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Long Term Dormant Storage Experiment of COTS Components Under Field Conditions

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

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Assessment of the Military Use of COTS

Project Goal: Determine if Components will Meet the Design Life

- **Objective: Assure the long term reliability of Commercial Off the Shelf (COTS) electronic components and new COTS fabrication technologies in weapons applications.**

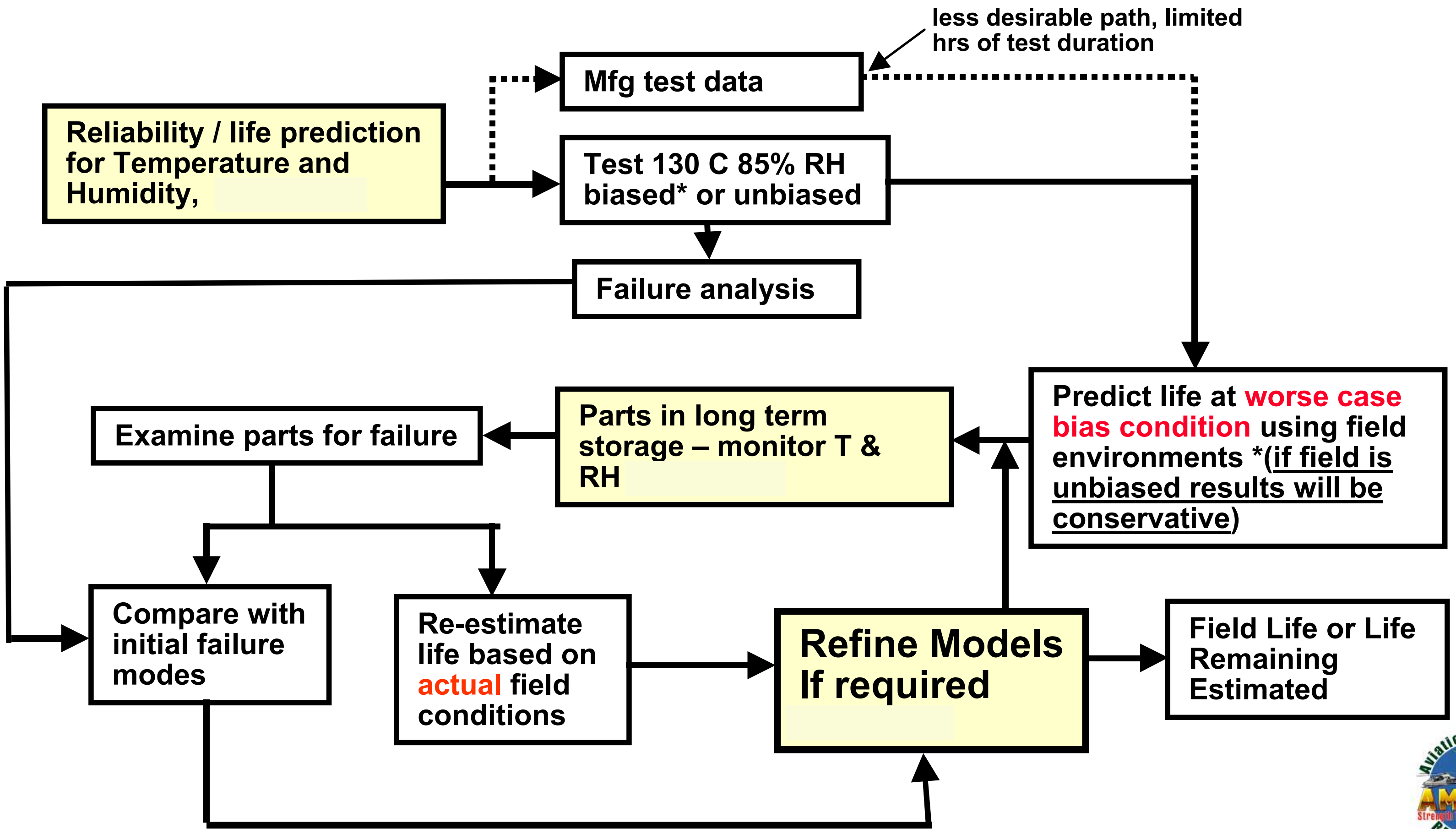
- **Approach: Develop and validate procurement / qualification methodology as well as life predictive models of COTS components and assemblies under a variety of environmental conditions. These include temperature, humidity, thermal cycling, and material finishes.**

- **Status: We have implemented a monitored long term dormant storage test to compare with life predictions made by model using highly accelerated test and in-use conditions. First group of parts are in 3rd year of storage and second group of parts are in their first year of deployment.**

Long Term Dormant Storage

- **Objectives**
  - Model the life of COTS electronic components under temperature/humidity conditions.
  - Develop deceleration factors relating short term test to field conditions
  - Identify manufacturing verses life failure modes in COTS components
  - Develop models that relate combined effects to life and life remaining in electronic components
  - Develop models for new COTS technologies
- **Prototype LTDS – Phase I**
  - Eight part types, 1000 each
  - Five field locations
  - Annual inspection
- **Expanded LTDS Phase II**
  - 32 part types (18 are currently in process), 1000 pieces of each type
  - Five locations
  - Annual inspection
- **Looking For:**
  - Model Agreement ⇨ Predict life remaining
  - Failures modes

Methodology to Determine if COTS Meet Lifetime Requirements



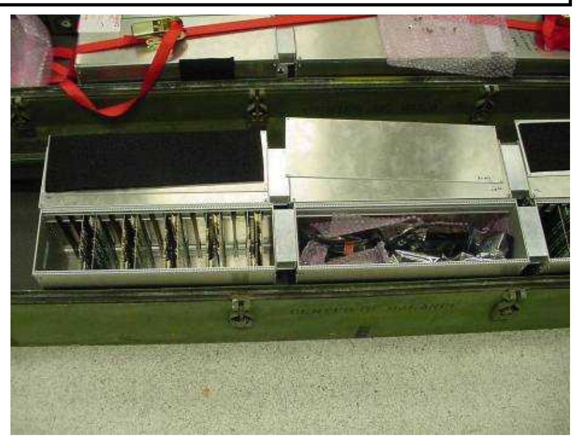
Long Term Dormant Experiment (Phase I): Locations & Parts (8000 Parts Total)

- Accelerated Stress
  - HAST;
  - Temperature Cycling;
  - Thermal Shock.

- Inspections:
  - Electrical Testing;
  - Scanning Acoustic Microscopy;
  - Failure Analysis.

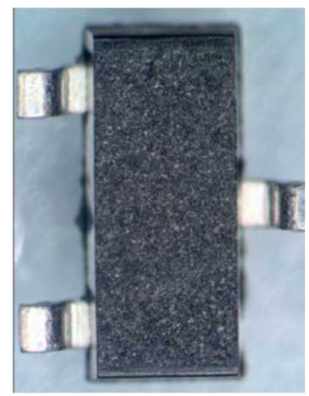
- **Locations**:
  - SNL, Albuquerque NM,
  - Yuma Arizona;
  - Eglin AFB, Florida;
  - Redstone Arsenal, Huntsville Alabama;
  - Fort Greeley, Alaska

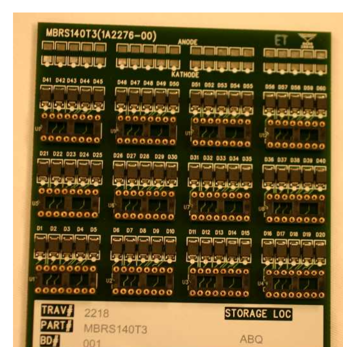
Component	Type	Mfg
CY7C199-15VI	SRAM	Cypress
OP400GS	Op Amp	Analog
HMC273MS10G	RF	Hittite
MMBT2222ALT1	Transistor	On Semi
MTB30P06V	MOSFET	On Semi
LM139AD	IC Comp	TI
AS186-302	RF	Alpha
FM1808	FRAM, parallel	Ramtron

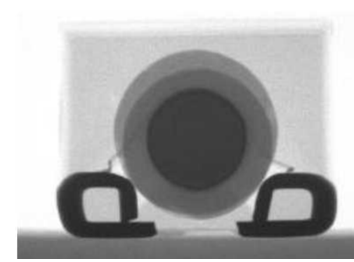


Long Term Dormant Storage Phase II

- **Parts Selection**
  - Thirty Two Additional Part Types (~32,000 New Parts limited by funding).
  - Variety of packages, technologies, and function.
- **Storage, Site Selection and Monitoring**
  - Five More Hellfire Missile Containers.
  - Same Storage Sites (NM, AZ, FL, Alabama and Alaska)
  - Use commercial data loggers to collect temperature and humidity data.
- **Parts packaged loose and soldered to boards.**
  - Investigate solder fatigue
  - Investigate tin whiskering on some capacitor leads
    - Populated as-is, Pb-plated and Pb-solder-dipped.
    - Some conformal coated and some not.
- **Initial inspection**
  - eDPA
  - Electrical tests
  - SAM
  - Visual solder inspection
- **No collection of accelerated data**
  - No HAST
  - No TC







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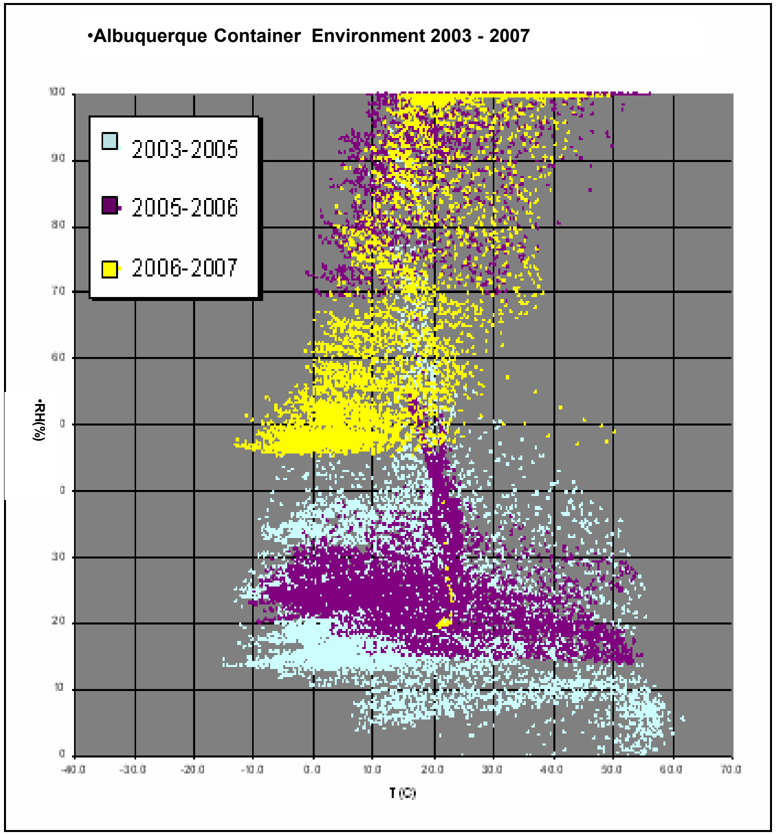
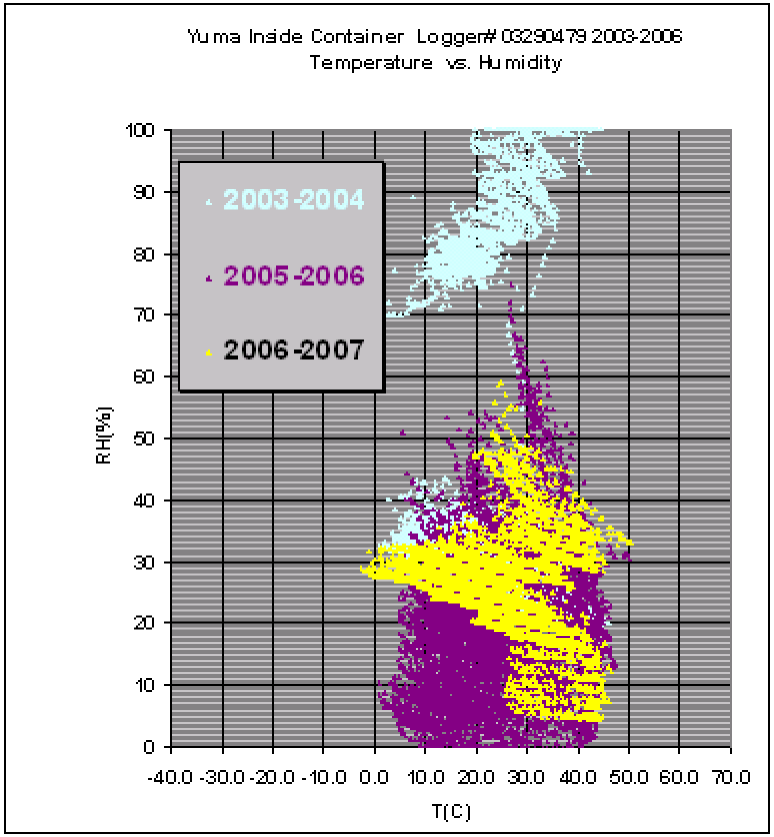
Long Term Dormant Storage Phase II

List of 18 Devices Currently Being Processed

Mfg. Part #	Quantity	Package	Manufacturer	Part type
ADG506AKR	1000	SOIC-28	Analog Devices Inc	Analog Multiplexer
BAS16LT1	1000	Sot-23	ON Semiconductor	Diode
BFS17A,215	1000	Sot-23	Phillips Semiconductor	Transistor
MBRS140T3	1000	SMB case 403A Plastic	ON Semiconductor	Diode
MMBT2369ALT1	1000	Sot-23	ON Semiconductor	Transistor
MMSZ5228BT1	1000	SOD-123	ON Semiconductor	Voltage Regulator
SP723AB	500	8L SOIC	Harris	Diode
ATC10301	1000	Refer to Drawing Kemet T491	American Technical Ceramics	Capacitor
T491D227M010AH4557	1000	EIA 7343-31	Kemet	Capacitor
LQW18ANR22J00	1000	0603	Murata (TTL)	Inductor
32797	1000	SM Chip	COAST/ACM	Inductor
HMC208	1000	MSOP 8	Hittite	RF Mixer
ATF54143	1000	SOT-343	Agilent	Amplifier
12103D106KAT2A	2000	EIA 1210	AVX	Capacitor
HMC484	1000	plastic encapsulated	Hittite	RF Switch
ERA-50SM	1000	WW107	MiniCircuits	Amplifier
ADXL203CE	1000	Ceramic LCC	Analog Devices Inc	MEMS Accelerometer
AD7827	1000	8L SOIC	Analog Devices Inc	Analog to Digital Converter

Temperature Verses Relative Humidity Profiles at Each Phase I Site





Yuma and ABQ sites experience both high temperature and RH concurrently.

Lifetime Prediction

- Assume that lifetime at use conditions is related to lifetime at accelerated test conditions by an *Acceleration Factor*.
  - Form of the time to failure distribution function is the same at accelerated test & use conditions.
- Utilize an acceleration factor which contains only a small number of parameters.
  - In *Real Life*, the parameters depend on the component and are not constants.
- Treat the parameters as random variables characterized by distribution functions.
- Use Monte Carlo technique to calculate time to failure distribution function at use conditions.

Acceleration Factors

- PEMs temperature & humidity aging
  - Parameters are temperature $\boldsymbol{T}$ and relative humidity $\boldsymbol{RH}$, s = (T,RH). **Field data**.
  - Use "Peck" form for acceleration factor with parameters $\boldsymbol{E_a}$ & $\boldsymbol{n}$. These are treated as **random variables**.

$$AF\left(T, RH, T_0, RH_0 \middle| E_a, n\right) = \exp\left[\frac{E_a}{k_B}\left(\frac{1}{T} - \frac{1}{T_0}\right)\right]\left(\frac{RH_0}{RH}\right)^n$$

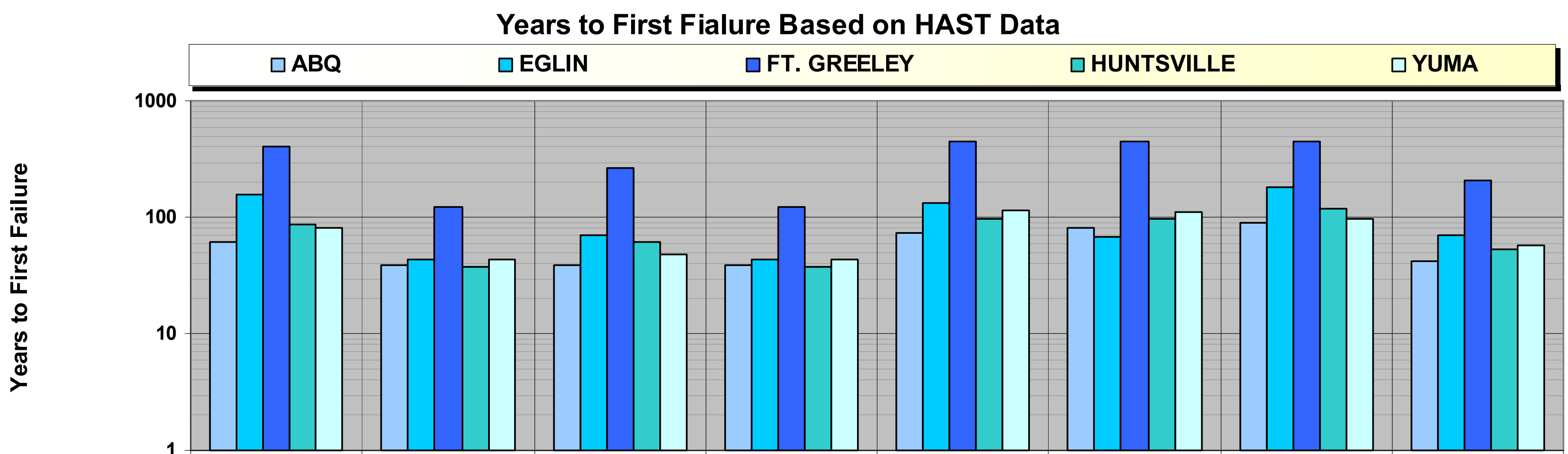
- Acceleration factor AF specifies how much the lifetime is extended at storage conditions relative to accelerated test conditions.

$$dt_{use} = AF\left(s(t), s_0\right) \times dt_{accel}$$

$$\langle DF \rangle = 1 \big/ \langle AF \rangle$$

$$t_f = \frac{t_{f0}}{\langle 1/AF \rangle}$$

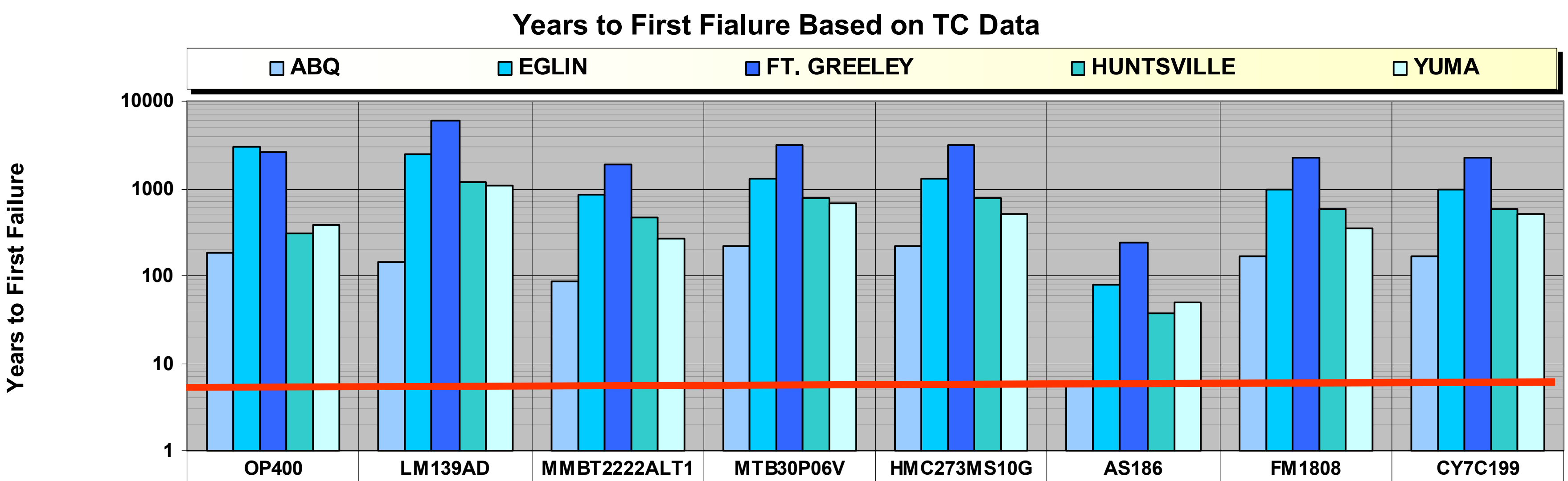
Lifetime Prediction Based on HAST Data and Corrosion Damage



	OP400	LM139AD	MMBT2222ALT1	MTB30P06V	HMC273MS10G	AS186	FM1808	CY7C199
ABQ	62	39	39	39	72	81	90	42
EGLIN	159	44	70	44	130	69	178	71
FT. GREELEY	407	124	263	124	449	445	447	210
HUNTSVILLE	86	37	62	37	97	97	117	54
YUMA	80	44	48	44	115	110	95	58

First predicted failures will be an at Huntsville 37 years into study.

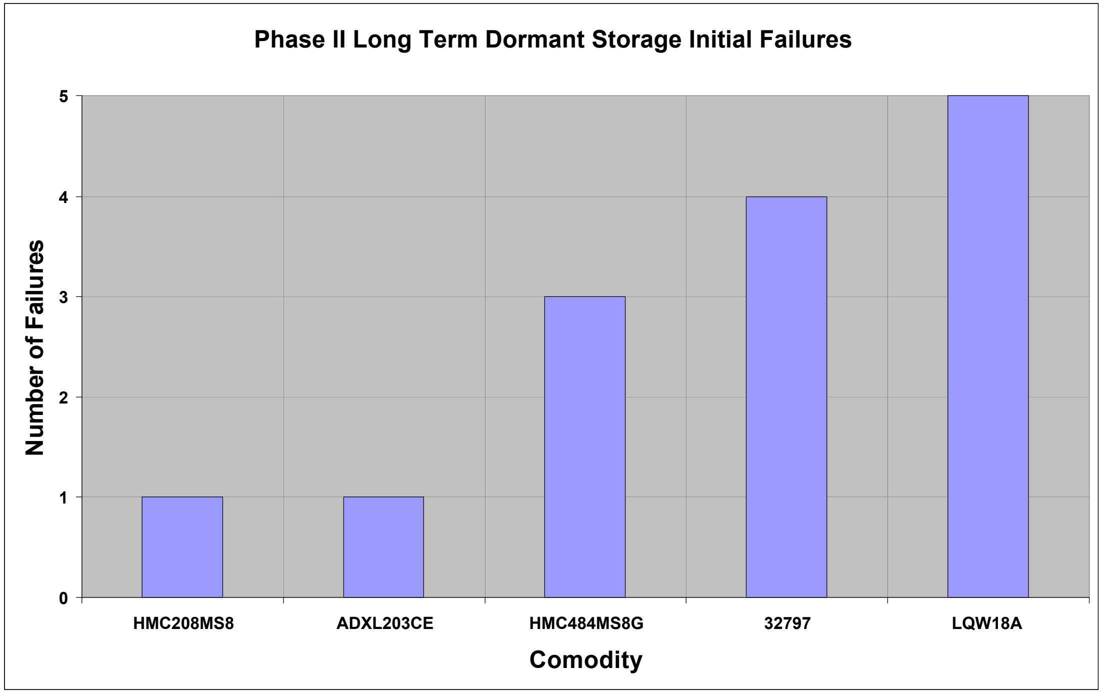
Lifetime Prediction Based on Temperature Cycle Data and Die-Crack Damage



	OP400	LM139AD	MMBT2222ALT1	MTB30P06V	HMC273MS10G	AS186	FM1808	CY7C199
ABQ	180	142	87	225	225	6	168	168
EGLIN	2933	2462	839	1307	1307	79	980	980
FT. GREELEY	2555	5916	1907	3060	3060	242	2295	2295
HUNTSVILLE	304	1203	460	780	780	38	585	585
YUMA	387	1083	268	668	512	50	346	512

First predicted failure will be an AS186 at SNL, 6 years into study.

LTDSII Initial Inspection Results



HMC208MS8: RF Mixer

ADXL203CE: Accelerometer

HMC484MS8G: RF Switch

32797: Inductor

LQW18A: Inductor

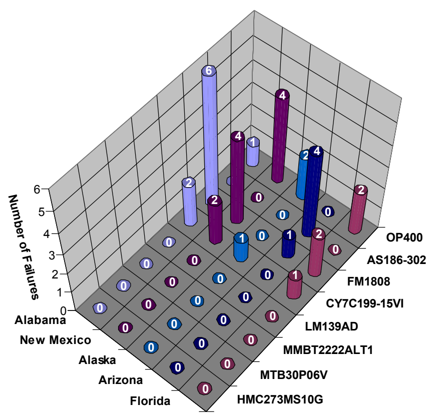
All tested before any handling or field storage – infant mortalities or defects;

All were replaced by functioning devices;

SAM showed no anomalies.

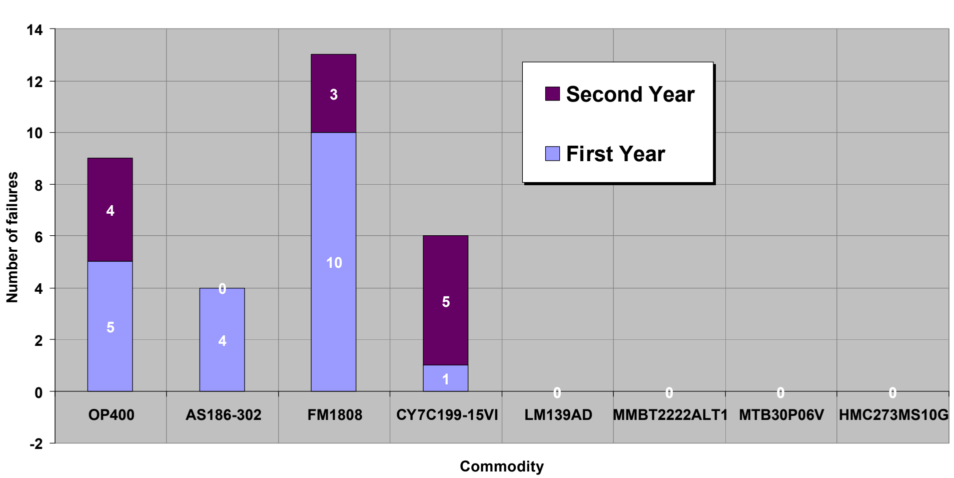
LTDSI Field Failures

Long Term Dormant Storage Failures 2003-2006



	OP400	AS186-302	FM1808	CY7C199-15VI	LM139AD	MMBT2222ALT1	MTB30P06V	HMC273MS10G
Alabama	1	0	6	2	0	0	0	0
New Mexico	4	0	4	2	0	0	0	0
Alaska	2	0	0	1	0	0	0	0
Arizona	0	4	1	0	0	0	0	0
Florida	2	0	2	1	0	0	0	0

Dormant Storage Field Failures Across All Sites 2003-2005



- **Due to:**
  - **Manufacturing Defects**
  - **Wear?**
    - **None predicted yet**
    - **AS186 or FM1808?**
  - **Handling**
    - **ESD packaging**
  - **Faulty Solder**
- **Failures Not Reproduced :**
  - **CY7C199 (2nd year)**
    - **Passed after re-test prior to DPA**
  - **FM1808 (2nd year)**

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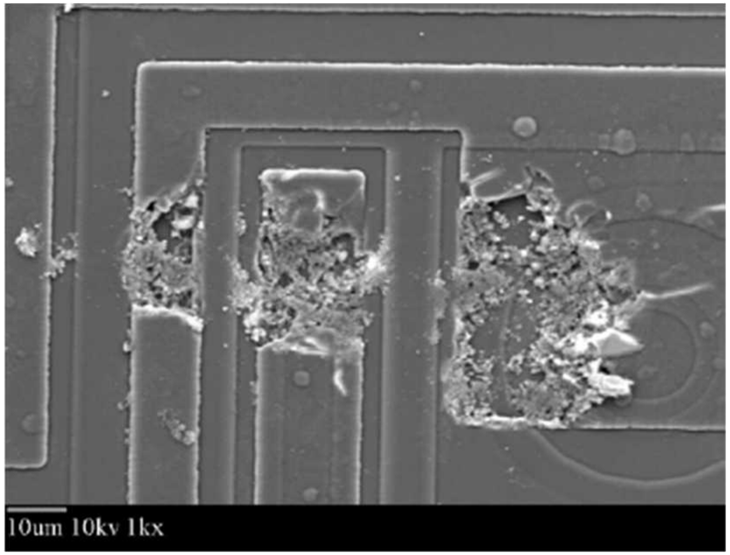
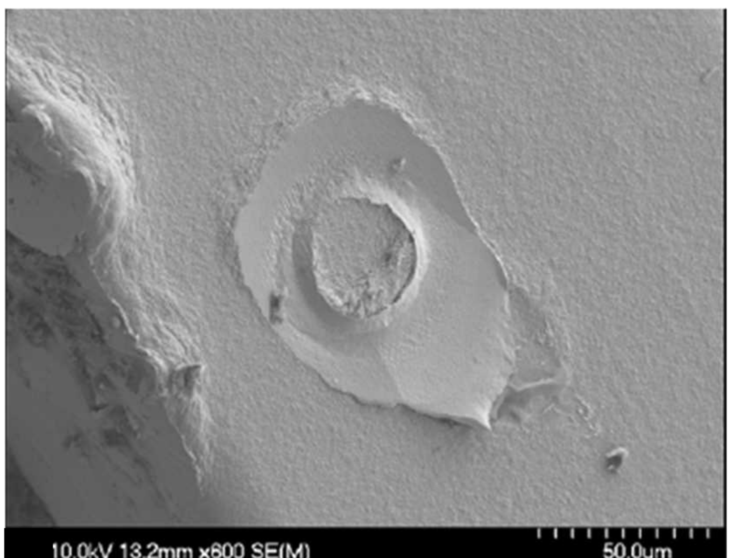
Manufacturing Defects

OP400 and CY7C199-15VI

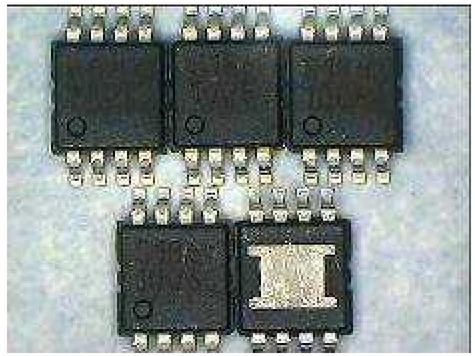




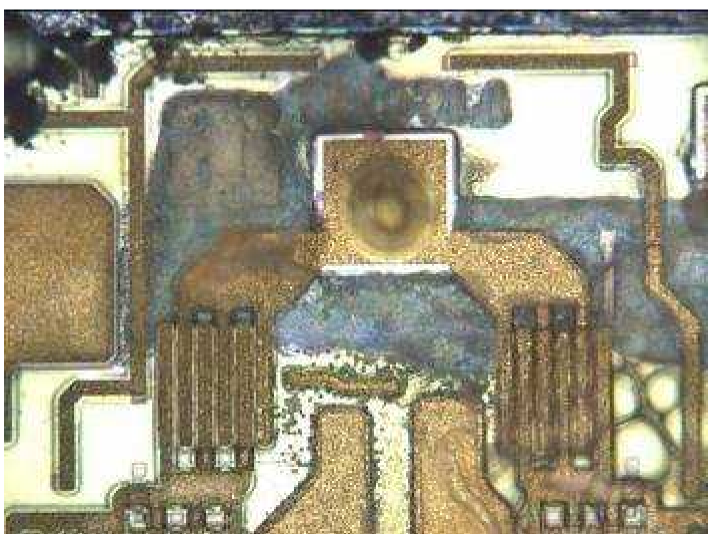
- **Passivation failure on OP400 die.**
  - **Scraped die during production**
- **One CY7C199 component failed electrical testing**
  - New Mexico after one year of storage.
  - Device intermittent failure at -40 C was caused by over-bonding.
  - Note excessive thinning at the heel.

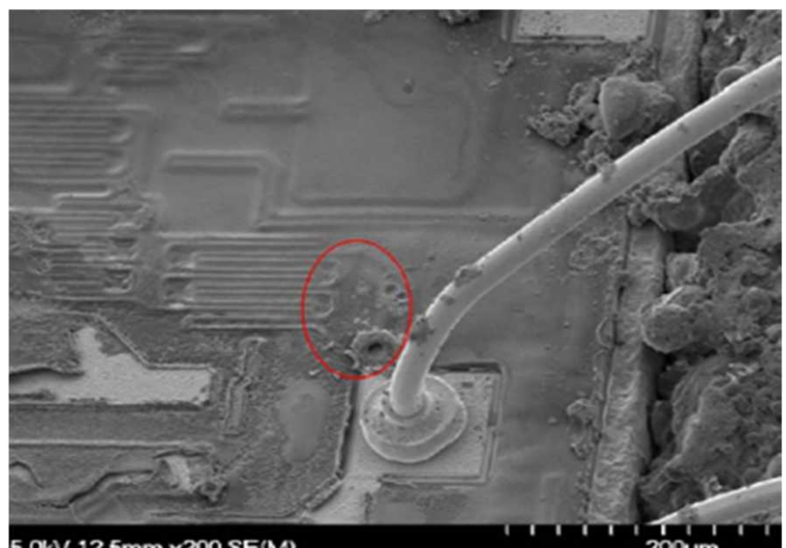
AS186 Failures
Tester Induced?

- Four AS186 components failed electrical testing
  - Yuma site
  - First year
- Types of Failures
  - Insertion Loss
  - Isolation
  - Return Loss



Devices failed due to apparent overheating which resulted in metal delamination, and damage to the GaAs substrate near and around J1 of all four failed devices.

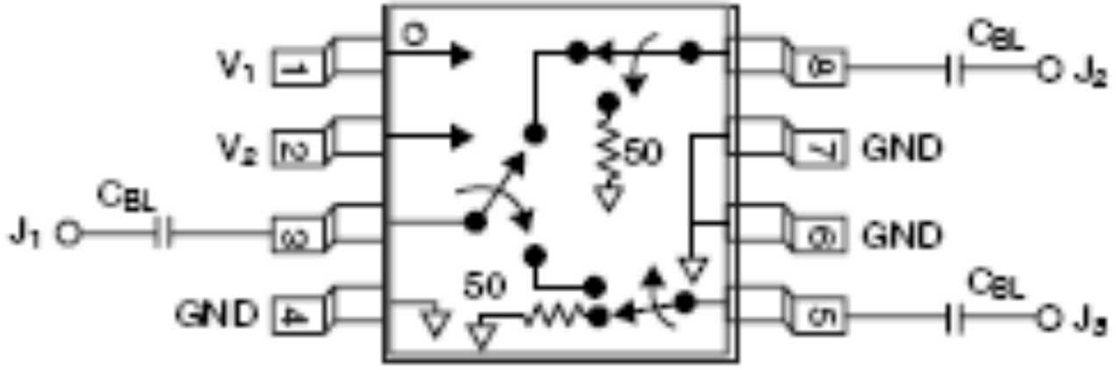




No failures recorded after second year of storage.

AS186 Failure Details

- External Visual Inspection: No visible problems observed.
- Scanning Acoustic Microscope (SAM): **Severe delamination** between the heat-sink and the molding compound was observed.
- Electrical Pin Test (curve Trace): No obvious electrical opens or shorts observed.
- De-capsulation/Internal Inspection: Device were de-capsulated. Subsequent optical and SEM inspections revealed **metal delamination and damage to the GaAs substrate near and around pin 3** (J1) on all four devices.

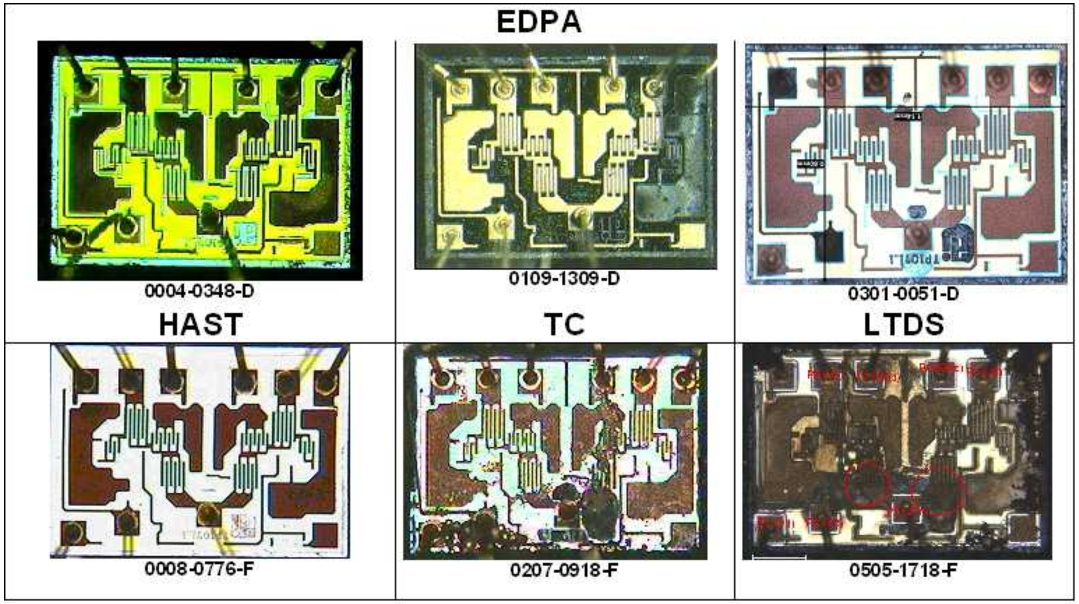


AS186 History

- **Post HAST**
  - **Device was determined to have failed due to electrical overstress damage on the die**, on the output loads to ground.
  - Jet-etched.
- **Post TC**
  - Failures appear to be due to **electrical overstress**.
  - Jet-etched.

- **Control Voltages:**
  - V Low = 0 to
  0.2 V @ 20 μA Max.
  - V High = **+3 V @ 100 μA** Max.
  to +**5 V @ 200 μA Max**.

- **Current Clamp set at 1mA**
  - **Destroyed part?**



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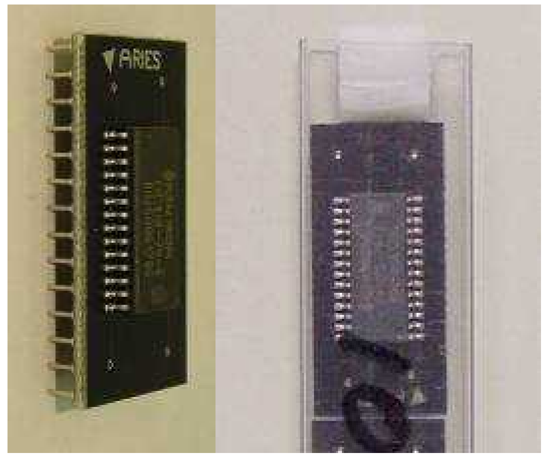
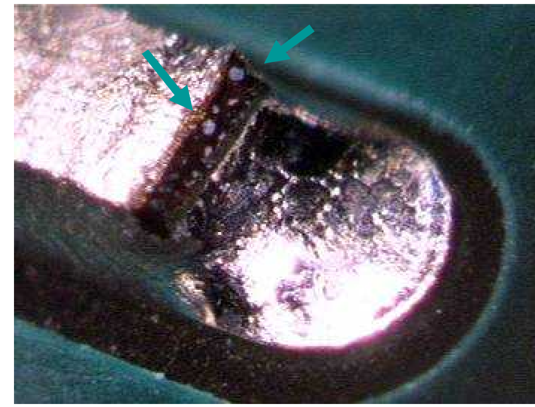
AS186 Failure due to Wear Prior to Tester-induced Damage?

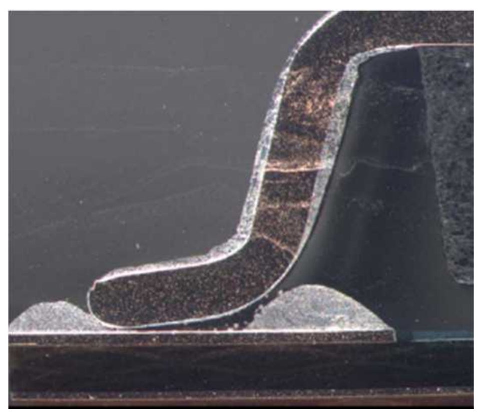
- Initial corrosion on die surface;
- Corrosion creates highly resistive connection;
- Current clamp set at 1mA;
- 200μA maximum tolerable current surpassed;
- Device fails due to apparent overheating.

Handling and Cold Solder Joints

- **Handling**
  - FM1808 (1^{st} year)
    - ESD
    - Memory retention
    - Resolved with ESD-safe packaging
  - OP400 (2^{nd} year)
    - CSAM contamination
    - Leakage current
    - Passed after cleaned
- **Faulty Soldering**
  - OP400 (1^{st} year)
    - Cold solder joints







Non-Reproduced Failures: CY7C199

- **Test:**
  - Five parts failed at -40 C.
  - Only Pass/Fail data available from test shop.
- **Retest:**
  - "No problems were found with any of the testing. Only minor voiding was detected on the CSAM images. The devices were electrically tested (both continuity and full functional) at +25C, +125C, -40C and -55C without failure." *

*Cliff Aldridge, Analytical Solutions

Non-Reproduced Failures: FM1808

- **Test**
  - The failures were all functional failures. All 3 were retested and failed. The data is attached. SNs 36 (ABQ), 291 (Eglin), 2244 (Yuma).
  - SN 36 failed:
    - All 4 Functional Tests
    - 2 static tests (VOH and VOL);
    - 11 dynamic tests);
    - and RETENTION test.
  - SN 291 failed: 3 Functional tests.
  - SN 2244 failed: 2 Functional tests
- **Retest**
  - "Applying all worst case data sheet parameters to a part at the same time is not necessarily valid. We were unable to definitively reproduce failures. The functional issues are mostly noise related. No pin to pin anomalies were detected. Xray and CSAM results also did not show any problems either. Some delamination of the die paddle noted, however believe not to be an issue." *

*Cliff Aldridge, Analytical Solutions

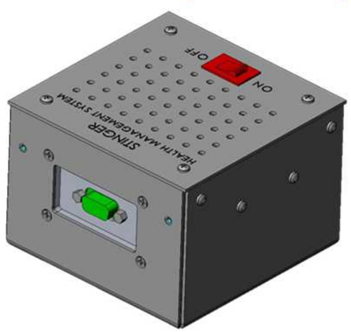
ABQ FM1808 Test Failures

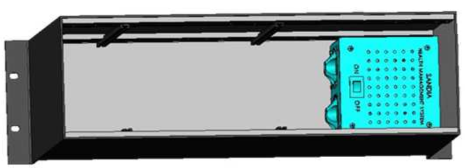
- **SN 53**
  - VOL on pin 19 D7 twice;
- **SN 39**
  - VOL on pin 18 D6 twice,
  - tCA (read cycle Chip Enable Active Time),
  - tRC (read cycle time),
  - tCW (Chip Enable to Write High);
- **SN104**
  - tCA (read cycle Chip Enable Active Time),
  - tRC (read cycle time),
  - tPC (Pre-charge Time),
  - tAH (Address Hold Time),
  - tOE (Output Enable Access Time),
  - tCW (Chip Enable to Write High),
  - tWC (Write Cycle Time),
  - tWP (Write Enable Pulse Width),
  - tDS (Data Setup),
  - VOL on pin 17 D5 at re-test,
  - passed all AC Parameters at re-test.

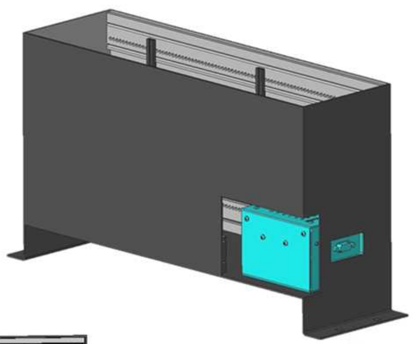
RRAPDS Data Logger at Sandia Site

- **RRAPDS Data loggers***
  - **Temperature, RH and Shock**

- **Remaining Useful Life Prediction.**
  - **Integrate following models into a single device that tells the user the remaining useful storage life (expressed as a percent):**
    - **Corrosion and Die-Crack in COTs;**
    - **Solder joint;**
    - **Tin whisker;**
    - **Adhesives (missiles);**
    - **Propellant (missiles).**

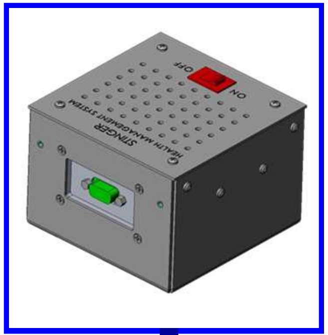


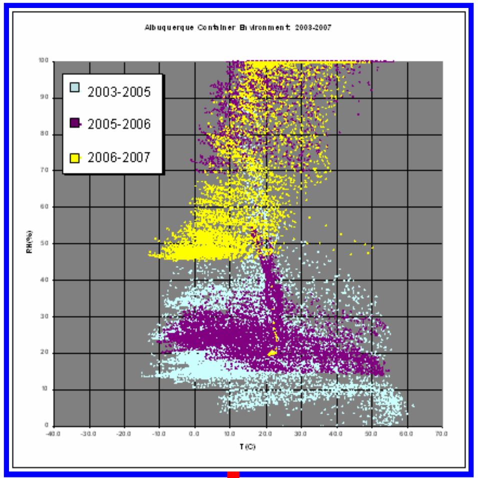


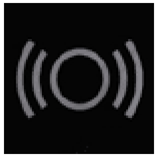


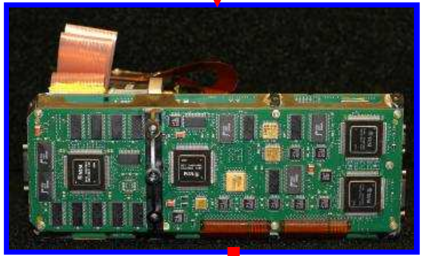
***Supplied by the U.S.Army, AMRDEC, Huntsville, Al**

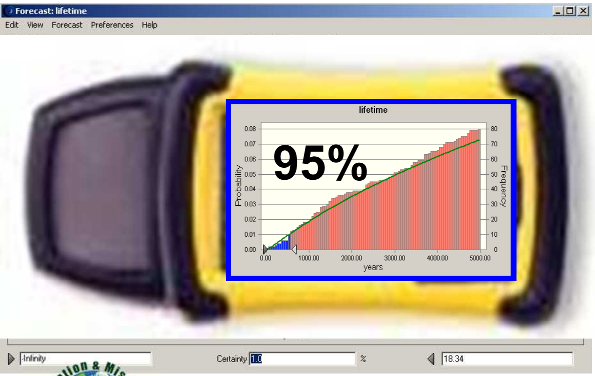
Prognostic Health Monitoring











MODELS

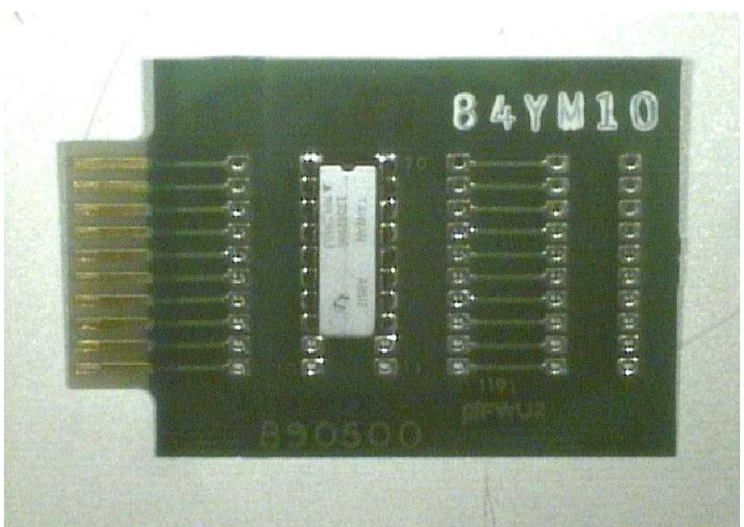
- Corrosion and Die-Crack in COTs;
- Solder joint;
- Tin whisker;
- Adhesives (missiles);
- Propellant (missiles).

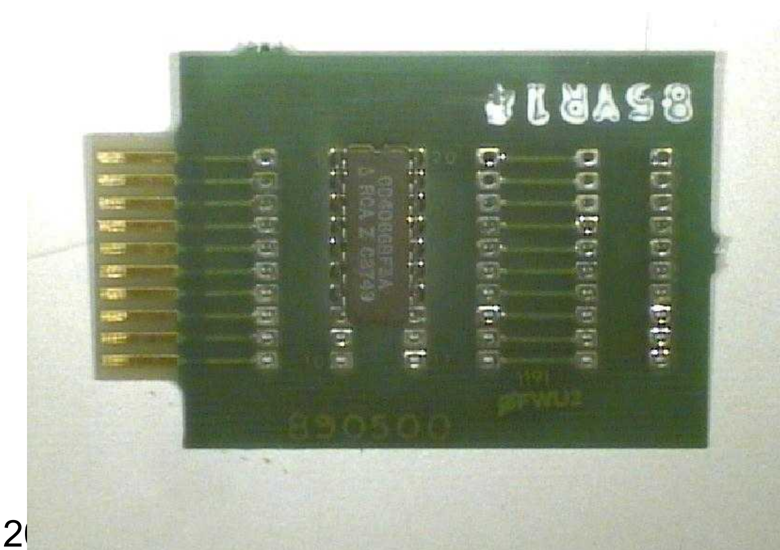
Prognostic Health Monitoring

- **Weapon System Reliability**
  - Determining the reliability of a system that is in dormant storage is of interest to DoD as well as to DOE.
  - Weapons systems are subjected to "aging" or degradation of electronic components, propellants, adhesives, foams, and coatings.
  - It is important to understand the reliability and life remaining of systems in the field under storage conditions.
- **Aging Models**
  - Rely on the input of environmental conditions of temperature, humidity, and time as well as knowledge of the mechanical, physical, and chemical make up of the system.
  - Outputs can be transformed into "health" or life remaining.
- **RRAPDS Health Monitoring Unit (currently used by several units)**
  - Collects and stores time-stamped sensor data including temperature, relative humidity, and drop distance.
  - Housed in a missile canister
  - The data are downloaded via a PDA and used in life prediction models

AMRDEC long term dormant study

- **Received 75 additional part types from AMRDEC long term Dormant Study (Alaska, and Yuma)**
  - **Ceramic**
  - **12 years in dormant storage in Alaska and Arizona**
  - **Will de-lid population sample for internal inspection**
  - **Tentative electrical test of sample population**





Long Term Dormant Storage Experiment

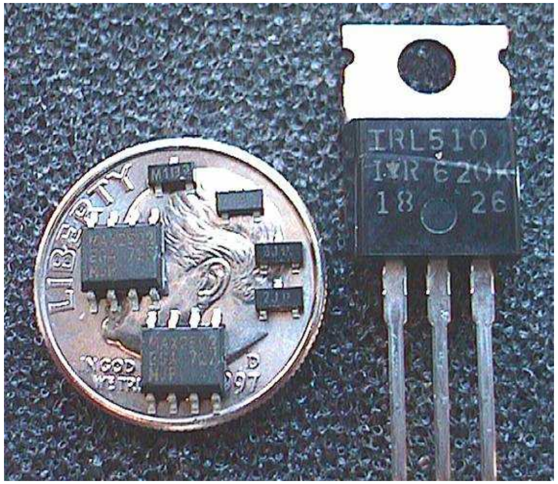
Conclusions

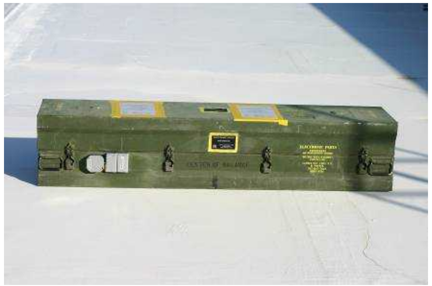
- We do not feel that we have definitively observed a wear out failure in dormant storage yet.
- The experiment does appear to have found some device defects.
- We need to be more mindful of handling, production and test related induced failures.

Future Activity

- Finish 3rd year inspection of Phase I Yuma parts and deploy.
- Collect RRAPIDS data logger.
- Complete PHM viability study.
- Inspect AMRDEC parts
- Refine lifetime prediction models.

Questions?





$$t_f = \frac{t_{f0}}{\langle 1/AF \rangle}$$

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