C01-05

Guidebook on the Use of PEMs at High Altitudes

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Objective: *To produce a guidebook for the use of PEMs in high altitude environments, focusing on the effects of rapid altitude cycling.*

Background

- There are a number of reliability concerns regarding the use of plastic encapsulated microcircuits (PEMs) in high altitude applications.
- These concerns are related to:
  - Outgassing effects at high altitude
  - Radiation effects at high altitude
  - High altitude cycling effects
    - Moisture absorption and chemical ingress
    - Temperature cycling effects
    - Pressure change effects
- This guidebook will provide information useful in assessing the reliability of PEMs in high altitude applications, especially those involving exposure to rapid altitude cycling.

Outgassing of PEMs at High Altitude

- Outgassing should not be a problem for PEMs at high altitudes
- One typical study indicating this was conducted in 1995 at NASA Goddard
  - Encapsulant samples taken from 21 microcircuits in a variety of package styles (DIP, SOIC, PQFP, PLCC)
  - Samples taken from 12 different manufacturers
  - PEMs heated to 125 °C and held at 50 μtorr for 24 hours
  - Total mass loss < 0.38%
  - Total moisture loss = 0.05% to 0.14%
  - This is significantly less than the 1.0% allowed by spec
  - Total condensed volatile material collected < 0.01%

Radiation Types

- Cosmic rays interact with oxygen and nitrogen nuclei in the atmosphere to generate secondary particles
  - Neutrons
  - Protons
  - Heavy ions
- Neutrons in the atmosphere vary with both altitude and latitude. The maximum flux, called the Pfotzer maximum, occurs at 60,000 ft. The neutron flux increases with increasing latitude.
- The distribution of protons is similar to the neutrons, low energy protons peak at 55,000 ft., and the high energy protons show a maximum between 55,000-65,000ft.
- Very few measurements have been made of the heavy ions in the atmosphere because the heavy ion flux is very rapidly attenuated with increasing atmospheric depth due to fragmentation.

Dyer, C. S., and P.R. Truscott, "Cosmic Radiation Effects on Avionics," Radiation Protection Dosimetry, vol.86, no.4 p. 337-342, 1999.

Failures Due to Radiation

- Single Event Effects (SEEs)
  - SEEs occur from a single particle
  - Atmospheric neutrons have been identified as the main cause of SEEs at high altitudes

  Normand, Eugene, "Single-Event Effects in Avionics," IEEE Transactions on Nuclear Science, Vol. 43, No. 2, April, 1996.
  - SEE failures:
    - Soft error - temporary upset of a single transistor element or output which is caused by the passage of a single energetic particle
    - Latchup - a major loss of device functionality due to the presence of a single event which induces a high current state in a portion of the device. This state may or may not cause permanent damage to the device, but requires the removal of power from the device to return to normal operation.
    - Burnout - device destruction due to the activation of a high current state
    - Dielectric/gate rupture - results in a conducting path through the gate oxide
- Total Ionizing Dose (TID)
  - TID effects accumulate from the action of numerous particles over a system's lifetime and can lead to premature performance degradation and system failure.
  - TID creates bulk-oxide and interface-trap charge that reduces transistor gain and shifts the threshold voltage and device frequency
  - TID can also cause loss of electrical isolation between devices
  - Most unhardened commercial CMOS circuits are typically able to withstand TID levels in the range from 5 to 30 kilorads at space-like dose rates

Radiation Effects Mitigation

- Use radiation hardened parts, especially in critical circuits
  - Radiation-hardened (RH) technology is technology in which the manufacturer has taken specific steps in materials, process, and design to improve the radiation hardness of a device

    Winokur, P., Lum, G., Shaneyfelt, M., Sexton, F., Hash, G., Scott, L., "Use of COTS Microelectronics in Radiation Environments," IEEE Transactions on Nuclear Science, Vol. 46, No.6, December, 1999.
  - Usually commercial parts are not guaranteed radiation-hardened by the manufacturer
- Employ shielding or localized shielding
  - Shielding provides significant protection but it does not provide complete TID or SEE protection.
  - Usually the part can be adequately shielded to prevent any issues associated with TID.
- Utilize error detection and correction (EDAC) with constant refreshing
- Build redundancy into the design of the system
- Design using radiation degraded parameters
- Select different process technology, i.e. CMOS, bipolar
- Use hardened nonvolatile memory, energy storage backup or ROM for storing critical data

Pressure Effects on Moisture Ingress at High Altitude

- An equation that models the change in the partial pressure over time* is:

$$\frac{P_i\{t\}}{P_o} = \left(1 - \frac{P_{in}}{P_o}\right)\left(1 - e^{-D_p t}\right) + \frac{P_{in}}{P_o},$$

where P_i is the internal partial pressure of water vapor,
P_o is the external partial pressure of water vapor,
P_{in} is the initial internal partial pressure of water vapor,
D_p is the permeation coefficient, and t is the time.

- Different plastic encapsulant materials will have different permeation coefficients, but due to the fact that they are all hygroscopic, P_i approaches P_o as time goes to infinity regardless of the materials used (epoxy novolac, biphenyl, or silicone.)
- So the limiting factor on the internal partial pressure of water vapor, and hence the limiting factor on the internal amount of moisture, is the external water vapor partial pressure.

*Pecht, M. "A Model for Moisture Induced Corrosion Failures in Microelectronic Packages," IEEE Transactions on Components, Hybrids, and Manufacturing Technology, Vol. 13, No. 2, p. 383-389, June 1990.

Proposed Movement of Moisture

- Since the limiting factor of internal moisture is the external water vapor partial pressure, no device at equilibrium can have more moisture inside it than outside (Unless it has desiccant properties which PEMs do not have).
- During the hot and humid dwell time on the ground, moisture will ingress into the PEM.
- When the aircraft takes off and climbs to cruising altitudes, some moisture will escape the package, but majority of the moisture will condense and freeze on the inside of the PEM because there is not enough time for the moisture to escape the package.
  - Time for typical fast jet ascent takes less than five minutes
  - Time for diffusion of moisture through molding compound takes hours/days
  - This freeze-thaw cycle was investigated in project C98-36.
- When the aircraft returns to ground environments, the pressure and temperature of the package will rise. If any moisture had solidified it will return to the vapor state. If any moisture had sublimated, it will be replaced by ingress.
- The internal partial pressure will return to its original state, no additional moisture will enter the package as a result of the pressure change.

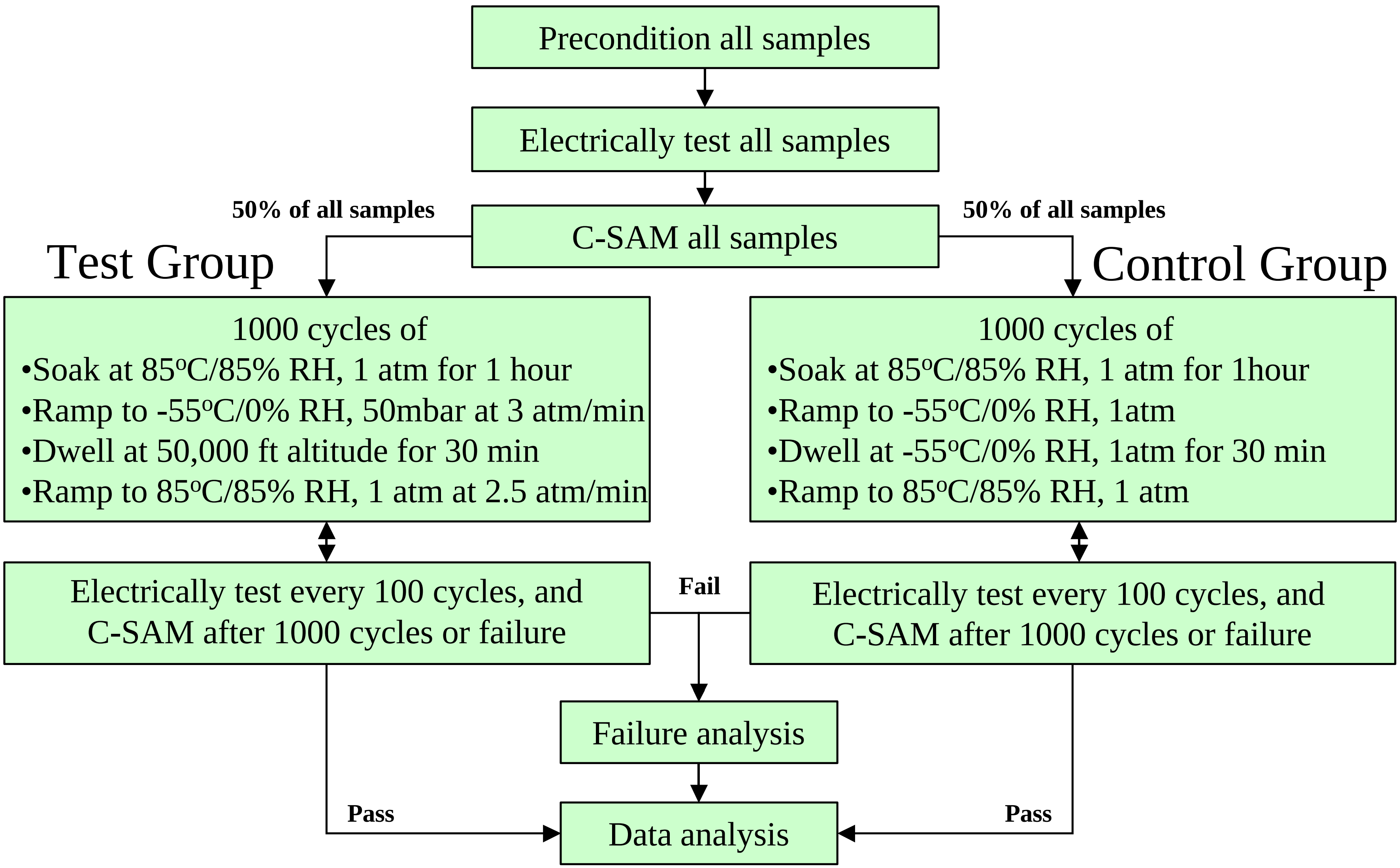
Partial Pressure is More Important Than Atmospheric Pressure

- Changes in atmospheric pressure levels do not directly relate to changes in moisture ingress through plastic encapsulants.
- Dalton's Law of Partial Pressure states that the total pressure of a gas mixture is the sum of the partial pressures of the gases in the mixture.
- Each gas in a mixture exerts the same pressure, its partial pressure, that it would if it were alone.
- The Earth's dry atmosphere is composed of 75.5% Nitrogen, 23.1% Oxygen, 1.3% Argon, and 0.1% other. For an atmosphere with moisture, the atmospheric pressure equals:

  $$P_{atmospheric} = P_{water\ vapor} + P_{Nitrogen} + P_{Oxygen} + P_{Argon} + P_{Other}$$

- The partial pressure of water vapor, $P_{Water\ Vapor}$, can remain constant while the partial pressures of other gases change, which will cause a change in the atmospheric pressure.
- Since atmospheric pressure can change while $P_{Water\ Vapor}$ remains constant, the correlation between atmospheric pressure changes and moisture ingress is in question.

Experimental Test Procedure

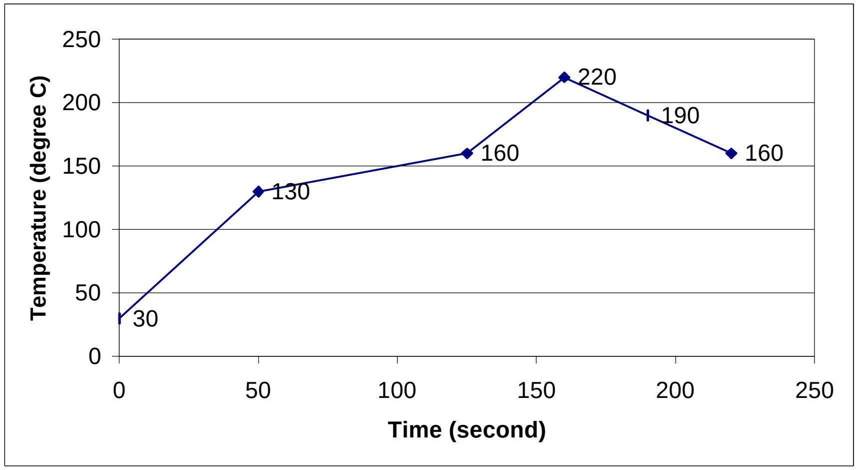


Part Information

Manufacturer	Part Type	Number of Parts	Package Type	JEDEC Moisture Sensitivity Level
Texas Instruments	TMS27PC010-15FML	30	32-pin PLCC	1
Texas Instruments	SN74ACT2235-30PAG	30	64-Pin TQFP	2
Texas Instruments	SN74ALS233BFN	30	20-Pin PLCC	1
AMD	AM26LS32SC	21	16-pin SOIC	3
AMD	AM29F010-120JC	30	32-Pin PLCC	2
AMD	AM27C1024-200JC	30	44-pin PLCC	3
Motorola	MC74AC245DW	30	20-pin SOIC	1
IDT	IDT7202LA35J	30	32-pin PLCC	1

Preconditioning

- Baking of the components at 125°C for 24 hours to dry out the components, thereby ensuring all components entered the next step with minimal moisture.
- Immediately after baking, soaking the sample at a JEDEC moisture sensitivity level specified by part manufacturers to simulate the allowable floor life and condition.
- Application of no clean rosin mildly activated (RMA) flux on the leads of all components to provide a level of corrodant typical of component assembly.
- Reflow at temperature profile shown.
- Cleaning of the leads after reflow in isopropyl alcohol (IPA) to remove flux residue and ensure proper electrical functional test.
- Surface examination for external cracking and damage using 40X microscope.
- Scanning Acoustic Microscopy examination for delamination.

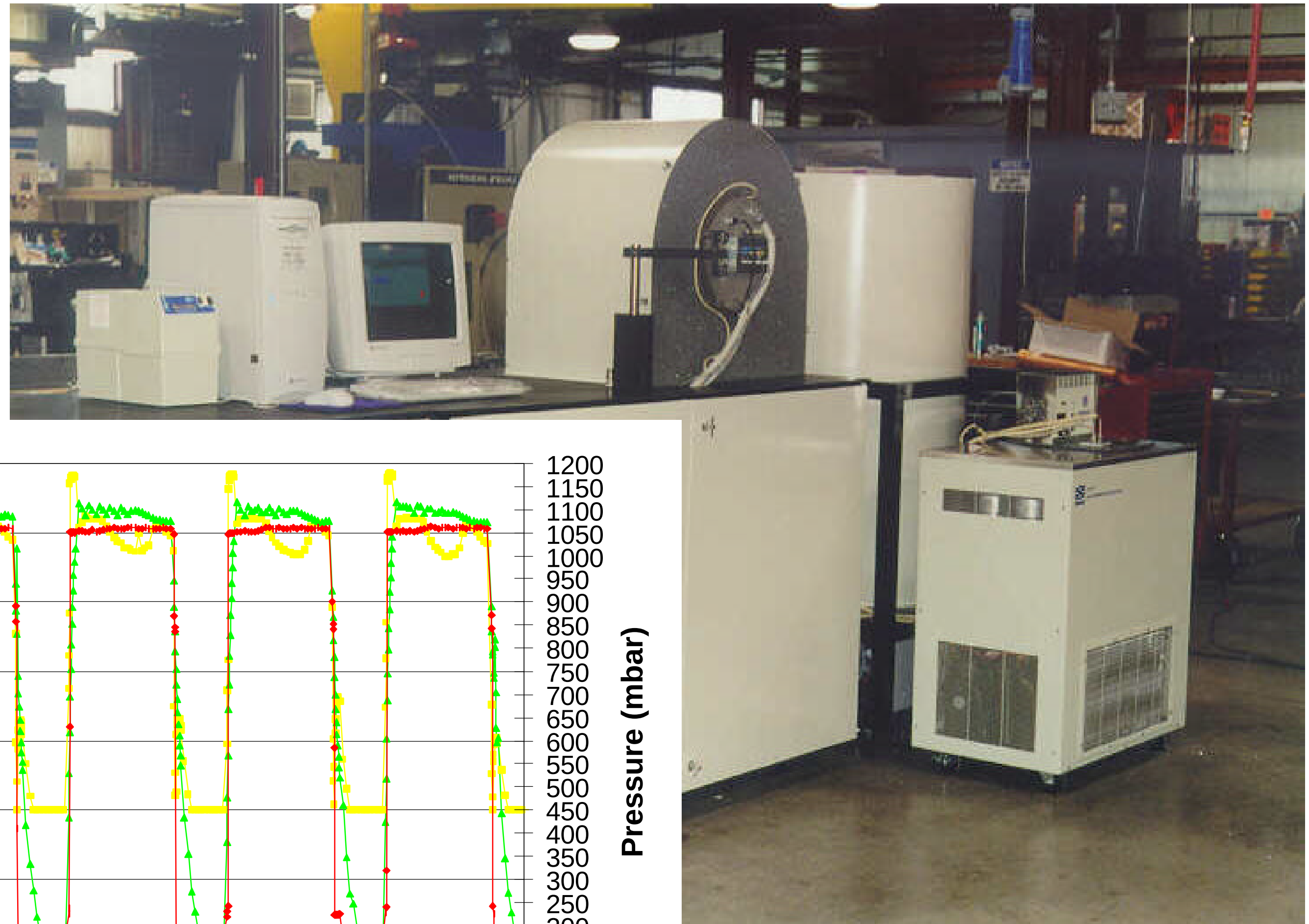


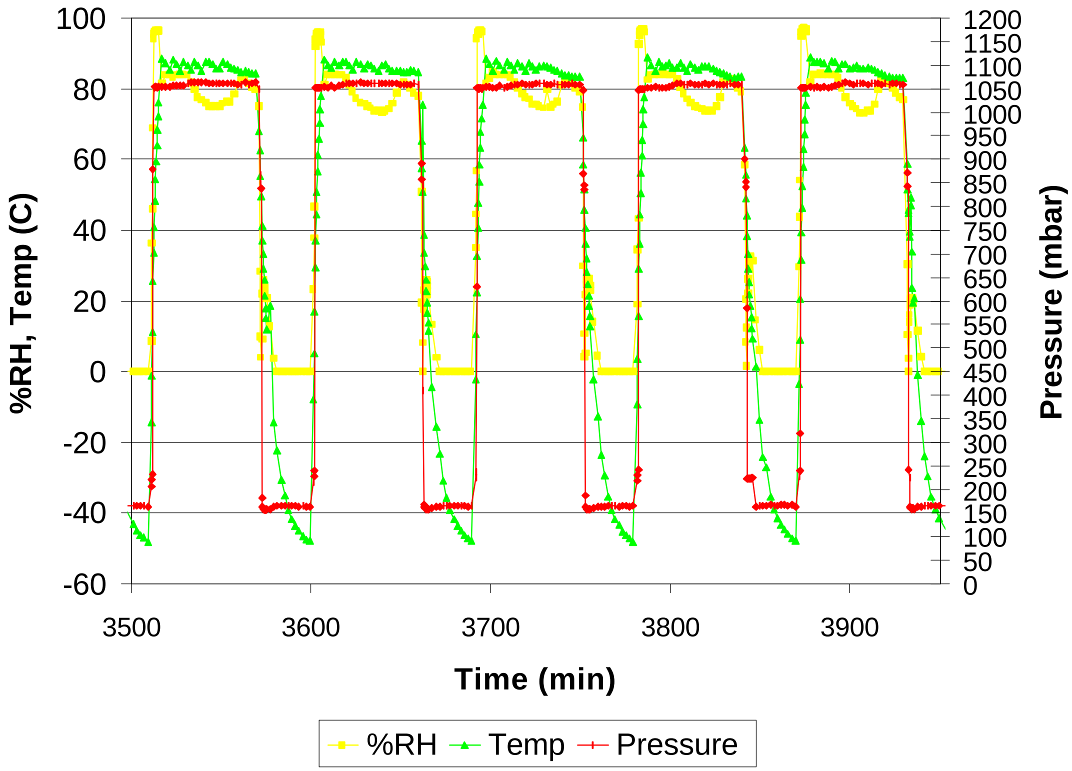
Electrical Testing

Manufacturer	Part Type	Test House
Texas Instruments	TMS27PC010-15FML	Amkor Technology
Texas Instruments	SN74ACT2235-30PAG	Bell Technologies
Texas Instruments	SN74ALS233BFN	Bell Technologies
AMD	AM26LS32SC	CALCE
AMD	AM29F010-120JC	Amkor Technology
AMD	AM27C1024-200JC	Amkor Technology
Motorola	MC74AC245DW	CALCE/Amkor Technology
IDT	IDT7202LA35J	Amkor Technology

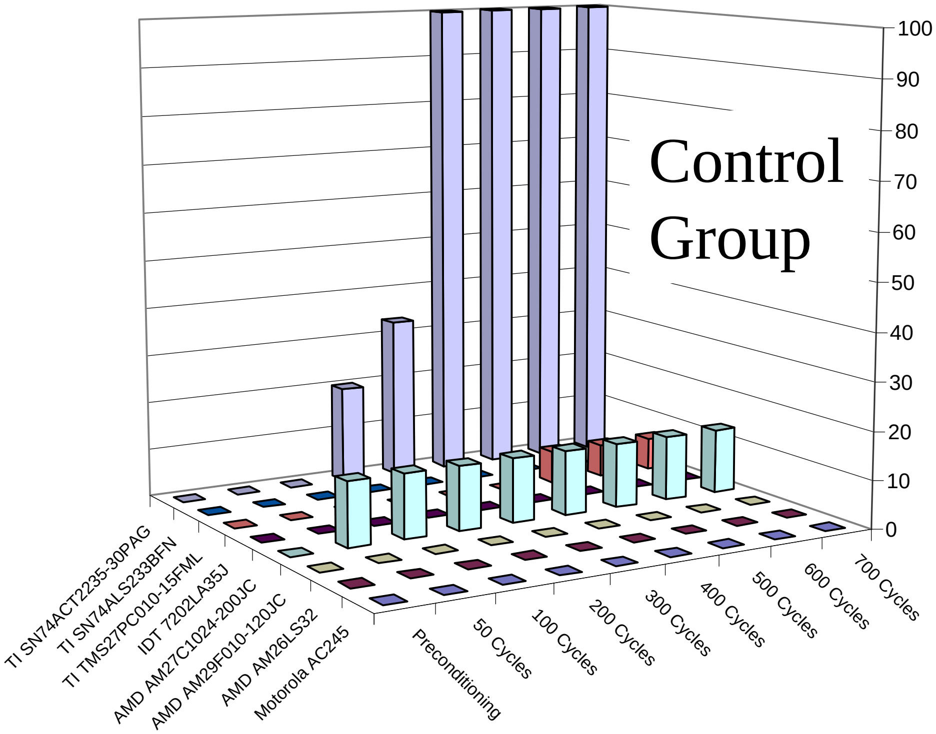
- Parts electrically tested in house were tested at 25^{o}C
- Parts tested at other facilities were tested at –55^{o}C, 25^{o}C, and 125^{o}C.
- All parts passed electrical testing after preconditioning.

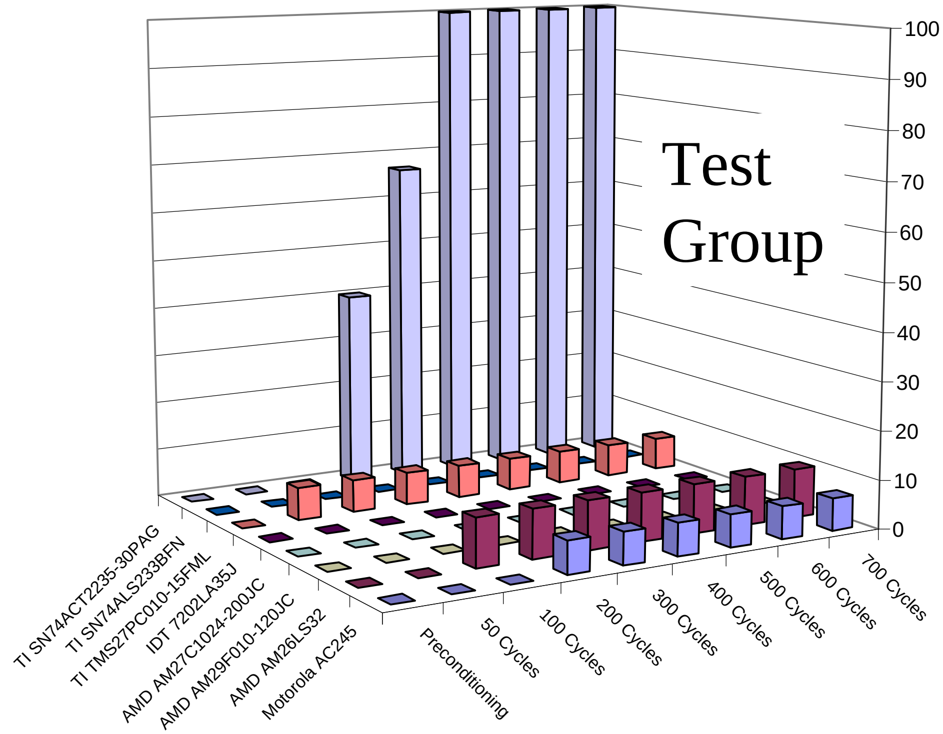
Altitude Cycling Profile





Test Results After 700 Cycles

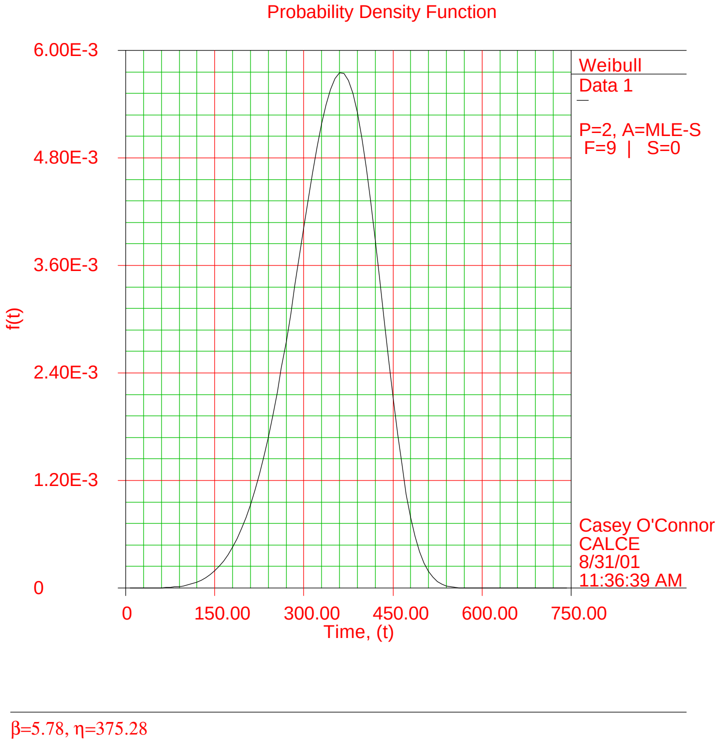




- Seven of eight part types have failures of 10% or lower.
- Only the TI SN74ACT2235-30PAG has a significant number of failures. It also performed poorly in long term storage. (C99-15)

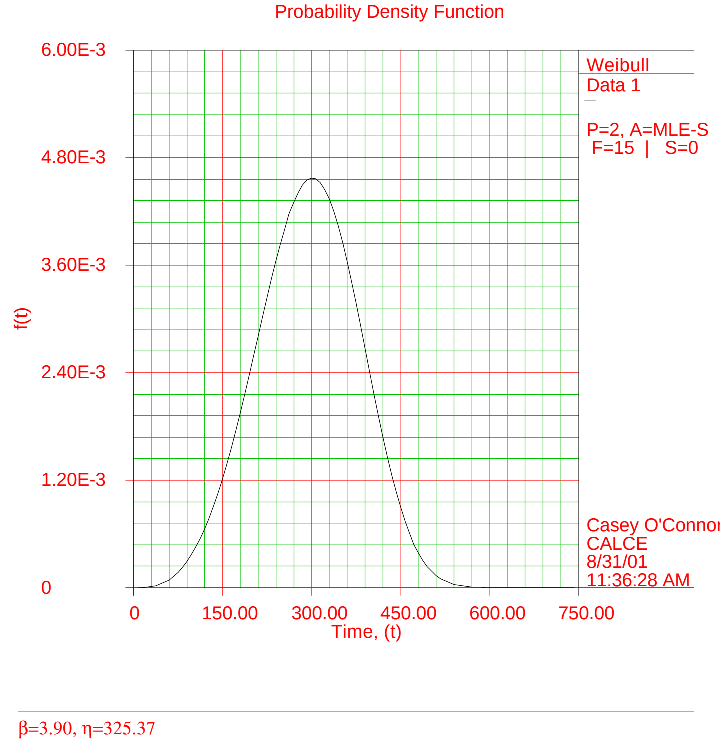
Weibull Fit of TI SN74ACT2235-30PAG

Control Group



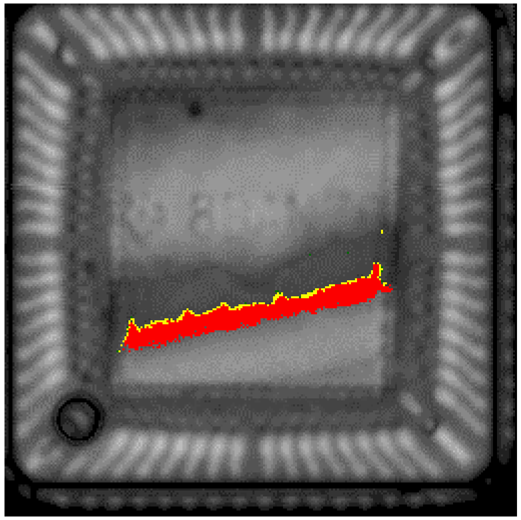
Mean Life = 347 cycles

Test Group

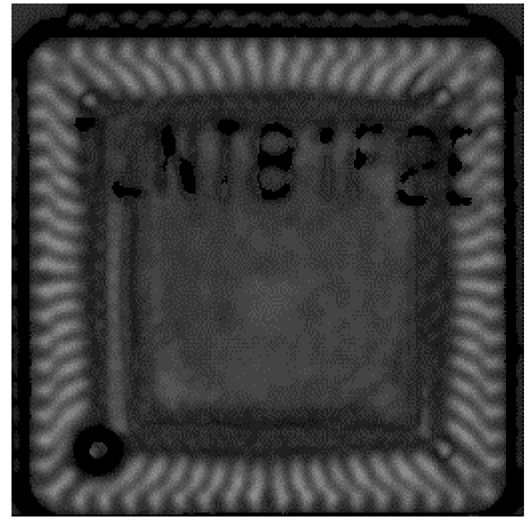


Mean Life = 294 cycles

Non-Destructive Failure Analysis



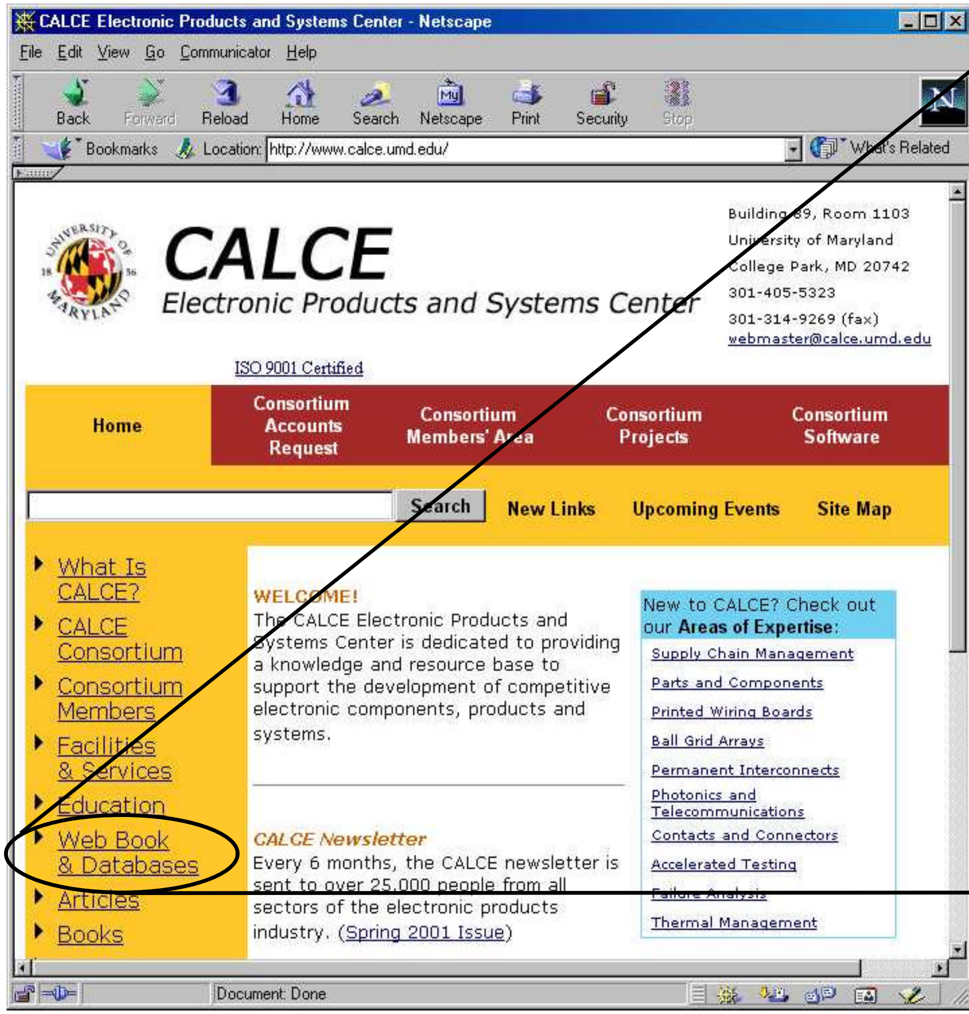
Test Group TI SN74ACT2235-30PAG



Control Group TI SN74ACT2235-30PAG

- Changes in pressure appear to result in die cracking. Preliminary scanning acoustic microscopy images have shown differences between test group parts and control group parts of type TI SN74ACT2235-30PAG.
- 6 out of 15 test group parts exhibit features like the one on the left above. This type of delamination typically indicates die cracking or tilt. There is no delamination, nor is there any indication of die cracking in the control parts.

Web Guidebook: Use of PEMs at high altitudes



- Basics of Using Commercial PEMs
- Failure Mechanisms in PEMs
  - Outgassing effects
  - Thermal cycling effects
  - Maximum temperature effects
  - Moisture absorption and chemical ingress
  - Radiation effects
  - Pressure cycling effects
- Methods to Mitigate Effects
- Accelerated Qualification and Screening Tests

Benefits to Members

- Members have access to a guidebook on the effects of high altitude on PEMs.
- The effects of pressure cycling on time to failure in PEMs have been documented after 700 cycles of altitude/control cycling.