shield before this test. It had become lodged on the housing of the Cernox thermal sensor. The flight system does not have the sensor so the membrane would likely have exited the ductwork.

BD radiation shield in opened position.

Cernox thermal sensor housing.



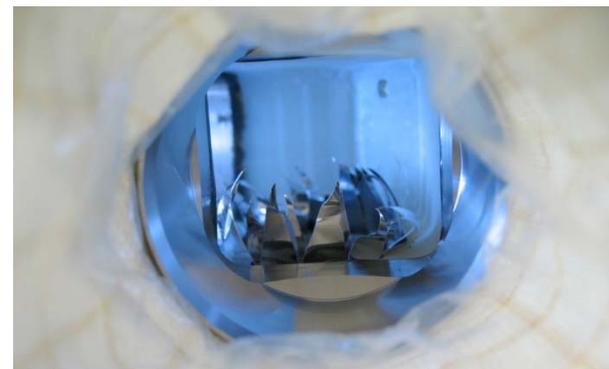
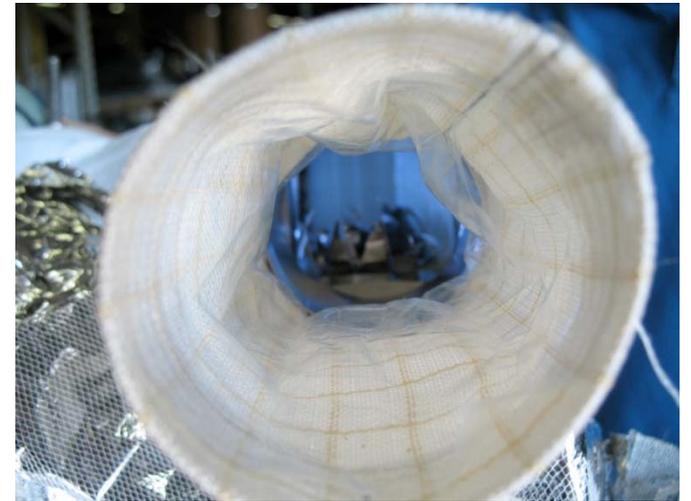
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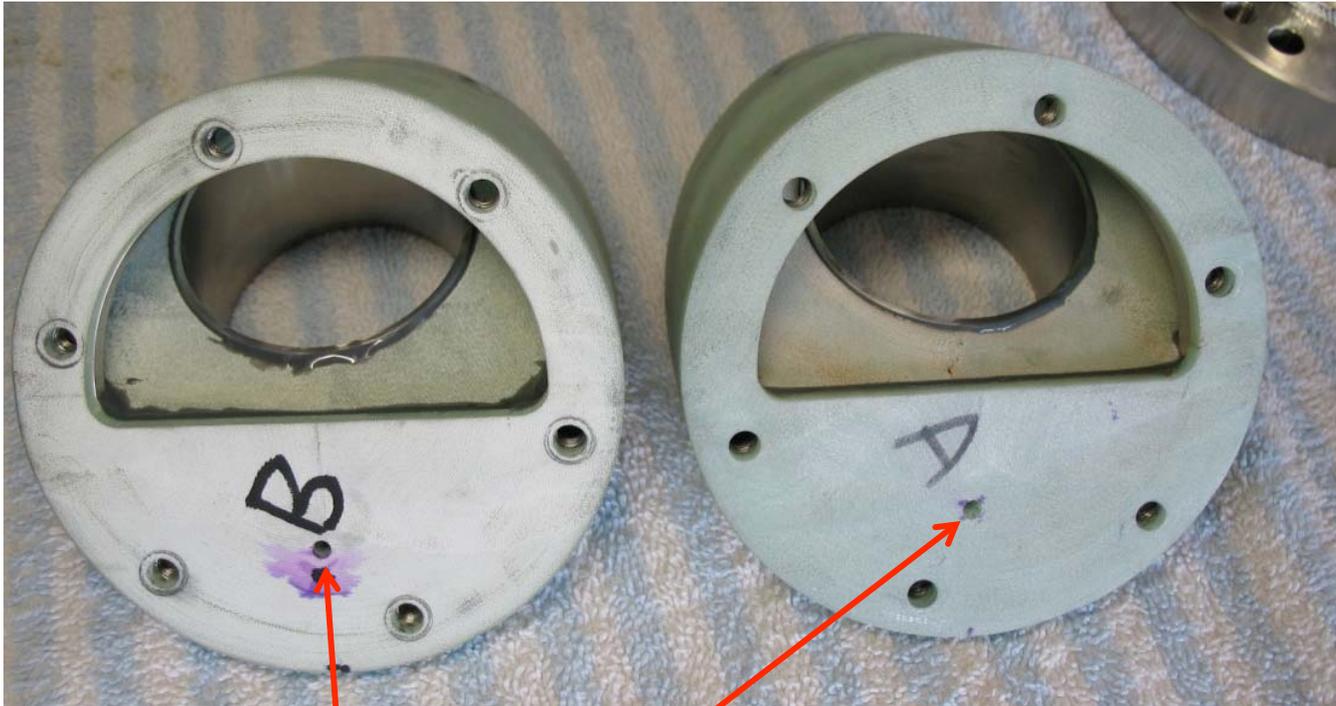
The MLI on the LHe vessel was still intact after several tests.





Continued disassembly revealed nothing significant.



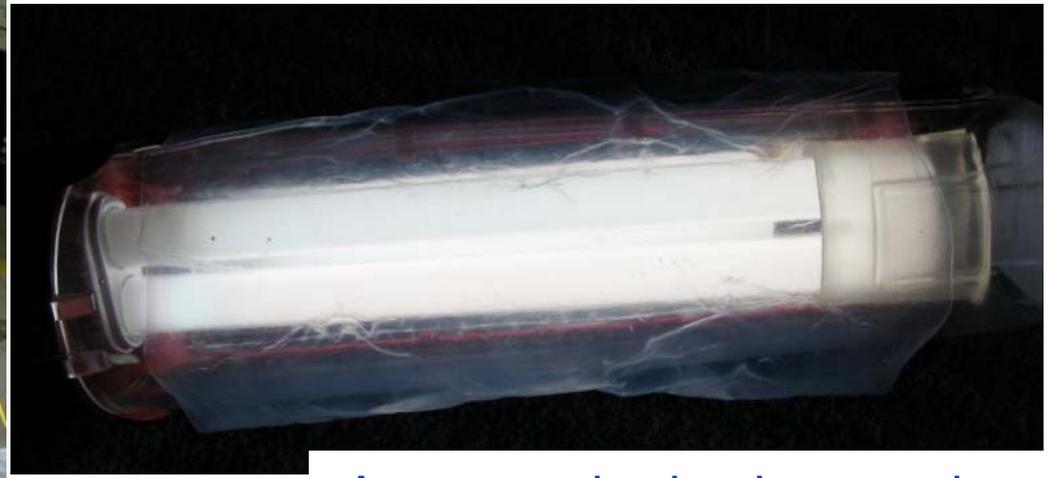
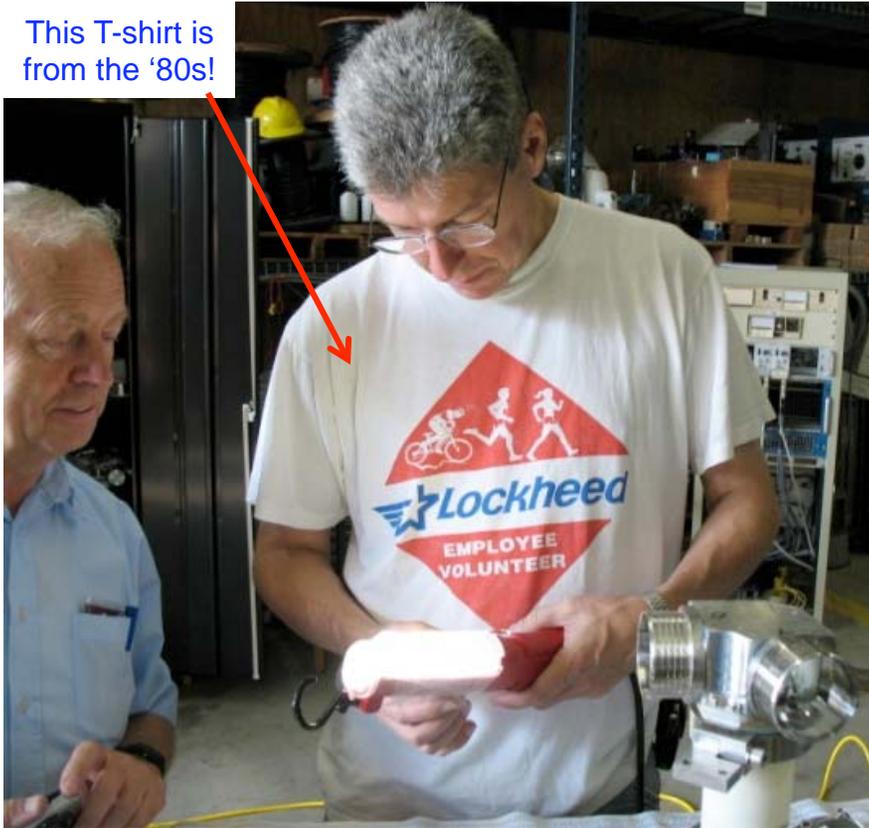


The Angled Adapter assemblies were fine.

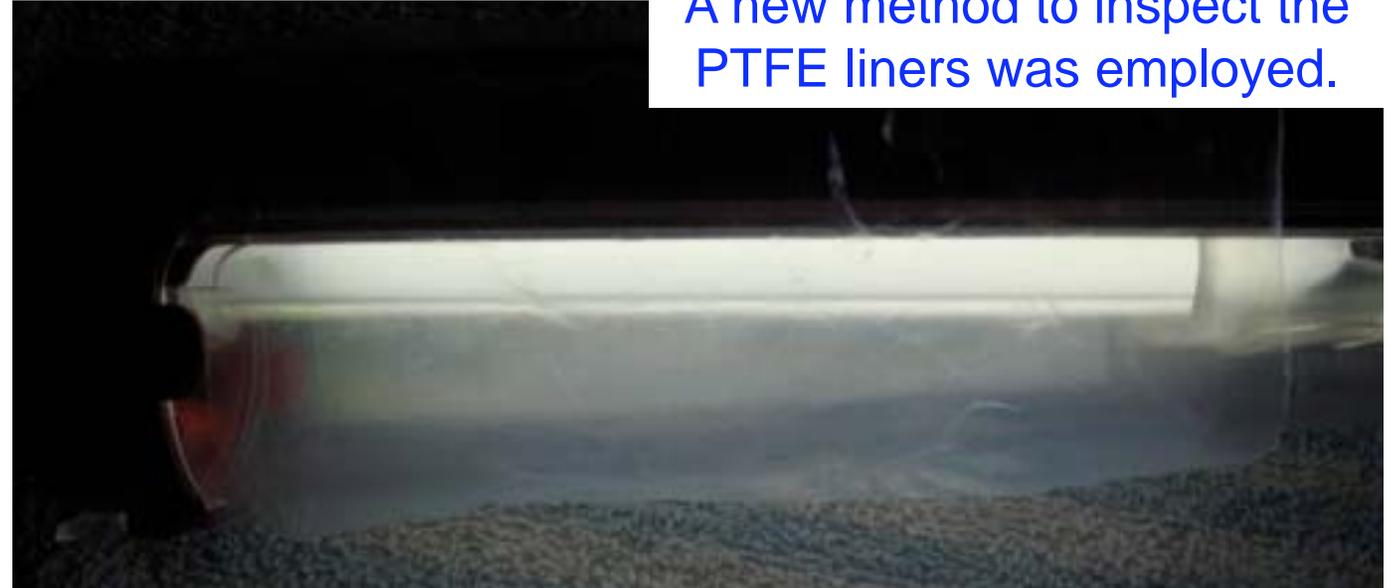
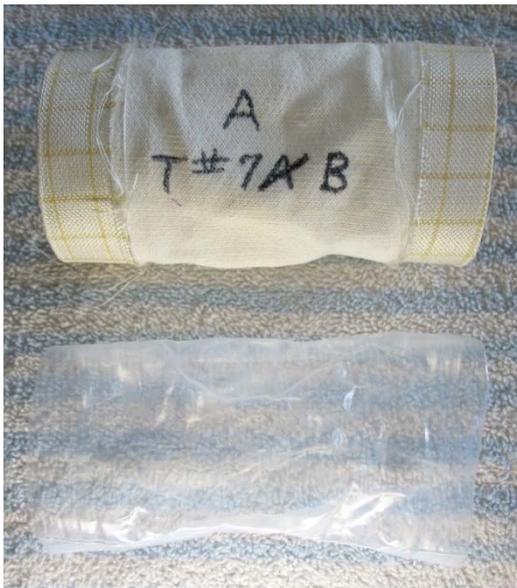
1/8" diameter vent holes.

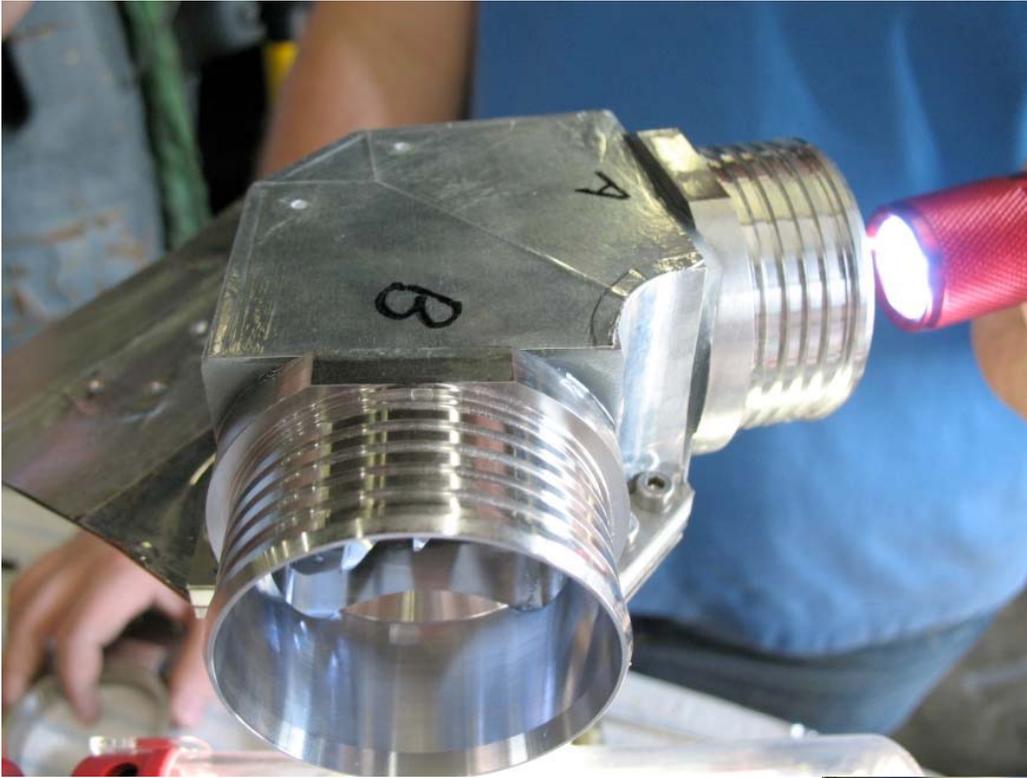


This T-shirt is from the '80s!

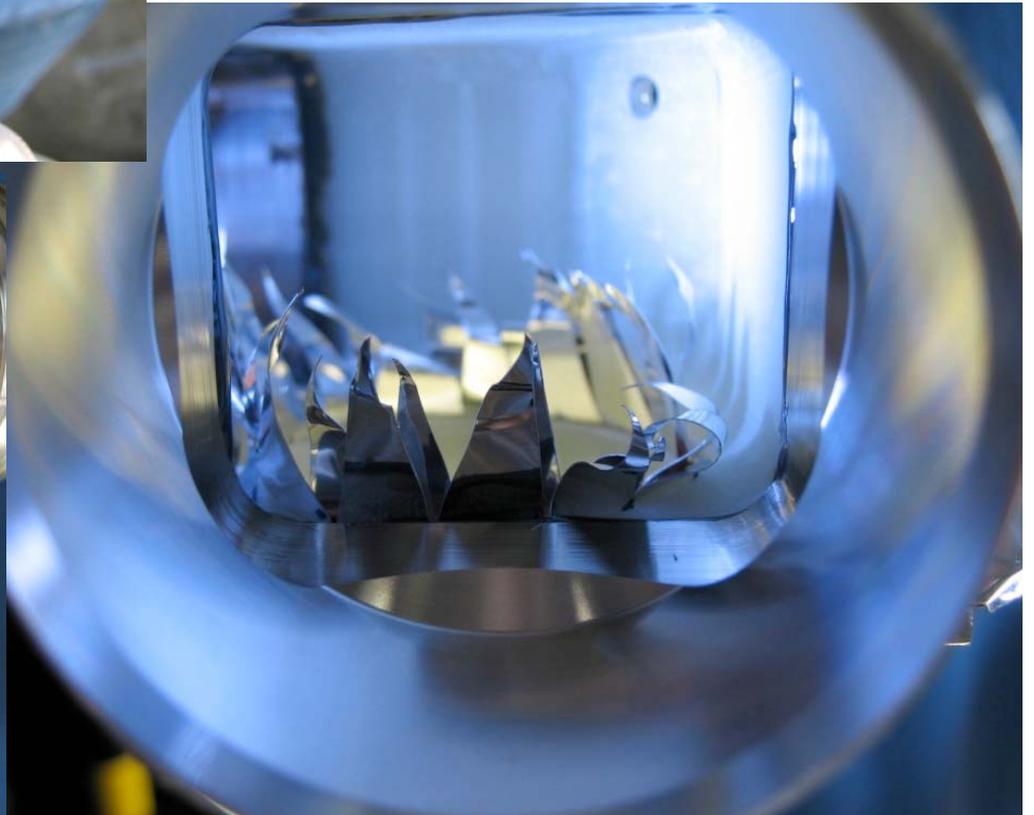


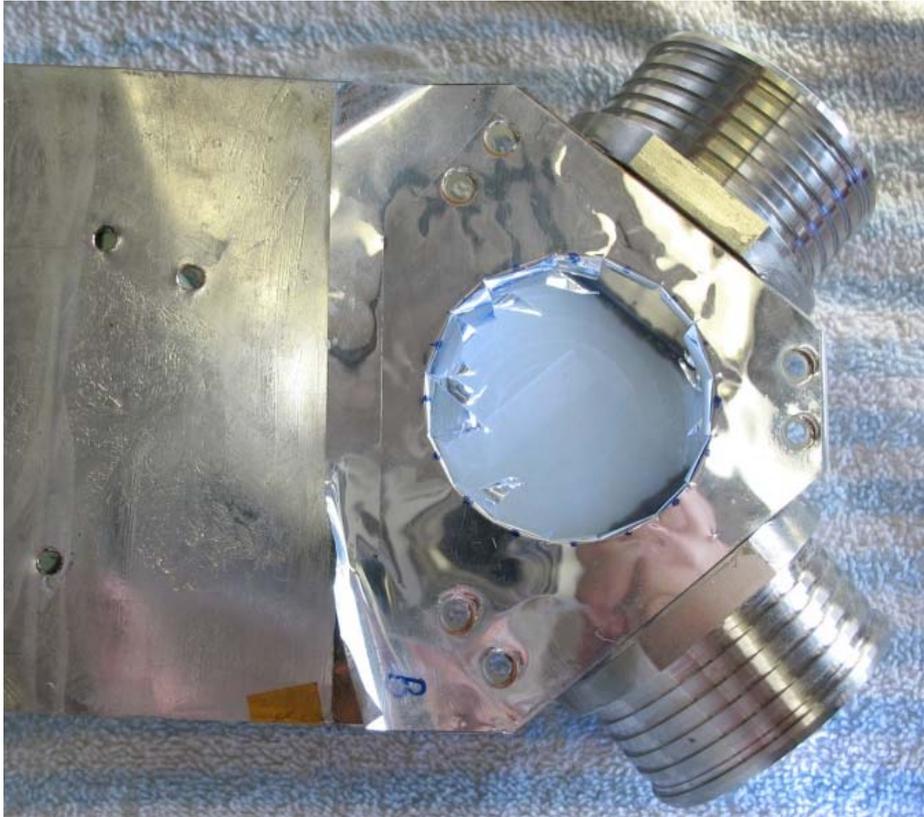
A new method to inspect the PTFE liners was employed.





The BD radiation shield opening pattern was similar to previous tests. The tips of the triangles were also intact.





It appeared that this test generated no detached debris, despite the attempt to “sabotage” it with the separated BD03 membrane.



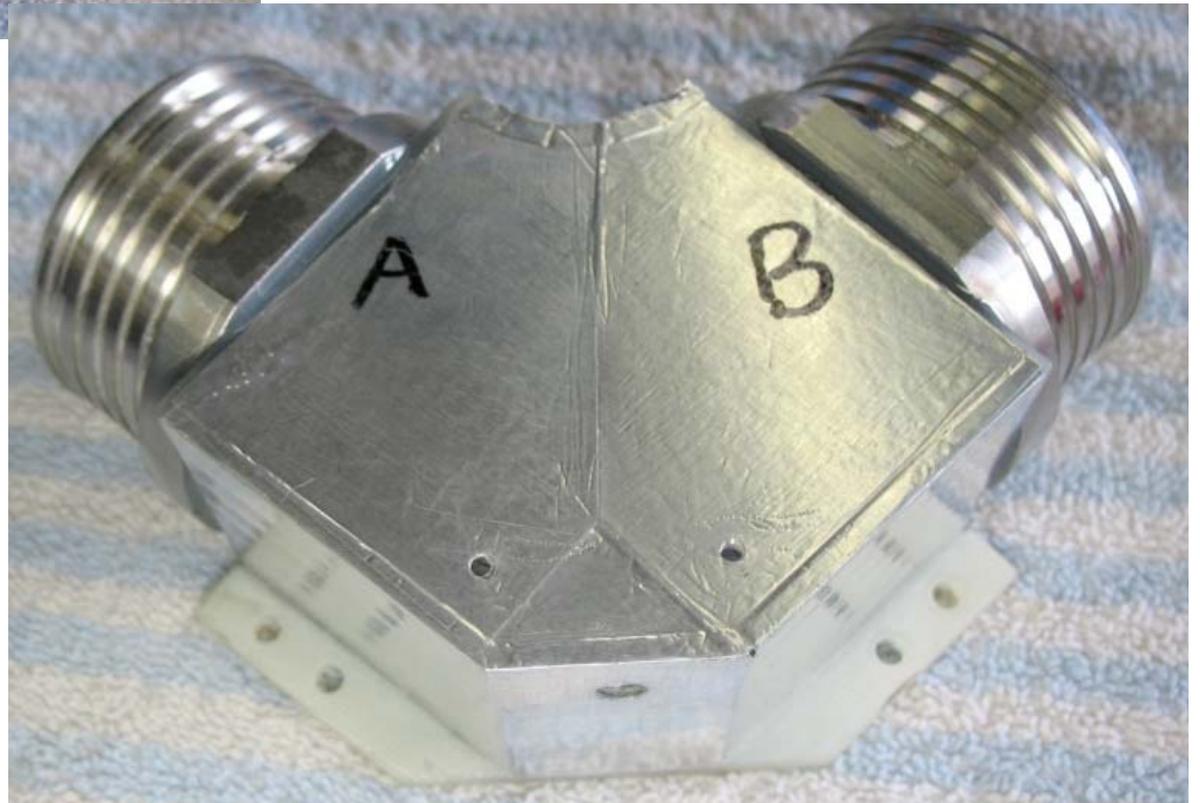


The usual opening pattern...

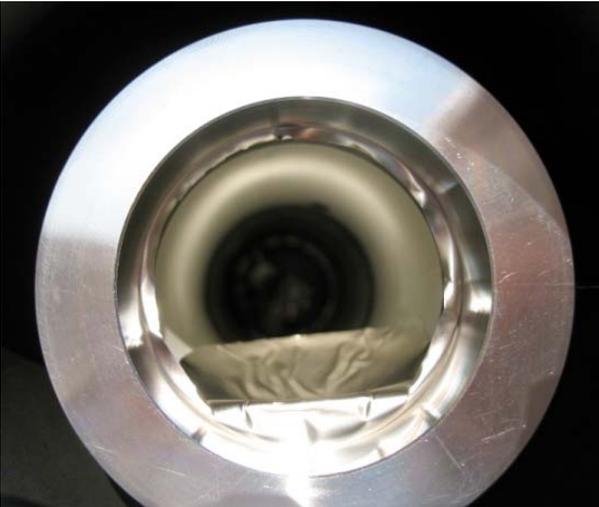




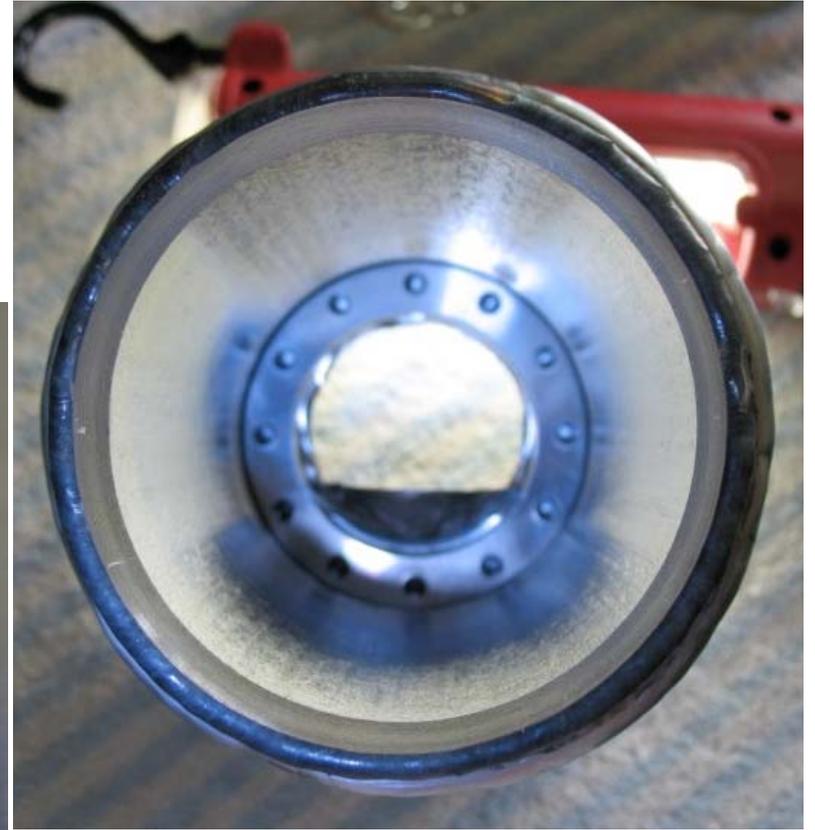
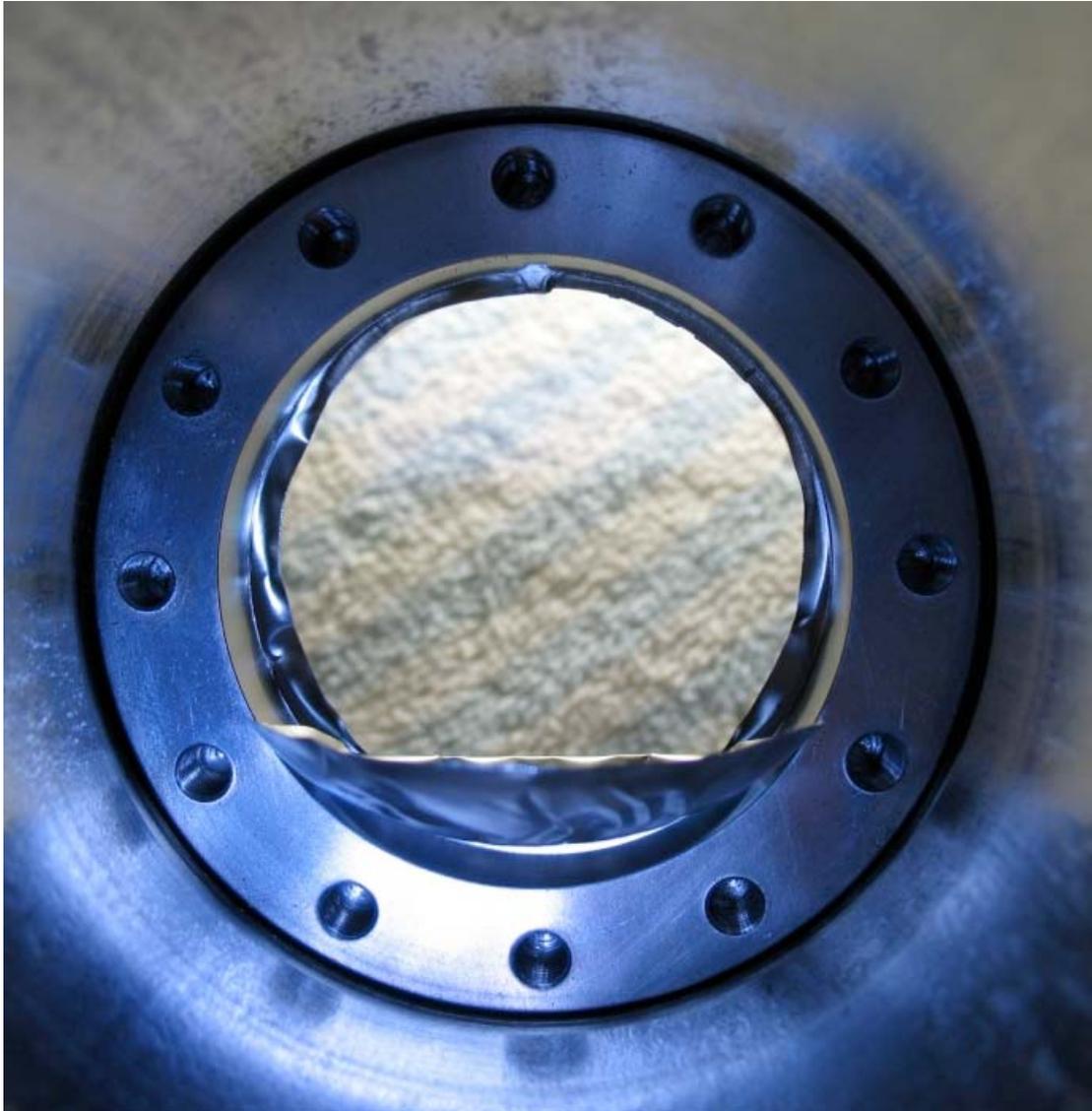
Nothing unusual with the Tee Box. It will be reused in Test #8.



Inspection of the inlet side of the BD03 flight-like assembly revealed nothing unusual. The membrane folded back nicely and remained attached.

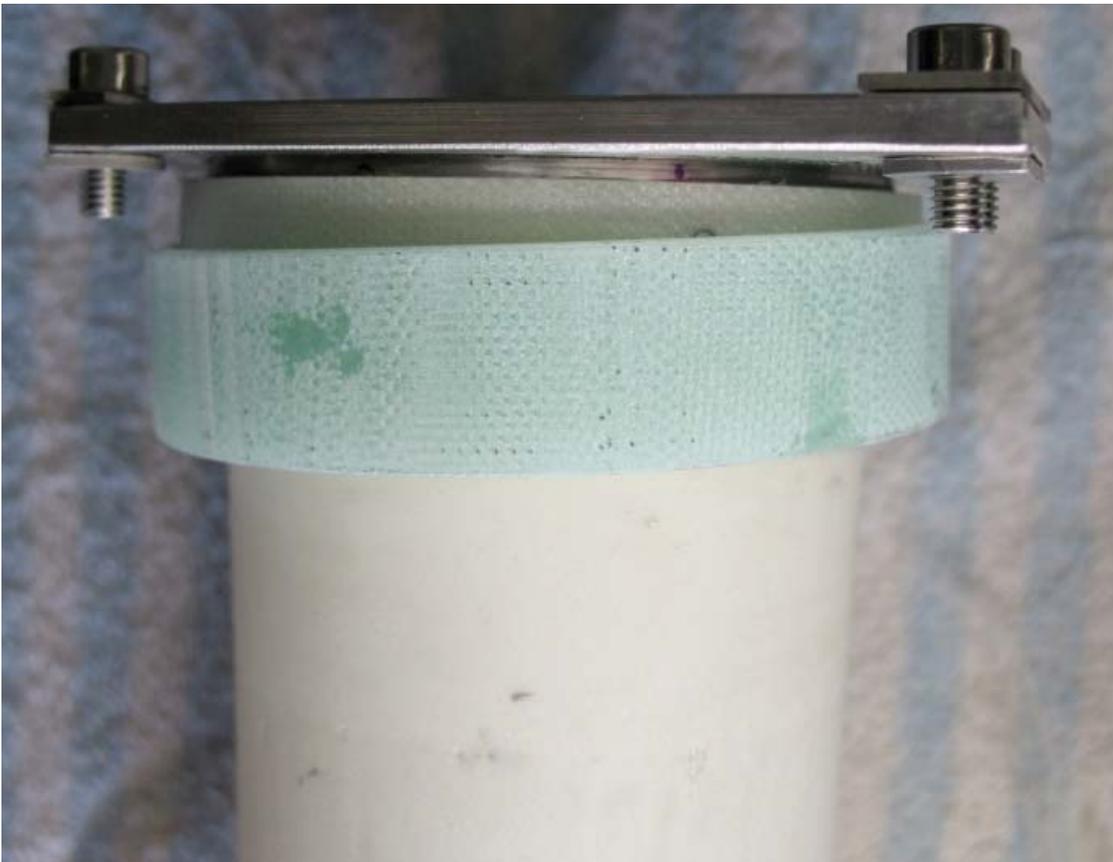


Inspection of the exhaust side of the BD03 flight-like assembly revealed nothing unusual either.





The only thing of note was that the external collar on the Telescoping Tube was found to be at an angle. This may have occurred during removal from the test set-up. It was realigned and the entire assembly will be reused in Test #8.



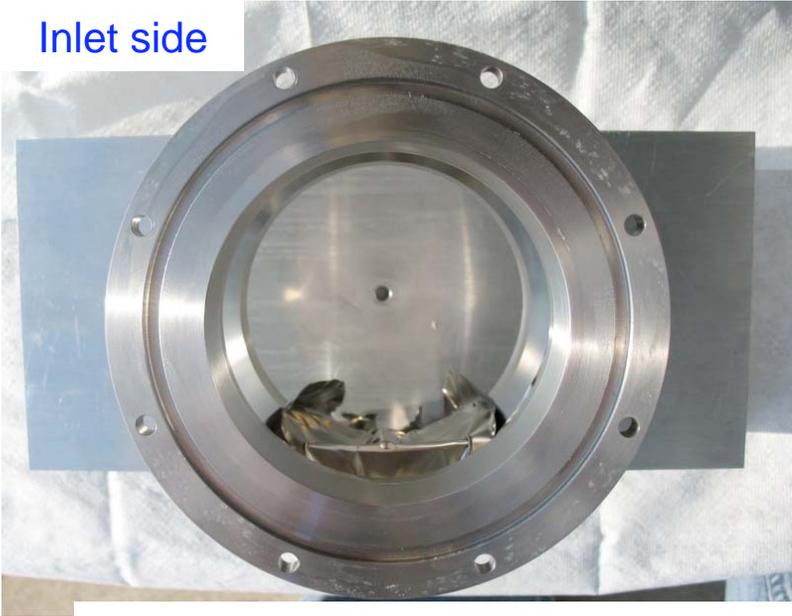


This is the detached BD03 membrane from the test at Culham installed on top of the BD radiation shield prior to the test.

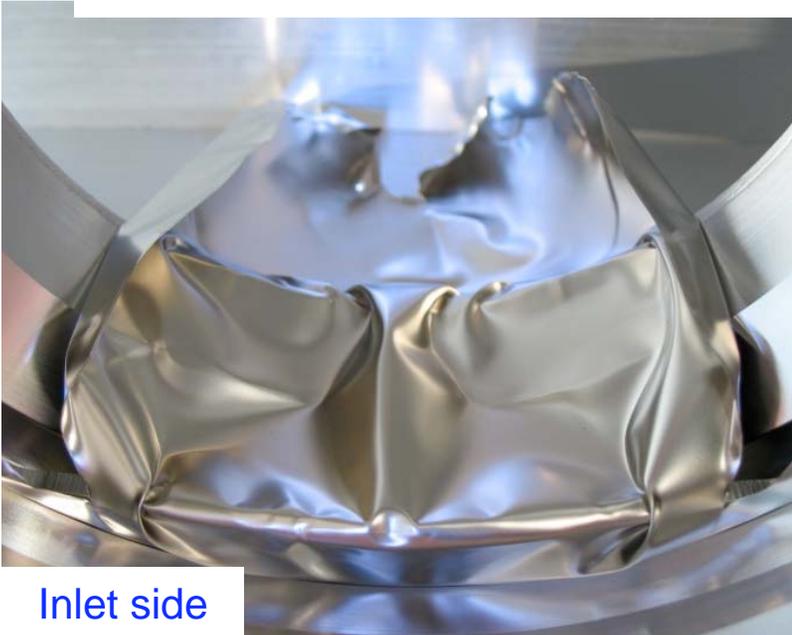
This imprint is from the Cernox temp sensor housing.



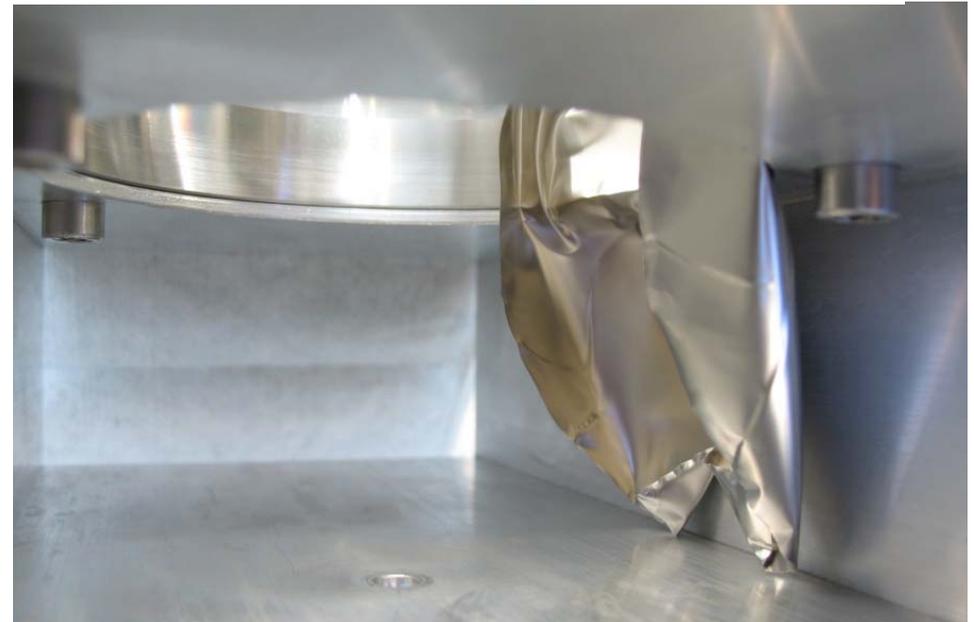
Inlet side



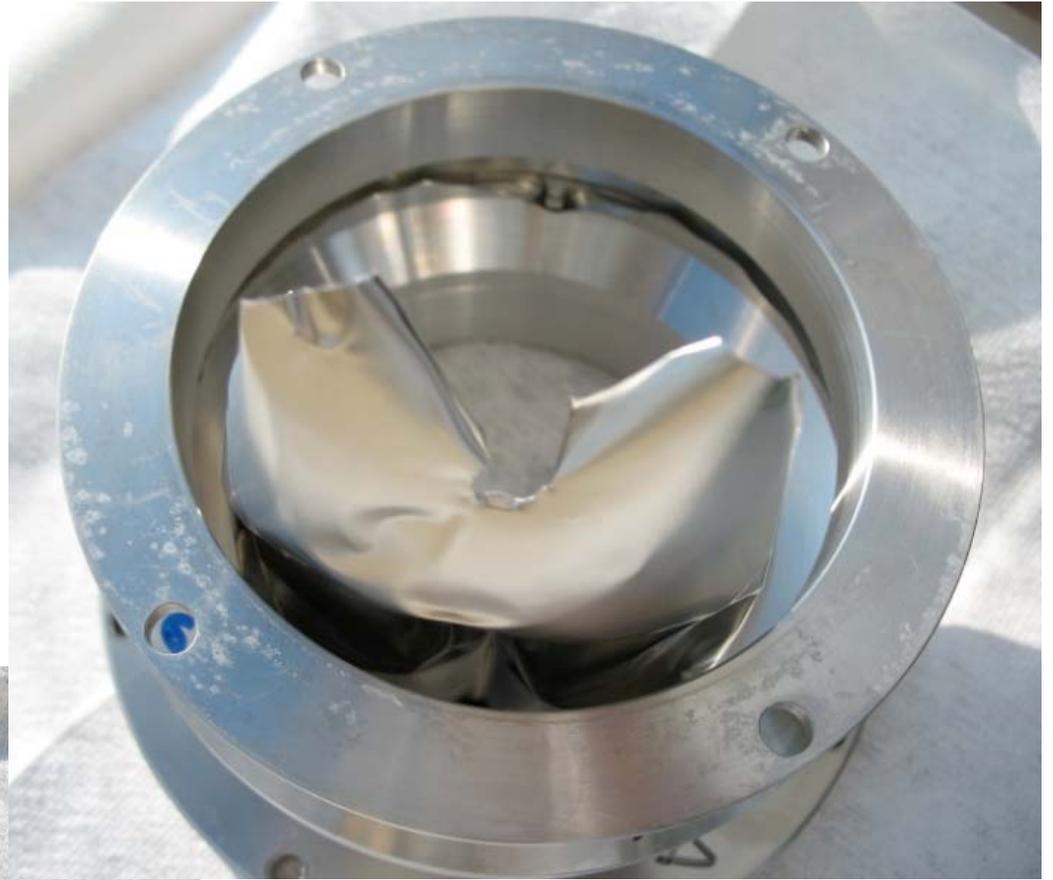
The new BD06A flight-like assembly performed as expected. The membrane folded back at the hinge line but remained attached. The membrane caused minimal obstruction to the shortened Zero-thrust Tee.



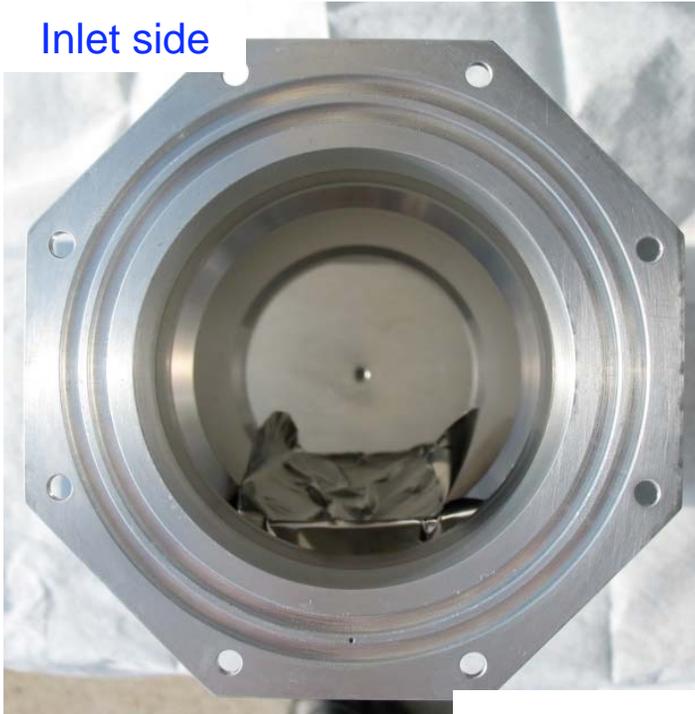
Inlet side



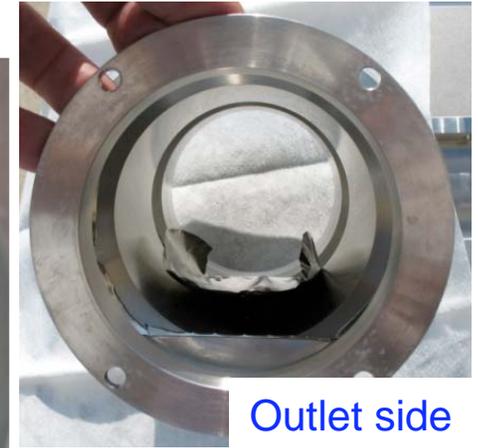
Views of the BD06A
assembly outlet side
with the Zero-Thrust
Tee removed.



Inlet side



Outlet side



Outlet side

"B" disc removed prior to test.

The BD06B assembly was a previous BD07A/B assembly with the "B" disc removed.

Outlet side



Inlet side

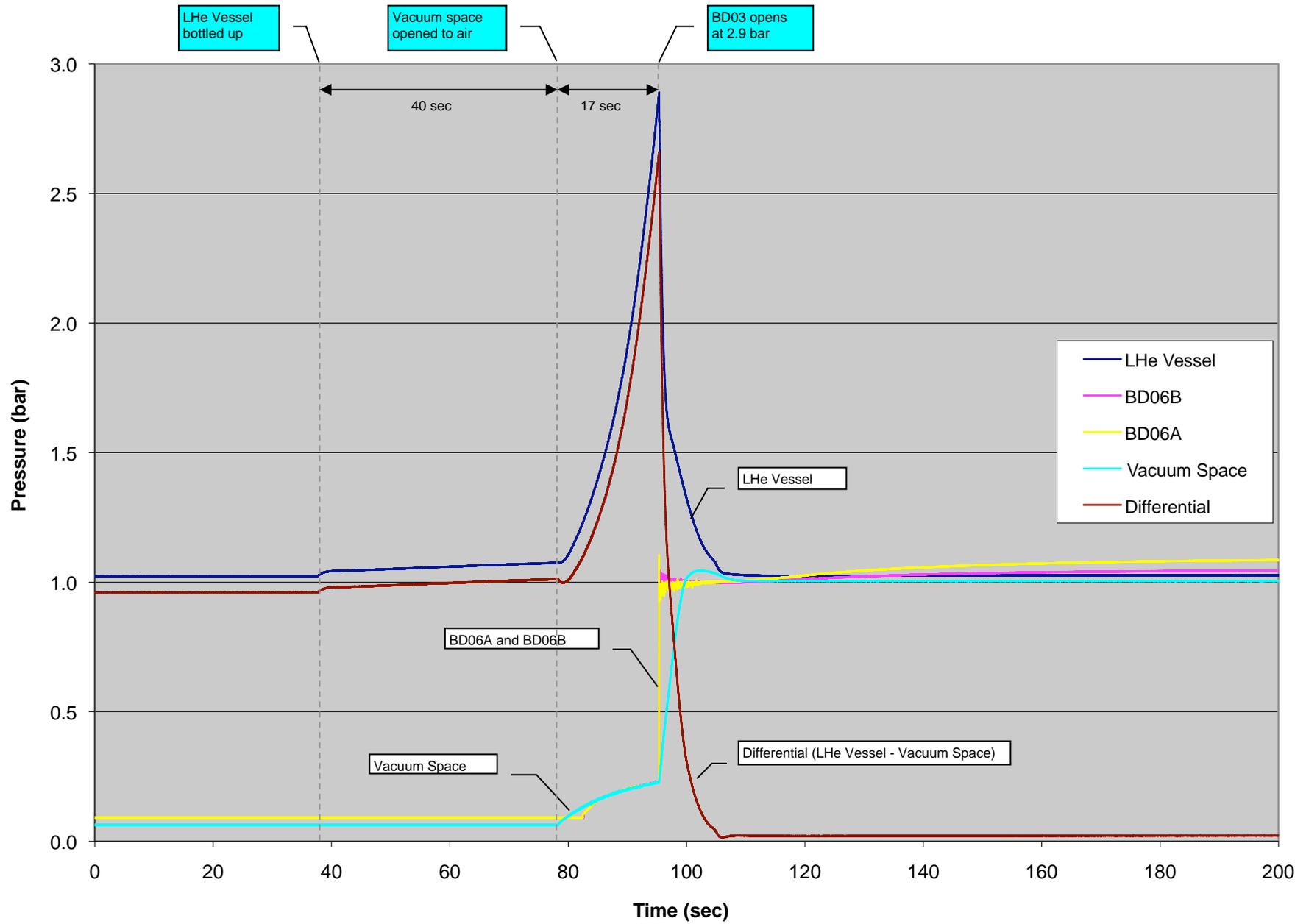




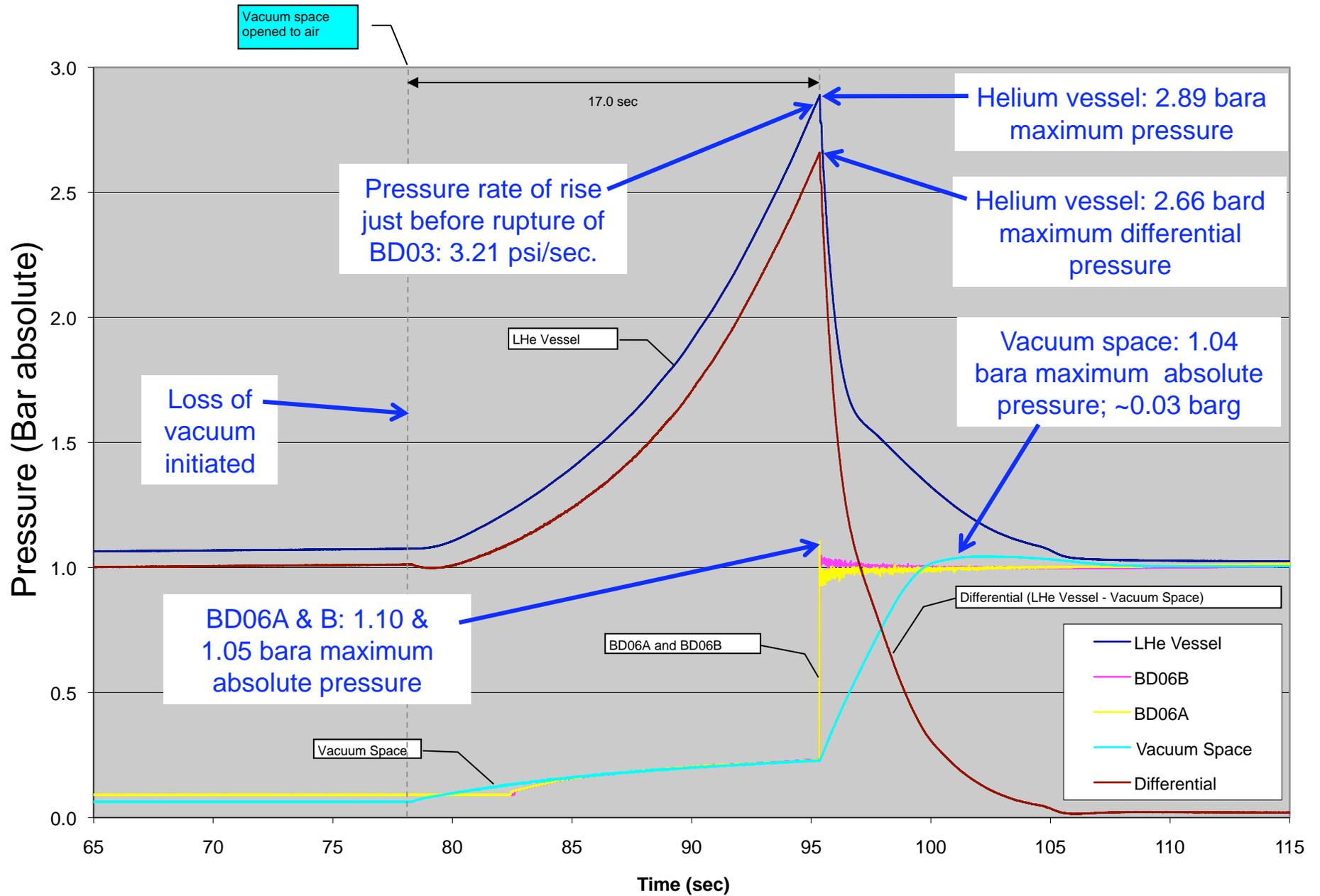
A large fan was placed under the test hardware to accelerate the drying prior to reassembly for Test #8.



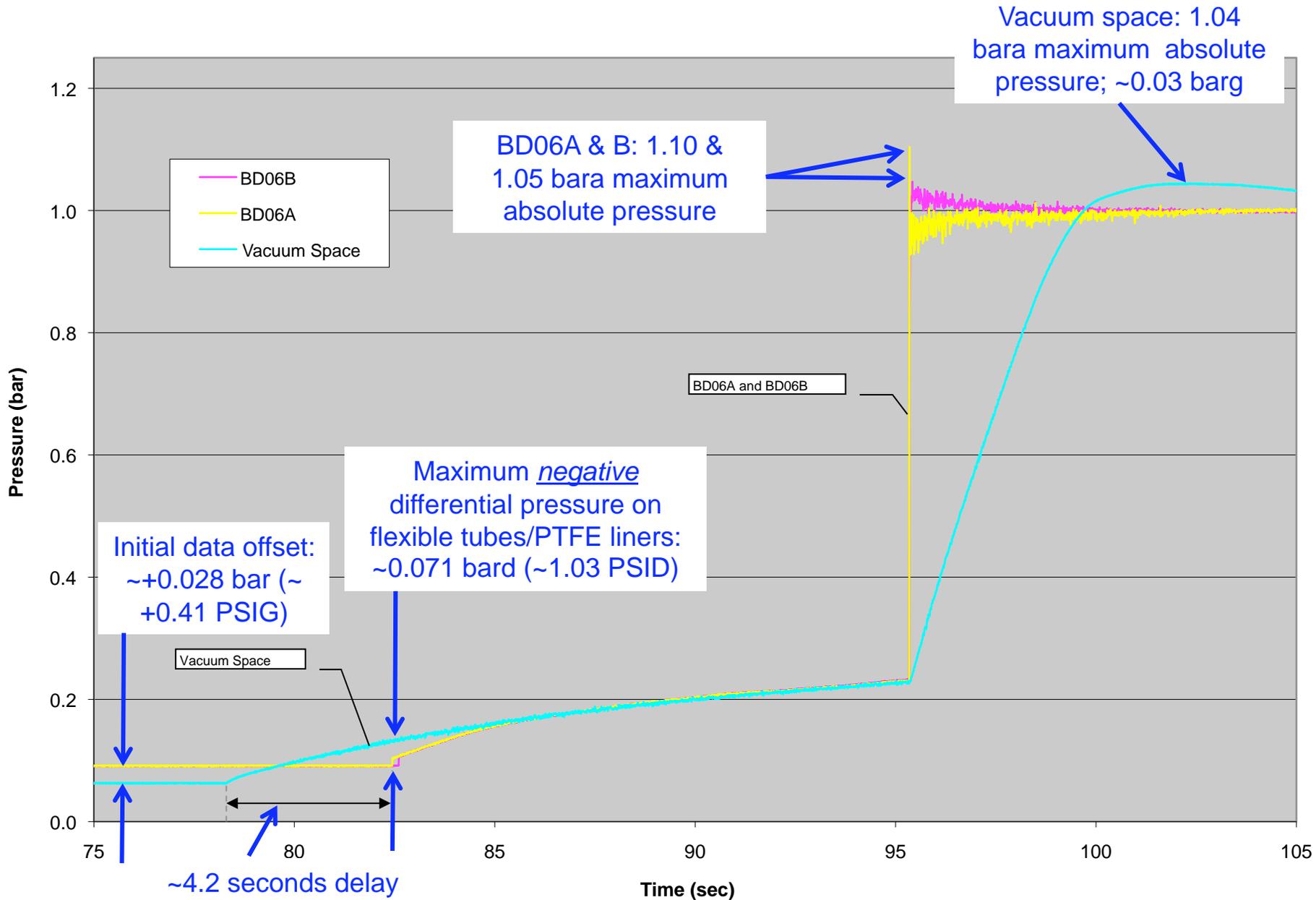
Burst Disc Test 7B Raw Data



Burst Disc Test #7B Preliminary Data



Burst Disc Test 7B
Raw Data



Test #7B Results & Conclusions

- The same 0.5" (12.7 mm) orifice used in Test #7A was used in Test #7B.
- The LHe vessel was bottled up and self-pressurization increased the pressure from one atmosphere to ~1.08 bara over the next ~40 seconds.
- Then a 1" ball valve was opened to the 0.5" orifice to allow humid ambient air into the vacuum space. The vacuum space pressure began to rise immediately and had reached a peak of ~0.23 bara when BD03 ruptured. This pressure would have risen *much* faster without the cryopumping onto the cold mass inside. (See slides 40 & 41.)
- The LHe vessel pressure rise began to accelerate ~0.7 seconds after breaking the vacuum.

Test #7B Results & Conclusions (continued)

- The BD06A/B pressures began to rise ~4.2 seconds after breaking the vacuum. This is an improvement over the ~6.4 second delay in Test #7A.
- After ~17.0 seconds, BD03 burst when the LHe vessel pressure reached 2.89 bara. The differential pressure between the LHe vessel and the vacuum space was 2.66 bard, which is less than the 3.0 bard maximum design requirement.
- The pressure rise rate in the LHe vessel during the last 0.1 second prior to BD03 rupture was 0.222 bar/sec = 3.213 psi/second.
 - This compares to 3.293 psi/sec in the LHe vessel in test #7A...which is quite consistent.
 - This also compares to 4.993 psi/sec in the LHe vessel in test #6 and 6.179 psi/sec in the Buffer vessel. This again supports the theory that the hardware was over-tested in test #6.
 - Thus, both Test #7A & #7B were still conservative when compared to the flight hardware, but as predicted, less conservative than test #6.
 - Test #8 will be run the same way as #7A & #7B.

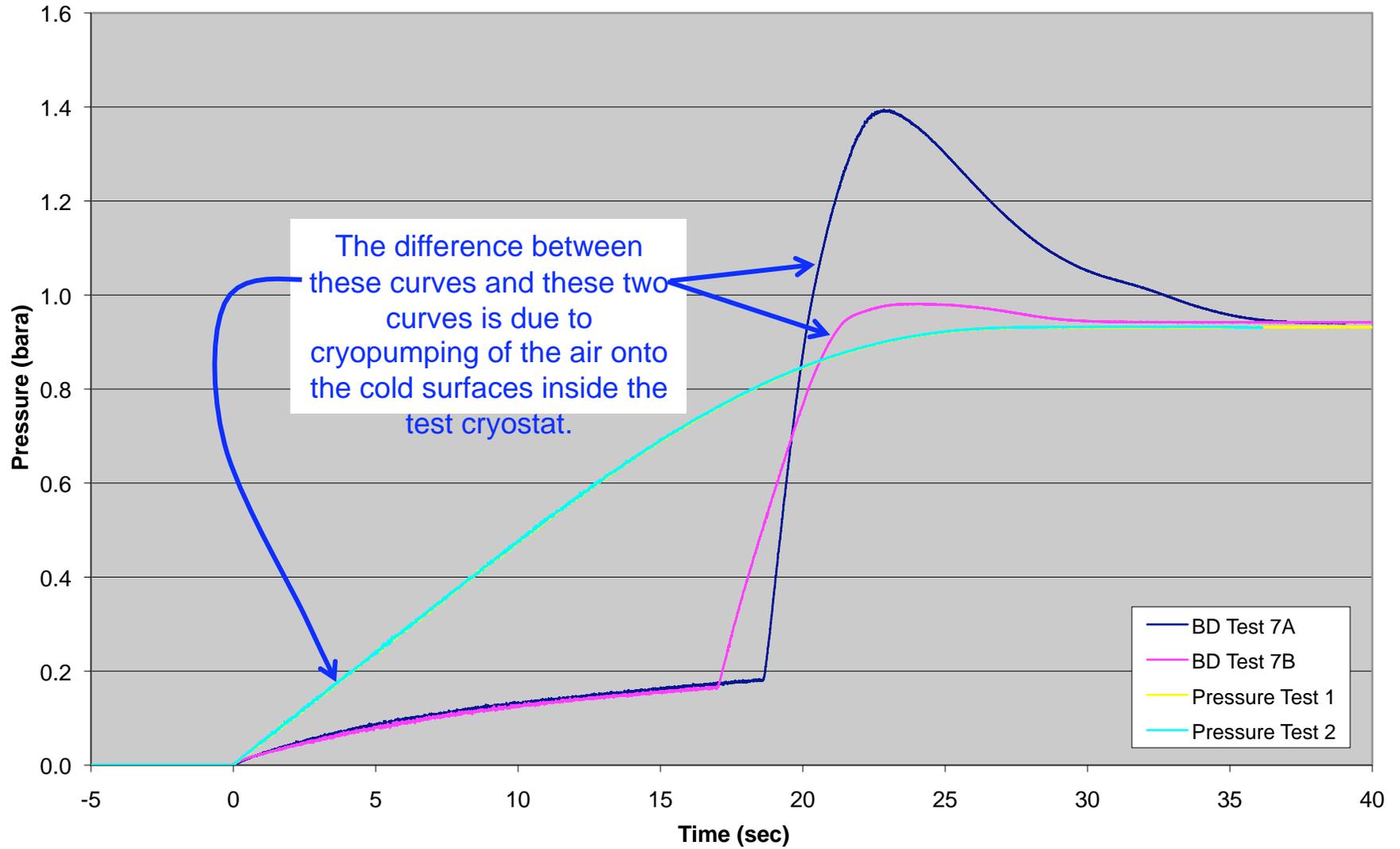
Test #7B Results & Conclusions (continued)

- The pressures on the BD06A & B transducers spiked at only 1.10 & 1.05 bara respectively (compared to 2.39 & 2.43 bara in Test #7A). This indicates the choke point is back near where it should be – at BD03. Within ~0.02 seconds BD06A & B ruptured simultaneously. This was also observed in the video recording of the event.
- After the burst, the vacuum space reached a peak pressure of only 1.04 bara or 0.03 barg. (It reached 1.46 bara in Test #7A.) **This compares very favorably with the BD07 rating of 0.56 to 0.80 barg.** Note that there was no other way of venting the vacuum space at this pressure like the lift-off plate in test #6.
- As agreed after Test #7A, 1/8” diameter vent holes were drilled in the Angled Adapters to reduce the negative differential pressure on the PTFE Liners inside the ortho-fabric Flexible Tubes.
 - The test results indicate the PTFE negative differential pressure was reduced from ~1.49 PSID in Test #7A to ~1.03 PSID in Test #7B.
 - The reaction time from loss of vacuum initiation was also reduced from ~6.4 seconds to ~4.2 seconds.

Test #7B Results & Conclusions (concluded)

- Test #8 will be conducted using all flight-like discs in a similar manner as Test #7A & #7B. However, this test will not have the separated membrane from the failed flight-like disc at SCL installed on top of the BD radiation shields.
- Test #8 will use the same orifice for the loss of insulating vacuum as test #7A & #7B.
- Two calibration runs with the cryostat warm were also done to establish a baseline for how long it takes for the vacuum space to repressurize with no cryopumping and no burst discs.
 - The results of these calibration runs are labeled “Pressure Test #1” & “Pressure Test #2” on the next slide. As can be seen, the two calibration runs are virtually identical.
 - The two vacuum space pressurization curves from Tests #7A & #7B are also plotted so the difference due to cryopumping onto the cold surfaces can be seen. Test #8 will also be added to these results.
 - From these test results, the heat load due to cryopumping can be calculated. V. Datskov has already begun this work.

Vacuum Space Pressurization



Enclosure 11

Memorandum



To: Jacobs Sverdrup

From: S Harrison

Attention: Chris Tutt

Date: 8 September 2009

Re: AMS ground venting calculations

CC:

Introduction

The venting calculations are based on classical thermodynamics. The heat flux under loss of vacuum conditions for a vessel insulated with CryoCoat Ultralight was determined empirically in a series of experiments. This work was peer reviewed and published in *IEEE Transactions on Applied Superconductivity*, Vol. 12, No. 1, pp. 1343-1346, and can be downloaded from www.scientificmagnetics.co.uk/technical.htm.

Isochoric Heating

Consider a vessel initially filled with superfluid helium in an insulating vacuum. At some time $t = 0$ the vacuum is catastrophically broken, and the vacuum space fills with air. The condensation and gas conduction lead to a heat flux on the surface of the helium vessel of 4.4 kW/m^2 . The helium is heated isochorically (Figure 1), and the pressure rises until it exceeds the set pressure of the burst disc.

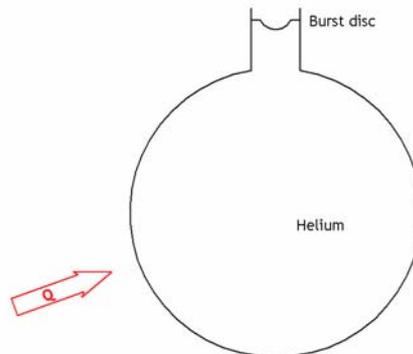


Figure 1

The energy balance is

$$Q = \frac{d(M_H u_H)}{dt}$$

where Q is the heat input, M_H is the mass of helium in the vessel, and u_H is the specific internal energy of the helium. Since the mass and density are constant, the internal energy and therefore the pressure of the helium can be calculated.



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In the specific case of the AMS helium vessel, the volume is approximately 2500 litres, and the surface area is around 19 m². If the vessel is initially filled with superfluid helium to a level of 95%, it will contain 2375 and 125 L of saturated liquid and vapour respectively. The relevant thermodynamic properties of saturated helium at 1.8 K are given in Table 1 below.

<i>Property</i>	<i>Liquid</i>	<i>Vapour</i>
Pressure (mbar)	16.38	
Density (kg/m ³)	145.4	0.4547
Specific internal energy (J/kg)	830.89	20,597.46

The overall mass, density, and internal energy of the helium are initially 345.42 kg, 138.17 kg/m³, and 288.1 kJ. (Note that the heat capacity of the aluminium vessel itself is negligible at this temperature.) To raise the pressure to 3 bar (the burst disc set pressure) without mass transfer, the specific internal energy has to be increased to 7,374.9 J/kg. The energy transfer required (the product of the change in specific internal energy and mass) is therefore 2.259 MJ.

The experiments referred to above demonstrated that the heat flux during loss of vacuum is fairly constant. With 4.4 kW/m² acting over the whole surface of the helium vessel, the time taken to transfer 2.259 MJ to the helium is 27 seconds. This is the elapsed time between the loss of vacuum event and the opening of the burst disc, leading to venting of the helium from the cryostat.

Helium Venting

Once the burst disc has opened, the pressurised helium vents into the atmosphere (Figure 2).

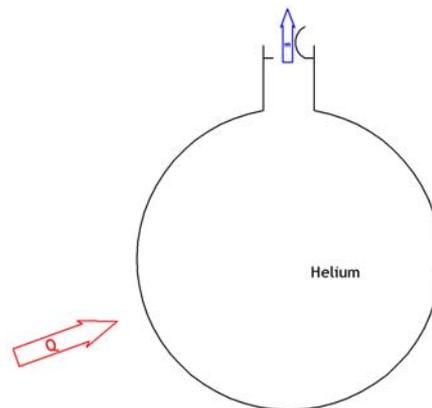


Figure 2

It is first necessary to calculate the flow rate of helium out of the vessel. As it is vented, the helium expands isentropically to the environmental pressure (1 atmosphere). The velocity of the venting gas is then related to the change in the enthalpy as follows.

$$\Delta h = \frac{1}{2} V^2$$

Continuing the AMS example above, at the instant of burst disc rupture the helium entropy is 3,093.13 J/kg-K, and the enthalpy is 9,546.21 J/kg. Expanding the helium at constant entropy to 1 atmosphere, the enthalpy falls to 8,085.525 J/kg, and the density to 133.72 kg/m³. The velocity of the venting helium is therefore 54 m/s, and the mass flux is 7,228 kg/m²-s. Since the diameter of the helium vent is 45 mm, the initial venting rate is 11.5 kg/s.

The energy balance on the helium in the vessel is now more complicated: energy continues to be added due to the condensation of air on the surface, but the venting helium also removes energy:

$$Q = \frac{d(M_H u_H)}{dt} - \dot{m} h_H$$

where \dot{m} is the flow rate of helium out of the cryostat, and h_H is the enthalpy of the helium.

$$Q = u_H \frac{dM_H}{dt} + M_H \frac{du_H}{dt} + \dot{m} h_H$$

but $\frac{dM_H}{dt} = -\dot{m}$

so $M_H \frac{du_H}{dt} = Q - \dot{m}(h_H - u_H)$

Knowing the properties of helium (available from commercial software), this equation can be iterated numerically to “time-march” a solution from a set of initial conditions. Figure 3 below continues the development of pressure and flow rate from the initial conditions used to illustrate the calculations above.

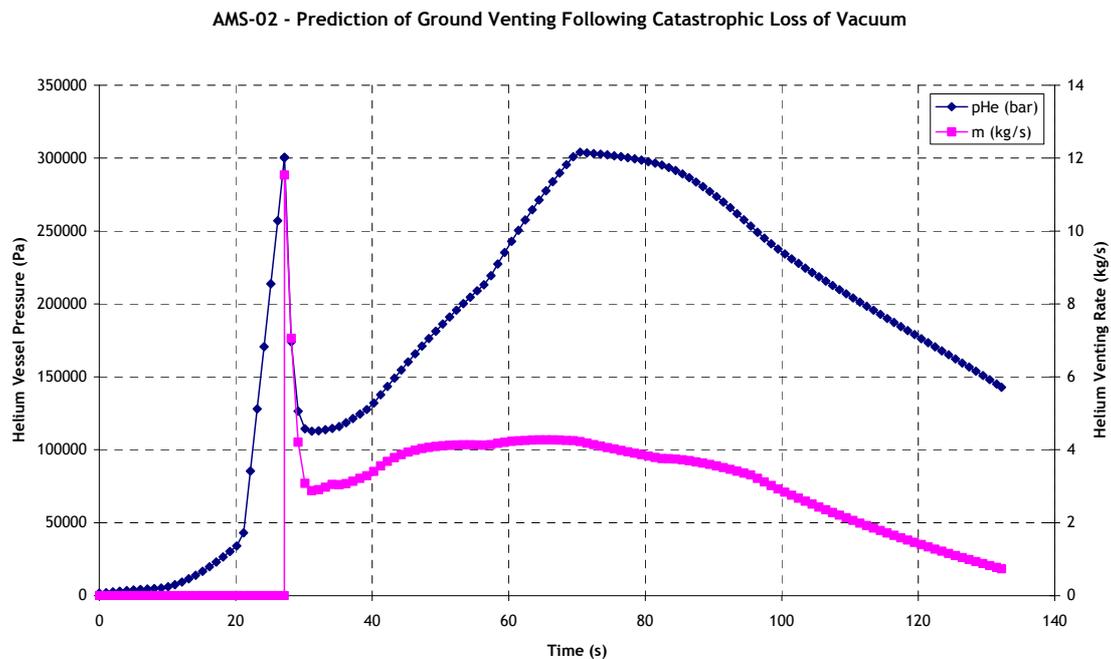


Figure 3