Correlating Cell Failing Delta OCV Testing with Cell Defects

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Acknowledgements

Glimpse
- Thank you to Amariah Condon, Peter Attia, Easton Rasgon, Eric Moch for providing the high-quality CT scans

Eric Darcy and Sam Russell
- Thank you for all the mentorship and technical guidance

Outline

- The importance of OCV screening
- Cell Strategic Reserve (CSR) dOCV Screening Process
- Results from dOCV Screen
- CT Scan Results of dOCV Screened Cells

NASA's Cell Strategic Reserve

- What is it?
  - A reserve of Li-Ion cells screened via NASA standards
  - Several cell designs are kept in stock with various key performance advantages (ex: High Energy vs High Power)
    - Molicel M35A
    - **Molicel P28B**
    - Samsung 30Q
    - LG M36

Our High Energy Cell Designs

LG INR18650 M36

- Previous heritage
  - 250 µm can wall
  - Safety fully characterized by JSC
  - Multiple variations beam tested in FTRC
  - 3 batches of ISCD trigger cells delivered to JSC
- At C/10 and room temperature
  - 270 Wh/kg, 710 Wh/L
  - ACR is 23.9 mohms
  - DCR is 29.8 mohms
- 70k lot (Nov 2020) delivered in Apr to JSC

Molicel INR18650-M35A

- Little previous heritage
  - Same manufacturer of ICR18650J, primary power for > 25 EVAs
  - Superior extreme cold performance
    - 214 Wh/kg at C/20 and -20°C
  - Multiple batches of ISCD trigger cells delivered to JSC
- At C/10 and room temperature
  - 277 Wh/kg, 725 Wh/L
  - ACR is 24.4 mohms
  - DCR is 32.5 mohms
- 120k lot (Feb 2021) delivered in Apr to JSC

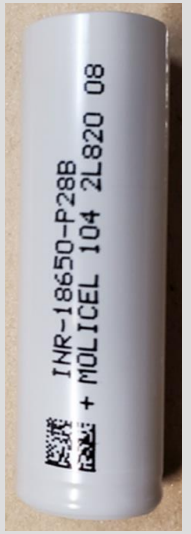
Our High Power Cell Designs

Samsung INR18650-30Q

- Previous heritage
  - X-57 Electric Airplane
  - Safe high power battery demo
- At 3C and room temperature
  - 2483 W/kg, 206.9 Wh/kg
  - 6340 W/L, 528.1 Wh/L
  - 12.4 mohm ACR
  - 26.2 mohm DCR
  - 8.3% average waste heat
- 60k lot (Mar 2021) delivered in June to JSC

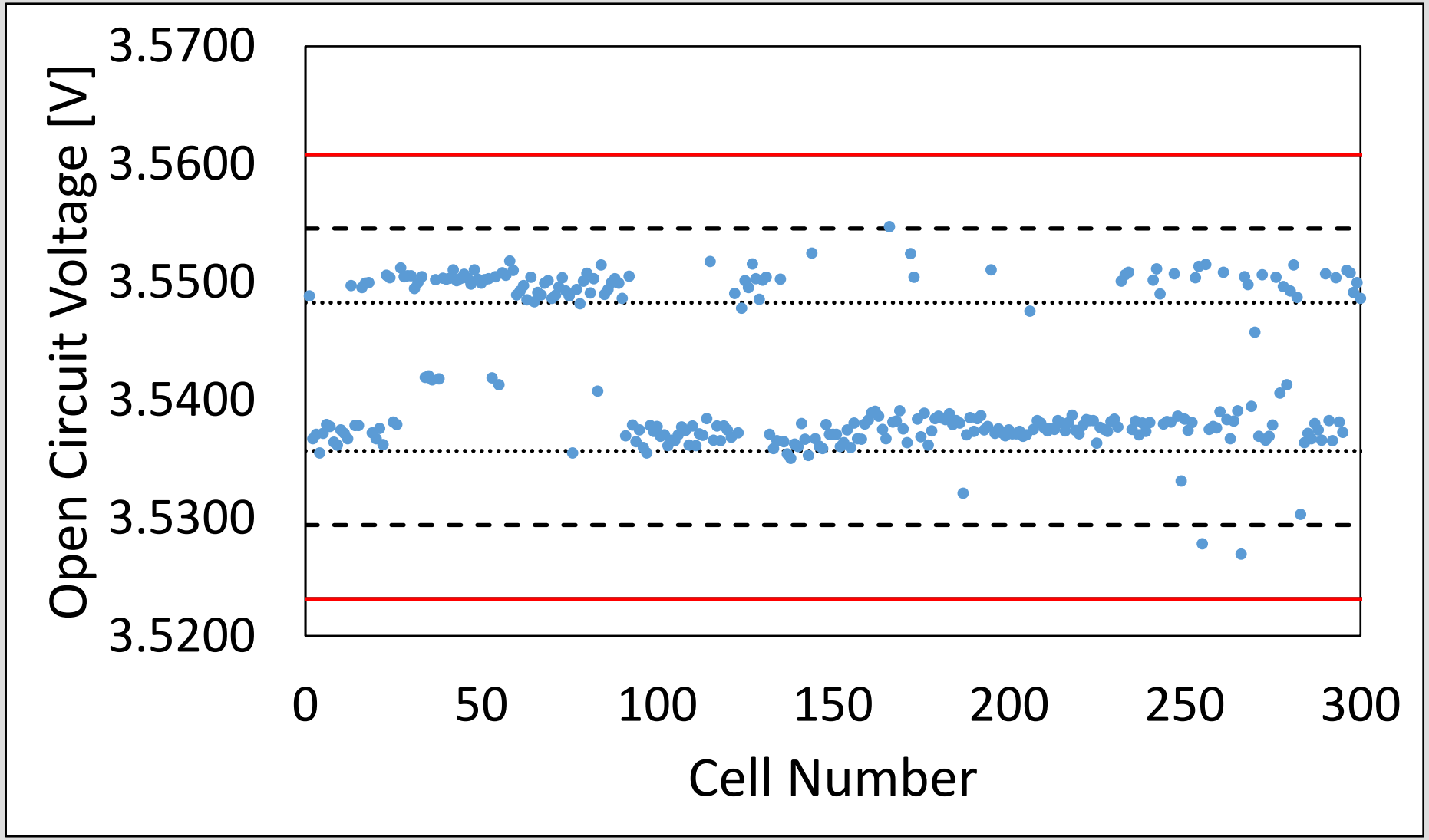
Molicel INR18650-P28B

- No previous heritage
- Not mass produced due to 2nd cathode tab
- At 3C and room temperature
  - 2528 W/kg, 202.3 Wh/kg
  - 6376 W/L, 510.3 Wh/L
  - 9.2 mohm ACR
  - 22.3 mohm DCR
  - 5.5% waste heat
- 60k lot (Aug 2021) delivered in Oct to JSC



Importance of dOCV Cell Screening

P28B Pre-Screen OCV Check



- OCV measurement 1 yr after fabrication
  - Want 10-12 mV range for +/-3 sigma, NOT 40 mV
- Trimodal distribution seen, decided a dOCV measurement was needed to pass or fail cells on OCV

Motivation for dOCV Screen

- Going from 95% to 65% SOC is ~200mV delta
  - Some NASA programs will condemn battery at a 50 mV un-balance (~7% SOC drop)
  - Spacesuit battery is NO GO for EVA if there is >20 mV difference
- Want to screen out potential latent internal cell shorts
  - Some latent defects could be showing very subtle OCV decays

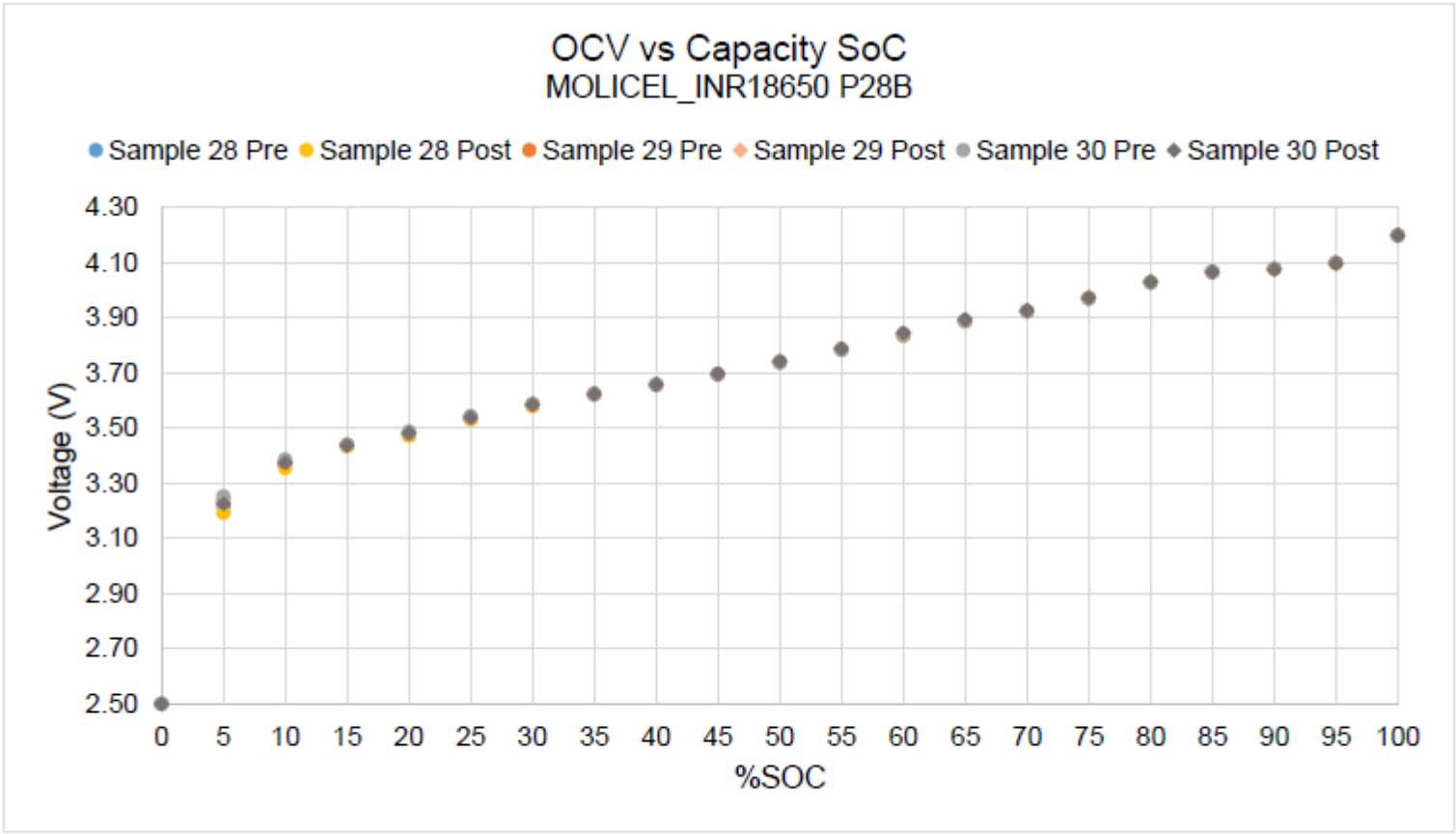
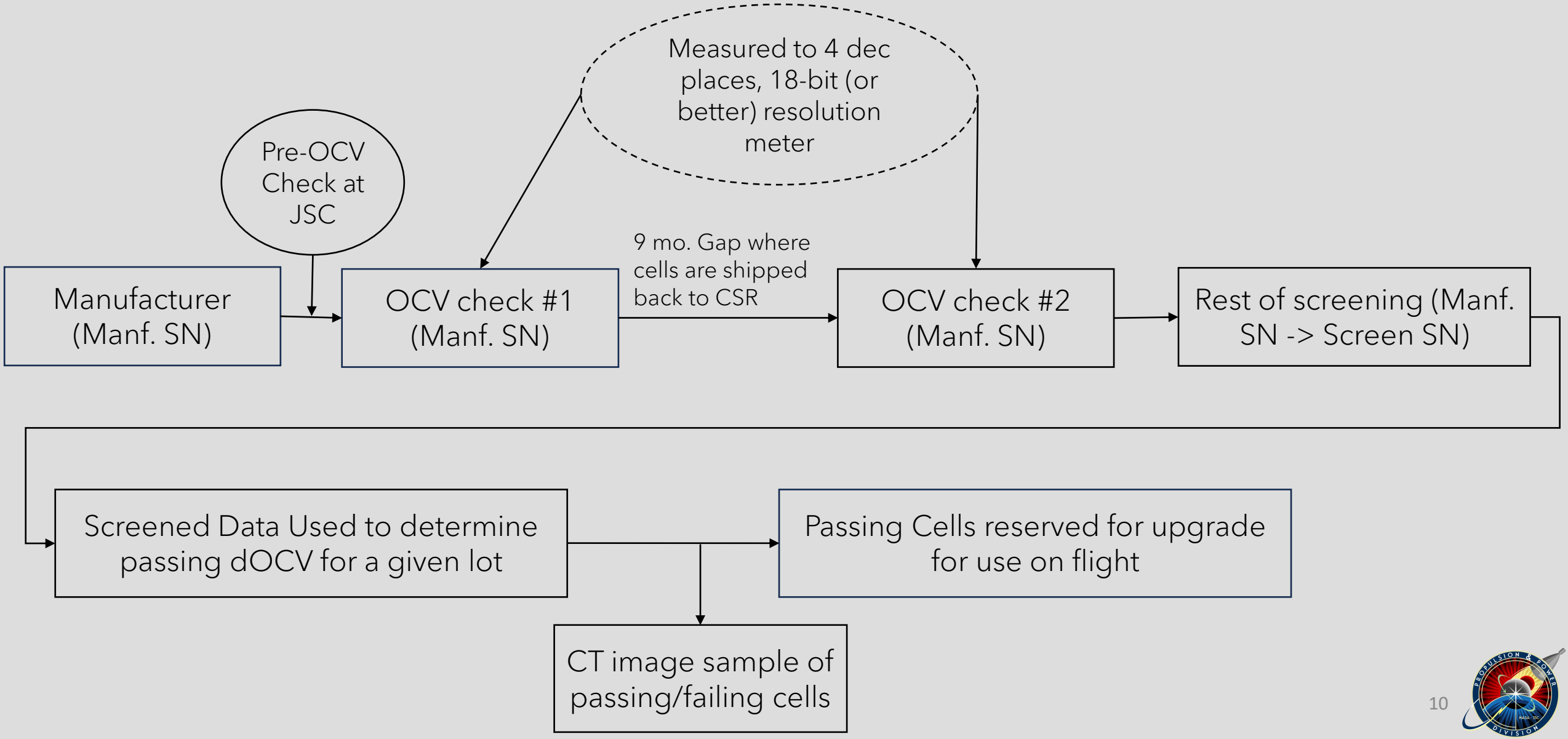


Figure 2.2.3.2 – Capacity vs Voltage at each 5% DoD.

Chart from "Capacity Performance, Environmental Test, and Post Environment Capacity Performance for Lot Assessment Test Report" done by PCTest for JSC CSR P28B Cell Lot

dOCV Process



Hypothesis

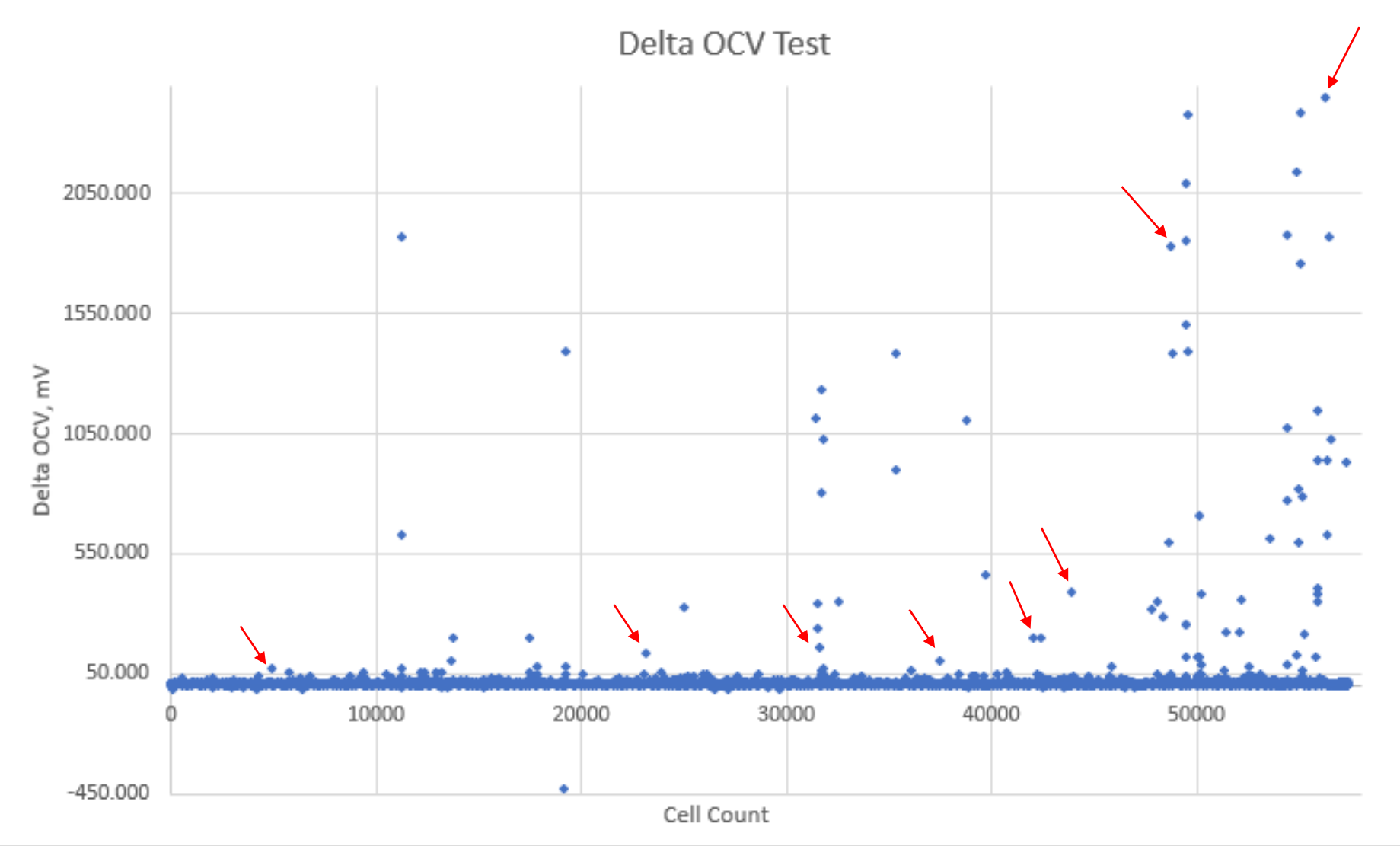
Question: Is there a correlation between dOCV failure and a bridging defect between anode and cathode visible by CT?

Hypothesis: Presence of high density (metallic) “bright spots” in JR could bridge anode to cathode causing internal shorts and leading to dOCV failures

P28B dOCV Screen Data

Pre-dOCV Screen Data

Arrow denotes failing Cell Selection for CT scans

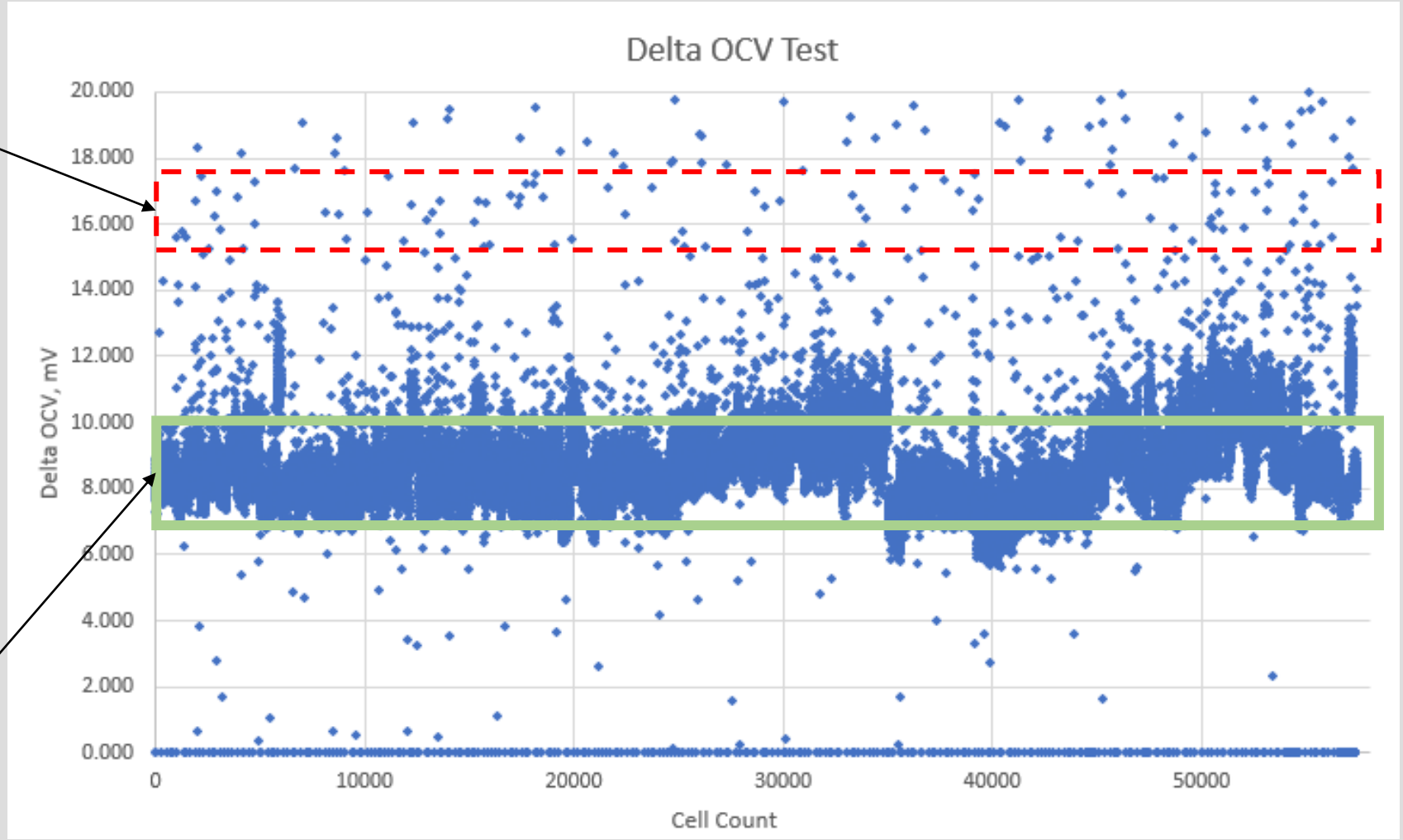


Pre-dOCV Screen Data

Failing Cell Selection for CT scans

	#	% Entire Lot (56,552)
Total Rejects	679	1.2%
Low Rejects	27	0.0477%
High Rejects	447	0.79%
No Data Rejects	205	0.362%

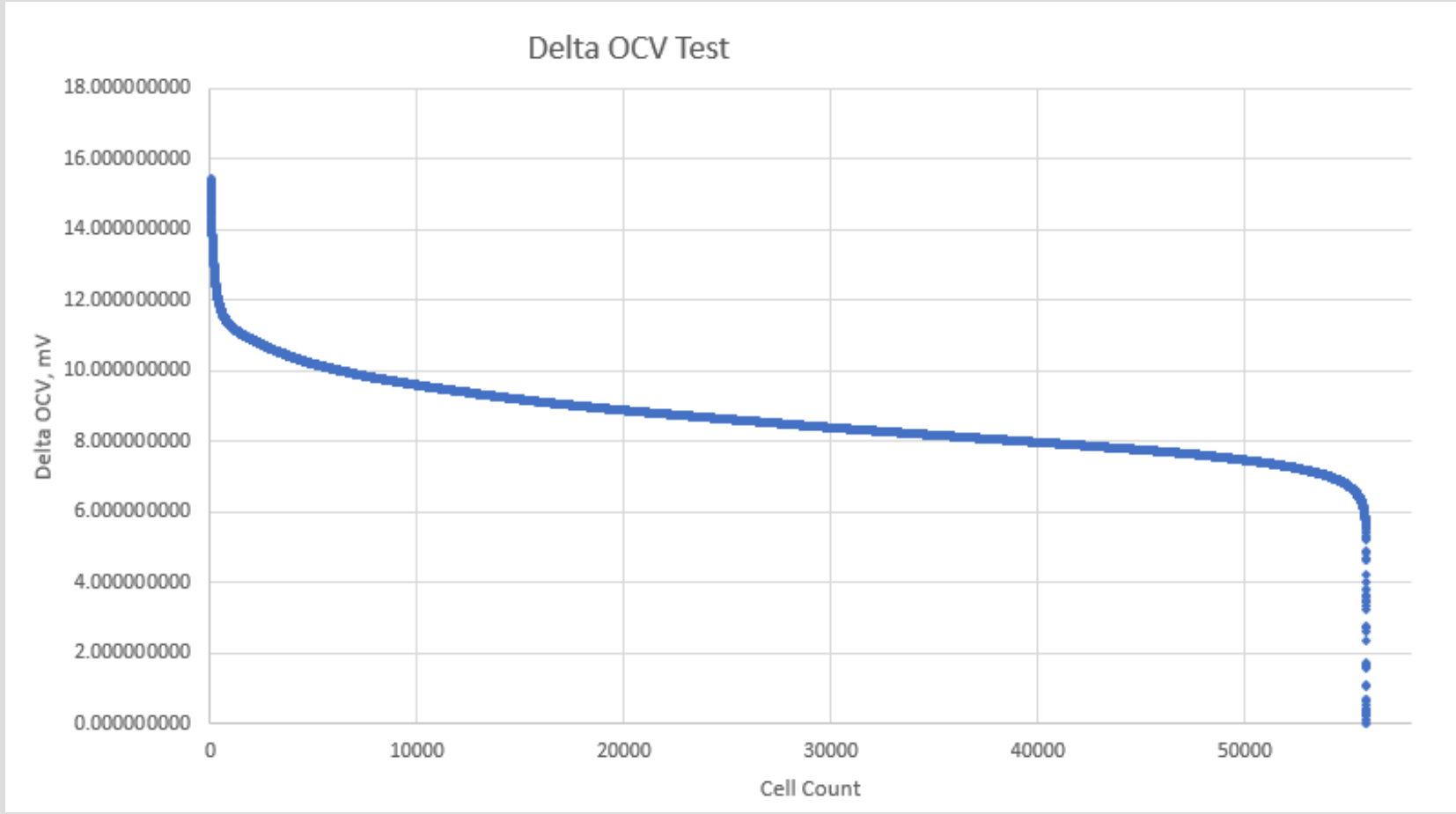
Passing Cell Selection for CT scan



- Note 2 cells from failing negative range were picked, range not shown on graph
- Ignored low rejects that were not negative

Passing Cell dOCV Data

- Removal of 3σ outliers until 3σ range is stable and 6σ% approaches 0
  - -/+3σ = 5.34 / 11.96 mV
  - 6σ% = 0.765%



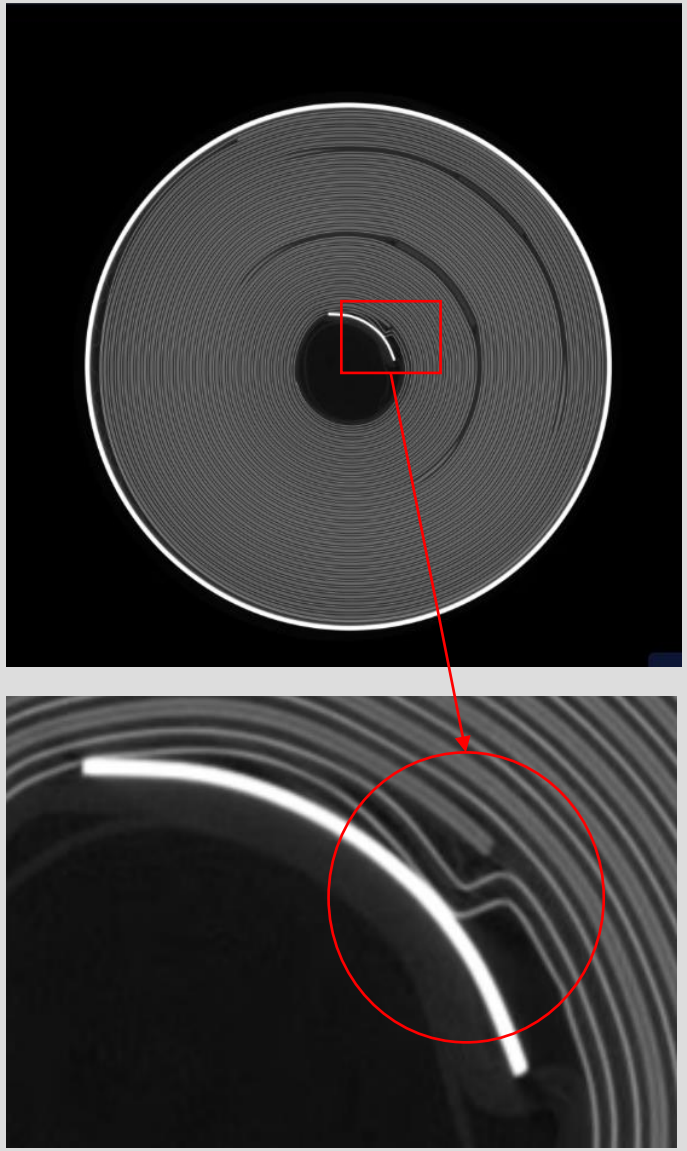
*Ignored low rejects that were not negative

CT Scan Findings

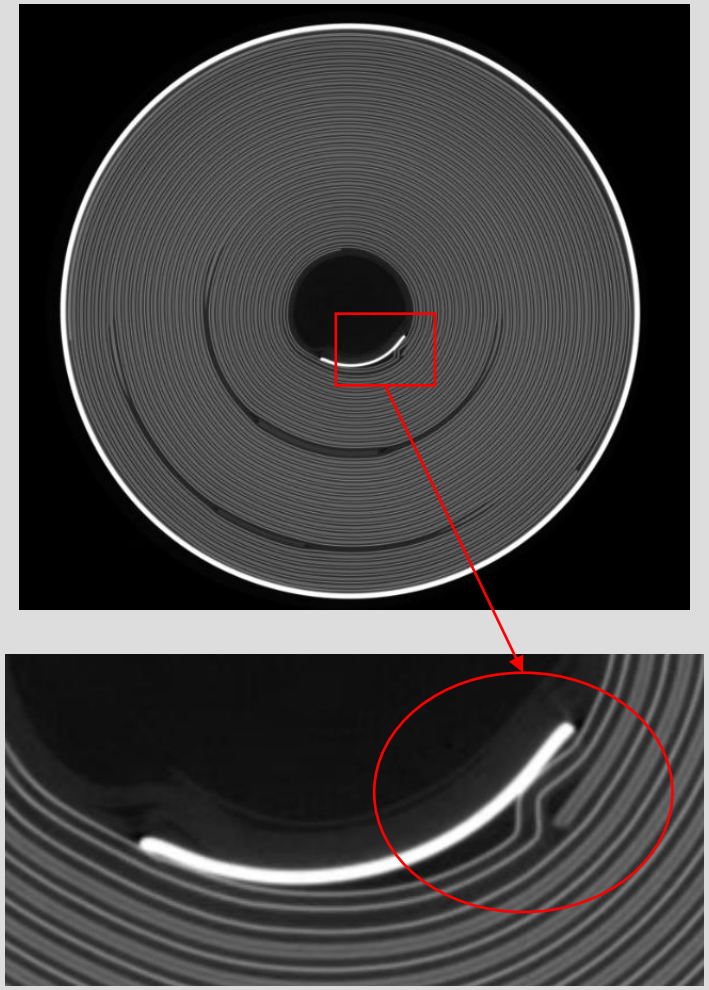
Key Cell Finding #1 – Anode Buckling

- Overlap of inner wind anode tab with start of cathode layer leading to severe buckling angle of anode
  - Buckling appears in both PASS and FAIL dOCV cells

FAILING Cell

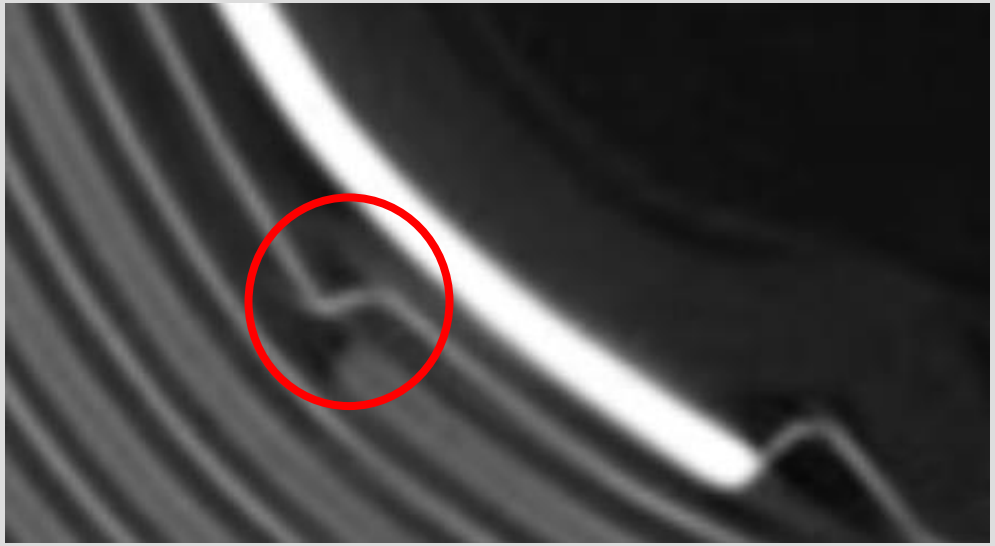


Passing Cell

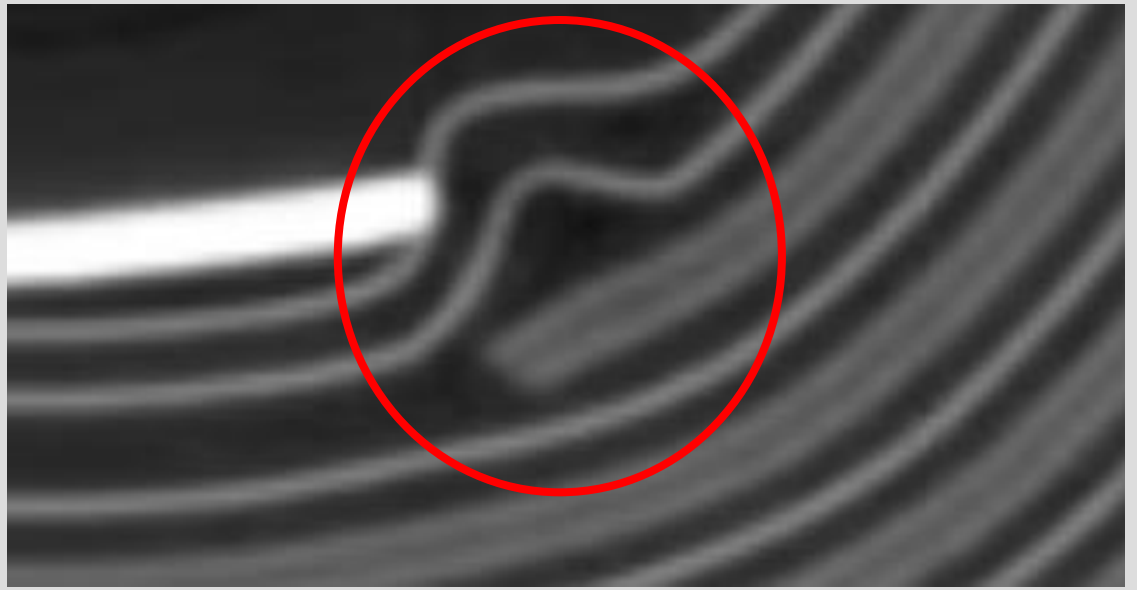


More Examples of Buckling

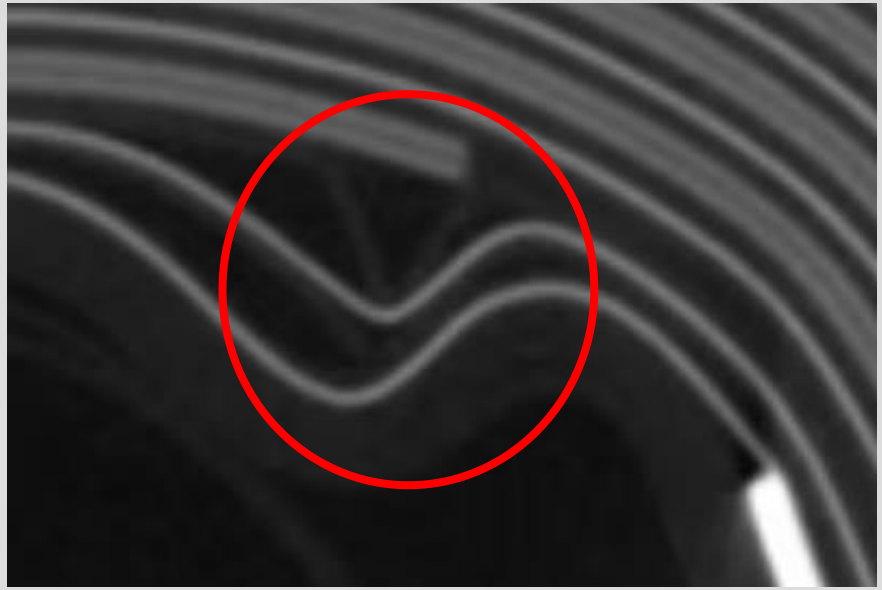
1 Fail



3 Pass



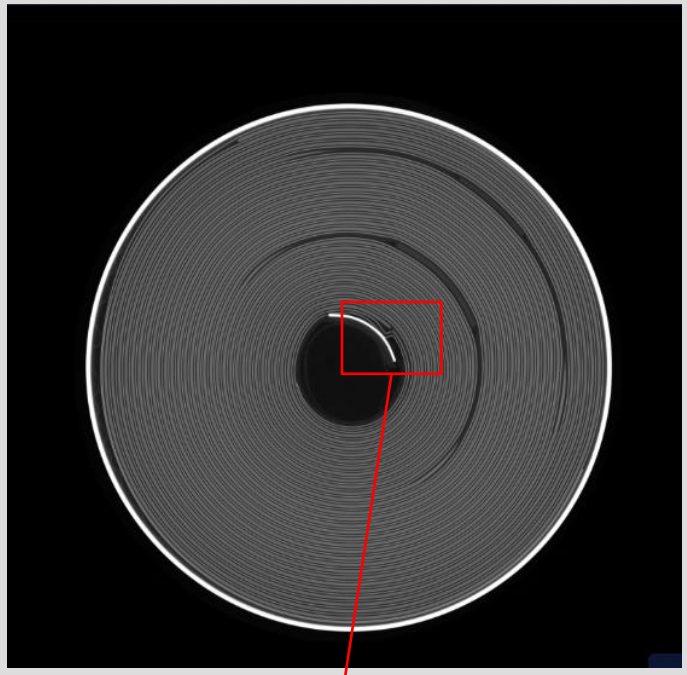
2 Fail

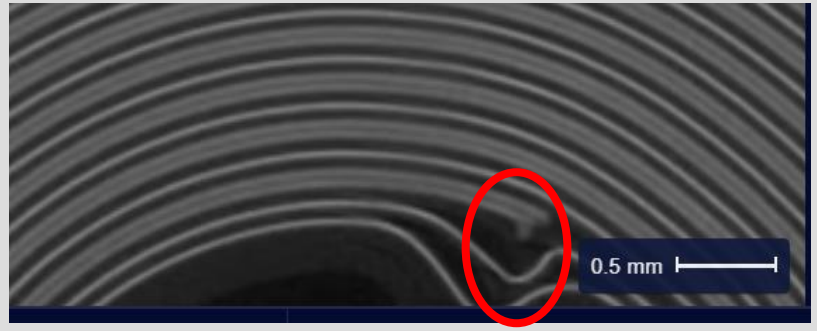


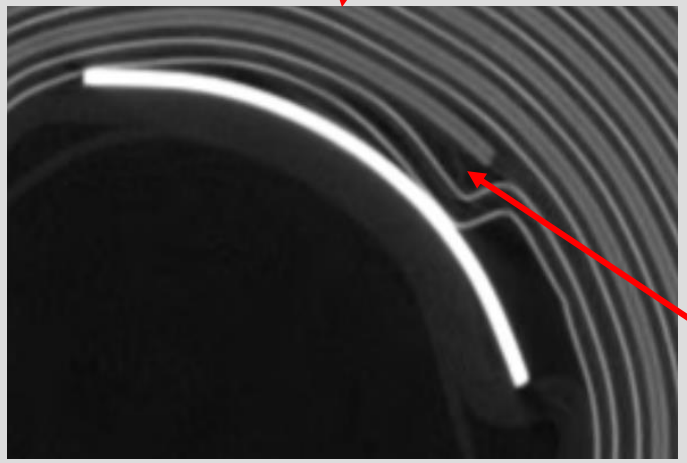
Key Cell Finding #2 – Delamination/Cathode Damage

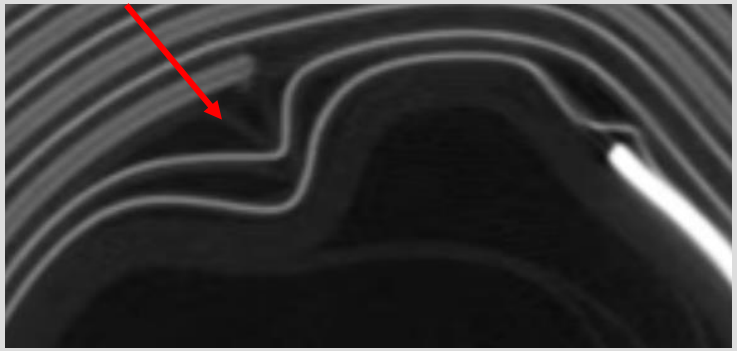
- Severe buckling on failing cells showed a trend of delaminating graphite from anode
- Severe dOCV fails tend to have delamination at start of cathode at the inner wind

FAILING Cells



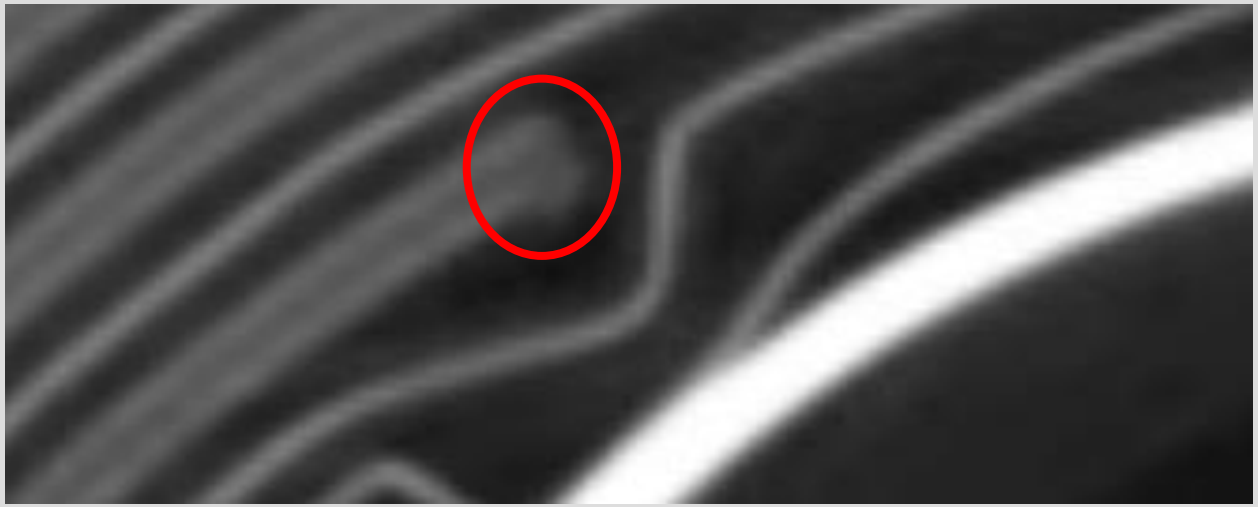




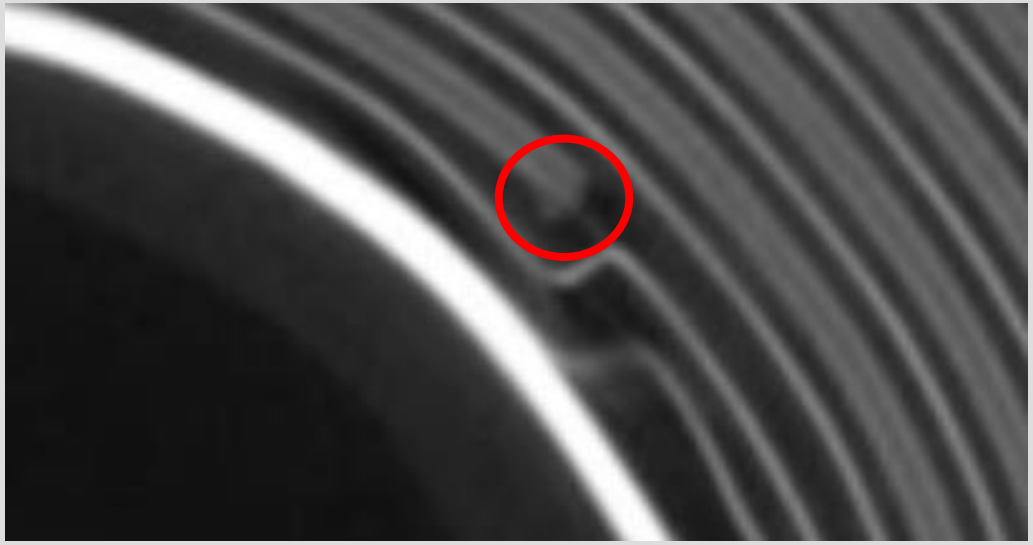


More Examples of Delam/Cathode Damage

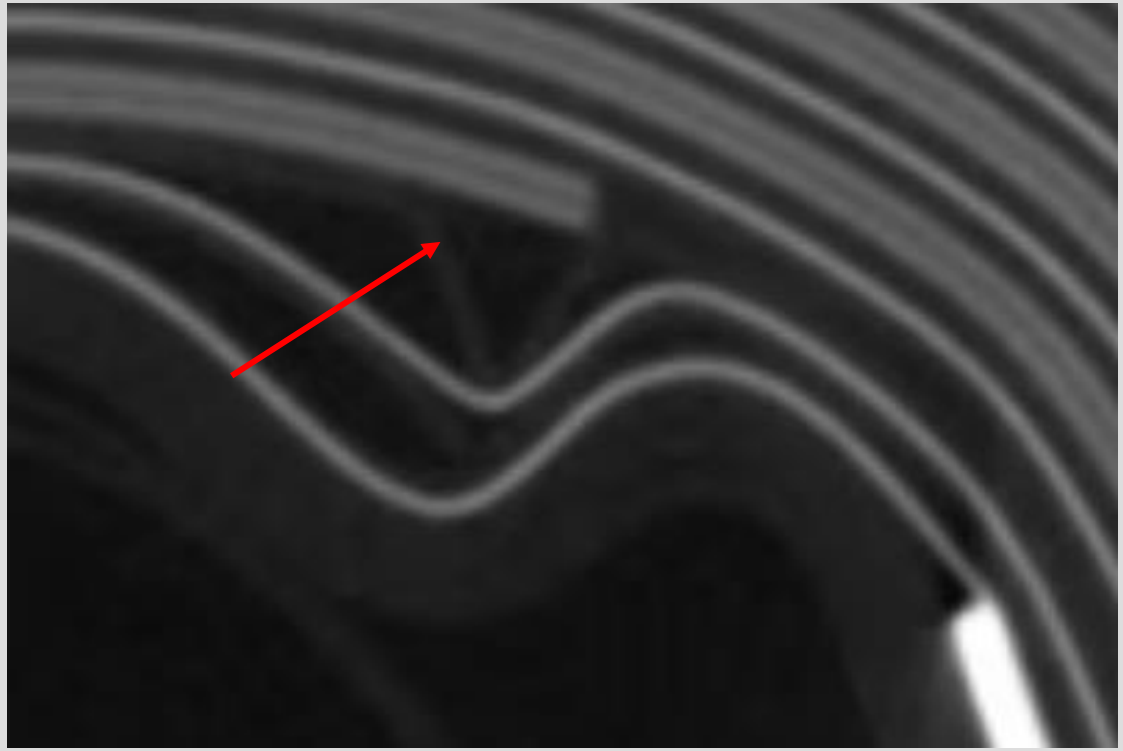
1 Fail – Cathode Damage



2 Fail – Liberated Active Material

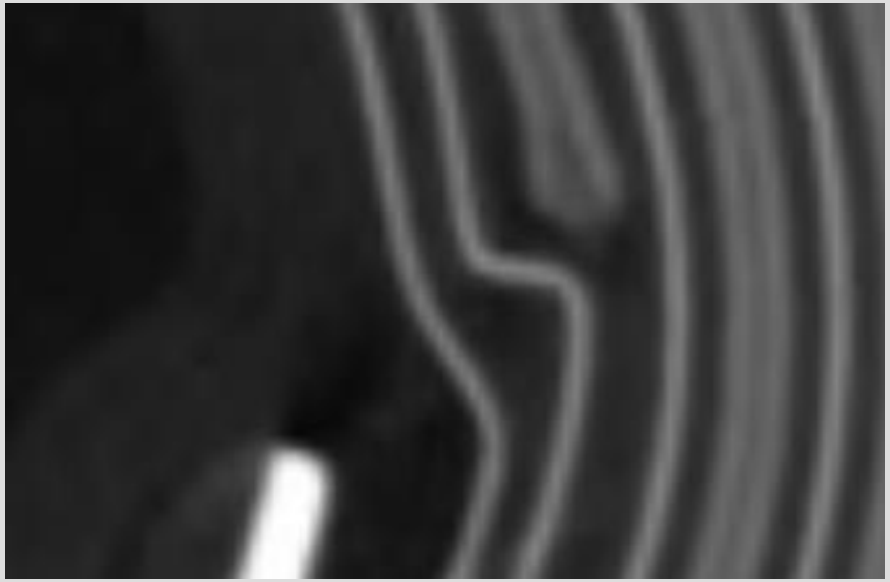


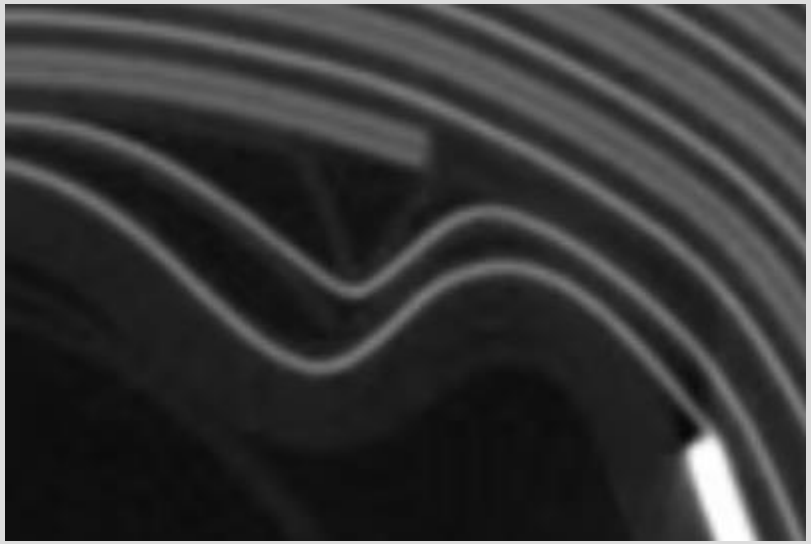
3 Fail – Delamination of Graphite(same image as #2 from slide #18)



Conclusions + Forward Work

- 1.2% of cells failed dOCV (-/+3σ = 5.34 / 11.96 mV)
- Both passing and failing dOCV cells show anode buckling at inner wind
- Passing cells have cleaner cathode starts at the inner wind
- Failing cells have a degree of delamination/ deformation at cathode start at inner wind that seems to track with severity of dOCV failure
- Initial hypothesis was presence of high density "bright spots" could be bridging anode to cathode
  - Not seen
  - Scans are 250 microns between radial layers, tiny bright spots could have been missed
- FORWARD WORK: Look for heat affected zones in separator through DPAs





End

Backup Slides

Samsung 53G1 Cell

MP date
- character 18 : J year of 2019 (A 2010, B 2011...)
- character 19 : 1 month of Jan (A Oct., B Nov., C Dec.)
- character 20 : 7 day of 7 (A 10, B 11, ...)

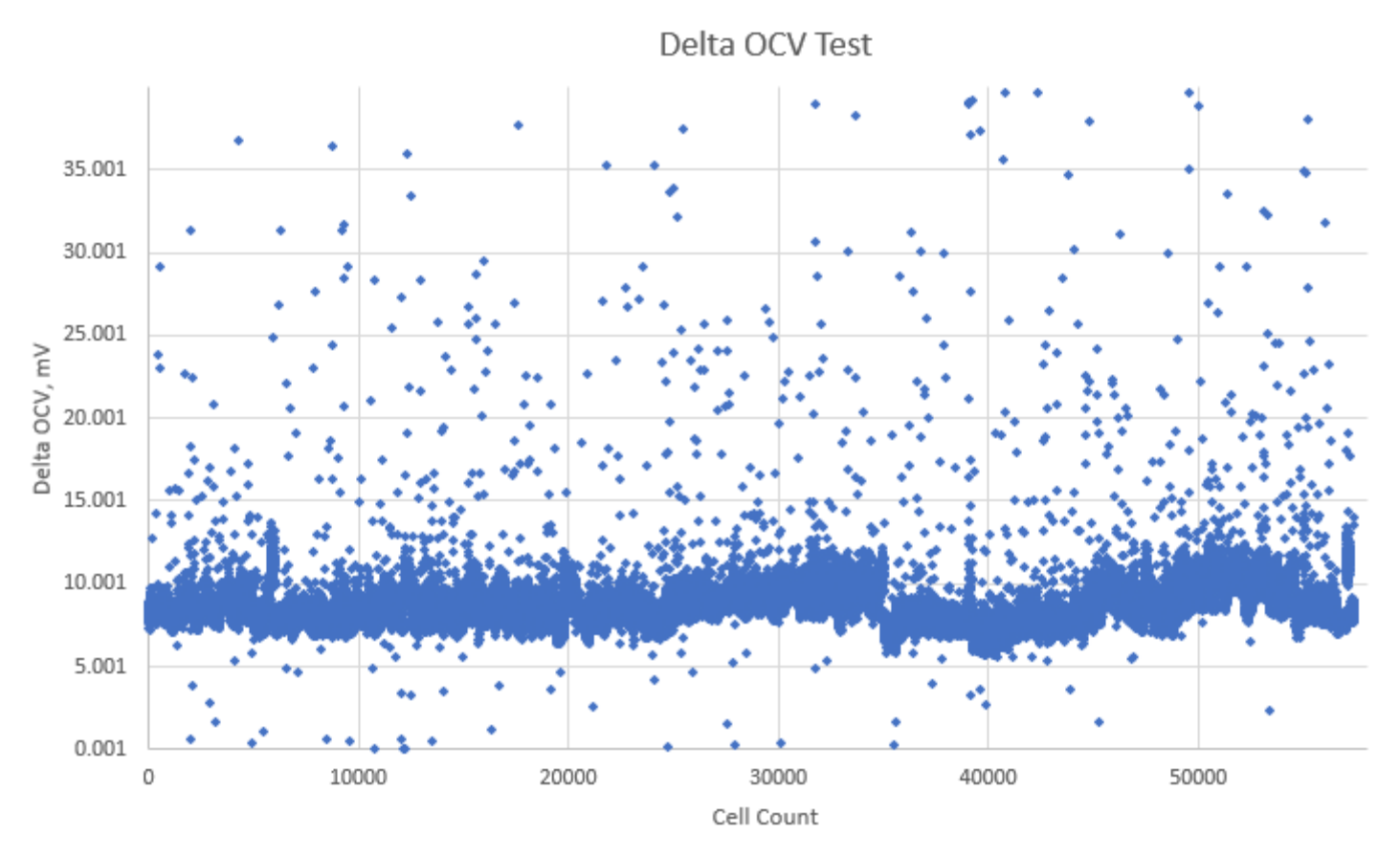
Version
- character 21 : 1 of 53G1 (2 53G2, 3 53G3, ...)

Assembly line
- character 22 : C, Cheon-An of Korea
- character 23 : I of 18 line (1 1line, 2line, A 10line, B 11line, ...)

OCV/IR
- character 24,25,26,27,28 : 3.5833mV
- character 29,30,31 : 13.5mohm

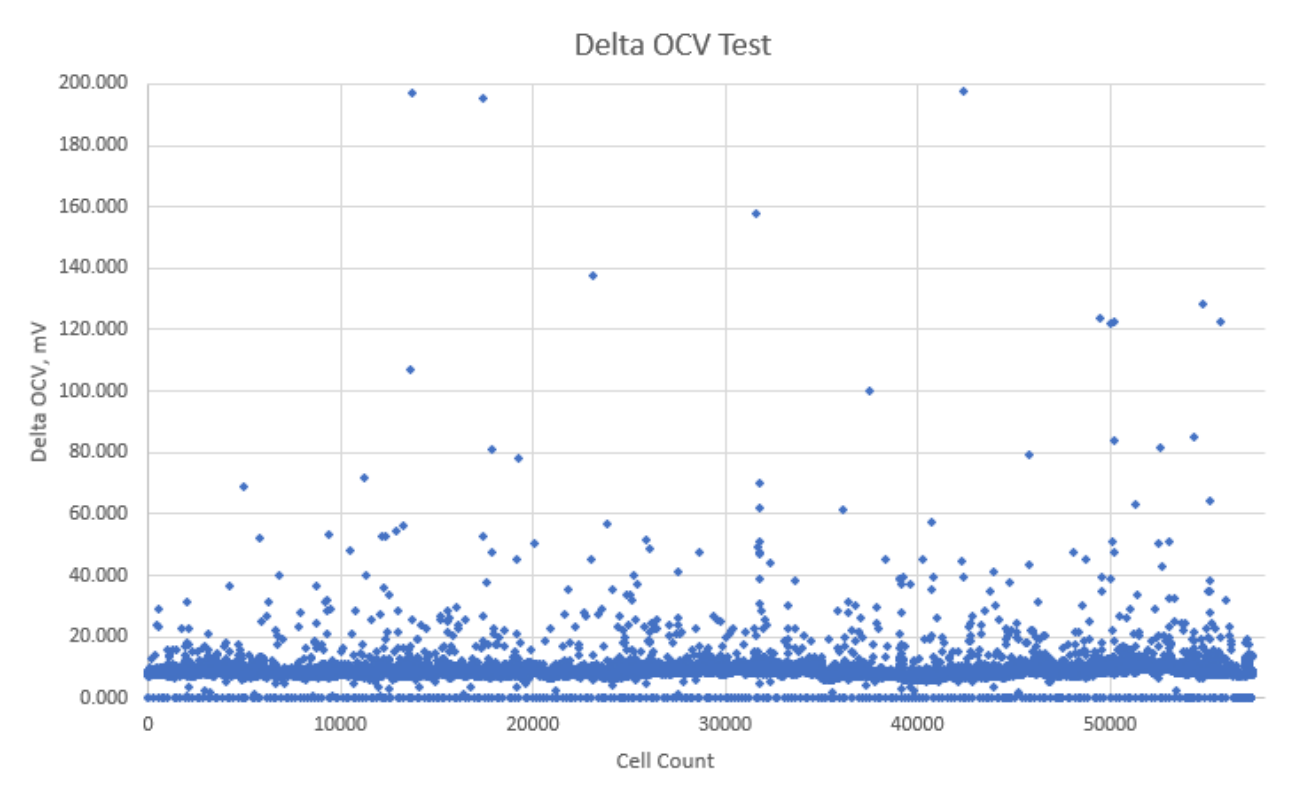
Samsung makes OCV data out to 4 decimal places available via QR code on each cell can

Raw Data*



*Graph does not show extreme outliers as it causes the rest of the graph to be unreadable

Raw Data*



*Graph does not show extreme outliers as it causes the rest of the graph to be unreadable

Raw Data ALL - Sorted