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Lithium-Ion Cell Screening: Non-Destructive and Destructive Physical Examination

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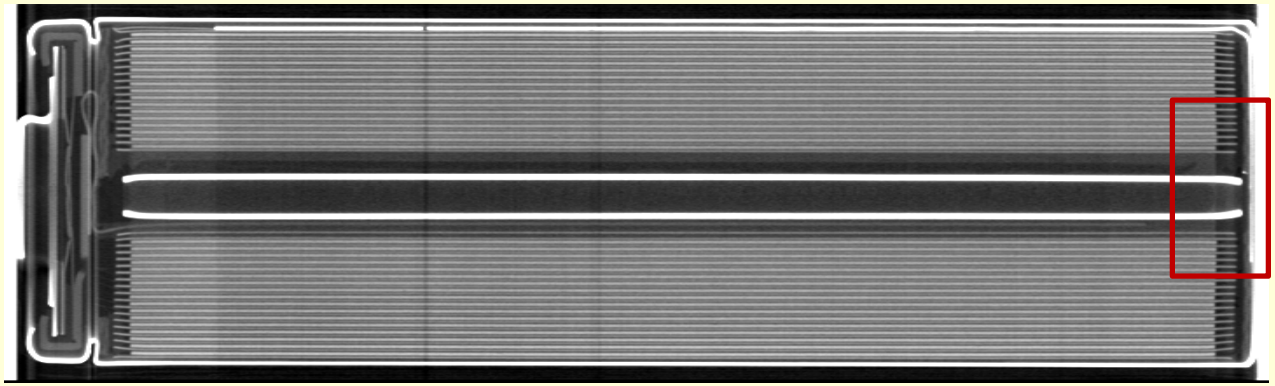
Background

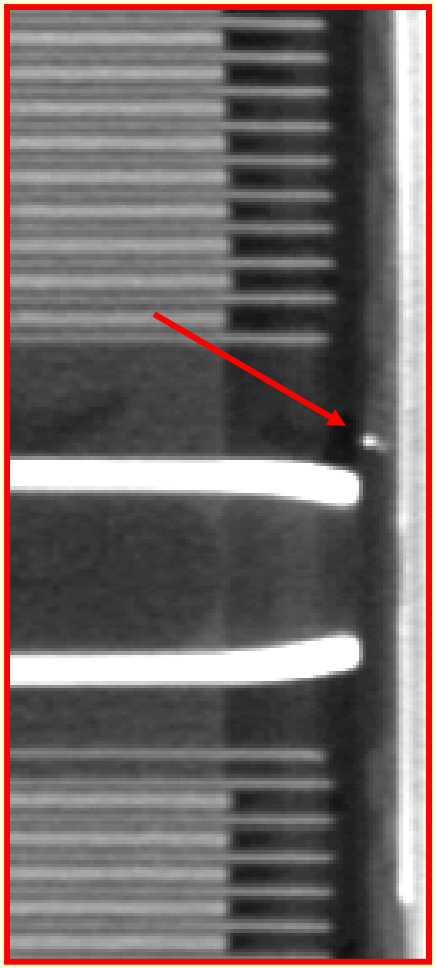
- NASA pre-acceptance testing program for Long Life Battery (LLB)
  - NASA had conducted various screening tests on cells from 2 manufacturers: LV and MJ
  - NASA had identified some outlying cells and submitted them to Exponent for physical examination
    - CT scanning (non-destructive)
    - Cell destructive physical analysis (DPA)
  - Exponent examination revealed:
    - Weld spatter in cap and base of LV cells
    - Cap corrosion in MJ cells

LV Cells: Weld Spatter

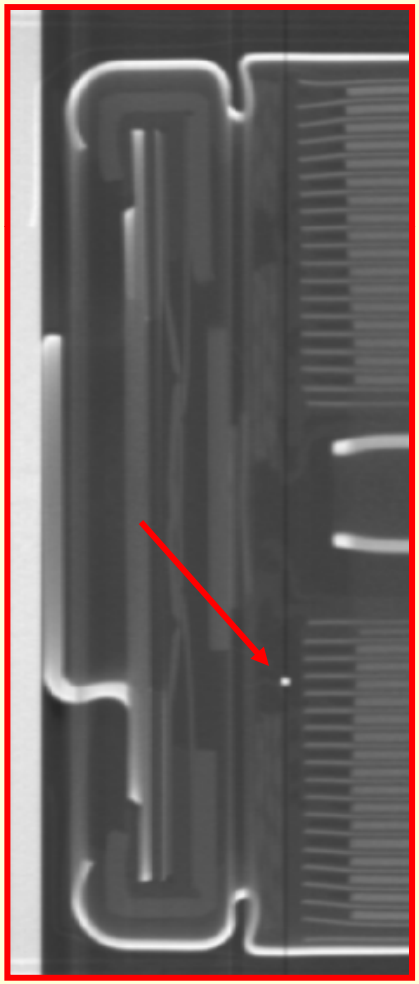
LV Cells: Contamination at Cell Base

- CT scans revealed high density material on cell base insulator, possibly weld spatter from anode lead weld

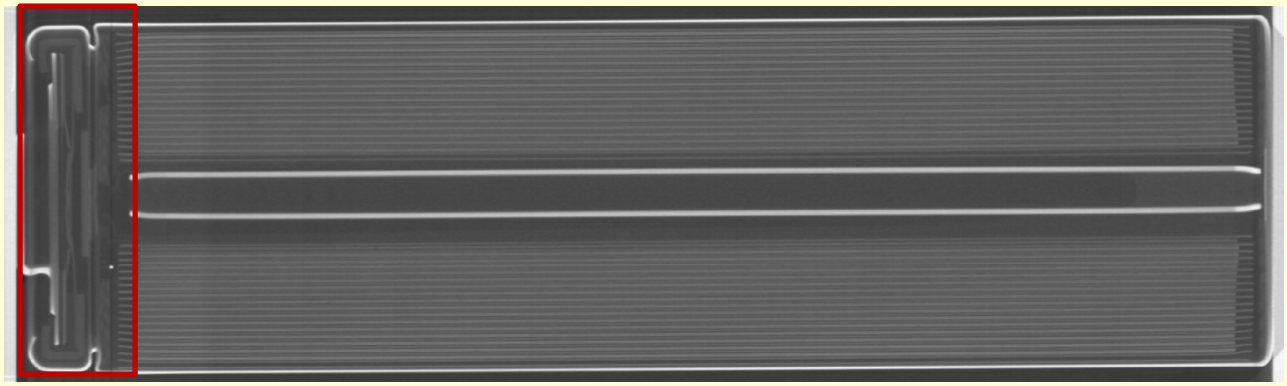


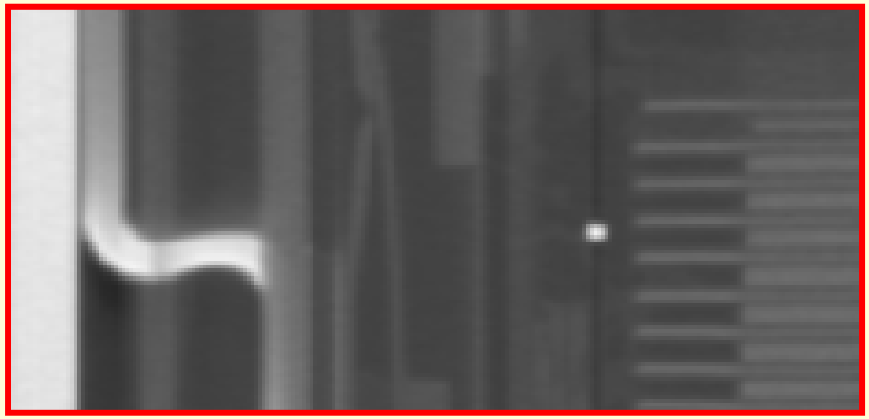


LV Cells: Contamination at Cell Cap

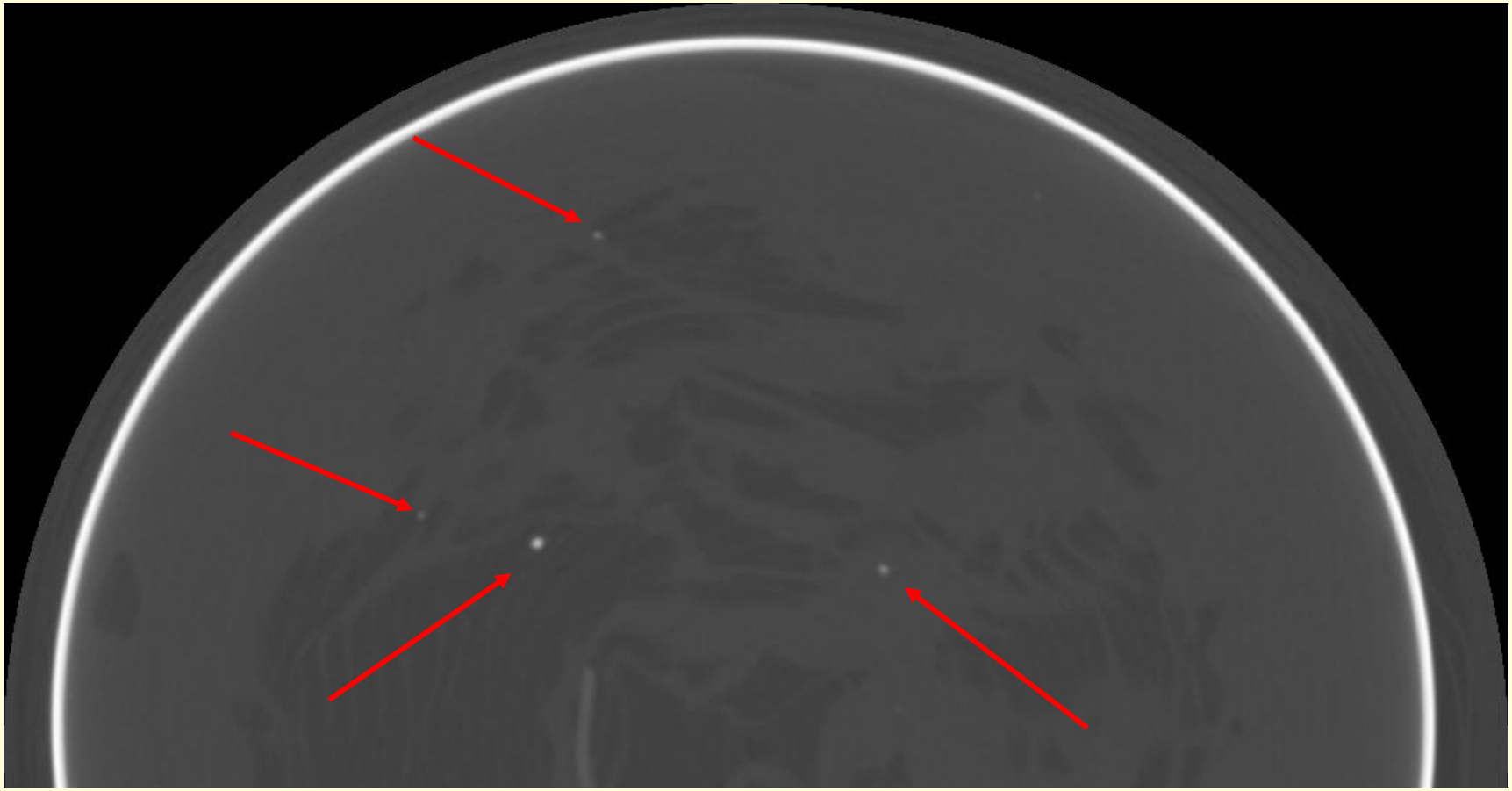


- High density particle near cell cap – possibly a detached burr or weld spatter



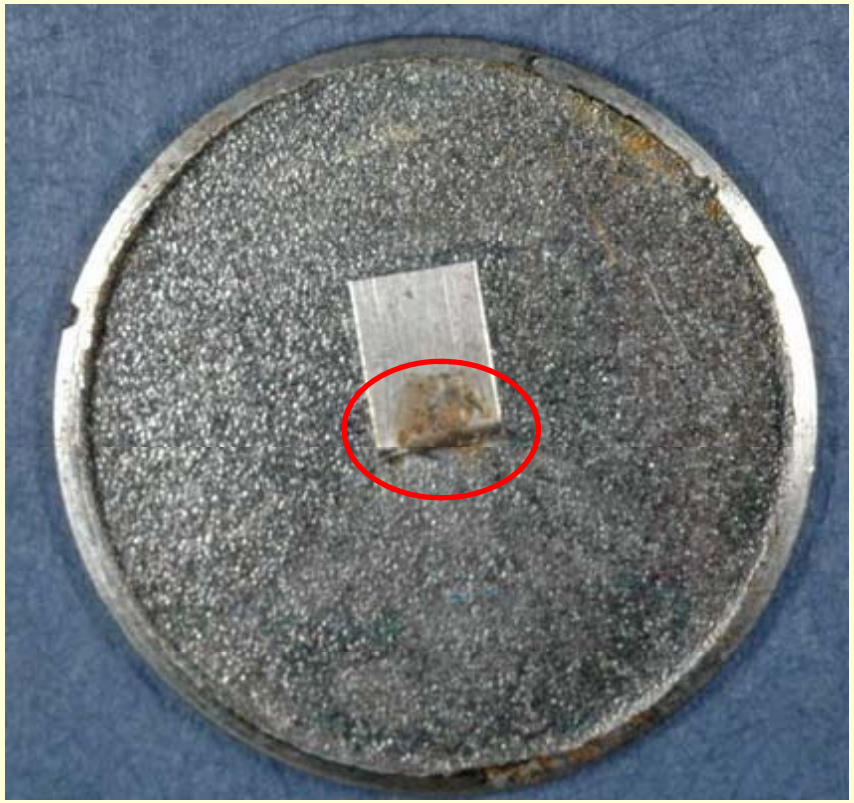


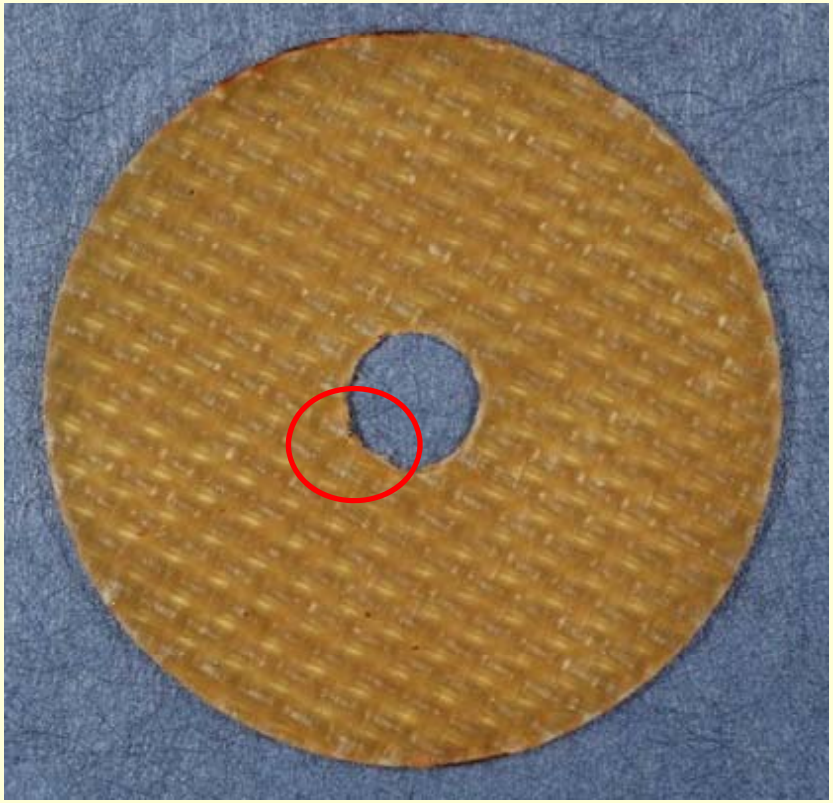
LV Cells: Contamination at Cell Cap



LV Cells: DPA of Cell Base

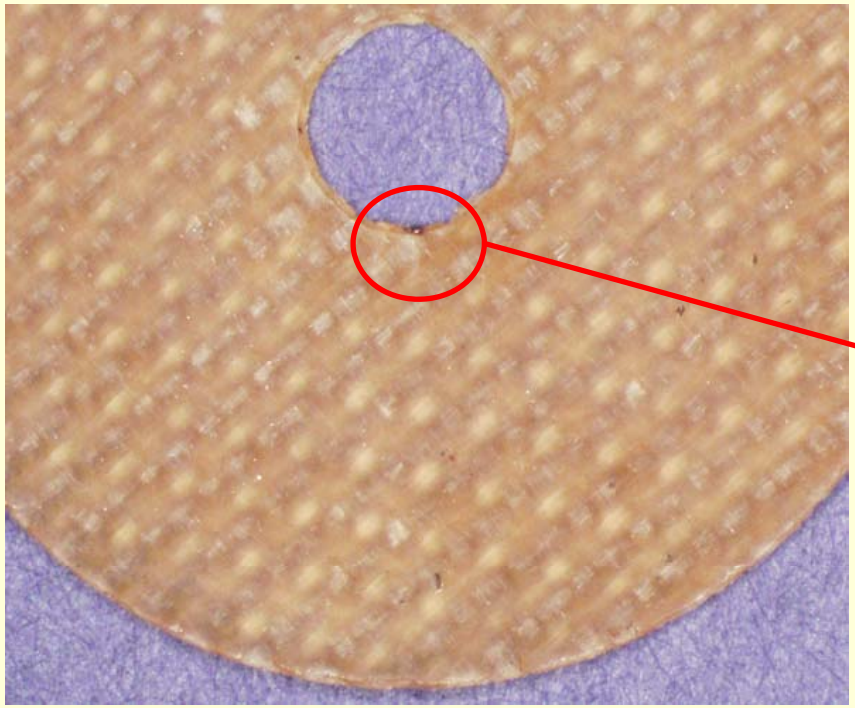
- Traces of the solder were found on the insulator at several locations
- Locations coincide with tab weld location on the bottom cap





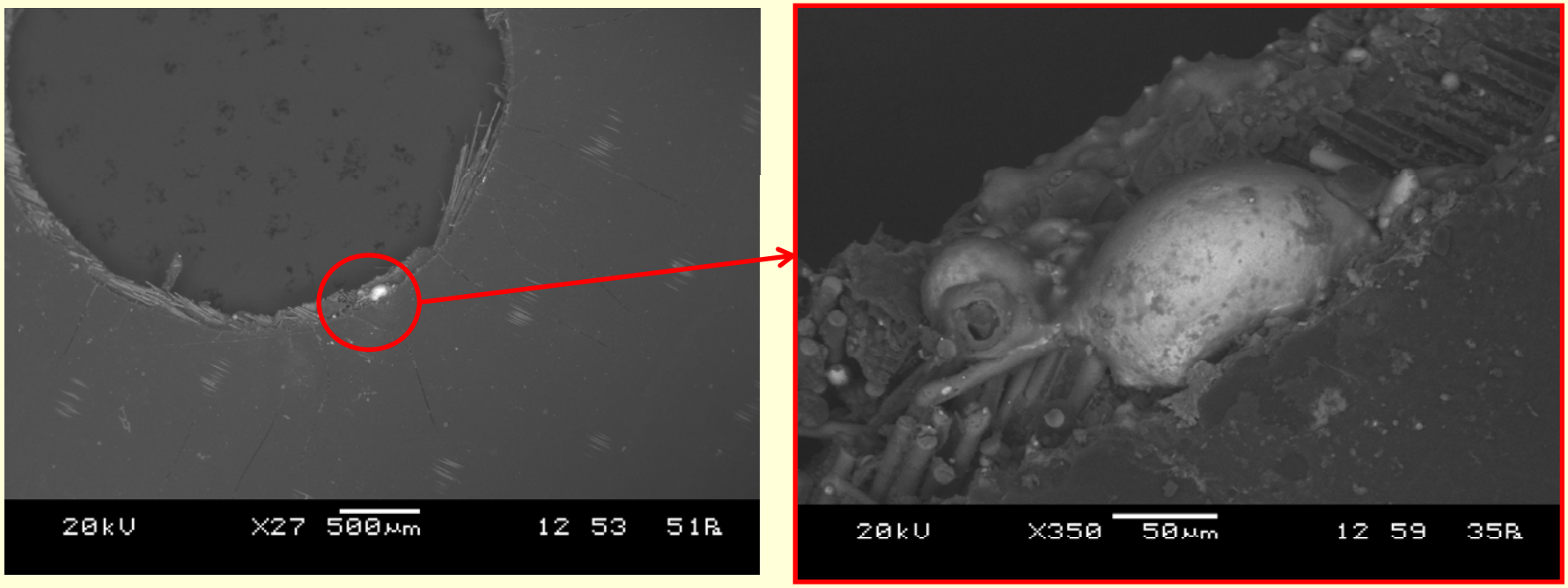
LV Cells: DPA of Cell Base

- Solder trace seen on the inner edge of the insulator surface - could be the result of weld splatter during the nickel tab welding process



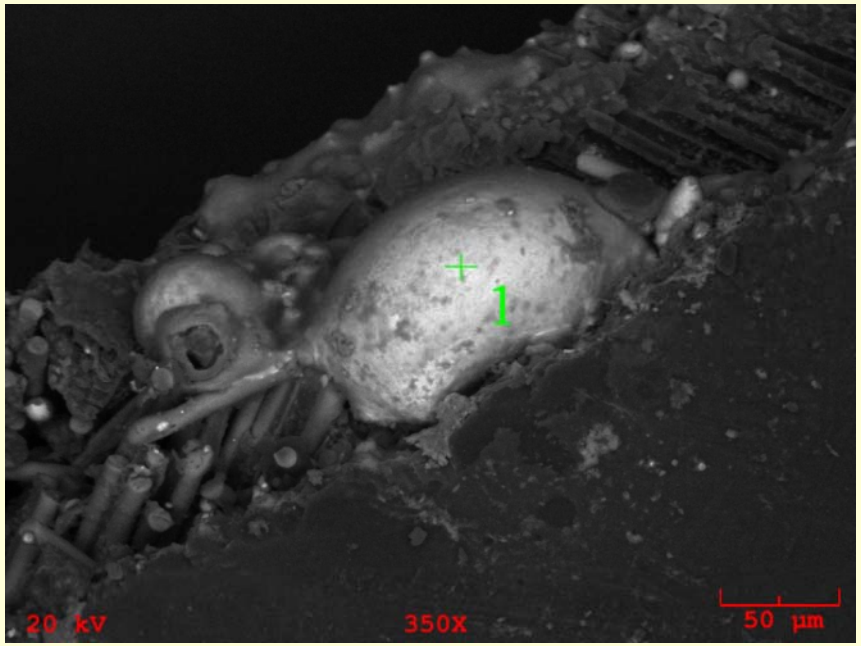
LV Cells: DPA of Cell Base

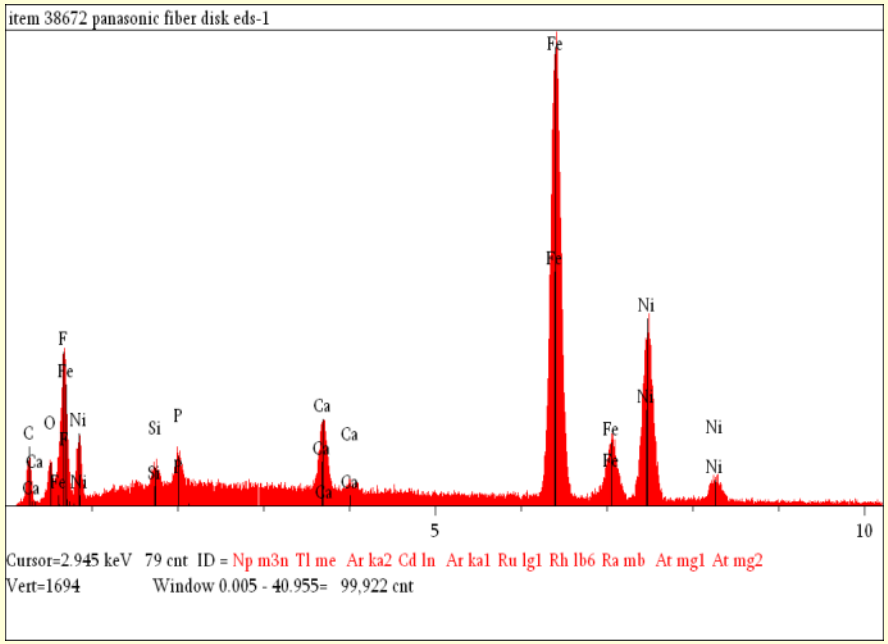
- SEM of insulator shows the presence of solder ball likely from the tab welding process



LV Cells: DPA of Cell Base

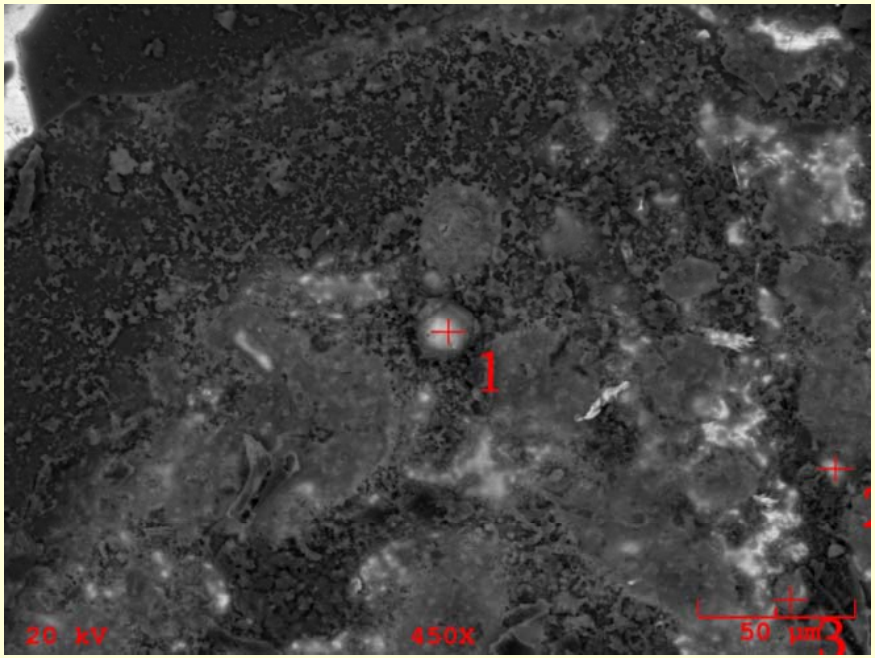
- EDS of solder ball indicates a composition of iron and nickel

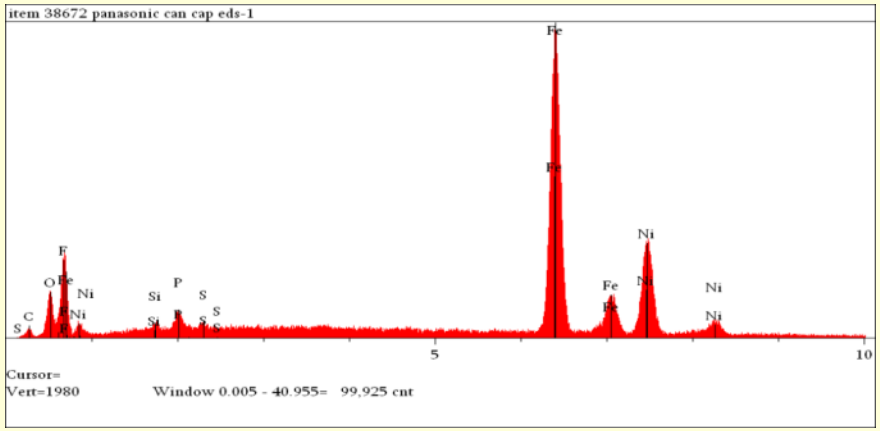


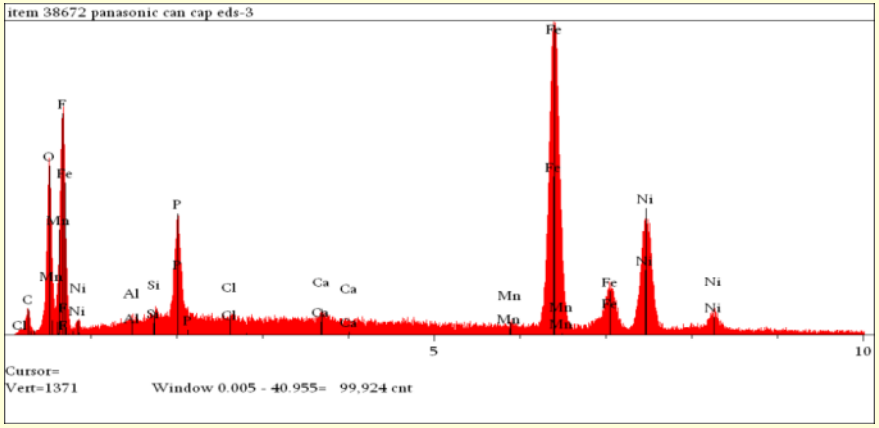


LV Cells: DPA of Cell Base

- EDS of the bottom cap shows the presence of circular solder ball similar to that seen on the insulator

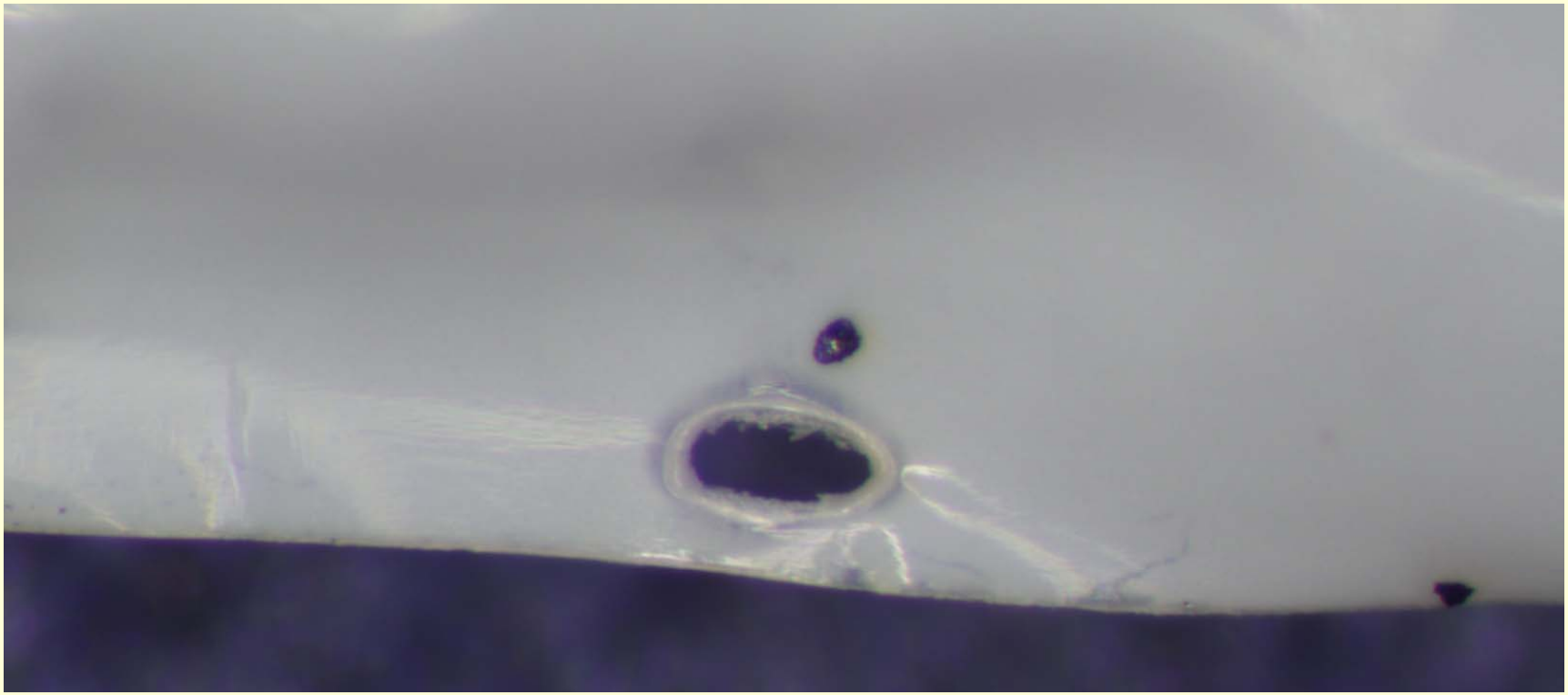






LV Cells: Contamination at Cell Cap

- Observed holes on separator edge consistent with melting on contact with hot weld spatter

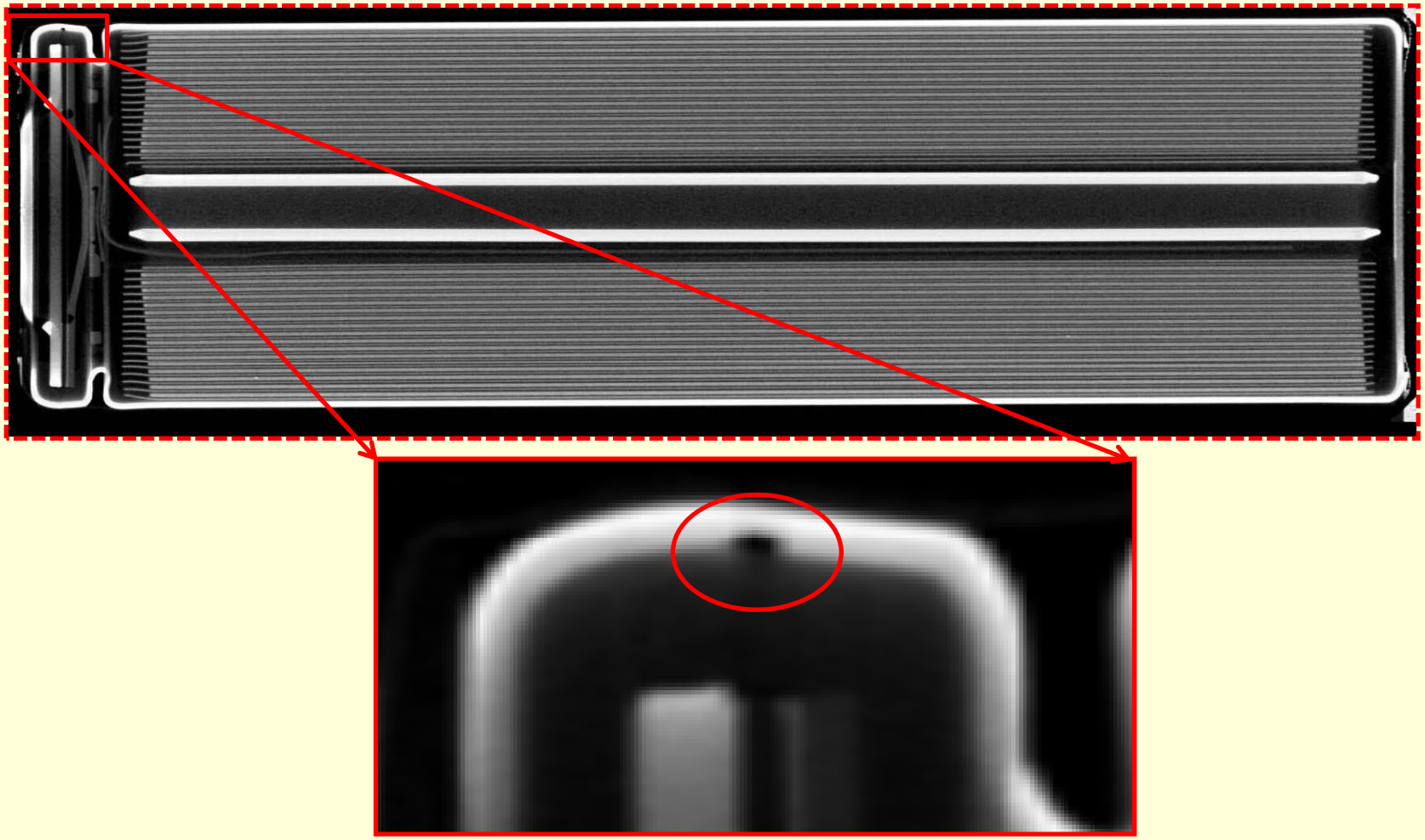


Conclusions – LV Cells

- Weld spatter resulting in metallic contamination of cell interior
- Metallic contamination has been implicated as the cause of numerous cell internal faults leading to cell thermal runaway
- Per NASA, this cell lot was disqualified

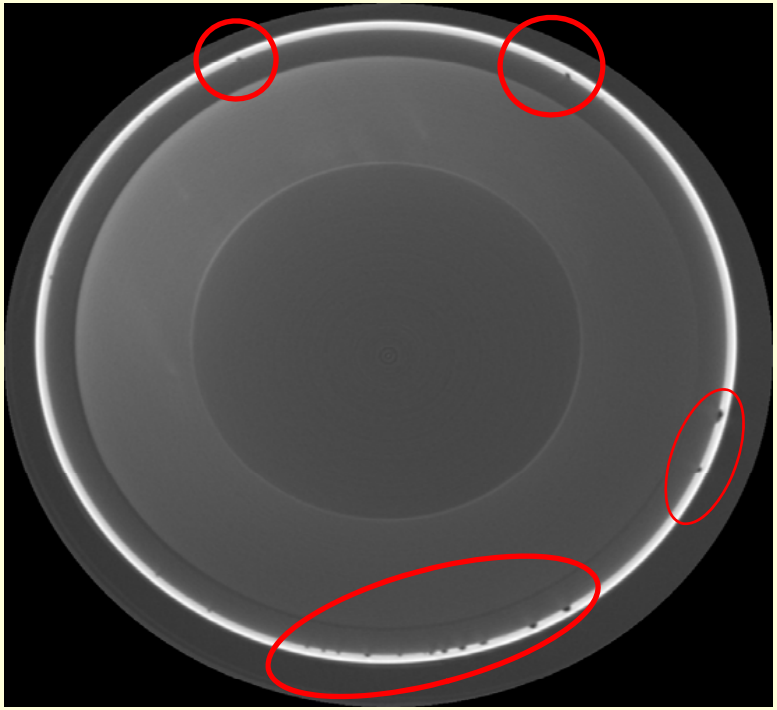
MJ Cells: Cap Corrosion

MJ Cells: Evidence of Corrosion



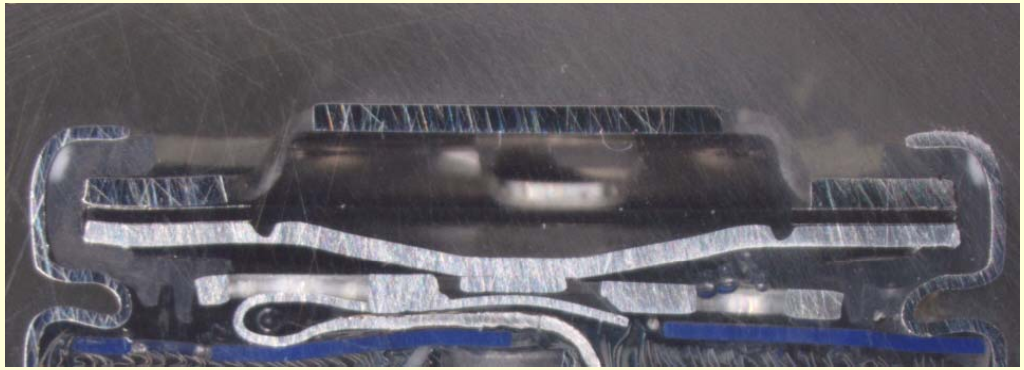
MJ Cells: Metallurgical Examination

- CT scan revealed small pits along the circumference of the cell's cap (circled)
- The seal was visually examined before being removed
- The interior surface of the cap's circumference was examined via stereo and scanning electron microscopes
- A metallographic cross section was prepared through the center of several pits

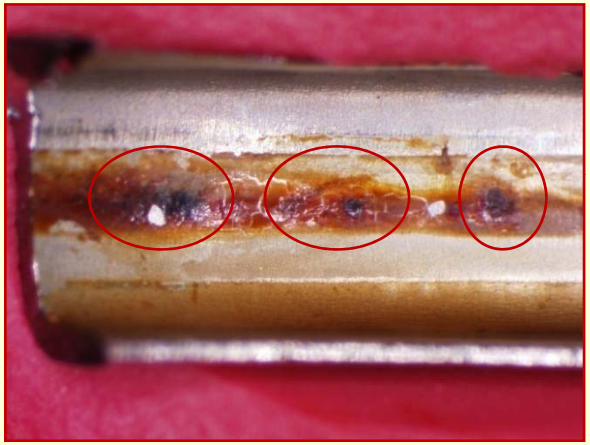


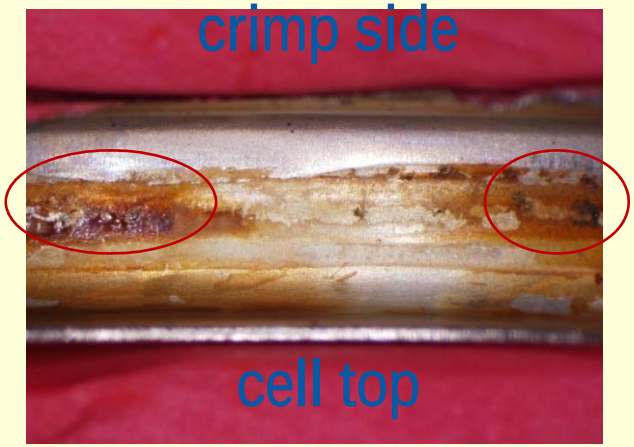
MJ Cells: Sectioning

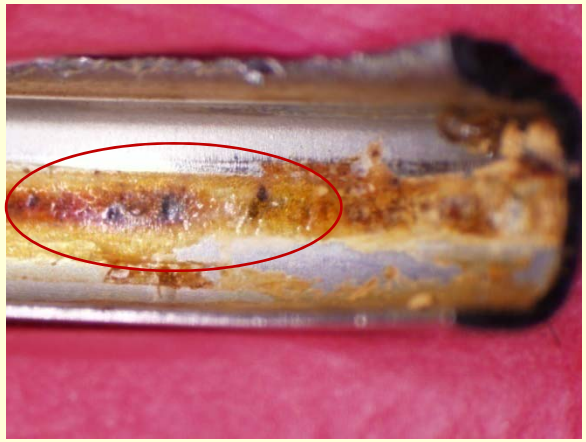
- In order to remove the seal and adhesive, the cap was sectioned across the length



MJ Cells: Prior to Cleaning

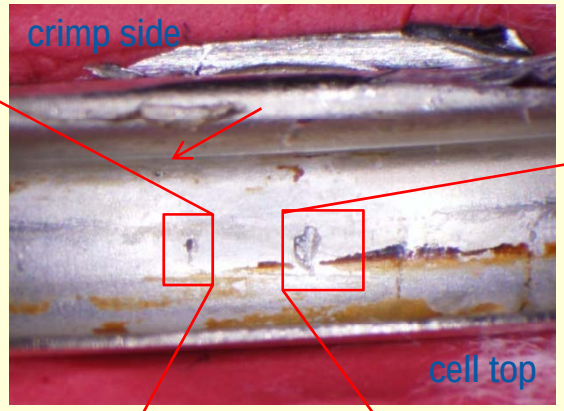






- Several areas of dark corrosion product (circled), covering pits, were seen along the interior surface of the cap's circumference
  - These areas were located about midway between the crimp and the cap top

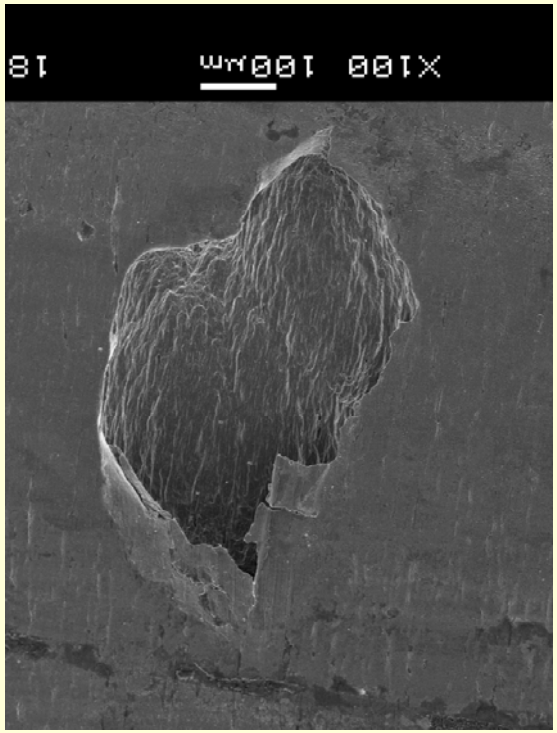
MJ Cells: After Cleaning



Some surface roughness, likely the precursors to pitting, was also seen on the interior surface (circled).

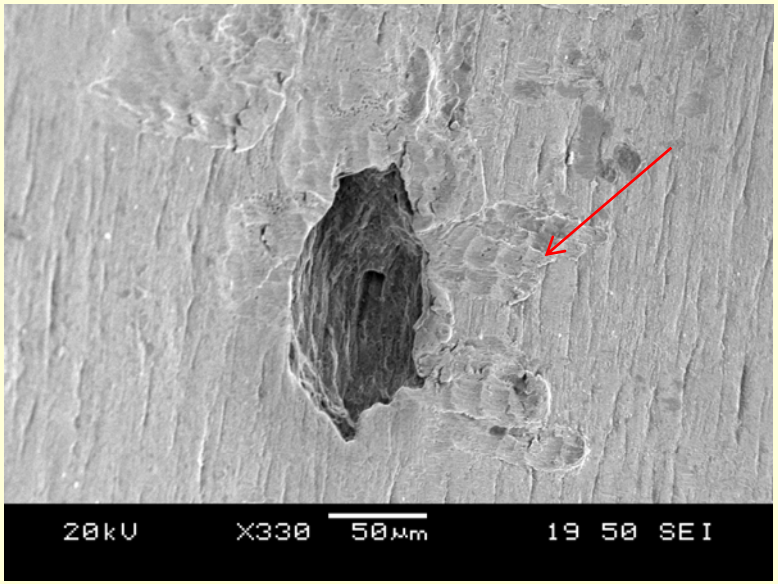
- After the electrolyte and corrosion product were removed, pits of varying sizes and depths could be seen
- Most pits were located approximately midway between the cap top and the crimp, though some were located closer to the crimp area (arrow)

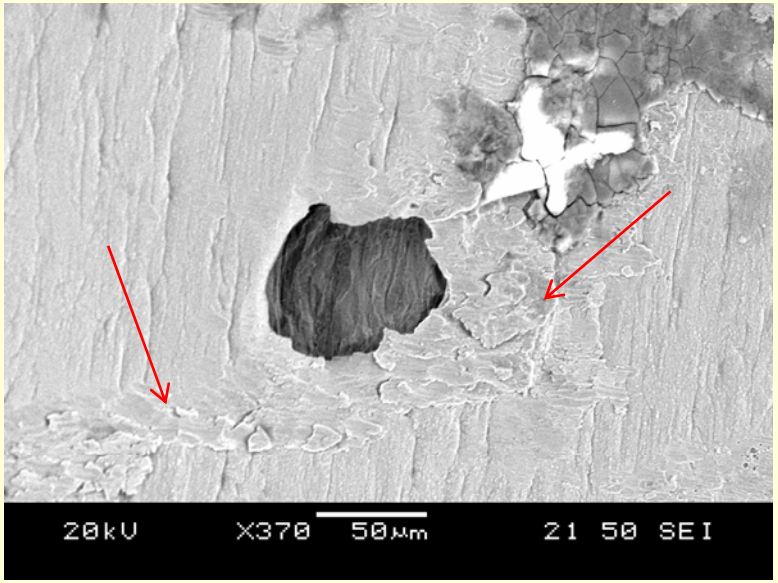
MJ Cells: Pit Morphology



- Pit surfaces are consistent with pitting corrosion
- The iron substrate corroded below the nickel coating, leaving the thin coating partially covering the hole

MJ Cells: Other Surface Features





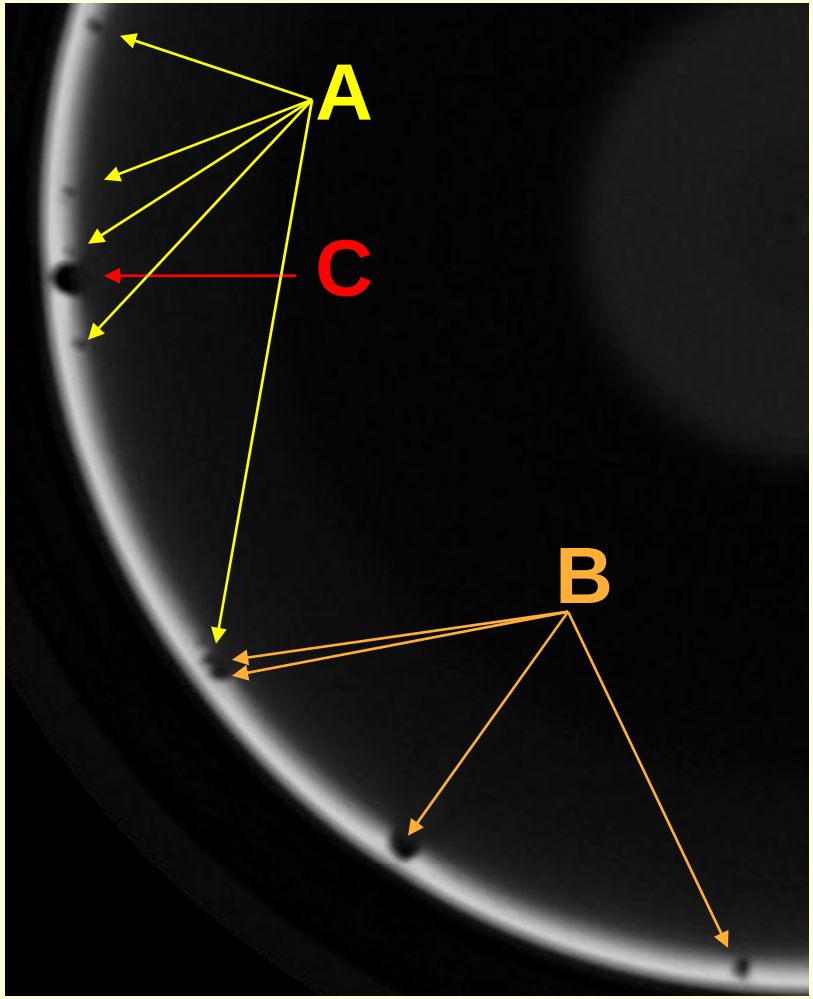
- Rub or scrape marks (arrows) were seen adjacent to several, but not all, pits
  - This may indicate the coating was broken or damaged, exposing the substrate material

MJ Cells: Follow-Up Examination

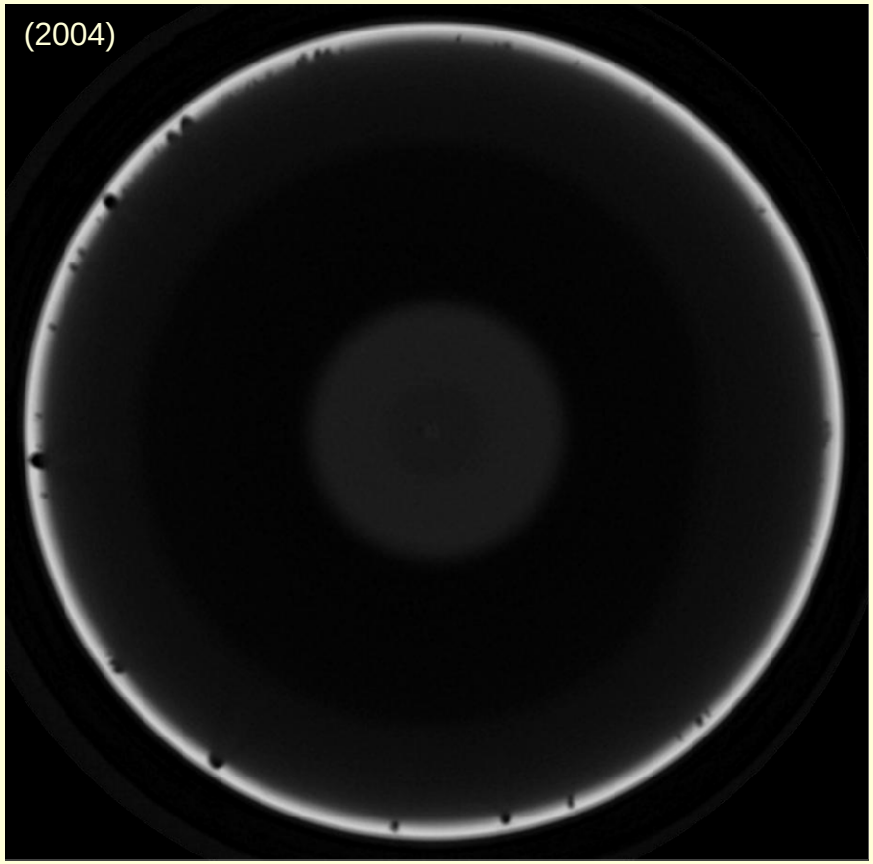
- Additional cells from different date codes (older) were examined non-destructively (CT scan) to get an understanding of the corrosion progression in the cells
- Question: will corrosion in this area lead to leakage of the cells within their expected lifetime?

MJ Cells: Assessment of Corrosion

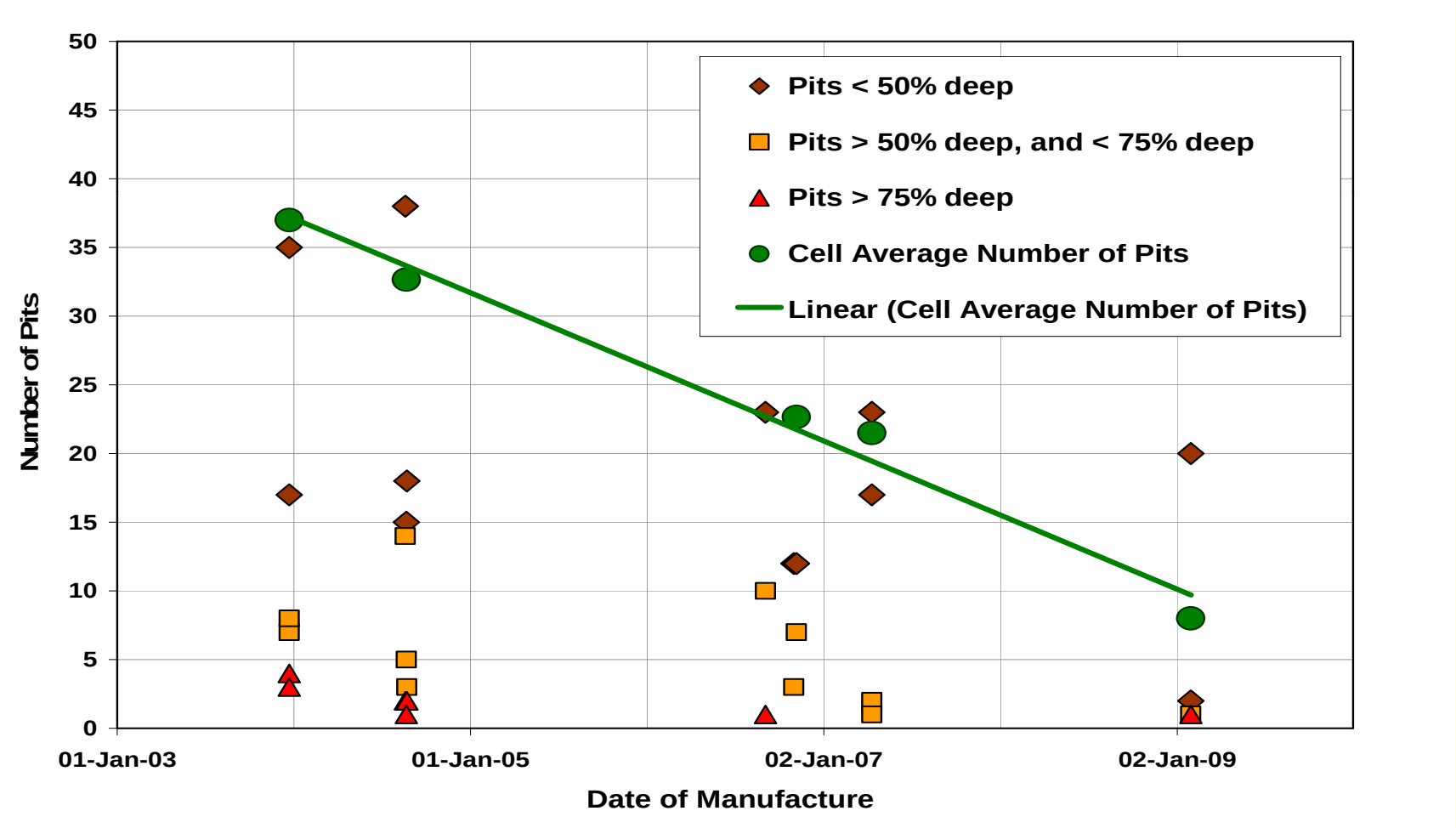
- Examined cap cross section images with deepest pitting (possible due to co-planar nature of pitting) to count and classify pits
- Classified pits by depth of penetration (visual analysis)
  - Type A penetrates less than 50% of case
  - Type B penetrates between 50% and 75% of the case
  - Type C penetrates more than 75% of the case



MJ Cells: Pitting Comparison



MJ Cells: Assessment of Corrosion



MJ Cells: Conclusions

- Number of observed pits is higher (on average) in older cells
- Number of very deep pits is higher in older cells
  - Pits develop a semi-circular shape
  - Deeper pits generally tend to be wider than shallower pits
  - Total pit volume is larger in older cells
- Despite deep pitting observed in CT scans no evidence of through-holes or electrolyte leakage has been observed
- The pits are all located adjacent to the cell seal which provides a barrier to leakage
- The LLB design encapsulates the cell cap of all cells providing added protection against leakage
- The manufacturer was contacted,
  - Aware the problem exists
  - No reported associated cell failures
- Scanned cells have been retained for future monitoring by CT scanning

General Conclusions

- Outlying cells identified by NASA from each manufacturer contained anomalies
- CT scanning
  - Was effective in detecting metallic contaminants, including small, loose contaminants that were difficult to collect on cell opening
  - Was effective in detecting and monitoring the corrosion progression of the cell case
- Cell DPA
  - Confirmed CT scan findings
  - Allowed examination of morphology, and composition of various anomalies detected in CT scans

Acknowledgements

- Exponent would like to thank NASA for the opportunity to work on this project, and in particular:
  - Eric Darcy
  - Judith Jeevarajan
  - Samuel Russell
  - John Weintritt (Jacobs Technology)

Questions?