Evaluation of Automotive Grade Resistors for Space

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Background and Scope

- Global product shortages and shipping delays are still an obstacle, and projects are still expected to meet deadlines that cannot take these global impacts into consideration.
- Many projects have found some alternative solutions to still meet deadlines, including the possibility of leveraging test data and requirements used in automotive grade parts.
- In addition, automotive grade parts may offer designers a wider range of parts to consider.
- A recent study conducted by NASA recommended the use of high-volume manufactured commercial components for space applications, provided they demonstrate evidence of well-monitored and tightly controlled reliability and fabrication practices [1].
- Automotive AEC-Q grade components have stringent qualification requirements, *but* the responsibility is on the user to assure parts compliance to datasheet specifications and to perform screening.

- *This study aims to evaluate the reliability of automotive grade chip resistors for space.*

Acronyms

- **AEC:** Automotive Electronics Council
- **AEC-Q:** Automotive Qualified
- **ALT:** Accelerated Life Test
- **COTS:** Commercial Off The Shelf
- **DC:** Direct Current
- **DUT:** Device Under Test
- **DPA:** Destructive Physical Analysis
- **EEE:** Electrical, Electronic, and Electromechanical
- **EEEE:** Electrical, Electronic, Electromechanical, and Electro-Optical
- **GSFC**: Goddard Space Flight Center
- **HAST**: Highly Accelerated Stress Test
- **HTOL**: High Temperature Operating Life
- **IPA:** Isopropyl Alcohol
- **ISO**: International Organization for Standardization
- **LAT**: Lot Acceptance Testing
- **MASCD:** Mission Assurance Standards and Capabilities Division
- **MIL**: Military
- **NEPP:** NASA Electronic Parts and Packaging Program
- **OSMA:** NASA Office of Safety and Mission Assurance
- **PDA**: Percent Defect Allowable
- **PMA**: Prohibited Material Analysis
- **PPM**: Parts Per Million
- **QML**: Qualified Manufacturers List
- **QUAL:** Qualification
- **SCRN:** Screening
- **SMD:** Surface Mount Devices
- **SPEC:** Specification
- **TCR:** Temperature Coefficient of Resistance
- **TTF:** Time to Failure

Overview of AEC-Q200

- **AEC:** Automotive Electronics Council
- **AEC-Q:** Automotive Qualified

- **AEC-Q200:** Stress Test Qualification For Passive Components [2]

  - **Table 7** : Stress Qualifications for Resistors
  - **Table 7A** : Resistors Process Change Qualification Guidelines for the Selection of Tests
  - **Table 7B-5**: Acceptance Criteria for SMD Chip Resistors

- Not required:
  - Traditional Screening (per EEE-INST-002 or MIL-SPECs)
  - Lot Acceptance Testing
- Parts are qualified once and then remain qualified as long as manufacturing process remains the same.
- Manufacturing Process Change Notifications are required and re-qualification is based on applicable tests.
- Other quality control processes are left up to the discretion of the manufacturer.

AEC-Q200 and EEE-INST-002

NEPP Study **Evaluation of Automotive Grade** **Resistors for Space**	**Test 1** Screening to EEE-INST-002, Table 2A	**Test 2** Life Test (shall be from 100% screened samples)	**Test 3** Accelerated Life Test (shall be from 100% screened samples)								
EEE-INST-002 [3] **Table 3A : Fixed Resistor Qualification Requirements**	**Group 1** Screening to Table 2A	**Group 2** Solderability Resistance to Solvents	**Group 3** Thermal Shock Resistance Temperature Characteristic Low Temperature Storage Low Temperature Operation Short-time Overload Terminal Strength Hermetic Seal	**Group 4** Dielectric Withstanding Voltage Insulation Resistance Moisture Resistance Terminal Strength Hermetic Seal	**Group 5** Shock Vibration, High Frequency Hermetic Seal	**Group 6** Life	**Group 7A** Resistance to Bonding Moisture Resistance	**Group 7B** Adhesion	**Group 8** Voltage Coefficient	**Group 9** High Temperature Exposure	**Group 10** Thermal Outgassing
AEC-Q200 (Rev E)[2] **Table 7B-5: Acceptance Criteria for SMD Chip Resistors**	**Test 1** Initial Limits (Pre- and Post Stress Electrical Test)	**Test 3** High Temperature Exposure (storage)	**Test 4** Temperature Cycling	**Test 7** Biased Humidity	**Test 8** Operational Life	**Test 9** External Visual	**Test 10** Physical Dimensions	**Test 12** Resistance to Solvents	**Test 13** Mechanical Shock	**Test 14** Vibration	**Test 15** Resistance to Soldering Heat
AEC-Q200 (Rev E) ***continued*** **Table 7B-5: Acceptance Criteria for SMD Chip Resistors**	**Test 17** ESD	**Test 18** Solderability	**Test 19a** Elec. Char. @25°C	**Test 19b** Elec. Char. @Min. operating temp	**Test 19c** Elec. Char. @Max operating temp.	**Test 20** Flammability	**Test 21** Board Flex (SMD)	**Test 22** Terminal Strength (SMD)	**Test 23** Flame Retardance		

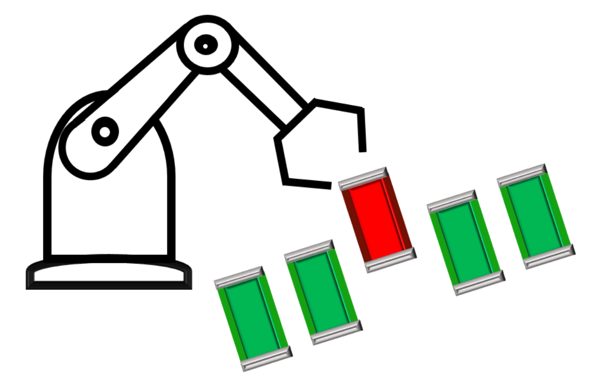
[2] *Stress Test Qualification for Passive Components.* AECQ -200 Rev. E. Automotive Electronics Council. March 2023.
[3] *Instructions for EEE Parts Selection, Screening, Qualification, and Derating.* EEE-INST-002. NASA/TP—2003–212242. NASA Goddard Space Flight Center. April 2008.

Resistor/Part Numbers Evaluated

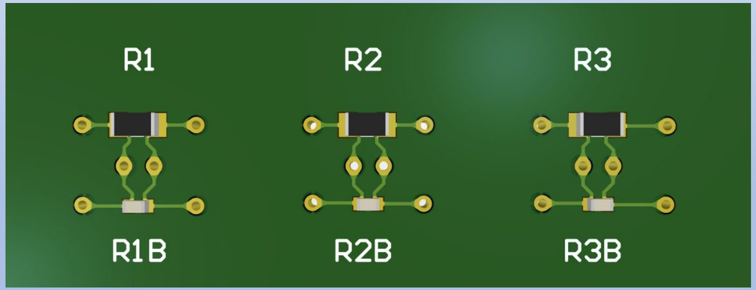
								Testing Performed		
Group ID (Part Number)	Manufacturer	Resistance (Ω)	Tolerance (%)	Wattage (W)	Chip Size	Resistor Technology	Maximum Rated Operating Temperature (°C)	Screening	Life	Accelerated Life
A	A	0.1	0.5%	1	2512	Metal Strip	+170°C	✓	✓	✗
B	A	49.9	1%	0.25	1206	Thick Film	+155°C	✓	✓	✗
C	B	49.9	1%	0.1	0603	Thick Film	+155°C	✓	✓	✗
D	A	1,000	1%	0.25	1206	Thick Film	+155°C	✓	✗	✗
E	B	1,000	1%	0.1	0603	Thin Film	+155°C	✓	✓	✓
F	A	10,000	1%	0.25	1206	Thin Film	+155°C	✓	✓	✗
G	B	10,000	1%	0.1	0603	Thin Film	+155°C	✓	✓	✗
H	A	100,000	1%	0.25	1206	Thick Film	+155°C	✓	✗	✗
I	C	100,000	1%	0.1	0603	Thick Film	+155°C	✓	✗	✓

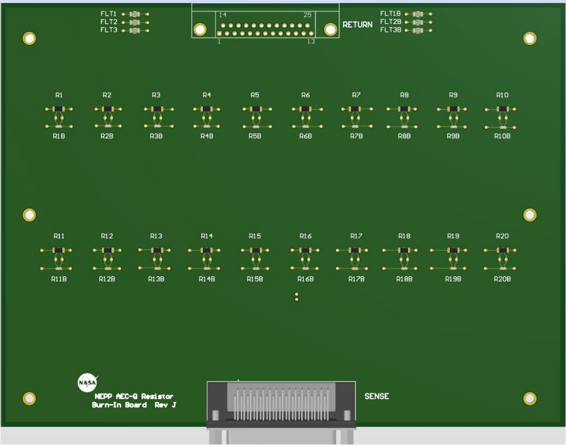
Testing Performed

Screening

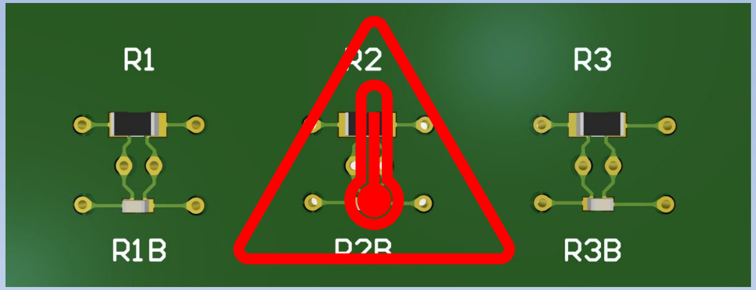


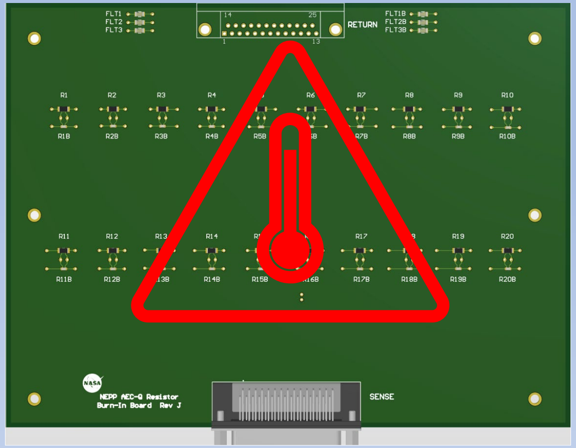
Life Test

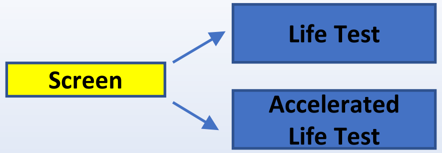




Accelerated Life Test

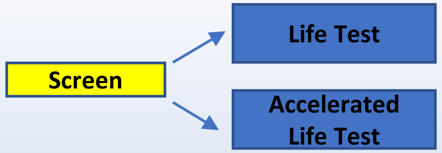





Screen
Life Test
Accelerated Life Test

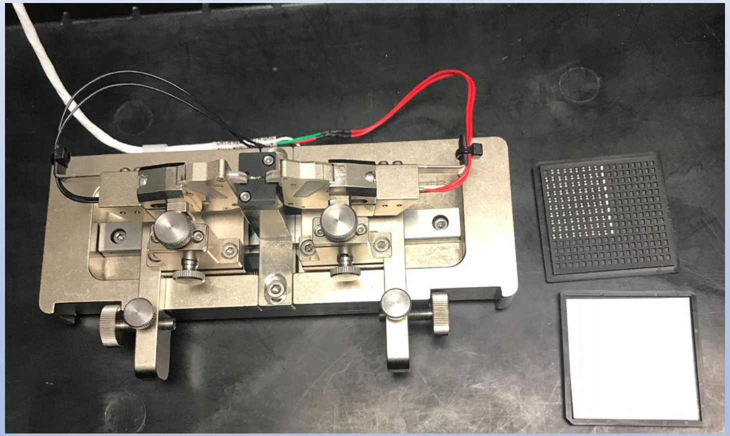
Screening Test Flow

Test	Test Description	Standard
[1] Initial External Visual Examination	External visual examination on 13 samples at 10X-30X.	EEE-INST-002, Table 2A MIL-PRF-55342J, para 4.8.1.1
[2] Mechanical Examination	Physical dimensions of 3 samples.	Manufacturer Drawing
[3] Prohibited Material Analysis	Prohibited Material Analysis on 3 samples.	GSFC S-311-M-70, Requirement 4.1.3
[4] Initial DC Resistance Measurements	DC Resistance at 22°C ± 3°C	MIL-STD-202, Method 303
[5] Thermal Shock	Thermal shock (100 cycles). High temperature - max. rated operating Low temperature - min. rated operating	MIL-STD-202, Method 107
[6] Final DC Resistance Measurements	DC Resistance at 22°C ± 3°C	MIL-STD-202, Method 303
[7] Final External Visual Examination	External visual examination on 13 samples 10X-30X.	EEE-INST-002, Table 2A MIL-PRF-55342J, para 4.8.1.1
[8] Percent Defective Allowable (PDA)	Level 1 : 5%	EEE-INST-002, Table 2A

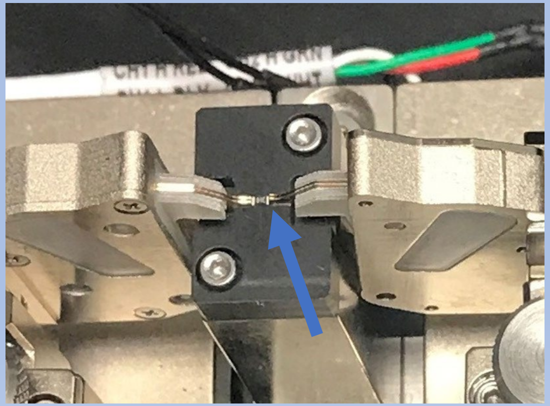


Screening Test Setup : DC Resistance

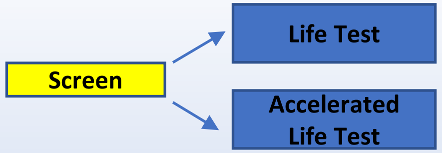
- DC Resistance Test per MIL-STD-202, Method 303 [4].
- Performed on all samples (Groups A – I)
- Measurements obtained pre and post thermal shock at room temperature
- Four-Wire Kelvin measurement method used (voltage is measured at the DUT and voltage drop in test leads is eliminated)
- Pass/Fail Criteria per datasheet specification limits



DCR Test Fixture



Device Under Test (DUT)


Screen

Life Test

Accelerated Life Test

Screening Test Setup : Thermal Shock

- Thermal Shock Test : per MIL-STD-202 Method 107 [5]
- Performed on all samples (Groups A – I)
- Test Conditions:
    - 100 cycles
    - -55°C to +125°C
    - 30-minute dwell time in air at temperature extremes

Test Pattern

Temp PV

H-Temp CHB +128°C

-56°C

L-Temp CHB -59°C

Set Point

H-Temp CHB +128°C Auto Manu

Test Area

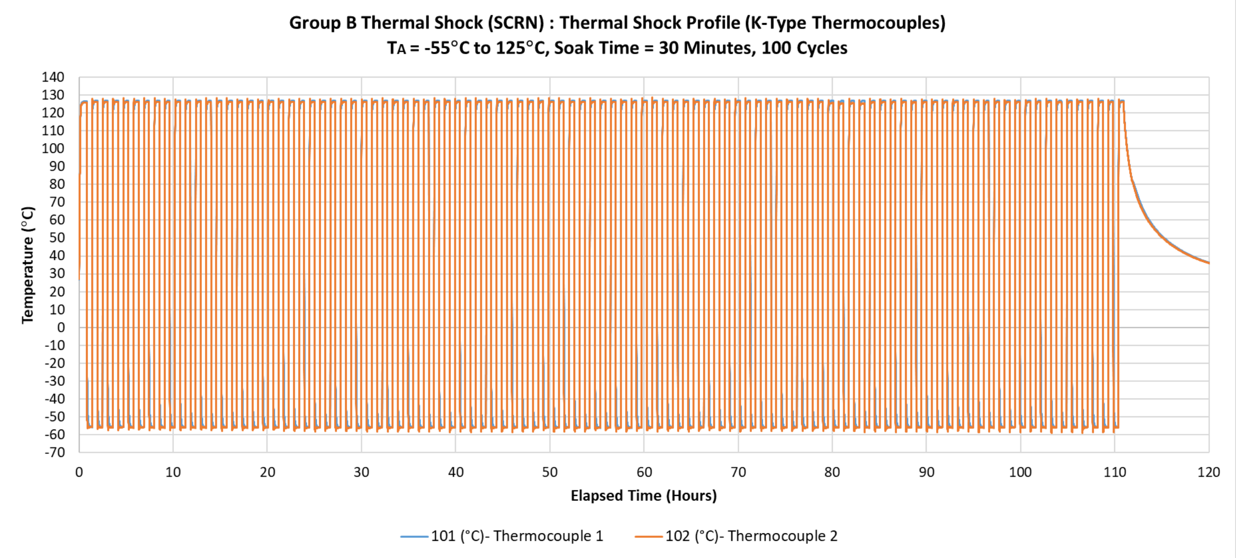
Hi Temp Exp +126°C

Low Temp Exp -56°C

L-Temp CHB -56°C Auto Manu

Def Cycle Count ----/---- times

Thermal Shock Chamber



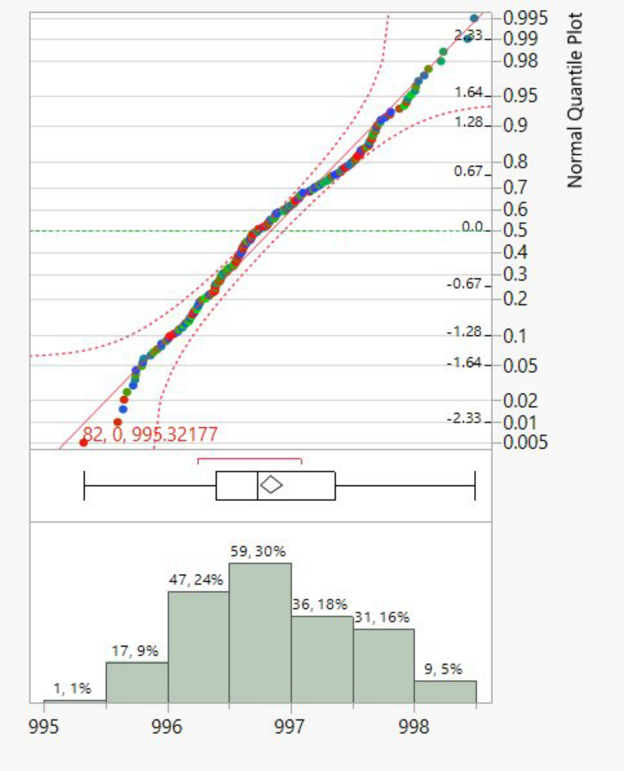
Thermal Shock Profile (Group B)

Screen

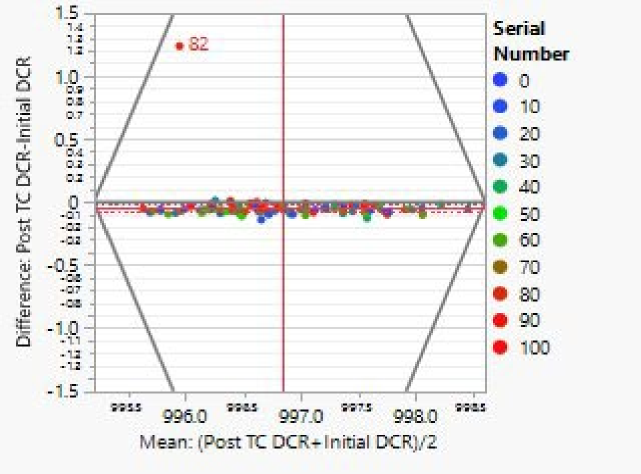
Life Test

Accelerated Life Test

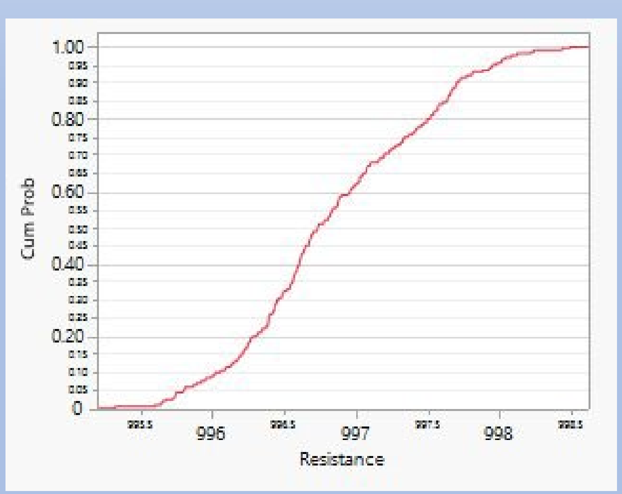
Screening Test Data/Results
DC Resistance Distribution (1k Ω) : Group D



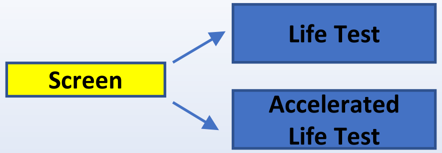
Normal Quantile Plot



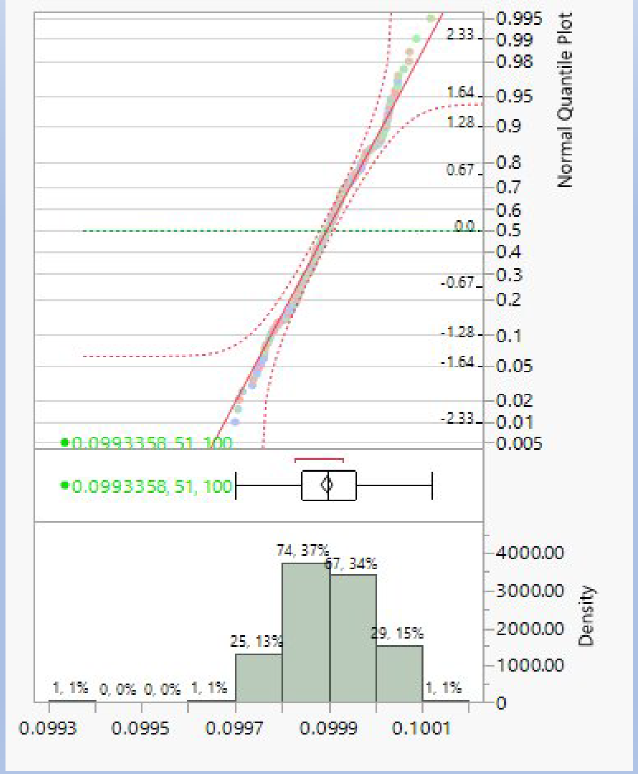
Mean Difference Plot



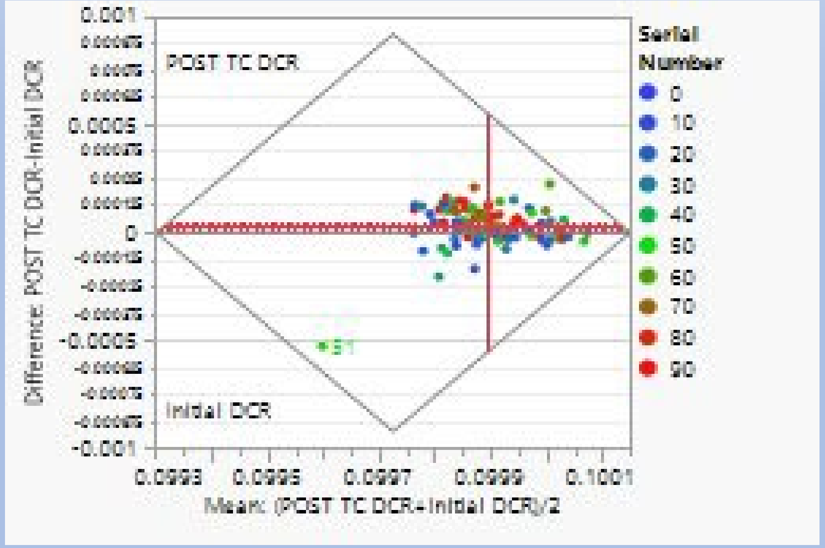
CDF Plot



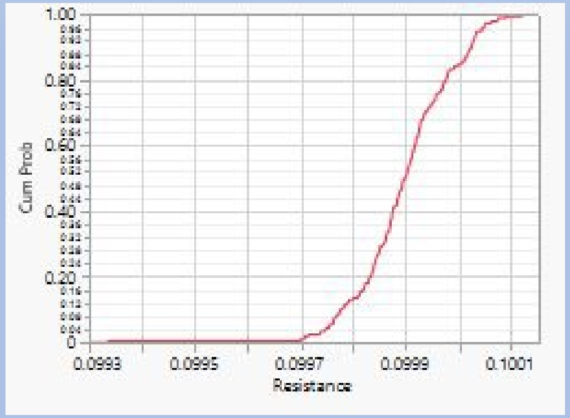
Screening Test Data/Results
DC Resistance Distribution (0.1 Ω) : Group A



Normal Quantile Plot



Mean Difference Plot



CDF Plot

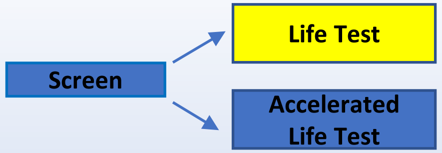
Screen

Life Test

Accelerated Life Test

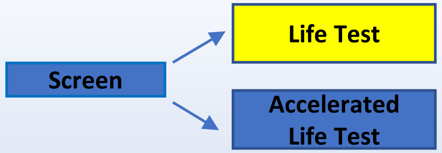
Screening Test Summary

Group ID	Resistance (Ω)	Tolerance (%)	Limits (Ω)	Total Qty Submitted	Qty Pass : Initial DCR (Pre-Thermal Shock)	Qty Fail : Initial DCR (Pre-Thermal Shock)	Qty Pass : Final DCR (Post-Thermal Shock)	Qty Faill : Final DCR (Post-Thermal Shock)	Notes
A	0.1	0.5%	**0.0995 Ω** ≤ R ≤ 0.1005 Ω	*99	99	0	98	1	Serial Number 51 ***failed final DCR test*** (below data sheet limit, ***SN 51 = 0.09934 Ω***) **Qty = 99 (shipping issues)*
B	49.9	1%	49.401 Ω ≤ R ≤ 50.399 Ω	100	100	0	100	0	All samples passed initial and final DCR measurements per datasheet.
C	49.9	1%	49.401 Ω ≤ R ≤ 50.399 Ω	100	100	0	100	0	All samples passed initial and final DCR measurements per datasheet.
D	1000	1%	990 Ω ≤ R ≤ 1010 Ω	100	100	0	100	0	All samples passed initial and final DCR measurements per datasheet.
E	1000	1%	990 Ω ≤ R ≤ 1010 Ω	100	100	0	100	0	All samples passed initial and final DCR measurements per datasheet.
F	10000	1%	9,900 Ω ≤ R ≤ 10,100 Ω	100	100	0	100	0	All samples passed initial and final DCR measurements per datasheet.
G	10000	1%	9,900 Ω ≤ R ≤ 10,100 Ω	100	100	0	100	0	All samples passed initial and final DCR measurements per datasheet.
H	100000	1%	99,000 Ω ≤ R ≤ 101,000 Ω	*62	62	0	62	0	All samples passed initial and final DCR measurements per datasheet. **Qty = 62 (shipping issues)*
I	100000	1%	99,000 Ω ≤ R ≤ 101,000 Ω	100	100	0	100	0	All samples passed initial and final DCR measurements per datasheet.



Life Test Flow

Test	Test Description	Standard
[*] Screening to EEE-INST-002, Table 2A	Screening.	EEE-INST-002, Table 2A
[1] Printed Circuit Board : Preparation/Assembly	Reflow samples onto PCB.	N/A
[2] Printed Circuit Board : Initial External Visual Examination	Verify samples were properly reflowed. External visual examination at 10X-30X.	MIL-PRF-55342J, para 4.8.1.1
[3] Initial DC Resistance Measurements *(0 Hours)*	DC Resistance at 22°C ± 3°C.	MIL-STD-202, Method 303
[4] Life Test (1,000 Hours) *DCR Measurements Obtained: 0, 100, 250, 500 and 1,000 hours*	1,000 Hour Life Test at 70°C, 1x rated power (90 minutes ON, 30 minutes OFF). DC Resistance at 22°C ± 3°C.	MIL-STD-202, Method 108
[5] Final DC Resistance Measurements *(1,000 Hours)*	DC Resistance at 22°C ± 3°C. Delta Resistance (ΔR) per datasheet specification.	MIL-STD-202, Method 303
[6] Printed Circuit Board : Final External Visual Examination	External visual examination at 10X-30X.	MIL-PRF-55342J, para 4.8.1.1



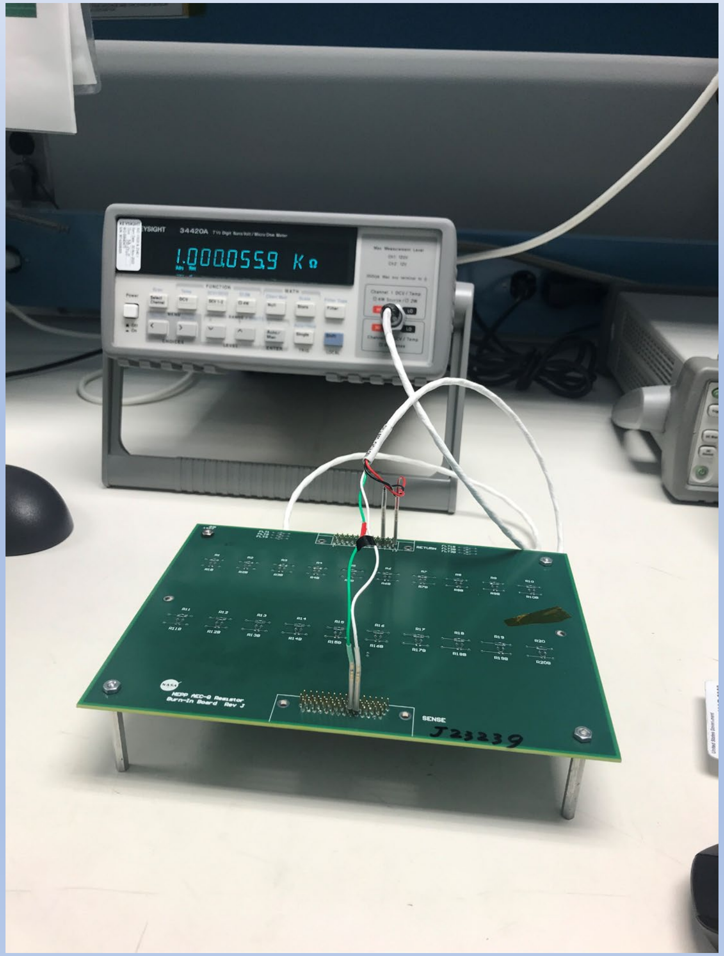
Screen

Life Test

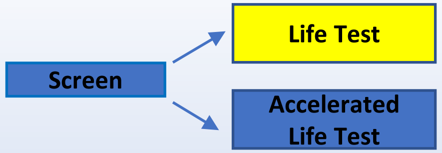
Accelerated Life Test

Life Test Setup

Group C and Group E samples in test chamber

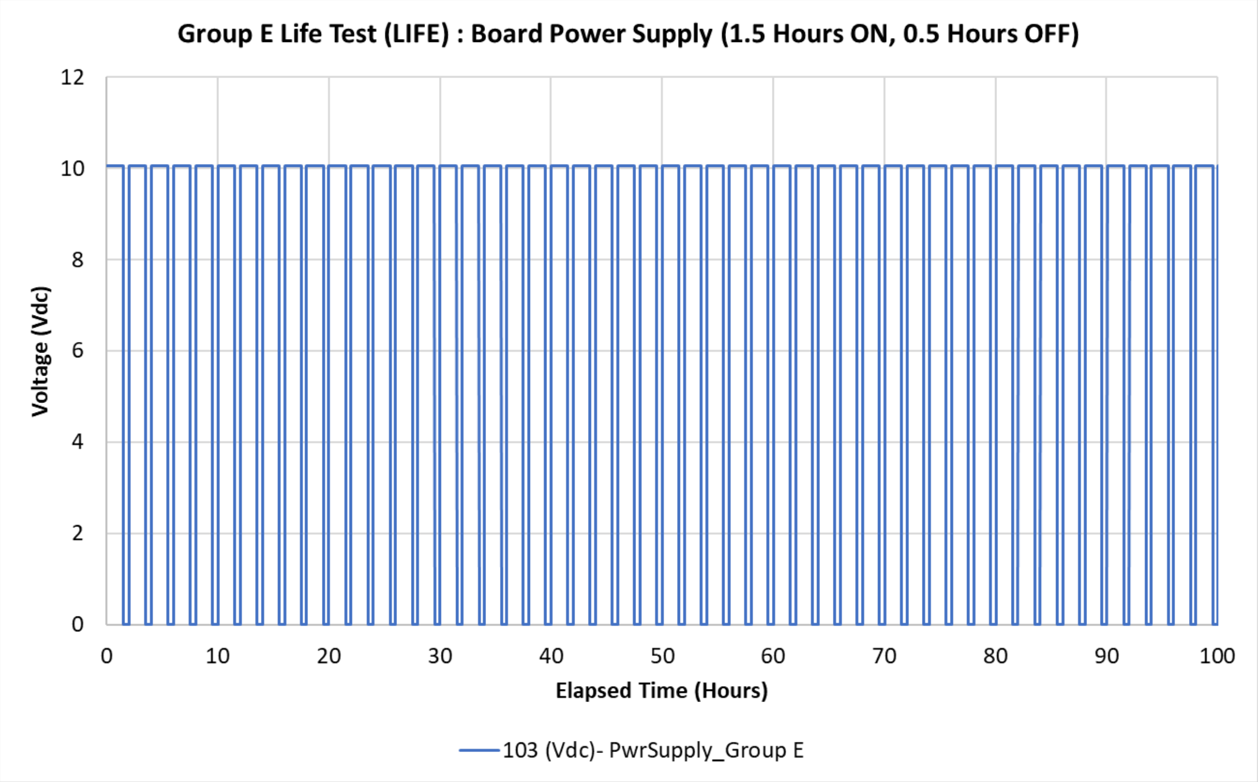


Test setup for obtaining DCR measurements



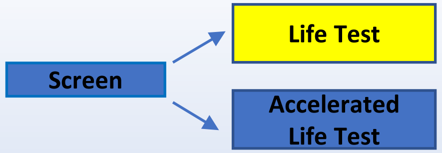
Life Test Criteria

- Applied Voltage: $V_{rms} = \sqrt{PR}$ or the maximum working voltage (V_{max}) per the datasheet whichever is less severe.
- Cyclical 90 min power ON and 30 min OFF
- Total test time: 1,000 hours
- Inspection times for room temperature DCR: 0, 100, 250, 500, and 1,000 hours
- 1,000-hour resistance shift failure criteria was tolerance on the datasheets (0.5% for Group A, 1% all other Groups).
- Degradation analysis and Time to Failure (TTF) projection:
    - Degradation Model: Linear
    - Fitted Distributions to Projected Time To Failure (TTF): Lognormal & Weibull shown on Lognormal probability paper.
    - Event Plots for Projected Time To Failure (TTF) are also shown.



Testing and Analysis Specifications

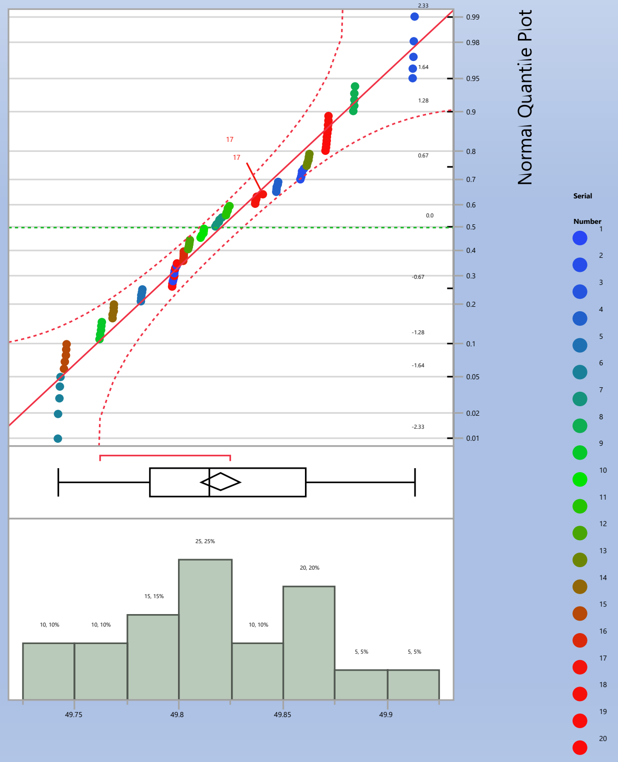
Displaying 100 hours out of the 1,000-hour Life Test (Group E)

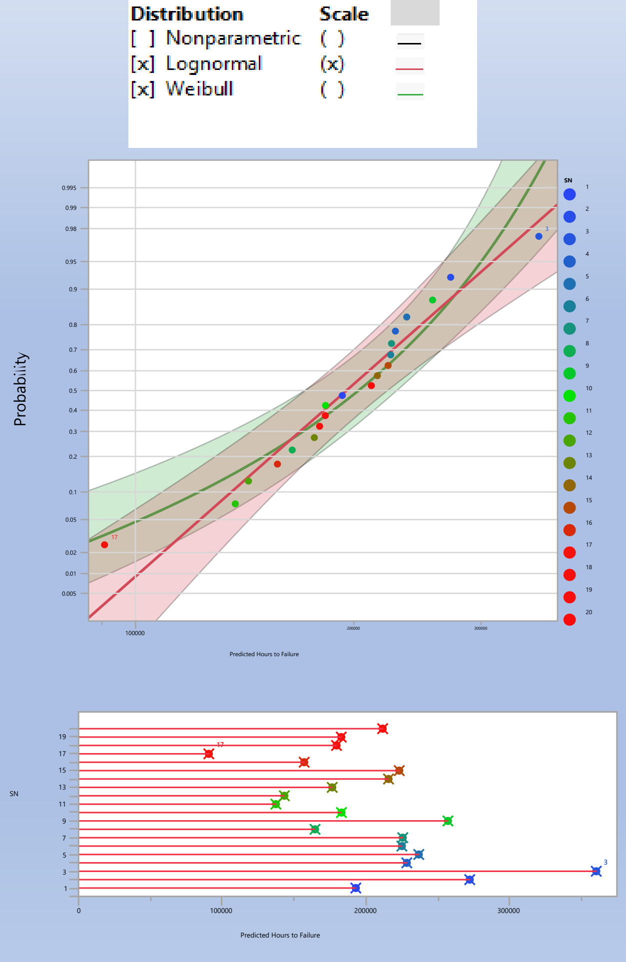

Screen

Life Test

Accelerated Life Test

Life Test Data/Results
DC Resistance Distribution (49.9 Ω) : Group B



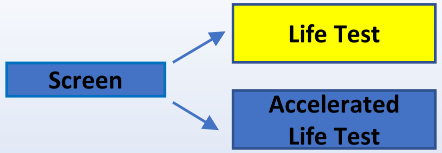


Distribution	Scale
[ ] Nonparametric	( )
[x] Lognormal	(x)
[x] Weibull	( )

Normal Quantile Plot

Mean Difference Plot

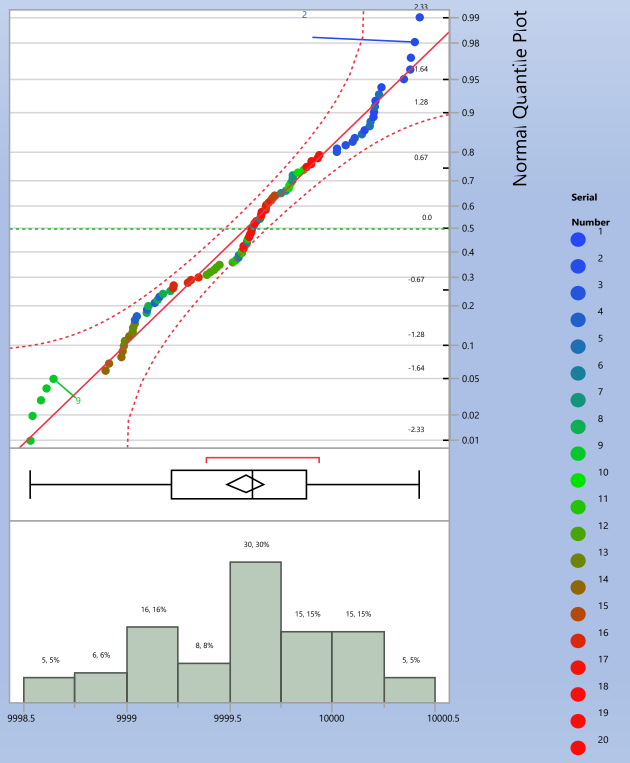
CDF & Event Plots


Screen

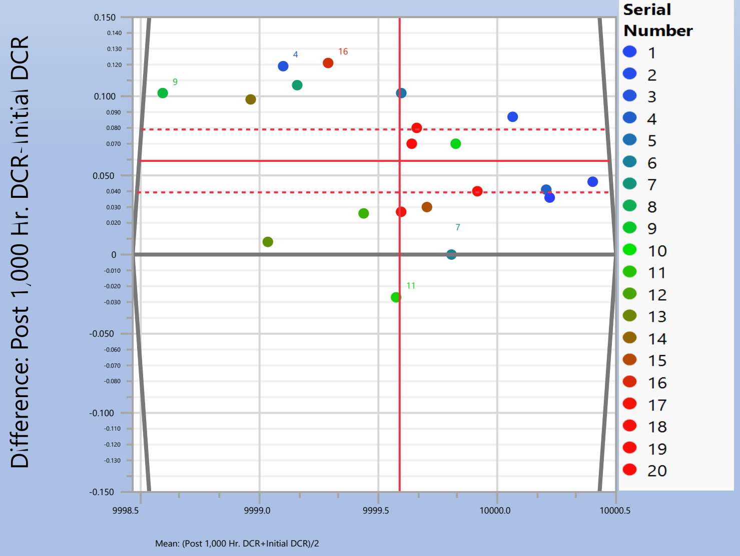
Life Test

Accelerated Life Test

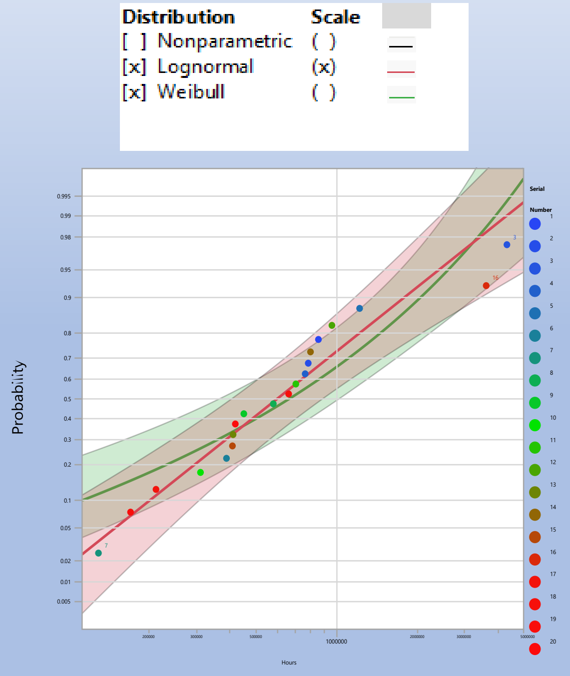
Life Test Data/Results
DC Resistance Distribution (10k Ω) : Group G

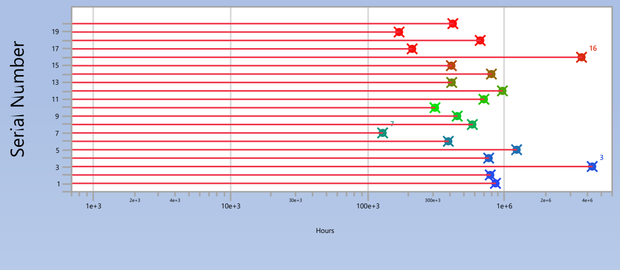


Normal Quantile Plot

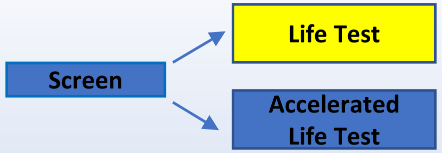


Mean Difference Plot





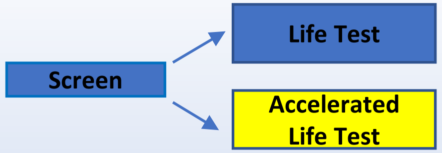
CDF & Event Plots



Life Test Data/Results Summary

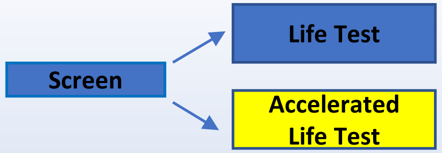
Group ID	Earliest Projected Failure (yrs)	Projected TTF 50% (yrs)
A	3.7	6
B	10	23
C	2.5	9
E	8	15
F	97	203
G	14	80

Summary of Life Test resistance shift degradation analysis.
20 resistors tested per Group.



Accelerated Life Test Flow

Test	Test Description	Standard
[*] Screening to EEE-INST-002, Table 2A	Screening	EEE-INST-002, Table 2A
[1] Printed Circuit Board : Preparation/Assembly	Reflow samples onto PCB.	N/A
[2] Printed Circuit Board : Initial External Visual Examination	Verify samples were properly reflowed. External visual examination at 10X-30X.	MIL-PRF-55342J, para 4.8.1.1
[3] Initial DC Resistance Measurements *(0 Hours)*	DC Resistance at 22°C ± 3°C.	MIL-STD-202, Method 303
[4] Life Testing (500 Hours) *DCR Measurements Obtained: 0, 100, 250 and 500*	Various life tests were performed: *@ 70°C: 0%, 70%, 120% and 150% applied power.* *@ 155°C: No applied power.* Each Life Test had 15 resistor samples.	Modified MIL-STD-202, Method 108
[5] Final DC Resistance Measurements *(500 Hours)*	DC Resistance at 22°C ± 3°C.	MIL-STD-202, Method 303
[6] Printed Circuit Board : Final External Visual Examination	External visual examination at 10X-30X.	MIL-PRF-55342J, para 4.8.1.1



Accelerated Life Temperature Models

Arrhenius based model put forth by R. W. Kuehl [9]:

$$\ln\frac{\Delta \mathrm{R}}{\mathrm{R}[\mathrm{ppm}]} = \mathrm{f}(\mathrm{t})\mathrm{R}[\mathrm{ppm} * \mathrm{K}] * \frac{1}{\mathrm{T}} + \ln\left(\frac{\Delta \mathrm{R}}{\mathrm{R}}\right)_{\mathrm{pot}}(t)[\mathrm{ppm}]$$

$$\ln(\Delta \mathrm{R}\ /\ \mathrm{R}\,[\mathrm{ppm}]) = (B * \ln(t) + C)\frac{1}{T} + \mathrm{D} * \ln \mathrm{t} + \mathrm{F}$$

Arrhenius with temperature dependent power law degradation.

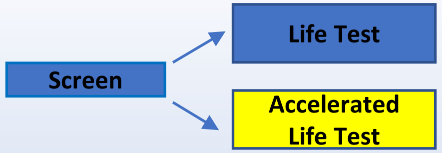
$$\frac{\Delta R}{R} = \mathrm{F}_1 t^{\left(\frac{B}{T}+D\right)} \cdot \mathrm{e}^{\frac{-E_a}{K_B T}}$$

$$\frac{\Delta R}{R} = \frac{\mathrm{t}}{\mathrm{t}_0} \cdot 2^{\frac{\mathrm{T}_1-\mathrm{T}_0}{30K}} \cdot \frac{\Delta \mathrm{R}}{\mathrm{R}_{\mathrm{t}_0,\mathrm{T}_0}}$$

$\frac{\Delta R}{R}$ ∝ t, Linear degradation

$$\frac{\Delta R}{R} = \mathrm{A}\frac{\mathrm{t}}{\mathrm{t}_0} \cdot e^{\frac{-E_a}{K_B}\left(\frac{1}{\mathrm{T}_0}-\frac{1}{\mathrm{T}_1}\right)} \cdot \frac{\Delta \mathrm{R}}{\mathrm{R}_{\mathrm{t}_0,\mathrm{T}_0}}$$

$\frac{\Delta R}{R}$ ∝ t, Linear with Arrhenius temperature dependance.



Single Mechanism Resistance Degradation Model

Degradation Model formula:

$$\frac{\Delta R}{R} = at^{n_1} e^{\frac{-n_1 E_a}{kT}} (p_1 + \%RP)^{n_2}$$

Where a, n_1, n_2, p_1 are fitting parameters, t is time, T is temperature in Kelvin, E_a is the activation energy and $\%RP$ is the percentage of rated power.

Model Assumptions: the model consists of a **power law time dependance**, an **Arrhenius temperature dependance,** and a **shifted power law percentage of rated power dependance**. This model assumes **independence** of the time, temperature and power.

Claim: The above **degradation model** is an Arrhenius temperature acceleration **time to failure** model with activation energy E_a.

Derivation: Suppose failure is defined to occur at a threshold resistance shift (e.g. 1%) and the time to failure follows an Arrhenius temperature dependance:

$$TTF = f(\%RP)\, e^{\frac{E_a}{kT}}$$

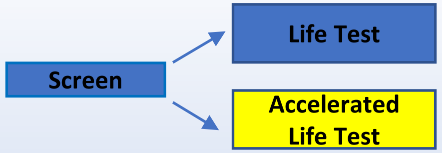
The resistance shift failure threshold occurs at the time to failure (TTF):

$$\frac{\Delta R}{R}_{Failure} = aTTF^{n_1} e^{\frac{-n_1 E_a}{kT}} (p_1 + \%RP)^{n_2}$$

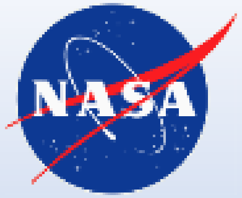
Solving for TTF:

$$TTF = \left(\frac{\Delta R}{R}_{Failure} \cdot \frac{1}{a(p_1 + \%RP)^{n_2}}\right)^{1/n_1} e^{\frac{E_a}{kT}}$$

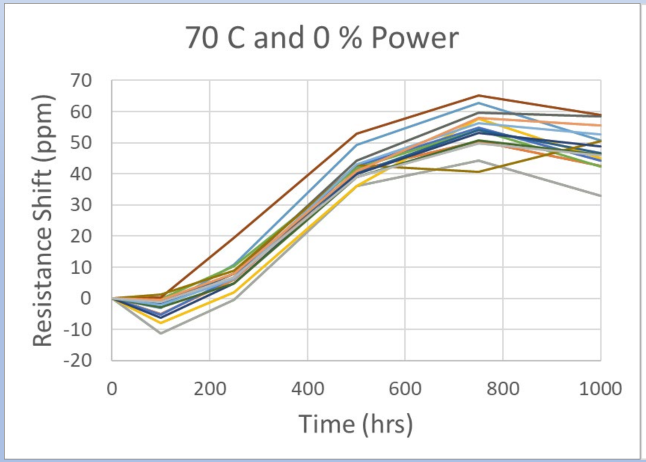
This is consisting of a function of only %RP and parameter constants with no dependance on temperature multiplied by an Arrhenius Law Temperature dependance factor as desired.

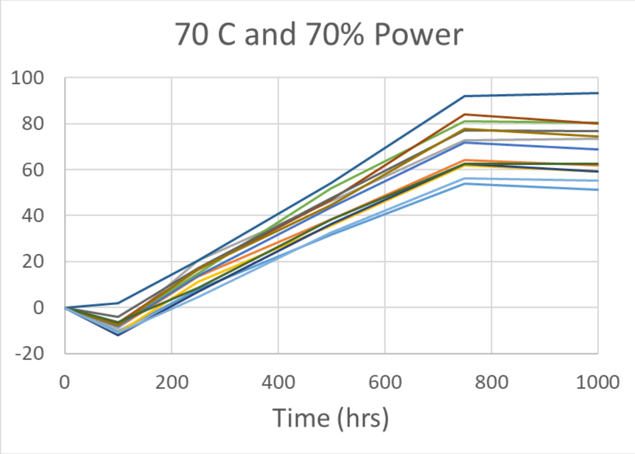


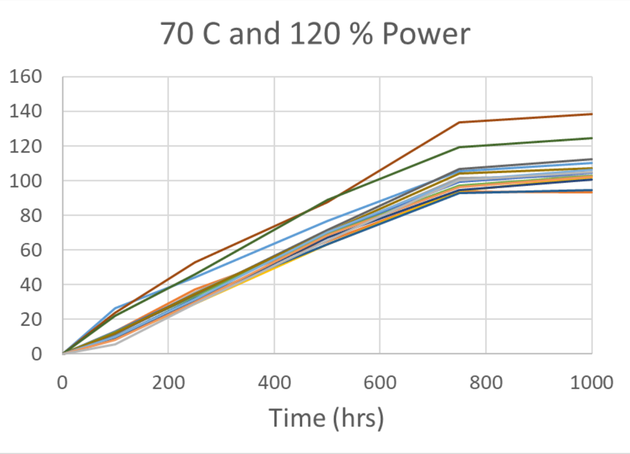
Accelerated Life Test Data/Results : Group E

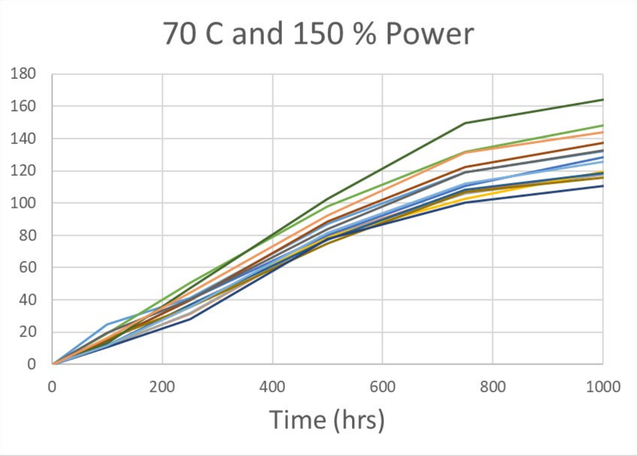


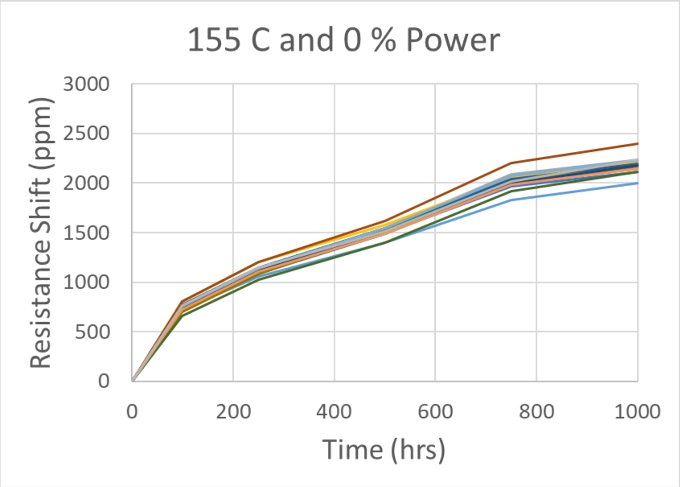
Resistance data has been corrected for ambient lab temperature using the measured Temperature Coefficient of Resistance (TCR) close to room temperature.

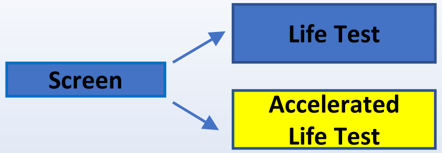

70 C and 0 % Power


70 C and 70% Power


70 C and 120 % Power


70 C and 150 % Power


155 C and 0 % Power

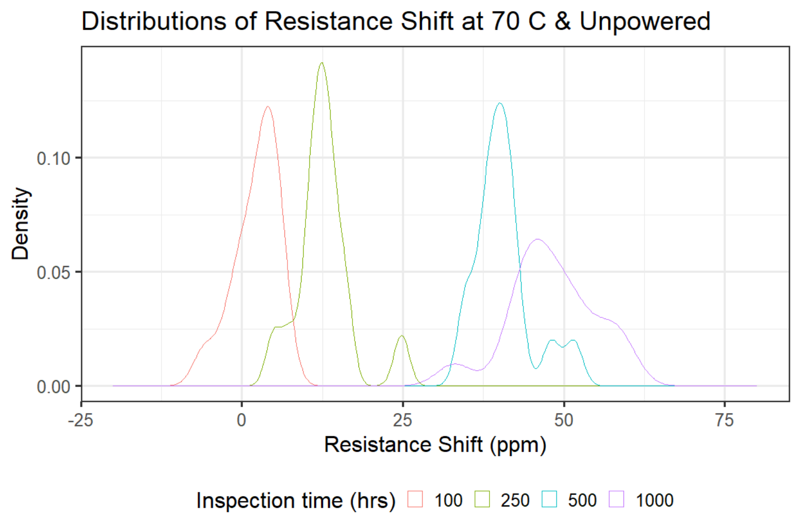


Screen

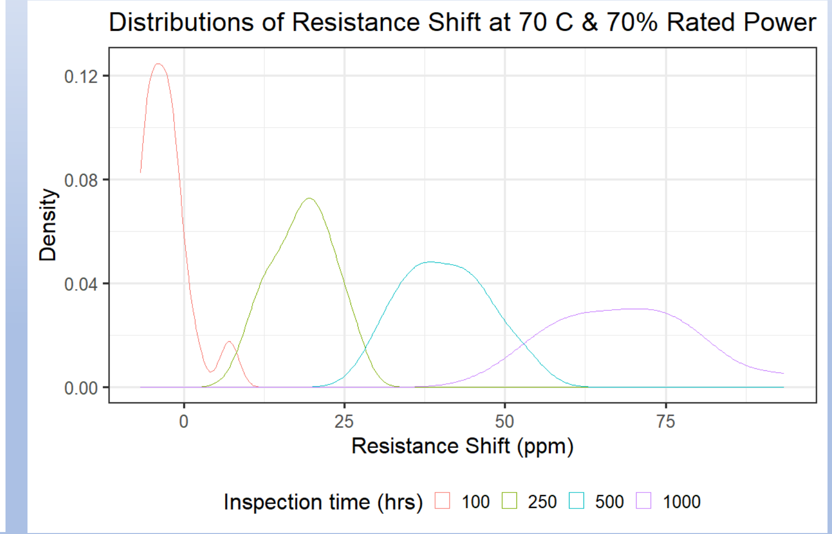
Life Test

Accelerated Life Test

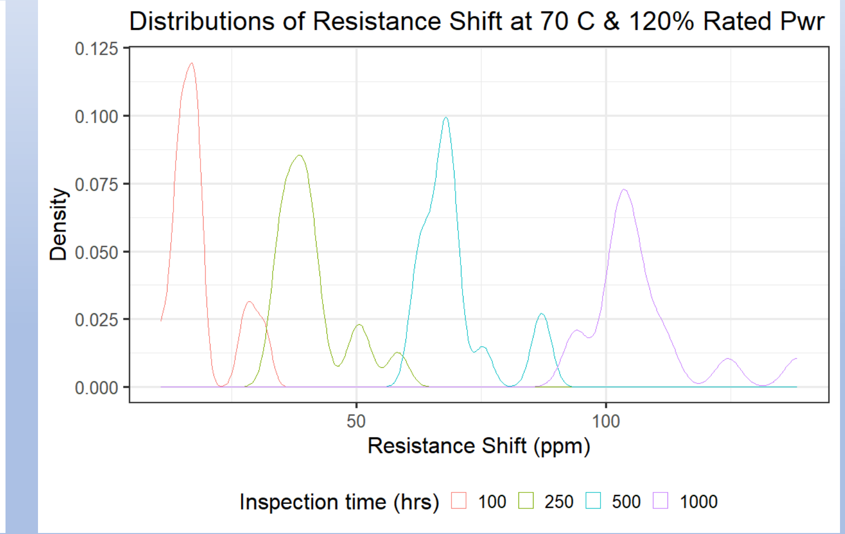
Group E: Accelerated Life Data



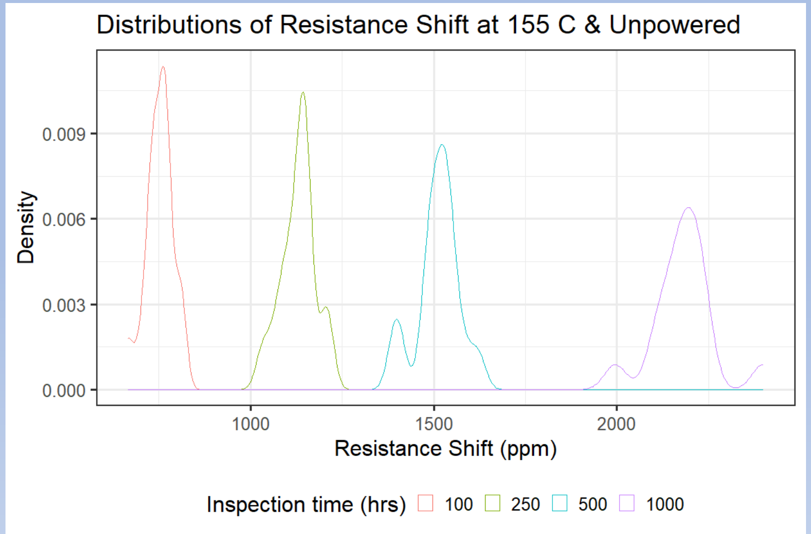
Distributions of Resistance Shift at 70 C & Unpowered



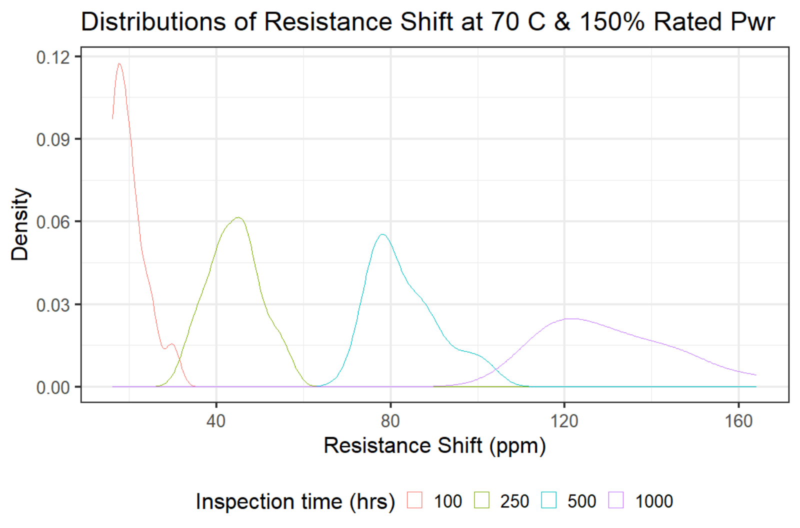
Distributions of Resistance Shift at 70 C & 70% Rated Power



Distributions of Resistance Shift at 70 C & 120% Rated Pwr



Distributions of Resistance Shift at 155 C & Unpowered



Distributions of Resistance Shift at 70 C & 150% Rated Pwr

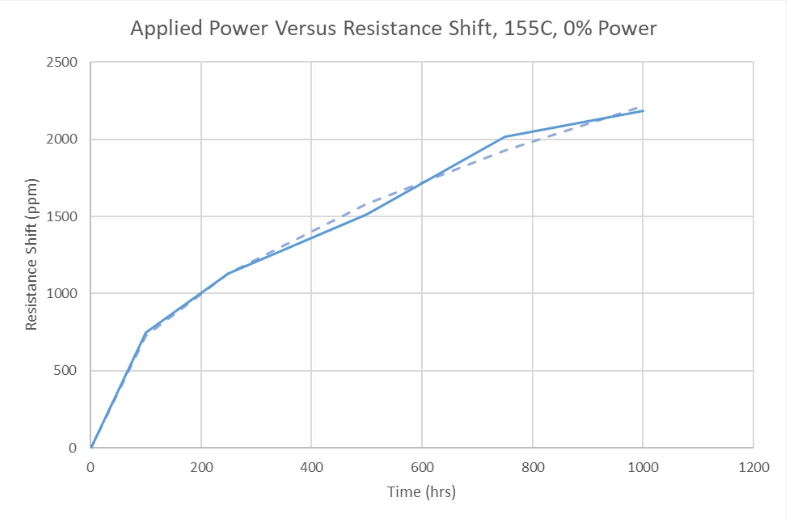
Screen
Life Test
Accelerated Life Test

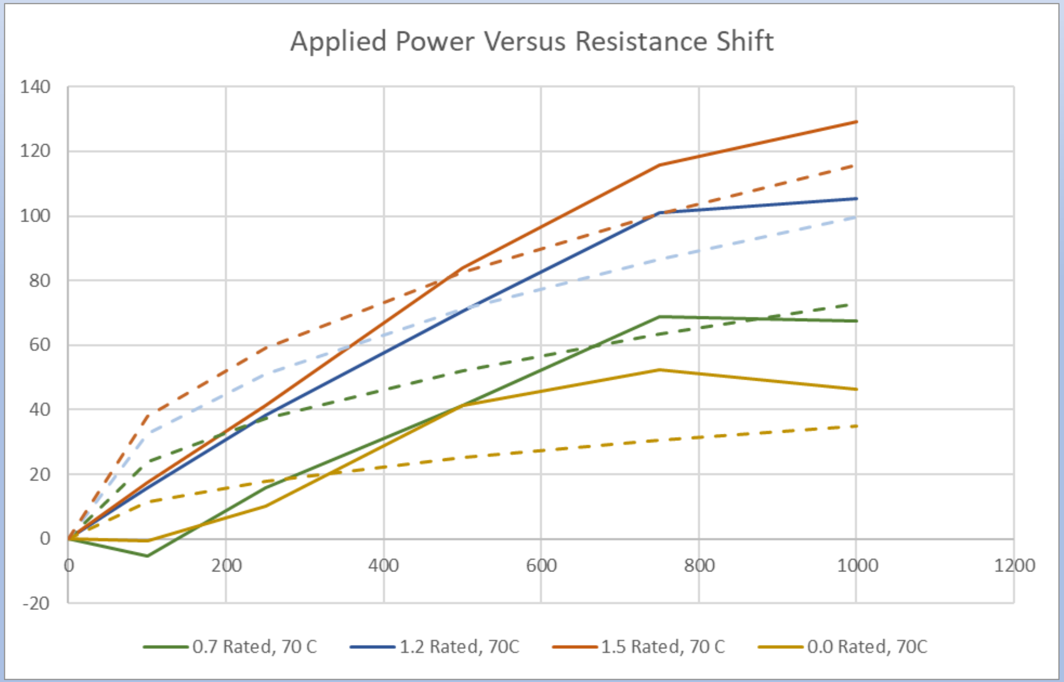
Group E: Accelerated Life Testing

Value (ohm)	Tolerance	Power (W)	Footprint	Type
1K	1%	0.1	603	Thin Film

Parameter	Estimate
E_a	1.273
n_1	0.485
n_2	0.970
a	$2.30 * 10^9$
p_1	0.619

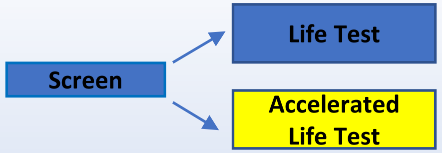
$$\frac{\Delta R}{R} = a t^{n_1} e^{\frac{-n_1 E_a}{kT}} (p_1 + \%RP)^{n_2}$$





There is departure from this single power law-based time dependance model seen by the fact that the degradation is lower than the model at first and then generally overshoots by the 1000-hour mark.

- Suggests either:
    - Power, Temperature, and Time dependance are not independent.
    - Competing mechanism present that disproportionately affect the low temperature and power data.

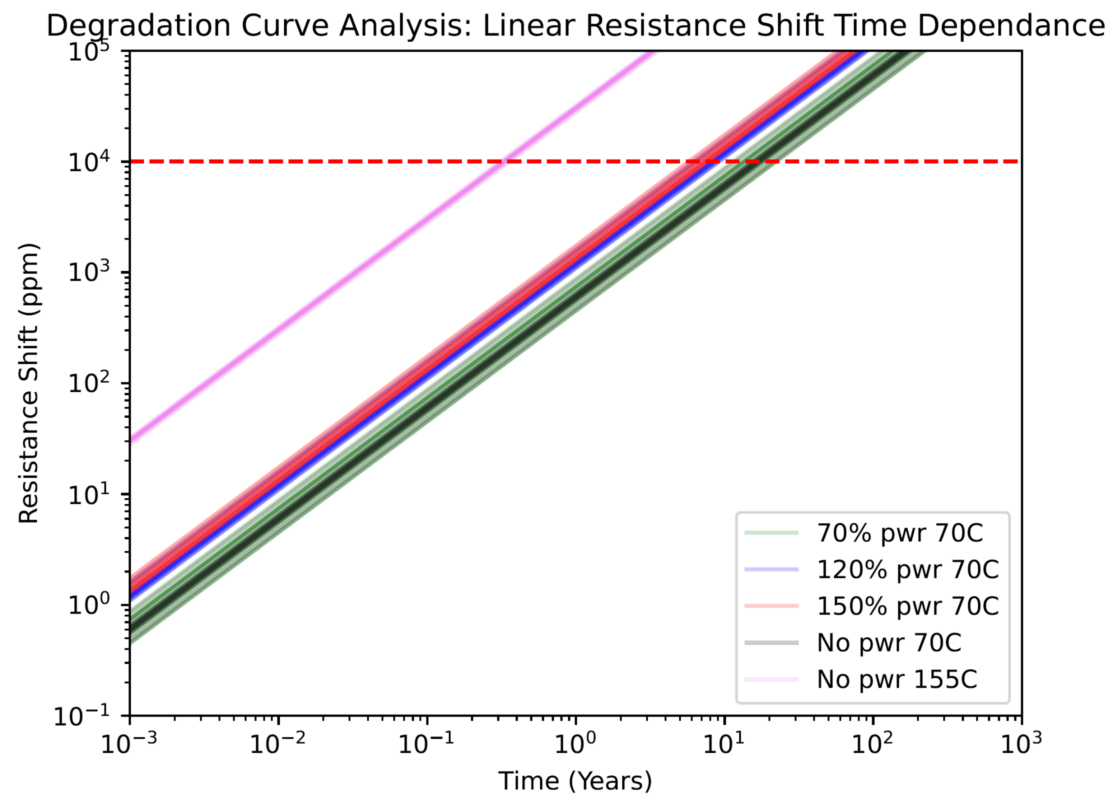


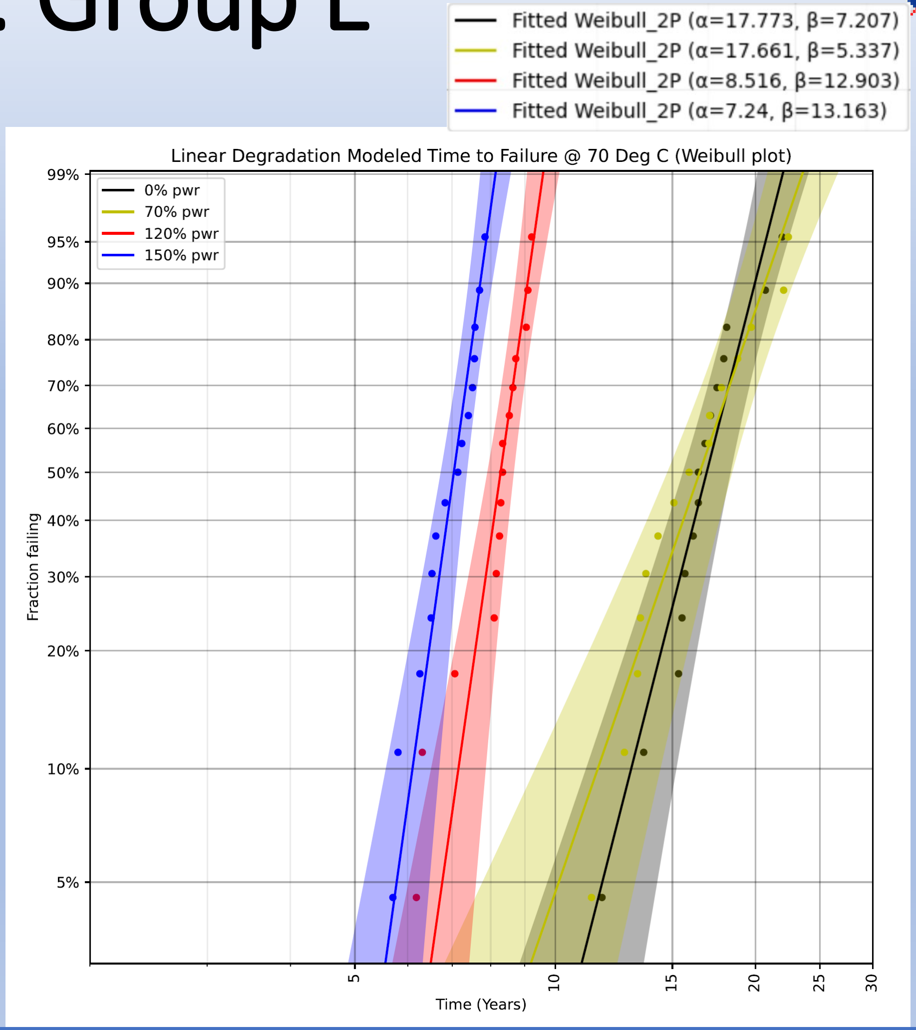
Screen

Life Test

Accelerated Life Test

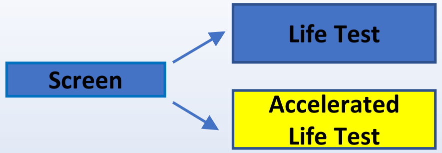
Accelerated Life Test Data/Results : Group E





Projected failure times are from where degradation curves meet the 1% shift failure threshold.

Projected failure times fit to Weibull distributions and plotted on probability paper. [8]

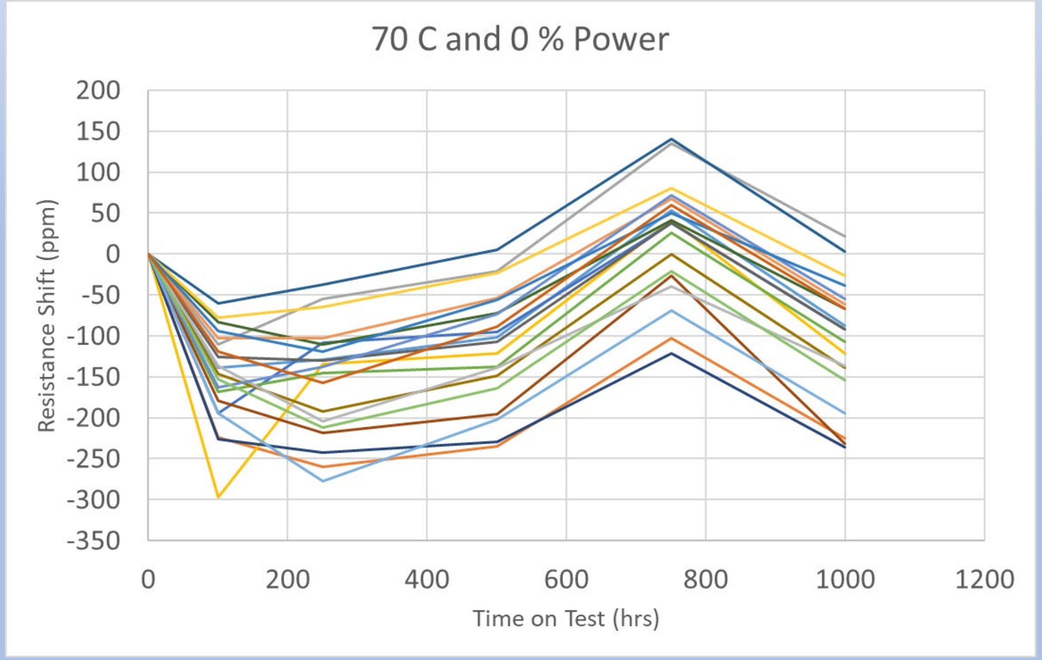


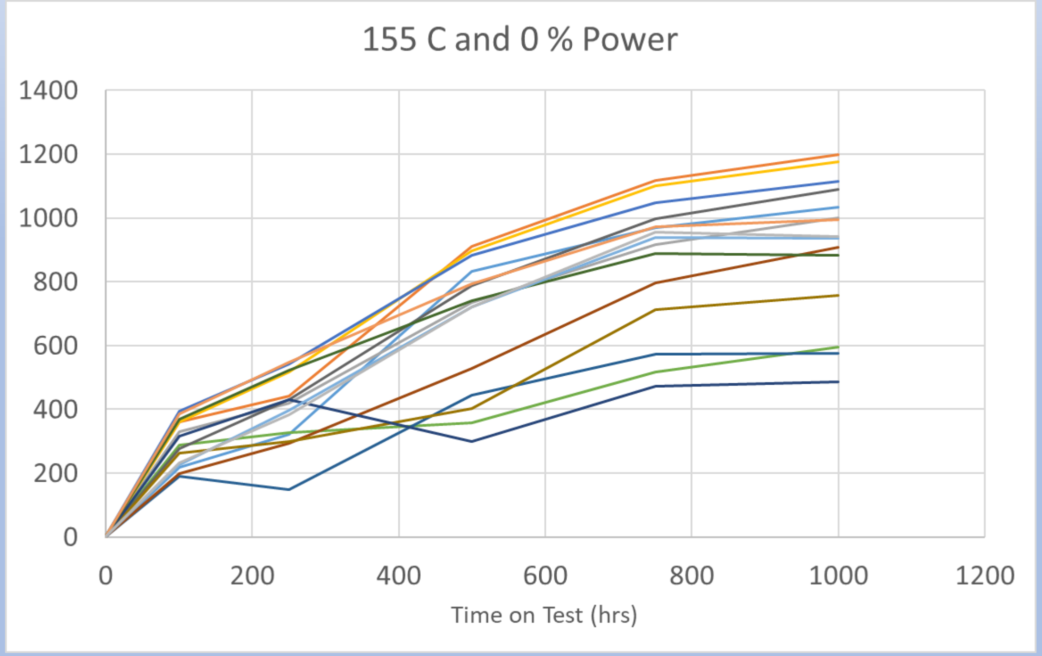
Screen

Life Test

Accelerated Life Test

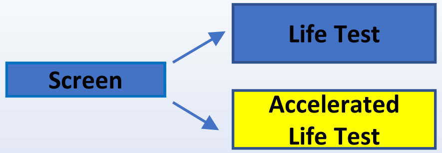
Accelerated Life Test Data/Results : Group H



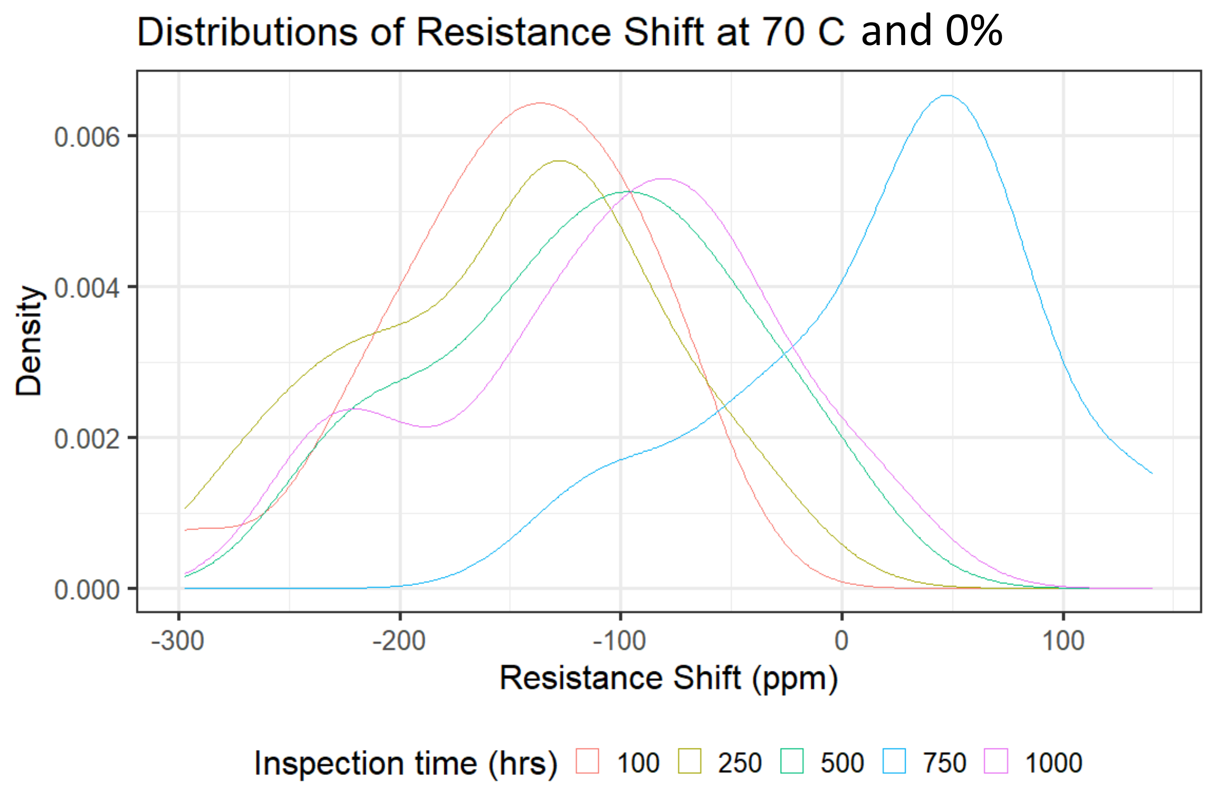


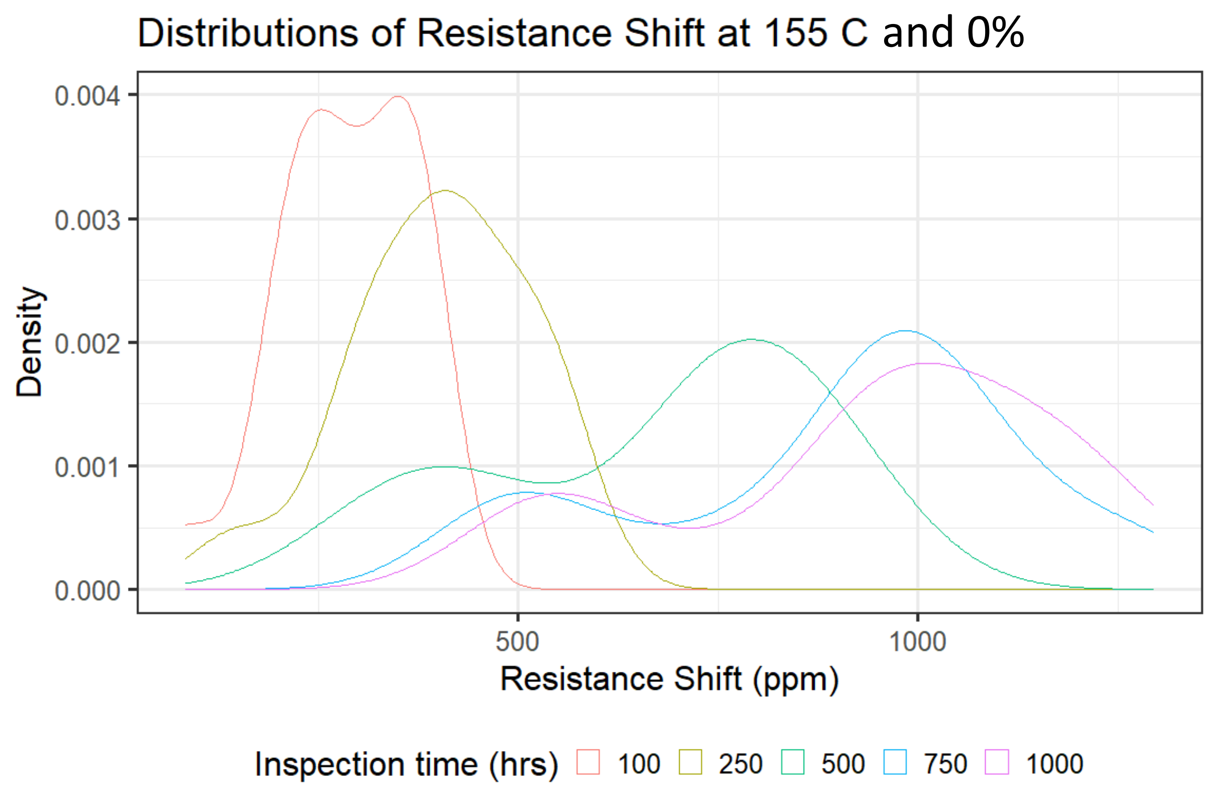
Resistance Degradation at 70 C for Group H

Resistance Degradation at 155 C for Group H



Group H: Accelerated Life Data





Group H Resistance Shift Density Estimates at 70°C.

Group H Resistance Shift Density Estimates at 155°C.

Screen

Life Test

Accelerated Life Test

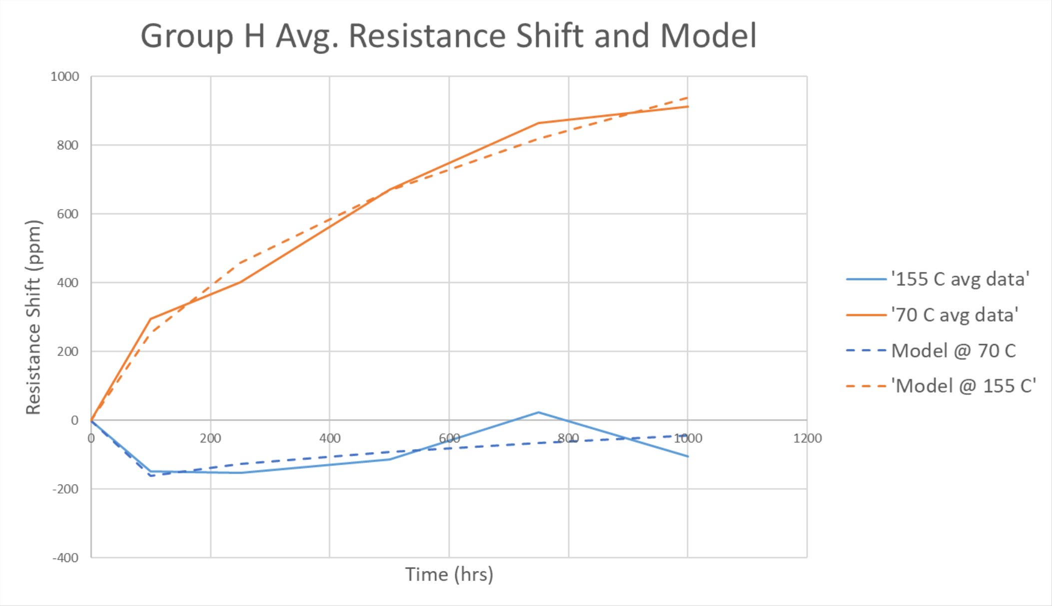
Group H: Accelerated Life Data

Value (ohm)	Tolerance	Power (W)	Footprint	Type
100K	1%	0.1	603	Thick Film

Data is suggestive of a competing mechanisms.

$$\frac{\Delta R}{R} = a_1 t^{n_1} e^{\frac{-n_1 E_a}{kT}} - a_2 t^{n_2} e^{\frac{-n_2 E_a}{kT}}$$

a1	n1	a2	n2	Ea
108206	0.374	249.5	0.0001	0.7



- a1,n1,a2,n2 were fit to the data while Ea = 0.7 was assumed.
- Single Mechanism Models are not appropriate for resistance shift data that changes sign.

Group H Average Resistance Shift with Fitted Competing Mechanism Model.

Summary and Future Work

- A single electrical failure was observed during the Screening Test (Group A, Serial Number 51) after the thermal shock test, with a out of tolerance DC resistance per the datasheet specifications. All remaining samples passed DC resistance measurements per the datasheet specification limits.

- Life Test based models show that some automotive resistors are likely to last 10 years at nominal usage conditions while others might fail earlier. The earliest projected time to failure in our data set is 2.5 years for the Group C samples, another early projected failing group are Group A samples with the earliest failure of 3.7 years.

- Extension of Life Tests is recommended to ensure that the proposed degradation models accurately reflect real long-term operating behavior.

- *Future Work* → Accelerated Life Test: Hot spot analysis on boards and resistors. Finishing accelerated life tests and analysis. 85 ℃ and 125 ℃ Life Tests can help confirm temperature dependance acceleration models. Combining Power and Temperature stress models for the Group E resistor. Finish Group I accelerated testing and analysis.

- *Future Work* → Life Test: Extend Life Tests of resistors and perform construction analysis on selected thin film and thick film automotive resistors to compare against MIL-STD equivalents.

- *Future Work* → Screening: Pulsed Power Screening tests of automotive resistors with thermal imaging.

Acknowledgements

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- Special thanks to: Jay Brusse, Susana Douglas, Lang Hua, Linh Le, Dr. Henning Leidecker, Timothy Mondy, Lyudmyla Ochs, and Christopher Tiu.

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[2] *Stress Test Qualification for Passive Components.* AECQ -200 Rev. E. Automotive Electronics Council. March 2023.

[3] *Instructions for EEE Parts Selection, Screening, Qualification, and Derating*. EEE-INST-002. NASA/TP—2003–212242. NASA Goddard Space Flight Center. April 2008.

[4] *Department of Defense Test Method Standard, Method 303, DC Resistance*. MIL-STD-202-303 Rev. H. Defense Logistics Agency. April 2015.

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[6] *General Specification for Resistor, Chip, Fixed, Film, No established Reliability, Established Reliability, Space Level.* MIL-PRF-55342 Rev. J. Defense Logistics Agency. May 2021.

[7] *Specification for the Performance of Destructive Physical Analyses*. S-311-M-70 Rev. D. NASA Goddard Space Flight Center. June 2015.

[8] Reid, M. (2022). Reliability – a Python library for reliability engineering (Version 0.8.2) [Computer software]. Zenodo. https://doi.org/10.5281/ZENODO.3938000

[9] R. W. Kuehl, *"Stability of thin film resistors - Prediction and differences base on time-dependent Arrhenius law,"* Microelectronics Reliability 49, pp. 51-58, 2009.

[10] T. Epp Schmidt et al, "*Long-Term Tin Whisker Risk Mitigation using a Conformal Coating."* NASA Goddard Space Flight Center NEPP Electronics Technology Workshop. June 2023.

[11] W. Nelson, “Weibull Analysis of Reliability Data with Few or No Failures,” *Journal of Quality Technology*, vol. 17, no. 3, pp. 140-146, Jul. 1985, DOI:10.1080/00224065.1985.11978953

Backup

Lab Test to Mission Life Estimation

- This is generally governed by the acceleration factor of the test compared to the mission environment. Suppose lab test is at 125 °C Rated Power while mission is at **55 °C**. Let **n=20** samples.

Arrhenius Acceleration:

- $ACC = \frac{TTF_{Mission}}{TTF_{test}} = \frac{Ae^{\frac{E_a}{kT_{Mission}}}}{Ae^{\frac{E_a}{kT_{Test}}}} = e^{\frac{E_a}{k}\left(\frac{1}{T_{Mission}} - \frac{1}{T_{Test}}\right)} = e^{0.7*11605\left(\frac{1}{55+273.15} - \frac{1}{125+273.15}\right)} = 77.7$

No Failures, 1-sided confidence limits, Weibull Scale parameter estimate [11]:

$$\widehat{\alpha} = \left(\frac{2\sum_{i=1}^{n} \mathrm{t_i}}{\chi^2(\mathrm{C}, 2\mathrm{r}+2)}\right)^{1/\beta}$$

Where C is the % confidence, r is the number of failures, t is the time on test for each sample and β is the Weibull shape parameter.

For **90% confidence**, **zero failures**, and assuming random failure (β =1):

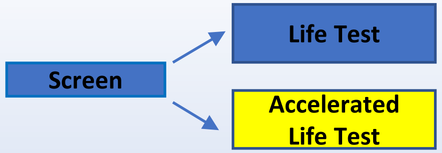
$$\widehat{\alpha} = TTF_{63\%} = \left(\frac{2*1000hrs*20}{\chi^2(0.9,2)}\right)^{1} = 8685.9 \text{ hrs}$$

The B10% life with 90% confidence is then [11]:

$$TTF_{p=10\%} = -ln(1-p)^{1/\beta} * \hat{\alpha} = 0.105 * 8685.9 = 915.2 \text{ hrs}$$

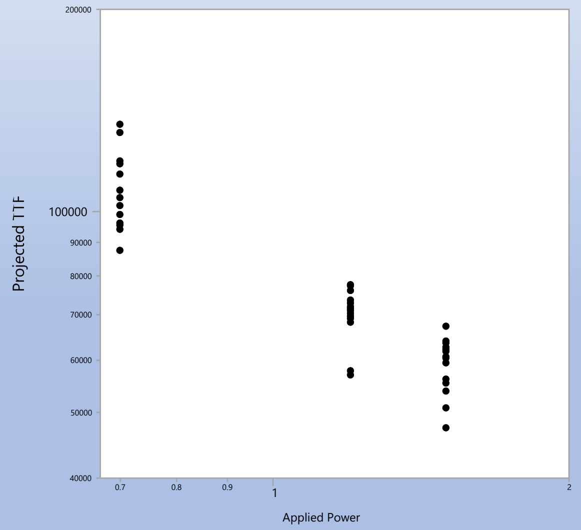
$$\mathbf{TTF_{Mission,10\%} = 77.7 * 915.2\ hrs = 71,100\ hrs = 8.1\ yrs}$$

$$\mathbf{TTF_{Mission,1\%} = 0.77\ yrs}$$

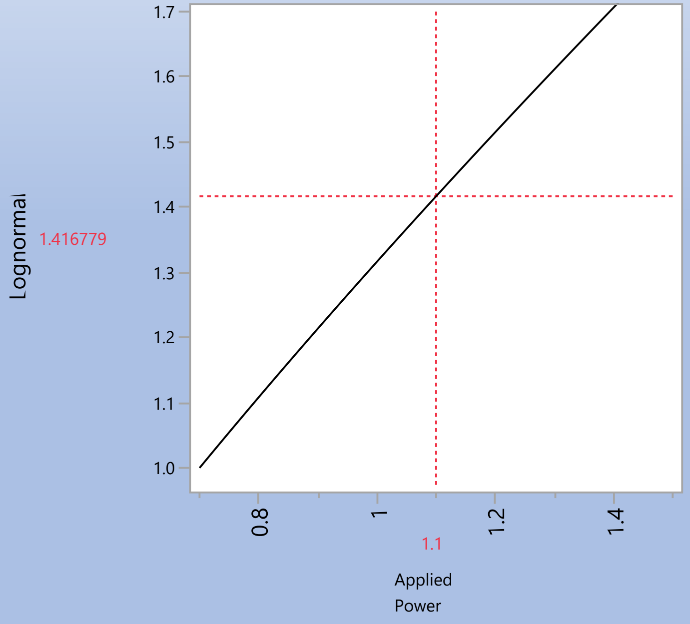


Accelerated Life Test Power Dependance : Group E

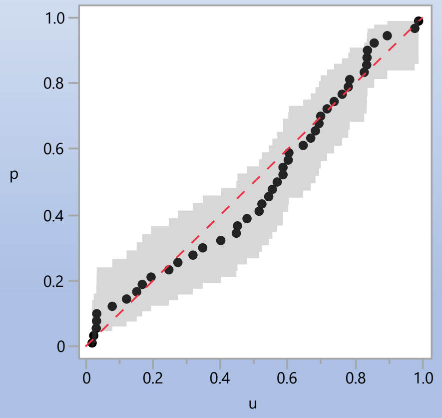
Data Scatter Plot



Acceleration Factor Plot



Cox-Snell Residual P-P Plot



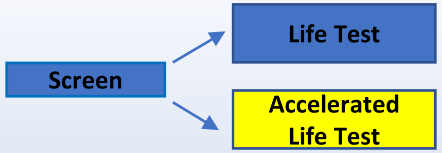
$$\mathrm{TTF}_{50\%} = e^{\beta_0} P^{\beta_1} = 80740 \cdot P^{-0.77}$$

$$\mathrm{R(t)} = 1 - \Phi\left(\frac{\ln t - \mu}{\sigma}\right)$$

Inverse Power Law Model Estimates

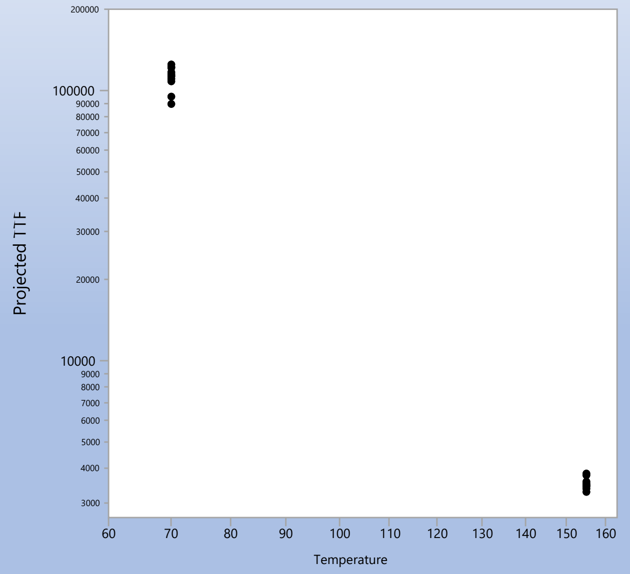
95% Confidence Interval (Wald)				
Parameter	**Estimate**	**Std Error**	**Lower**	**Upper**
β0	11.29873	0.01613825	11.26710	11.33036
β1	-0.77079	0.04904206	-0.86691	-0.67467
σ	0.10525	0.01109435	0.08351	0.12699

$$\mu = 11.29873 - 0.7707909 \cdot \mathrm{Log}\left(\text{Applied Power}\right)$$

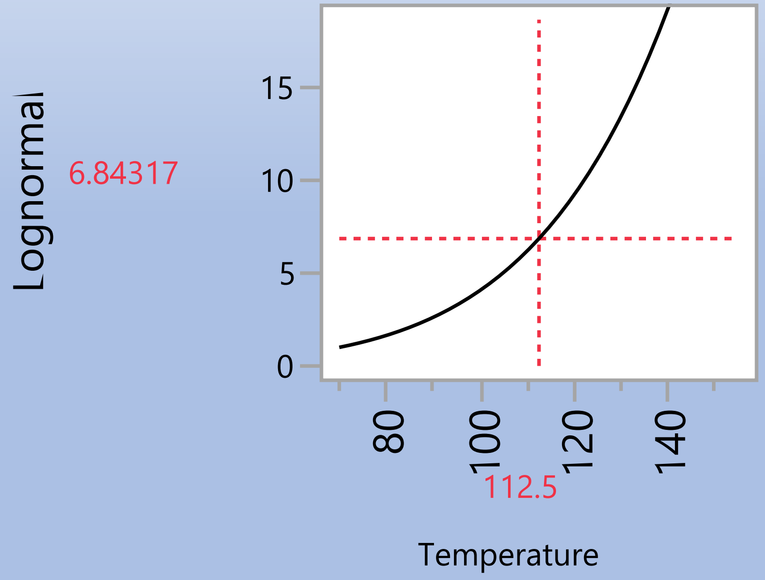


Accelerated Life Test Basic Arrhenius Temperature Dependance : Group E

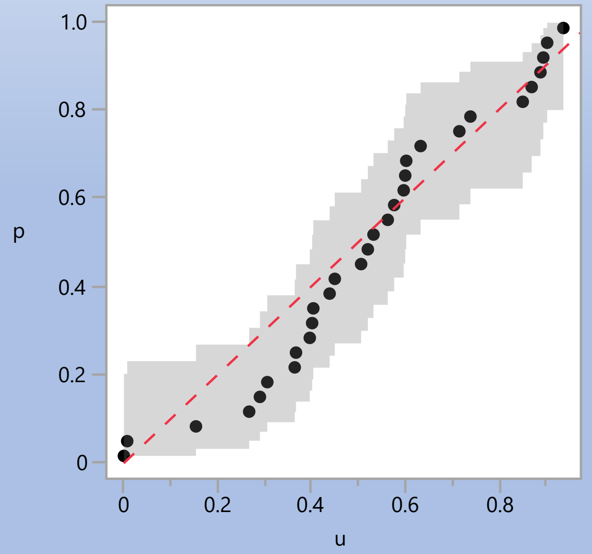
Data Scatter Plot



Acceleration Factor Plot



Cox-Snell Residual P-P Plot



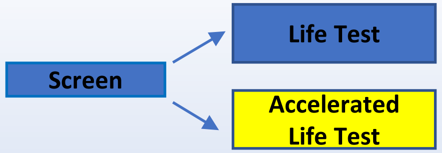
Arrhenius Celsius Law Model Estimates

95% Confidence Interval (Wald)				
Parameter	**Estimate**	**Std Error**	**Lower**	**Upper**
β0	-5.821685	0.11521687	-6.047506	-5.595864
β1	0.516057	0.00375971	0.508688	0.523425
σ	0.069128	0.00892432	0.051636	0.086619

$$\mu = -5.821685 + \frac{(0.5160565 \cdot 11604.518122)}{(\text{Temperature} + 273.15)}$$

$$\text{TTF}_{50\%} = e^{\beta_0} e^{\frac{\beta_1}{K_B T}}$$

$$R(t) = 1 - \Phi\left(\frac{\ln t - \mu}{\sigma}\right)$$


Screen

Life Test

Accelerated Life Test

Modified Arrhenius Temperature Dependance Model[9]: Group E

Avg. Resistance Shift [ppm]	100 hrs	250 hrs	500 hrs
70 Deg C	-3.140	7.376	41.917
155 Deg C	745.7	1125.6	1512.9

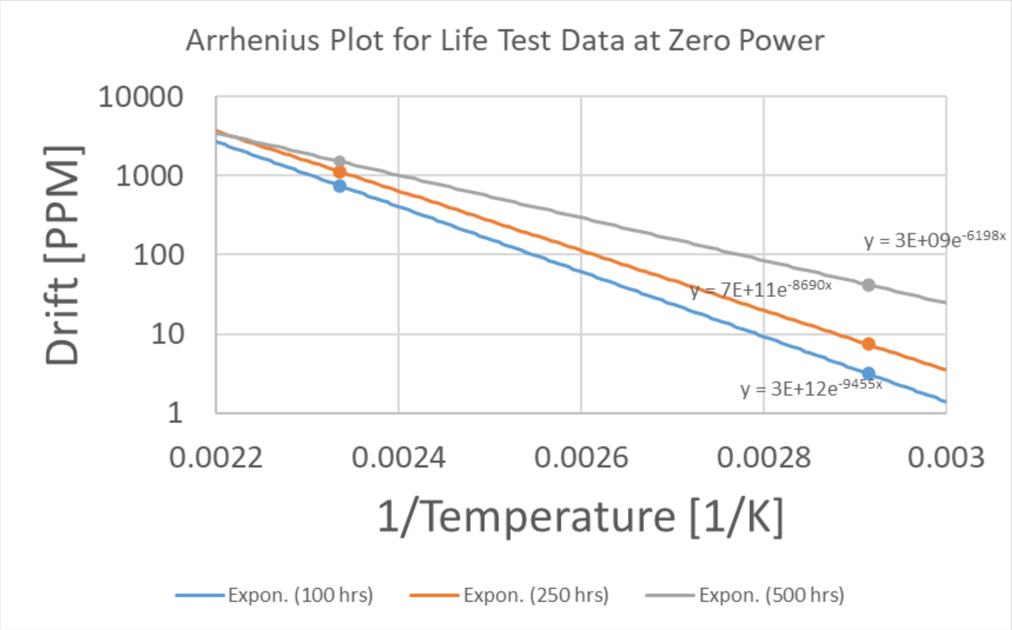
$$\ln\frac{\Delta R}{R[\mathrm{ppm}]} = f(t)R[\mathrm{ppm} * K] * \frac{1}{T} + \ln\left(\frac{\Delta R}{R}\right)_{pot} (t)[\mathrm{ppm}]$$

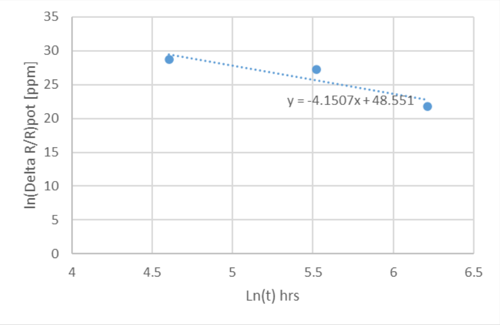
$$\ln(\Delta R/R)_{pot}\ (t) = D * \ln(t) + F = -4.151 \ln(t) + 48.55$$

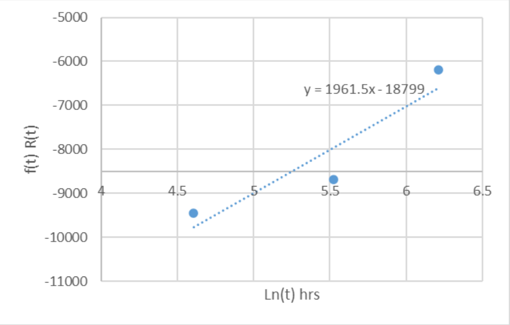
$$f(t)R(t) = B * \ln(t) + C = 1961.5 \ln(t) - 18799$$

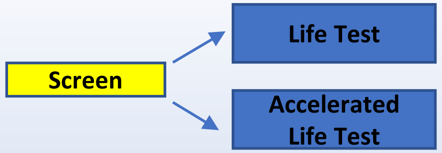
$$\xrightarrow{yields}$$

$$\ln\frac{\Delta R}{R[\mathrm{ppm}]} = (1961.5 \ln(t) - 18799) * \frac{1}{T} - 4.151 \ln(t) + 48.55$$









Backup – Screening Test Data/Results: Prohibited Material Analysis

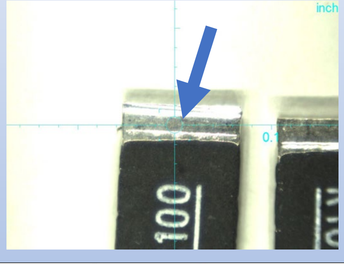
- Prohibited Material Analysis (PMA) was performed on 3 samples per part number/group.

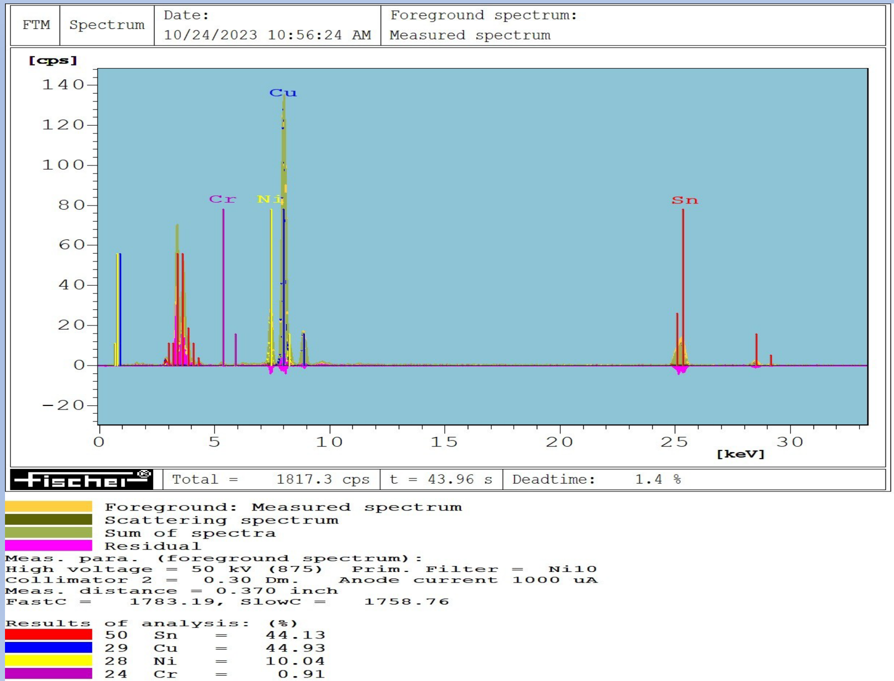
- Pure Tin (Sn) plating was observed on the terminations of various part numbers.

- Due to the possibility of tin whisker growth on pure tin-plated surfaces, pure tin plating on terminations has been prohibited historically from use in space applications. However, pure Tin coated terminations are standard for automotive and commercial grade parts.

- While GSFC S-311-M-70 [7] considers the use of Tin (Sn) finishes containing
< 3 % wt. Lead (Pb) as a failure, the use of conformal coating is an accepted technique by NASA for whisker growth mitigation and has been shown effective at capturing long-term whisker growth. [10]

- EEE parts such as these with pure tin terminations can be used in NASA applications with appropriate whisker mitigation practices are used.





FTM	Spectrum	Date: 10/24/2023 10:56:24 AM	Foreground spectrum: Measured spectrum

Total = 1817.3 cps | t = 43.96 s | Deadtime: 1.4 %

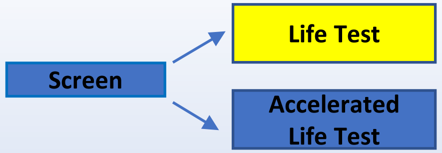
- 🟨 Foreground: Measured spectrum
- 🟫 Scattering spectrum
- 🟩 Sum of spectra
- 🟪 Residual

Meas. para. (foreground spectrum):
High voltage = 50 kV (875) Prim. Filter = Ni10
Collimator 2 = 0.30 Dm. Anode current 1000 uA
Meas. distance = 0.370 inch
FastC = 1783.19, SlowC = 1758.76

Results of analysis: (%)

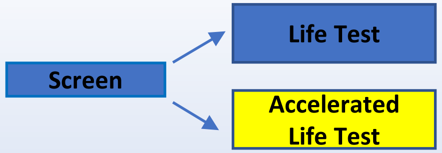
🟥	50	Sn	=	44.13
🟦	29	Cu	=	44.93
🟨	28	Ni	=	10.04
🟪	24	Cr	=	0.91

PMA on terminations of a Group A sample



Backup –Life Test Criteria : Delta R

Group ID	Delta R
A	± (1.0 % + 0.0005 Ω)
B	± (1 % R + 0.05 Ω)
C	± (1.0%+0.05Ω)
D	± (0.5 % R + 0.05 Ω)
E	± (0.1%+0.05Ω)
F	± (0.05 % R + 0.01 Ω)
G	± (0.1%+0.05Ω)
H	± (1 % R + 0.05 Ω)
I	±3 %

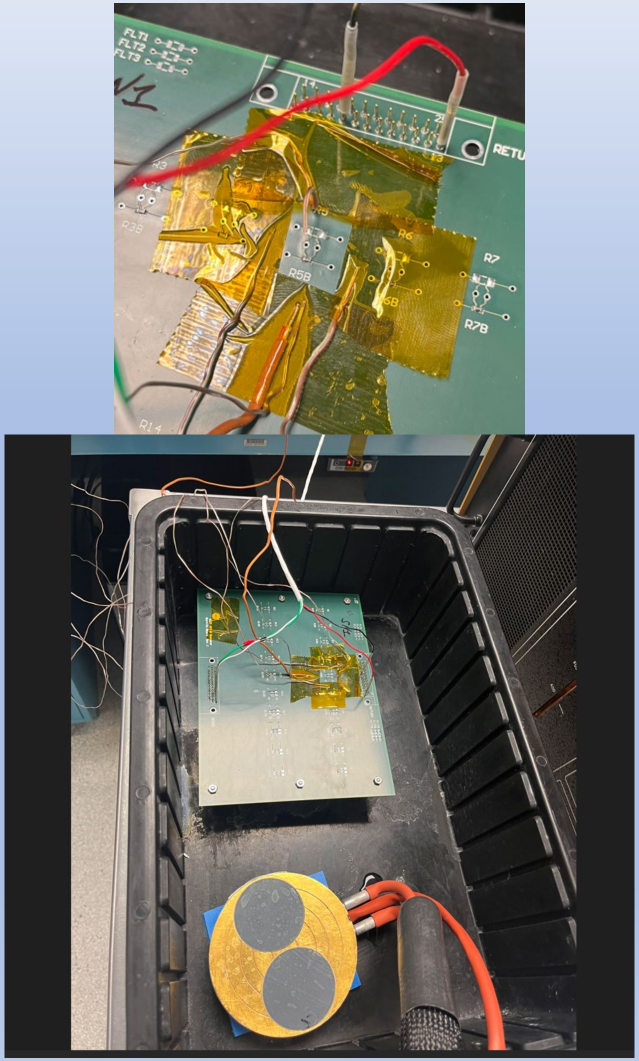


Screen

Life Test

Accelerated Life Test

Backup – Group E, TCR



TCR Measurement Setup