DEVELOPMENT OF GUIDELINES FOR USE OF ELECTRON (EEEE) DEVICES SUBJECTED TO LONG TERM STORAGE
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California Institute of Technology
Jet Propulsion Laboratory
“Today’s electronic components rely on principles of physics and science with no manufacturing precedence and little data on long term stability and reliability.” [Fozard]

With Little Knowledge and perhaps a dangerous amount of Hope, we are placing our bets that electronics we will need decades from now will be ready for use; and we are just now calling in our bets that electronics we stored decades ago are now up to the task.

[Fozard]
AGENDA
I. Introduction
II. Impetus
III. Research and Method
IV. First Findings
V. Further Study
VI. Conclusion
VII. Acknowledgements
With 10 Major Research Centers (such as the Jet Propulsion Laboratory & Glenn Research Center) and numerous other facilities, NASA truly is in the Parts Business – not only using them, but storing them as well.

As of last June, JPL had in its own Flight Electronic Component Stores facility over 2 Million Devices. Devices designed, tested and qualified for Space application (Classes S, V, and K)

This same tale is told again and again for every NASA Center – for every contractor of every center.

For an Institution as advanced as NASA, there are no guidelines for the use of devices that have been subjected to Long-Term Storage

CAN THE RISKS ASSOCIATED WITH LTS-devices BE DEFINED?
COMPLICATING THE ISSUE is that the Market Share of Aerospace/Hi-Rel Components has been shrinking or collapsing, causing Institutions, e.g. JPL, to rely more and more on Commercial Grade or Industrial Grade components.
Long-Term Storage: Defined

LTS: Defined

• The very definition of Long-Term Storage is as flexible as there are Dialects
• For the purposes of this study, Long Term is defined as anything kept in a non-energized state for a continuous period of 5 Years or more
  • Everything from Desk Drawers to Barns to tightly sealed Moisture Barrier Bags

• Based on the Research into the Body of Knowledge, can a Reasonable, Affordable, and Enforceable set of Guidelines be developed for application NASA-Wide on the use of LTS devices?
  • How Old is Too Old?
  • What Reassurances (tests) are necessary to ensure Mission Assurance that devices in hand are just as reliable – and usable – as devices brand new?

A 1925 mica capacitor – still offered for sale
[partsdiver.com]

[propertycasualty360.com]
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III. RESEARCH AND METHOD

- 125 Journal Articles were Read and Catalogued
- 17 Telephone and In-Person Interviews were Conducted
- 4 Facility Tours Conducted
- Countless E-Mails from Academia and Institutional Experts
  - Aerospace to Automotive, Computers to Radios

- Professional Affiliations – Committees Joined and Active
  - JEDEC JC-14 (Quality and Reliability of Semiconductor Products)
  - SAE G-21 and TEASSTCG12 (Long Term Storage Guidelines)
  - IEC
THERE IS A LOT OF INTEREST IN THIS TOPIC
WHETHER BASED UPON BUDGET RESTRICTIONS OR SCHEDULE RISK REDUCTION, EVERY INSTITUTION CONTACTED IS EITHER DEVELOPING OR ALREADY HAS IMPLEMENTED A GUIDELINE ON THE USE OF LTS DEVICES

- All over the Map
  - Don’t Use At All - to - Hey Whatever!
  - Difficult to Assess Risk to Budget and Schedule
  - Especially when More than One Institution is Involved

images courtesy [jimwilliams.blogspot.com]
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With a few exceptions (below), this investigation could find no compelling evidence to distrust components that have been subjected to Long-Term Storage

*Provided that they are properly stored*

- SEALED MOISUTRE BARRIER BAGS with DESICCANT

**MAJOR FINDINGS**

- **Solderability:** Of 389 Components stored for a period of 17 years, only 4 did not pass initial solderability requirements [Anderson]
- **Capacitors:** Anecdotal evidence shows epoxy sealed, wound film capacitors may experience swelling due to moisture intrusion
- **Resistors:** One instance of Wirewound capacitor shorted to Aluminum case due to LTS in heated area
- **Semiconductors:** Moisture Intrusion in Package is Largest Culprit
  - Delamination and Popcorning due to improper bake-out
  - Bond-wire corrosion
  - Shift in Radiation Tolerance

*All photos courtesy Hi-Rel Labs*
## KNOWN ISSUES RELATED TO LONG TERM STORAGE

<table>
<thead>
<tr>
<th>Technology Focus</th>
<th>Hazard</th>
<th>Issue</th>
<th>Seen In / Seen By</th>
<th>Suggested Remedy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Die</td>
<td>Bond Pads</td>
<td>Corrosion</td>
<td>Visual</td>
<td></td>
</tr>
<tr>
<td>MOS and Bipolar</td>
<td>Reduction of TID</td>
<td>Moisture intrusion reduces TID significantly over time</td>
<td>Witnessed by effective energy increase in field oxide leakage</td>
<td>Re-run Radiation Lot Acceptance Test (RLAT)</td>
</tr>
<tr>
<td>Capacitor, Molded Ceramic</td>
<td>End-Cap</td>
<td>Delamination</td>
<td>Visual Inspection</td>
<td>Visually Inspect before use</td>
</tr>
<tr>
<td>Oscillators, Crystal</td>
<td>Frequency, stability</td>
<td>Frequency shift due to moisture on crystal surface</td>
<td>Electrical check</td>
<td>Electrical check. RGA if lot permits</td>
</tr>
<tr>
<td>Microcircuits, Hybrid</td>
<td>Electrical Performance</td>
<td>Out of bounds.</td>
<td>Electrical check</td>
<td>Perform RGA. If insufficient to obtain usable statistical result: reject lot.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Microcircuits, Monolithic, PEM</td>
<td>Electrical Performance</td>
<td>Out of bounds.</td>
<td>Electrical check</td>
<td>Perform RGA. If insufficient to obtain usable statistical result: reject lot.</td>
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<tr>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Microcircuits, Monolithic, PEM</td>
<td>Mechanical fail of frame or wire bonds</td>
<td>Package deformation due to moisture engorgement distorts frame and or strains/snaps wire bonds.</td>
<td>Electrical check</td>
<td>Perform X-ray &amp; C-SAM. If insufficient to obtain usable statistical result: reject lot.</td>
</tr>
<tr>
<td>Relay, electromagnetic, non-sealed</td>
<td>Contact resistance</td>
<td>Oxidation of surface</td>
<td>Visual inspection</td>
<td>Perform numerous cycles then re-examine</td>
</tr>
<tr>
<td>Transistors, metal case</td>
<td>Leakage, moisture</td>
<td>Change in characteristics; intermetallic corrosion</td>
<td>DPA, RGA</td>
<td>Perform DPA and RGA; if insufficient lot to promote statistical validity, reject lot.</td>
</tr>
</tbody>
</table>
CAUTION PHOSPORUS

- The Avoidance of any plastic package device with Lot Date Codes indicating packaging and assembly from late-1999 to 2003

WHY?

- Manufacturers introduce Bromine-based compounds for flammability reduction
- Bromine fell fast out of Favor due to Environmental Contamination
- In 1996, use of Red Phosphorus as a Fire Retardant was developed
- In 2001, Fairchild Semiconductor issued the first of many Product Alert Notices that Plastic packages were experiencing an unprecedented rate of frame and bond failures
  - Traced to Phosphoric Acid being formed by moisture and exposed Phosphorus promoting corrosion and dendritic growth

[theriac.org]
Testing by numerous parties show a notable shift in radiation tolerance due to moisture intrusion.

- In some cases the intrusion of Hydrogen – Oxygen is disruptive to the device Oxide and alters electrical characteristics and radiation response.

Modeling from Pantelides shows disruption of oxide bonds during (a) and (b) and after (c) Oxygen intrusion.

Disruption increases number of Traps at the Interface increasing leakage
Decreasing Total Ionizing Dose tolerance

**THIS IS ESPECIALLY TRUE OF MODERN Hi-K DIELECTRICS**

**THE DAMAGE IS IRREVERSIBLE**
Are We Crying Wolf?

In many cases, the number of devices tested in published reports is in the two’s and three’s. Too few to draw a strong mathematical reference – but rather counting on a strong inference.

<table>
<thead>
<tr>
<th>Study</th>
<th>Number of Devices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anderson</td>
<td>389</td>
</tr>
<tr>
<td>Batyrev</td>
<td>6</td>
</tr>
<tr>
<td>Casanovas</td>
<td>65 analog, 21 digital</td>
</tr>
<tr>
<td>Djoric-Velijkovic</td>
<td>30</td>
</tr>
<tr>
<td>Jones</td>
<td>10</td>
</tr>
<tr>
<td>McCulskey</td>
<td>10</td>
</tr>
</tbody>
</table>
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## V. AREAS CONSIDERED FOR FURTHER STUDY

ANALYSIS OF DATA SUGGESTS THESE AREAS MAY BE WORTHY OF FURTHER INVESTIGATION

<table>
<thead>
<tr>
<th>TECHNOLOGY</th>
<th>ISSUE</th>
<th>CAUSE</th>
<th>REALM</th>
<th>PROPOSED INVESTIGATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field Programmable Gate Array, Antifuse</td>
<td>Inability to complete programming</td>
<td>Ability to program compromised by excessive ONO element leakage</td>
<td>Electrical</td>
<td>Perform programming on devices that have been subjected to LTS</td>
</tr>
<tr>
<td>Hi-K Dielectrics</td>
<td>Shift in radiation tolerance</td>
<td>Water vapor attracted to surface of Hi-K dielectrics degrading TID</td>
<td>Electrical/Radiation</td>
<td>Perform TID on PEM encapsulated devices</td>
</tr>
</tbody>
</table>
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VI. CONCLUSION

Over 125 papers reviewed, interviews and surveys conducted

• Evidence strongly suggests that the use of LTS devices which have been properly stored may be done so with little risk to the board or element.
• That cursory examinations, such as visual and solderability, should be performed as a matter of course.
• That C-SAM for Plastic and RGA for Hermetic is recommended

• Some studies show a significant change in radiation characteristics attributed to moisture intrusion – but these studies are not without outside comment or controversy due to possibly improper storage, characterization or limited lot size.

A course of further study was recommended.

THANK YOU

Pre-Print Copies of the Report for the SAE Aerospace Journal, Sp. 2015, upon which this presentation is based can be obtained by emailing the author.

kstrauss@jpl.nasa.gov kindly include LTS in the Subject line.
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http://nepp.nasa.gov

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(first author)

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Fozard, D., *Do You Know Who Is Storing Your EOL Parts?*, 2011

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A Useful Way to Use Old, Unwanted Components

Copyright: Honeywell