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Verification Sciences & Engineering Case Study of Counterfeit COTS Li-Ion Cells

***Albert H. Zimmerman and Edward Jung
The Aerospace Corporation***

***For presentation at the
NASA Aerospace Battery Workshop
19-21 November 2019; Huntsville, AL***

Approved for public release. OTR 2020-00049.

Public Release Authorized



Goals of the Case Study

- **Supported under Verification Sciences and Engineering program, Systems Engineering Division**
 - *Four-month case study*
 - *Focus is on one type of commercial off the shelf (COTS) cell commonly used in small satellites, LG 18650MJ1*
 - *Focus on methods for verifying authenticity of small cell batch procurements, typically purchased from 3rd-party distributors*
 - *Evaluate for a range of other potentially deceptive commercial practices*
- **Goals of case study**
 - *Examine how common counterfeit LG MJ1 cells are in the COTS marketplace*
 - *Evaluate perceptivity of easily applicable non-destructive screening methods*
 - *Define and recommend a minimum set of tests capable of detecting counterfeit cells*
 - *Determine whether other types of deceptive practices related to cell labeling, repurposing, handling, and storage are a concern in the COTS marketplace*
 - *Recommend how programs, small satellite manufacturers, and universities can minimize exposure to counterfeits and other deceptive practices*
- **Case study results and recommendations are presented and discussed here**



The COTS Discussion

“ [...] we built the glass houses before the invention of stones.”

–Heather Wilson; former Air Force Secretary

- **“Proliferated LEO” constellations**

- *Large constellations of satellites provide a more resilient defense architecture in space.*
- *Higher risk of satellite failure may be allowed.*

- **Standardization of size**

- *Identical mechanical format allows for easier mechanical design iteration.*
- *Standardized size allows for use of innovation in private sector.*
- *Higher risk of counterfeit due to large quantities available in marketplace.*

- **Quality and reliability**

- *Higher volume manufacturing generally enables greater levels of automation.*
- *Cells are designed and engineered to optimize \$/kWh, not cycle life.*
- *“Black box”: No knowledge of manufacturing process, quality checks, testing.*

- **Lower cost of getting objects into space**

- *Dozens of small launch vehicles are currently under development*
- *Reusability of rockets enabling “SmallSat Rideshare Program”*
- *Entities with minimal experience & purchasing power to get objects into space*



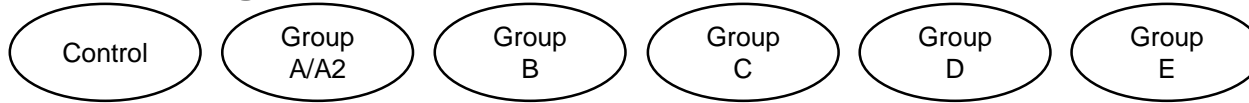
Selection of Cell Type and Cells to Study

- **Focus on a COTS cell commonly used in small satellites and CubeSats**
- **LG 18650MJ1 cell selected for study, 3.4 Ah rating**
 - *No counterfeit exploits were found reported in searches related to this cell*
 - *Unsure whether this is due to lack of systematic study, or perhaps this cell type is not frequently counterfeited*
- **Twelve control LG 18650MJ1 cells obtained**
 - *Procured by a trusted supplier directly from LG with a single date code*
- **Six other batches (groups) of LG 18650MJ1 cells purchased from e-commerce vendors**
 - *Batches labeled as A, A2, B, C, D, and E*
 - *Cost per cell ranged from \$3.74 to \$13.99 (including shipping)*
 - *All cells labeled as LG 18650MJ1, but labels showed variations compared to control cells*

Test Procedure



Purchasing



Incoming Inspection

- Visual Inspection
- Weight
- Dimension
- OCV
- AC-IR

Non-destructive Evaluation

- Computed Tomography (CT)

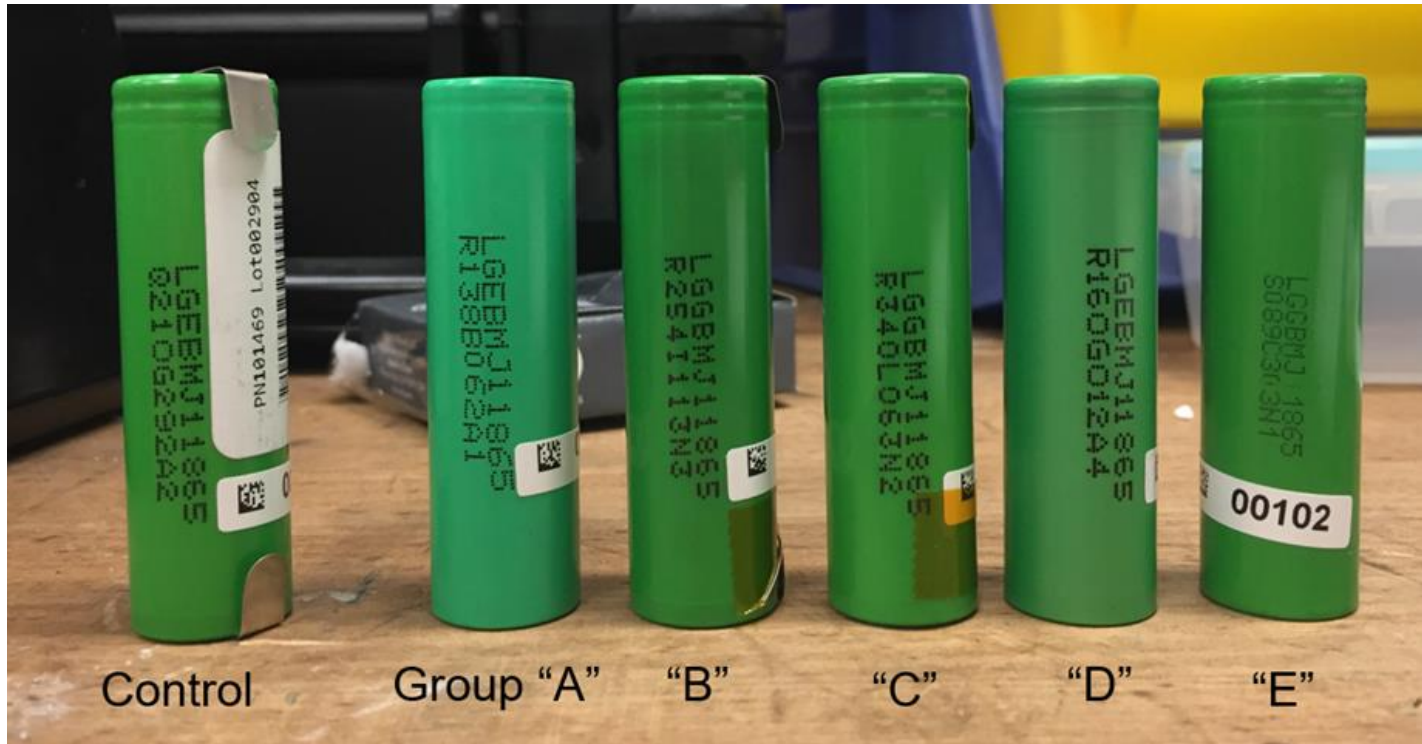
Electrical Screening (5 cycles)

- DC Resistance
- OCV vs. Apparent SOC
- Differential Capacity (dV/dC)
- Overall Capacity



Visual Inspection

White labels, bar codes, Kapton added during inspection

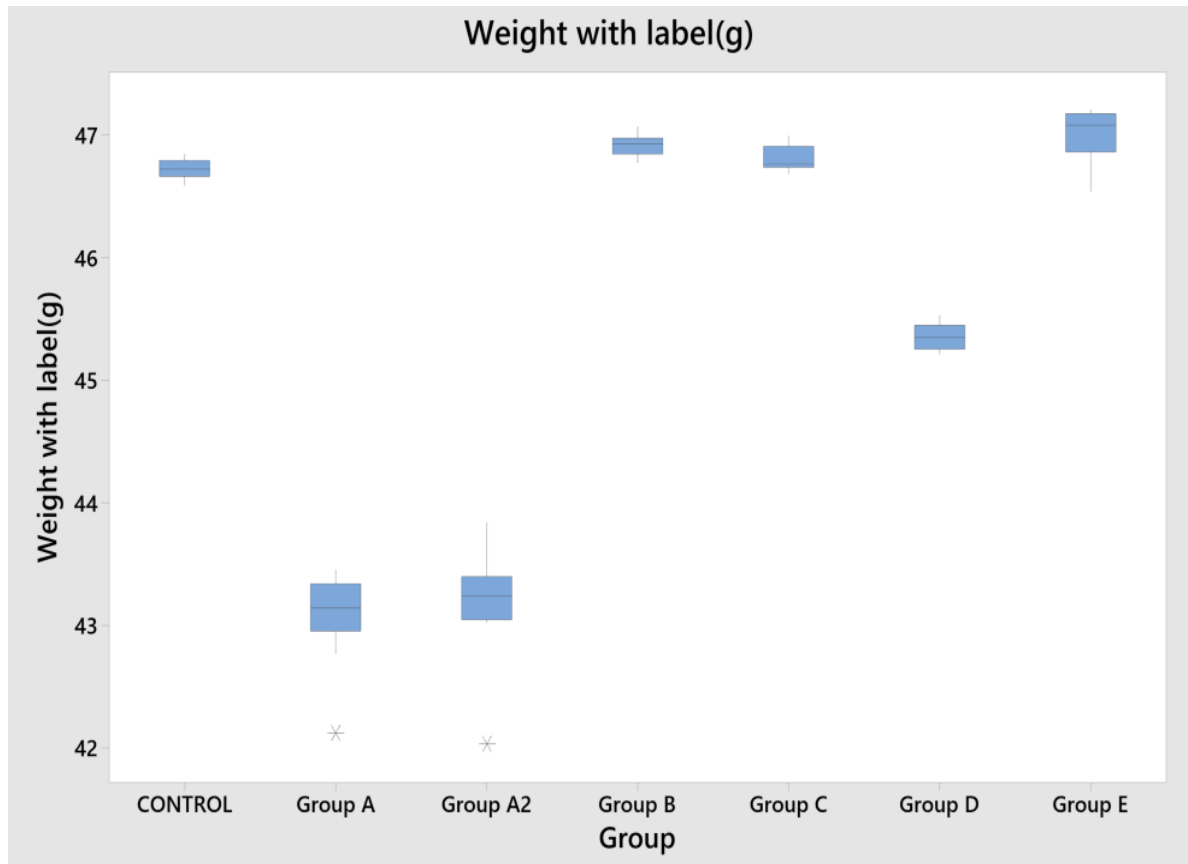


Standardization of size (18650) makes it impossible to use solely the appearance of cell wrapper and print to ensure authenticity.



Physical Inspection Measurements

- Cell dimensions (height, width) were all nominal for 18650 cells
- Cell weights suggested that groups A, A2, and D were counterfeit, with group E having a suspiciously wide spread





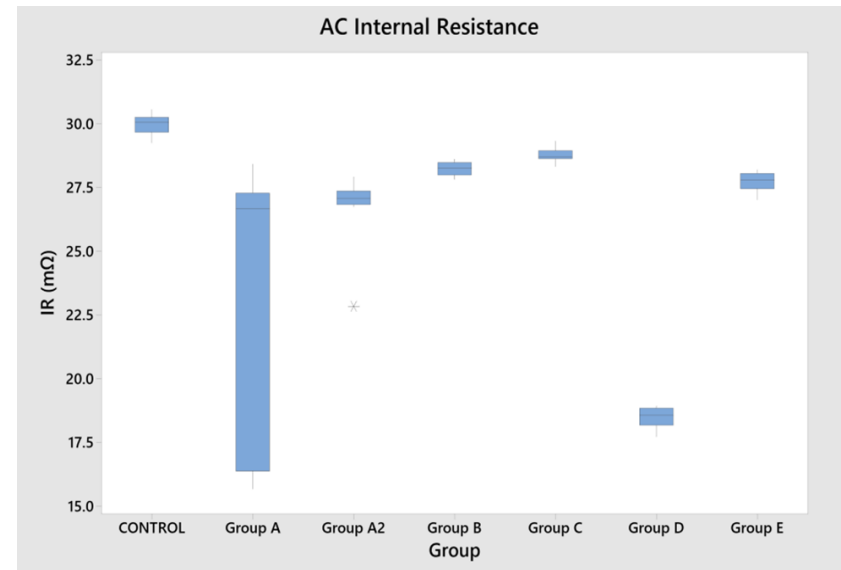
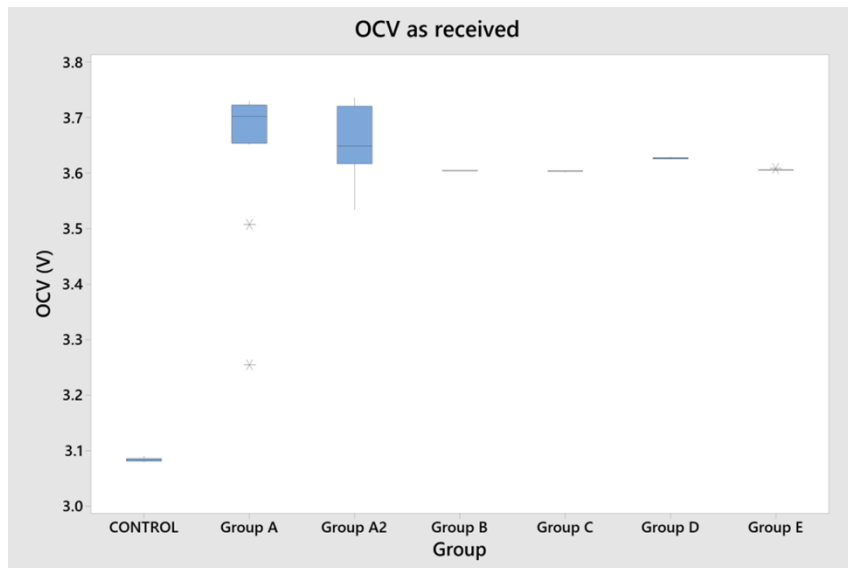
Electrical Inspection Measurements

Open circuit voltage:

- All groups deviated from control
- Extremely wide range in A and A2 groups (including several cells below 2 volts*, not included in statistics)

AC resistance:

- Groups A and D deviated considerably from control
- Extremely wide range in A group

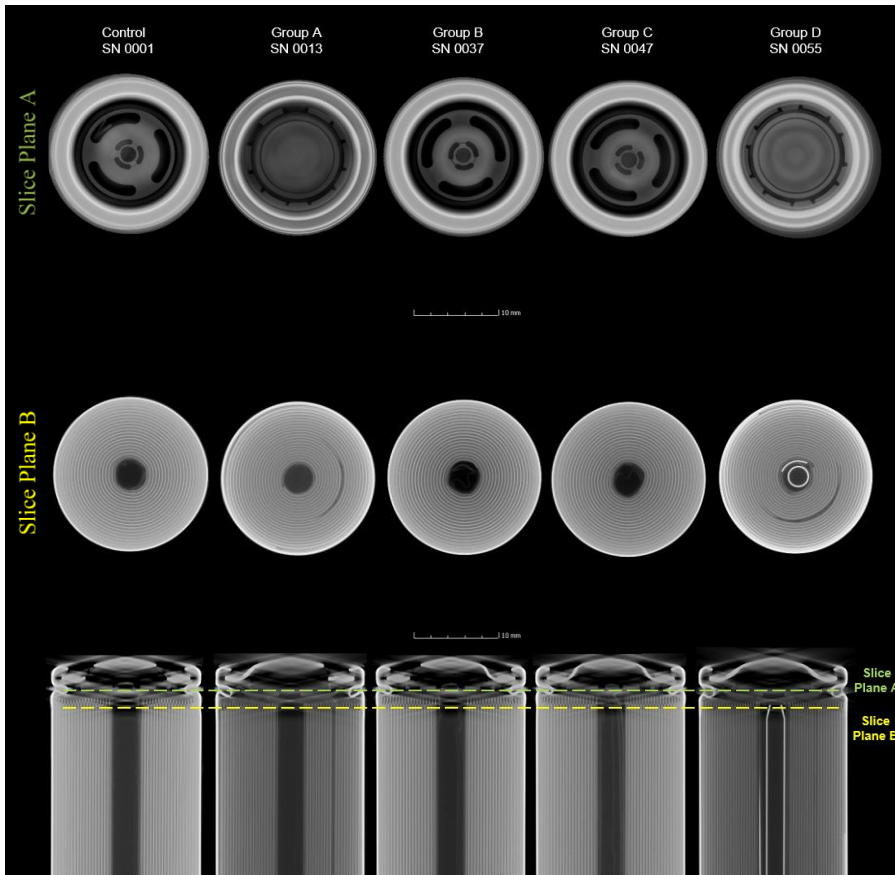


****X-ray showed broken tab to negative terminal in low voltage cells***

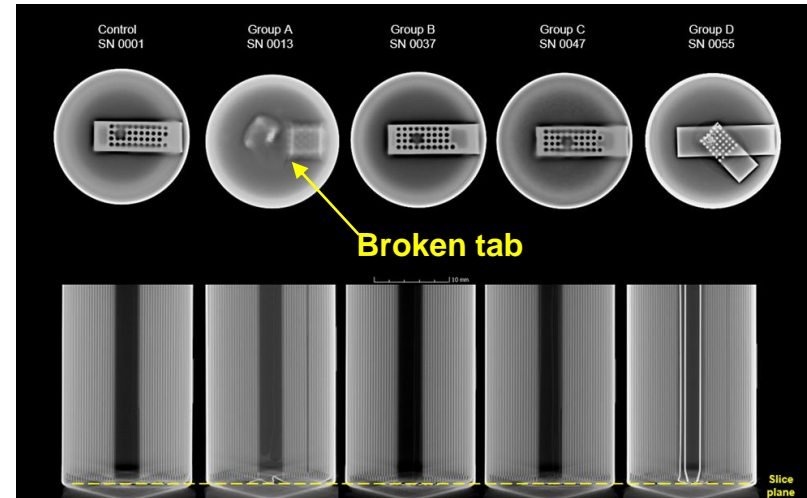


Low-Resolution X-Ray Inspection of Cells

Scans at tops of cells



Scans at bottoms of cells



- Groups A, A2*, and D are internally different design from control
- Groups B, C, and E* are similar

*Not shown in x-ray line-up



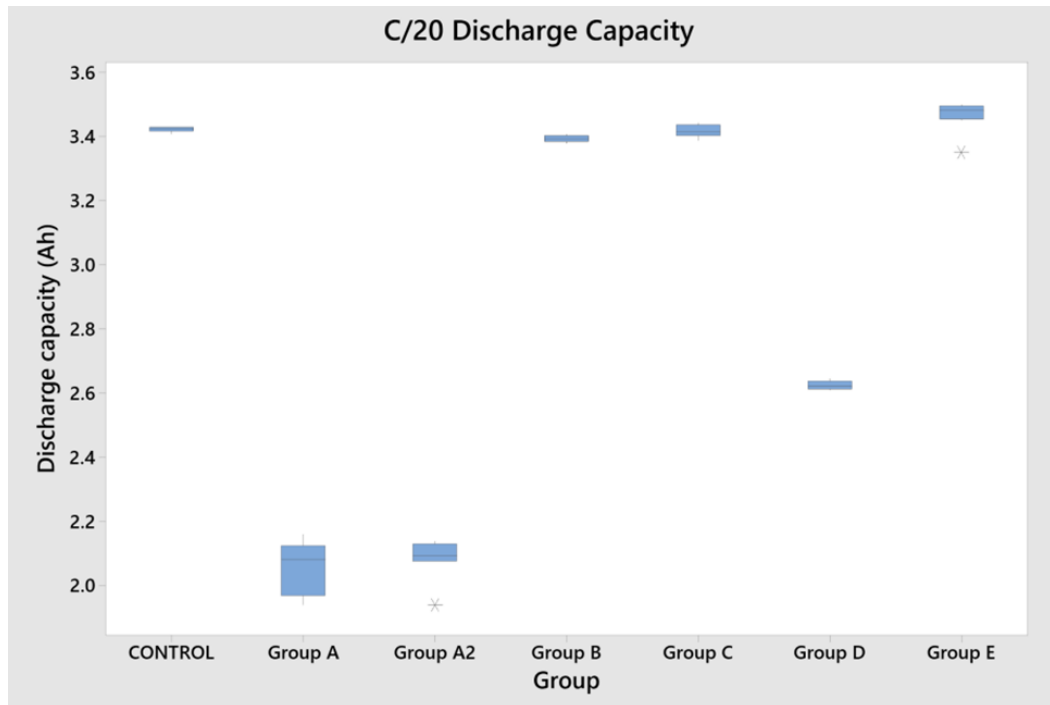
Electrical Screening Tests

- **Cell capacity: five cycles performed**
 - *Two C/5 charge and C/2 discharge cycles*
 - *Two C/10 charge/discharge cycles*
 - *One C/20 charge/discharge cycle*
- **Cell DC resistance**
 - *Evaluated from separation between C/20 charge and discharge voltage curves*
- **“Apparent” open circuit voltage (OCV) vs. state-of-charge**
 - *Taken as midpoint between C/20 charge and C/20 discharge voltage*
 - *Differential capacity plotted as a function of OCV*
 - Provides a fingerprint for cell chemistry
- **Differential capacity signatures**
 - *During recharge from C/20 charge voltage curves*
 - *During discharge from C/20 discharge voltage curves*
- **All these electrical tests can be readily performed by any program to validate cell authenticity**



Capacity

- **Groups B, C, and E are similar to control group**
 - *Within range of 3.4 to 3.5 Ah*
 - *C and E groups show higher variability*

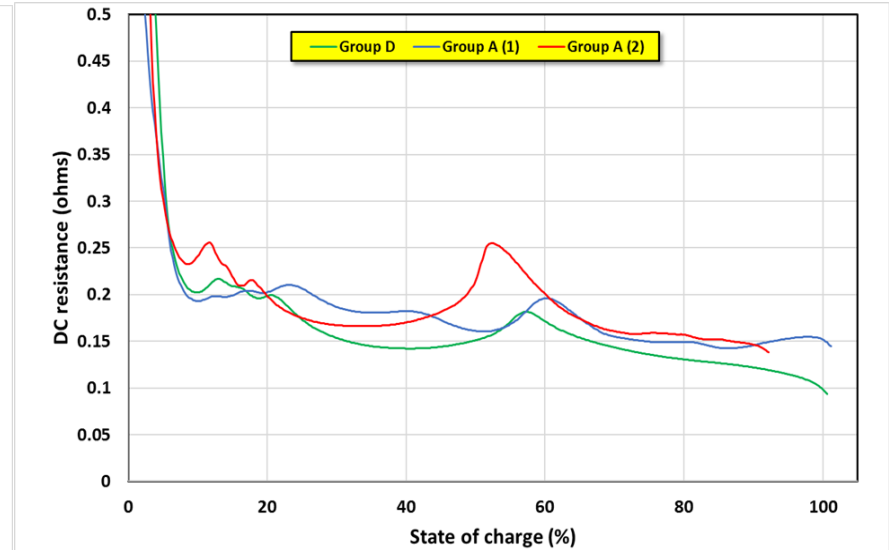
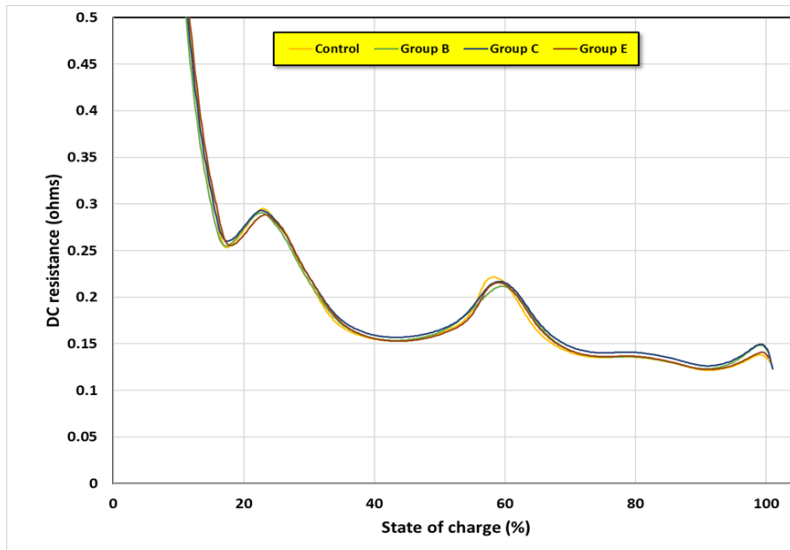


- **Groups A, A2, and D are not like control group**
 - *A and A2 groups contain several types of cells (1.9 and 2.1 Ah)*
 - *D group is very uniform at 2.6 Ah*



DC Resistance

- **Groups B, C, and E are very similar to control group**
 - Control cells have slightly sharper peak at 60% SOC
 - C group is slightly higher

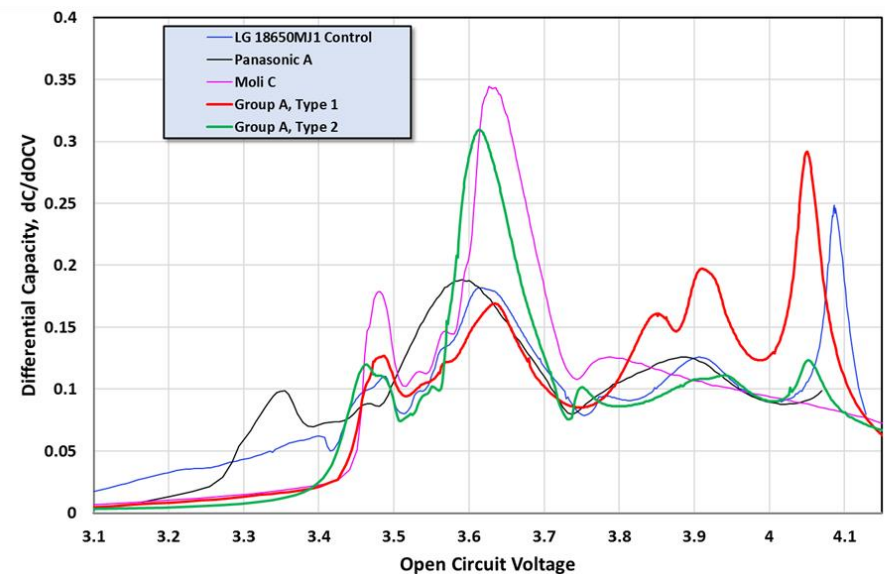
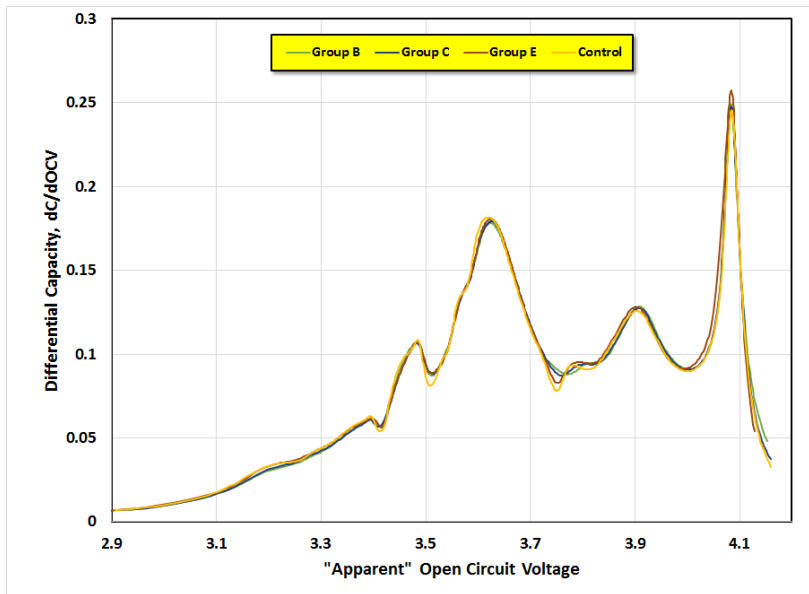


- **Groups A, A2, and D are not like control group**
 - A and A2 groups appear to contain several distinct types of cells



OCV Signatures

- **Groups B, C, and E are very similar to control group**
 - *Control cells have generally sharper peaks below 3.9 volts*

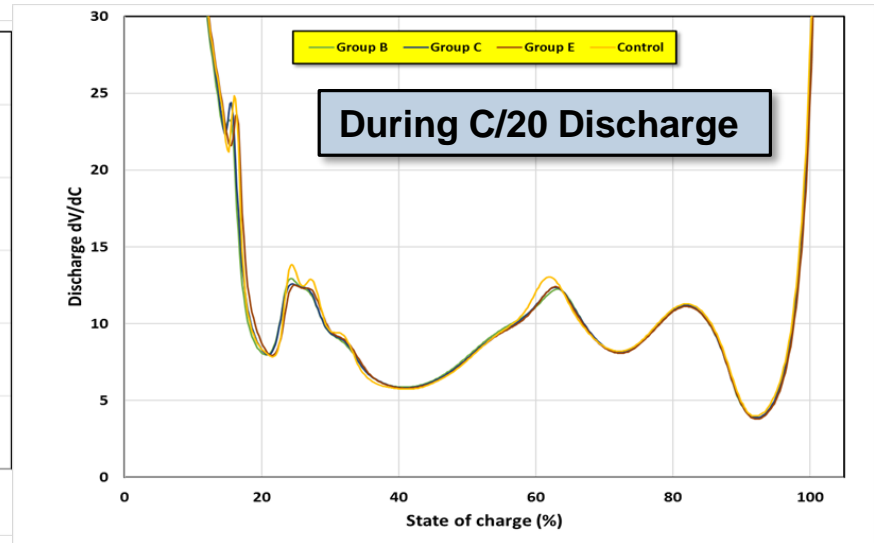
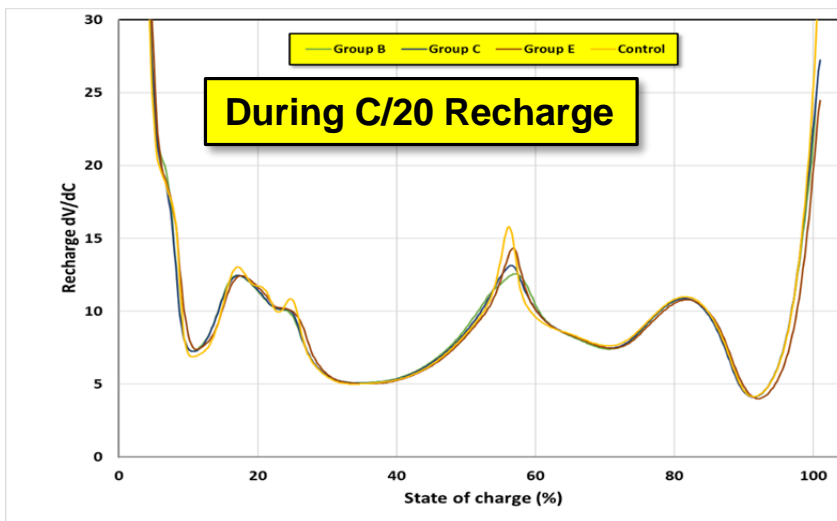


- **Groups A, A2, and D are not like control group, or any other type of 18650 cell commonly used in space systems**
 - *Appear to be some LCO-based chemistry*



Differential Capacity Signatures

- **Groups B, C, and E are very similar to control group**
 - *Control cells have generally sharper peaks below 70% state of charge*



- **Groups A, A2, and D are not like control group**
 - *A and A2 groups have two distinct types of signatures*
 - *D group is different from all the other groups*



Conclusions

- **50% of LG MJ1 cells obtained from the commercial marketplace were counterfeit**
- **Labeling variations gives no assurance of either authenticity or being counterfeit**
- **Cell cost is no indication of either counterfeit or authentic cells**
 - *Lowest cost likely indicates increased probability of deceptive practices*
- **Authentic cells may be subject to deceptive practices**
 - *Mixed cell lots, used or repurposed cells, exposure to temperature extremes in storage or handling, storage at high states of charge*
- **Weight and x-ray are best inspection methods to evaluate authenticity**
- **DC resistance, open circuit voltage, and differential capacity signatures easily identified fake cells**
 - *Also detected lot variability, materials changes, storage/handling issues*
- **All authentic cells purchased shipped at elevated (~30%) SOC**
 - *Best storage practice is at low SOC*



Recommendations for Space Use of COTS Cells

- **Follow space standards to the maximum extent possible**
 - **Where the complete suite of verification tests is not possible, apply the following minimum test suite to mitigate risk**
- **Obtain cells from trusted suppliers with a single date code, and as recently produced as possible to minimize storage issues.**
 - *This should minimize exposure to deceptive practices*
 - **Perform 100% incoming inspection**
 - *Visual inspection, dimension, weight, OCV, AC resistance*
 - **100% verification that all cells are authentic and not degraded at BOL**
 - *Physical & x-ray inspection, analysis of cycling data as discussed here*
 - **Verify from performance and x-ray inspection that cell designs tolerate expected space vibration levels**
 - *Evidence of movement could be seen in x-ray of vibrated cells*
 - **Store cells and batteries at low states of charge and controlled temperatures to the maximum extent possible**



Acknowledgements

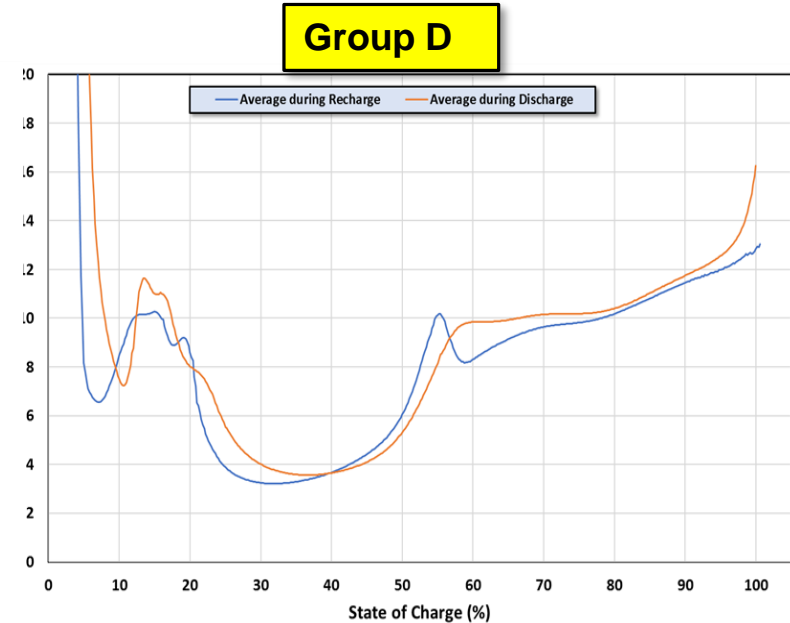
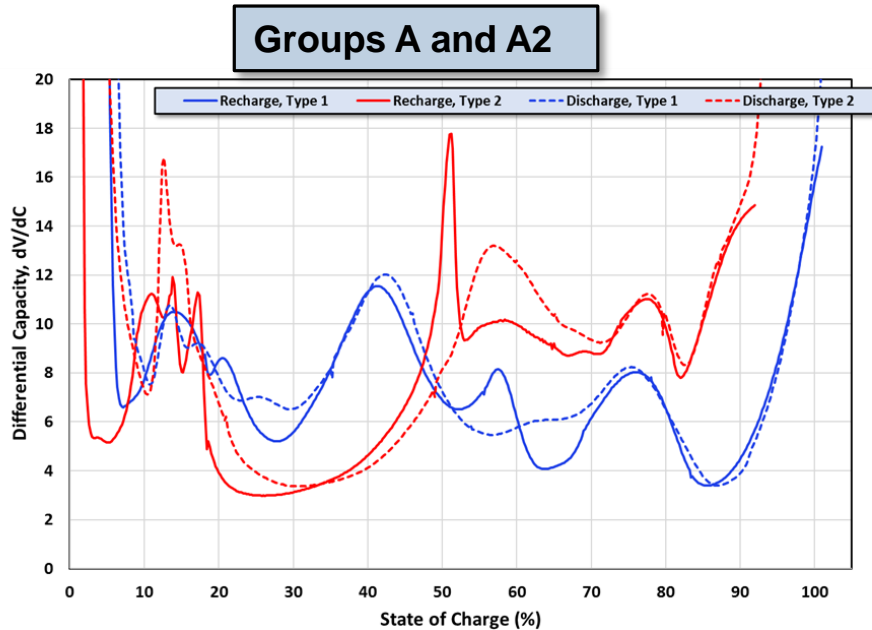
We gratefully acknowledge the VS&E case study program for support of this work.



Back-up Charts

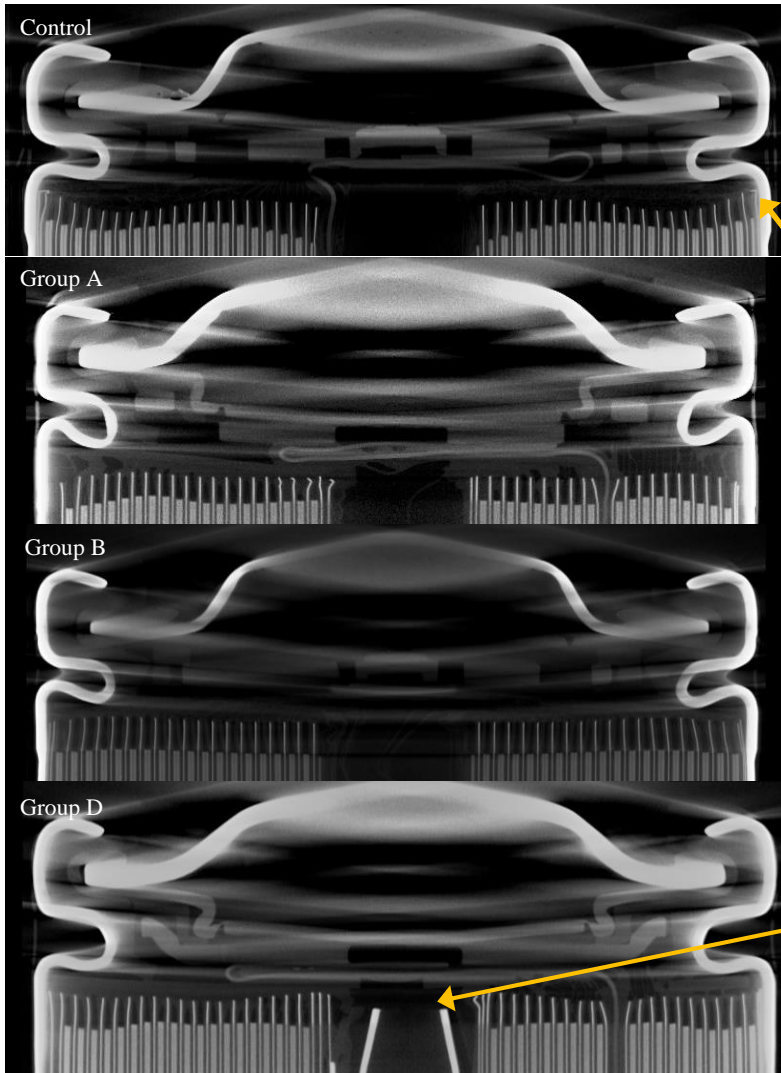


Groups A, A2, D Differential Capacity Signatures



- **Groups A, A2, have two distinct types of signatures**
- **Groups D has its own unique signature**

CT X-rays



Top cap design comparison of control, A, B and D groups

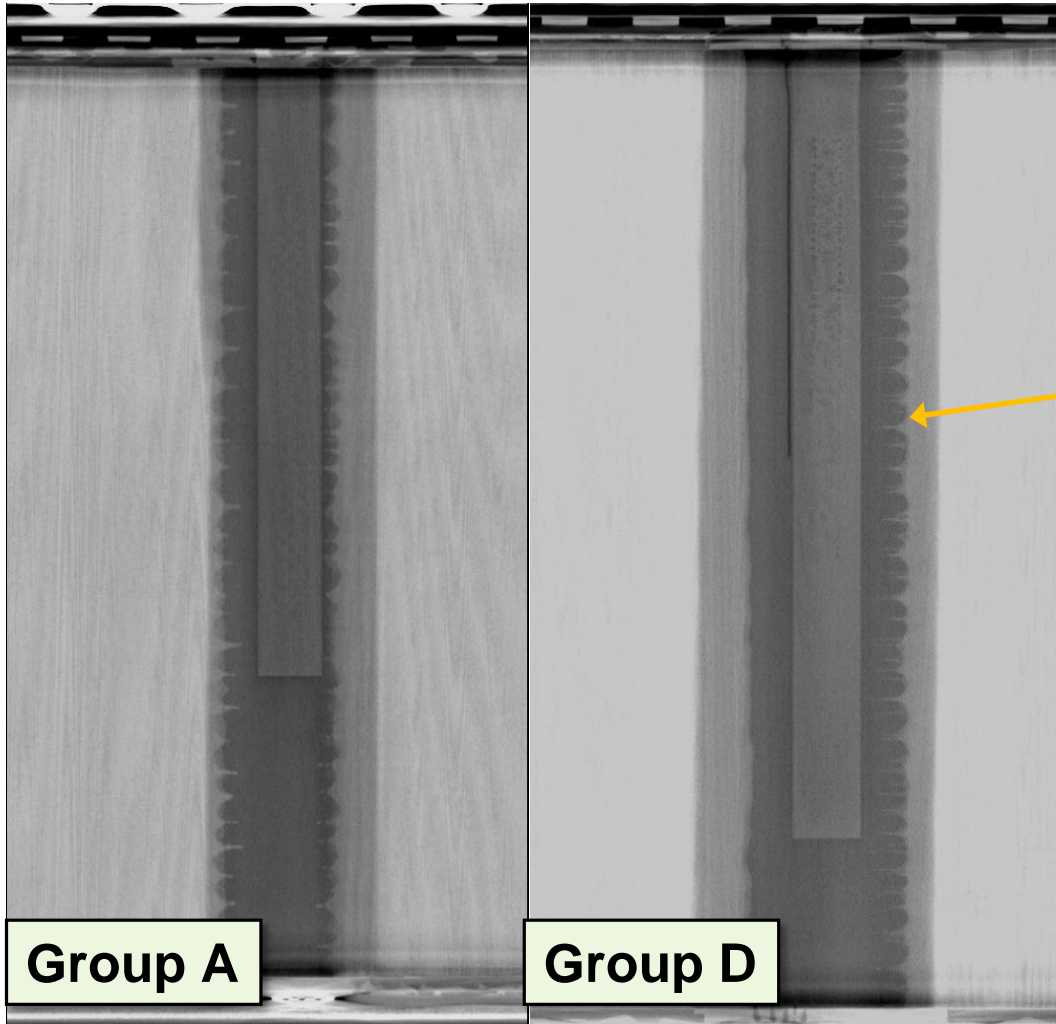
Poorer alignment and flattened electrode edges in vibrated cells

Mandrel present in D group cells



CT X-rays of Positive Cathode Tab

Coating defects seen in counterfeit cells



Non-uniform streaks of coated material (obikis)

Group A

Group D