Hydrogen Fueling Infrastructure Research and Station Technology

Dispenser Reliability
2019 DOE Annual Merit Review

Presenter: Mike Peters[1] (PI)

Nalini Menon[2], Matt Ruple[1], Josh Martin[1], Erin Winkler[1],

[1] National Renewable Energy Laboratory

[2] Sandia National Laboratories

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Project ID # in008

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Overview

TIMELINE

- Start date: 10/1/2016
- End date: 09/30/2019*

* Project continuation and direction determined annually by DOE

BARRIERS

Multiyear RD&D Barriers

Technology Validation Barriers

- ***D.*** Lack of Hydrogen Refueling Infrastructure Performance and Availability Data
- ***E. Codes and Standards -*** *Validation projects will be closely coordinated with Safety, Codes and Standards*

BUDGET

Project funding:

- **NREL**
  - FY19: $266k (carryover)
  - Project Total: $1,740k
- **SNL**
  - FY19: $590k
  - Project Total: $677k

PARTNERS

Funded

NREL: Hardware testing and lifetime analysis

SNL: Material testing*

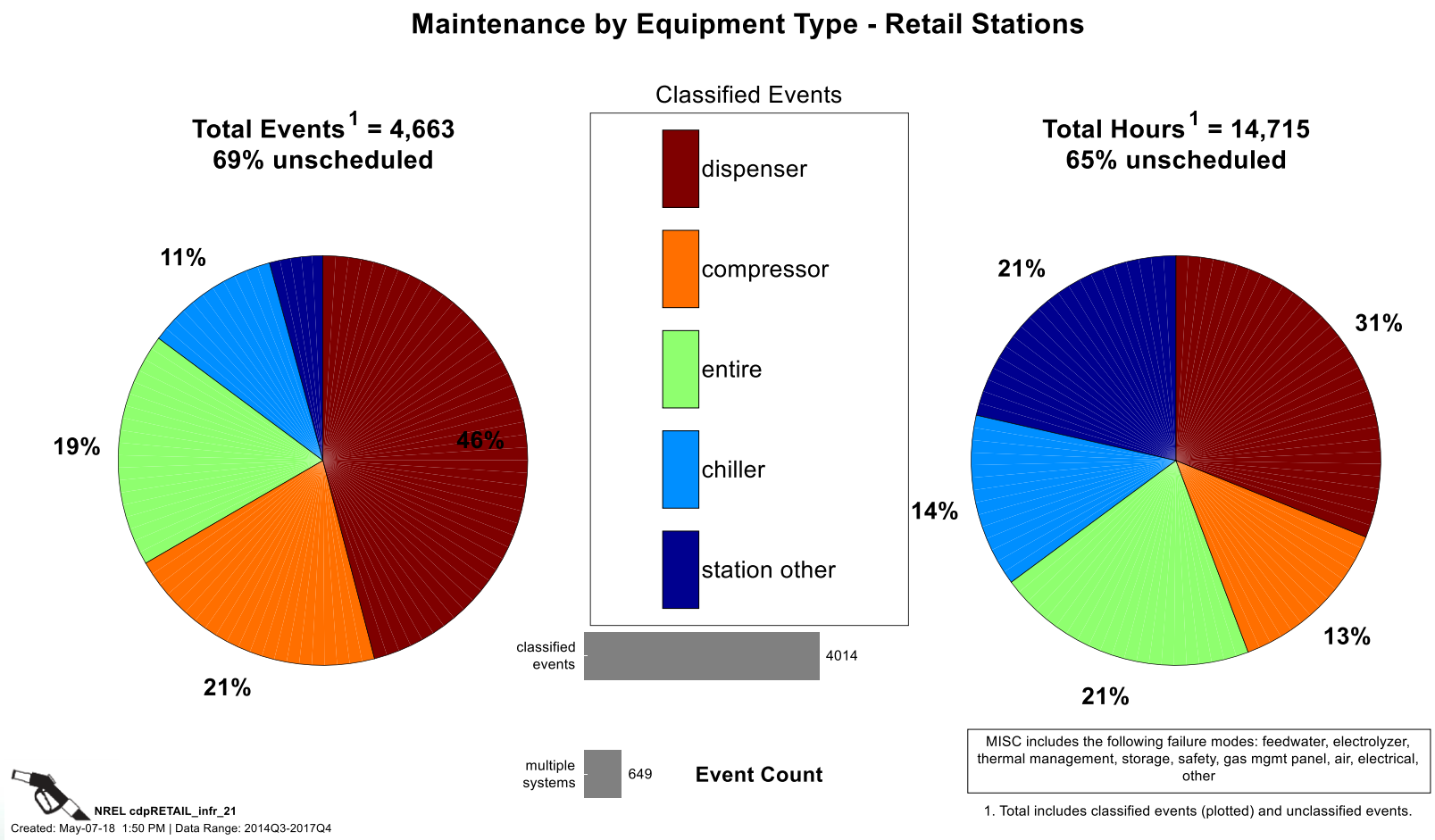
*SNL presenting their work at AMR poster session
Title: Dispenser Reliability R&D: Materials Compatibility

Close Collaboration

Walther-Präzision GmbH & Weh GmbH: Material consulting and lifetime monitoring

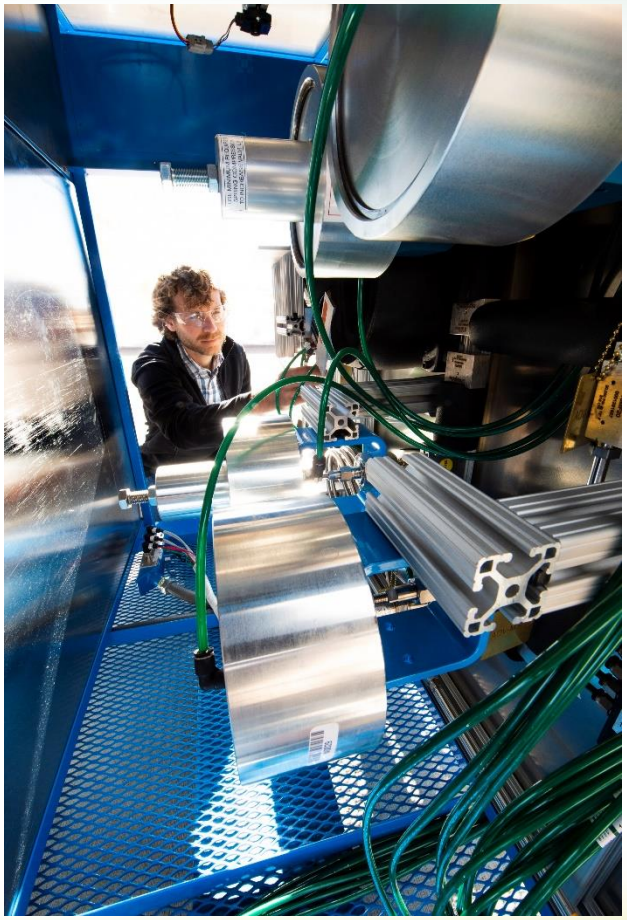
Relevance: Dispensers are #1 in Downtime

Dispensers are the top cause of maintenance events and downtime at retail hydrogen stations



Relevance: Literature Review

- There are some test campaigns on performance of piping components at the pressures and temperature in a fueling dispenser, but:
  - Available information is qualitative only, or
  - Results of specific qualification tests do not assess effects other than pass/fail
- SNL adds an additional level of detail with material characterization pre and post exposure to hydrogen
  - Early results shown at the poster session

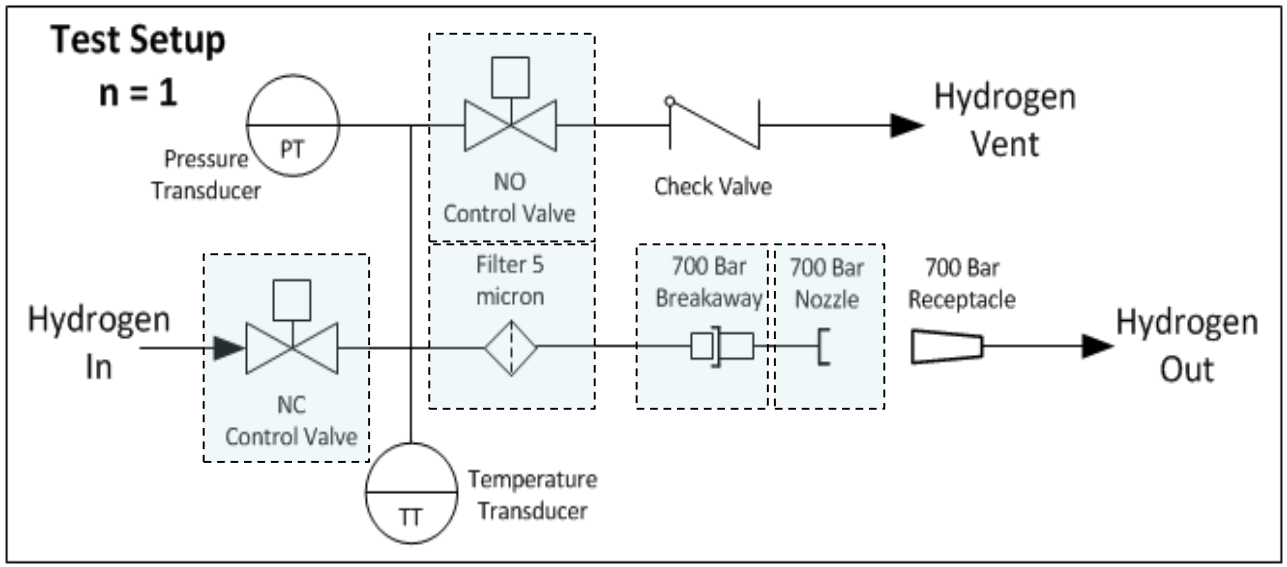


Approach: Accelerated Reliability Testing

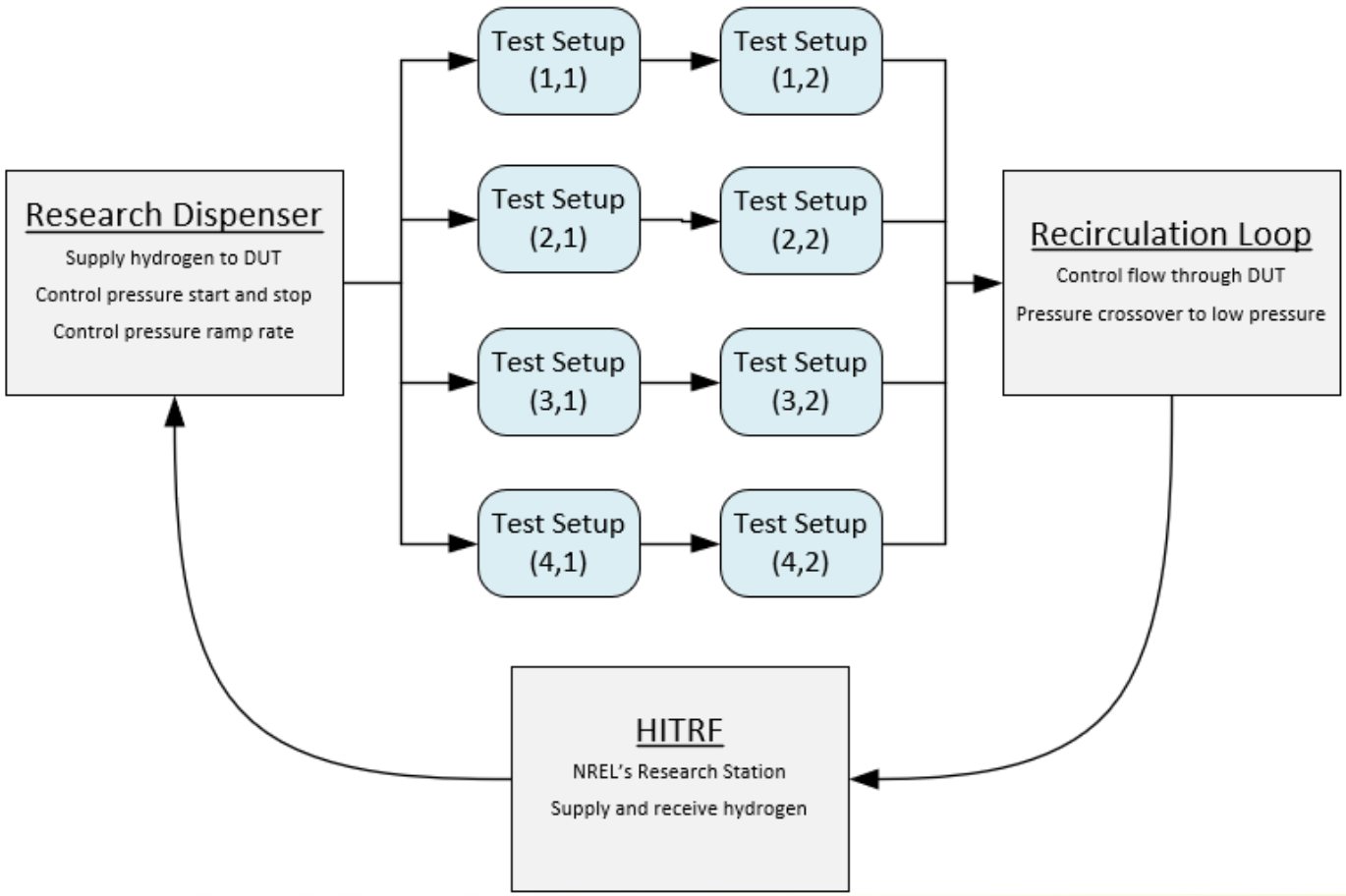
Measure the mean fills between failures (MFBF) and mean kilograms between failures (MKBF) of hydrogen components subjected to pressures, ramp rates, and flow rates similar to light duty fuel cell electric vehicle fueling at -40°C, -20°C, and 0°C

Devices Under Test (DUTs):

- Nozzles, breakaways, normally closed valve, normally open valve, filter



Approach: Recirculation System



Approach: Leak Detection & Material Testing

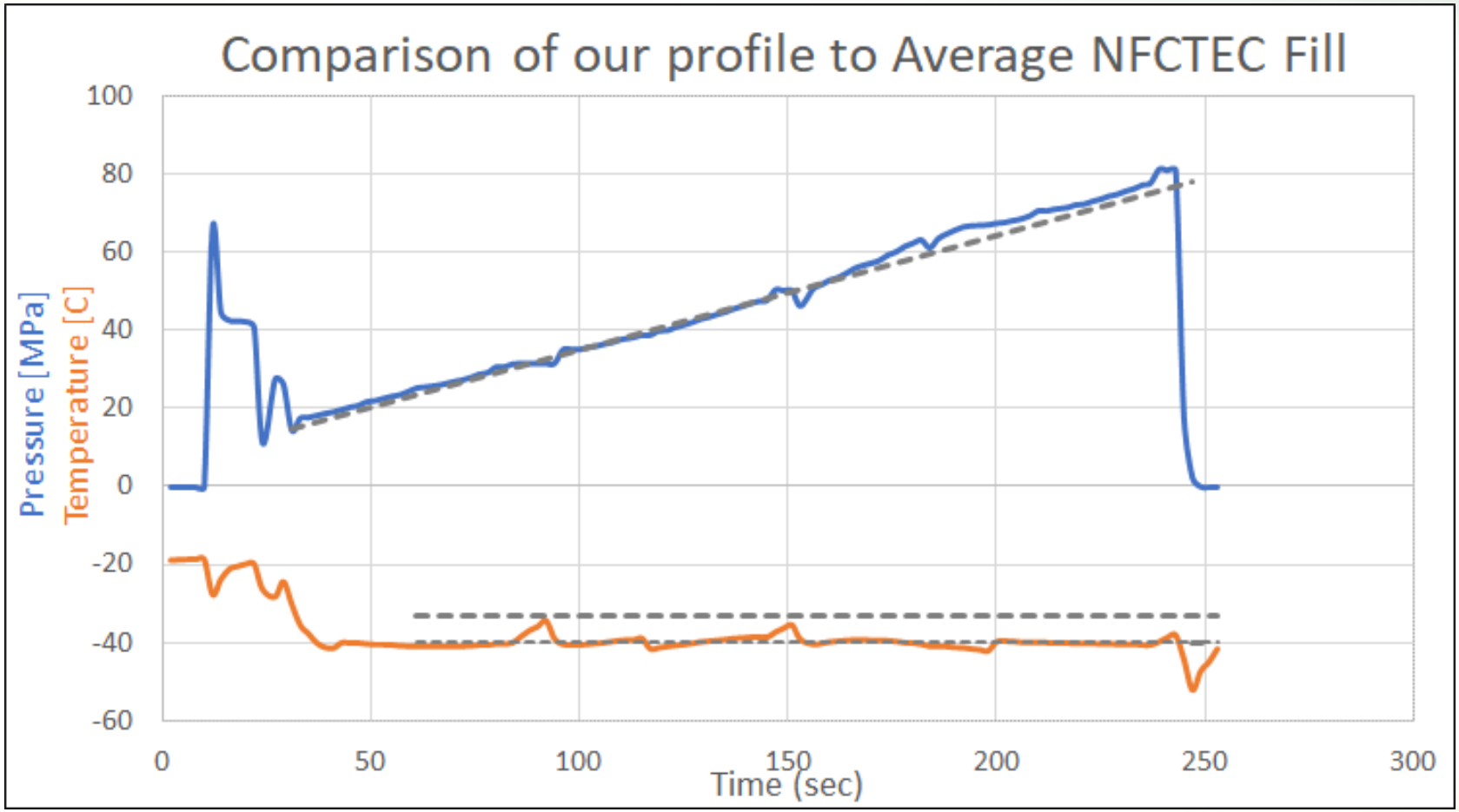
Leak Detection: Sensors and Mass and Pressure Tracking

- The system looks for leaks with two different methods: mass calculation using the PVT method and hydrogen sensors

Material Testing: SNL to perform polymer characterization on components to establish material requirements

- First efforts will involve establishment of baseline properties on polymers not exposed to H_2
- Baseline properties will be compared to polymeric materials from failed and passed components

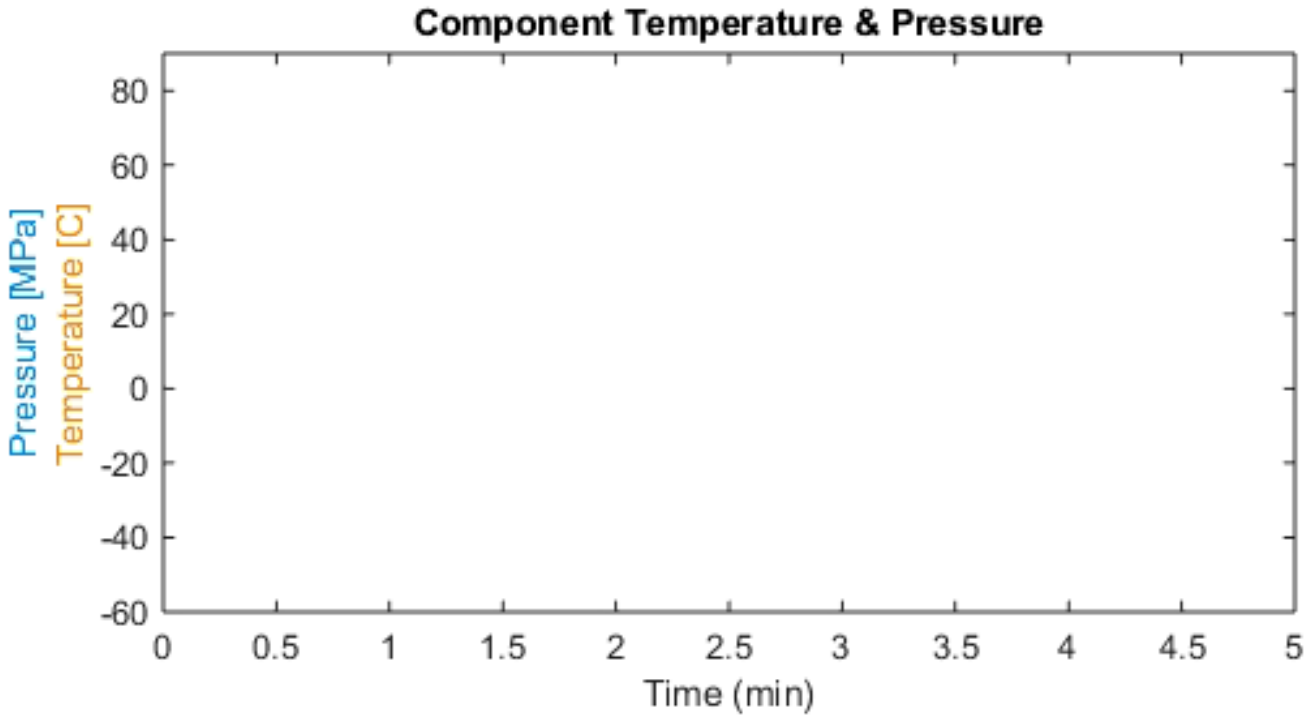
Accomplishment: Average Retail Fill Profile



Progress: Cycles

Cycle Count	Kilograms through DUTs	Total DUTs
0	0	40

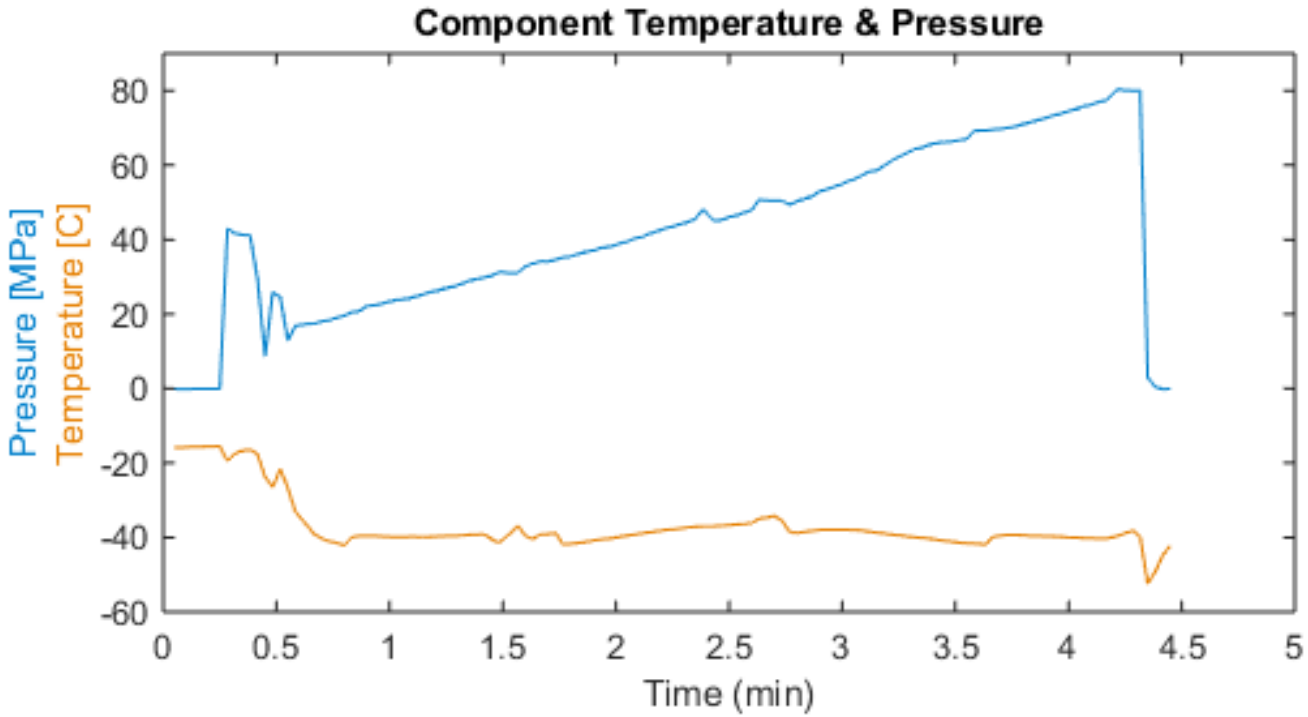
Leaks Detected		Failure Tracking	
DUTs	BoP	Part Removed	Fixed in Place
0	0	0	0



Accomplishment: First Failure

Cycle Count	Kilograms through DUTs	Total DUTs
108	124.2	40

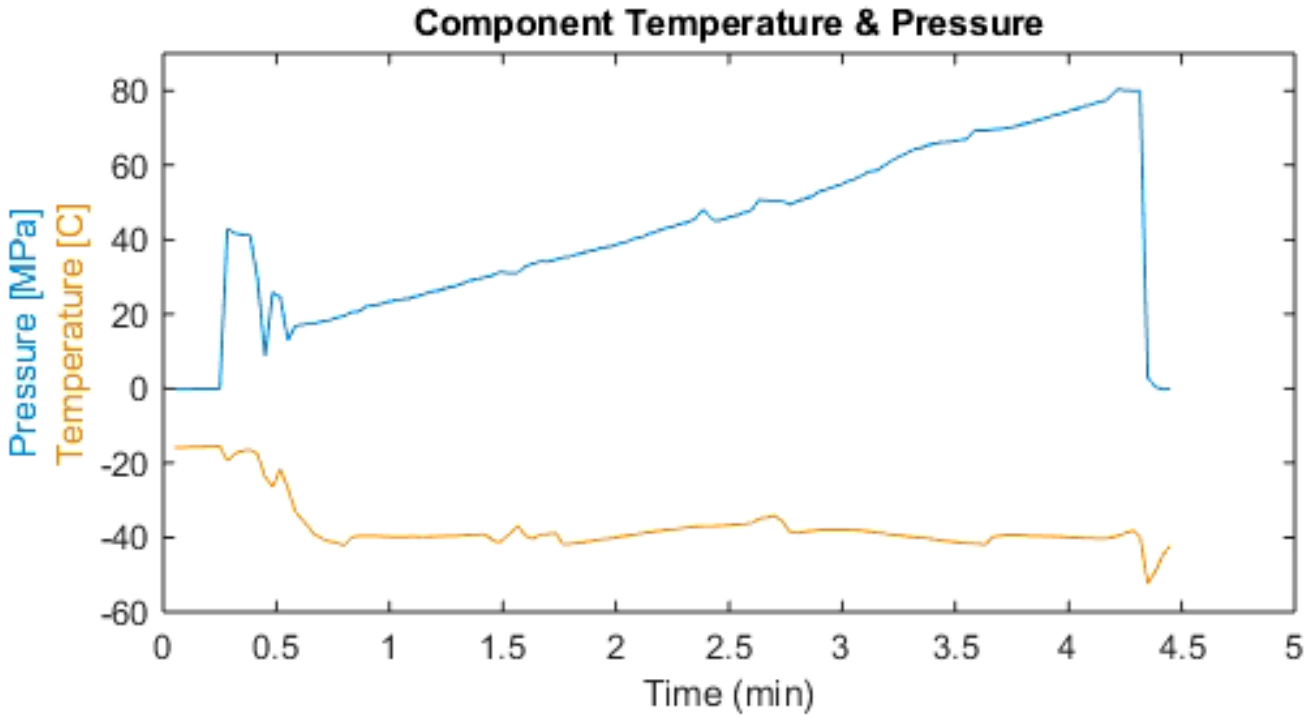
Leaks Detected		Failure Tracking	
DUTs	BoP	Part Removed	Fixed in Place
1	0	2	0



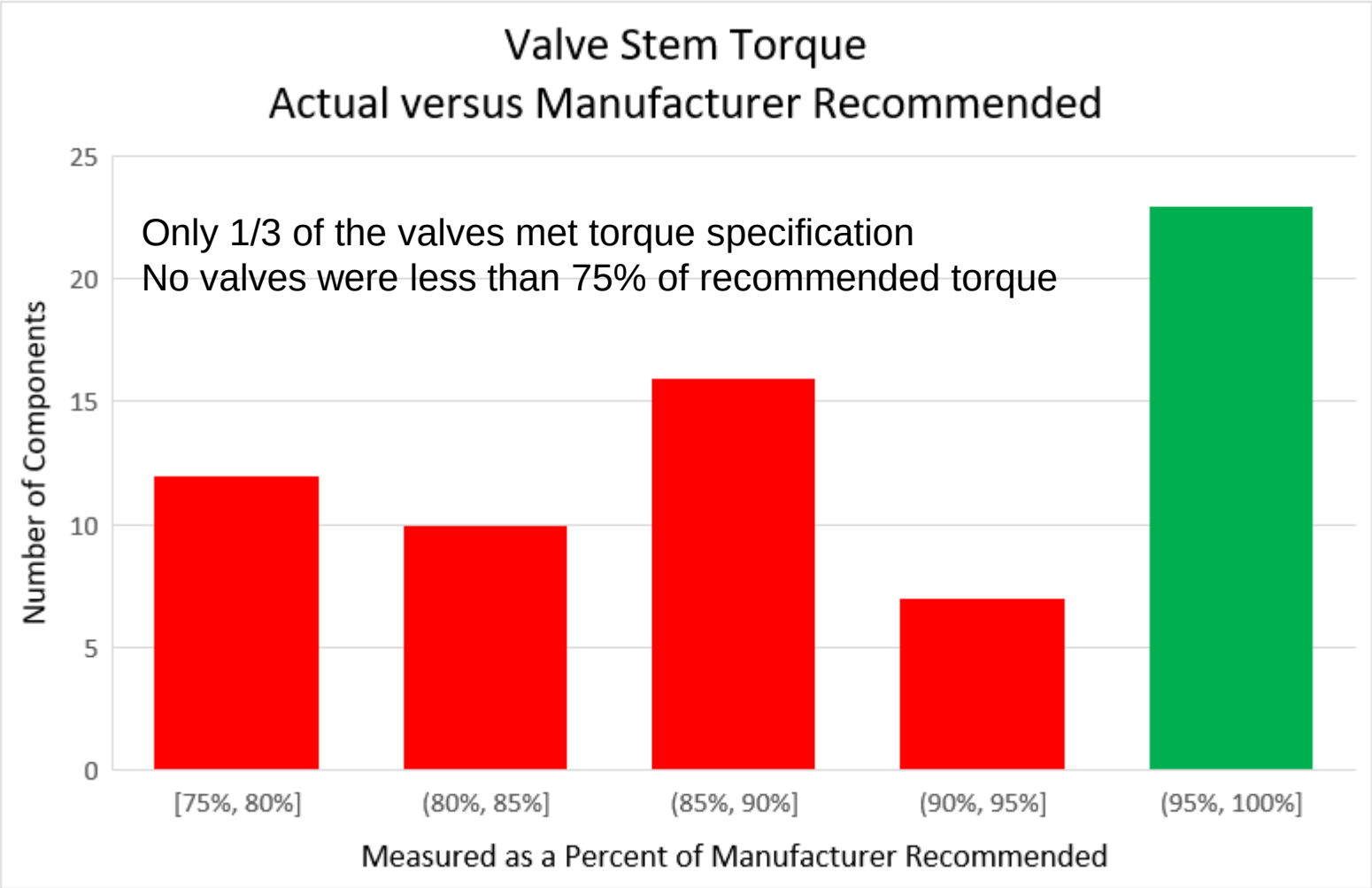
Progress: Cycles

Cycle Count	Kilograms through DUTs	Total DUTs
108	124.2	40

Leaks Detected		Failure Tracking	
DUTs	BoP	Part Removed	Fixed in Place
1	0	2	0



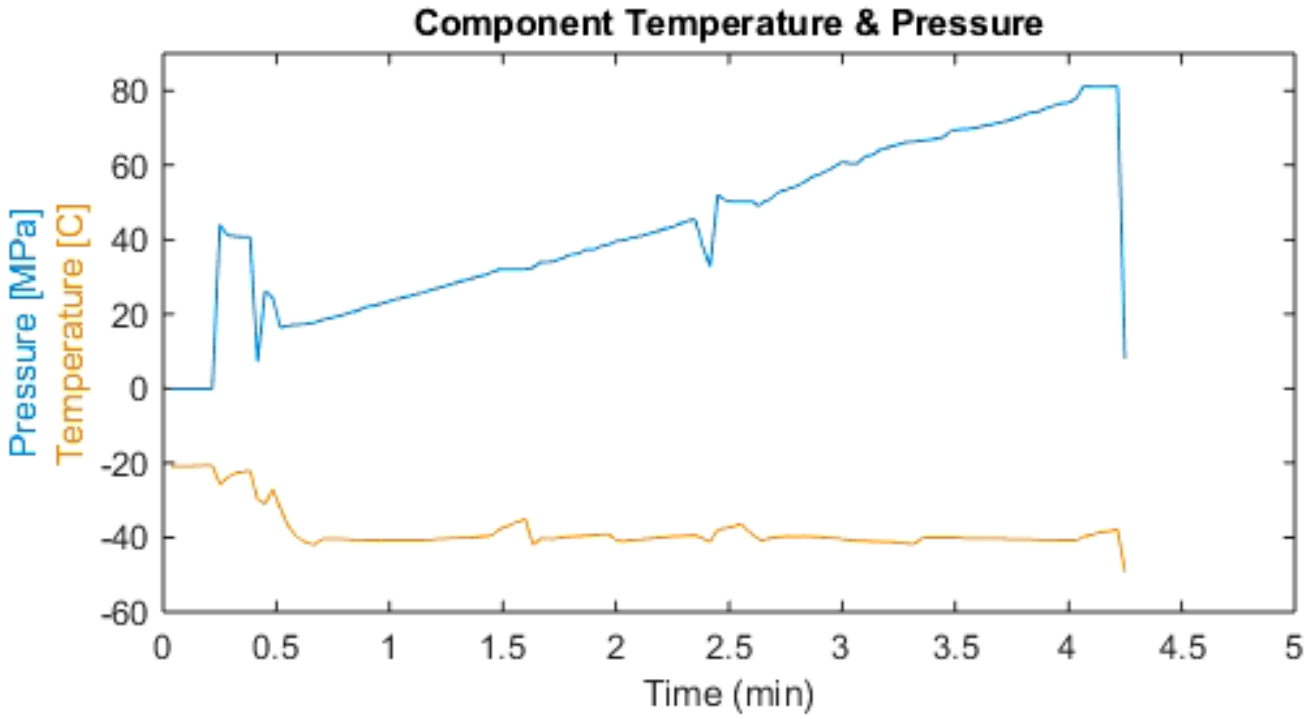
Accomplishment: Manufacturing Setpoint



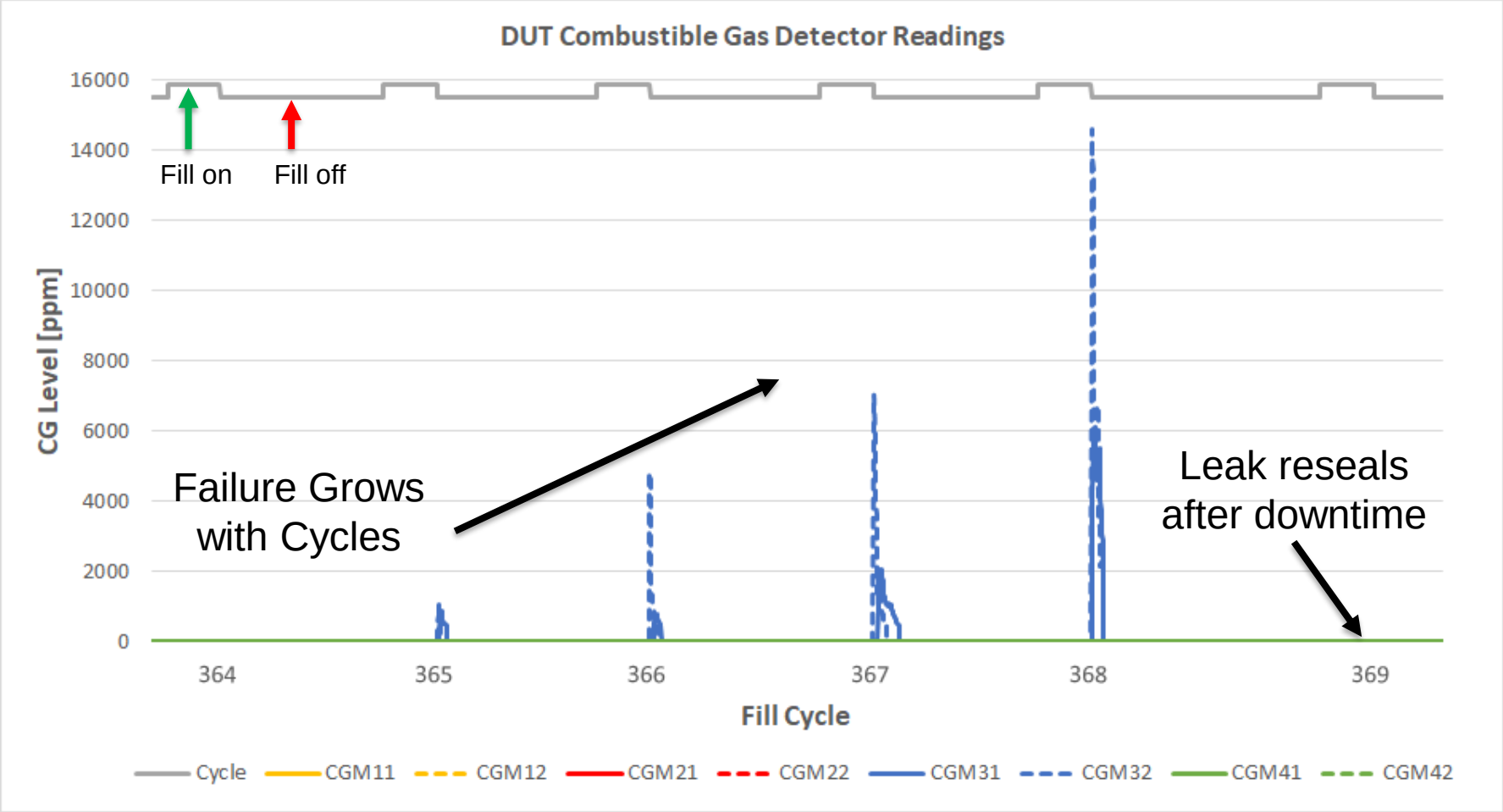
Progress: Cycles

Cycle Count	Kilograms through DUTs	Total DUTs
131	151.9	42

Leaks Detected		Failure Tracking	
DUTs	BoP	Part Removed	Fixed in Place
3	0	2	1



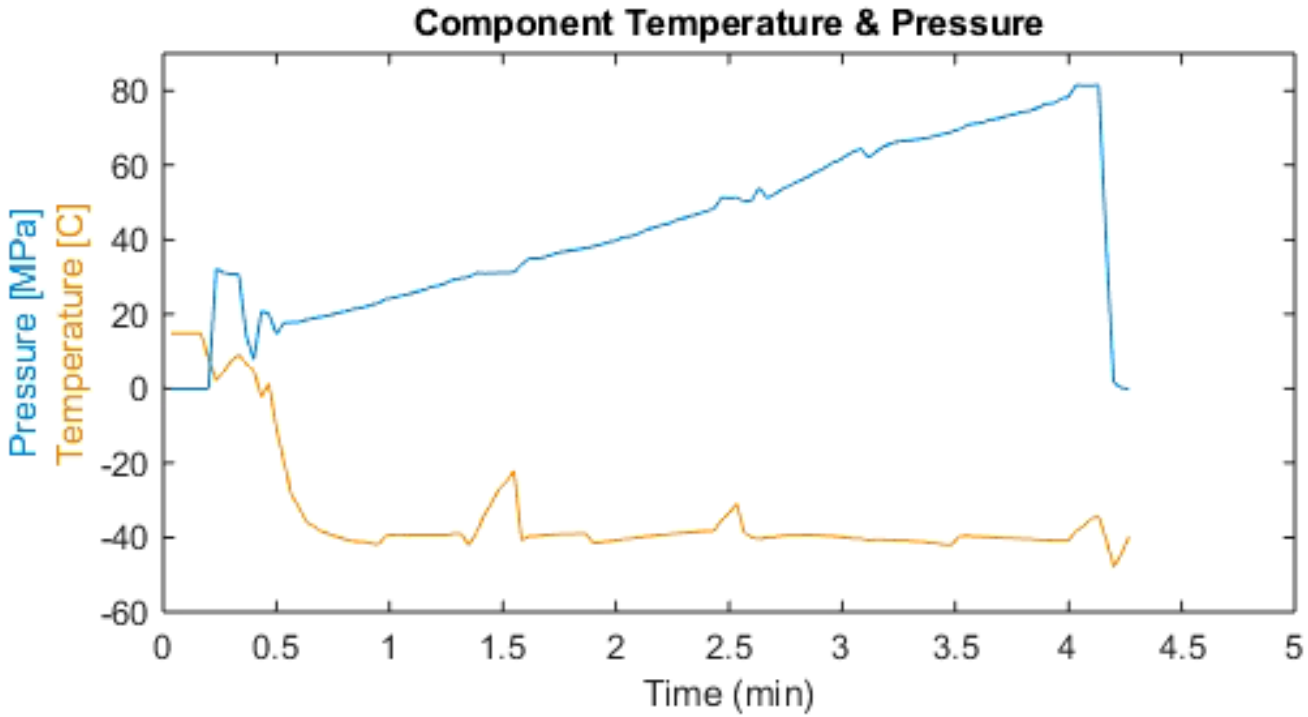
Accomplishment: Leaks Resealing After Downtime



Progress: Cycles

Cycle Count	Kilograms through DUTs	Total DUTs
369	428.5	46

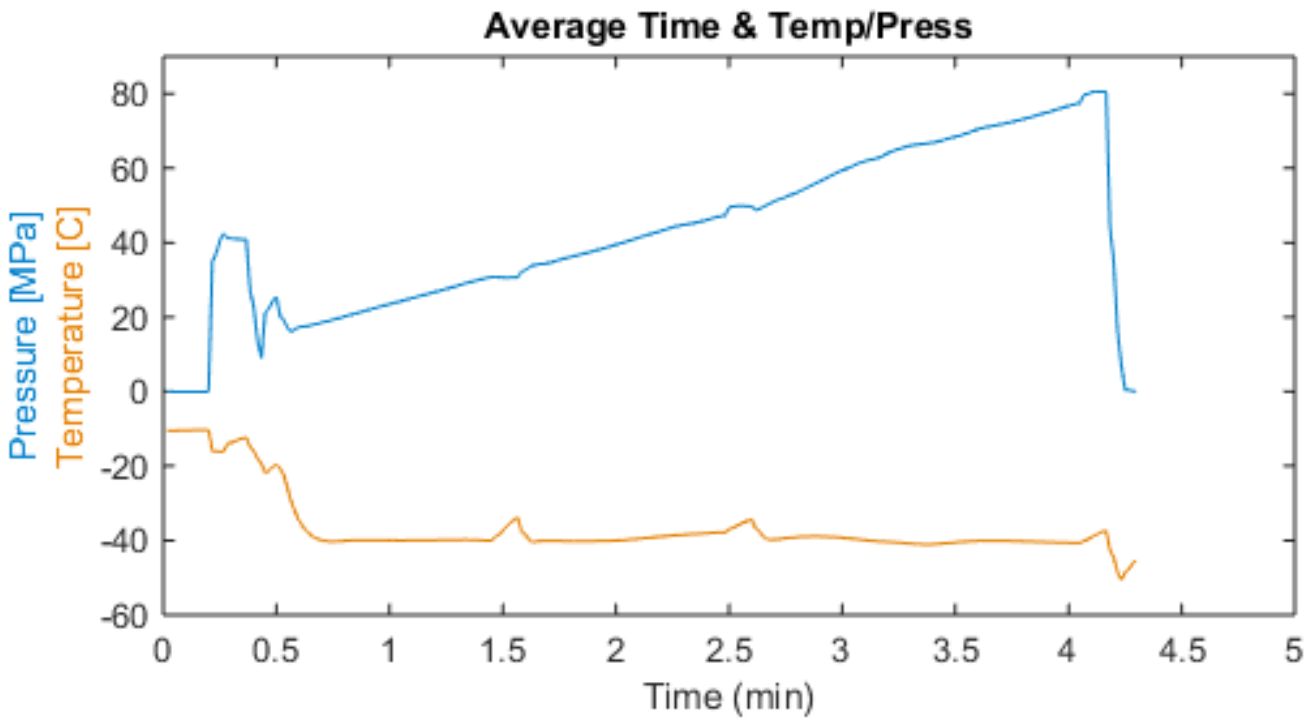
Leaks Detected		Failure Tracking	
DUTs	BoP	Part Removed	Fixed in Place
15	10	7	16



Accomplishment: Last Cycle to Date

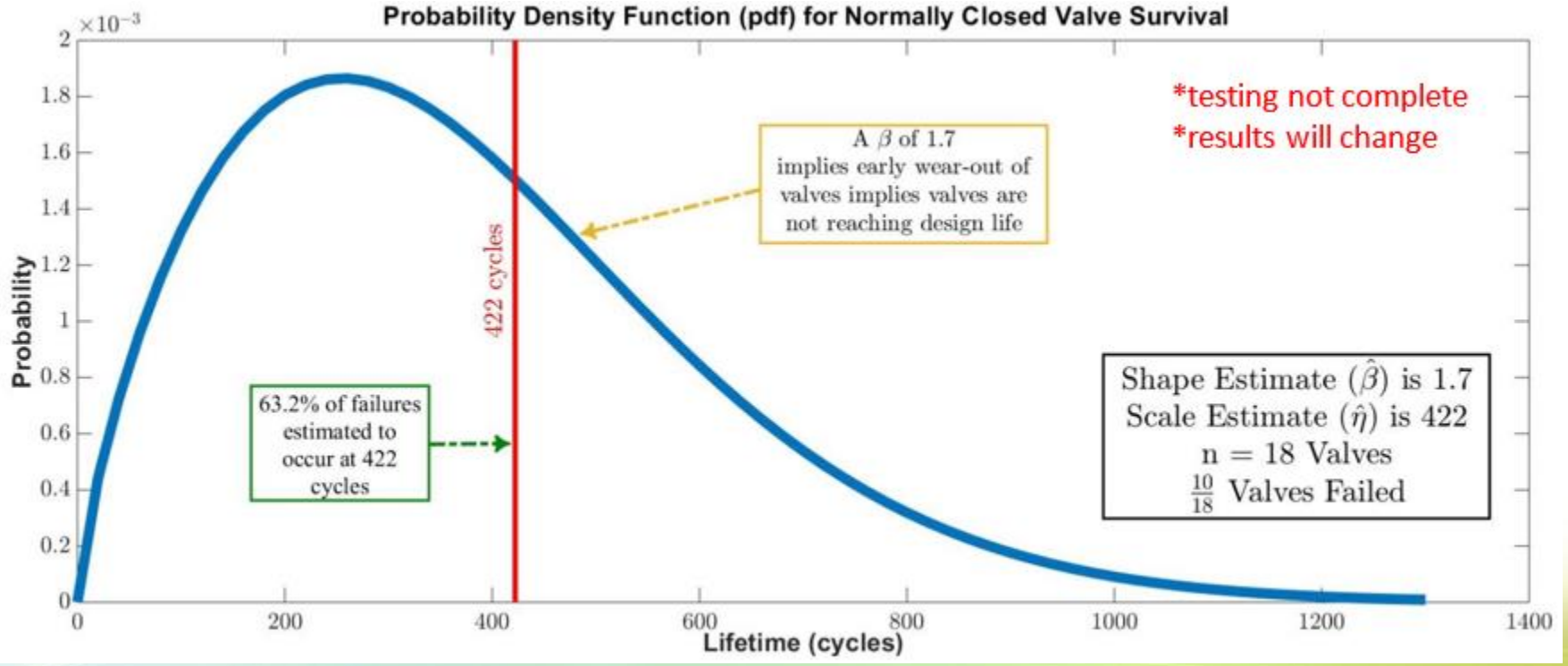
Cycle Count	Kilograms through DUTs	Total DUTs
575	655.1	56

Leaks Detected		Failure Tracking	
DUTs	BoP	Part Removed	Fixed in Place
21	13	9	21

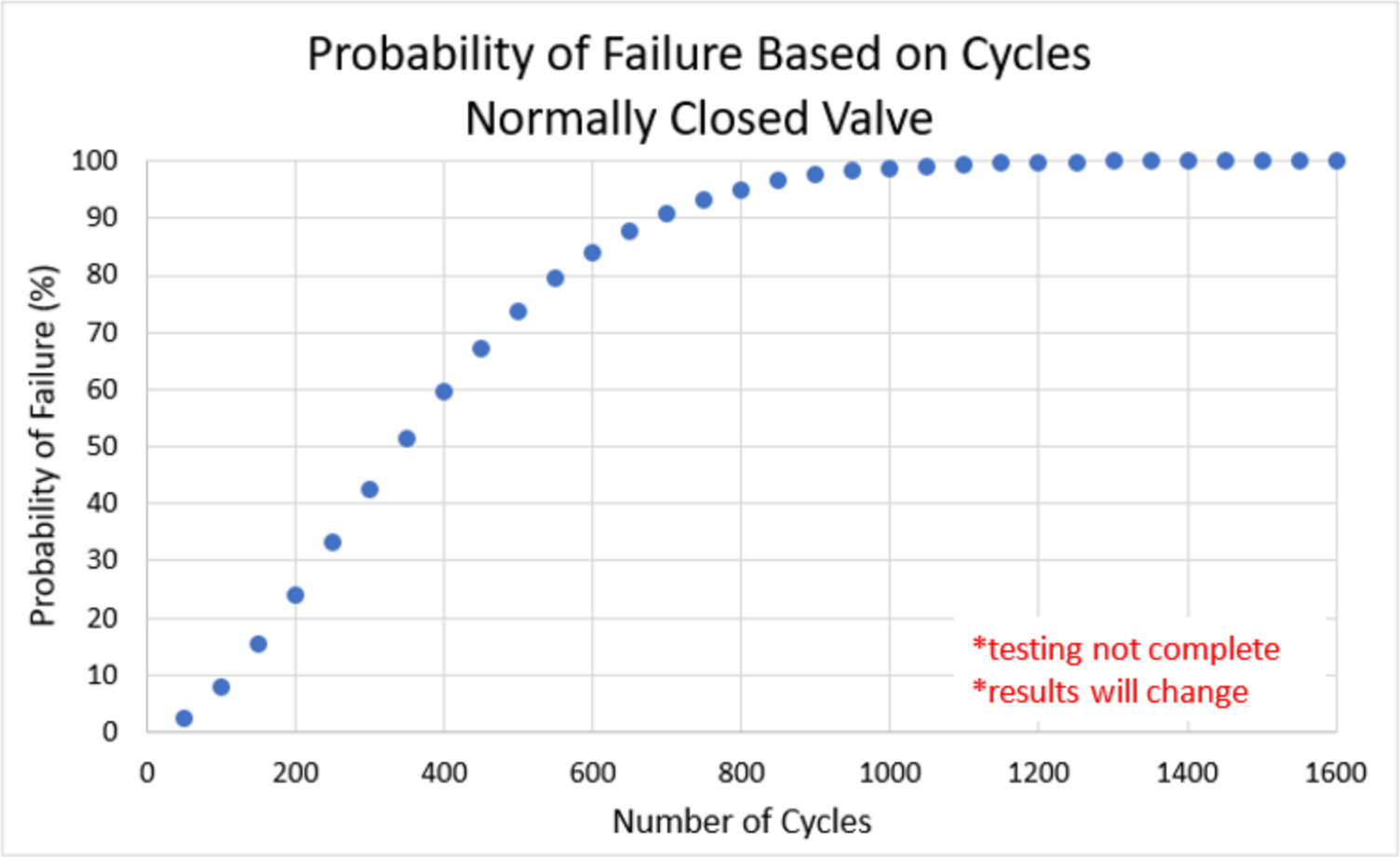


Progress: Preliminary Statistical Analysis

- Number of cycles and censoring indicator fit a Weibull distribution with shape parameter ($\hat{\beta}$) 1.7 and scale parameter ($\hat{\eta}$) of 422
- A β of 1 is most ideal implying random failures independent of time (old part = new part)
- β of 1 means hazard rate remains constant



Progress: Preliminary Statistical Analysis



Response to Reviewers Comments

Reviewer: Now that all the preliminary work is complete, the next phase of the project (actual testing) is the most important and should be given time to continue. It looks as though the project is slated to be complete by the end of September, but consideration should be given to the team's continuing testing until multiple failures have occurred and there is enough data to draw conclusions.

Response: Our project continuation is determined annually, as indicated by last year's slides, but the plan is for the project to end in September of 2019. Gaining enough failure data to make strong conclusions on the lifetime of the components is essential to the success of this project. Cycles will continue to be collected at each temperature level until there is enough data to make these conclusions. So, if we get to September and still need more cycles (and have money) we will continue.

It is not clear what materials analysis will be provided to materials manufacturers. It is also not clear that a well-thought-out process is in place for such an analysis.

Response: For the material analysis, we have a great partnership with Sandia National Laboratories on this project but it is hard to fit all of the project information into one 20 minute presentation each year. DOE has accommodated this issue by enabling SNL to have a poster this year: Dispenser Reliability R&D: Materials Compatibility. Please go visit their poster tonight for more information about the material analysis. Next year, we plan on having two separate orals: 1) Component testing and lifetime analysis and 2) Material analysis and conclusions.

Collaboration and Technology Transfer

Component Manufacturers

- Team has secured NDAs to discuss material analysis and testing with Walther and Weh
  - Walther visited NREL September, 2018
  - Weh Visited NREL June, 2018

Challenges and Barriers

Time it Takes to Perform Lifetime Testing

- The project team needs to ensure that enough failures occur that solid conclusions can be made. Sometimes this can take longer than expected.

Future Work: Detailed

- The team has concerns around the role of ambient temperature and/or humidity as it relates to failures occurring
  - Colder + more humid ambient conditions seems to indicate a higher likelihood of failures – testing will prove/disprove this
- What does a leak mean in terms of $ lost to the station operator?
  - Time to get to leak + time to fix a leak + lost revenue during that time
- If a component leaks and then reseals is that okay? Does it depend on leak rate and/or potential for exposure?
- Once testing is complete the statistical analysis will be able to predict the likelihood certain components last 1 week, 1 month, 1 year, or any given time
  - Initial work on early detection of failure

Any proposed future work is subject to change based on funding levels.

Future Work: Project Level

- Continue -40°C until there is enough data to make statistical conclusions
- Complete -20°C and 0°C testing
- Continue to send failed/non-failed samples to SNL for analysis
- Report findings out to public

Any proposed future work is subject to change based on funding levels.

Summary

- Relevance
  - Dispensers are top cause of downtime in the field
  - Component testing is beneficial to better understand the effects of temperature on these components
- Approach
  - Perform accelerated life testing of components to failure under different temperature conditions
  - Define field-like test requirements
  - Design system capable of testing multiple dispensers at once
- Accomplishments
  - Operated system for 575 cycles at -40°C
  - Experienced 34 leaks during that duration and removed 9 parts
  - Observations have been made related to low temperature/high humidity ambient conditions leading to a higher failure rate
- Future Work
  - Testing will continue with -20°C and 0°C testing starting soon
  - SNL will continue with the material analysis
  - Provide feedback to industry and the public

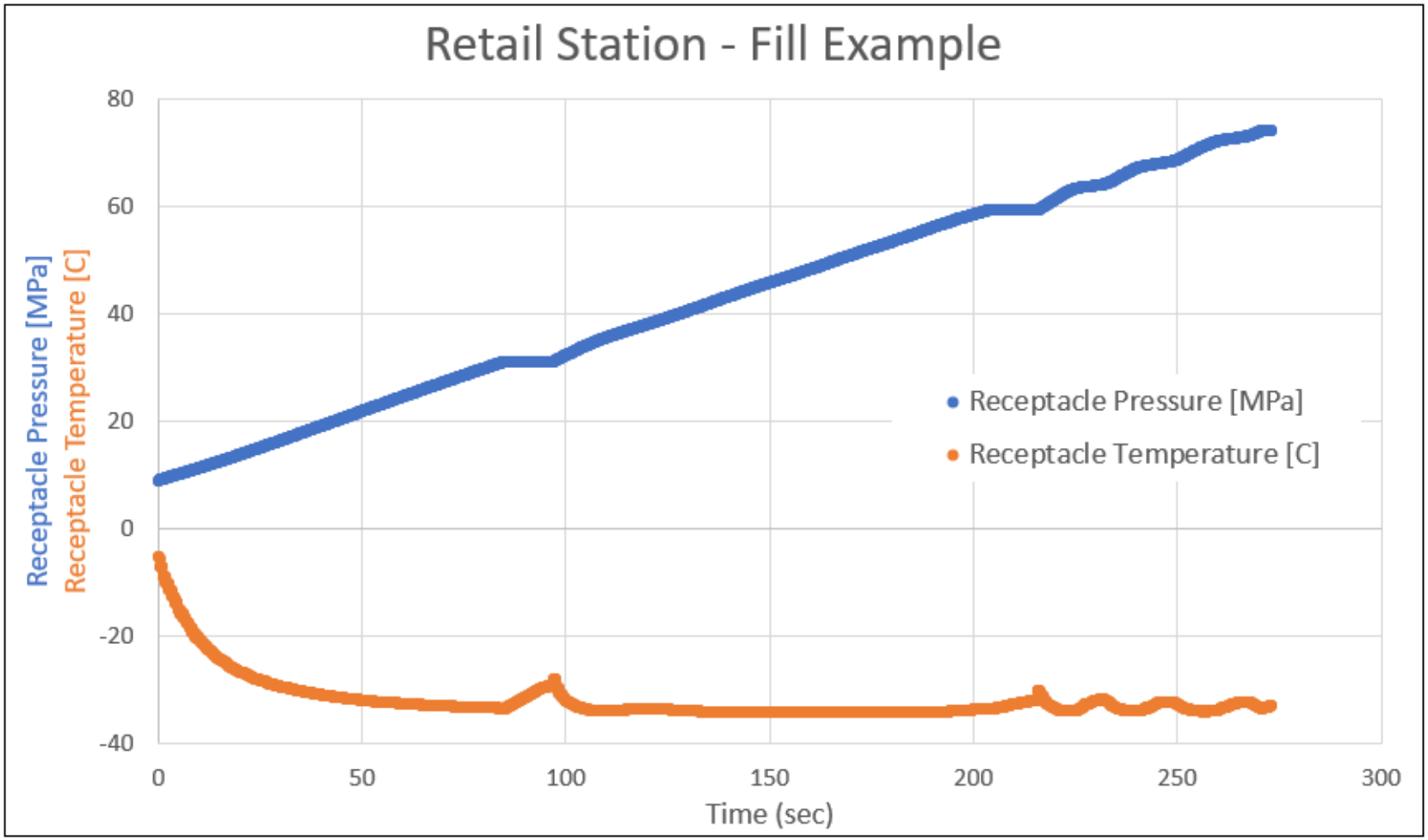
Michael Peters – NREL – Michael.Peters@NREL.gov

Nalini Menon – SNL – ncmenon@sandia.gov

THANK YOU

TECHNICAL BACKUP SLIDES

Approach: Simulate Retail Fills



Approach: NFCTEC Data to Define Parameters

Variable Factors

Controlled

Hydrogen Temperature
- -40°C
- -20°C
- 0°C

Component Type*
- Nozzle
- Normally Open Valve
- Breakaway
- Normally Closed Valve
- Filter

*Components can be broken into subgroups by manufacturer but individual company performance will not be reported. Each component type has two manufacturers.

Uncontrolled

Ambient Temperature
- Varies between -10°C and 40°C

Ambient Humidity
- Varies between 10% and 100% R.H.

Fixed Factors

Controlled

Fill Time[1]
- 3.6 minutes

Hydrogen Flow Rate[2]
- 0.8 kg/min

Hydrogen Start Pressure[3]
- 14.7 MPa

Hydrogen Stop Pressure[4]
- 77.9 MPa

Response Variables

Unpredictable

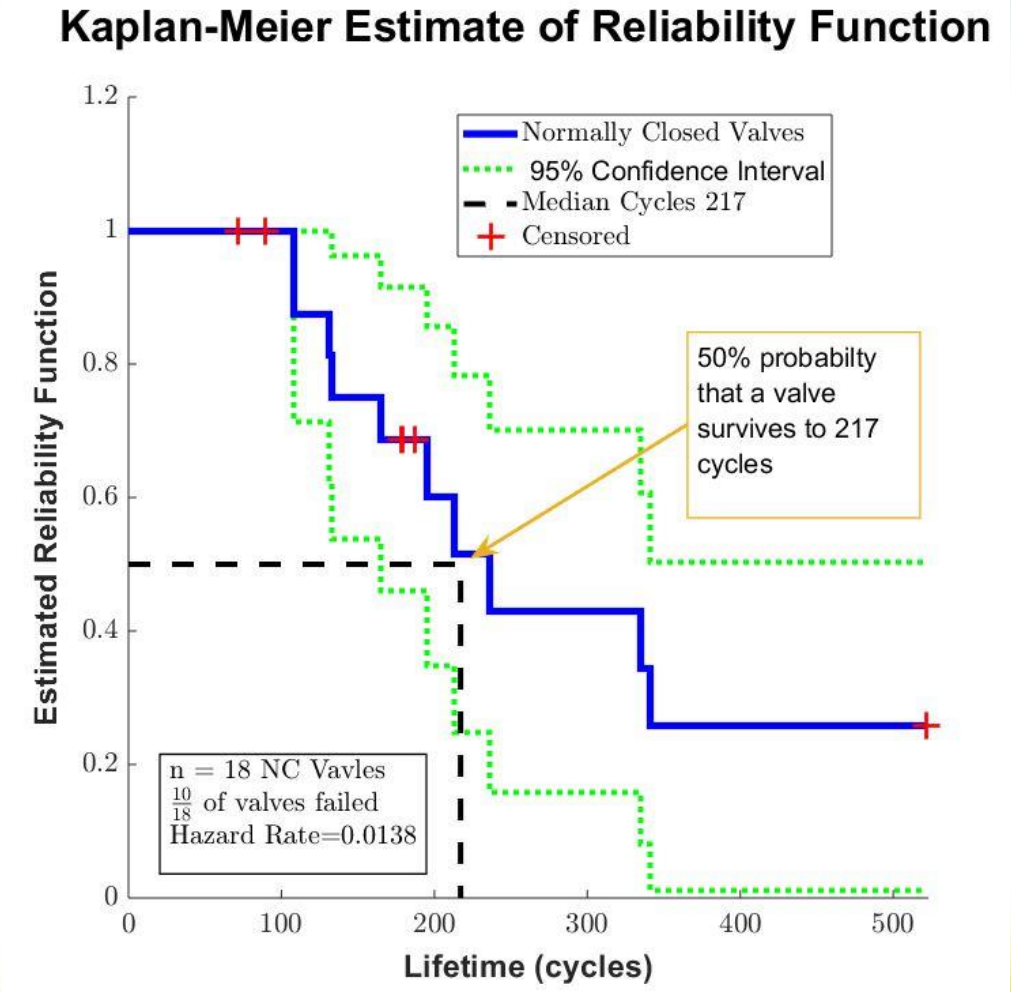
Hydrogen Leak?
- Yes
- No

# of Fills or Kilograms to Failure
- Value
- kilograms

Leak Rate
- grams/sec

Other Failure
- Non-leak issue

Sources: Fill Time (1) - https://www.nrel.gov/hydrogen/assets/images/cdp-retail-infr-03.jpg Hydrogen Flow Rate (2) - https://www.nrel.gov/hydrogen/assets/images/cdp-retail-infr-02.jpg
Hydrogen Start Pressure (3) - https://www.nrel.gov/hydrogen/assets/images/cdp_fcev_15.jpg Hydrogen Stop Pressure (4) - https://www.nrel.gov/hydrogen/assets/images/cdp-retail-infr-09.jpg

Progress: Kaplan Meier Analysis

- Kaplan Meier: a nonparametric way to estimate reliability functions ($\hat{R}$(t))
  - Estimates the probability the life is longer than t
  - Estimates time-to-failure of parts
- Kaplan Meier gives insight into true underlying lifetime distribution of parts
  - In this case, the Kaplan-Meier estimator fits to a Weibull reliability function
  - $\hat{R}$(t) estimates 50% of failures to occur at 217 cycles
- An estimate for a distribution gives parameters to compute time-between-failures, mean-time-to-fails and so on
- Can aid in determining cost-efficacy of repairing or replacing parts