Evolvable Cryogenics (eCryo) Project Technology Workshop with Industry

Engineering Development Unit (EDU) Workshop

Pressurization Test Results

Jonathan Stephens

EDU Pressurization System Testing

OBJECTIVE

- **Evaluate the performance of the EDU Pressurization System**
  - **Apply pressurant directly to the EDU tank ullage using the forward diffuser**
  - **Apply pressurant to the EDU tank ullage through the LH2 by utilizing the aft (submerged) diffuser**
- **Evaluate the pressurization performance characteristics of both methods**

BACKGROUND

- **A lot of data currently exist for pressurizing a propellant tank filled with a settled liquid.**
  - **Ground test articles**
  - **Vehicle propellant tank prepressurization on the ground**
  - **Vehicle propellant tank repressurization/pressurization while on ascent**
  - **Vehicle propellant tank repressurization after a settling maneuver**
- **In a micro / zero gravity environment, the exact location of the liquid/ullage is not well understood.**
- **For a given pressurization system configuration, the diffuser may be exposed to the tank ullage when the propellant is settled, but submerged when the propellant is unsettled (CPST Payload).**

EDU Pressurization System Testing

BACKGROUND (continued)

- **Potential issues associated with submerged diffuser pressurization:**
  - **Pressurant gas is collapsed once it enters the tank ullage. As a result, more helium is required.**
  - **Ability to control pressure within a specific range is unknown.**
  - **Helium can dissolve within the propellant leading to a reduction of LH2 purity**
    - **Can potentially affect TVS performance**
    - **Will likely affect engine performance (thrust, flows, Isp)**
    - **Potential concern with ingestion of gaseous helium in turbo-pumps**

EDU Pressurization System Testing

BACKGROUND (continued)

- **Completed EDU Test Objectives**
  - **Perform ambient helium pressurization system under vacuum conditions**

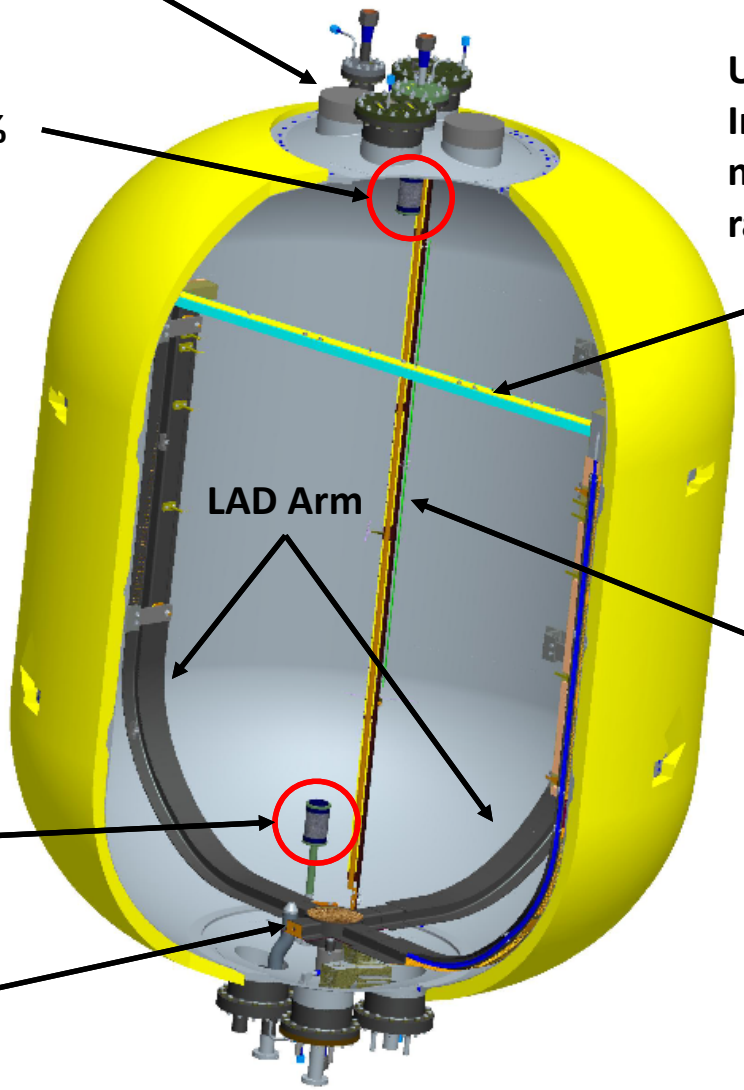
- **Completed EDU Success Criteria**
  - **Safely perform pressurization system testing**
  - **Gather data at a sampling rate of 10Hz**

- **Test Priorities**
  - **Pressurization system testing was priority #11 of 14**

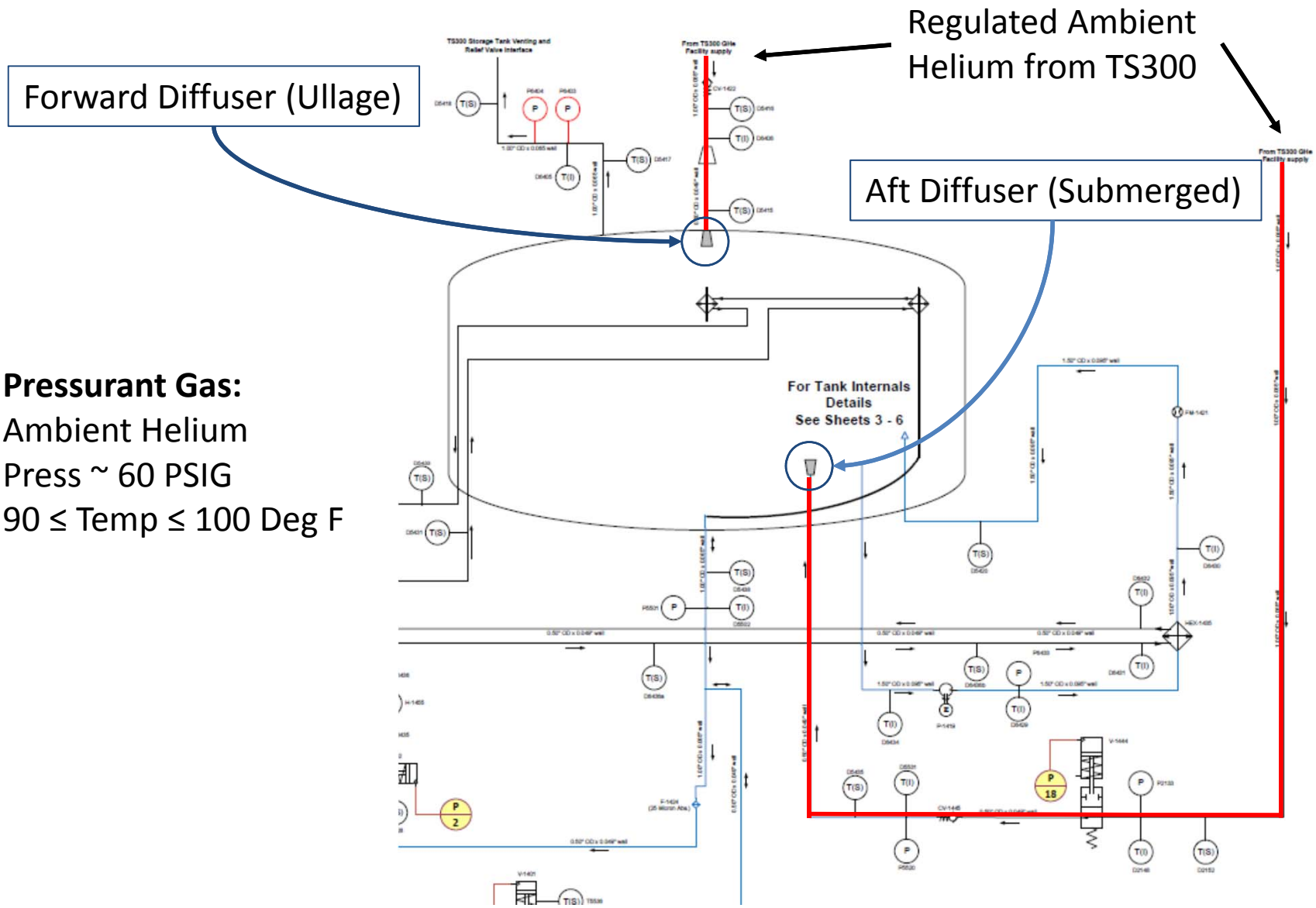
- **EDU Pressurization System Configuration**
  - **EDU pressurization system has two diffusers**
    - **Forward (ullage)**
    - **Aft (submerged)**

  - **Pressurant Gas**
    - **Regulated helium (P ~ 60 PSIG)**
    - **Flowrate manually adjusted by a variable position valve**
    - **Max flowrate ~ 275 ALPM**

EDU Tank Assembly

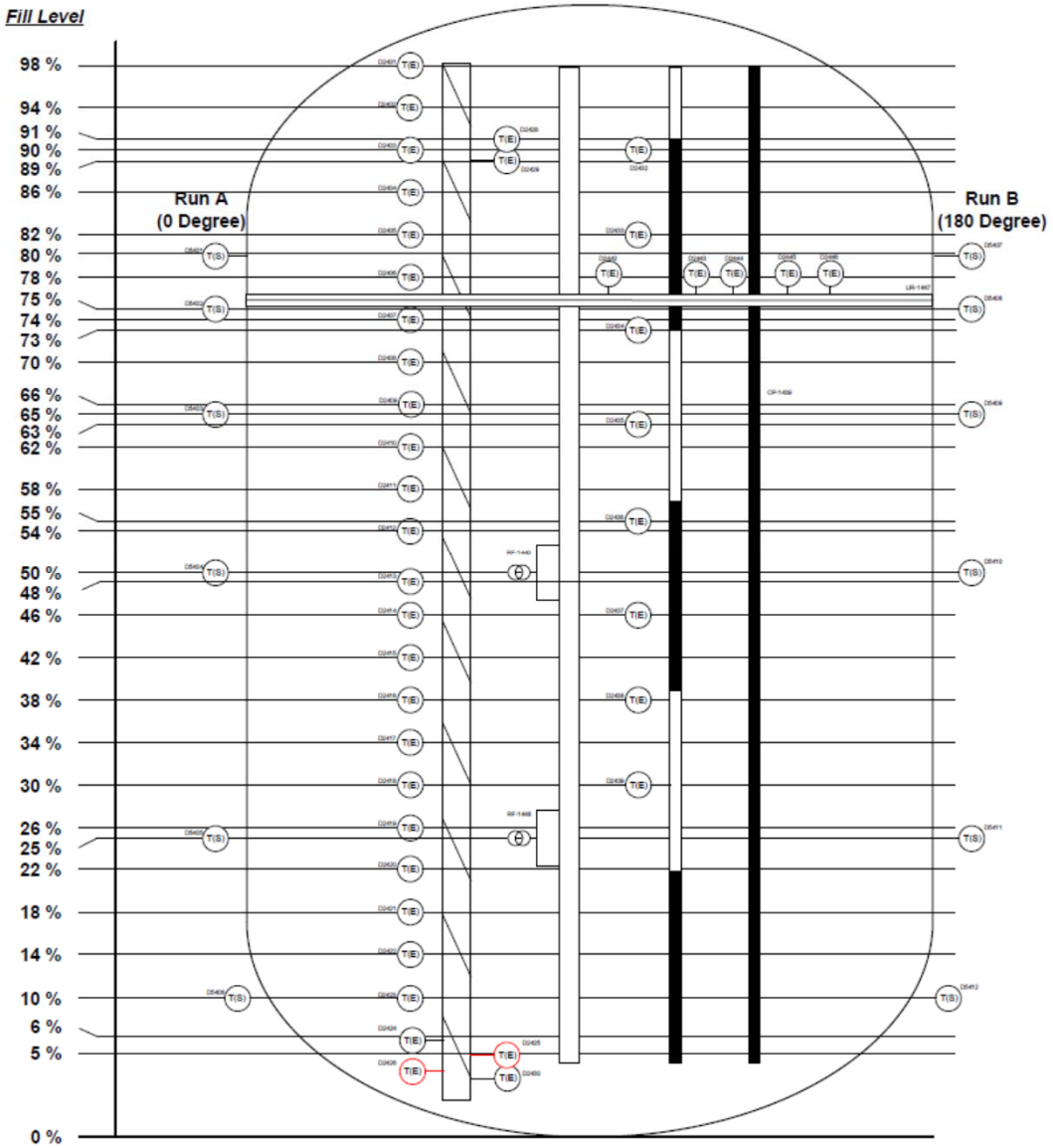


Pressurization Sub-System



Pressurant Gas:
Ambient Helium
Press ~ 60 PSIG
90 ≤ Temp ≤ 100 Deg F

Storage Tank Mass Gauging



Fill Level (%)	Tank Station (in)	Temperature Rake
98	85.2	D2401
94	80.2	D2402
91	77.3	D2428
90	76.4	D2403
89	75.6	D2429
86	73.1	D2404
82	70	D2405
78	67	D2406
74	64	D2407
73	63.3	
70	61	D2408
66	58	D2409
63	55.7	
62	55	D2410
58	52	D2411
55	49.7	
54	49	D2412
50	46	
48	51.3	D2413
46	43	D2414
42	40	D2415
~~38~~	~~37~~	~~D2416~~
34	34	D2417
30	30.9	D2418
26	27.9	D2419
25	27.1	
22	24.9	D2420
18	21.9	D2421
14	18.8	D2422
10	15.5	D2423
6	11.7	D2424
5	10.6	D2425
	10.2	D2426
	9.8	D2430

Planned Test Objectives for Test Day 12

HT-48 Pressurize tank from atmospheric to 27 PSIA using ambient helium and forward diffuser when tank liquid level is ~ 78%

HT-49 Once tank ullage pressure reaches 27 PSIA, discontinue pressurization and lockup tank. Allow tank to self pressurize to ~ 30 PSIA.

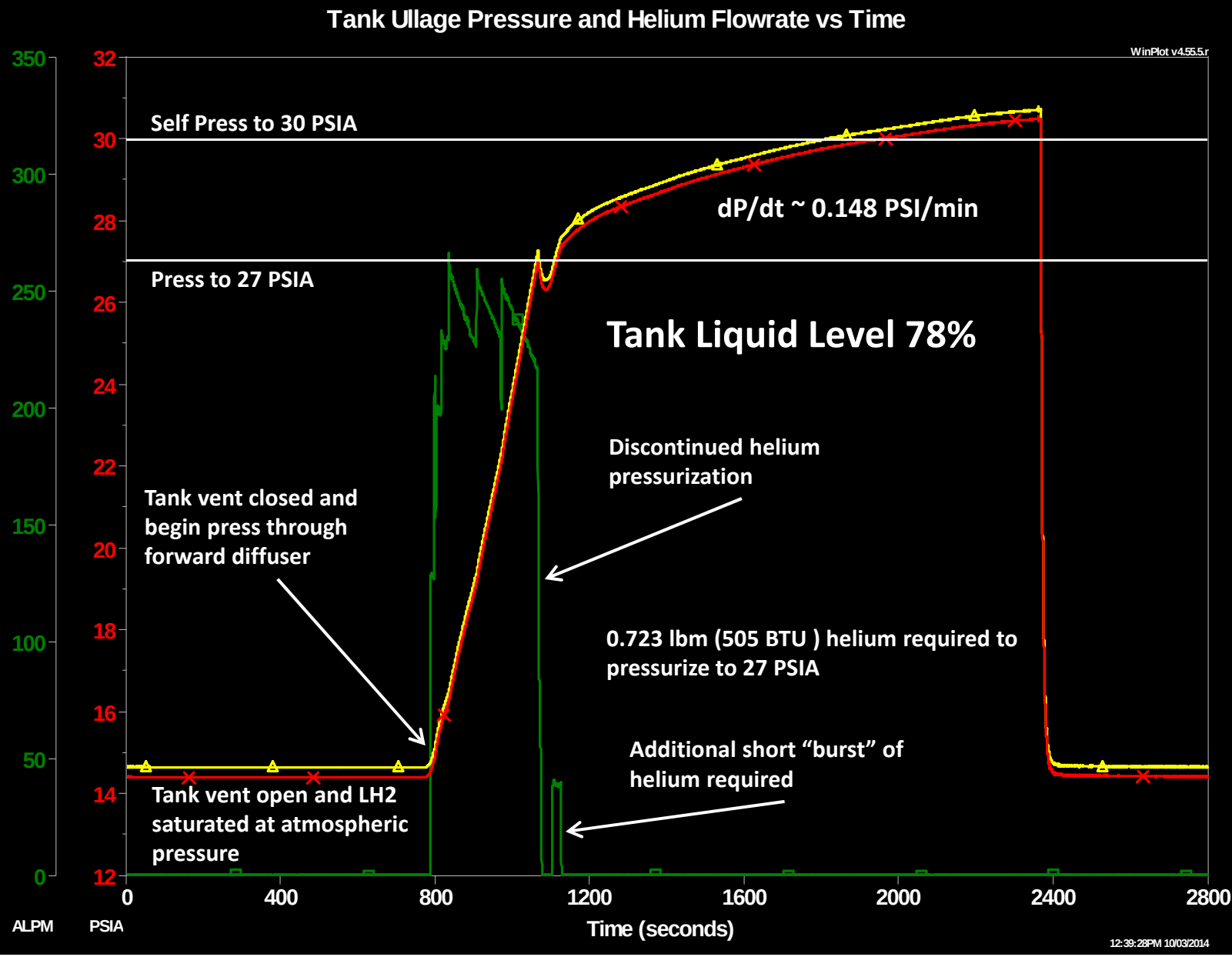
HT-50 Vent tank back down to atmospheric and allow at least 15 minutes to stabilize.

HT-51 Press tank from atmospheric to 27 PSIA using ambient helium and submerged diffuser when tank liquid level is ~ 78%

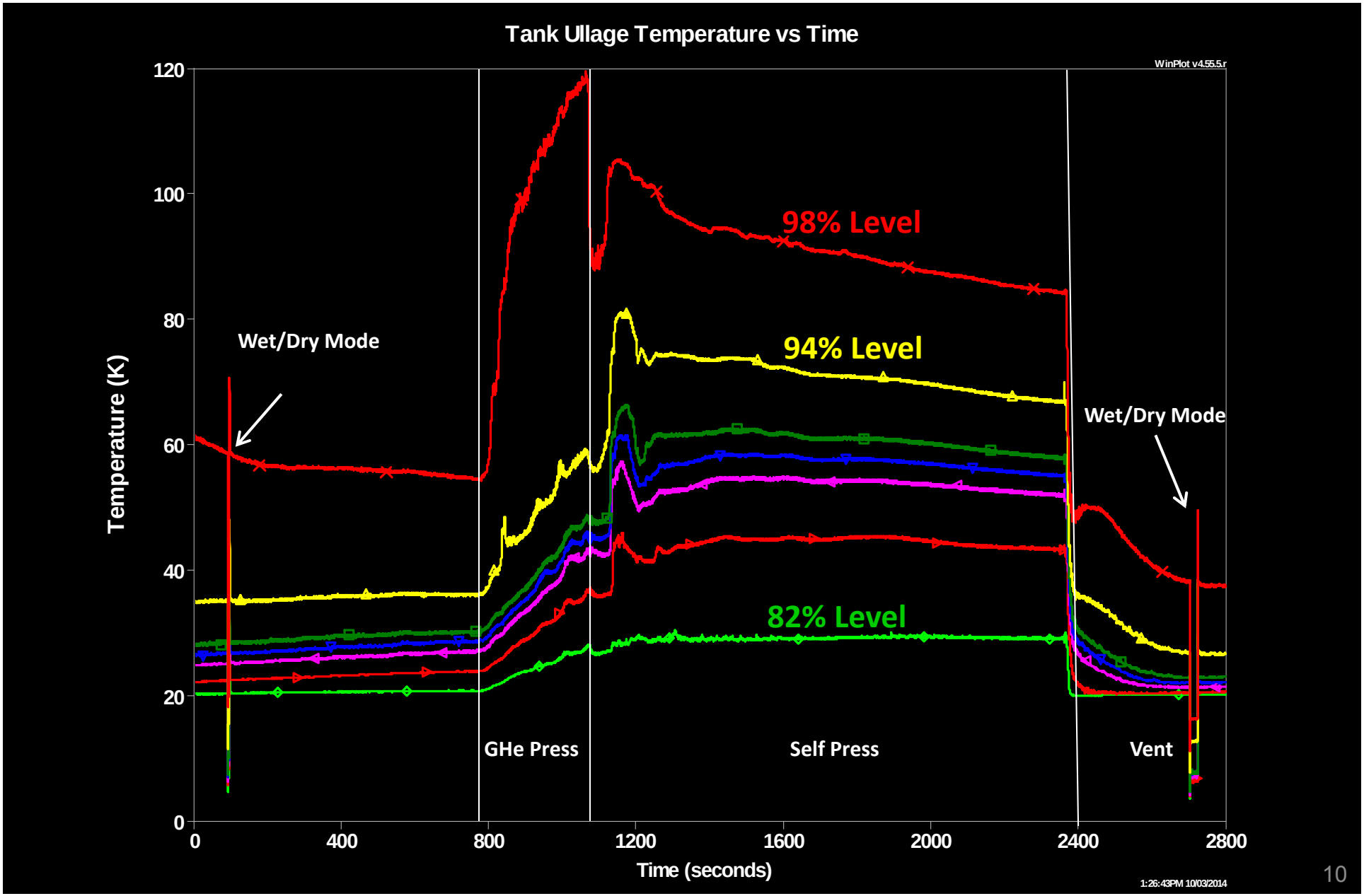
HT-52 Once tank ullage pressure reaches 27 PSIA, discontinue pressurization and lockup tank. Allow tank to self pressurize to ~ 30 PSIA.

HT-53 Vent tank back down to atmospheric and allow at least 15 minutes to stabilize.

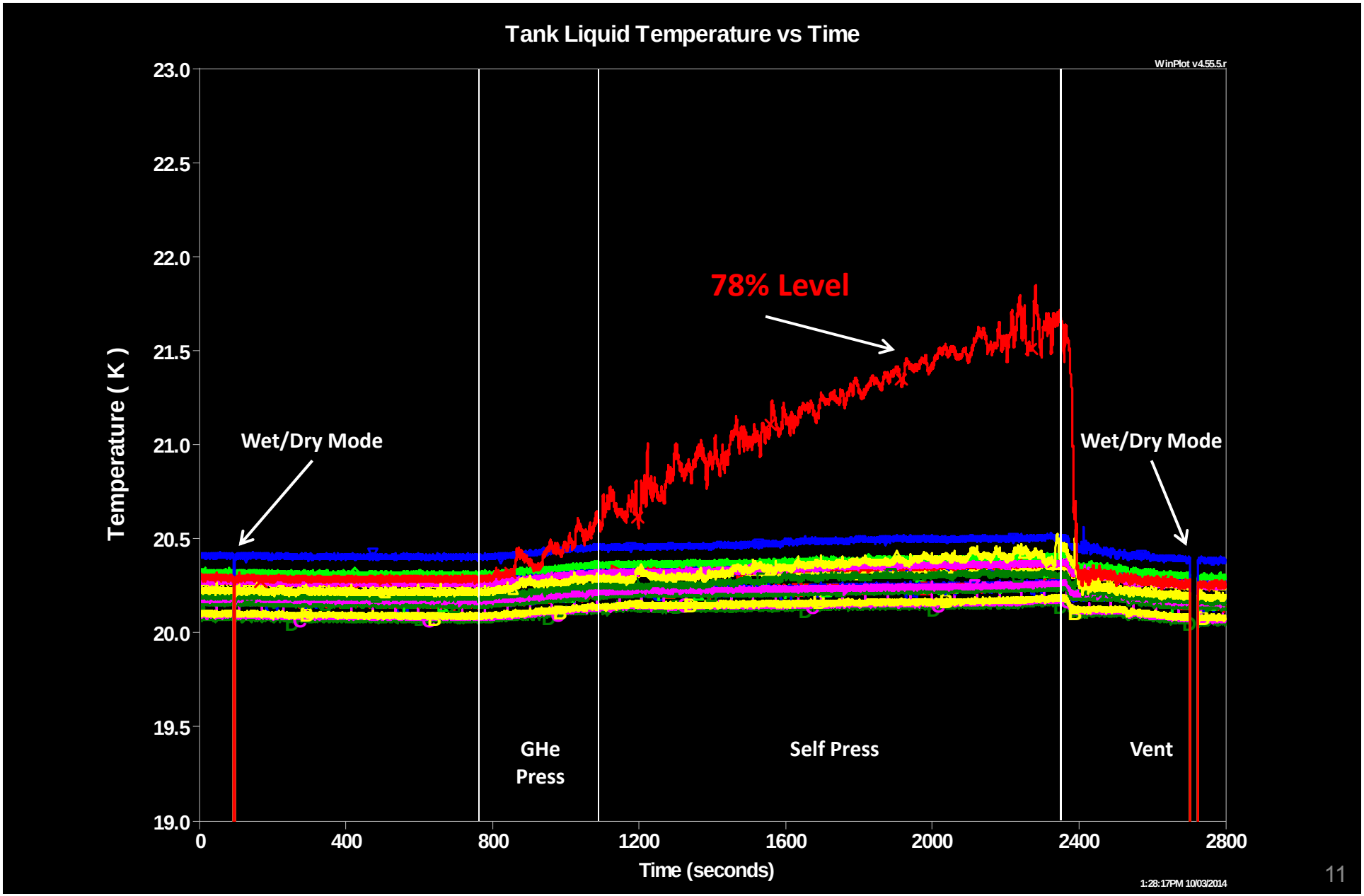
Pressurization Tests (HT - 48, 49, and 50)



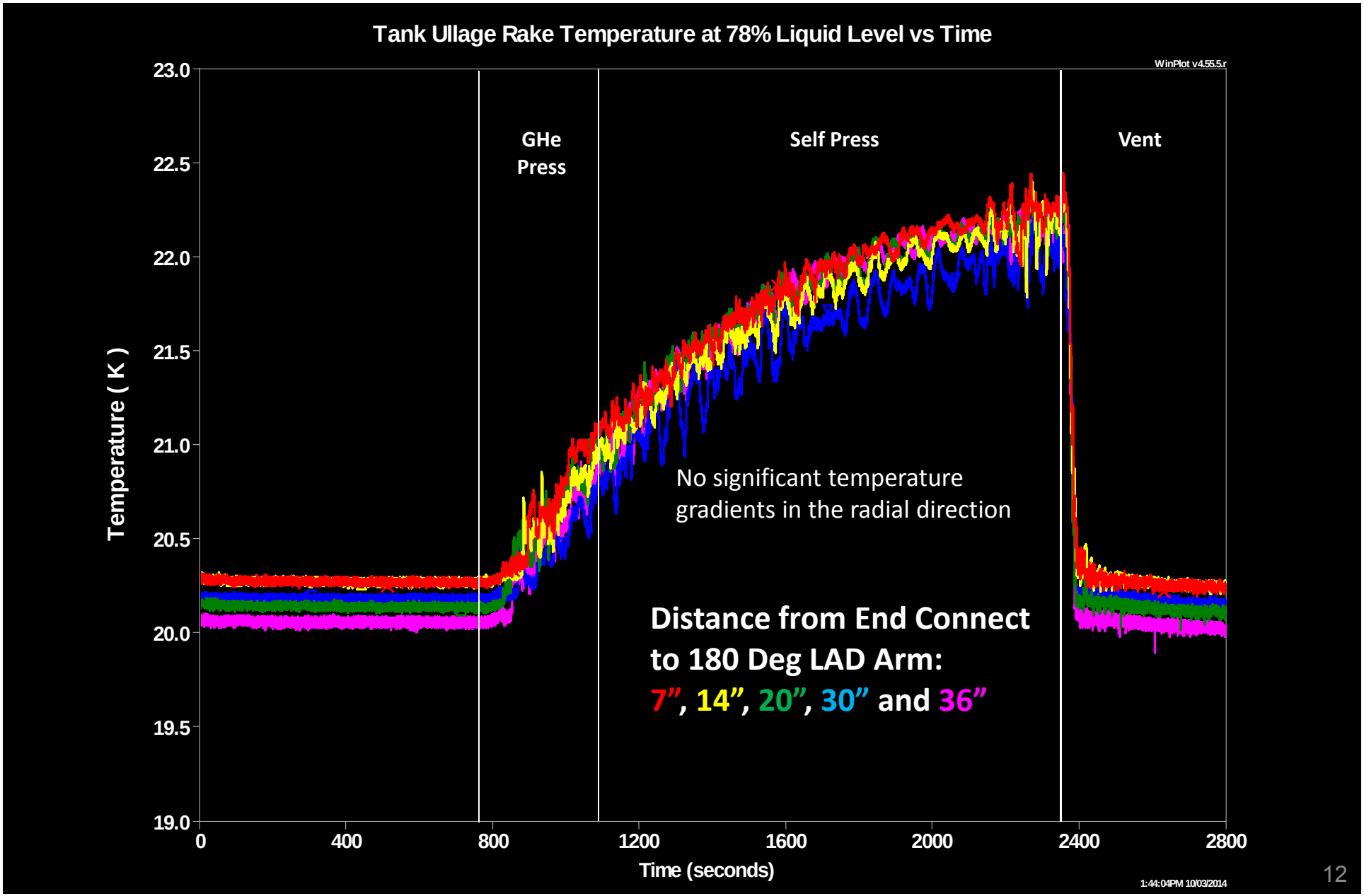
Pressurization Tests (HT - 48, 49, and 50)



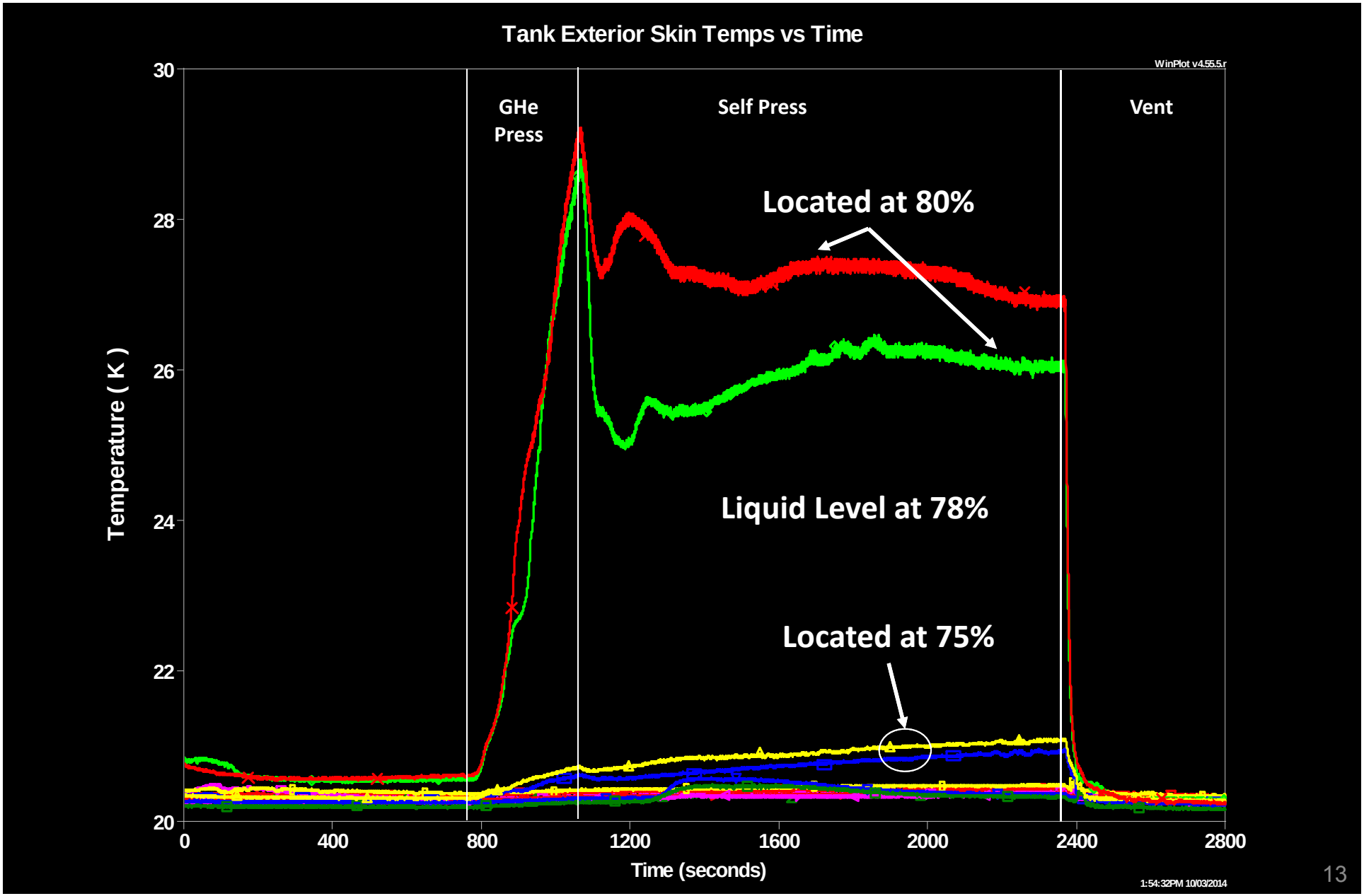
Pressurization Tests (HT - 48, 49, and 50)



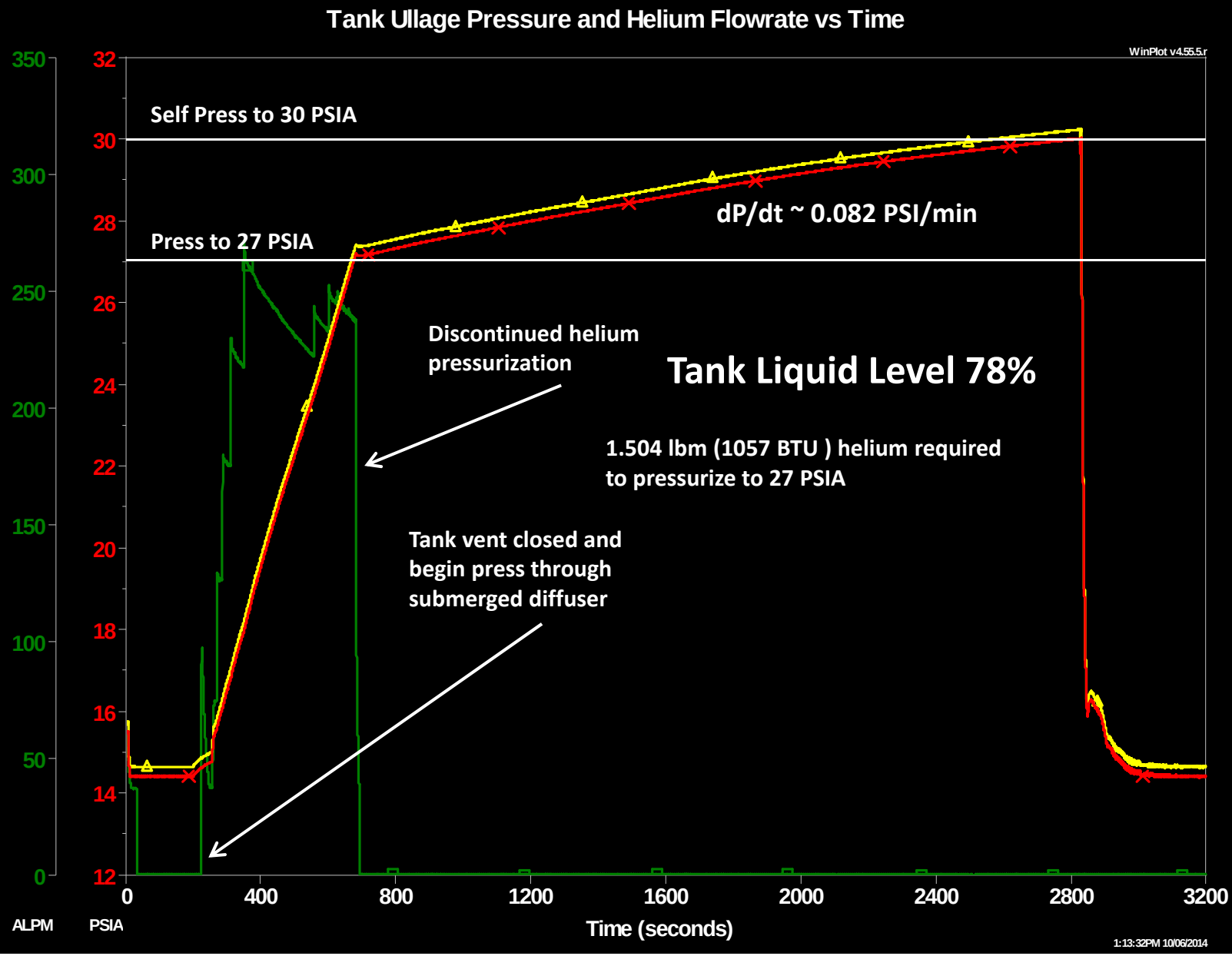
Pressurization Tests (HT - 48, 49, and 50)



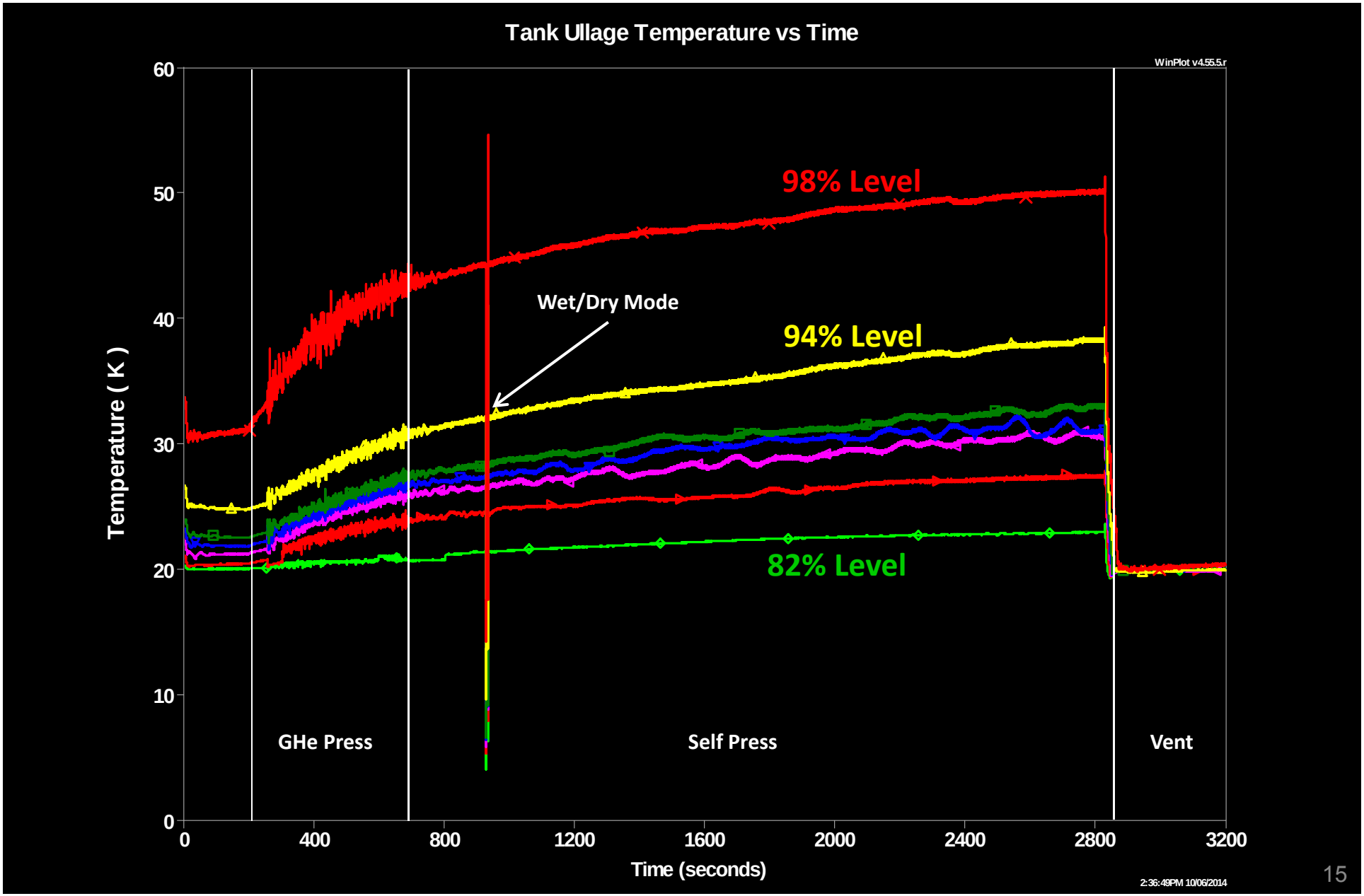
Pressurization Tests (HT - 48, 49, and 50)



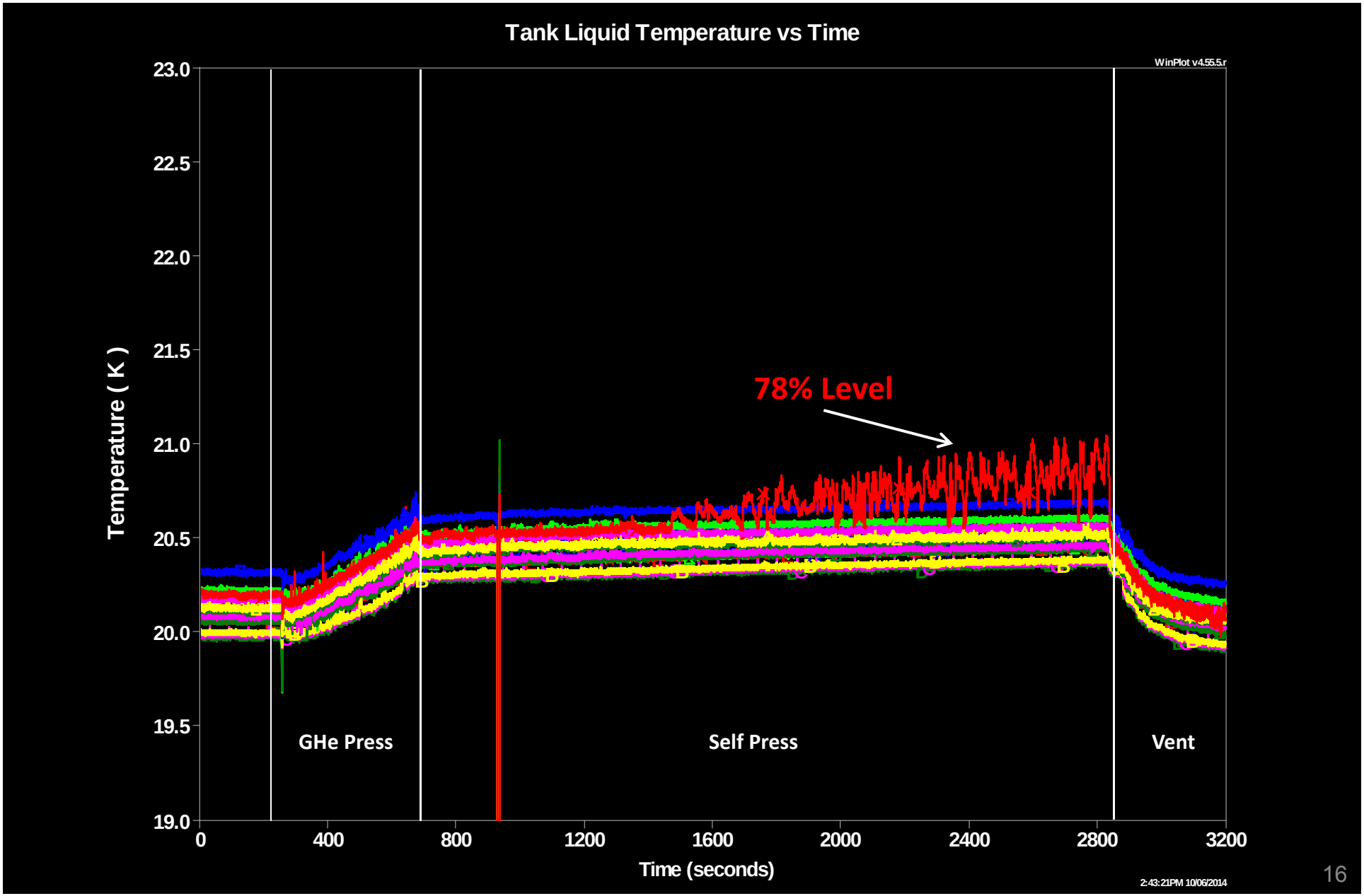
Pressurization Tests (HT - 51, 52, and 53)



Pressurization Tests (HT - 51, 52, and 53)



Pressurization Tests (HT - 51, 52, and 53)



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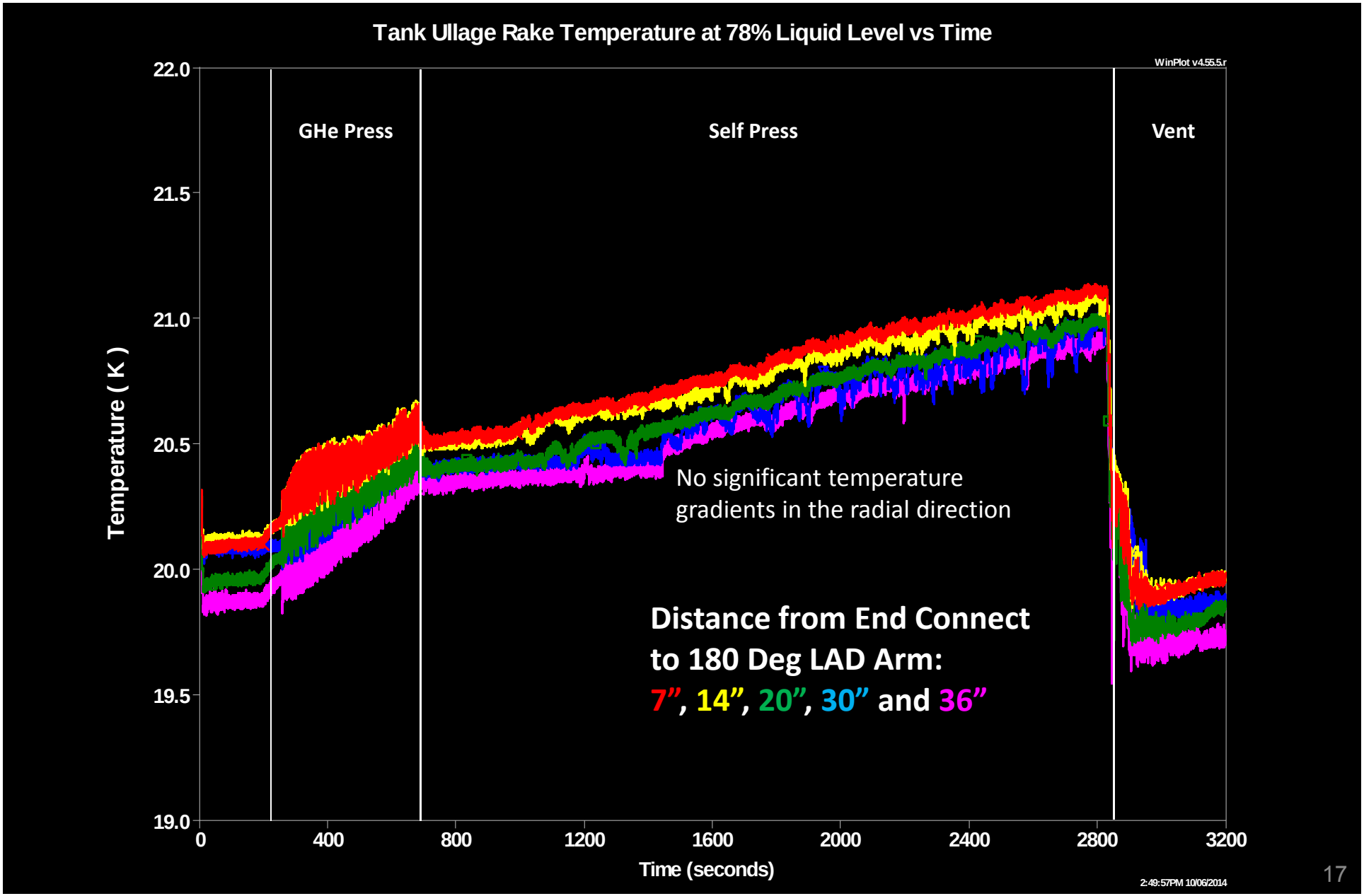
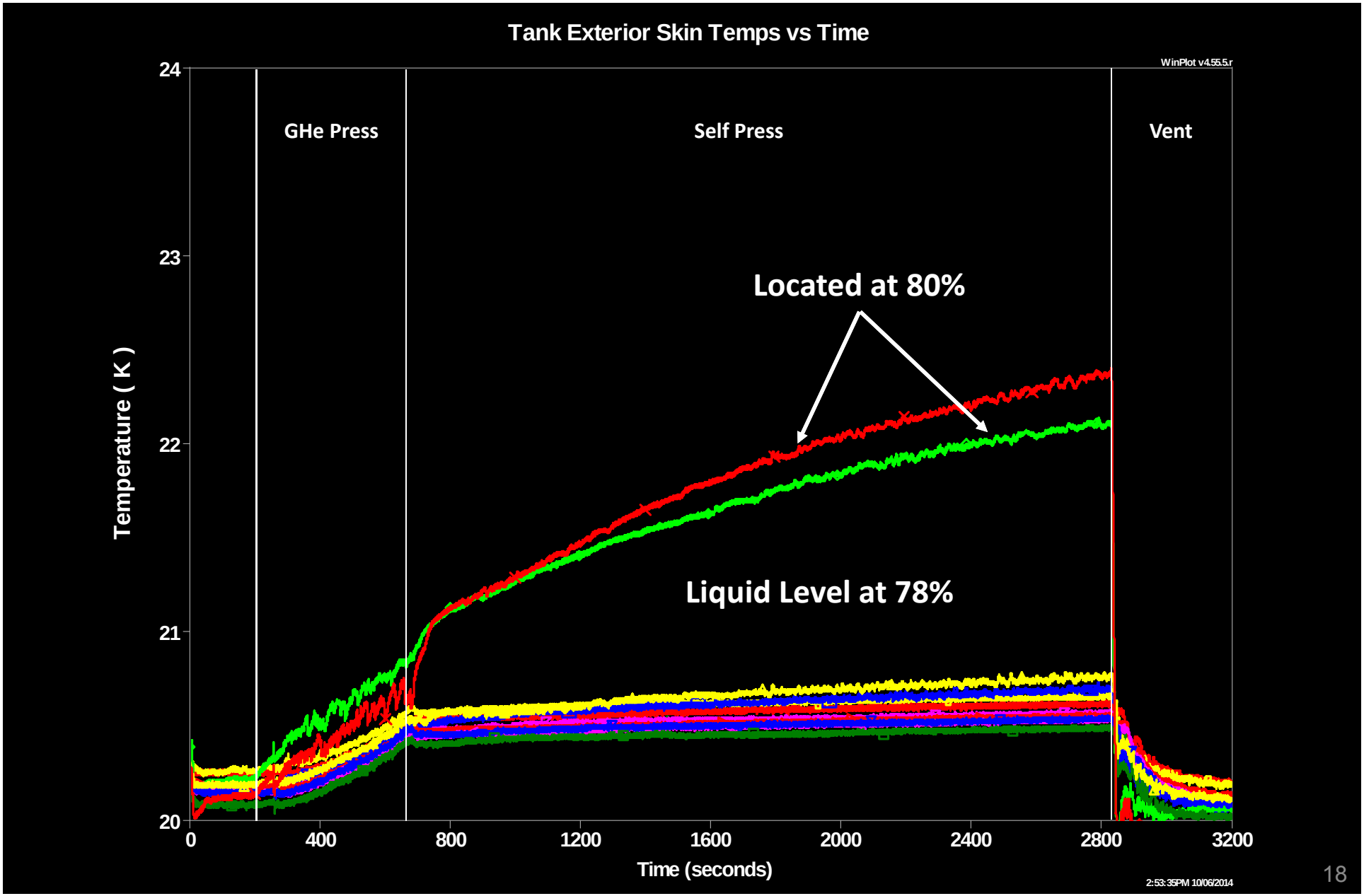


Pressurization Tests (HT - 51, 52, and 53)



Added Test Objectives for Test Day 12

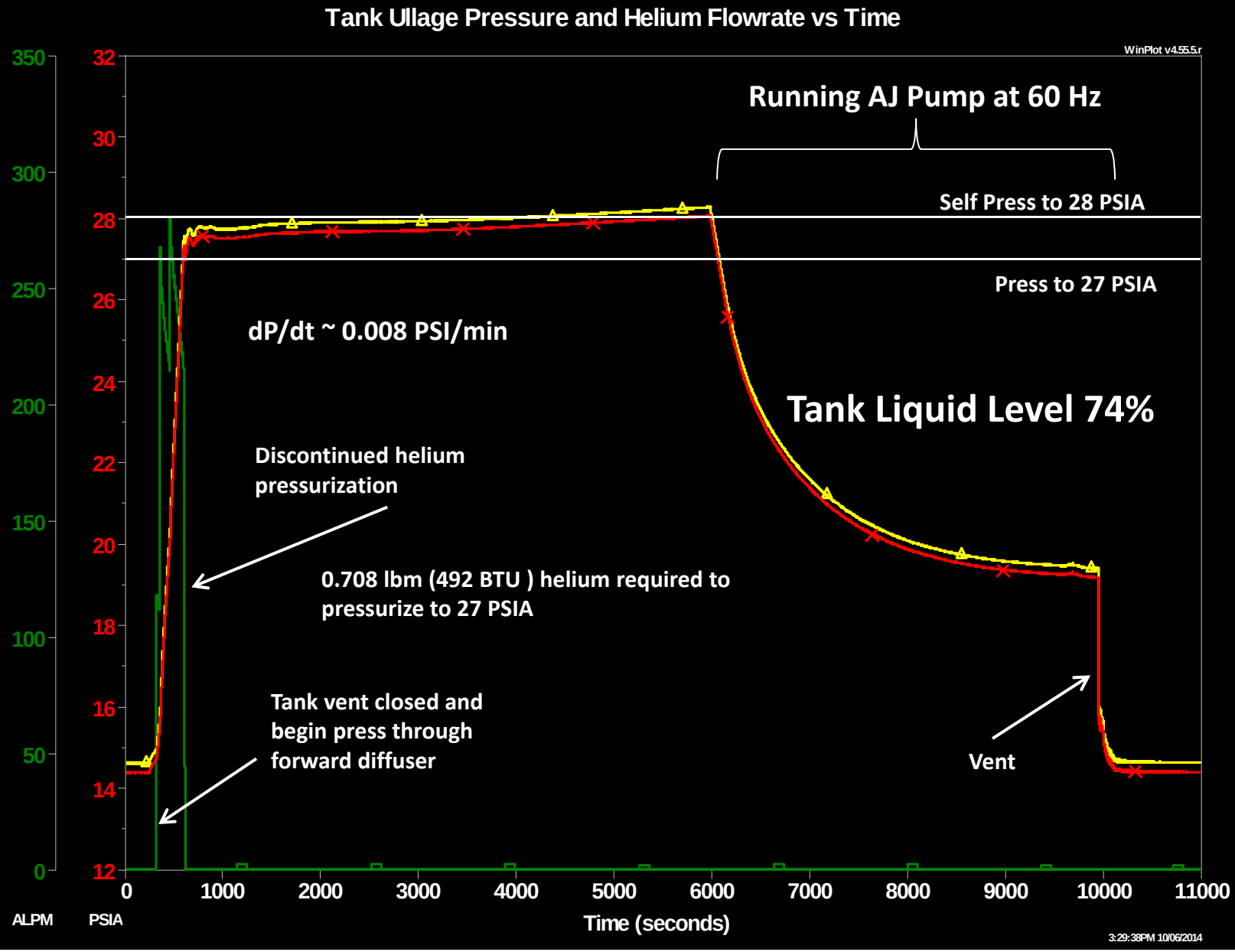
HT-48B **Pressurize tank from atmospheric to 27 PSIA using ambient helium and forward diffuser when tank liquid level is ~ 74%**

HT-49B **Once tank ullage pressure reaches 27 PSIA, discontinue pressurization and lockup tank. Allow tank to self pressurize to ~ 28 PSIA.**

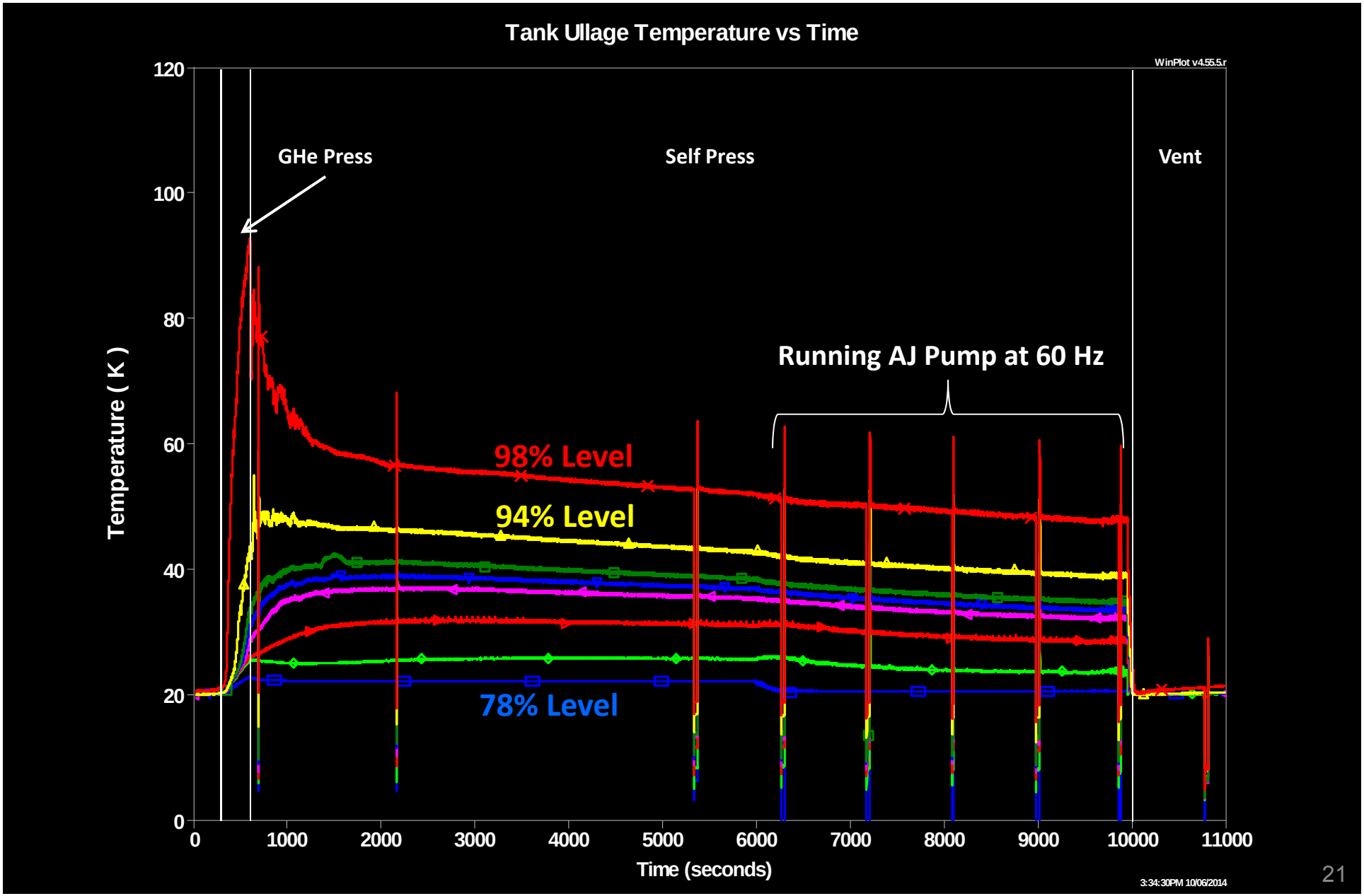
Demonstrate Axial Jet Mixing to reduce pressure as much as possible.

HT-50B **Vent tank back down to atmospheric and allow at least 15 minutes to stabilize.**

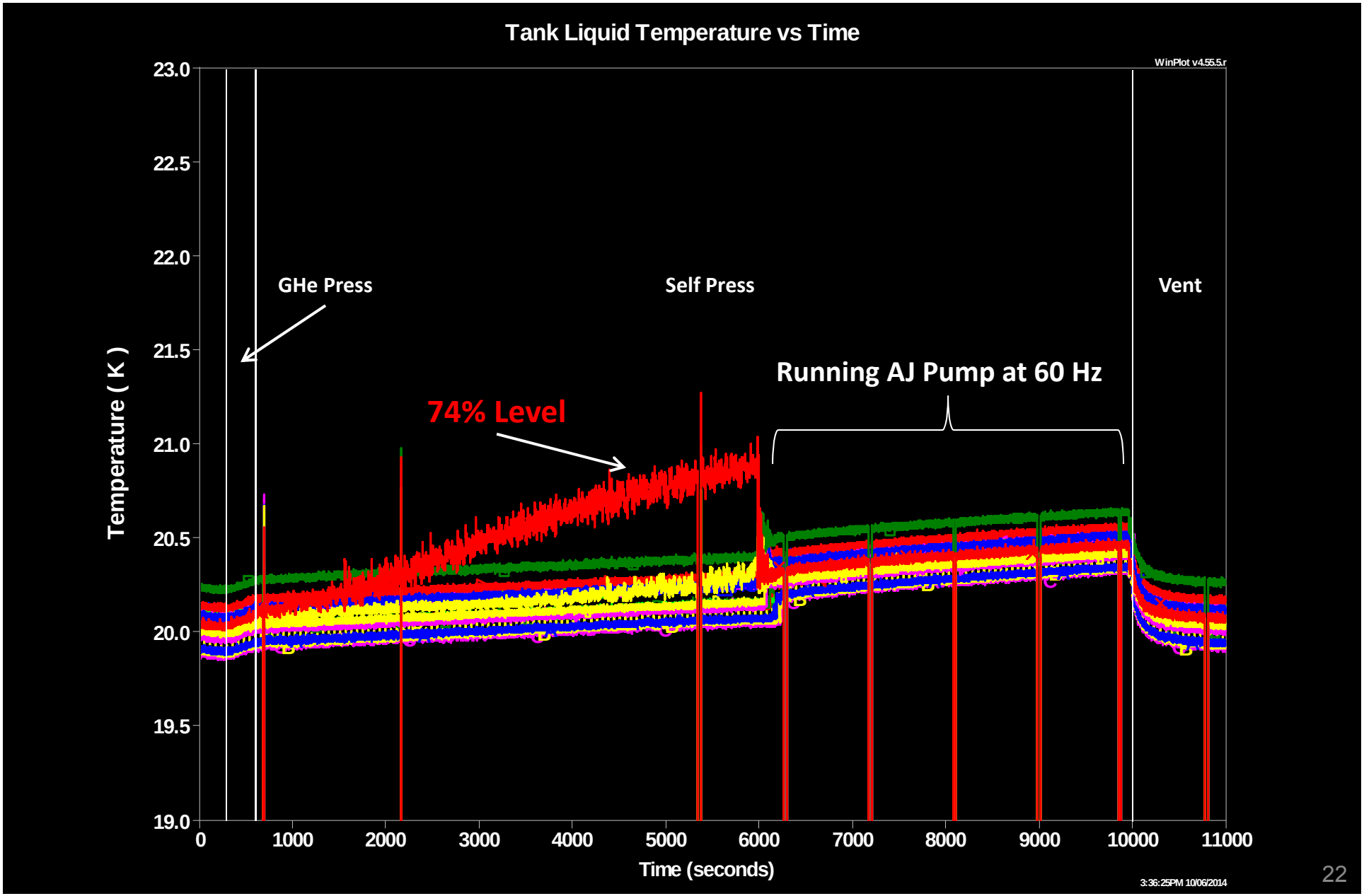
Pressurization Tests (HT – 48B, 49B, and 50B)



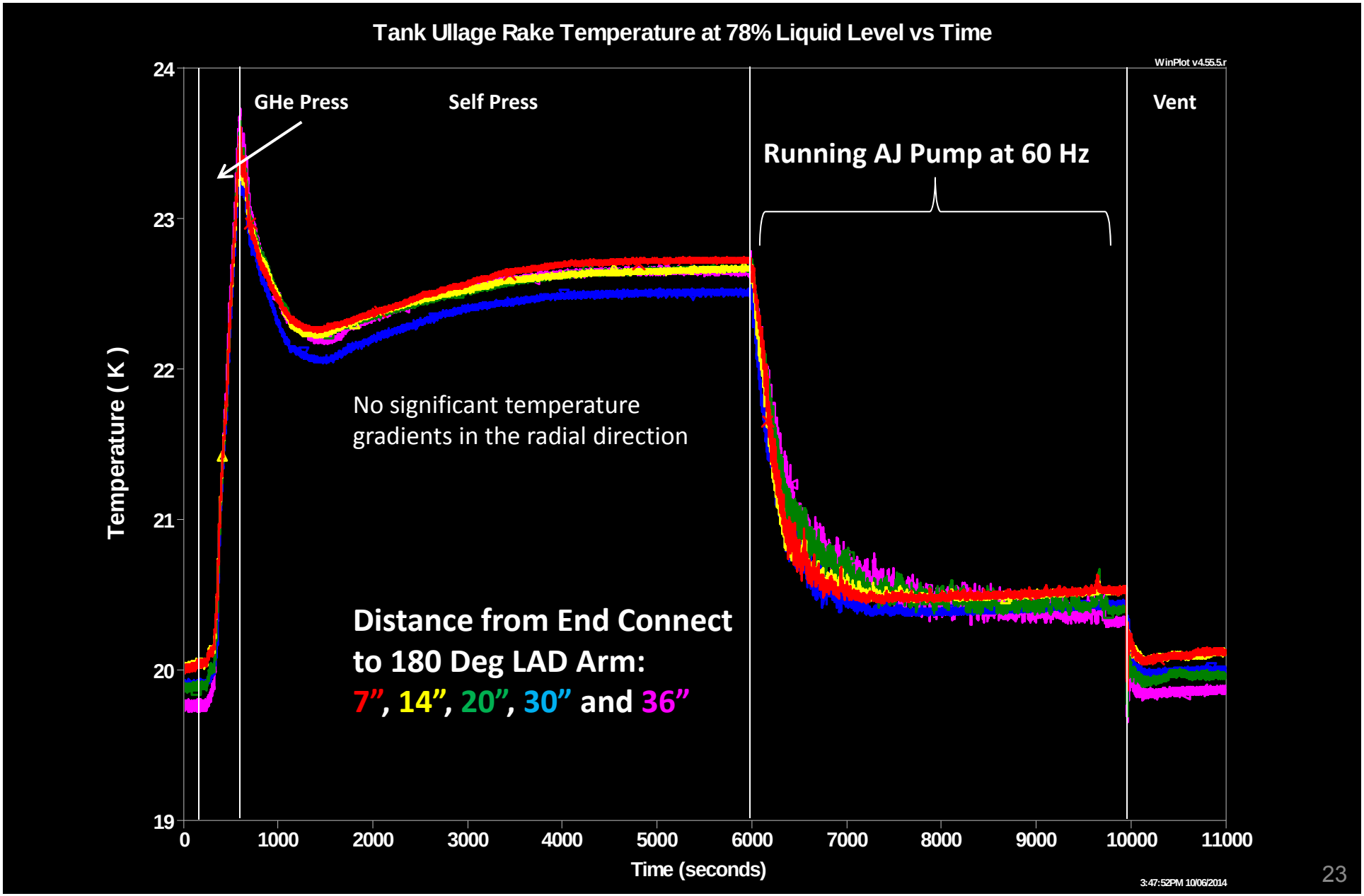
Pressurization Tests (HT – 48B, 49B, and 50B)



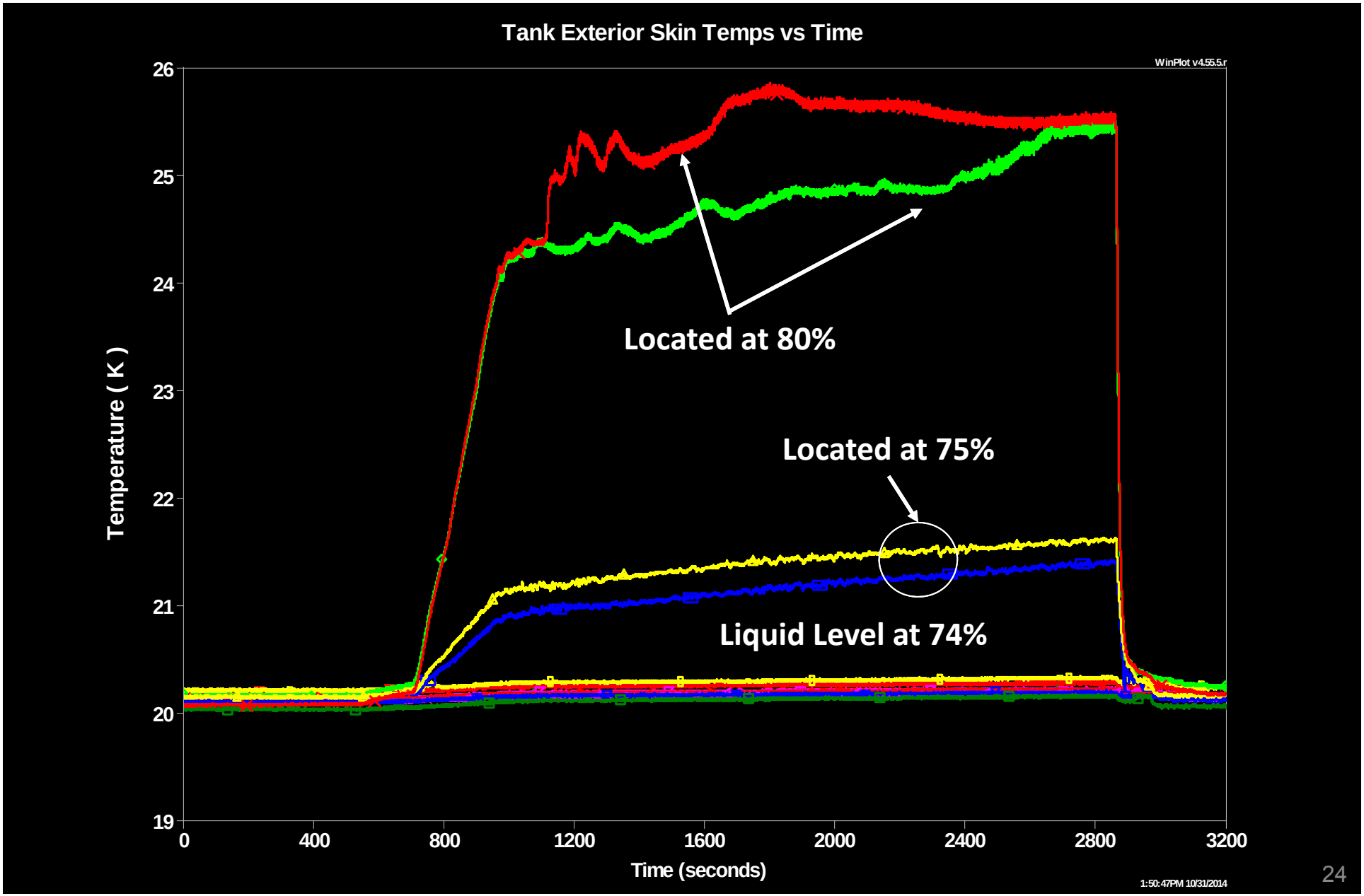
Pressurization Tests (HT – 48B, 49B, and 50B)



Pressurization Tests (HT – 48B, 49B, and 50B)



Pressurization Tests (HT – 48B, 49B, and 50B)



Added Test Objectives for Test Day 13

HT-48E Pressurize tank from atmospheric to 27 PSIA using ambient helium and forward diffuser when tank liquid level is ~ 34%

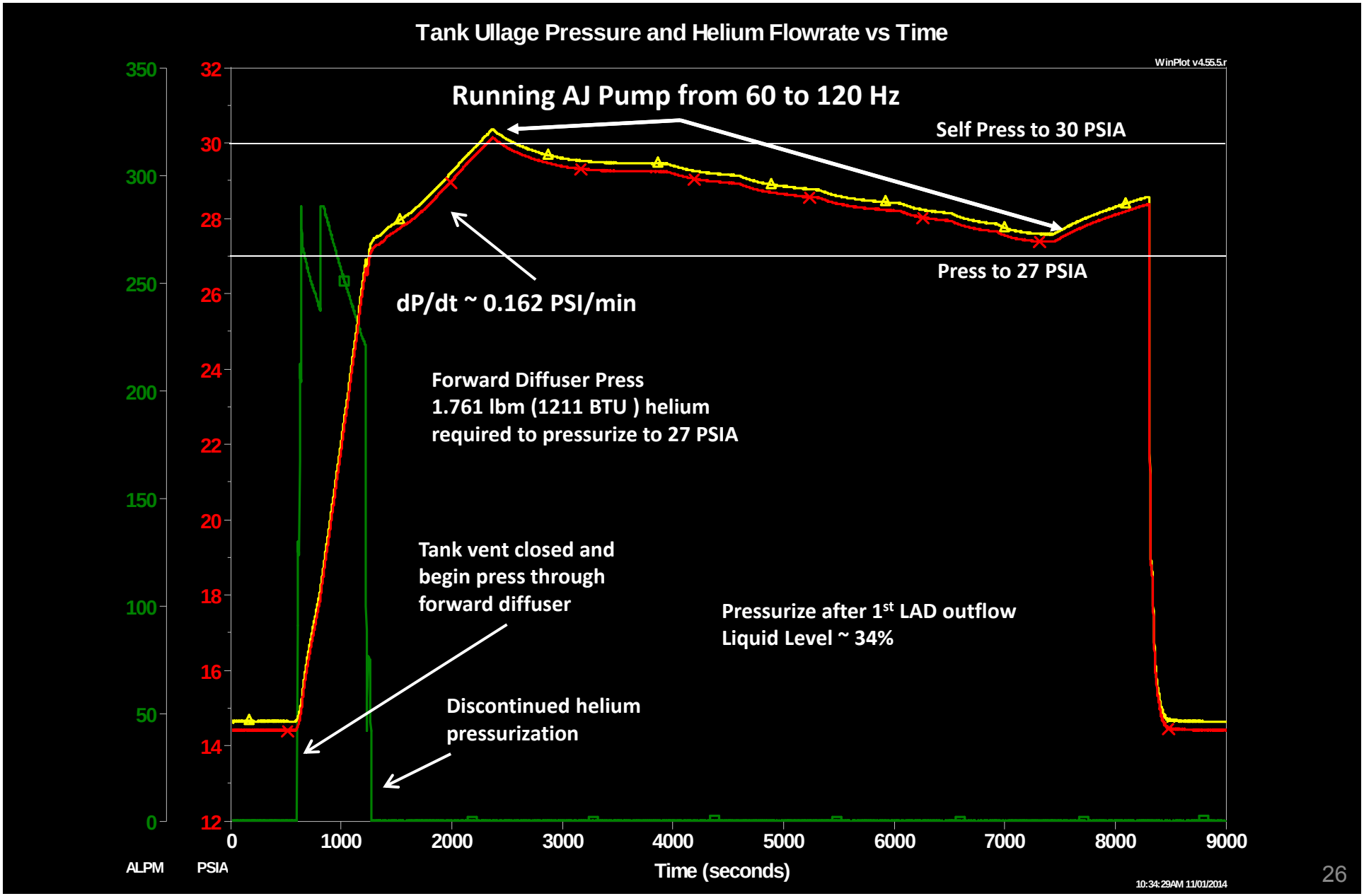
HT-49E Once tank ullage pressure reaches 27 PSIA, discontinue pressurization and lockup tank. Allow tank to self pressurize to ~ 30 PSIA. *Demonstrate Axial Jet Mixing to reduce pressure as much as possible.*

HT-50E Vent tank back down to atmospheric and allow at least 15 minutes to stabilize.

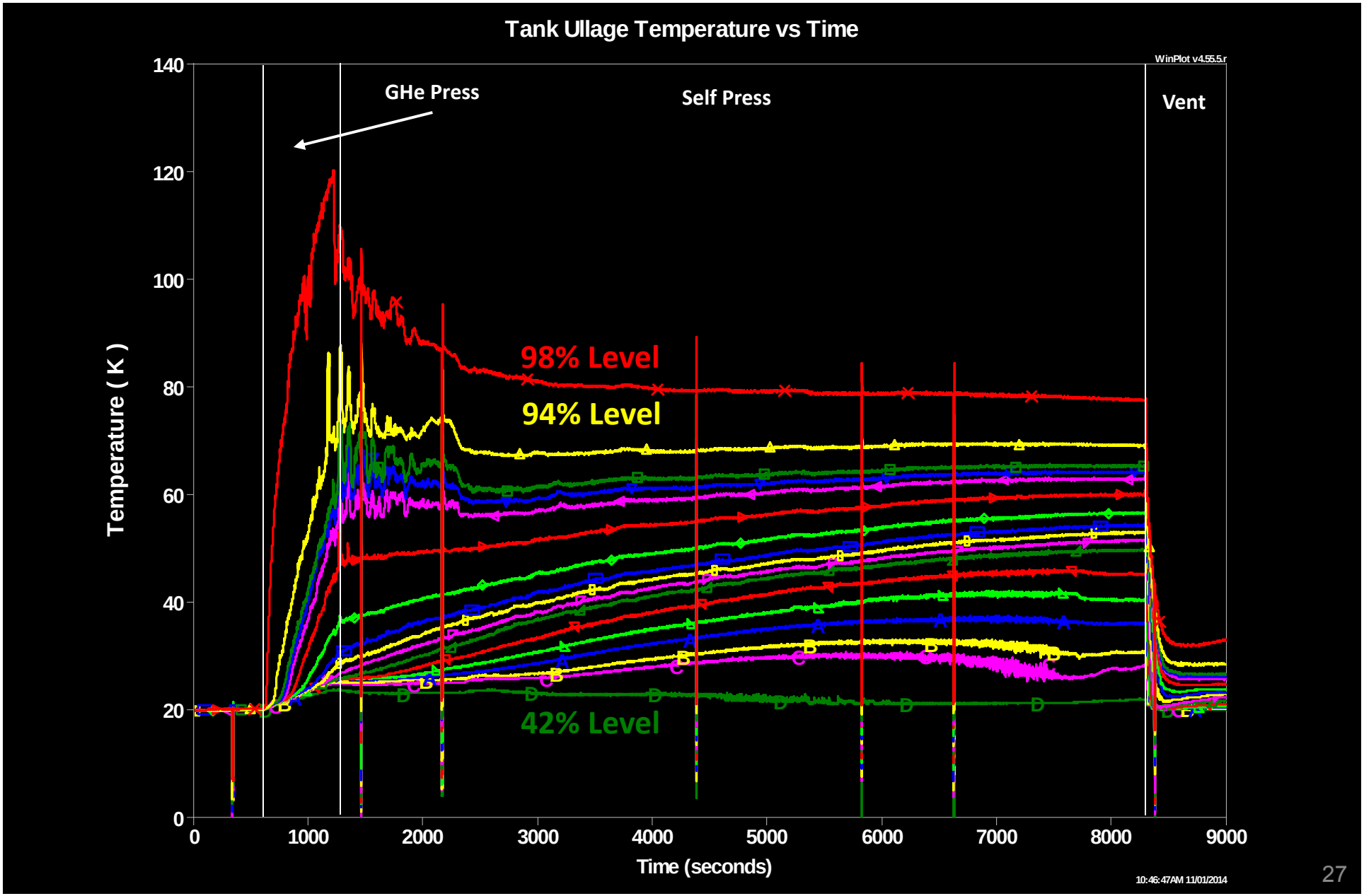
HT-51C Pressurize tank from atmospheric to 27 PSIA using ambient helium and Submerged diffuser when tank liquid level is ~ 34%

HT-52C Once tank ullage pressure reaches 27 PSIA, discontinue pressurization and lockup tank. Allow tank to self pressurize to ~ 28 PSIA.

Pressurization Tests (HT – 48E, 49E, and 50E)



Pressurization Tests (HT – 48E, 49E, and 50E)



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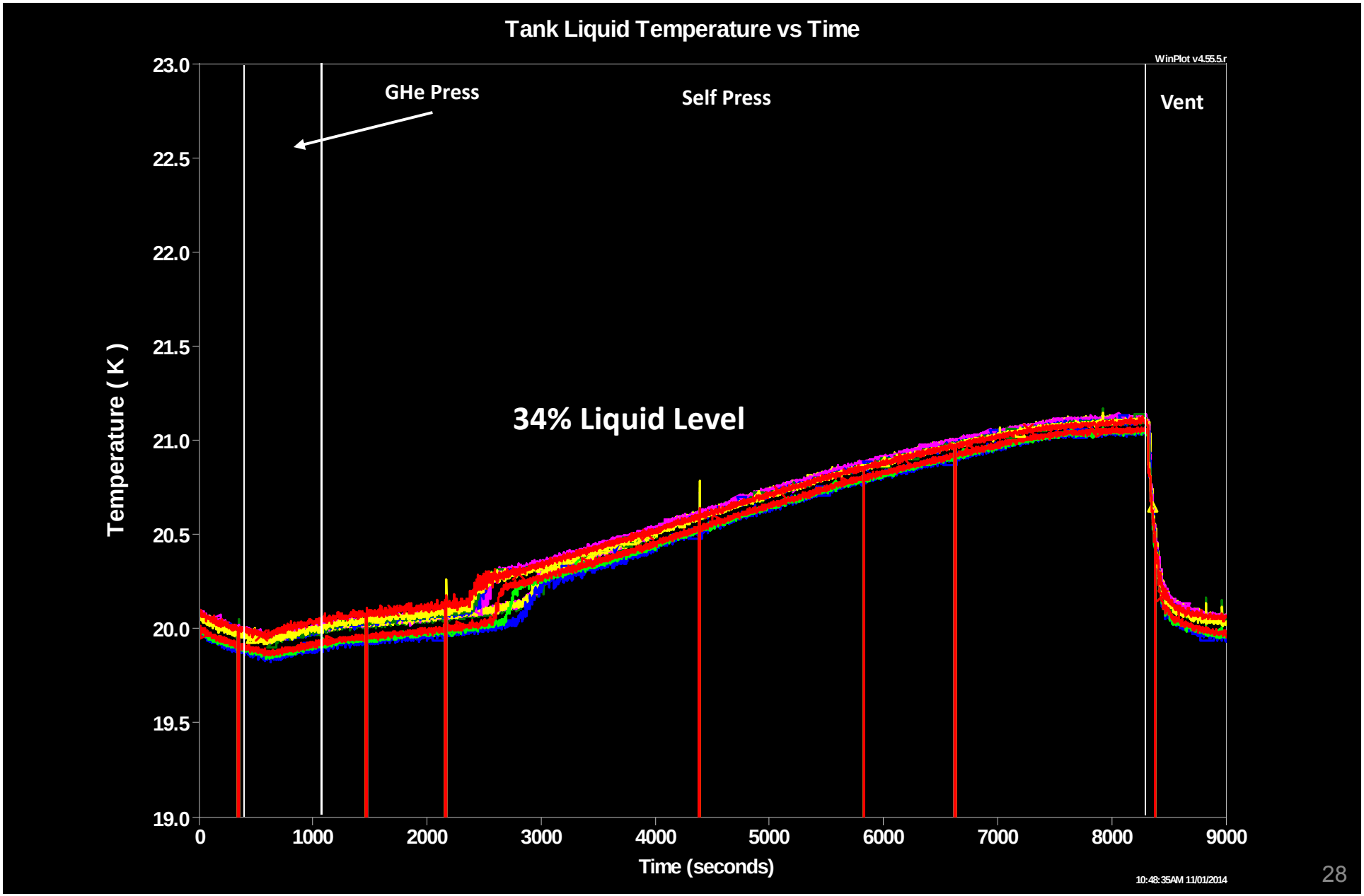

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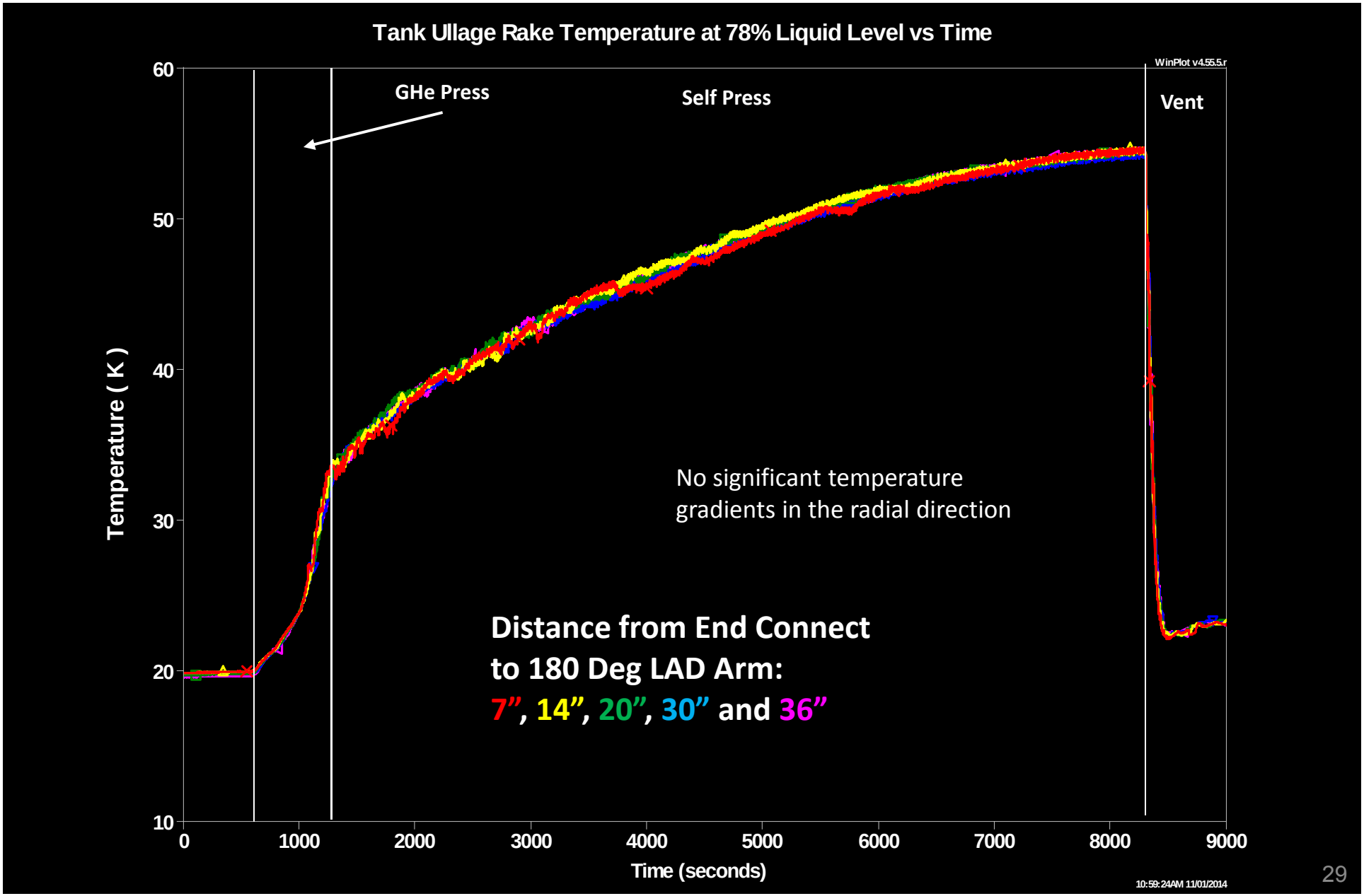

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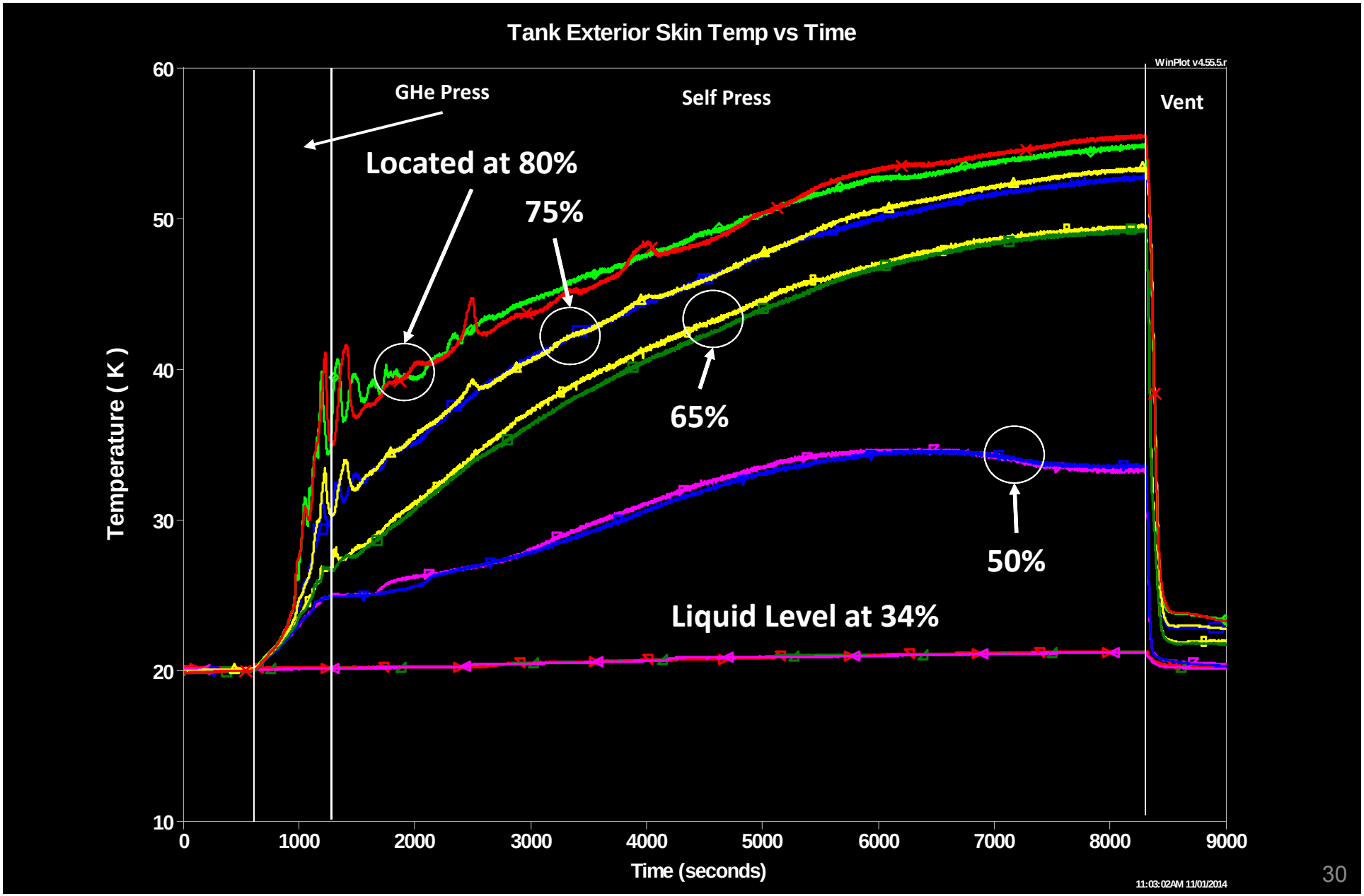
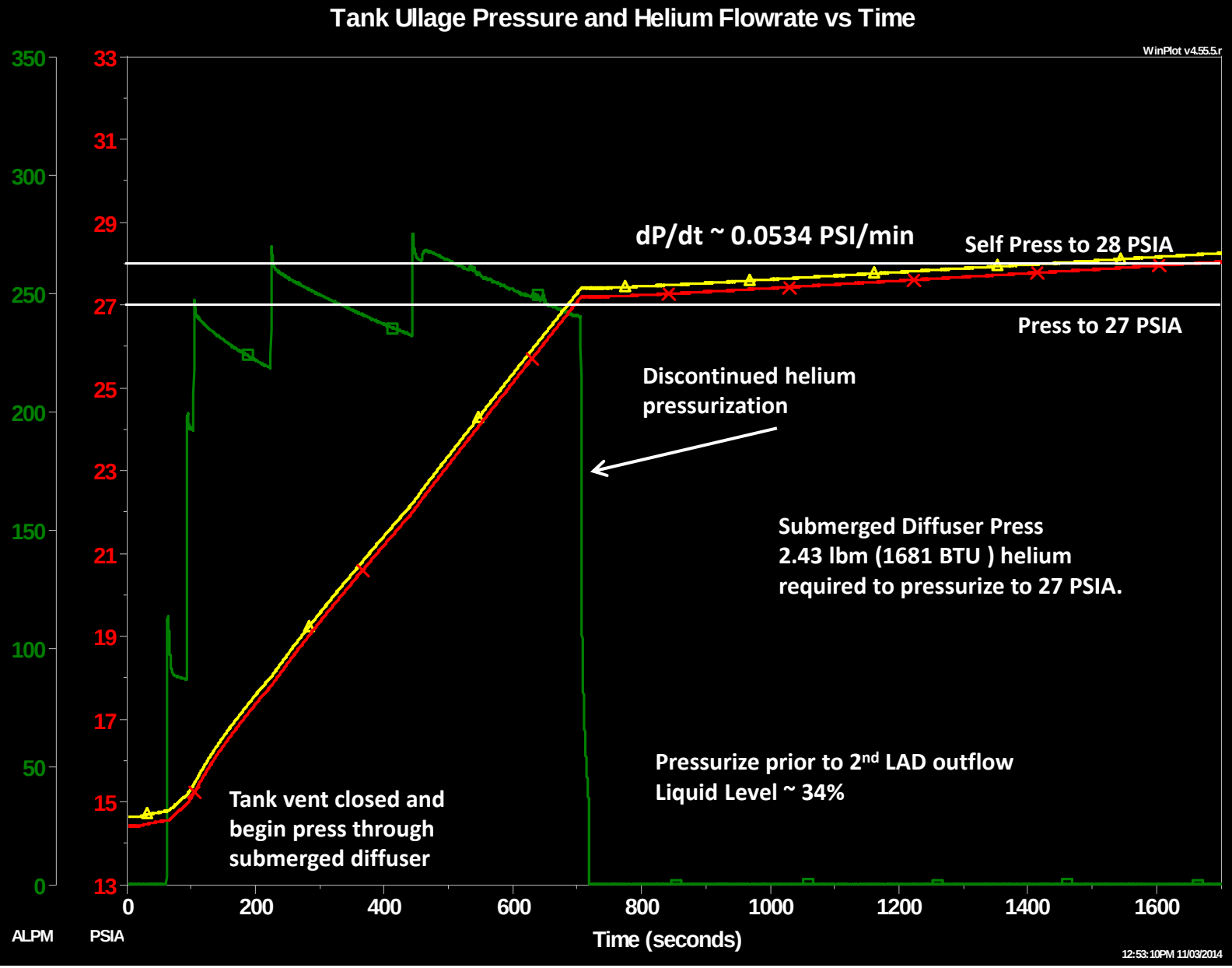
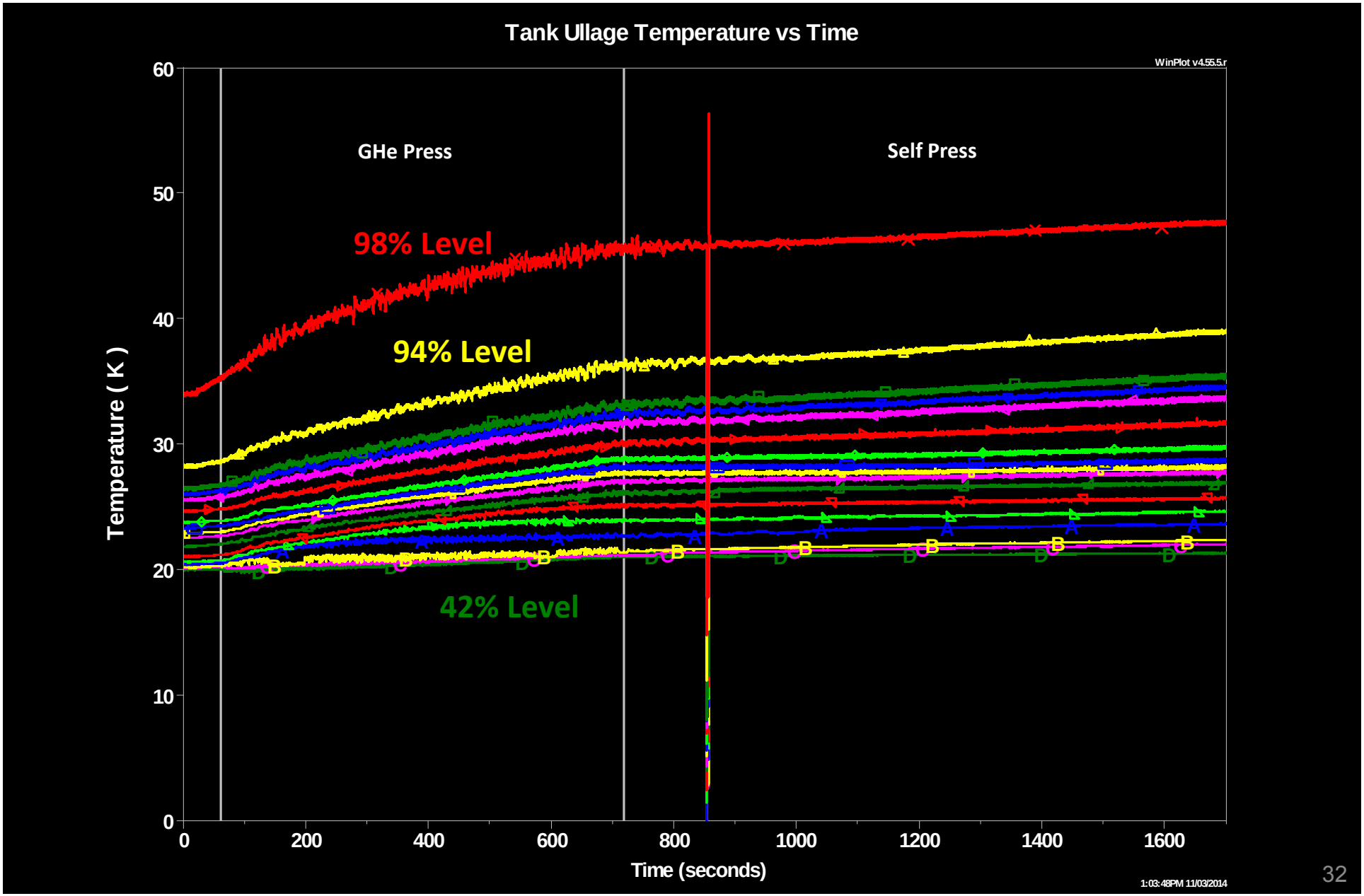


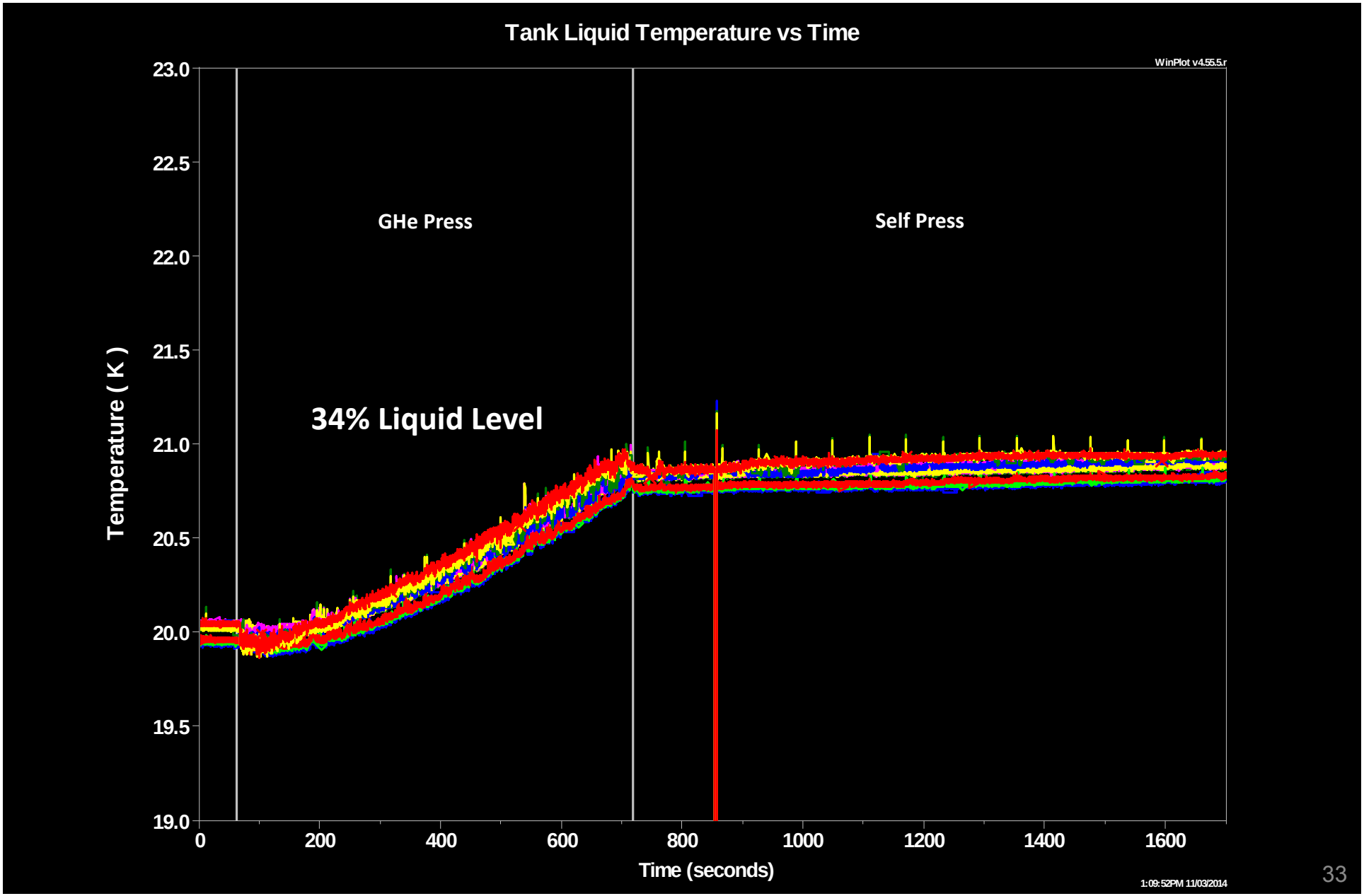
Pressurization Tests (HT – 51C and 52C)



Pressurization Tests (HT – 51C and 52C)



Pressurization Tests (HT – 51C and 52C)



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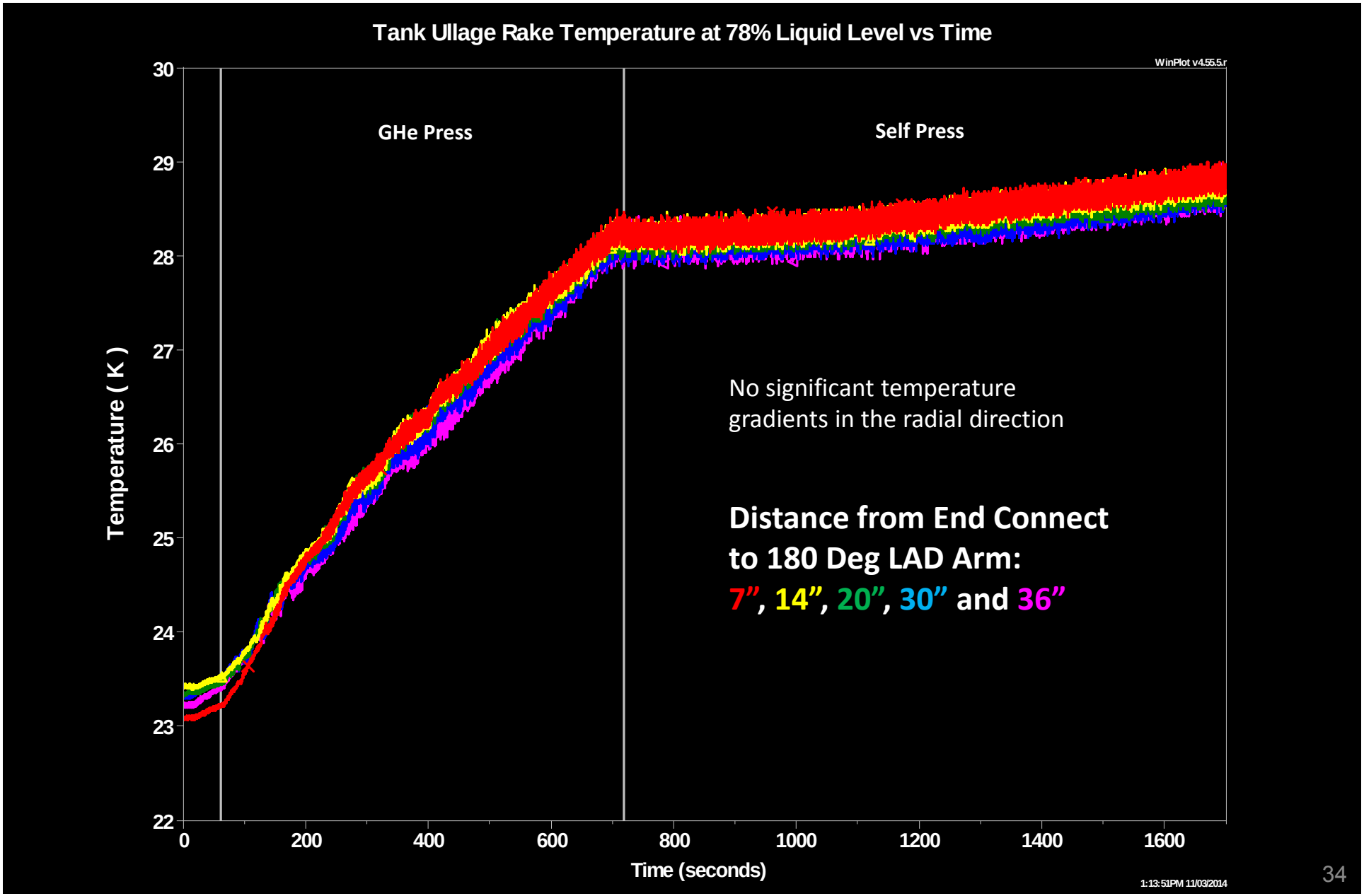
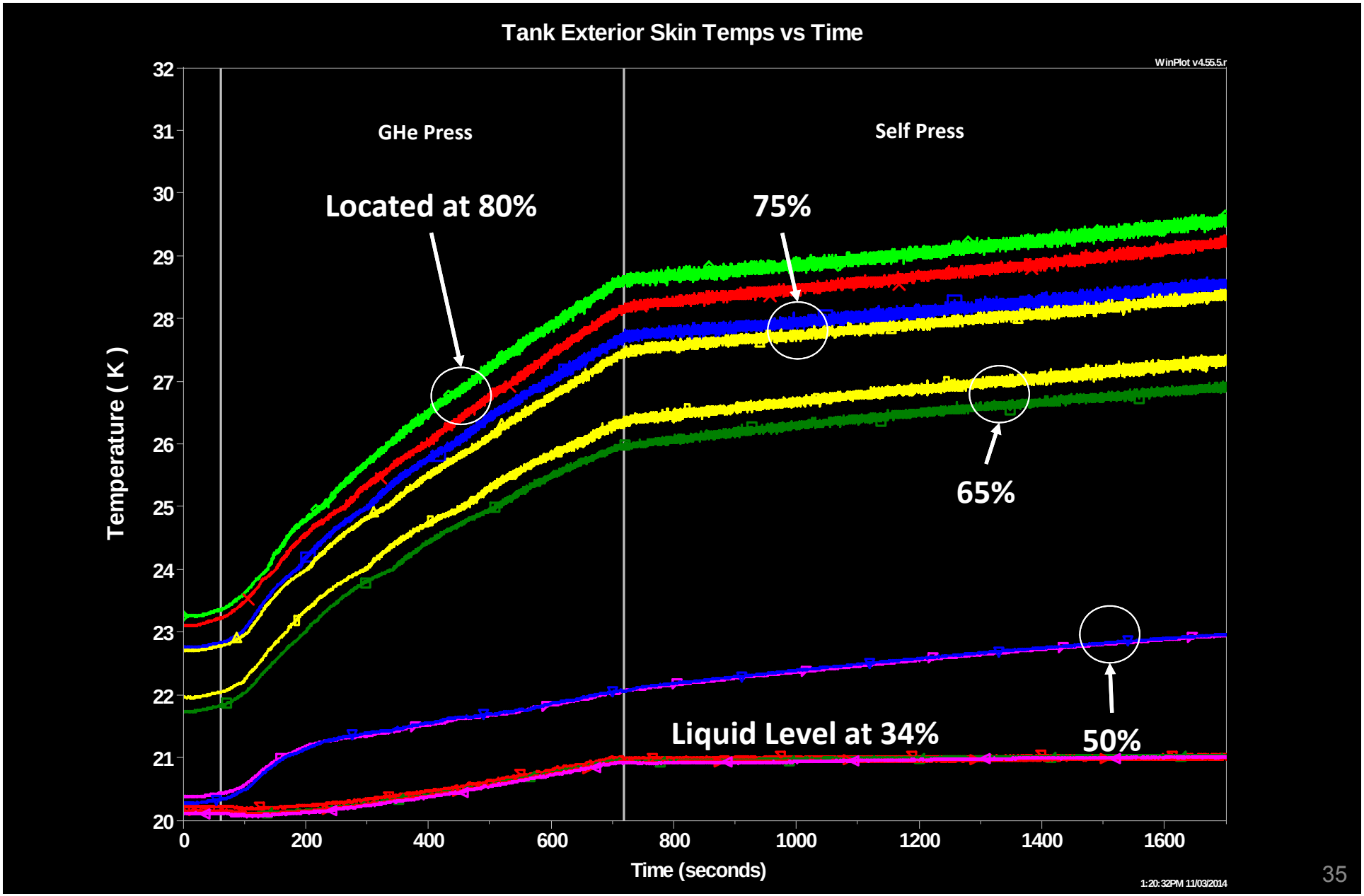


Pressurization Tests (HT – 51C and 52C)



Added Test Objectives for Test Day 13

HT-48F Pressurize tank from atmospheric to 27 PSIA using ambient helium and forward diffuser when tank liquid level is ~ 18%

HT-49F Once tank ullage pressure reaches 27 PSIA, discontinue pressurization and lockup tank. Allow tank to self pressurize to ~ 30 PSIA. *Demonstrate Axial Jet Mixing to reduce pressure as much as possible.*

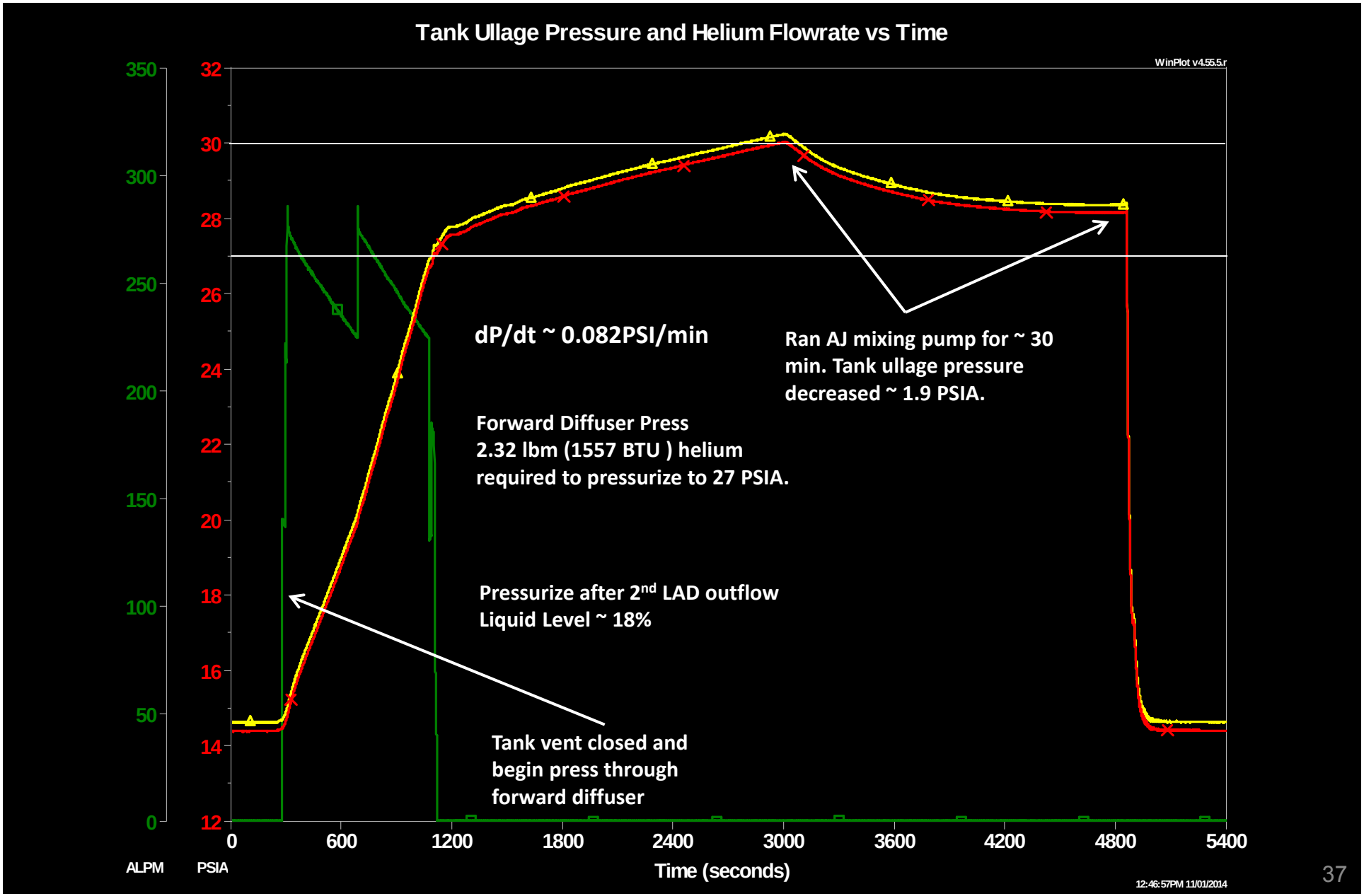
HT-50F Vent tank back down to atmospheric and allow at least 15 minutes to stabilize.

HT-51D Pressurize tank from atmospheric to 27 PSIA using ambient helium and Submerged diffuser when tank liquid level is ~ 18%

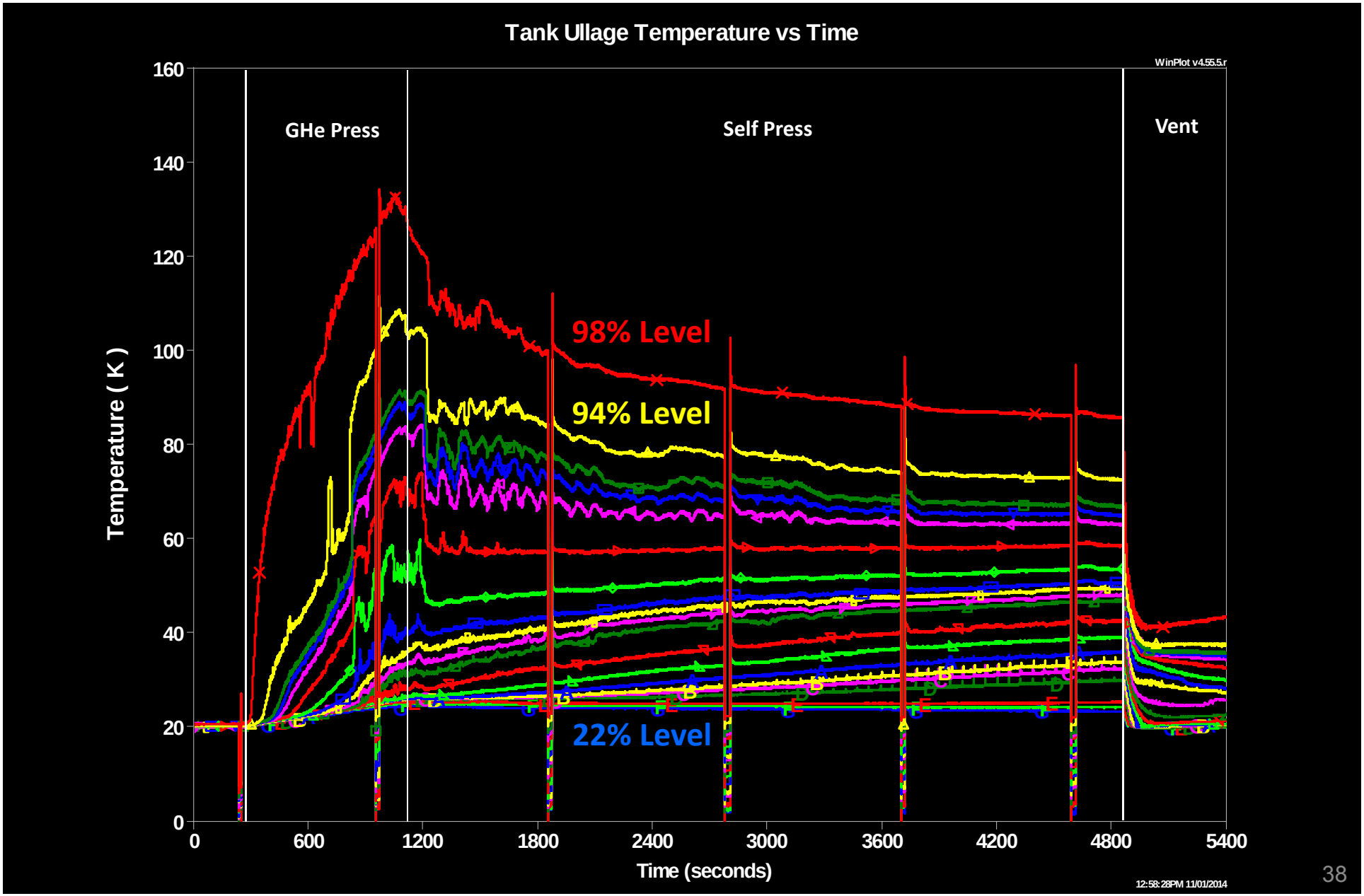
HT-52D Once tank ullage pressure reaches 27 PSIA, discontinue pressurization and lockup tank. Allow tank to self pressurize to ~ 30 PSIA.

HT-53D Vent tank back down to atmospheric and allow at least 15 minutes to stabilize.

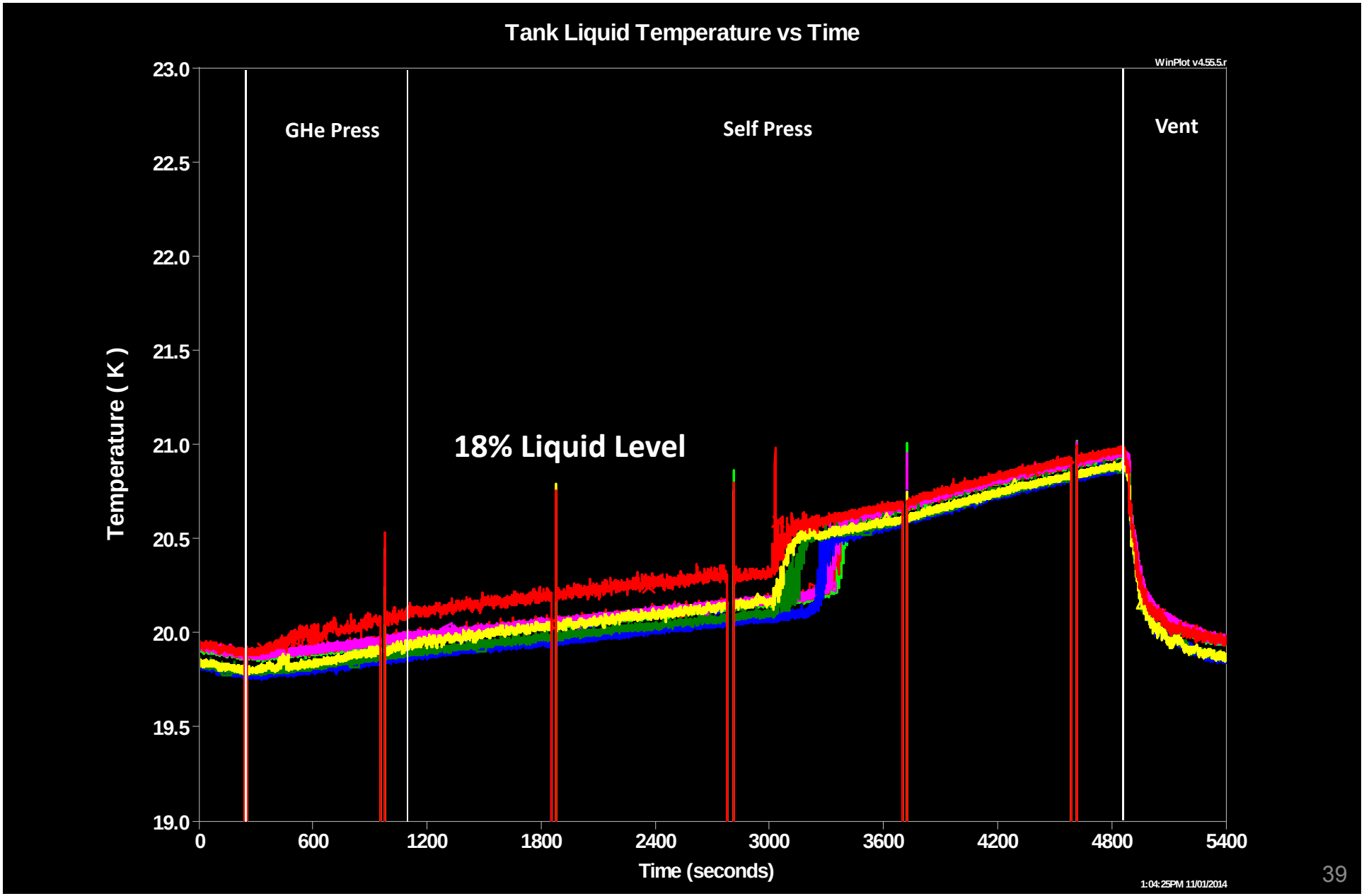
Pressurization Tests (HT – 48F, 49F, and 50F)



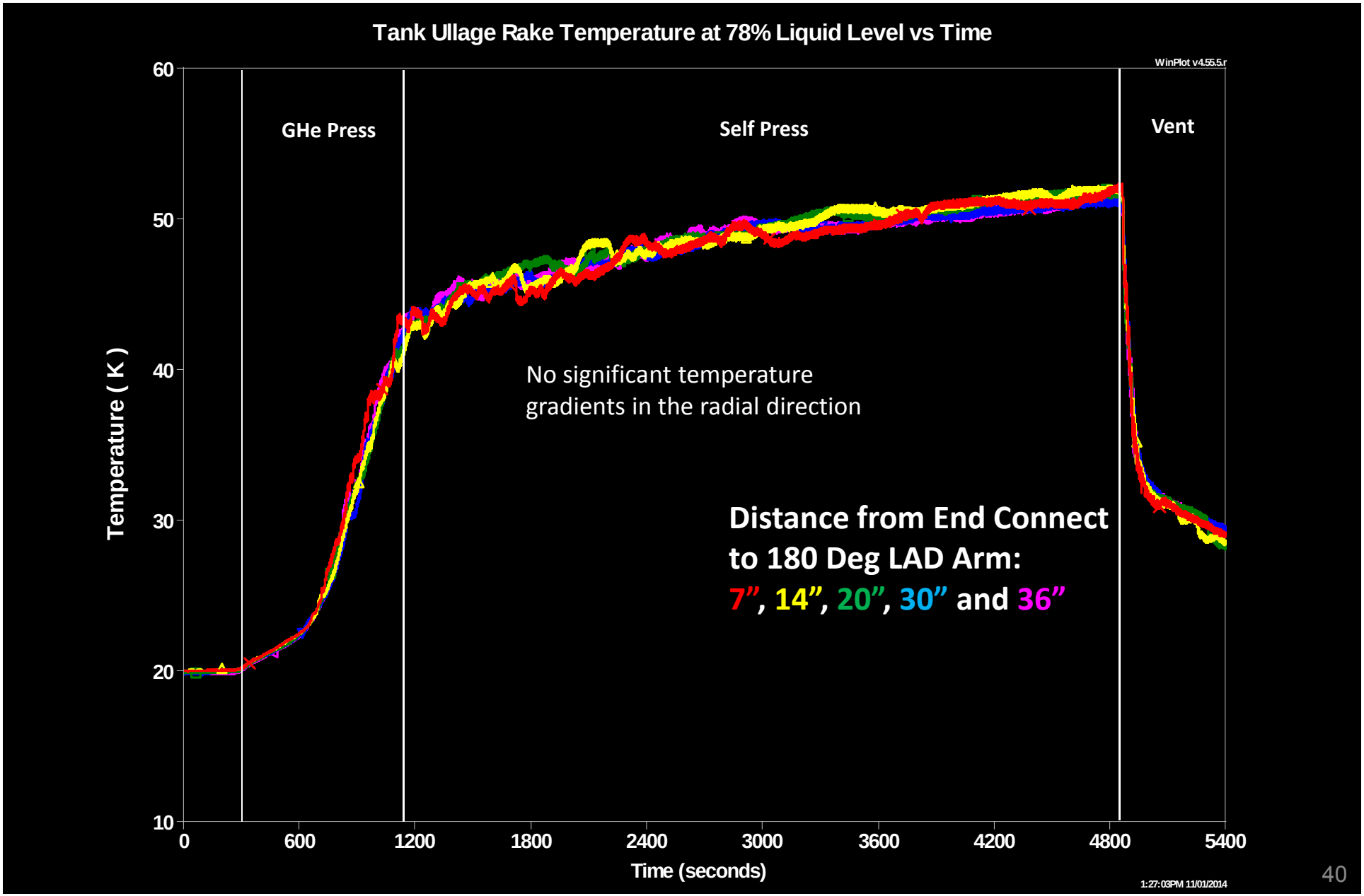
Pressurization Tests (HT – 48F, 49F, and 50F)



Pressurization Tests (HT – 48F, 49F, and 50F)



Pressurization Tests (HT – 48F, 49F, and 50F)



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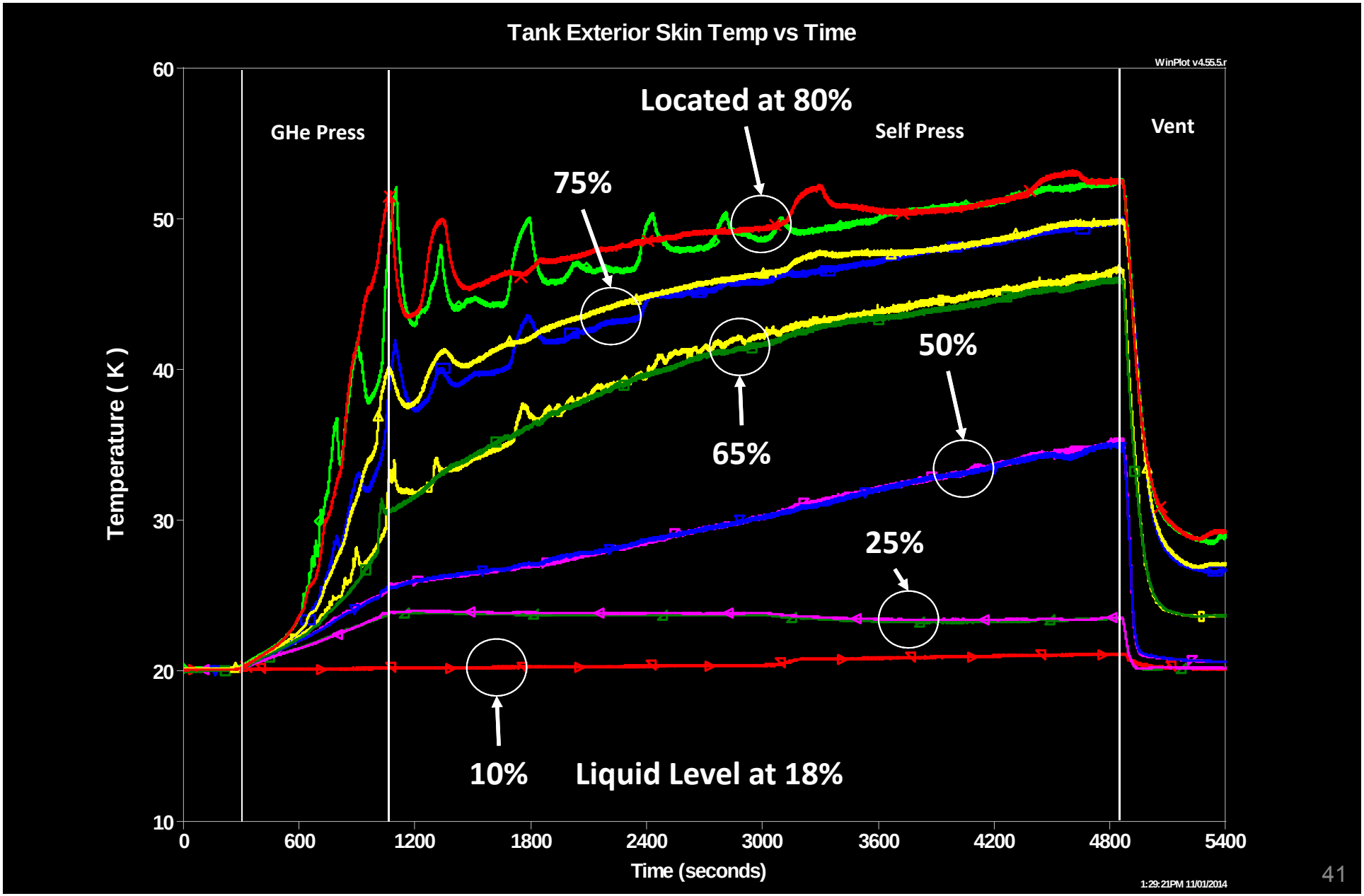

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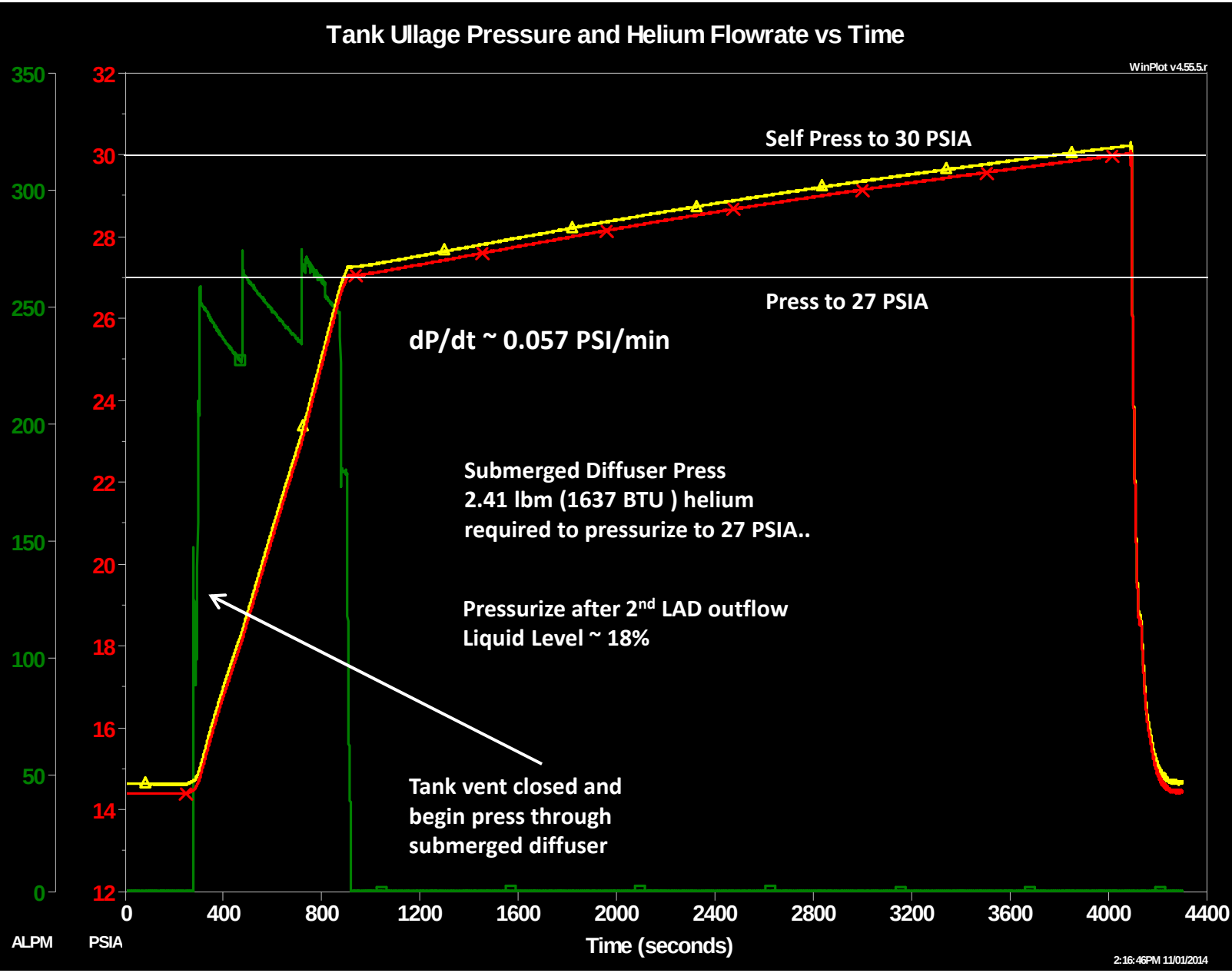

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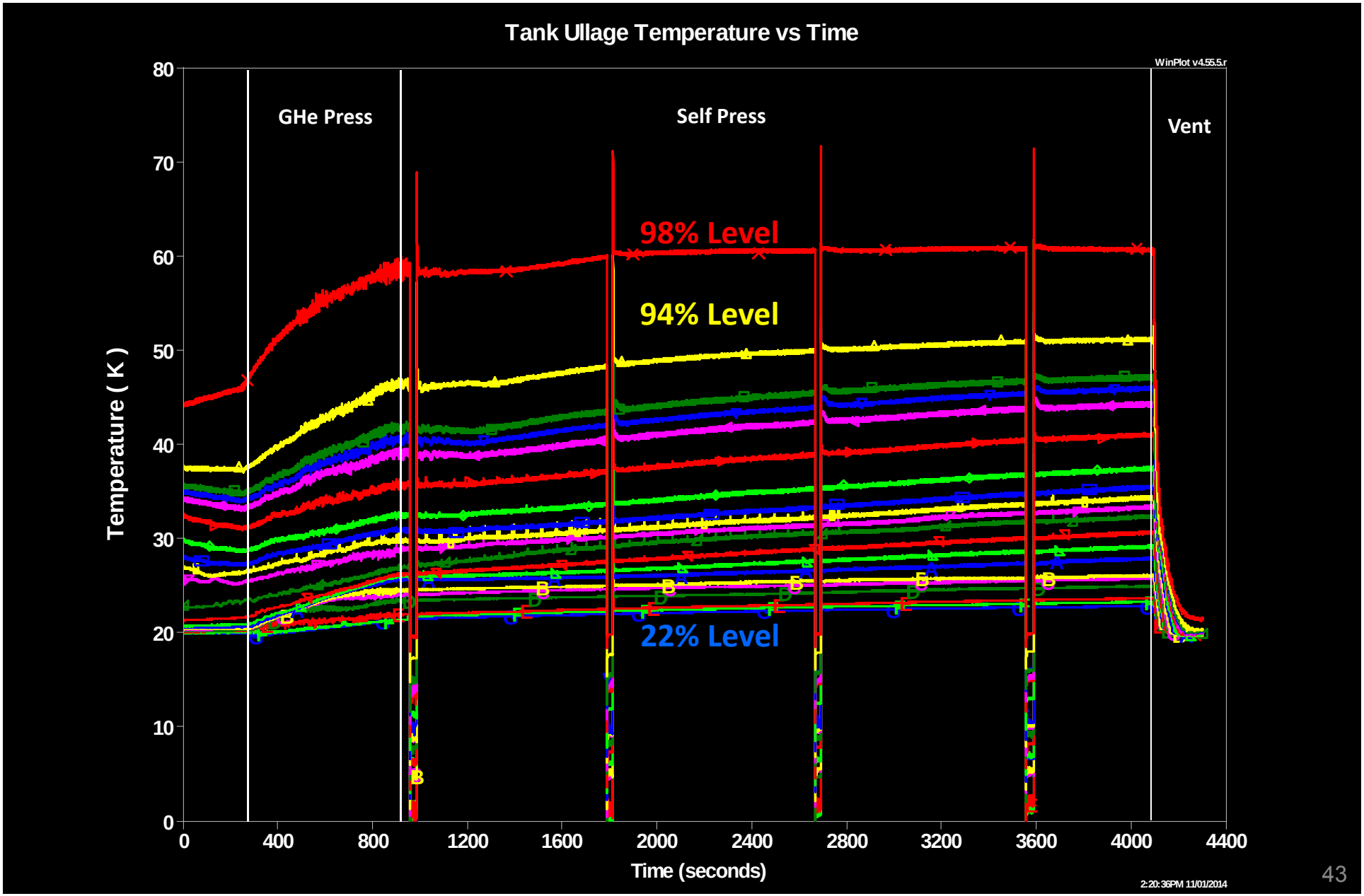

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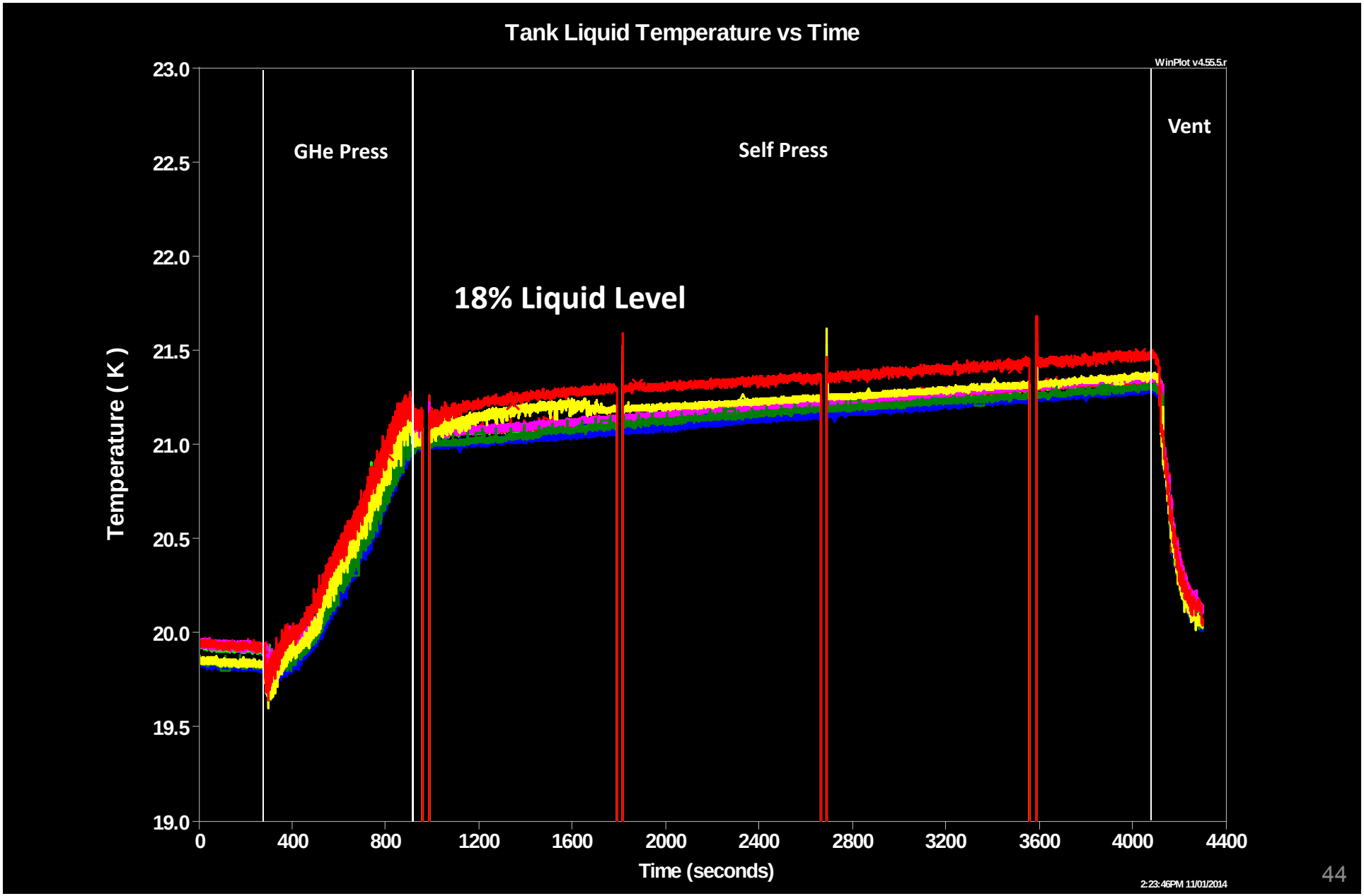

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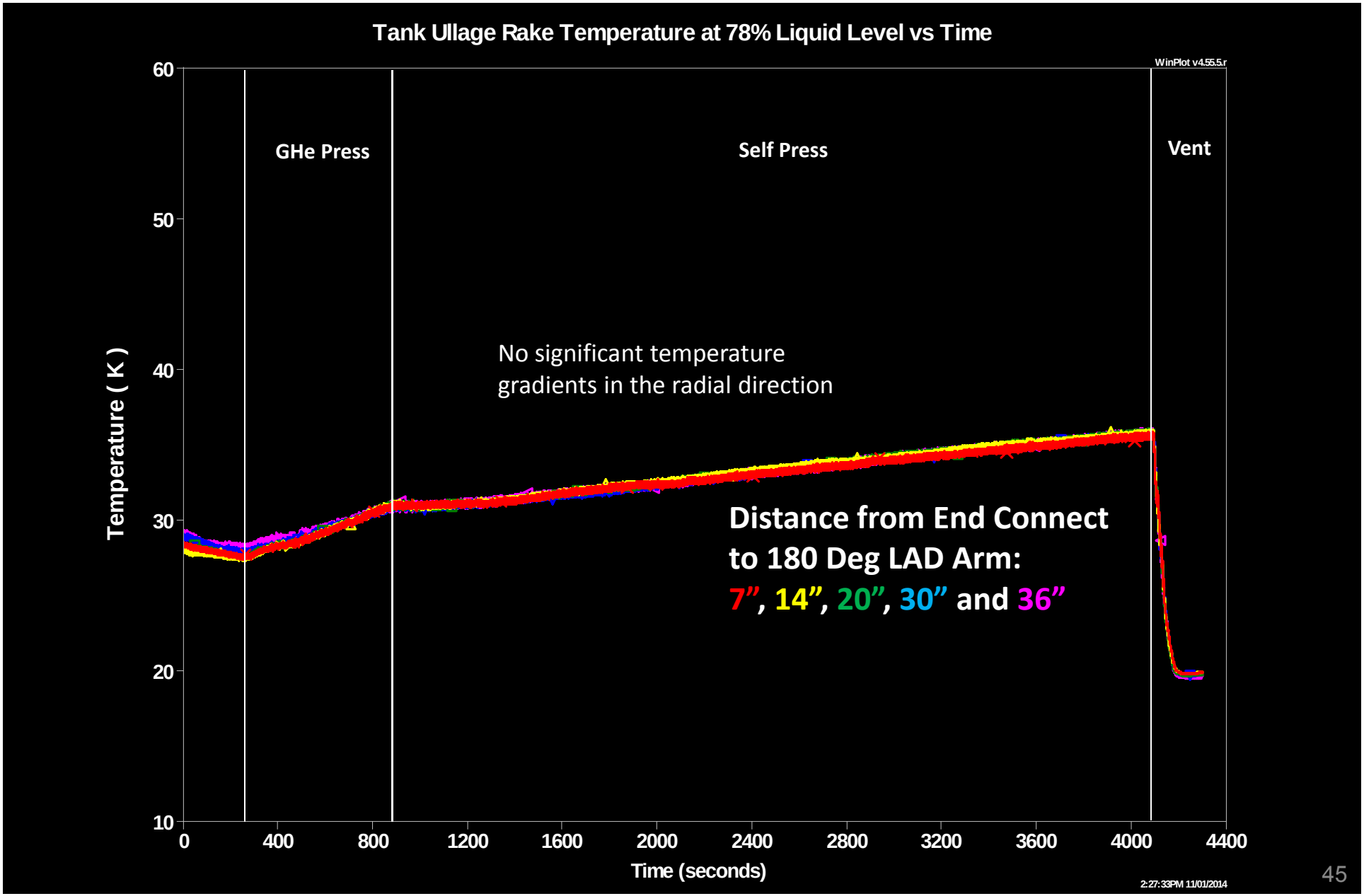

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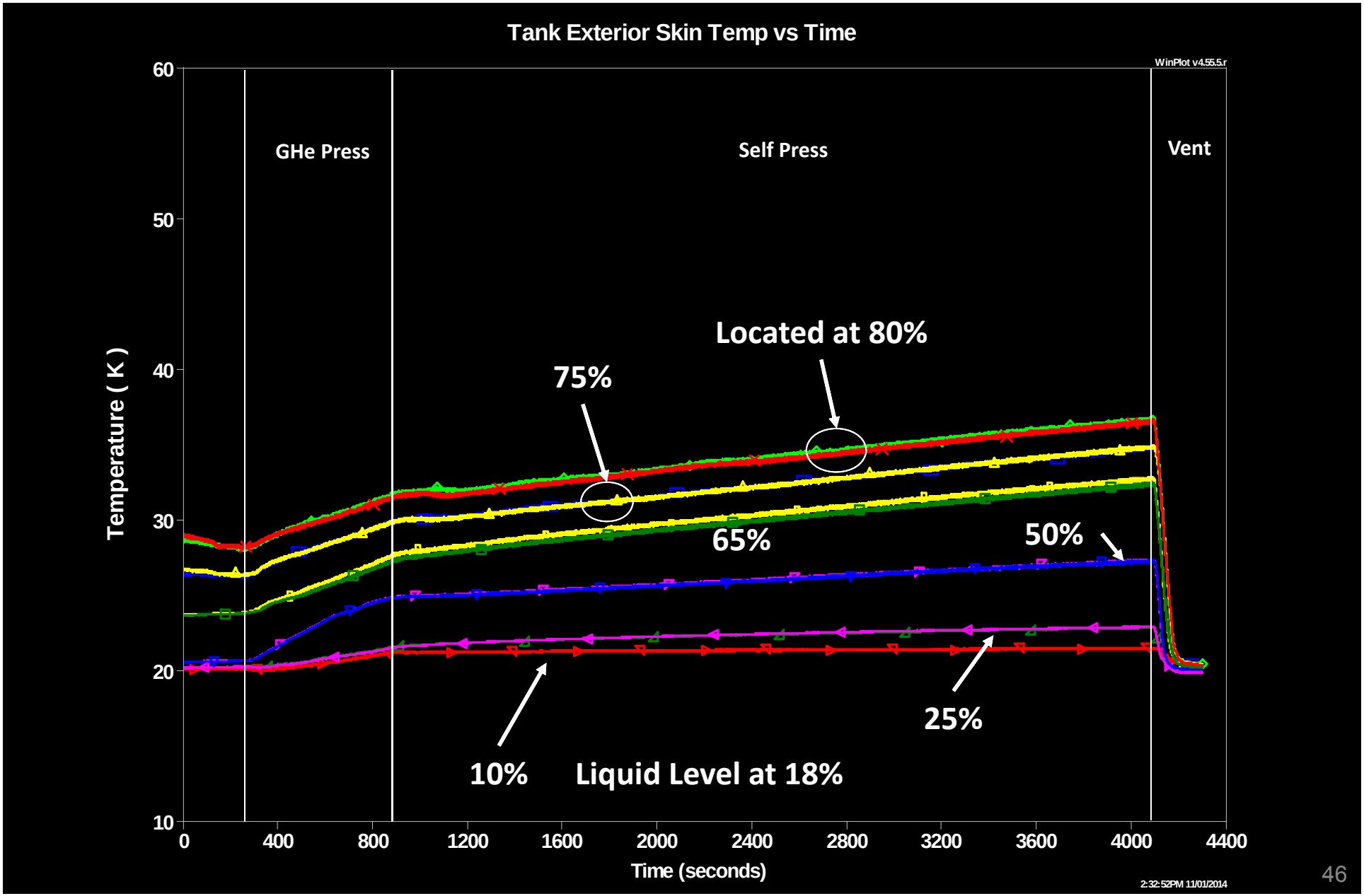


EDU Pressurization System Testing

CONCLUSION / OBSERVATIONS

- **EDU planned test objectives were successfully completed**
- **Additional pressurant gas was required when pressurizing through the aft diffuser**
  - **Was a function of the liquid level in the tank**
    - **108% more helium required when at 78% liquid level**
    - **38% more helium required when at 34% liquid level**
    - **4% more helium required when at 18% liquid level**
- **The AJ mixing pump was most effective at the higher liquid levels**
- **Additional objectives added were successfully completed except for the cold helium test. Due to the heat leak downstream of the LN2 heat exchanger, the pressurant gas entered the chamber at ambient temperature rather than cryogenic temperature.**
- **The targeted tank pressure was easily achieved using the regulated helium pressurant and a manual flow control valve which was adjusted real-time**
  - **The pressurization system testing on EDU was not conducive to evaluate the dynamic effects associated with a bang-bang system with a submerged diffuser (ITAP Testing).**

EDU Pressurization System Testing

FUTURE WORK

- **Pressurization system and heat load data will be used to validate the Computational Propellant and Pressurization Program – One Dimensional (CPPPO) and the GFSSP pressurization system model**
- **Paper to be submitted to the 26th Space Cryogenics Workshop, June 24-26, 2015, Phoenix, Arizona.**
- **ITAP Testing**
  - **EDU was only able to evaluate the performance of a pressurization system utilizing regulated helium with a variable position valve adjusted manually to decrease pressurant flow as the targeted pressure is reached.**
  - **EDU pressurization system was demonstrated with a relatively large ullage (liquid level of 78%, 34% and 18%)**
  - **Repeat pressurization test and LAD outflow utilizing a bang-bang pressurization system starting with the LH2 tank at ~ 98% liquid level**
    - **Evaluated the overshoots and slumps resulting from the associated delays in valve and control system response, and LH2 boiling/foaming resulting from the sub-surface pressurization (submerged diffuser).**

Backup Data

Added Test Objectives for Test Day 13

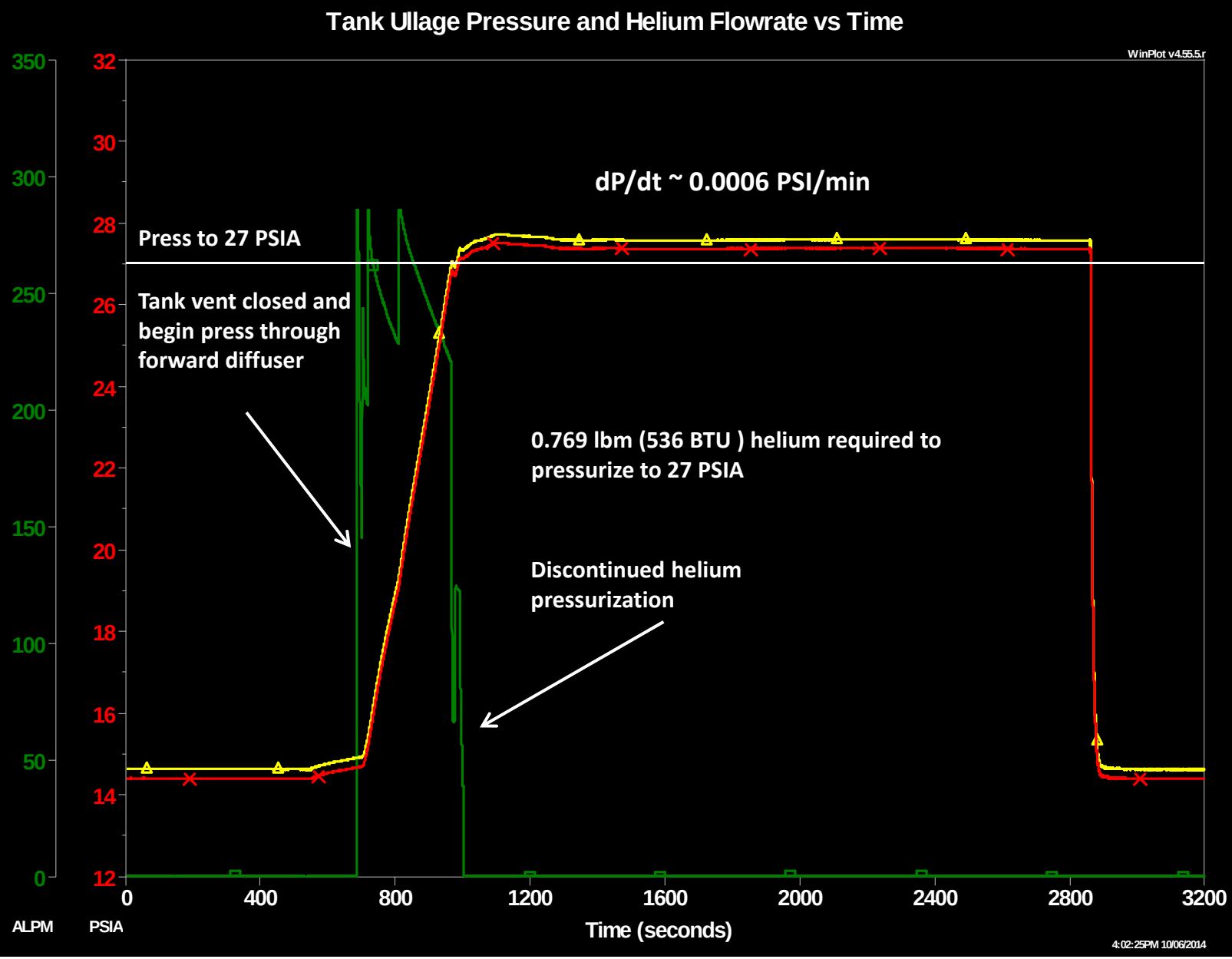
HT-48C Pressurize tank from atmospheric to 27 PSIA using cold helium and forward diffuser when tank liquid level is ~ 78%

HT-49C Once tank ullage pressure reaches 27 PSIA, discontinue pressurization and lockup tank. Allow tank to self pressurize to ~ 30 PSIA.

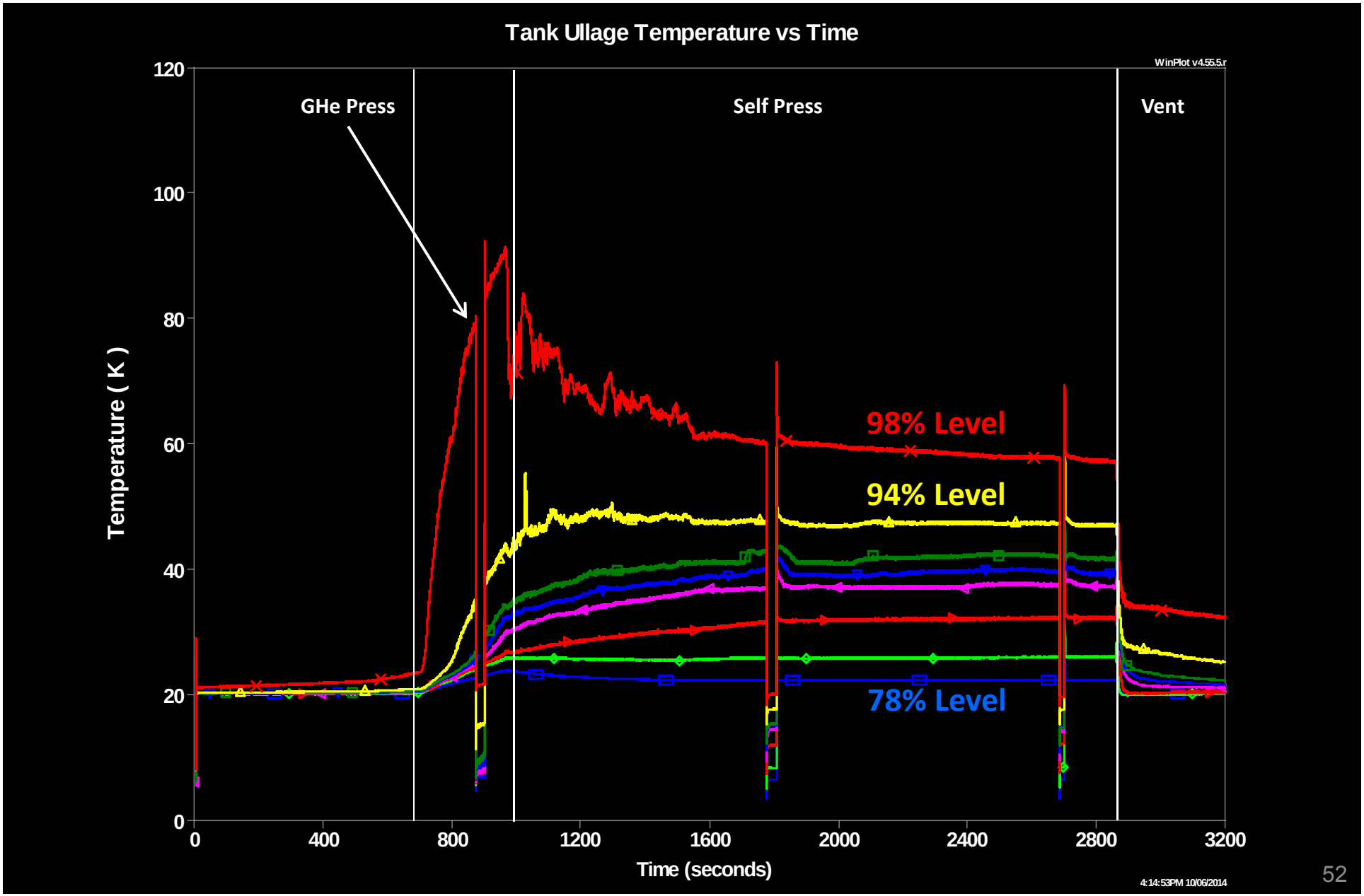
HT-50C Vent tank back down to atmospheric and allow at least 15 minutes to stabilize.

The LN2 HTX did not successfully chill the helium as expected
Helium temperature was close to ambient

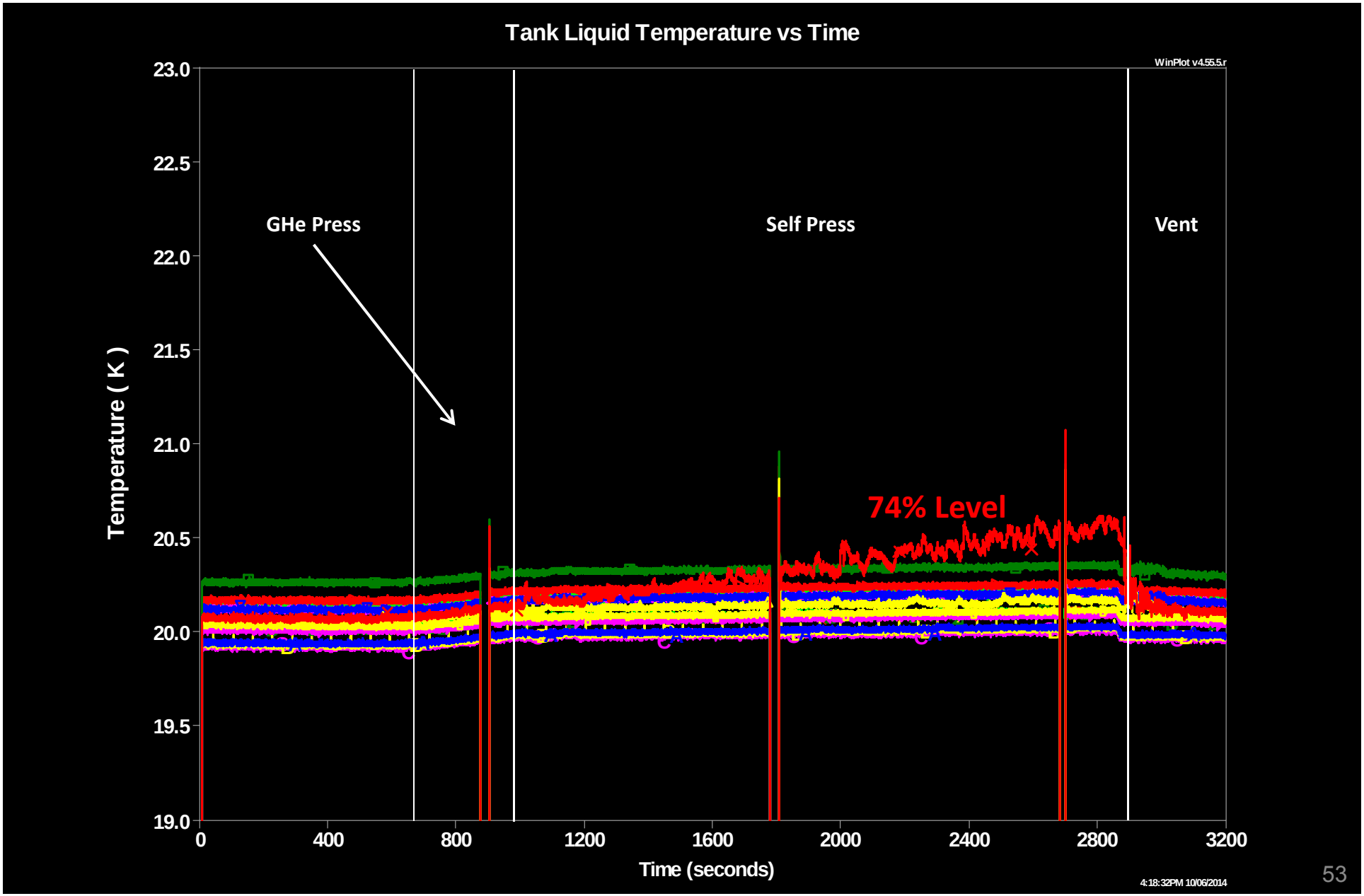
Pressurization Tests (HT – 48C, 49C, and 50C)



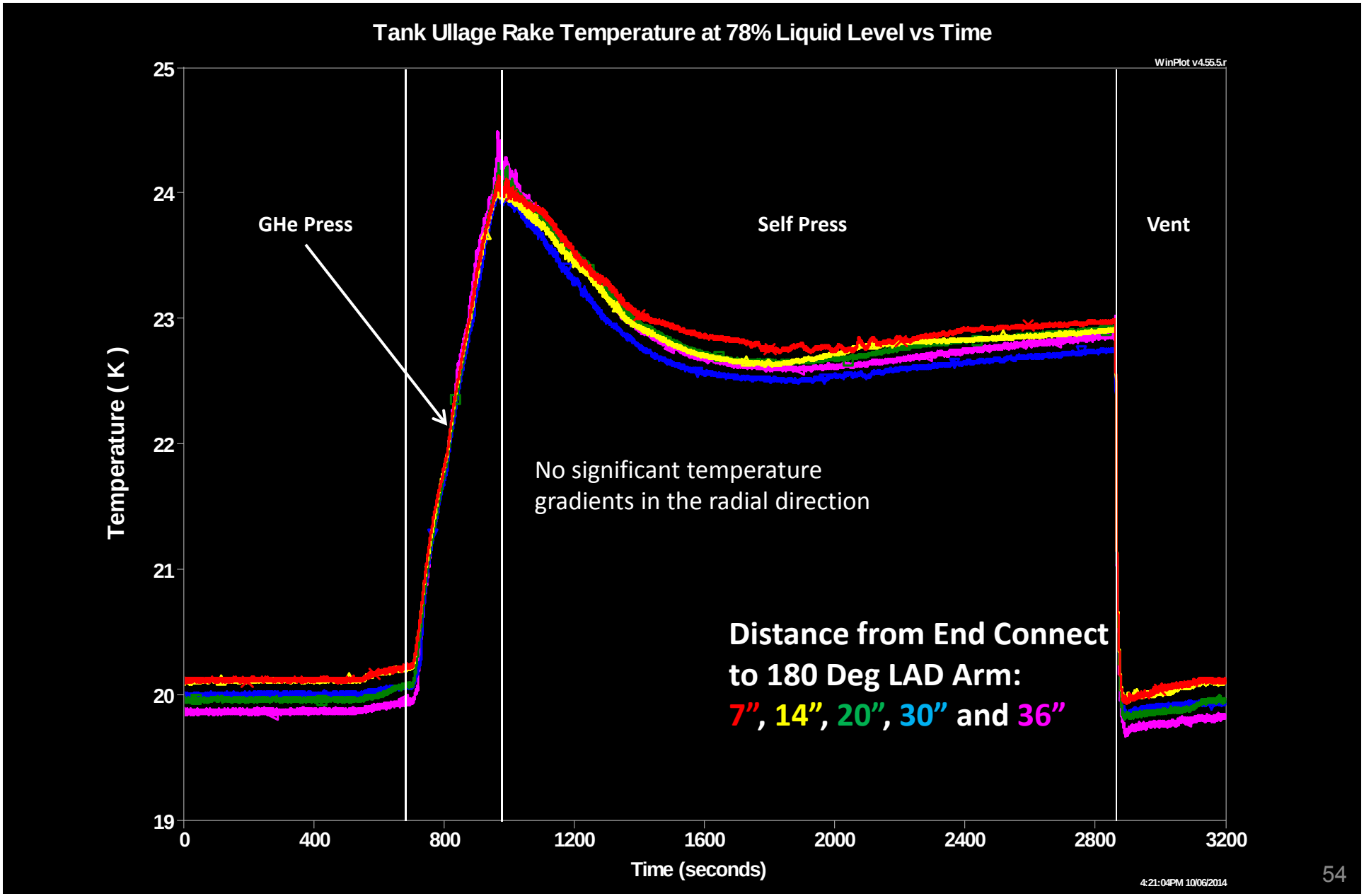
Pressurization Tests (HT – 48C, 49C, and 50C)



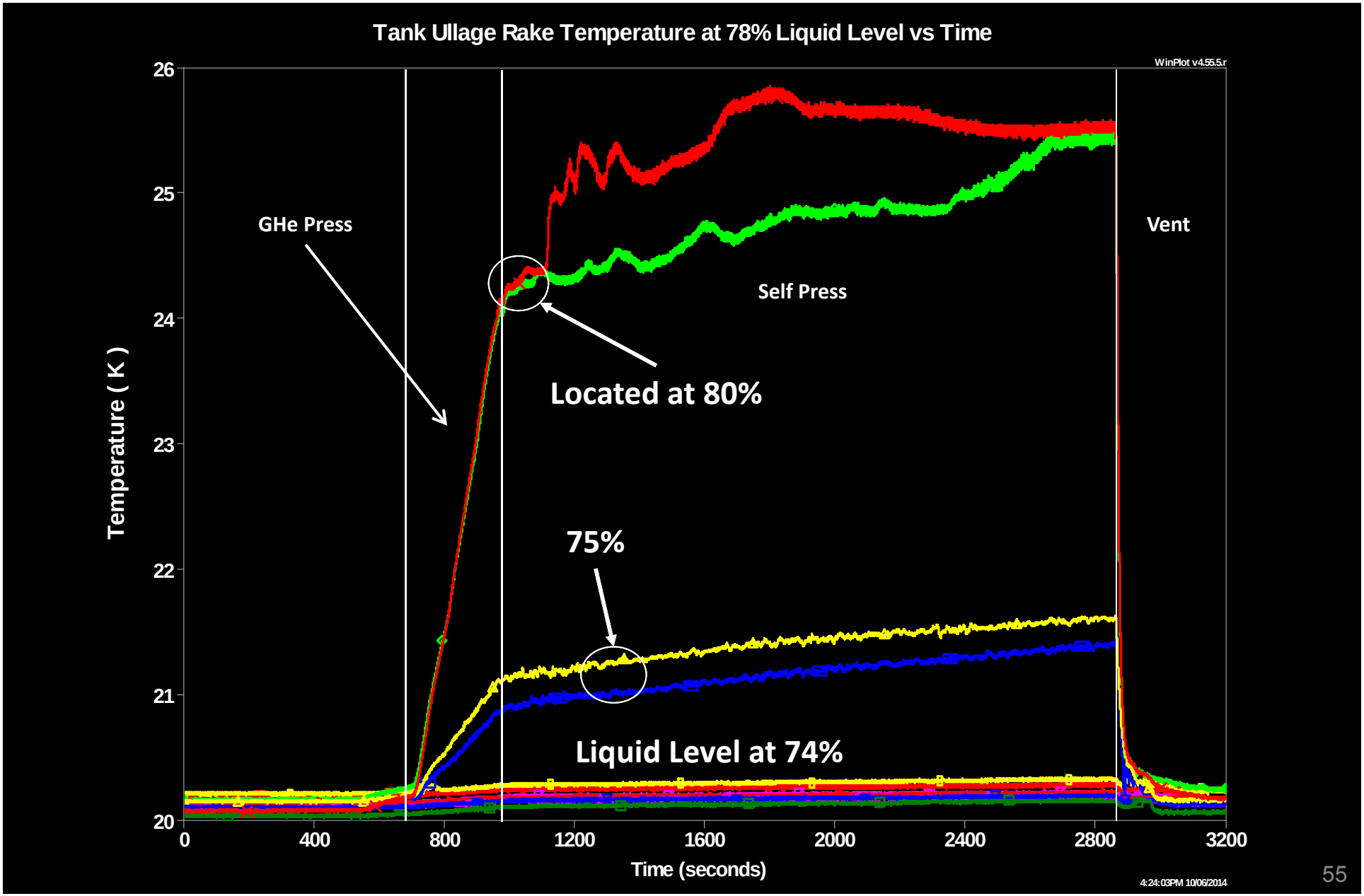
Pressurization Tests (HT – 48C, 49C, and 50C)



Pressurization Tests (HT – 48C, 49C, and 50C)



Pressurization Tests (HT – 48C, 49C, and 50C)



Added Test Objectives for Test Day 13

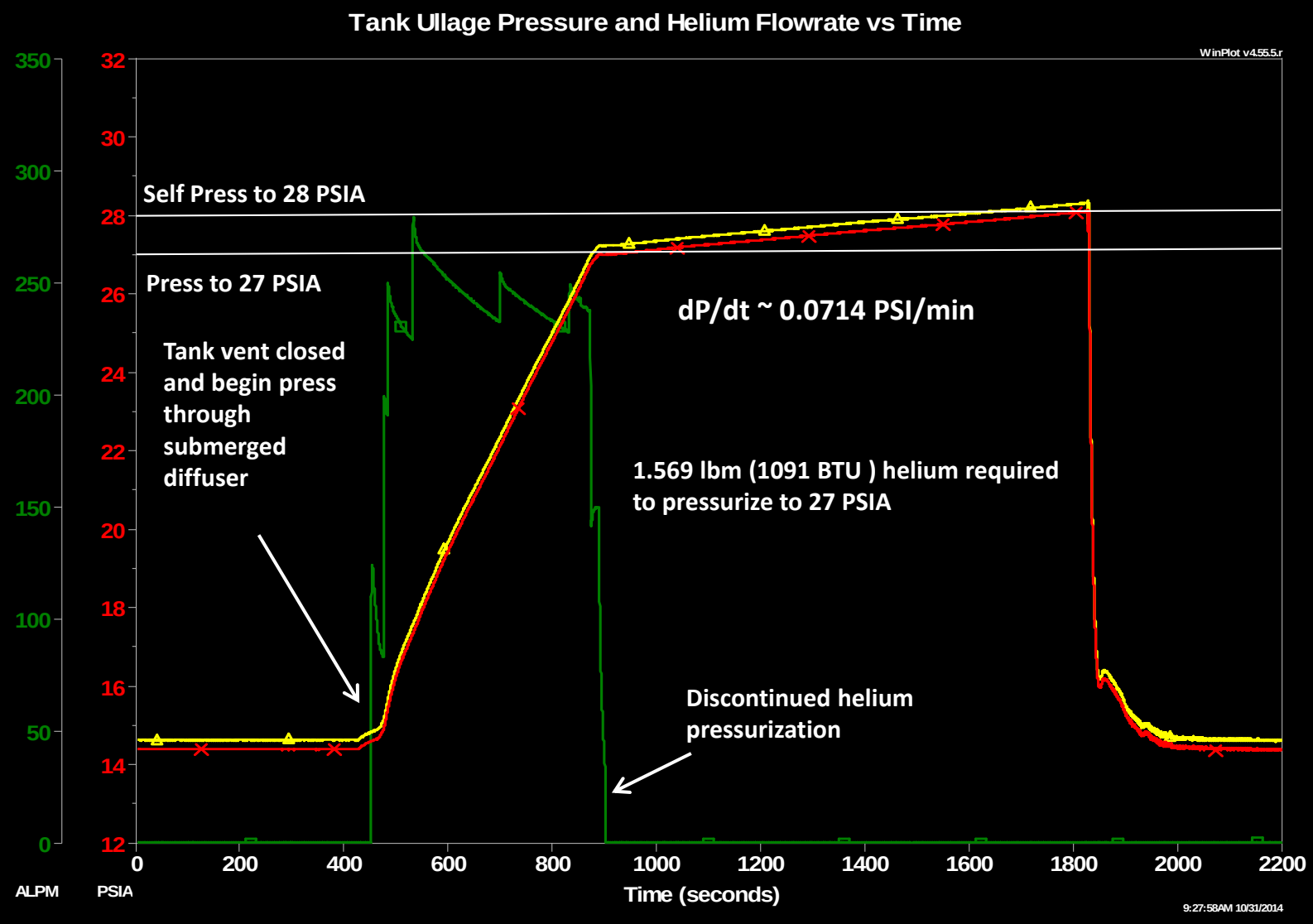
HT-51B Pressurize tank from atmospheric to 27 PSIA using cold helium and Submerged diffuser when tank liquid level is ~ 78%

HT-52B Once tank ullage pressure reaches 27 PSIA, discontinue pressurization and lockup tank. Allow tank to self pressurize to ~ 30 PSIA.

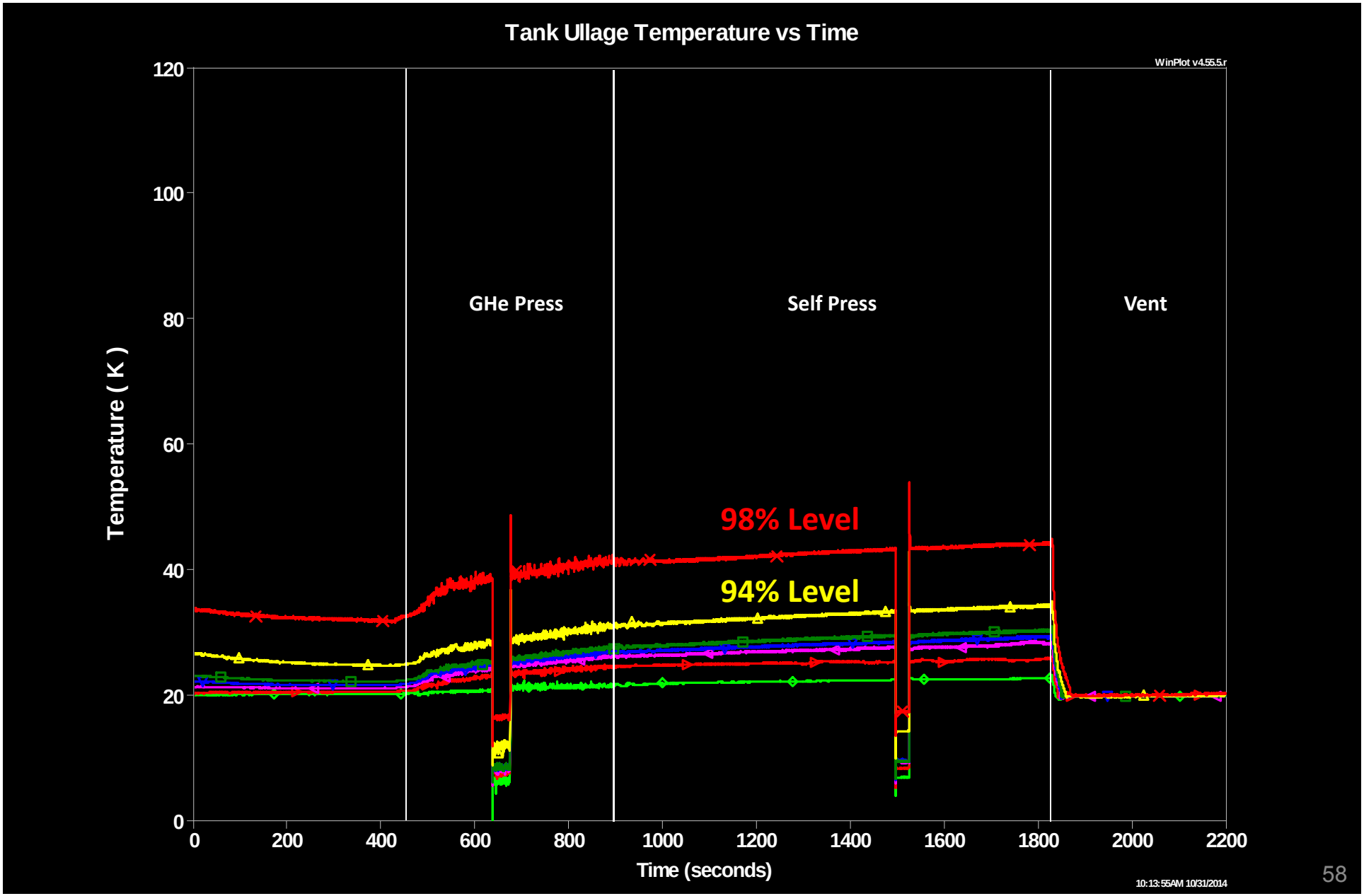
HT-53B Vent tank back down to atmospheric and allow at least 15 minutes to stabilize.

The LN2 HTX did not successfully chill the helium as expected
Helium temperature was close to ambient

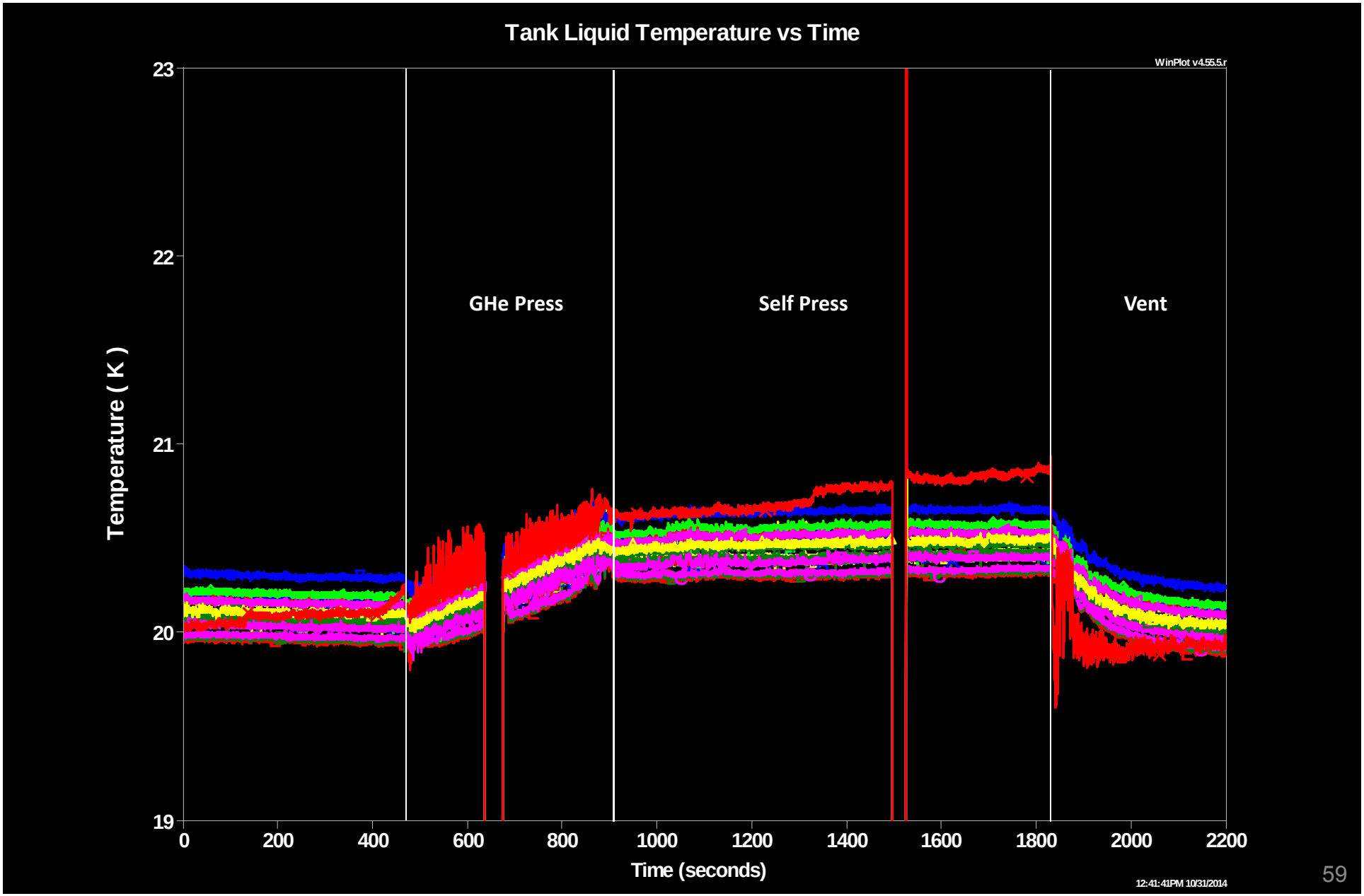
Pressurization Tests (HT – 51B, 52B, and 53B)



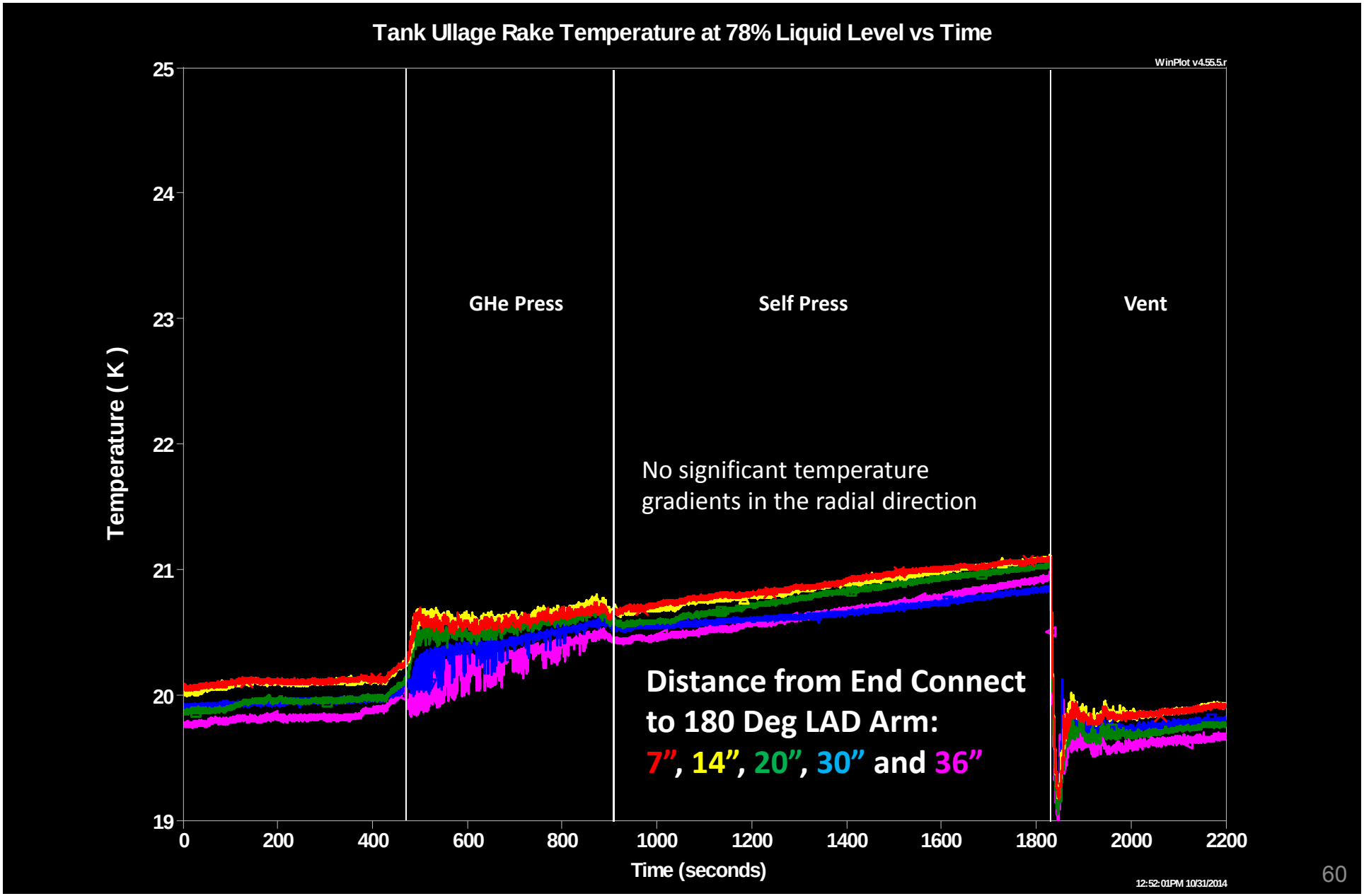
Pressurization Tests (HT – 51B, 52B, and 53B)



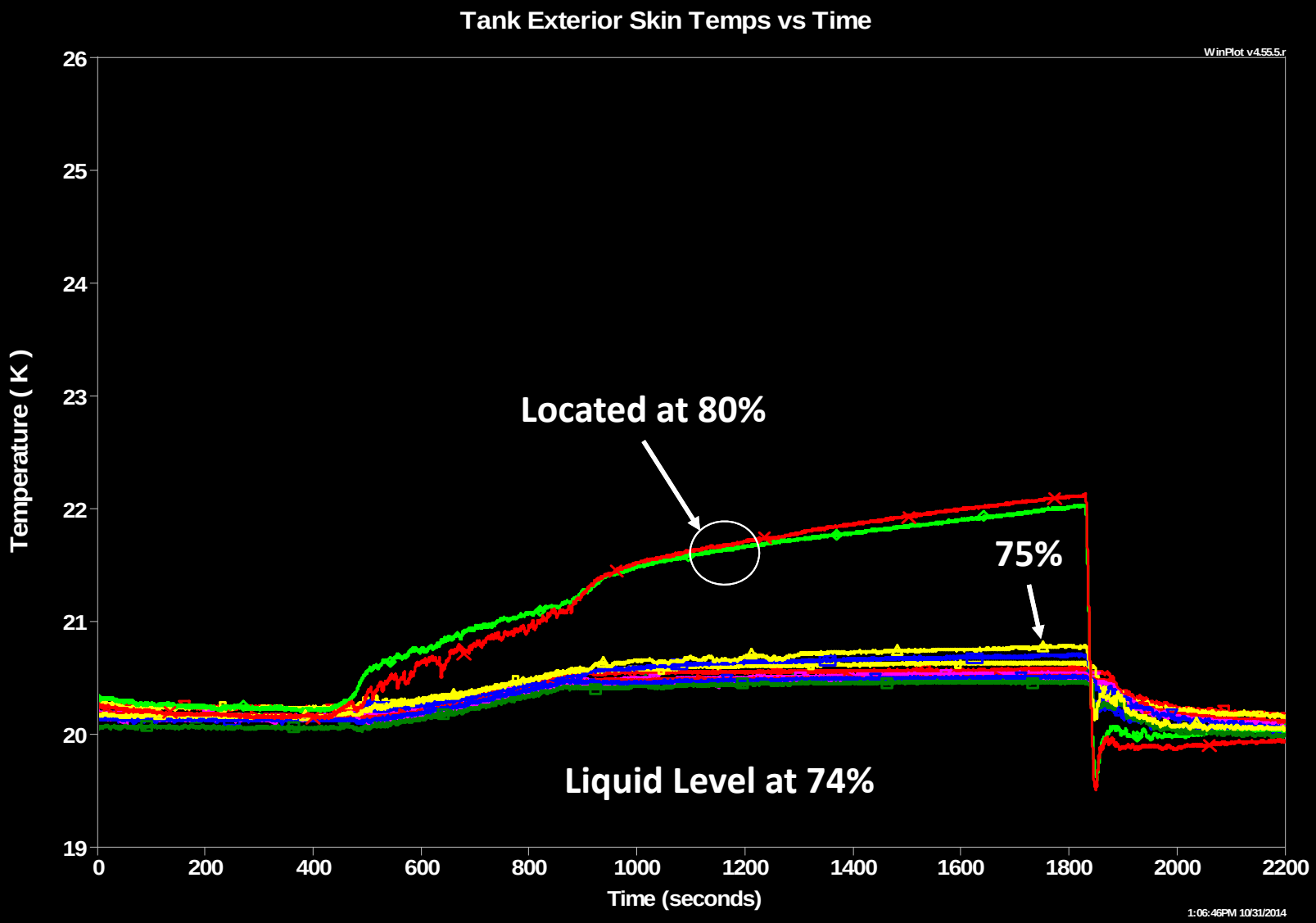
Pressurization Tests (HT – 51B, 52B, and 53B)



Pressurization Tests (HT – 51B, 52B, and 53B)



Pressurization Tests (HT – 51B, 52B, and 53B)



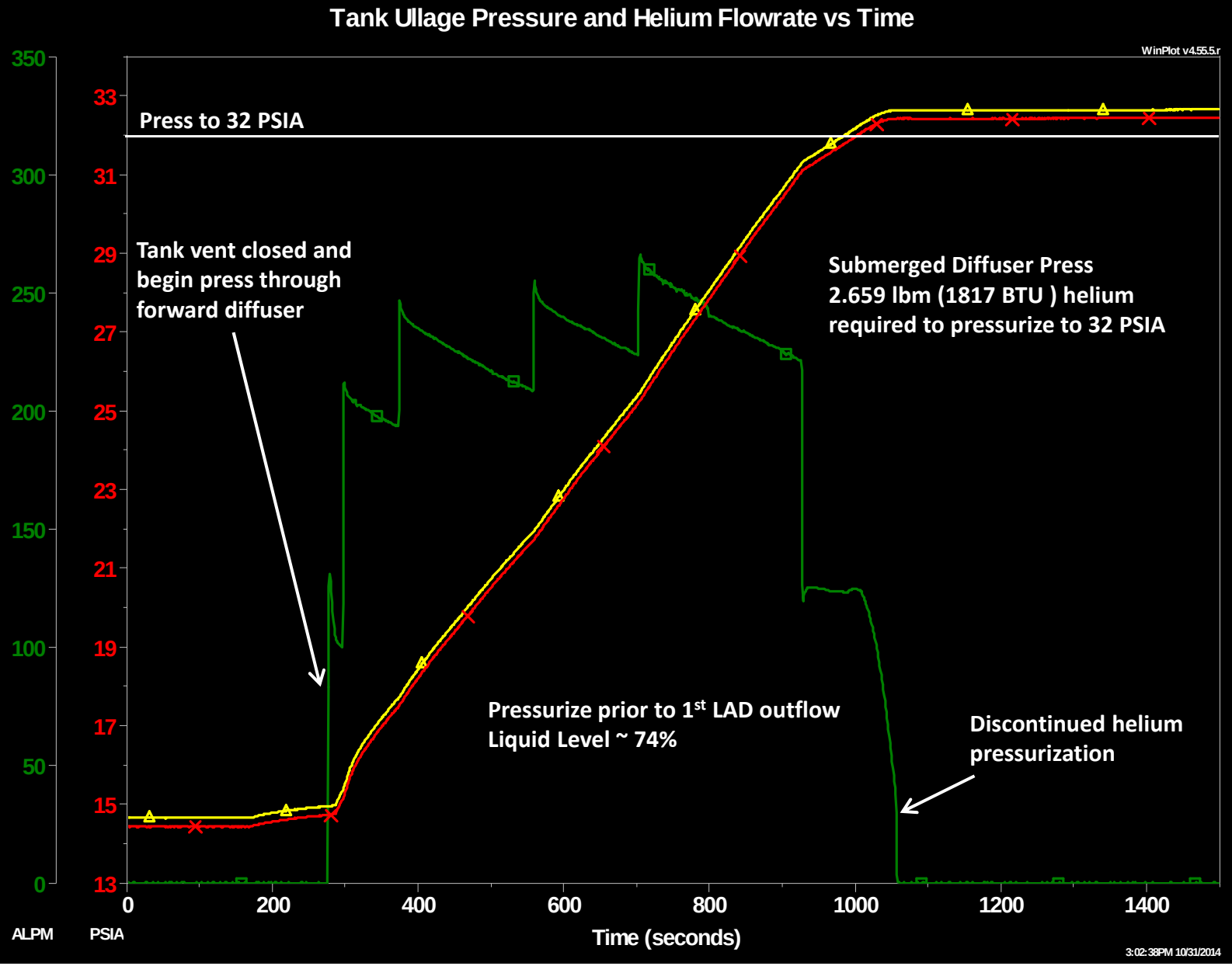
Added Test Objectives for Test Day 13

HT-79 **Pressurize tank from atmospheric to 32 PSIA using ambient helium and submerged diffuser when tank liquid level is ~ 78%**

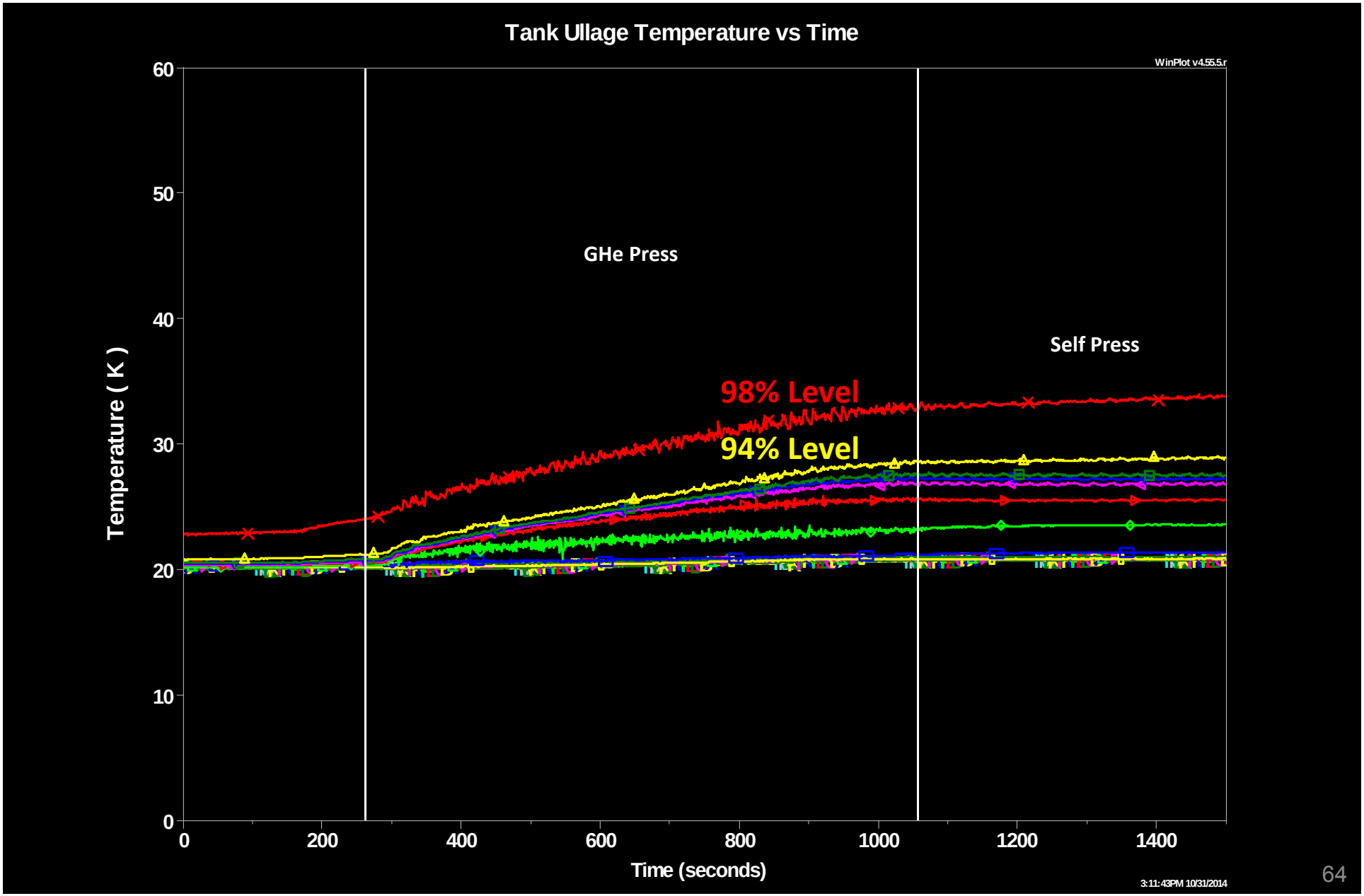
Decrease tank liquid level to ~ 34% via LADs outflow

Vent tank back down to atmospheric and allow at least 15 minutes to stabilize.

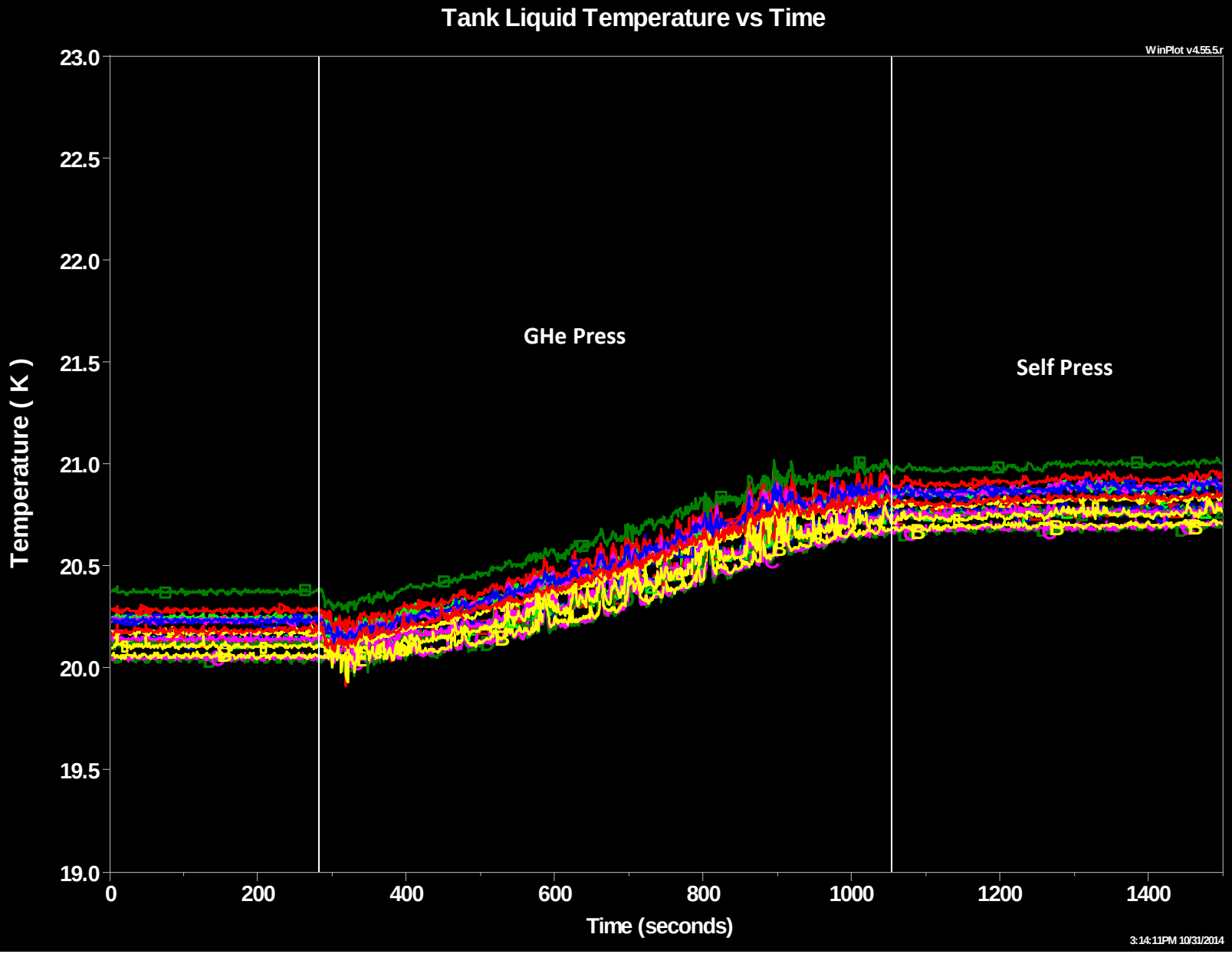
Pressurization Tests (HT – 79)



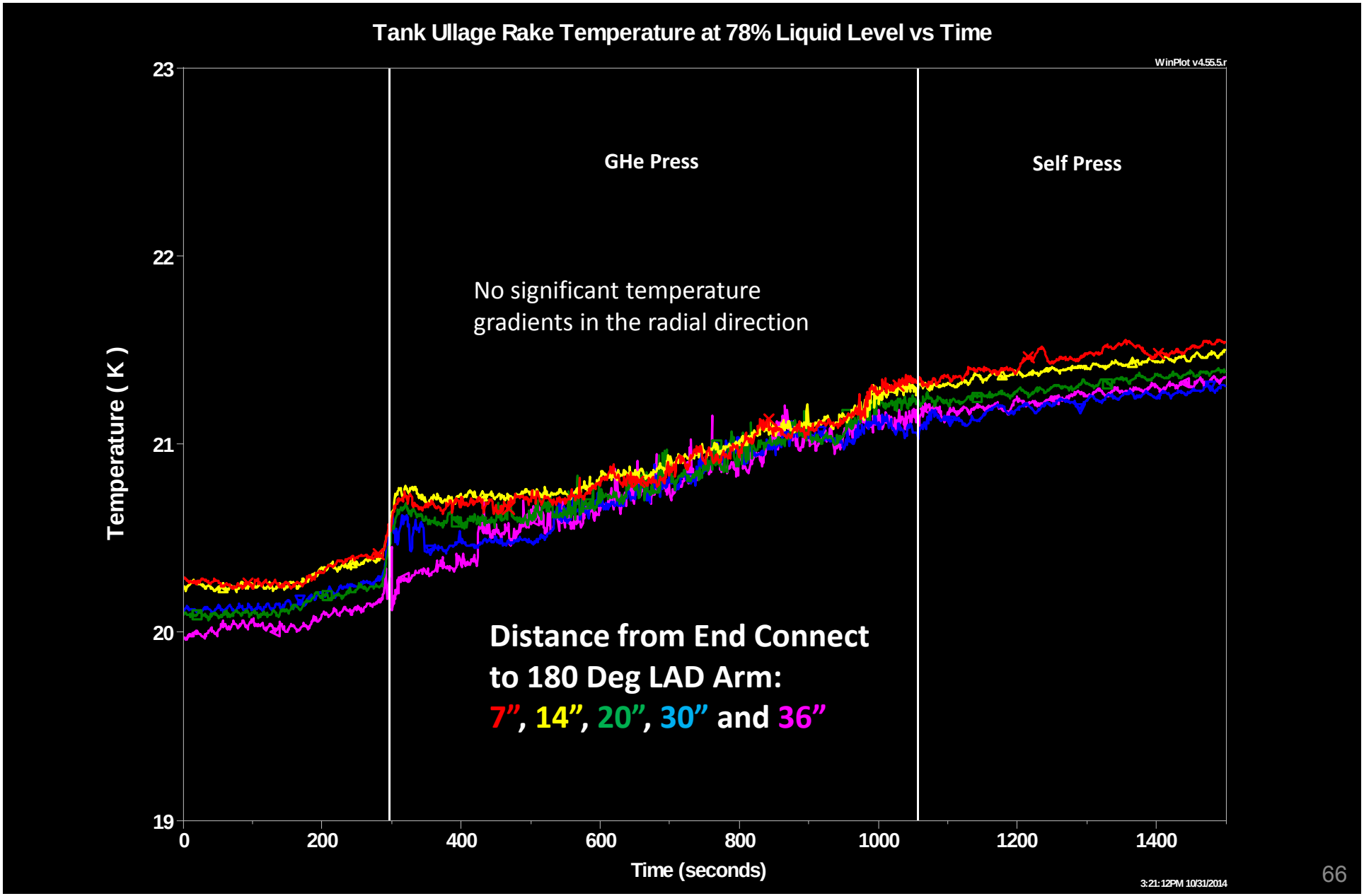
Pressurization Tests (HT – 79)



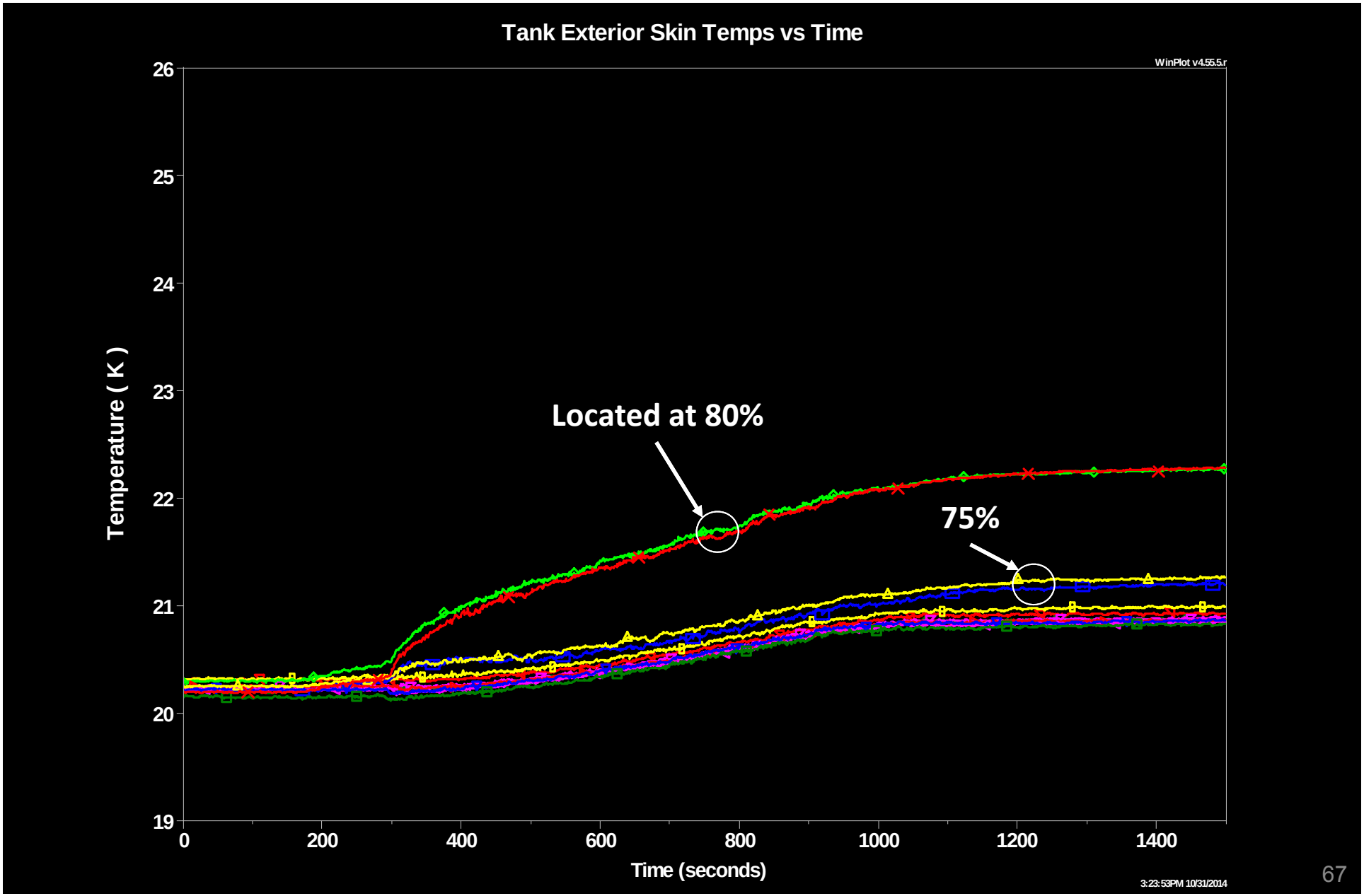
Pressurization Tests (HT – 79)



Pressurization Tests (HT – 79)



Pressurization Tests (HT – 79)



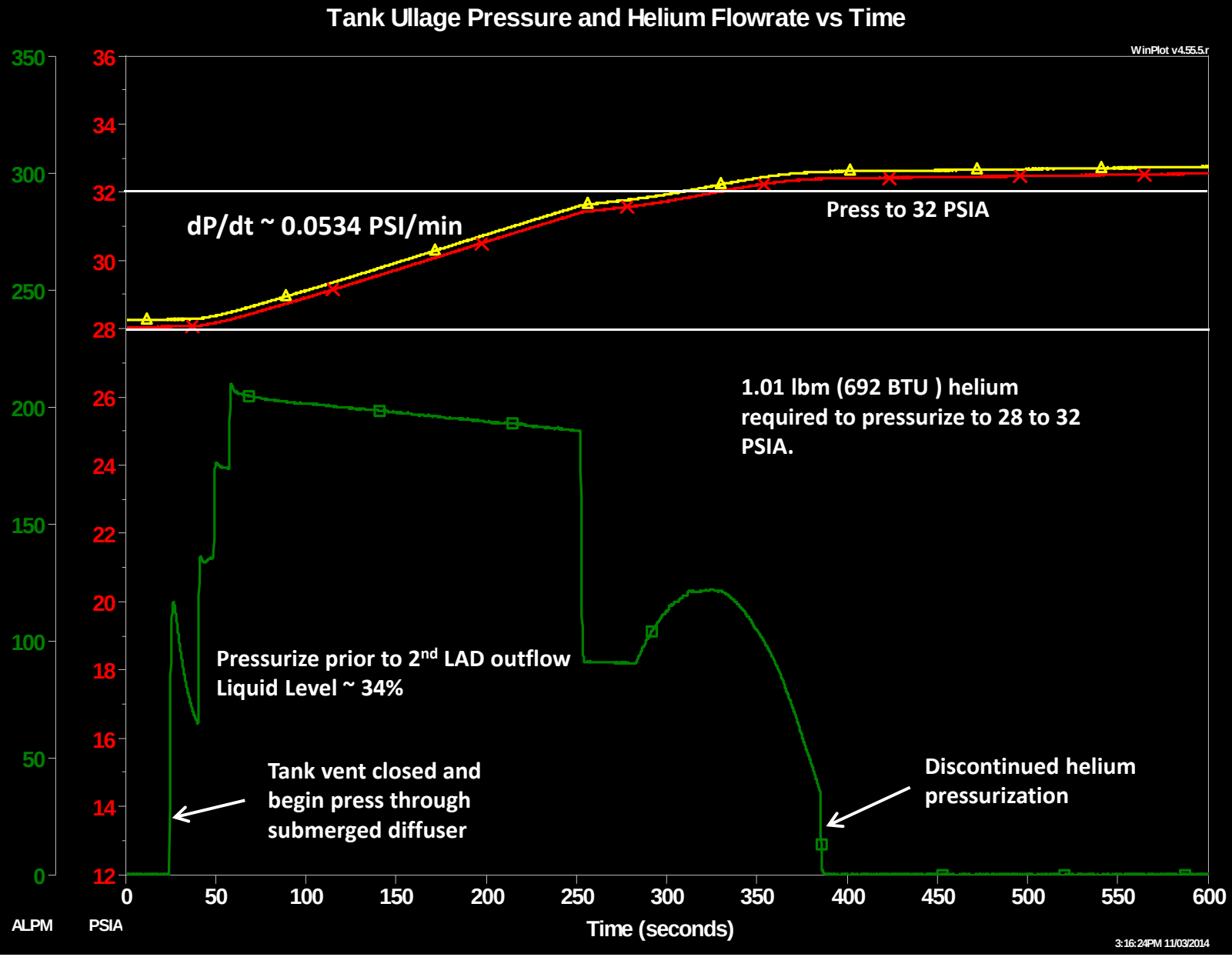
Added Test Objectives for Test Day 13

HT-79B **Pressurize tank from 28 to 32 PSIA using ambient helium and submerged diffuser when tank liquid level is ~ 43%**

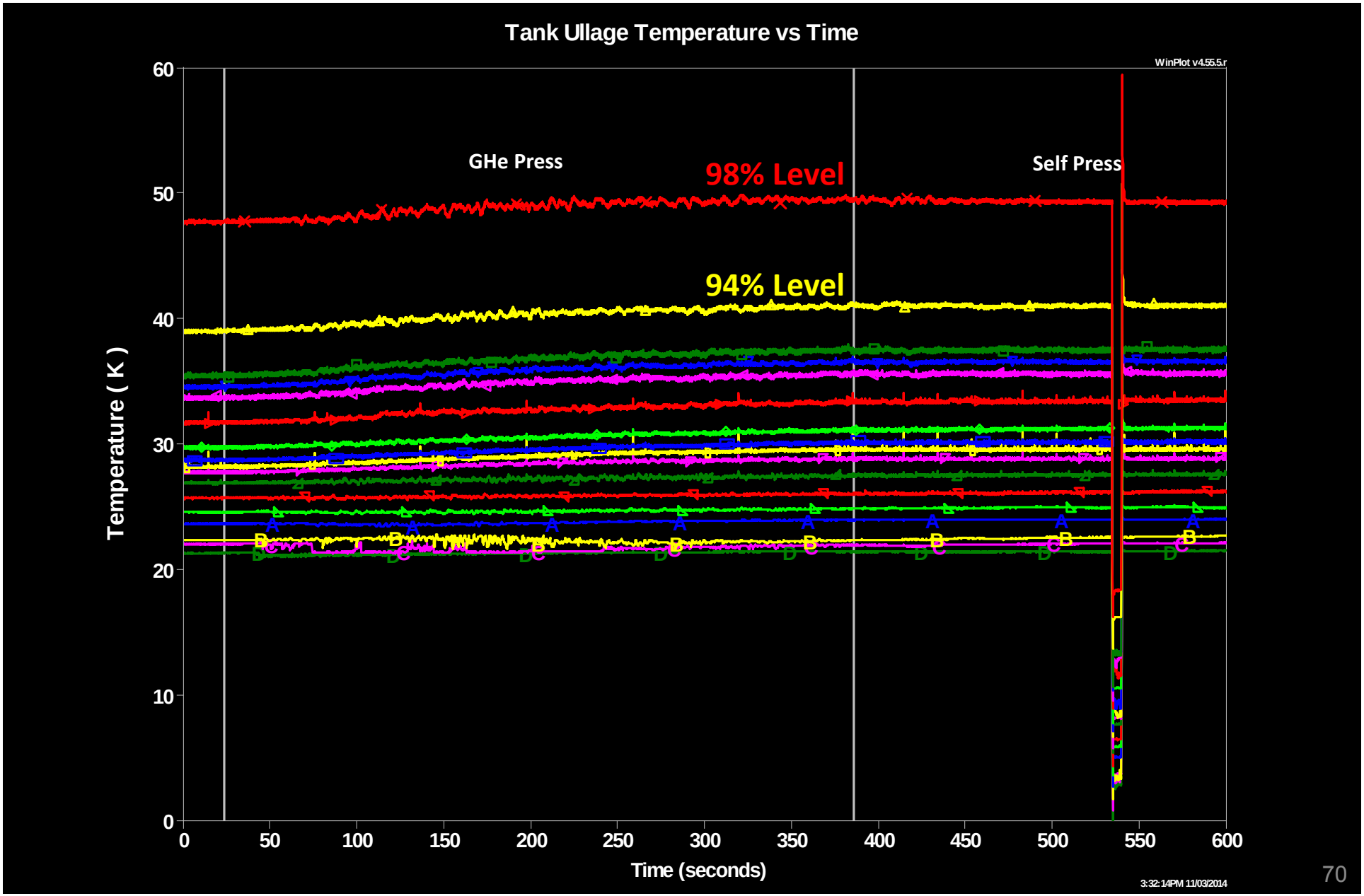
Decrease tank liquid level to ~ 18% via LADs outflow

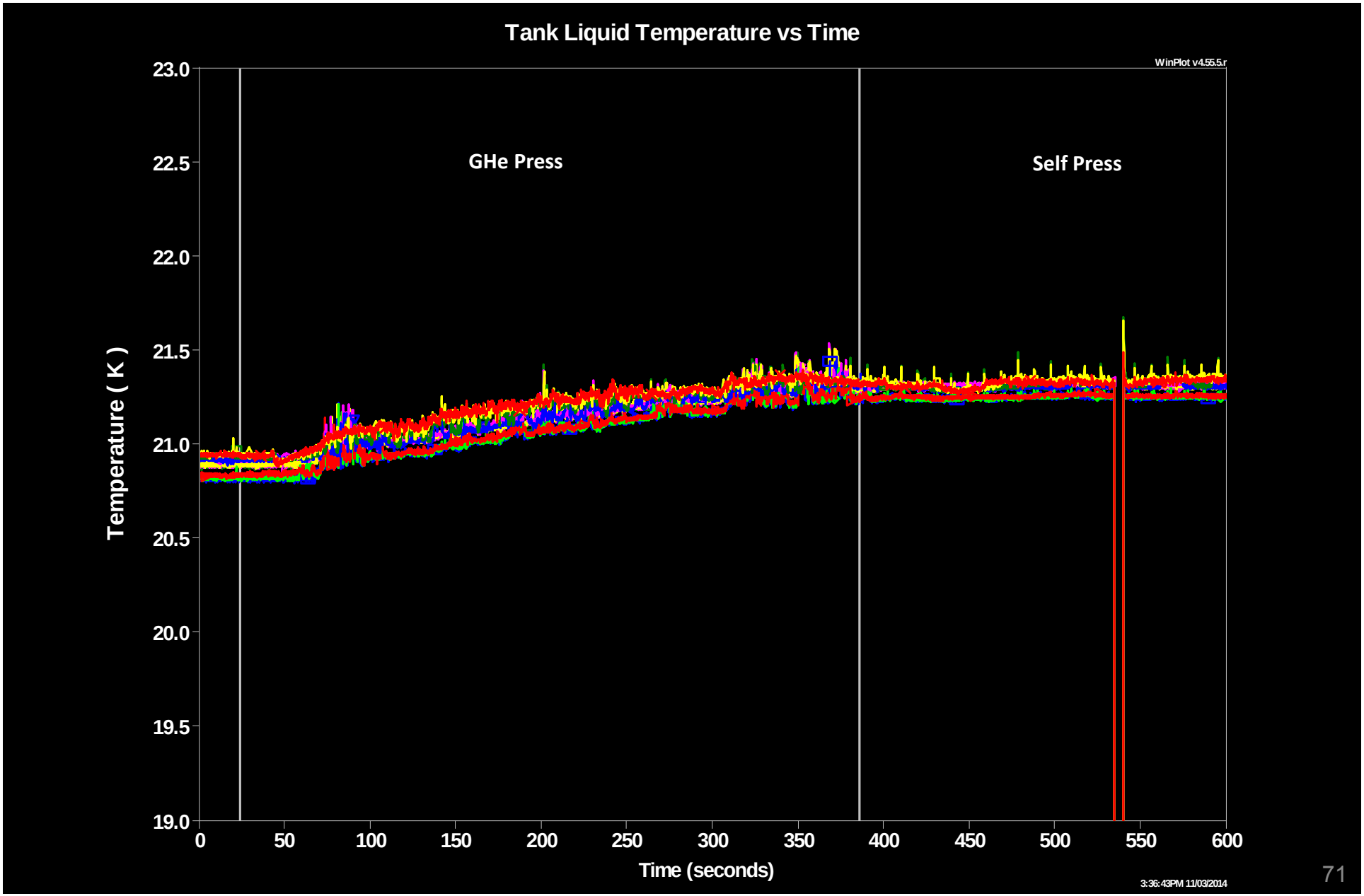
Vent tank back down to atmospheric and allow at least 15 minutes to stabilize.

Pressurization Tests (HT – 79B)

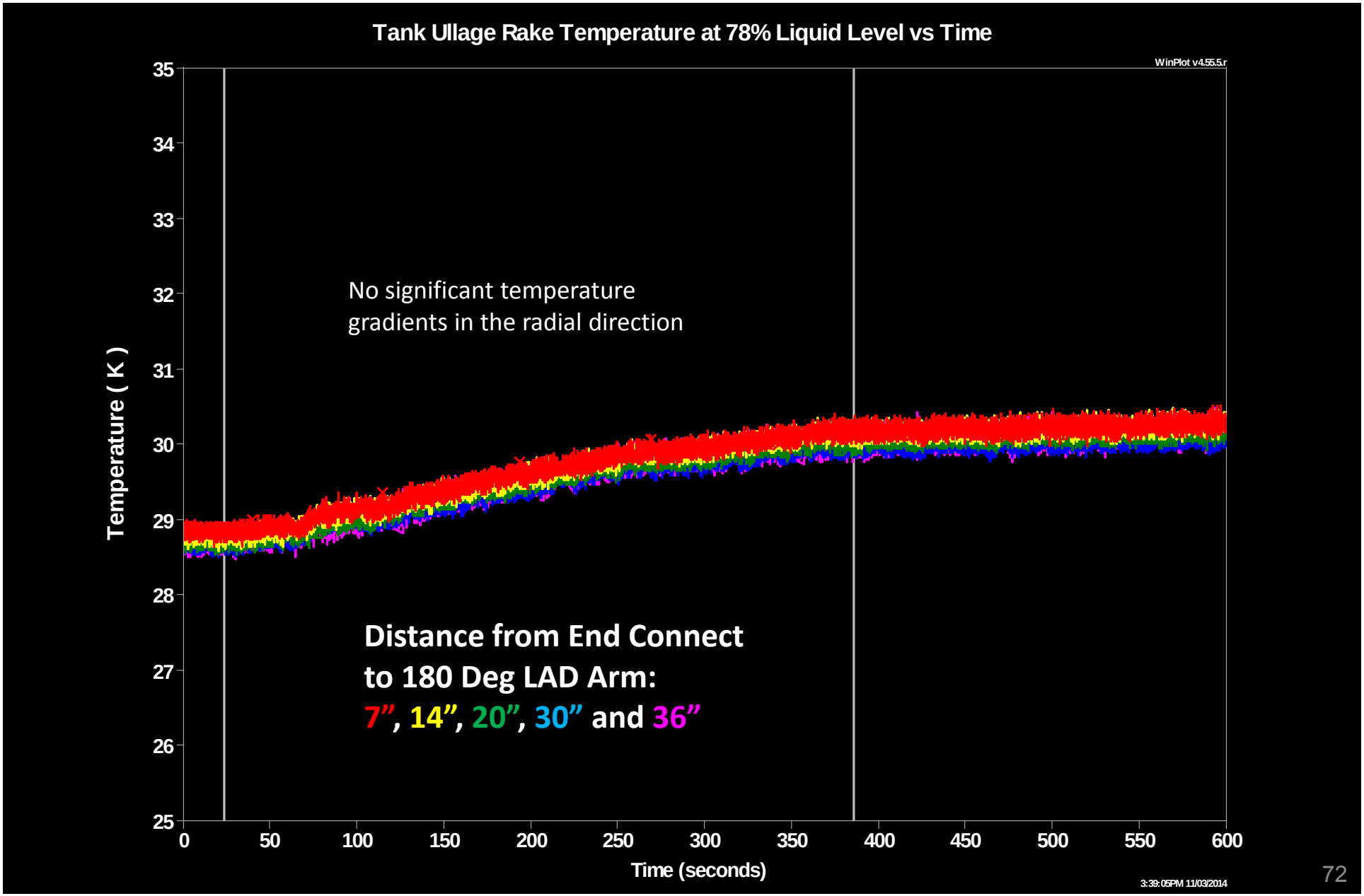


Pressurization Tests (HT – 79B)




Tank Liquid Temperature vs Time
WinPlot v4.55.5.r
GHe Press
Self Press
Temperature (K)
23.0
22.5
22.0
21.5
21.0
20.5
20.0
19.5
19.0
0
50
100
150
200
250
300
350
400
450
500
550
600
Time (seconds)
3:36:43PM 11/03/2014

Pressurization Tests (HT – 79B)



Pressurization Tests (HT – 79B)