Agenda – Day 1

November 18, 2014 (Day 1)		
Time (CST)	**Topic**	**Presenter**
8:00 – 8:30 am	Registration, Welcome and Introductions	
8:30 – 9:15 am	History and Manufacture of the EDU	Arthur Werkheiser
9:15 – 10:00 am	Multi-Layer Insulation (MLI)	Jessica Wood
10:00 – 10:15 am	BREAK	
10:15 – 11:30 am	Thermal Analysis of EDU	Tim Page
11:30 – 1:00 pm	LUNCH	
1:00 – 1:45 pm	Radio Frequency Mass Gauge (RFMG)	Greg Zimmerli
1:45 – 2:45 pm	Pressurization Test Results	Jonathan Stevens
2:45 – 3:15 pm	Fill model	Ali Hedayat
3:15 – 4:00 pm	Cryogenic Isolation Valves	Becky Crownover
4:00 – 4:20 pm	Liquid Acquisition Device (LADs)	Arthur Werkheiser
4:20 – 4:45 pm	Thermal Venting System (TVS)	Joe Zoeckler
4:45 – 5:00 pm	Success Criteria and Wrap-up	Arthur Werkheiser
	Adjourn to the Firehouse Pub	

Evolvable Cryogenics (eCryo) Project
Technology Workshop with Industry

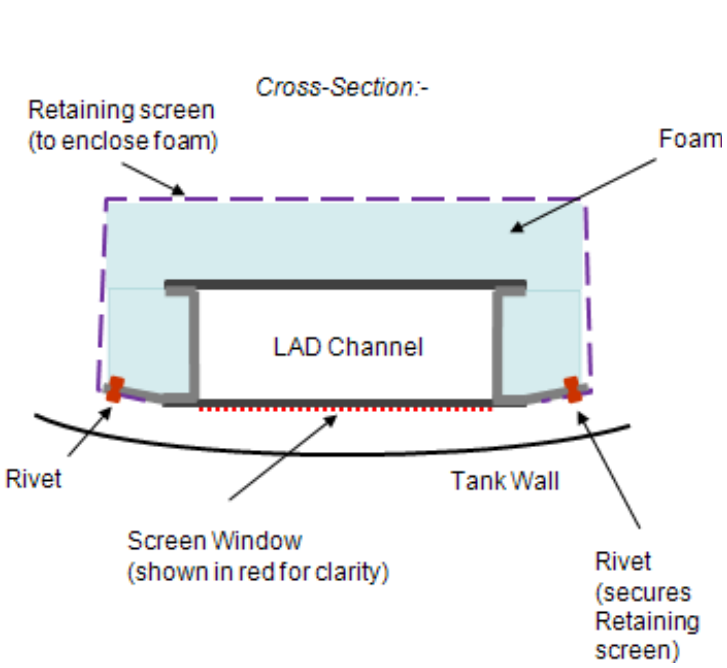
Engineering Development Unit (EDU) Workshop

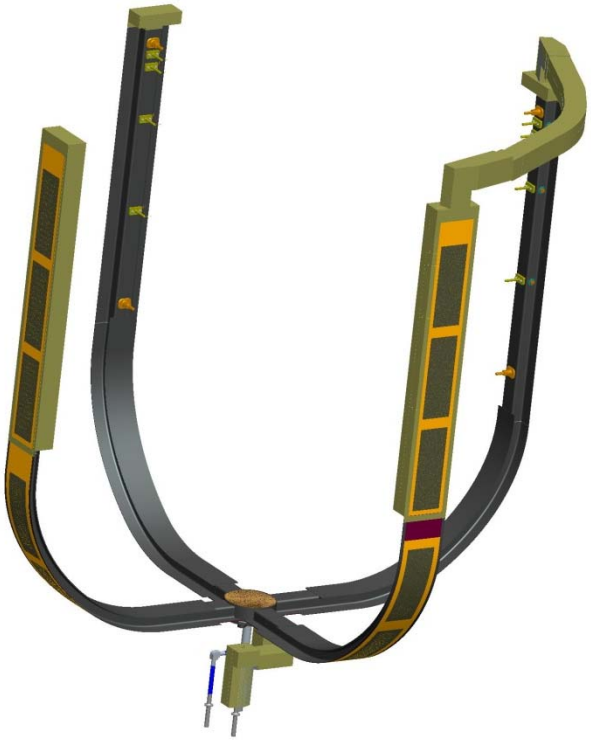
Liquid Acquisition Device (LADs)

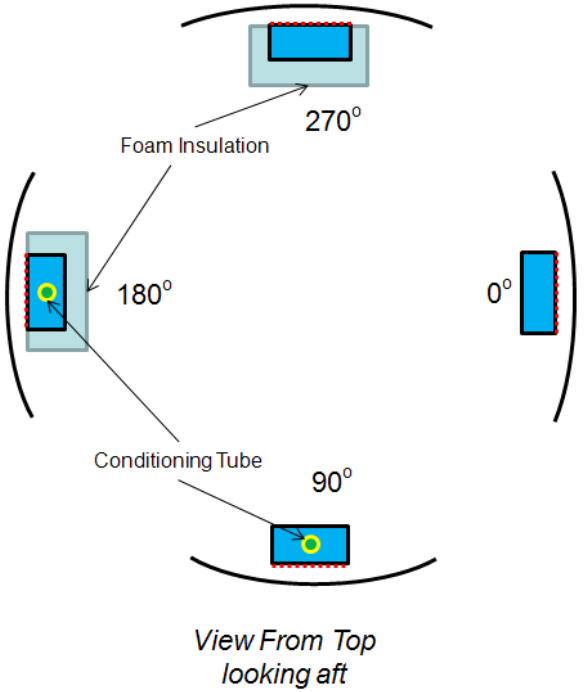
Arthur Werkheiser

GTA Storage Tank LAD Configuration

- Utilizes screen channel gallery arms
- Screen size: 325 x 2300 (based on seam welding capability)
- Truncating LAD arms at the top of the storage tank barrel allows us to collect data for a longer period of time before the arms break down
- Four (4) different LAD configurations to determine the best method for mitigating heat transfer into LAD arms

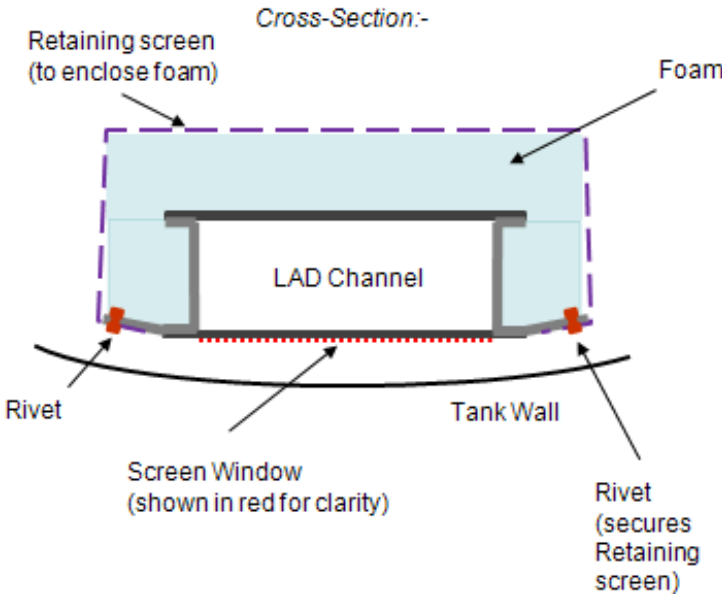


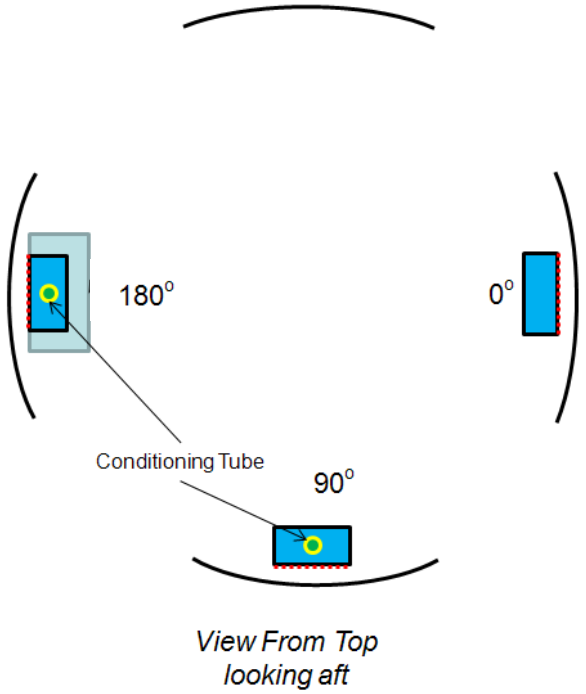




EDU Storage Tank LAD Configuration

- Utilizes screen channel gallery arms
- Screen size: 325 x 2300 (based on seam welding capability)
- Truncating LAD arms at the top of the storage tank barrel allows us to collect data for a longer period of time before the arms break down
- *Three (3) different LAD configurations to determine the best method for mitigating heat transfer into LAD arms*

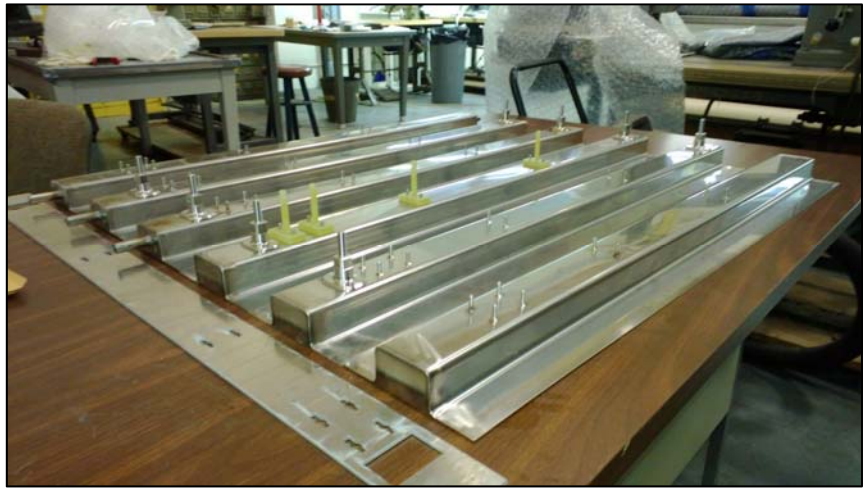




LAD Manufacture

Curved Arm Perforated Plate/Screen Assembly

Back Side – LAD Straight Sections

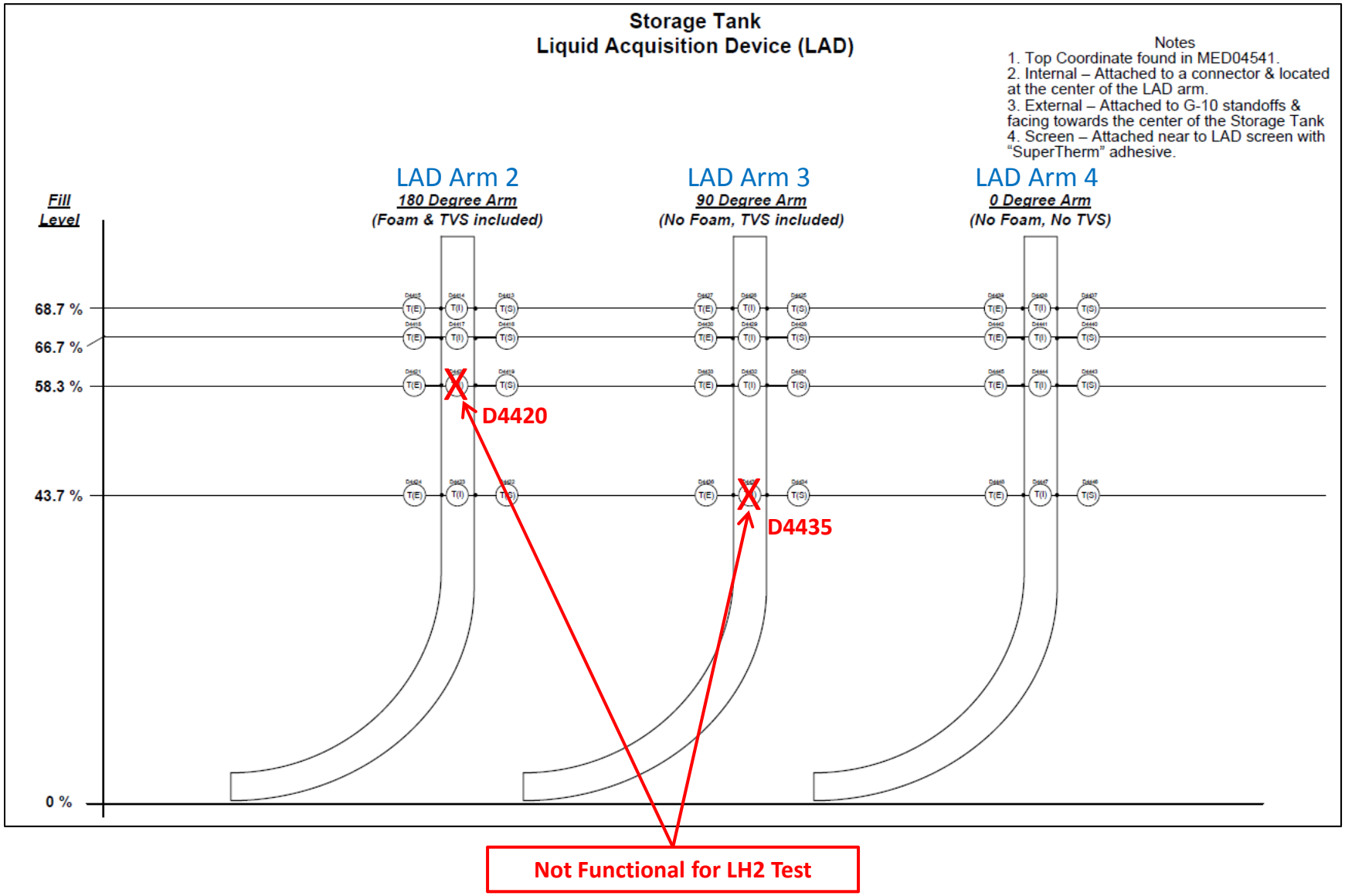


Screen Side – LAD Straight Sections

LAD Assembly/Installation

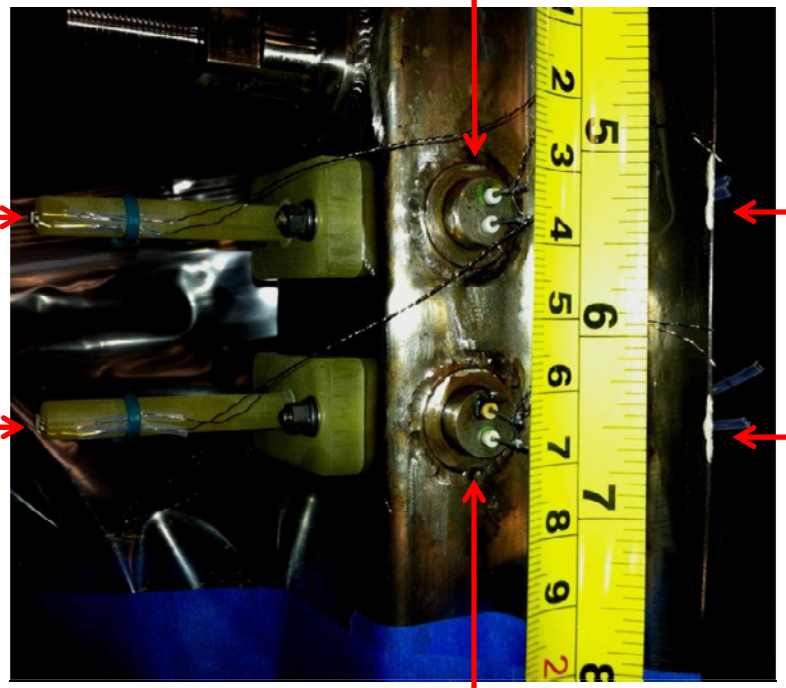
LAD Diode Placement

CPST EDU Schematic Rev B



Physical Location – LAD Diodes

LAD Arm 4
68.7% and 66.7% Locations
Stations A and B



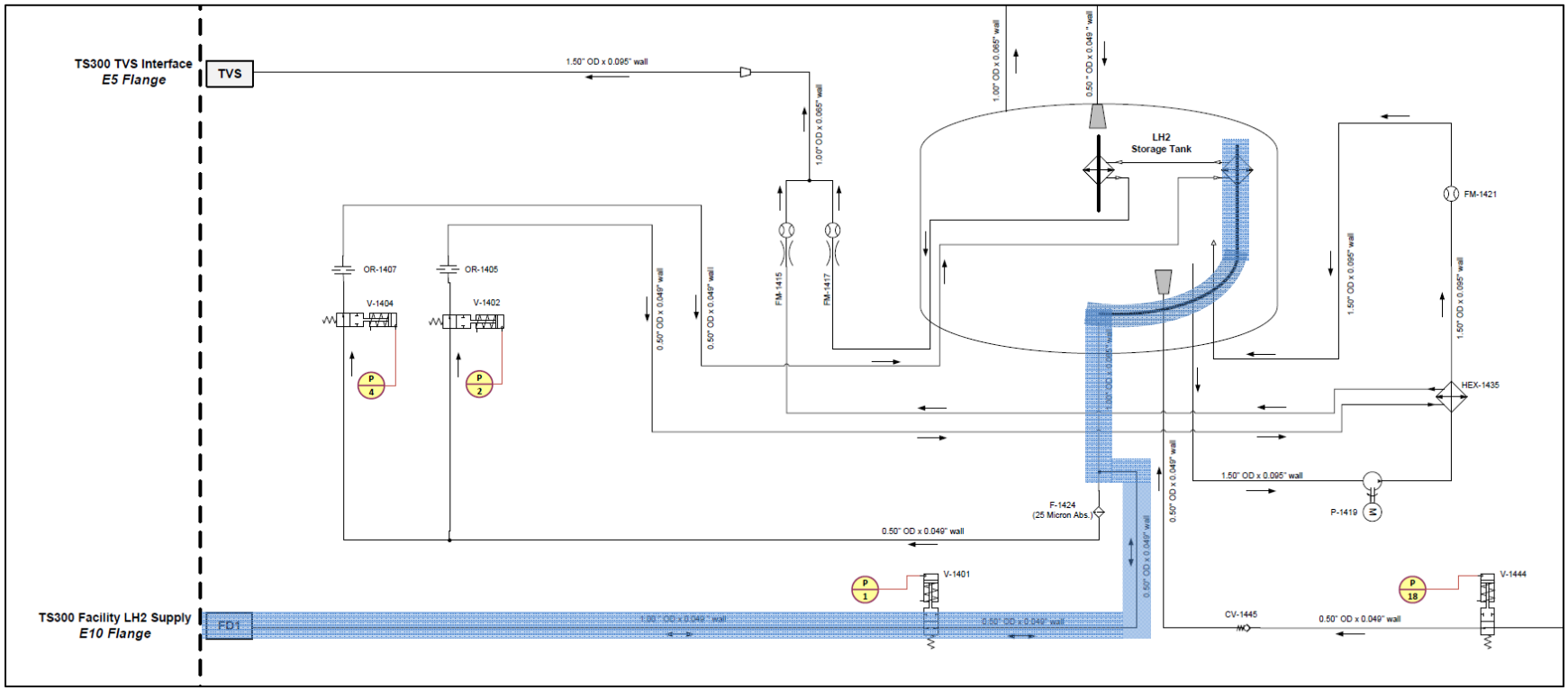
Diode Not Functional for LH2 Test

Diodes Shown in Picture

			LAD Arm 2			LAD Arm 3			LAD Arm 4		
Station Level	Fill Level	Distance from Tank Bottom	180 Degree Arm			90 Degree Arm			0 Degree Arm		
			Screen	Internal	External	Screen	Internal	External	Screen	Internal	External
A	68.7%	85.2"	D4413	D4414	D4415	D4425	D4426	D4427	D4437	D4438	D4439
B	66.7%	80.2"	D4416	D4417	D4418	D4428	D4429	D4430	D4440	D4441	D4442
C	58.3%	77.3"	D4419	D4420	D4421	D4431	D4432	D4433	D4443	D4444	D4445
D	43.7%	76.4"	D4422	D4423	D4424	D4434	D4435	D4436	D4446	D4447	D4448

Storage Tank Fill/Drain Operation

- The excerpt from the CPST EDU Schematic Rev B below shows the fill/drain flow path.
- All storage tank fill and drain operations are through the LADs. There is not an alternate path for either fill or drain operations.



Test Events

- Data is presented on the following test events:
  - Test Day 1: Tank Fill
  - Test Day 8: LAD Break Down During Storage Period
  - Test Day 13: LAD Outflow #1
  - Test Day 19:
    - Nucleate Boiling Test
    - LAD Outflow #2
    - LAD Outflow #3
    - LAD Outflow #4
  - Test Day 20:
    - LAD Outflow #5
    - LAD Outflow #6

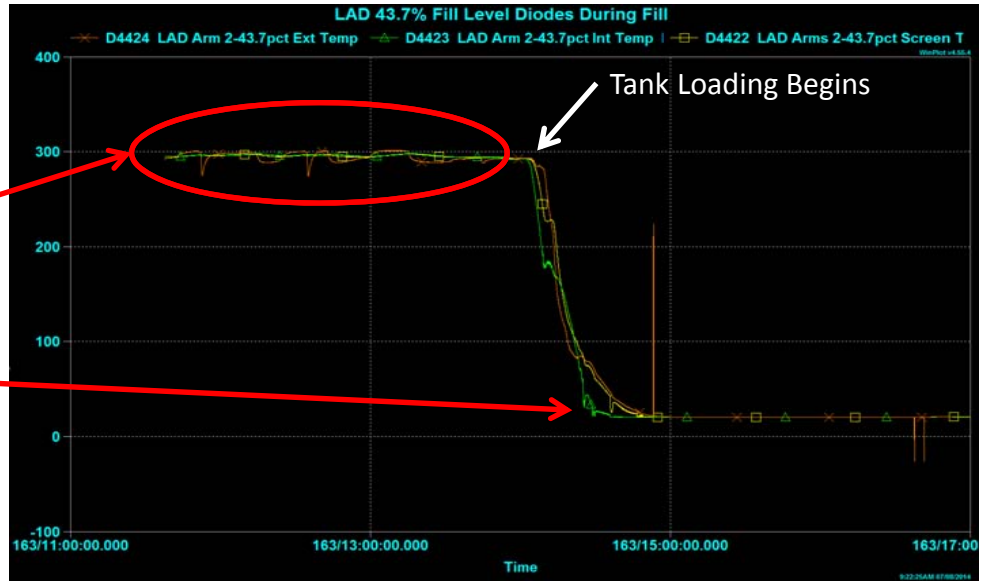
LAD Break Down Summary

- The 61 minute total time from uncover to break down for LAD Outflow #5 is the longest hold period in 1g of any data we have seen published.

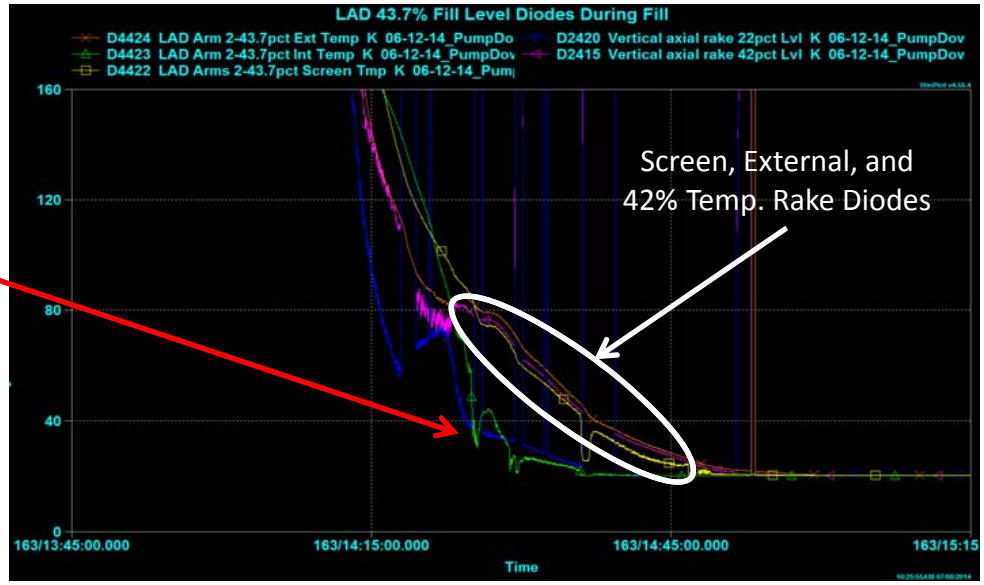
Test Day	Event	Fluid Level (CP%)	Holds	Pressure Source	Ullage Temp (K)	Ullage Pressure (psia)	Total Hold Before Break Down (Minutes)
8	Controlled Boiloff Test (after venting event)	66	N/A	N/A	21	15	N/A
13	LAD Outflow #1	45	N/A	AFT	22	32	29
19	LAD Outflow #2	68	N/A	FWD	42	32	<3
19	LAD Outflow #3	67	N/A	FWD	41	32	<3
19	LAD Outflow #4	55	5m @62% 5m@55%	AFT	24	32	27
20	LAD Outflow #5	45	30m@65% 5m@56%	AFT	22	23	61
20	LAD Outflow #6	67	N/A	FWD	32	23	<3

Test Day 1 – Tank Fill

- LAD Arm 2 – 43.7% Diode Data
- Helium pressure/vent cycles prior to tank loading affect the external diode most (orange).
- As expected, LAD internal diode is wetted first (green).

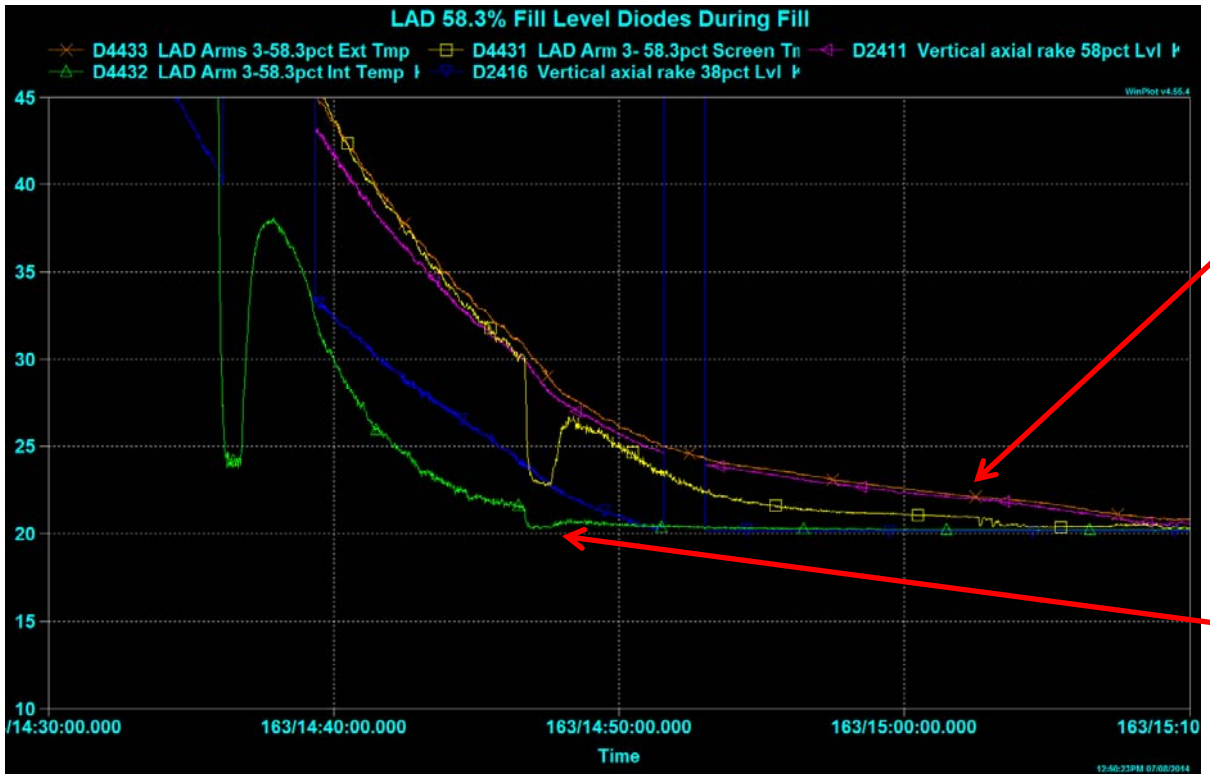


- LAD Arm 2 – 43.7% Diode Data with Temperature Rake Data
- Internal LAD diode (green) goes wet at nearly same time as 22% temperature rake diode (blue)
- LAD screen (yellow) and external (orange) diodes follow the 42% temperature rake diode (pink) as expected



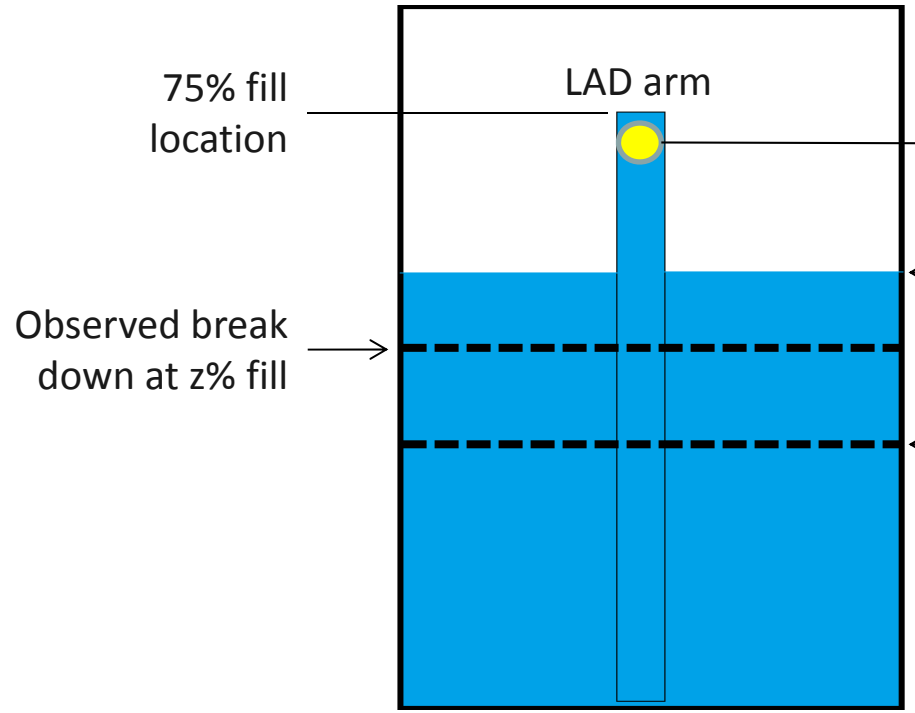
Test Day 1 – Tank Fill continued…

- LAD Arm 3 – 58.3% Diode Data with Temperature Rake Data



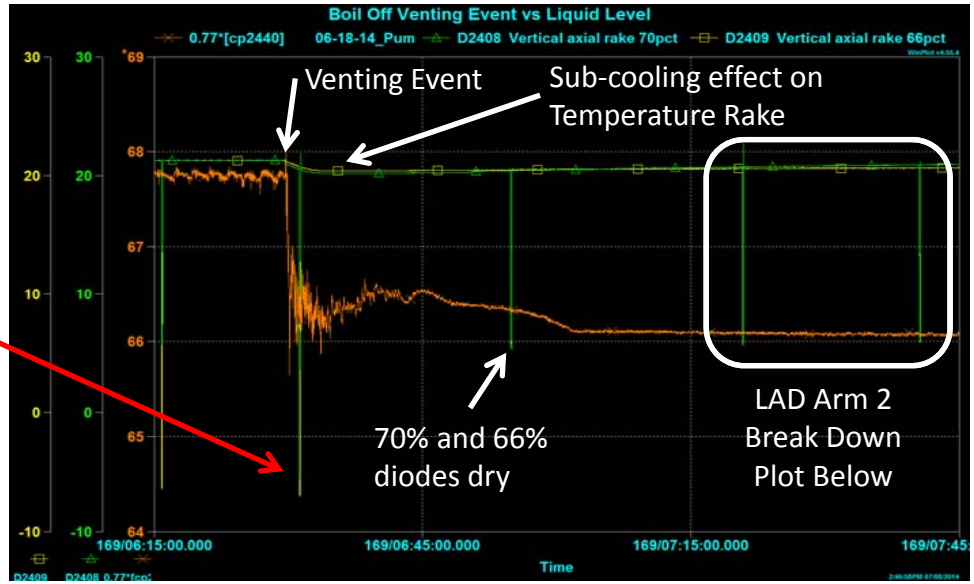
- External LAD diode (orange) follows the 58% temperature rake diode (pink) as expected
- Internal LAD diode (green) goes wet at nearly the same time as 38% temperature rake diode (blue)

LAD Break Down



Test Day 8 – LAD Break Down During Storage

- Unintentional Venting Event: Temperature Rake and Capacitance Probe Data (orange)
- Temperature Rake 70% diode (green) is dry and 66% diode (yellow) is wet at beginning of event
- 25 minutes later, both 70% and 66% diodes are dry



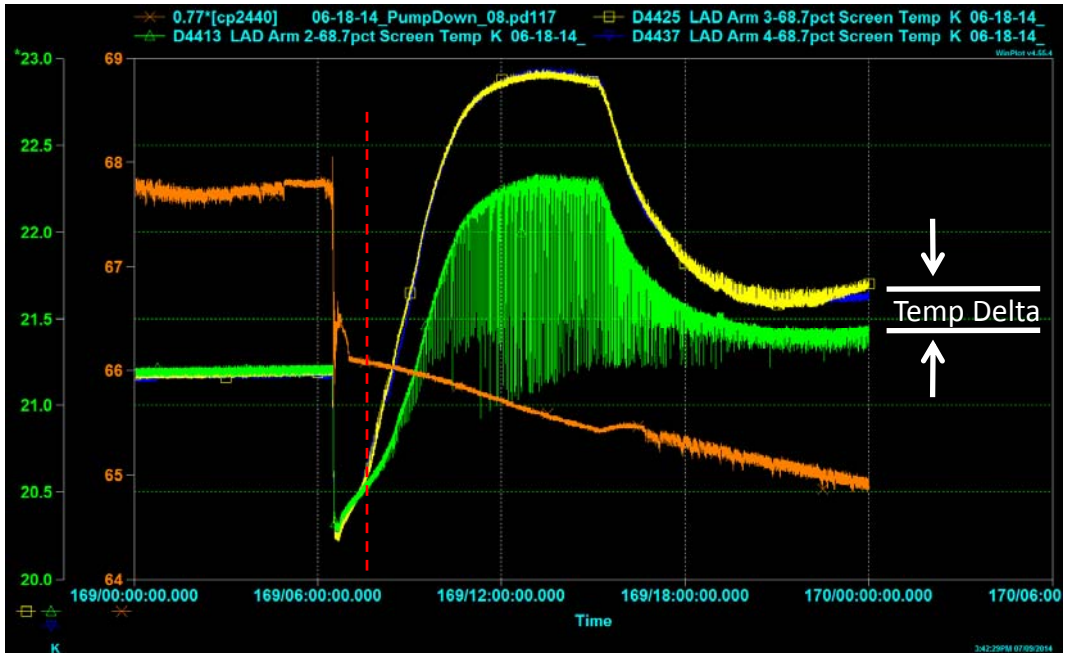
- LAD Arm 2 – 68.7% Diode Data with Capacitance Probe Data (orange)
- External diode (green) is dry and internal diode (yellow) is wet
- Internal diode goes dry on next check

Test Day 8 – LAD Break Down During Storage cont…

- The LAD arm broke down with the tank at 66% full during the unintentional venting event.

Test Day	Event	Fluid Level per Capacitance Probe (% full)
8	Controlled Boiloff Test (after venting event)	66

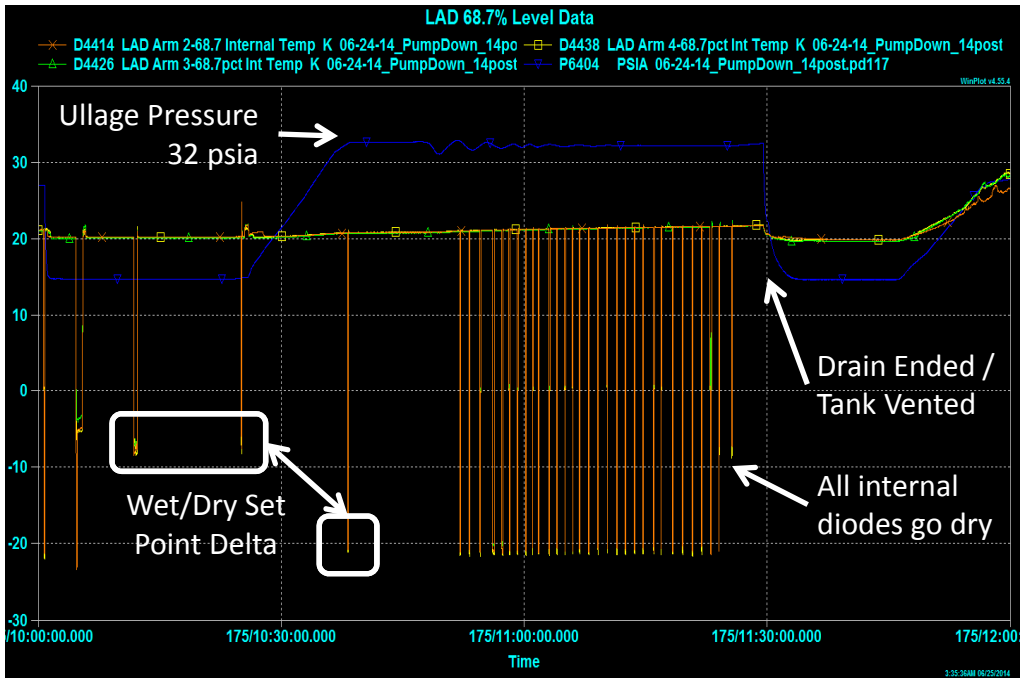
- The plot below shows the 68.7% screen temperatures of all three arms after LAD break down.
- Notice that the screen temperature of the foam covered LAD arm 2 (green) stayed cooler than the other two LAD arms (yellow/blue).



Test Day 13 – LAD Outflow #1

- LAD Outflow #1 was conducted with the ullage pressure at 32 psia using the AFT diffuser for pressurization with gaseous helium.
- Total hold time before LAD breakdown was 29 minutes.

Test Day	Event	Fluid Level per Capacitance Probe (% full)
13	LAD Outflow #1	45



- LAD Arms 2, 3 & 4 – 68.7% Internal Diode Data with Ullage Pressure (blue)
- First indication of LAD internal diode nucleation
  - Wet/dry set point dependent on pressure
  - Higher ullage pressure has lower wet/dry set point

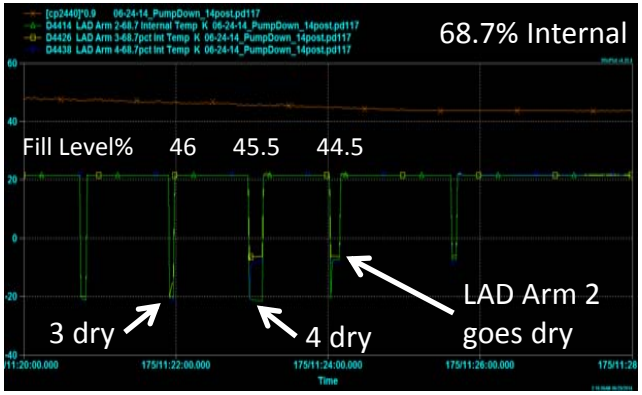
Test Day 13 – LAD Outflow #1 continued…

- LAD internal diodes are plotted with the Capacitance Probe (orange)
- Plot 1: The non-foam LAD internal diodes go dry before the foam LAD internal diode / the foam LAD arm breaks down last
  - Plot 1 & 2 Legend

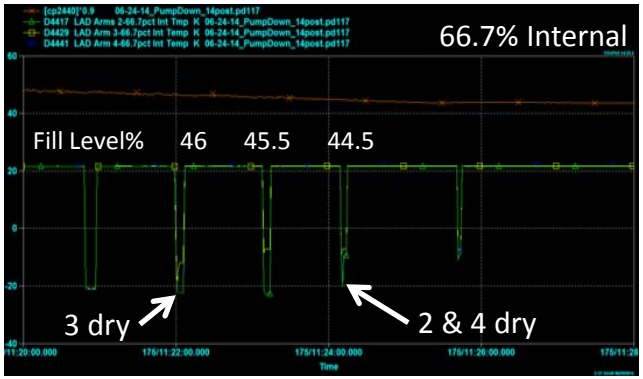
LAD Arm 2 – Foam TVS
LAD Arm 3 – TVS only
LAD Arm 4 – Bare

- Plot 2: The TVS only LAD goes dry several minutes before the Foam TVS and Bare LAD arms
- Plot 3: The TVS only LAD goes dry several minutes before the Bare LAD arm
  - Diode D4420 is not functional, so no foam LAD diode data at this level
  - Plot 3 Legend

LAD Arm 3 – TVS only
LAD Arm 4 – Bare



1



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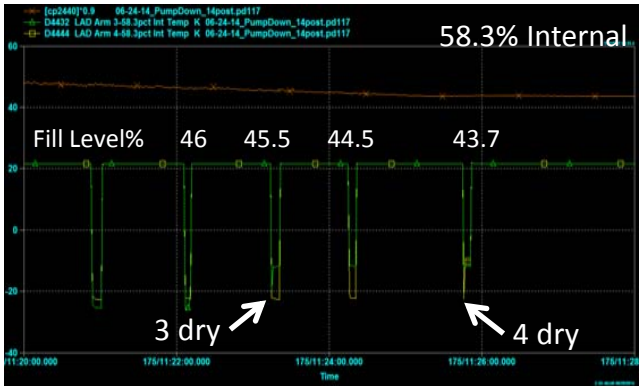
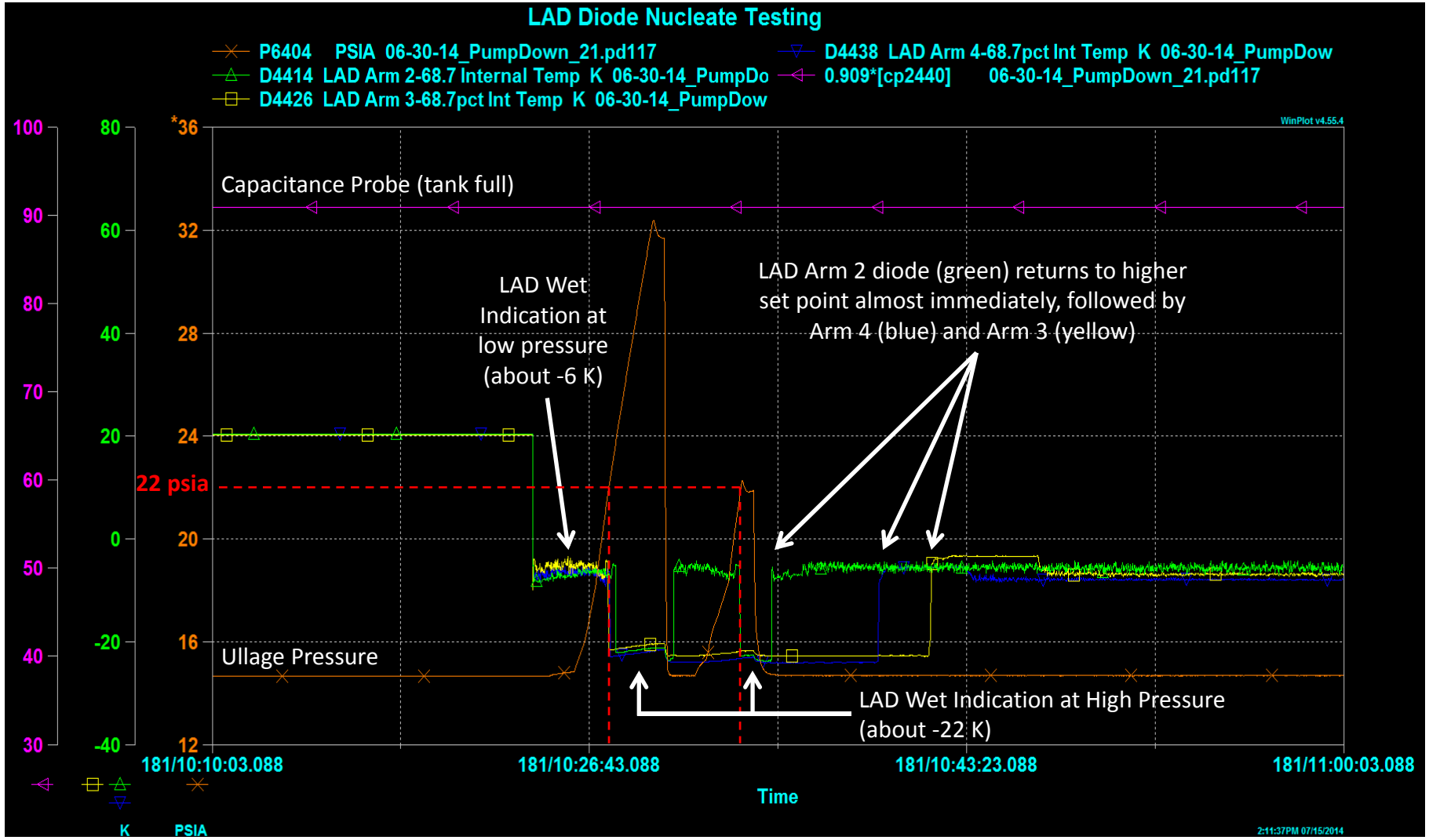


3

Test Day 19 – Diode Nucleate Boiling Test

- Due to the shift of the wet/dry transition point with ullage pressure seen on Test Day 13 during Outflow #1, a diode nucleate boiling test was conducted prior to Outflow #2.
- Determined that the transition point is an ullage pressure of approximately 22 psia for the 68.7% and 66.7% diodes (plot on next slide).
  - Test was shown to be repeatable for multiple pressurizations.
  - LAD arm 2 diode returns to higher wet set point almost immediately upon venting ullage pressure, followed by arm 4 (about 5 minutes) then arm 3 (about 7 minutes).
- The transition point for the 58.3% diodes was 18.5 psia.
  - When ullage pressure vented, diodes did not return to previous wet set point.
- The transition point for the 43.7% diodes was 18 psia.
  - When ullage pressure vented, diodes did not return to previous wet set point.
- Subsequently determined that the most efficient ullage pressure for outflow is 23 psia – conducted outflows #5 and #6 at this ullage pressure on Test Day 20.

Test Day 19 – Diode Nucleate Boiling Test cont.



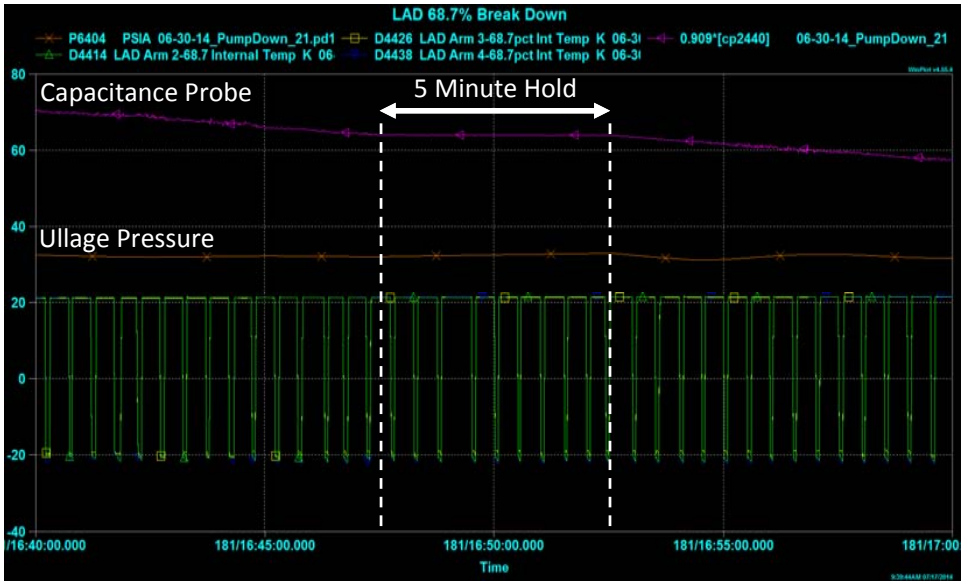
Test Day 19 – LAD Outflows #2, #3 and #4

- LAD Outflows #2 and #3 were conducted with the ullage pressure at 32 psia using the FWD diffuser for pressurization with gaseous helium.
  - Total hold time before LAD breakdown for both was less than 3 minutes.
  - Outflow #2: LAD Arms 3 (TVS) and 4 (bare) break down prior to LAD Arm 2 (Foam & TVS) – Arm 2 breakdown occurs at 68% fill level
  - Outflow #3: LAD Arms 3 (TVS) and 4 (bare) break down prior to LAD Arm 2 (Foam & TVS) – Arm 2 breakdown occurs at 67.5% fill level
- LAD Outflow #4 was conducted with the ullage pressure at 32 psia using the AFT diffuser for pressurization.
  - Outflow #4 had some hold periods in the drain; 5 minute hold at 62% fill level and 20 minute hold at 55% fill level.
  - All LAD Arms remained wet during the 62% hold.
  - LAD Arm 4 (bare) breaks down just before the 55% hold.
  - LAD Arm 3 (TVS) breaks down prior to Arm 2 (Foam & TVS) during the 55% hold.
  - Total hold time before final LAD breakdown was 27 minutes.

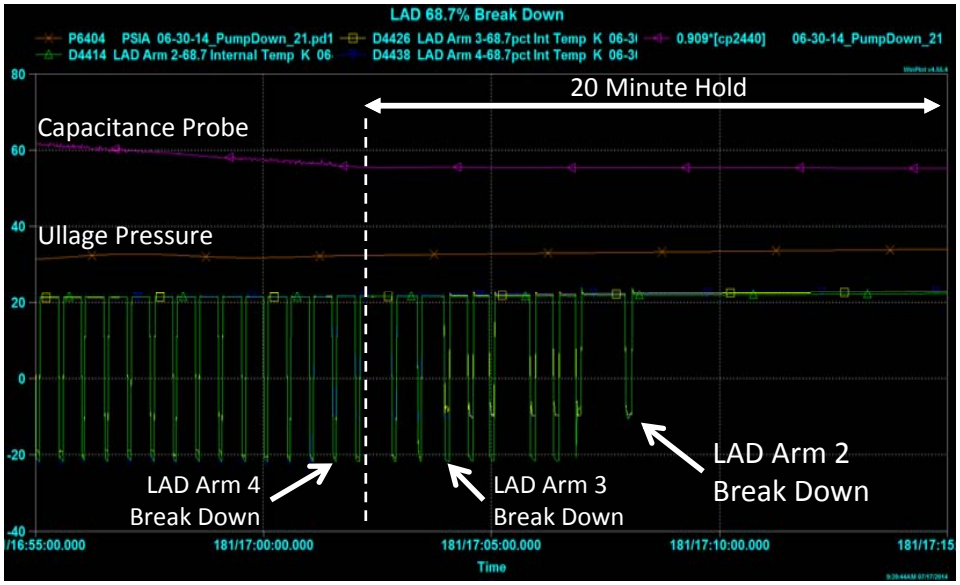
Test Day	Event	Fluid Level per Capacitance Probe (% full)
19	LAD Outflow #2	68
19	LAD Outflow #3	67
19	LAD Outflow #4	55

Test Day 19 – LAD Outflow #4

- Scheduled drain hold during LAD Outflow #4 at 62% fill level shown in plot to right.
- Internal diode data for all three LAD arms at 68.7% level (green/yellow/blue).
- All LAD Arms remained wetted for the duration of the hold.

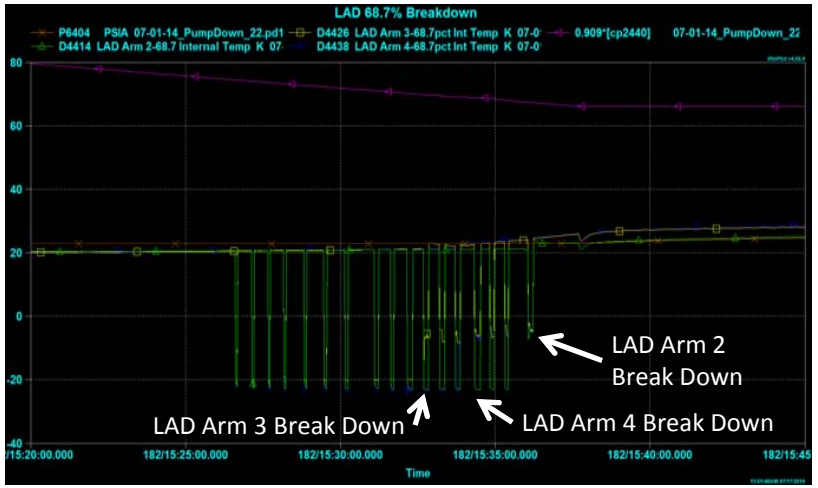


- Scheduled drain hold during LAD Outflow #4 at 55% fill level shown in plot to right.
- Arm 4/bare (blue) breaks down just before hold at 56% fill level.
- Arm 3/TVS (yellow) breaks down less than 2 minutes into the hold.
- Arm 4/foam & TVS (green) breaks down about 5-1/2 minutes into the hold.



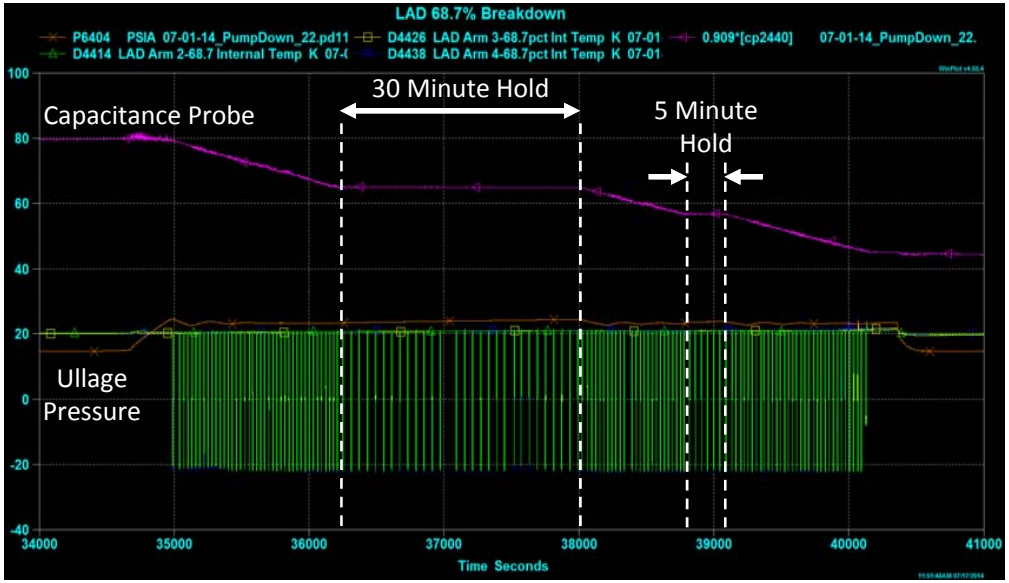
Test Day 20 – LAD Outflows #5 and #6

- LAD Outflow #5 was conducted with the ullage pressure at 23 psia using the AFT diffuser for pressurization with gaseous helium.
  - Hold periods during drain; 30 minute hold at 65% fill level and 5 minute hold at 56% fill level.
  - All LAD Arms remained wet during BOTH hold periods.
  - LAD Arm 4 (bare) breaks down at 47.5% fill level.
  - LAD Arm 3 (TVS) breaks down at 46.5% fill level.
  - LAD Arm 2 (Foam & TVS) breaks down at 45% fill level.
  - ***Total hold time before final LAD breakdown was 61 minutes.***
- LAD Outflow #6 was conducted with the ullage pressure at 23 psia using the FWD diffuser for pressurization with gaseous helium.
  - No hold periods for this outflow.
  - Arm 3/TVS (yellow) breaks down at 70% fill level.
  - Arm 4/bare (blue) breaks down at 69% fill level.
  - Arm 2/Foam & TVS (green) breaks Down at 67% fill level, less than 3 minutes after exposure.

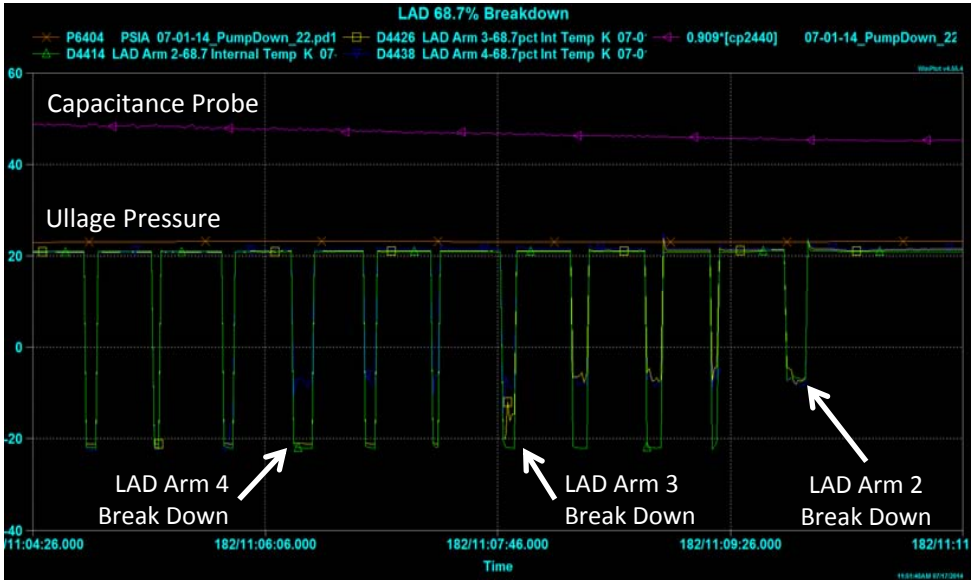


Test Day 20 – LAD Outflow #5

- LAD Outflow #5 is shown in its entirety in the plot to right.
- 30 minute hold at 65% fill level.
- 5 minute hold at 56% fill level.
- All LAD Arms remained wetted for the duration of both holds.
- Ullage pressure – orange line.



- Arm 4/bare (blue) breaks down at 47.5% fill level.
- Arm 3/TVS (yellow) breaks down about 1-1/2 minutes later at 46.5% fill level.
- Arm 4/Foam & TVS (green) breaks down about 2 minutes later at 45% fill level.



LAD Overview Summary

- Foam insulation on the LAD arms made a positive impact of approximately 2% in regards to break down time and screen temperatures.
  - The foam insulated LAD Arm 2 always broke down later than the other arms.
  - Note that this added a day to the schedule and associated costs.
- Total hold time before break down was greatly influenced by whether the FWD (in ullage) or AFT (in bulk fluid) diffuser was used for pressurization.
  - Pressurization using the FWD diffuser resulted in hold times less than 3 minutes at both high and low ullage pressures.
  - Hold times with the AFT diffuser were 27 and 29 minutes at high ullage pressure and 61 minutes at low ullage pressure.
- Ullage pressure during drain also impacts the total hold time before LAD arm break down.
  - Low ullage pressure (23 psia) drain was more than twice as long as high ullage pressure (32 psia) drain; 61 minutes versus 27/29 minutes.
- LAD Outflow Testing met all test objectives and success criteria.
  - Objectives: 2 runs at high pressure (32 psia) using FWD/AFT diffusers and 1 run at low pressure (23 psia) using FWD/AFT diffusers.
    - Attempted to use cooled helium, but the heat exchanger was too far from the test article and the helium heated up to 275K prior to entering the tank.
  - Success Criteria:
    - Safely perform LAD Outflow Testing.
    - Collect data for above test objectives.

LAD Back-up Charts

Silicon Diode Wet/Dry Readings

- The wet-to-dry transition value of the diodes was dependent on several factors:
  - Location
    - Internal to LAD or external
  - Tank Pressure

mV	K
1974.49	-24.0
1961.49	-23.0
1948.49	-22.0
1935.49	-21.0
1922.49	-20.0
1909.49	-19.0
1896.49	-18.0
1883.49	-17.0
1870.49	-16.0
1857.49	-15.0
1844.49	-14.0
1831.49	-13.0
1818.49	-12.0
1805.49	-11.0
1792.49	-10.0
1779.49	-9.0
1766.49	-8.0
1753.49	-7.0
1740.49	-6.0
1727.49	-5.0
1714.49	-4.0
1701.49	-3.0
1688.49	-2.0
1675.49	-1.0
1662.49	0.0
1649.49	1.0
1644.29	1.4
1642.99	1.5
1197.75	20.0
1089.02	40.0
1022.98	80.0
559.64	300.0

LAD Internal Wet/Dry Indication @ 22 psia

LAD Internal Wet/Dry Indication @ 15 psia

Temperature Rake, LAD External Wet/Dry Set Point

LH2 Temperature

LNe Temperature

LN2 Temperature

Room Temperature

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