
# Construction Analysis of Plastic Encapsulated Microcircuits Containing Copper Bond Wire

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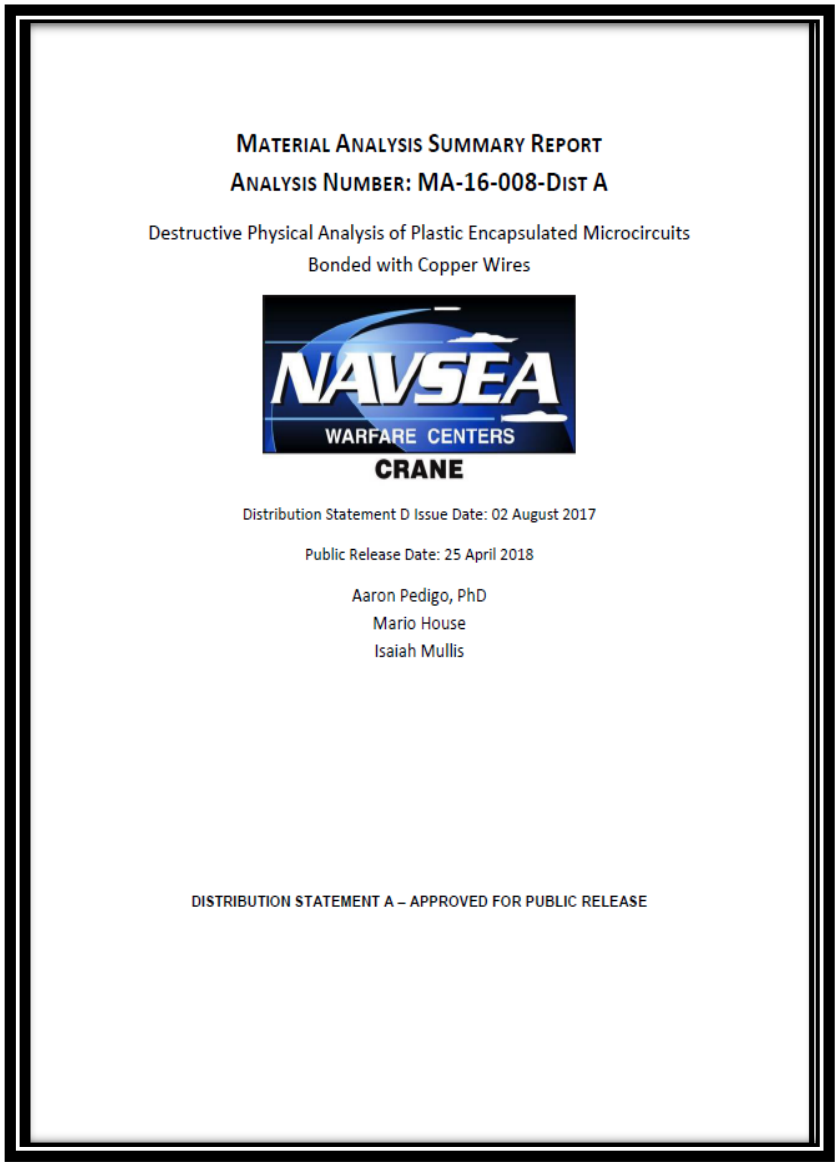
# Construction Analysis of Cu-PEM's at NSWC Crane

- NSWC Crane has been developing processes and performing construction analyses on plastic encapsulated microcircuits containing copper bond wires (Cu-PEM's) since 2015
- NSWC Crane has independently shown correlation between Cu-PEM specific process indictors discovered during DPA and failures modes observed during wire pull
  - Evaluated over 40 unique part numbers including a range in manufacturer, package style, and part functionality
  - Summary report available for distribution in both Dist A (public release) and Dist D (DoD and DoD contractors)



MATERIAL ANALYSIS SUMMARY REPORT

ANALYSIS NUMBER: MA-16-008-DIST A

Destructive Physical Analysis of Plastic Encapsulated Microcircuits Bonded with Copper Wires

NAVSEA WARFARE CENTERS CRANE

Distribution Statement D Issue Date: 02 August 2017

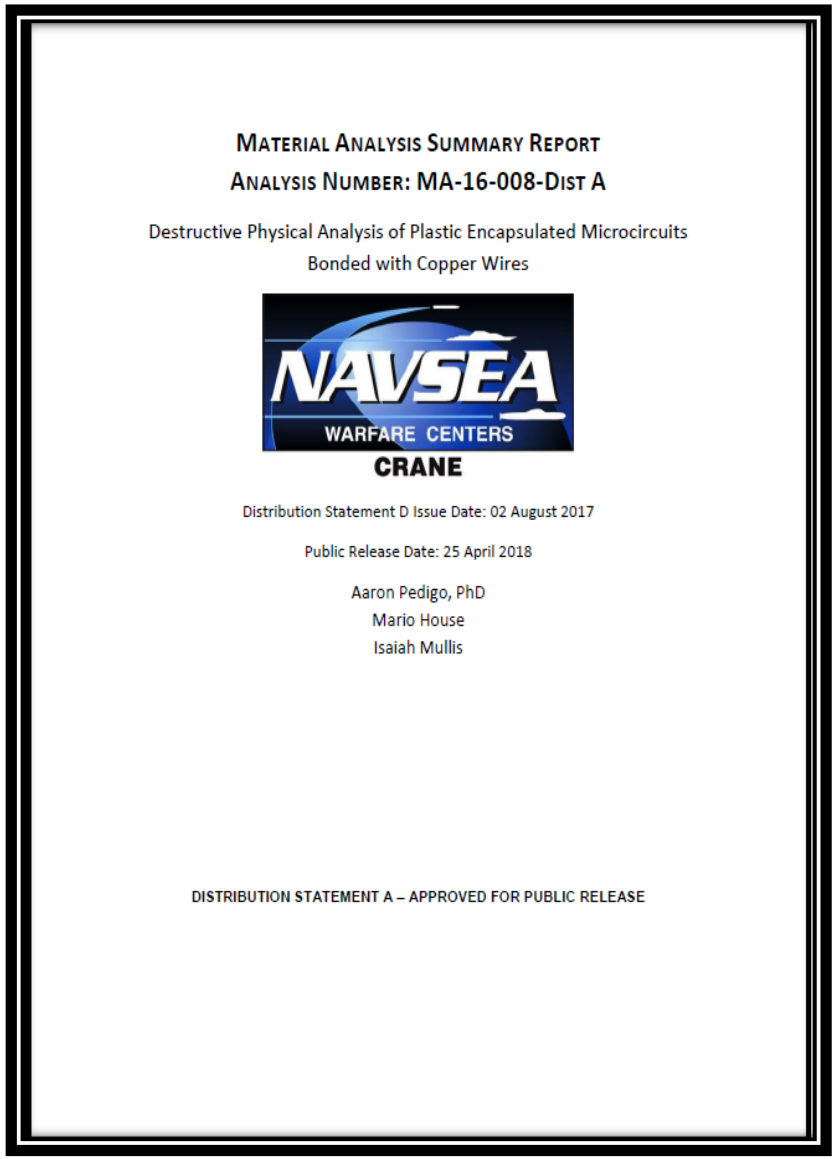
Public Release Date: 25 April 2018

Aaron Pedigo, PhD
Mario House
Isaiah Mullis

DISTRIBUTION STATEMENT A – APPROVED FOR PUBLIC RELEASE

# Construction Analysis of Cu-PEM's at NSWC Crane

- Fluid transition dates
  - Manufacturers estimate transition dates on PCN's but actual transition may occur months to years afterwards
  - Manufacturers reserve the right to transition between copper and gold
- Non-destructive screening
  - A qualified x-ray technician can discern the difference between gold and copper bond wires via real-time x-ray
- Multiple detection techniques for common process indicators
  - Correlation between dielectric cracking in cross-section, wire pull failure mode, and force to failure
  - Correlation between bond floor morphology, wire pull failure mode, and force to failure
- 17 of 41 parts contained processes indicators not typically observed on PEM's with Au wire bonds
  - Includes direct comparison of same part numbers in gold and copper



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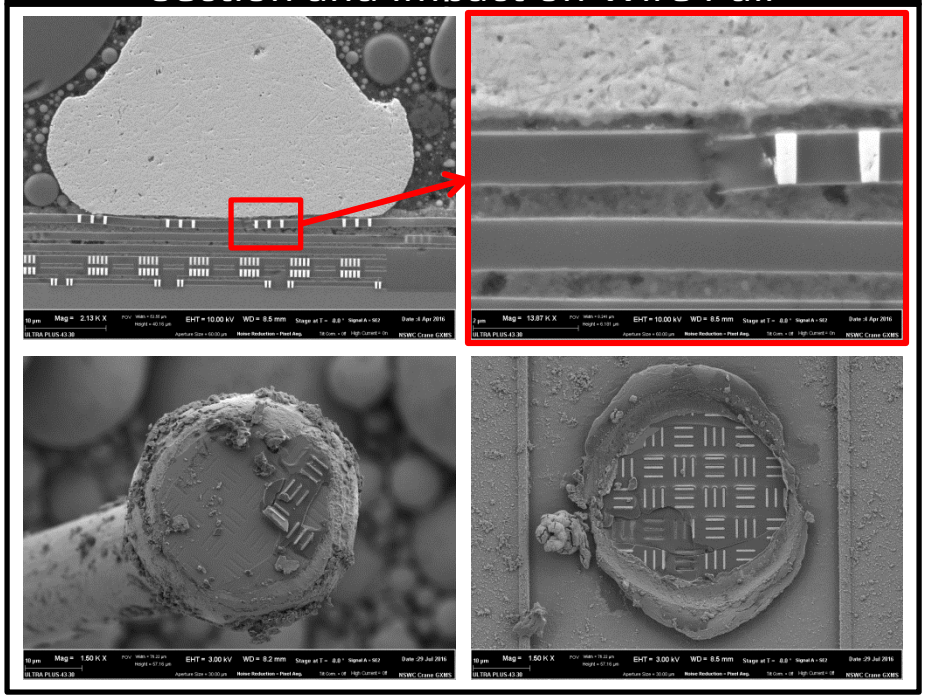
# Examples of Findings

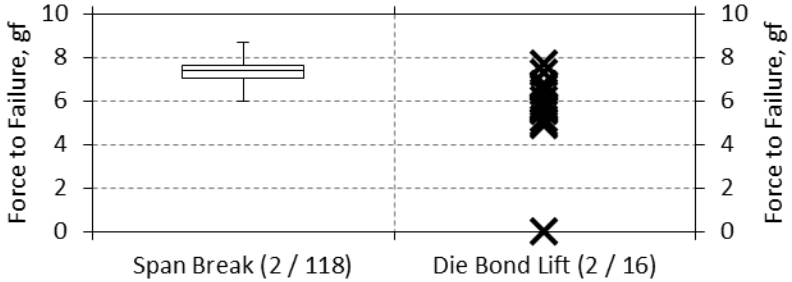
- All the following examples were performed at NSWC Crane:
  - All parts tested in the as-received condition
    - Smaller parts were hand soldered to substrates
  - All parts were chemically decapsulated, exposing the entire bond wire
  - All wire pulls were performed with the hook located between the apex and the ball (near center)

# Significant Findings:
## *Example 1: Cracked Dielectric*

- MA-16-008-01 (Crane Analysis #)
  - Low-cost commercial FPGA
  - Significant dielectric cracking observed in cross section
  - 16 of 134 (12%) of wires pulled failed via die bond lift
  - 20% reduction in pull strength correlated to die bond lift failure mode, including one <1g force to failure (shock and vibe concern)
- Manufacturer contacted concerning results. Per manufacturer:
  - Part is intendent to be a low-cost commercial FPGA
  - Manufacturer maintains a gold-wire alternative for automotive industry to meet the automotive reliability requirements

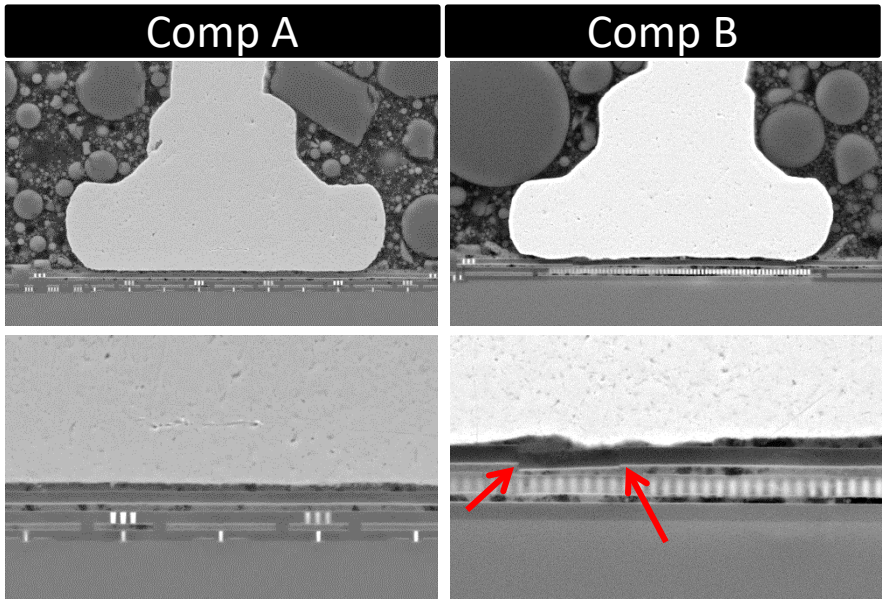
Dielectric Cracking in Observed in Cross Section and Impact on Wire Pull

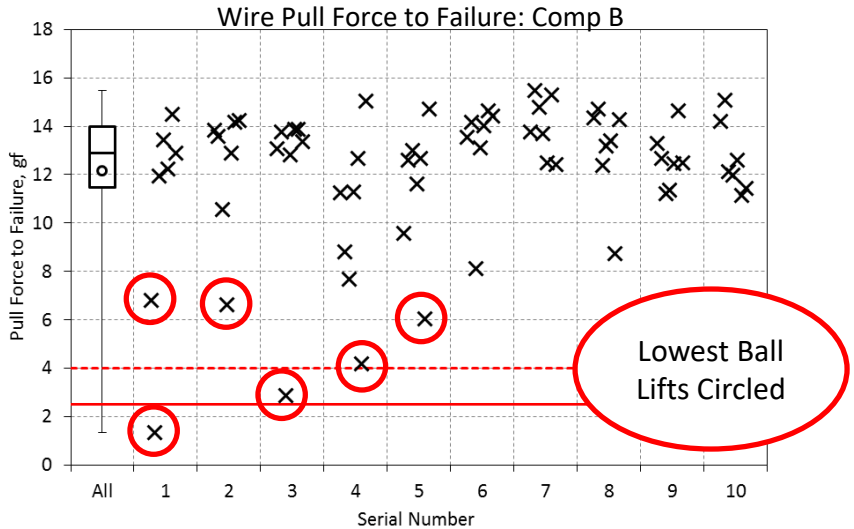




# Significant Findings:
## *Example 2: Manufacturer Comparison*

- Comparison of components MA-16-008-02 (Comp A) and MA-16-008-25 (Comp B) from same manufacturer
  - Both use palladium coated copper wire
  - Both bonded to aluminum with intermetal dielectric
  - Comp A had 'ideal' ball bond morphology without dielectric cracking; comp B had an uneven bond floor with dielectric cracking
  - Comp B exhibited multiple die bond lifts; comp A did had none
- Use of palladium coated copper does not guarantee manufacturing success
- Correlation shown between bond morphology and wire pull force to failure/failure mode for other components, including bonds to Al on Si, Al on W on Si, and Al on $SiO_2$ to Si
  - Not a function of manufacturer (i.e. manufacturer and past experience cannot necessarily be used a predictor of quality)

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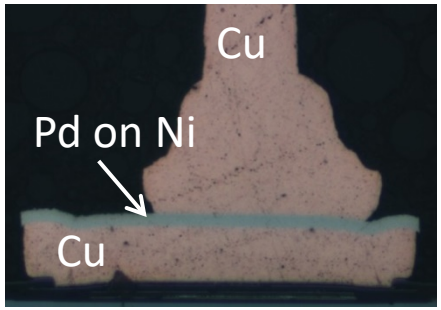
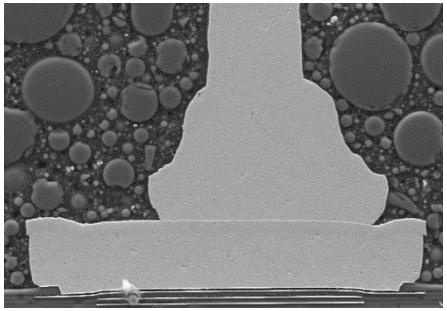
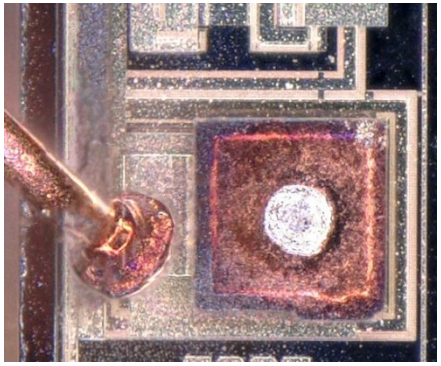
# Significant Findings:

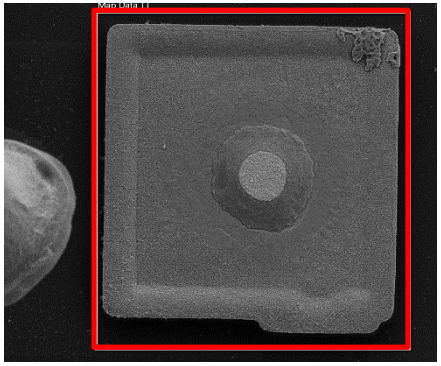
## *Example 3: Die Bond Pad Adaptation for Copper Wire*

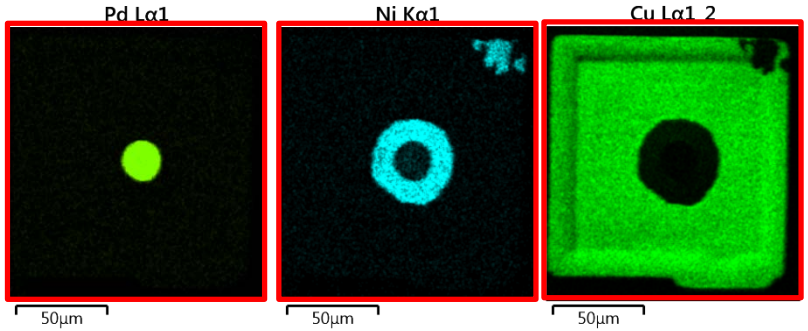
- MA-16-008-14
  - Thick copper pad grown on die, finished with palladium on nickel
  - Thicker pad would accommodate higher bonding forces without damaging underlying silicon
- Unexpected failure modes related to die bond lifts were observed including:
  - **<u>Incomplete bonding between ball and pad at the bond center</u>**
  - Incomplete bonding between the ball and pad along an axis
  - Lifting of the nickel plating from the copper pad
- Adapting the die for copper bond wire does not guarantee success and may introduce new failure modes









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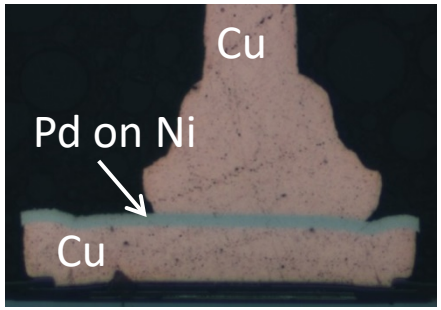


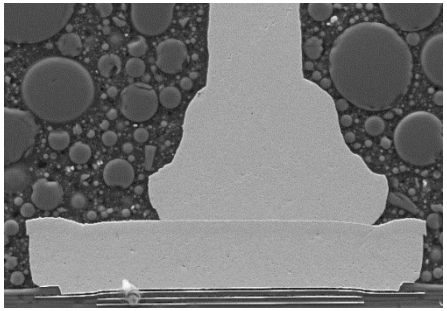

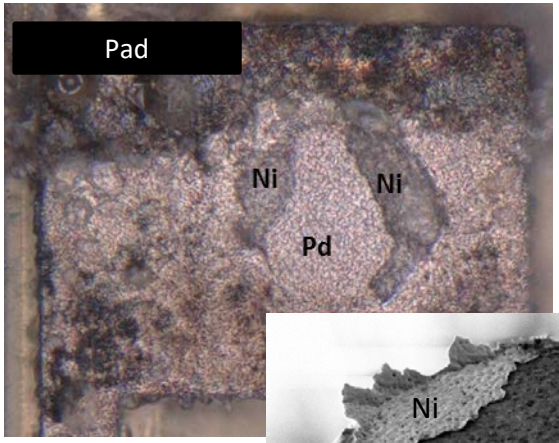


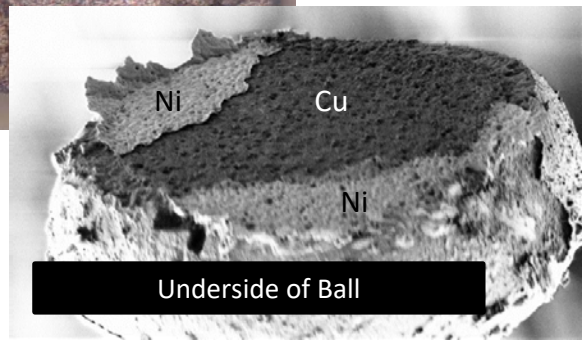

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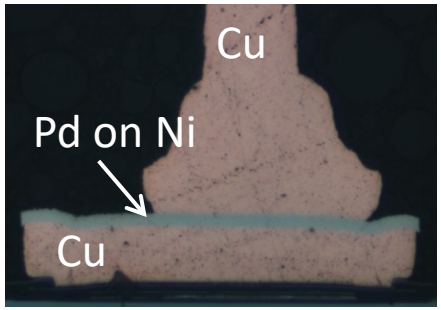
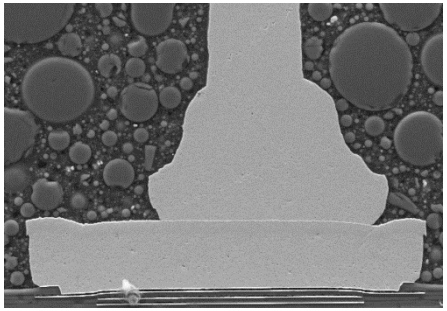
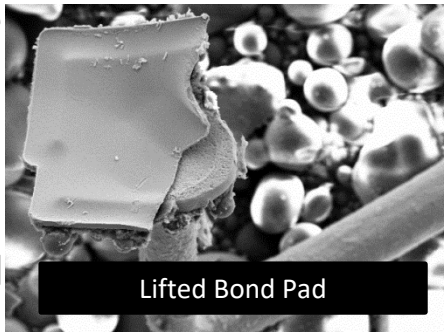
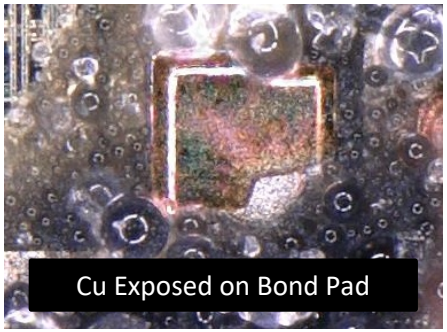
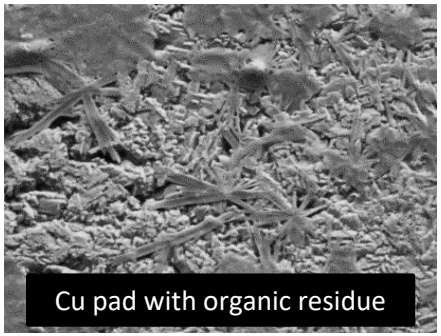
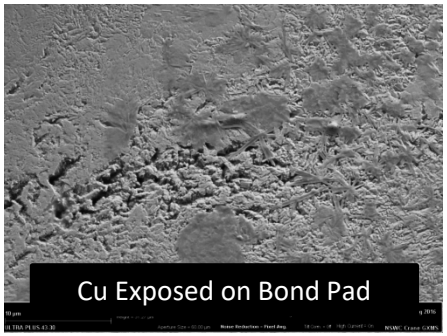




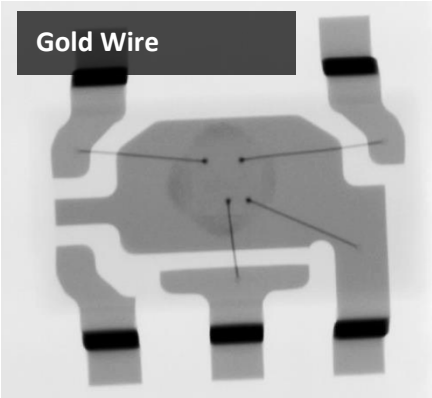



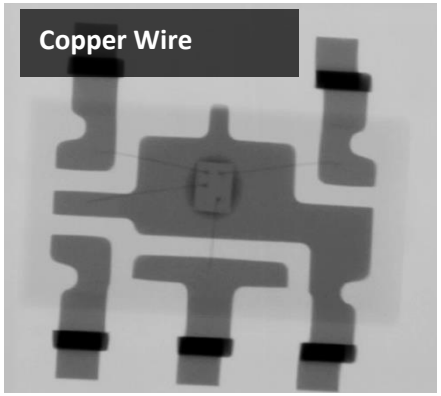



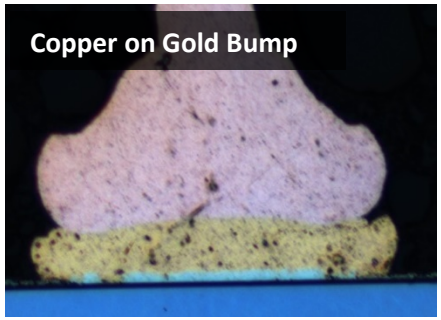



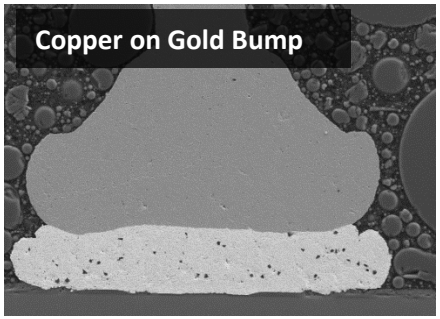
# Other Significant Findings Summary

- The transition date to copper bond wires cannot be determined from manufacturer's product change notifications
- It cannot be assumed that once a manufacturer transitions to copper bond wires, future productions runs will use copper wires or that that determination that a date code with gold wires exonerates previous date codes as having copper wire
- Additional changes to the packaging may occur with the transition to copper bond wires
- X-ray inspection is an effective technique to non-destructively determine if a component has copper or gold bond wires
- The current state of the copper wire bonding process results in manufacturing process indicators and defects not typically seen from the gold wire bonding process
- Construction analysis is capable of detecting process indicators specific to the copper wire bonding process including defects at the die and lead frame bonds





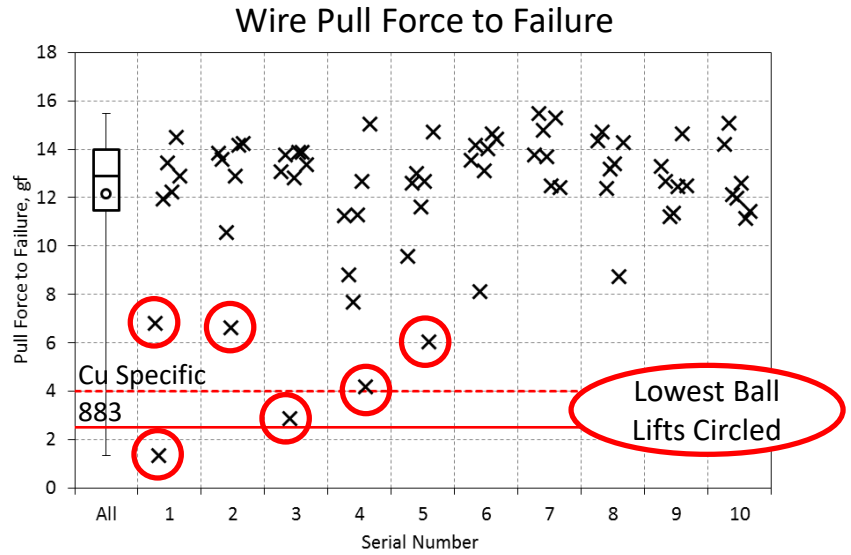
# Difficulties in Application

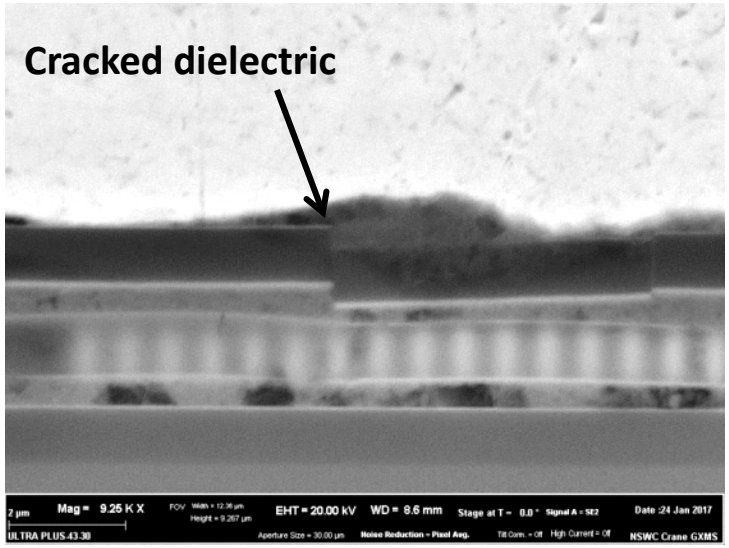
- Accessing copper wire bond quality requires looking at inspection criteria on the aggregate
  - Enough samples to establish confidence in coverage of the processing margins
    - Supported by AEC-Q-006 & IBM 57G9271
    - Requires testing more parts than may be used in the production run
  - Inspection criteria becomes weighted decision points instead of black and white pass/fail criteria though some hard fail criteria remains
    - Supported by AEC-Q-006 & IBM 57G9271
    - Requires back-and-forth between government authority and the contractor
    - Requires environmental stress data to drawdown risk
- How bad is bad enough when weighing cost and schedule?

# Difficulties in Application

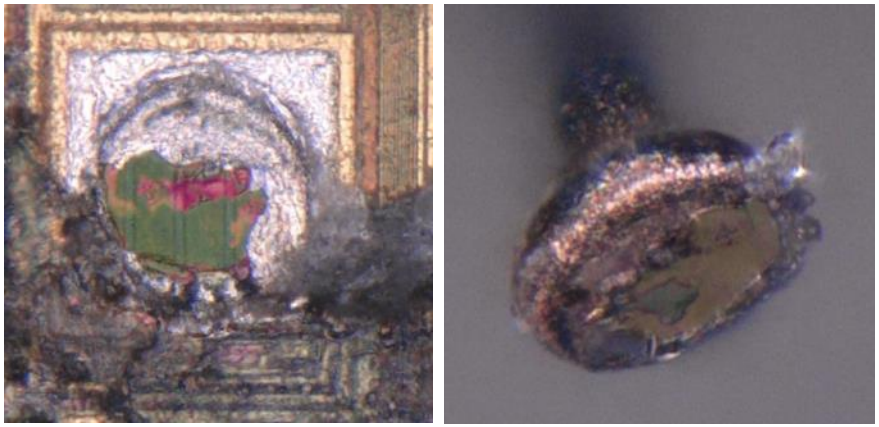
## Ex. Cracked dielectric with ball lifts

- Cu on Al-IMD on $SiO_2$ on Si
  - Cracked dielectric observed in cross section and wire pull (rejection criteria)
  - Standard Deviation > 10% average (rejection criteria)
  - 2x failure to meet enhanced pull criteria
  - 1x failure to meet 883 criteria
- Should this lot be rejected?
  - What if SN1 and SN3 weren't tested?




Ball bond lift with cracked dielectric: Force to failure, 1.3gf.

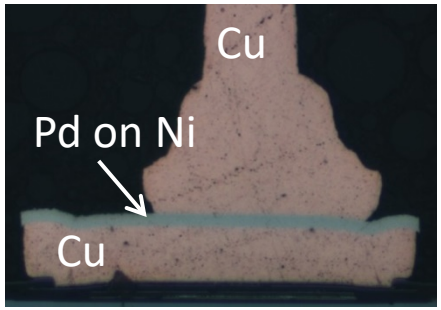


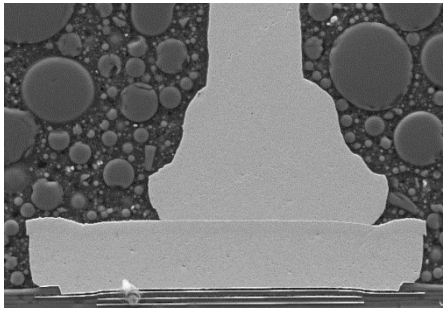
Distribution Statement A: Approved For Public Release

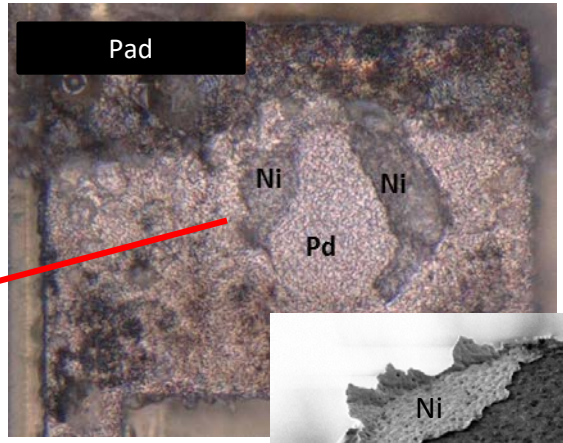
# Difficulties in Application

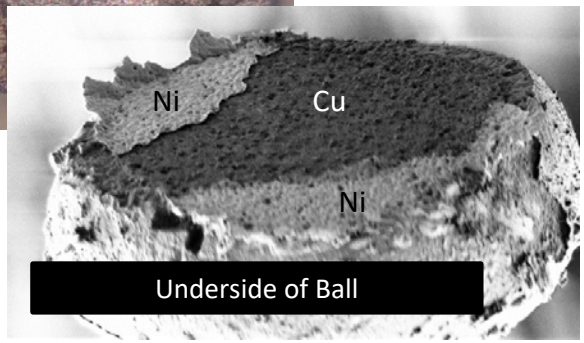
## Ex. Non-standard bond pad with ball lift

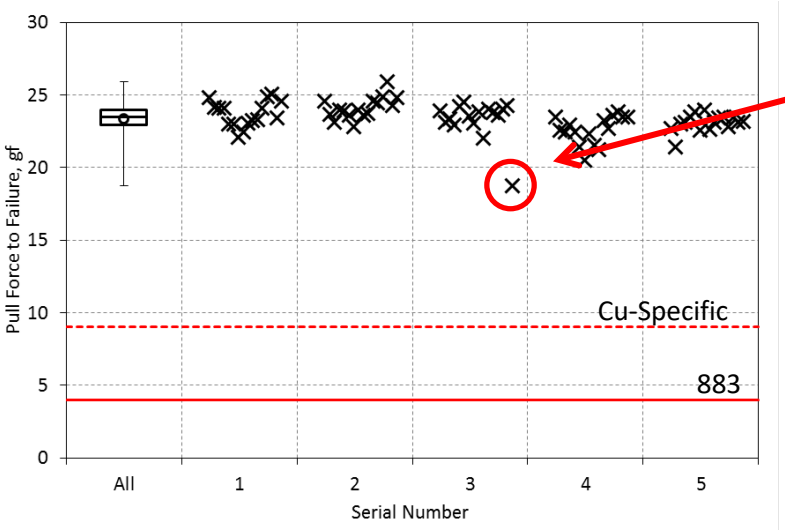
- Cu on Pd on Ni
  - No IMC formation between Cu and Ni (cannot inspect to IMC criteria)
  - Ball lift shows an effective bonding area of 55% (rejection criteria: <75%)
  - Ball lifted (rejection criteria: any failure mode but span) but <u>exceeded minimum enhanced pull strength by over 2x</u>
- Should this lot be rejected?





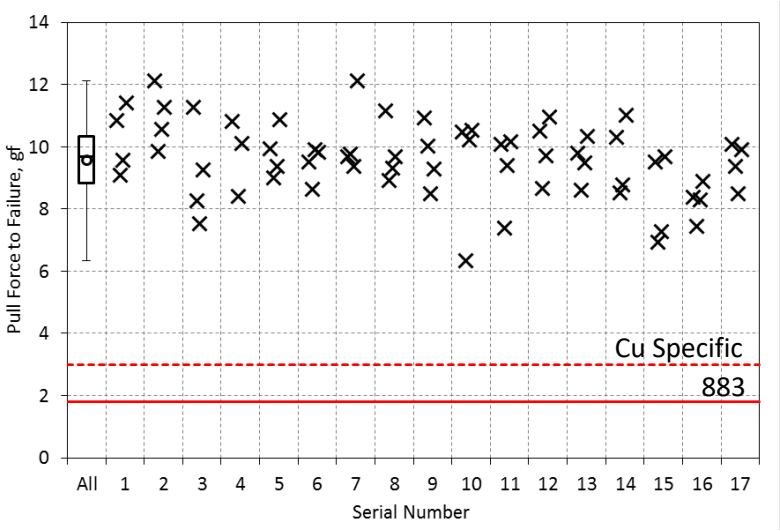



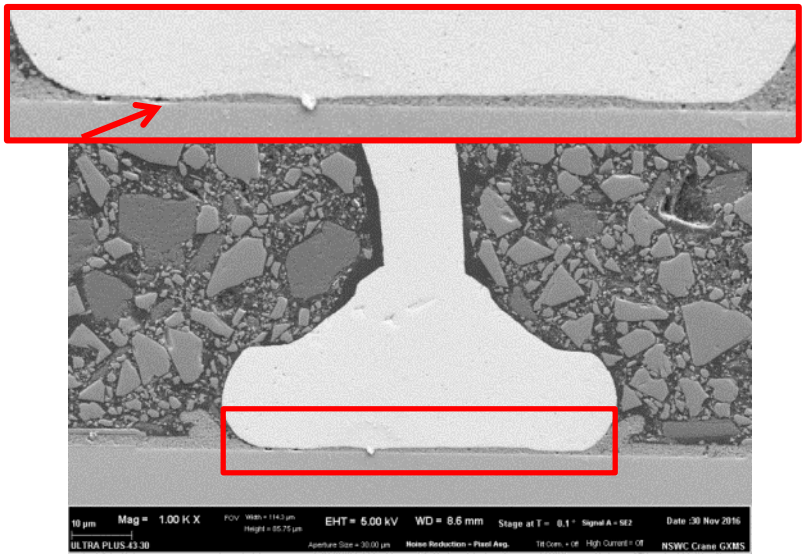



# Difficulties in Application

## Ex. Less than ideal ball bond formation and bonding

- Cu on Al on Si
  - Aluminum thickness reduced to less than 200nm as observed in cross section, rejection criteria
  - Standard deviation exceed 10% of the average, rejection criteria
  - Non-span, ball neckdown failrue modes, rejection criteria
  - All pull forces exceed enhanced criteria by at least 2X
- Should this lot be rejected?



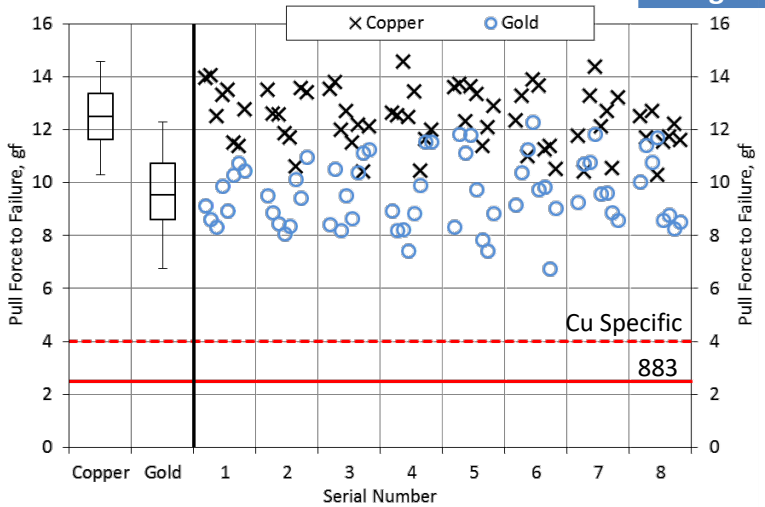

| | Frequency | Minimum, gf | Average, gf | Standard Deviation, gf |
|---|---|---|---|---|
| Overall | 67 | 6.3 | 9.6 | 1.2 |
| Ball Neckdown | 17 | 6.9 | 9.1 | 1.1 |
| Span | 50 | 6.3 | 9.8 | 1.2 |

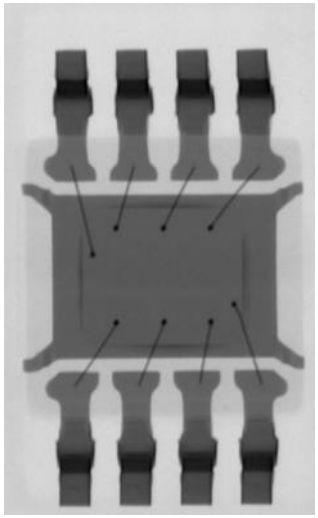
# Difficulties in Application

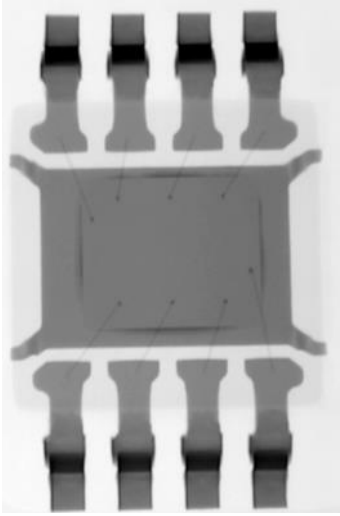
## Ex. Gold and copper comparison with non-span failure modes

- Cu vs Au Comparison
  - Ball neck and wedge neck breaks observed in both Au and Cu packages (Cu specific reject criteria)
  - All pulls (Au and Cu) exceeded enhanced pull force requirements
- Should this lot be rejected?

| | Copper: 64 Wires Pulled | | | Gold: 64 Wires Pulled | | |
|---|---|---|---|---|---|---|
| Failure Mode | Frequency | Ave, gf | Std Dev | Frequency | Ave, gf | Std Dev |
| All | -- | 12.42 | 1.09 | -- | 9.63 | 1.30 |
| Ball Neckdown | 14% | 12.78 | 0.94 | 16% | 10.18 | 1.35 |
| Span | 16% | 13.25 | 1.00 | 0% | -- | -- |
| Die Bond Lift | 0% | -- | -- | 0% | -- | -- |
| Frame Bond Lift | 0% | -- | -- | 0% | -- | -- |
| Die Metal Lift | 0% | -- | -- | 0% | -- | -- |
| Frame Metal Lift | 0% | -- | -- | 0% | -- | -- |
| Die Fracture | 0% | -- | -- | 0% | -- | -- |
| Frame Fracture | 0% | -- | -- | 0% | -- | -- |
| Wedge Neck | 70% | 12.16 | 1.05 | 84% | 9.52 | 1.28 |



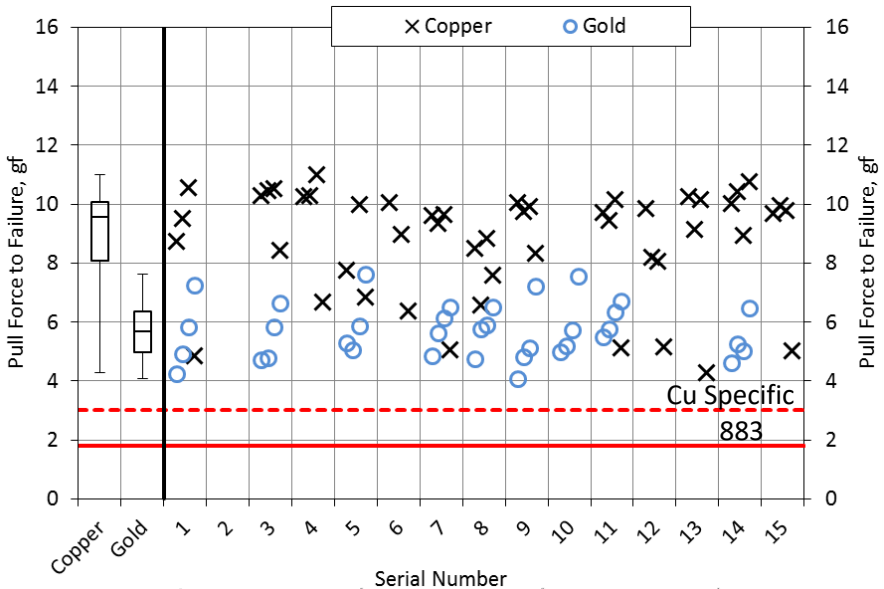



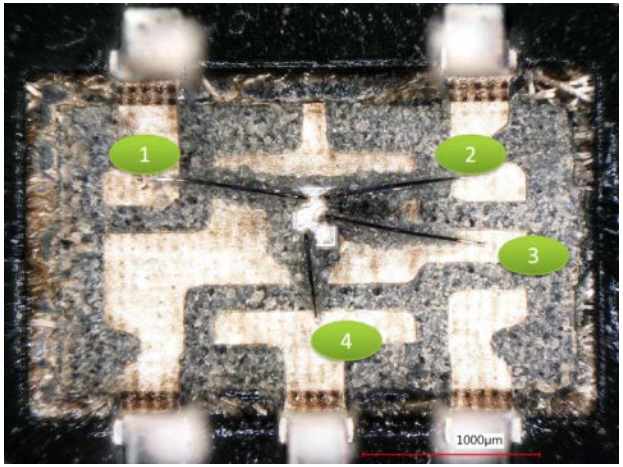


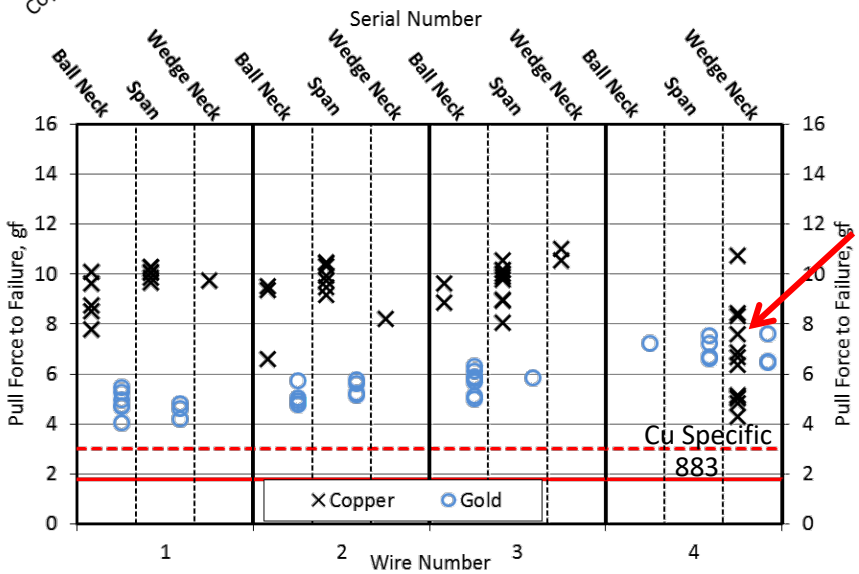
# Difficulties in Application

## Ex. Gold and copper comparison wire specific concern

- Cu vs Au Comparison
  - Ball neck and wedge neck breaks observed in both Au and Cu packages (Cu specific reject criteria)
  - Wire dependent low force to failure and exclusive wedge neck failure mode (rejection criteria captures in standard deviation requirements)
  - All pulls (Au and Cu) exceeded enhanced pull force requirements
- Should this lot be rejected?



# Summary

- NSWC Crane has been conducting construction analysis of Cu-PEM's since 2015 and a summary document is available in both Dist A (public) and Dist D (DoD and DoD Contractors)
- Construction analysis of Cu-PEM's can detect process indicators with correlation between indicators and detection methods
- Further understanding of how processes indictors correlate to simulated life failure modes is need to find the line between needed confidence and over test
  - Test parts with known process indicators and test to failure with different accelerated life conditions to establish failure modes and acceleration factors
  - Establishing surveillance programs for configuration control, baseline construction analysis, and analysis of failed parts when removed from circuit card assemblies