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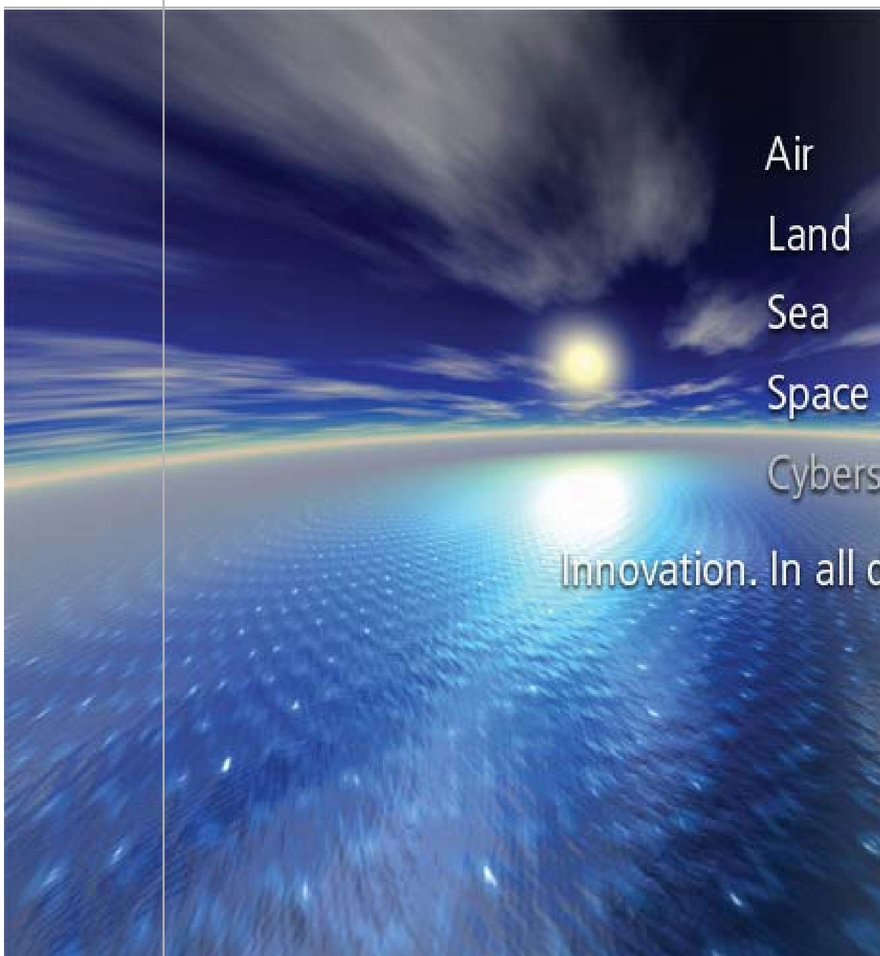

Microwave Device Reliability Characterization -The Mechanics of Life Test Execution and Analysis

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Microwave Device Reliability Characterization -The Mechanics of Life Test Execution and Analysis

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Reliability Lab Charter

- Perform All Due Diligence Testing to Establish and Maintain the MMIC Fab Process Reliability to ensure ‘NoDoubt’ Mission Assurance
- Provide Reliability Expertise Within RFC, IDS and Company Wide
- Anticipate Test Capability and Capacity Needs to Enable Nimble Response to Programs’ Needs
- Search for New Paradigms in Testing and Reliability Benchmarks Industry Wide
- Implement Lean Methods and Automation to Optimize Quantity and Enhance the Quality of Test Execution and Data Analysis

Reliability Lab Test Capabilities

- Life Testing:
- Process Reliability Monitoring
- DC Biased Temperature Accelerated Life Test
- RF Operational Life Test (S & X-Band)
- RF Temperature Accelerated Life Test (X-Band)
- Pulsed DC Electromigration (DC TALT)
- Current Density Testing (DC TALT)

- Characterization:
- Capacitor Time Dependent Dielectric Breakdown Testing
- LabVIEW Based Parametric Characterization
- Resistor TCR Characterization
- Light Emission Microscopy
- Liquid Crystal Failure Analysis

What Affects Reliability?

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- Technical or lay, we all know that the reliability or longevity of “things” is driven by stress
- The list of life reducing stresses include: temperature, temperature cycling, humidity, voltage/electric field, current density, mechanical stress, thermo-mechanical stress cycling, radiation etc
- The dominating stresses depend on the application environment.
- Most of us would instinctively recognize Temperature as a common stress for many “things”.

Temperature is a common stress driver of reliability

The Focus of Today's Presentation

- Our "things" of interest are microwave devices made of compound semiconductor materials (GaAs, GaN etc)

- Temperature and voltage/electric field are the important stresses in the application of microwave devices

- In the space/defense environment many of the others are mitigated by the application environment.

- This presentation will focus on temperature activated degradation. The reliability metrics from the statistical formalism will be introduced and the procedures to obtain them will be detailed

Main Theme: Thermally activated reliability metrics

Elements of the Statistical Formalism

- The Lognormal Lifetime Distribution
  – Failures are distributed ‘normally’ when plotted on log time scale

- The Cumulative Failure Fraction Plot
  – A linear plot can be taken as evidence for lognormal lifetime distribution

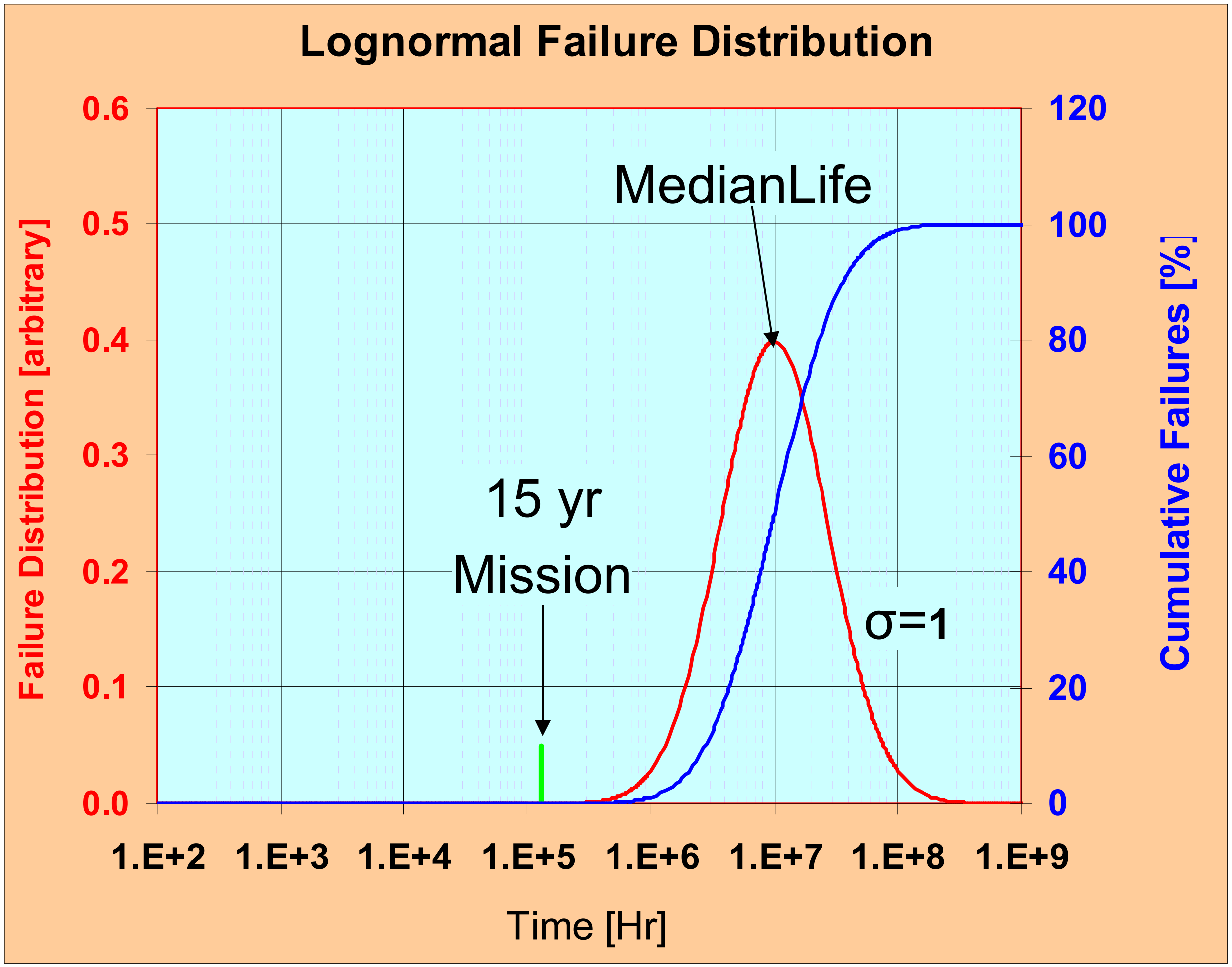
- The Arrhenius Reaction Rate Model - $t = t_o * e^{Ea/kT}$
  – The Arrhenius acceleration relationship is then

  – $ML1/ML2 = e^{Ea/kT1}/e^{Ea/kT2}$

- The Reliability Metrics from above are:
  – Median Life (ML) or MMTF
  – Sigma (σ) the dispersion – standard deviation of the log of lifetimes
  – Activation Energy

The Metrics: Median Life, Sigma and Activation Energy

The Lognormal Failures Distribution



Distribution is 'normal' when plotted on log time scale

Trade Off Between ML and σ

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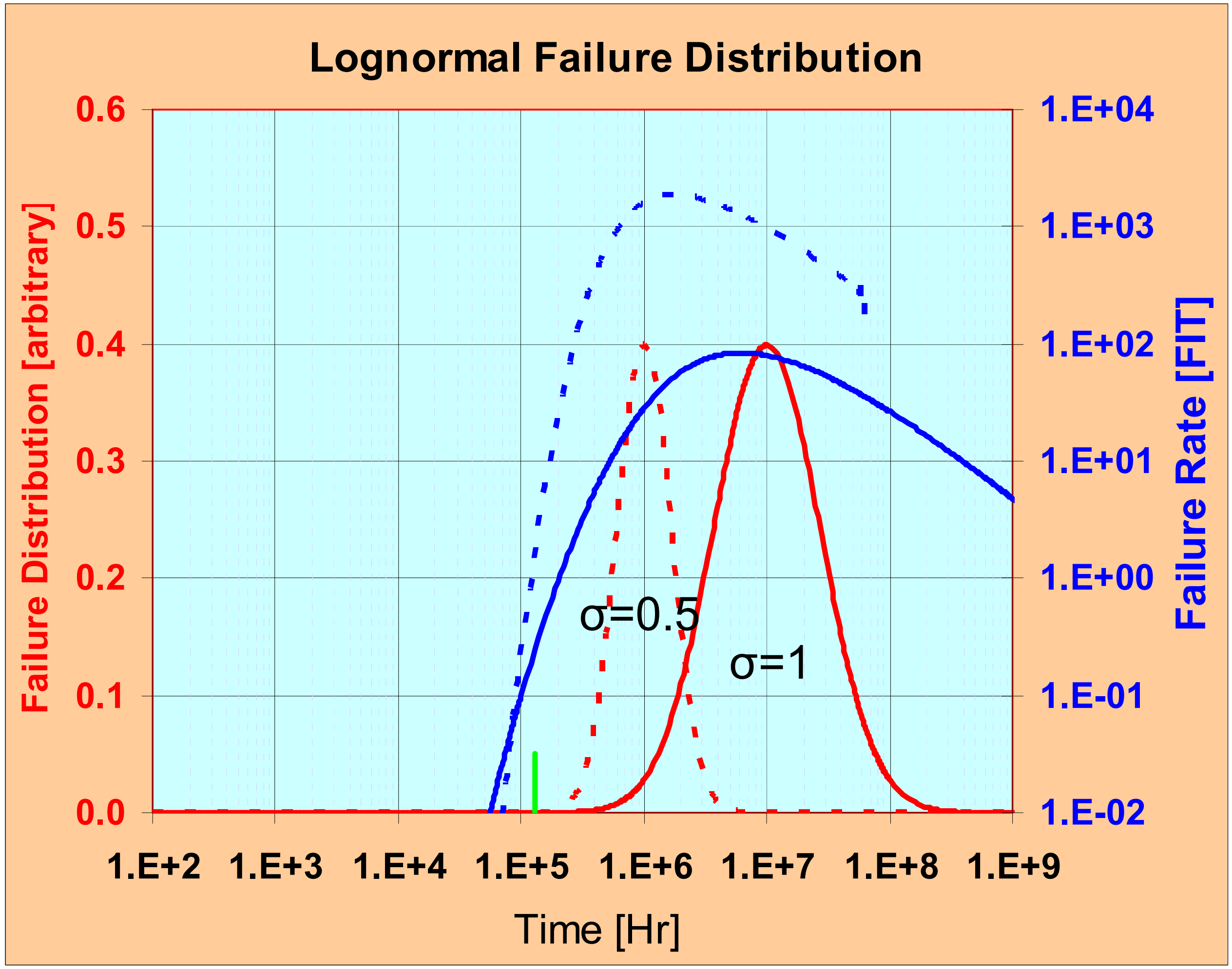
Failure Rate in FITs through mission time is negligible

FIT is a failure unit
And it is equivalent with 1 failure/10^9 hr



To maintain 'Same' Reliability at lower ML, σ has to be smaller

The Lognormal Failures Distribution

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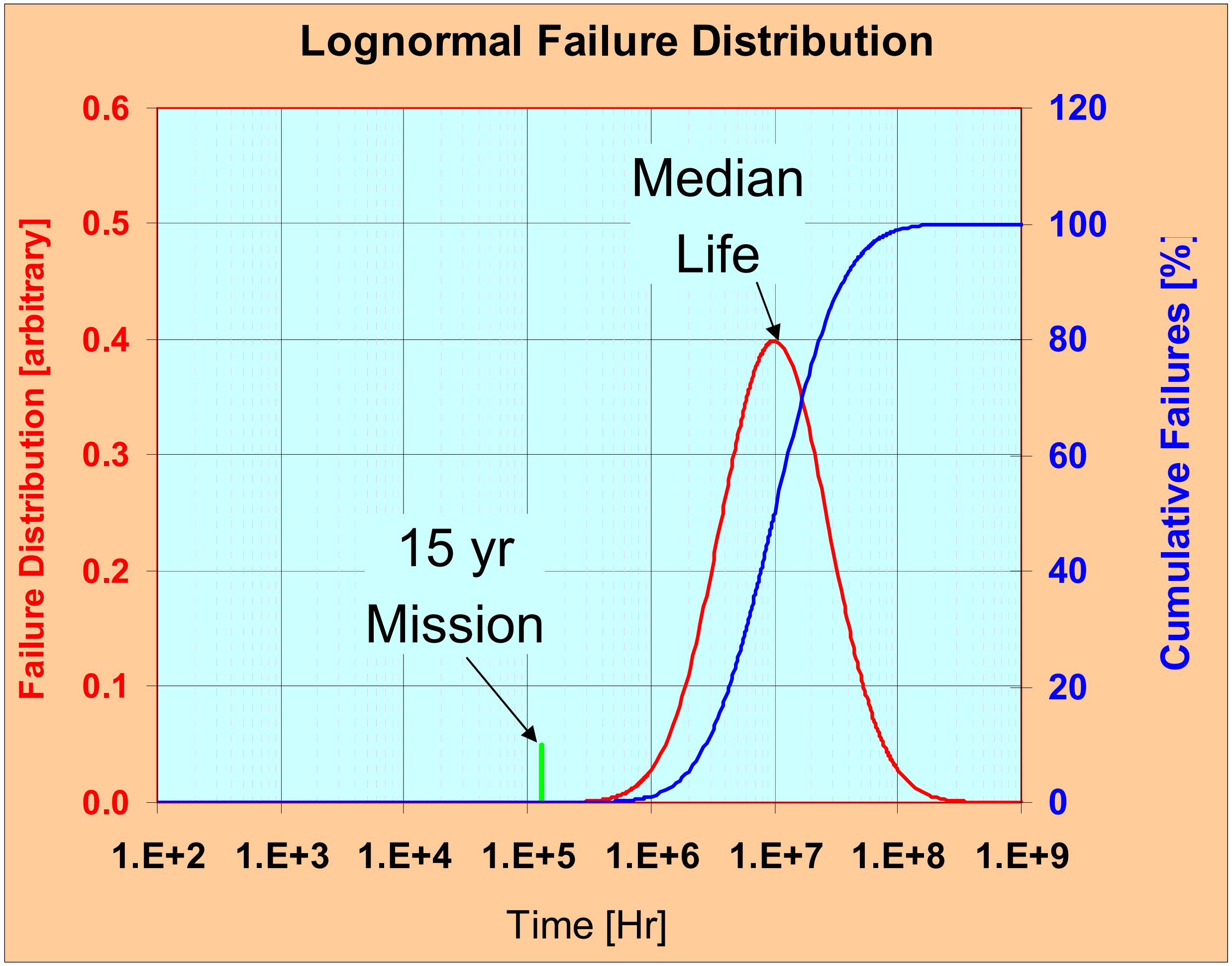

Note Margin Between Distribution Tail and Mission Time

The Cumulative Failure Fraction Plot

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Note on the X scale both the Probability and Score scales are shown

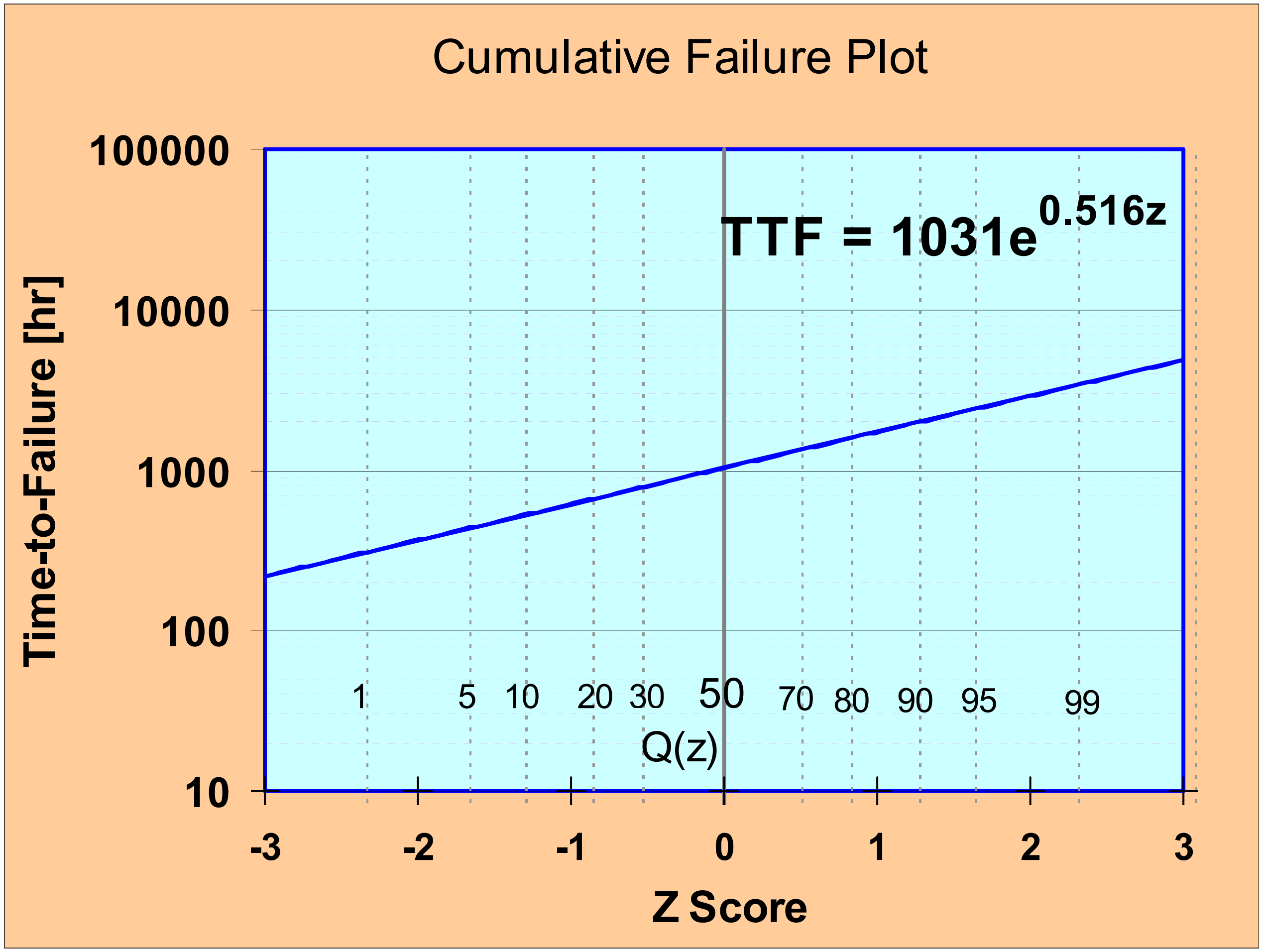
The Plot is linear

$Ln(TTF) = \sigma * z + Ln(ML)$

The exponential curve fit in Excel returns the form

$TTF = ML * e^{\sigma * z}$

The extraction of ML and σ is direct



A linear plot is taken as evidence for lognormal lifetime distribution

The Arrhenius Reaction Rate Model

$ML = C * e^{Ea/kT}$

Or

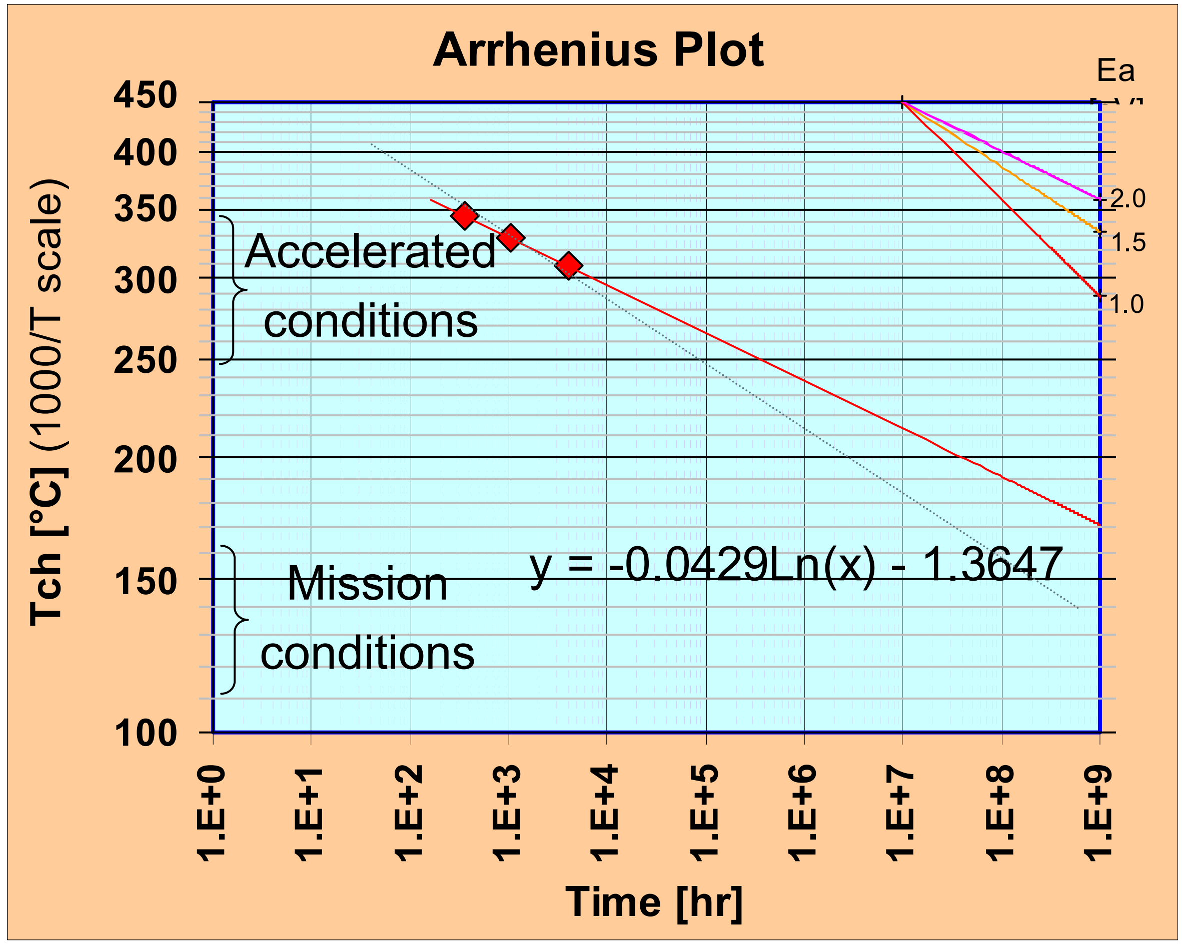
$1000/T = A*\ln(ML)+C$

The Plot is a straight line using these scales

The logarithmic curve fit in Excel returns this form and from the slope A the Activation Energy

$Ea = 1000k/A = 0.0862/A$

k is Boltzman's constant in $eV*K^{-1}$



The Ability to Thermally Accelerate Aging is Key to the Process

Life Test Scope

- Life Tests at minimum 3 temperatures are required to establish a credible trend
- Tch for the Life Tests is determined from self heating due to DC operating power dissipation and base plate temperature setting
- Test Vehicles are 12 Schottky Gate Field Effect Transistors per temperature group
- 20% Decrease in Drain Current is the Failure Criterion
- Drain Current is a key performance parameter and it is correlated with RF Power output capability

FET Test Vehicles and -20% ΔId Failure Criterion

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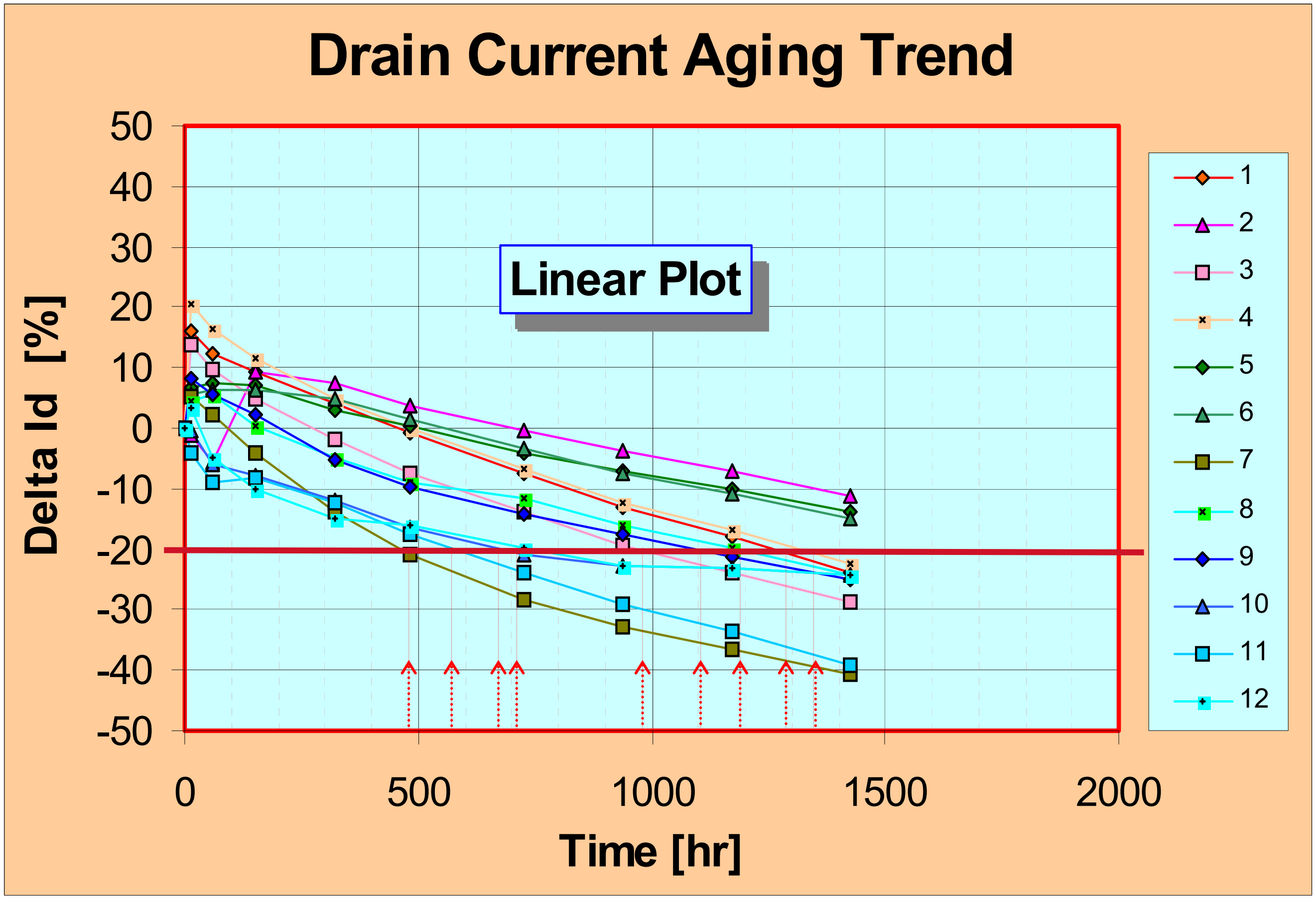
Life Test Data Analysis

- Drain Current aging at Tch=329°C - Linear trend plot

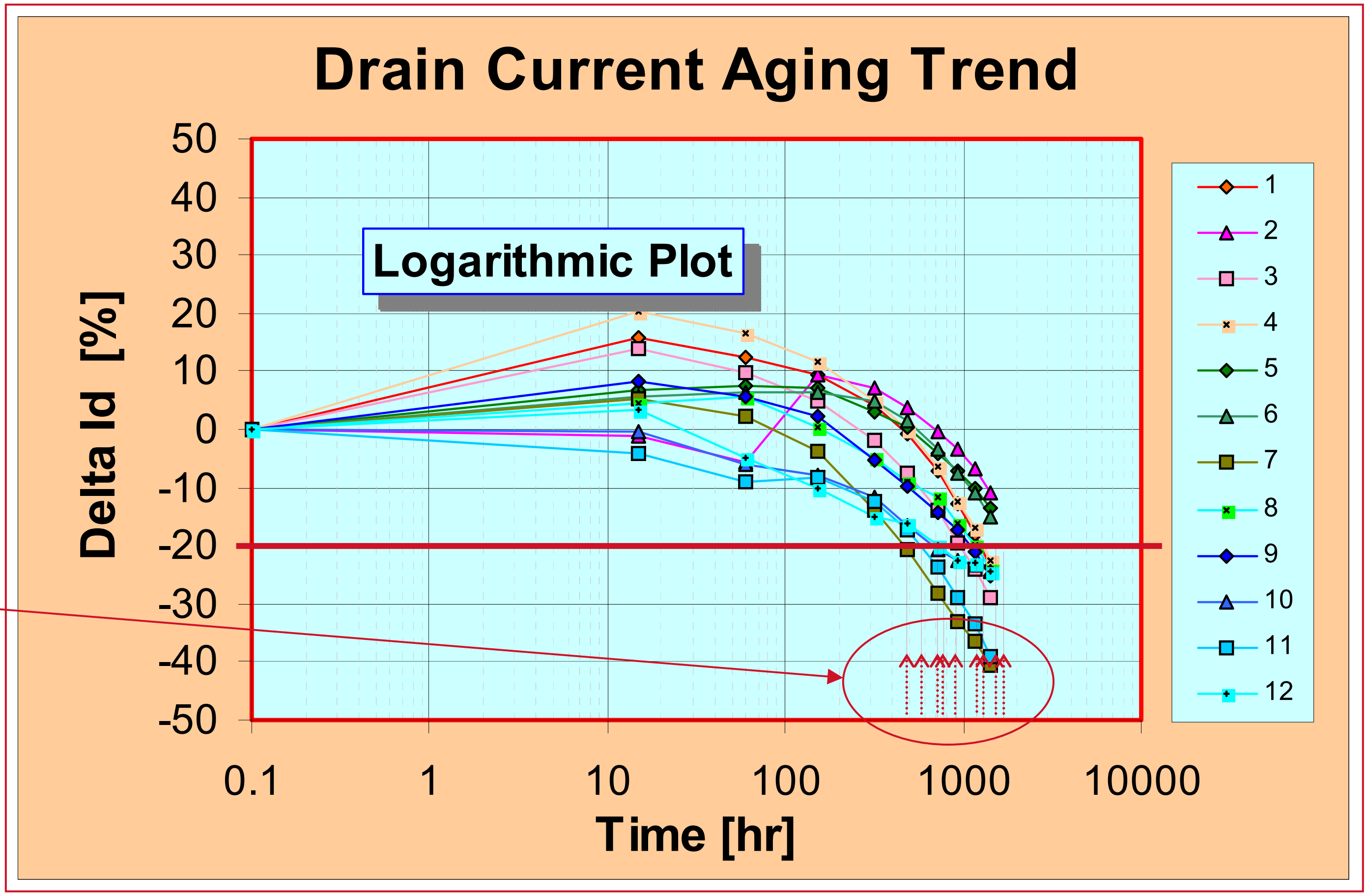


Times to Failure are indicated by arrows on the Time Scale

Life Test Data Analysis

- Drain Current aging at Tch=329°C - Logarithmic trend plot

The Times-to-Fail are tabulated and ranked and used in the next step



Logarithmic trend plot is a better visual indicator of ML

Life Test Data Analysis

- The Time-to-Fail values are tabulated and ranked
- For each failure the cumulative failed fraction, Q, is calculated using the median ranking formula:
  Q=(F-0.3)/(N+0.4) F is the number of failed parts; N is the number of parts in the test
- Q is converted to the z score using NORMSINV function in Excel

The resulting z-score and TTF data is plotted using the Cumulative Failure Fraction Plot

F cum # failures	Q [fraction] (F-0.3)/(N+0.4)	Z score	TTF [hr] sorted
1	0.05645	-1.58528	450
2	0.13710	-1.09346	570
3	0.21774	-0.77984	670
4	0.29839	-0.52904	700
5	0.37903	-0.30802	950
6	0.45968	-0.10125	1100
7	0.54032	0.101246	1174
8	0.62097	0.308024	1200
9	0.70161	0.529045	1200
10	0.78226	0.779842	1700
11	0.86290	1.093456	1900
12	0.94355	1.585278	2100

The Id trend plot is reduced to the TTF and Z-score data array

The Cumulative Failure Plot: Tch=329°C

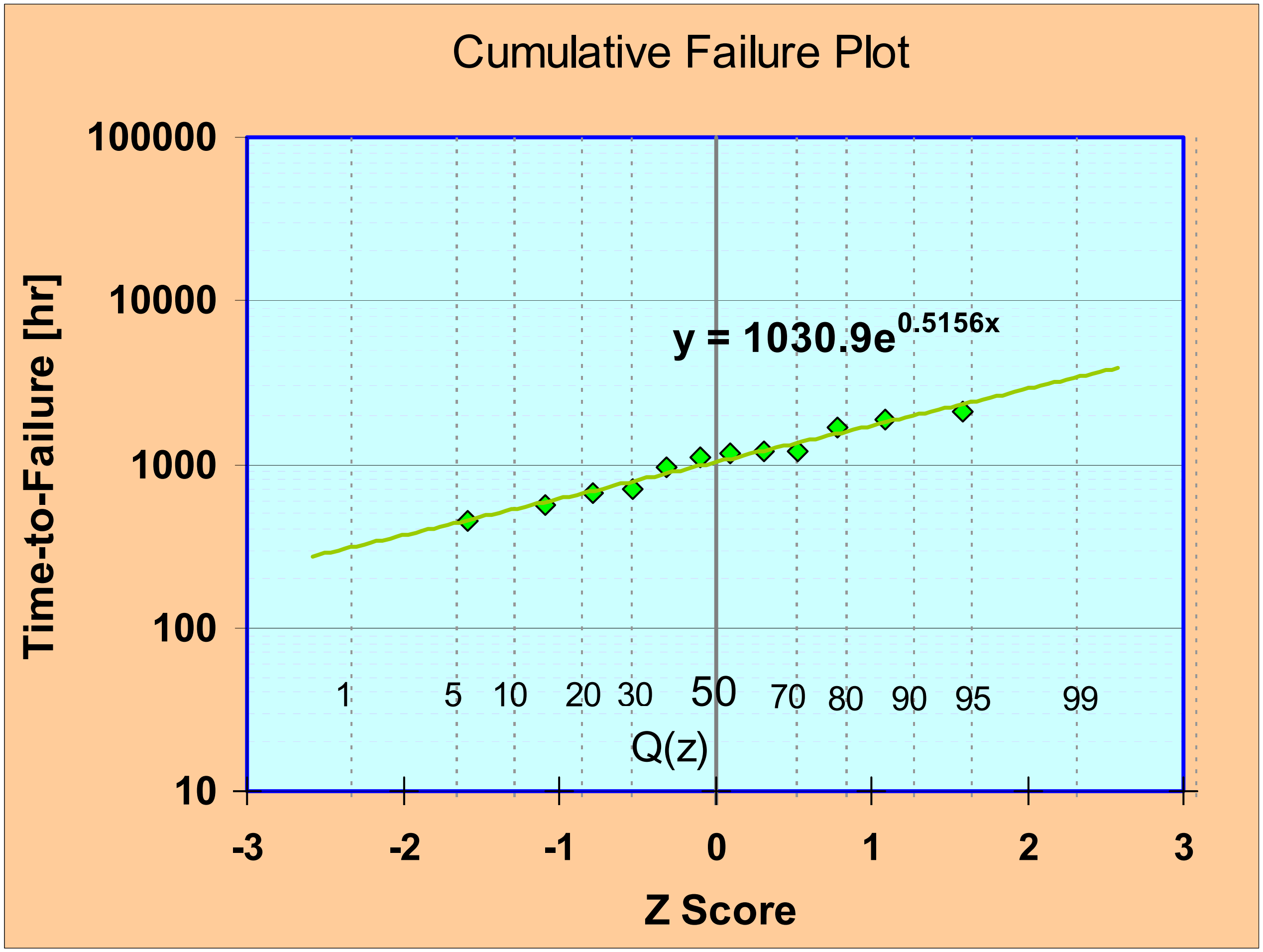
The exponential curve fit in Excel returns the form

TTF = ML* $e^{\sigma * z}$

The extraction of ML and σ is direct

ML=1031hr

σ=0.52



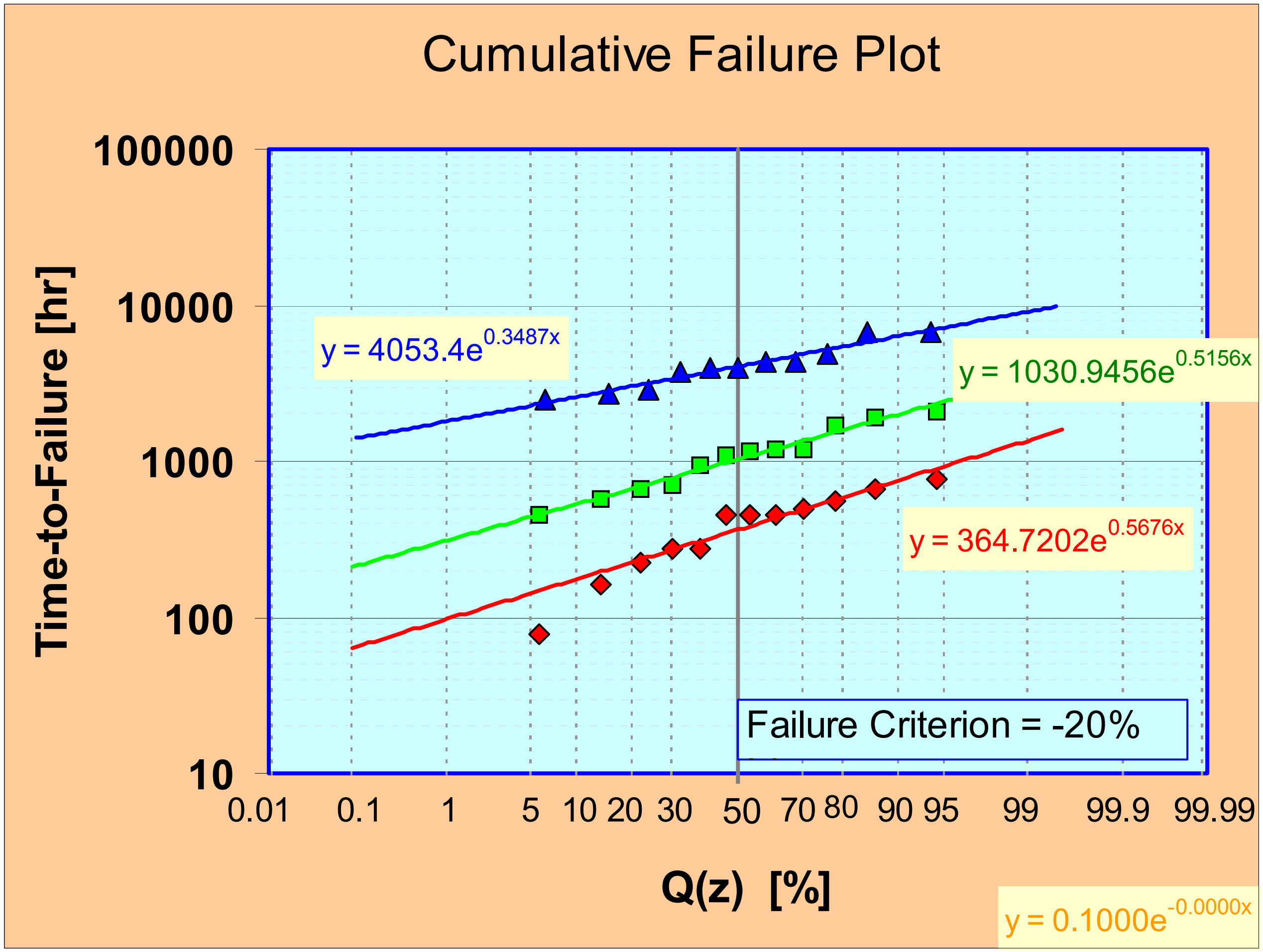
The Cumulative Failure Plot Provides ML and σ Directly

All 3 Cumulative Failure Plots

The extraction of ML and σ is direct for all 3 temperature groups

Tch[°C]	ML[hr]	σ
345	365	0.57
329	1031	0.52
308	4053	0.35

Tch and ML are ready to be plotted on the Arrhenius coordinates



The Cumulative Failure Plot Provides ML and σ Directly

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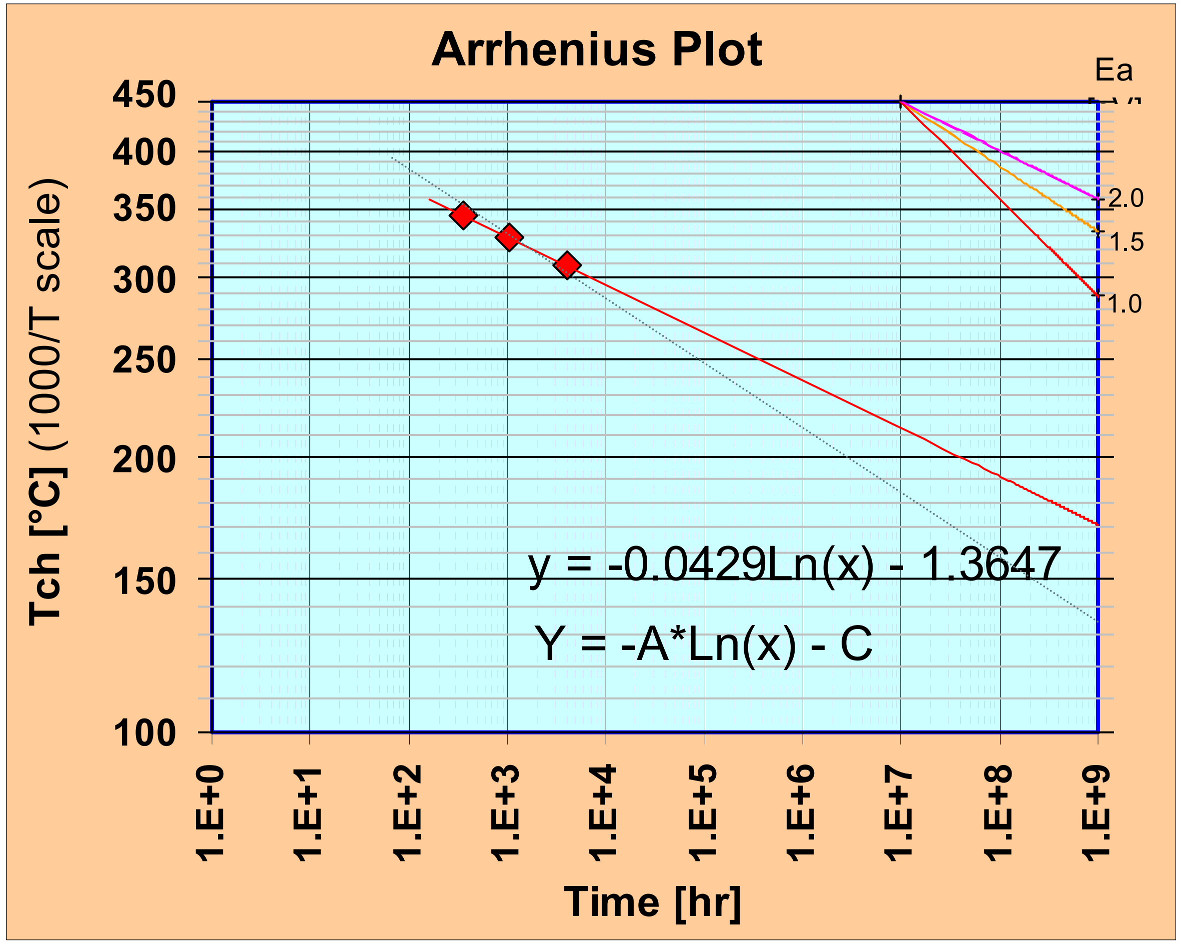
The Arrhenius Plot for the 3 Life Tests

- Tch is converted to 1000/Tch in [°K^{-1}]
- Note negative sign forces Temperature increase bottom to top

Tch [°C]	ML [hr]	1000/Tch [°K^{-1}]
345	365	-1.618
329	1031	-1.661
308	4053	-1.721

- ML and 1000/Tch are plotted on the Arrhenius Coordinates
- Ea=0.0862/A
- Ea=2.01eV



The Arrhenius Plot Provides Ea Directly

Reliability Metrics Summary

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The Reliability Metrics based on all 3 temperature groups used in this example are

Tch[°c]	ML[hr]	σ	Ea[eV]
345	365	0.57	
329	1031	0.52	2.01
308	4053	0.35	

Projections are based on the Arrhenius relationship

$ML1/ML2 = e^{Ea/kT1}/e^{Ea/kT2}$

Extrapolate Time			Unknown	
Ea (eV)	t1 [hr]	T1 [°C]	t2=?? [hr]	T2 [°C]
2.01	**4.05E+03**	**308**	1.313E+10	**150**
1.50	**1.03E+03**	**329**	2.116E+08	**150**

The 2.01eV Arrhenius Line Projects ML= 1.3E10 at a Mission Tch=150°C
The Conservative 1.5eV Arrhenius Line Projects ML= 2.1E8 at Tch=150°C

Reliability Metrics Summary

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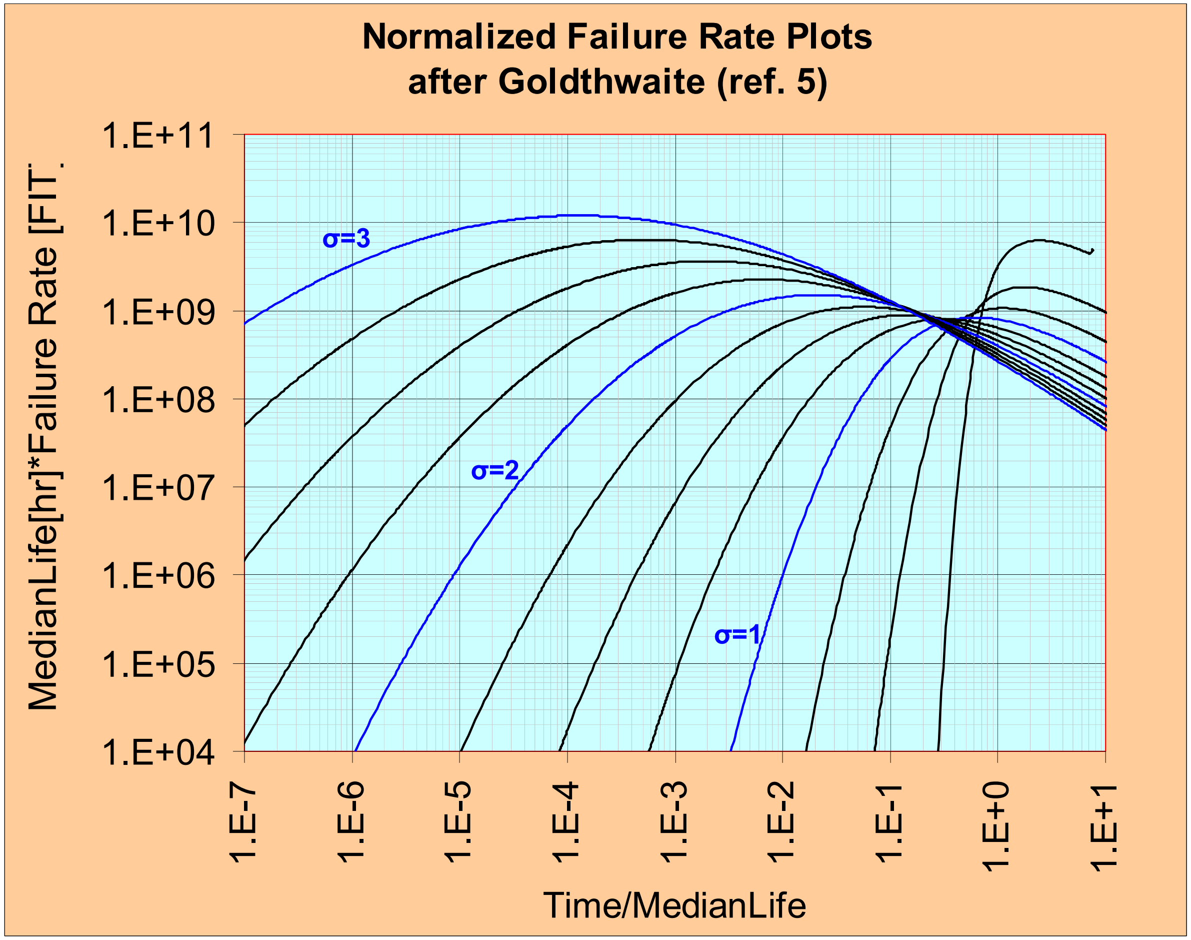

Normalized Failure Rate Plot is Used to Validate Our Extraction and Calculation Protocols

The Equipment/Set Up

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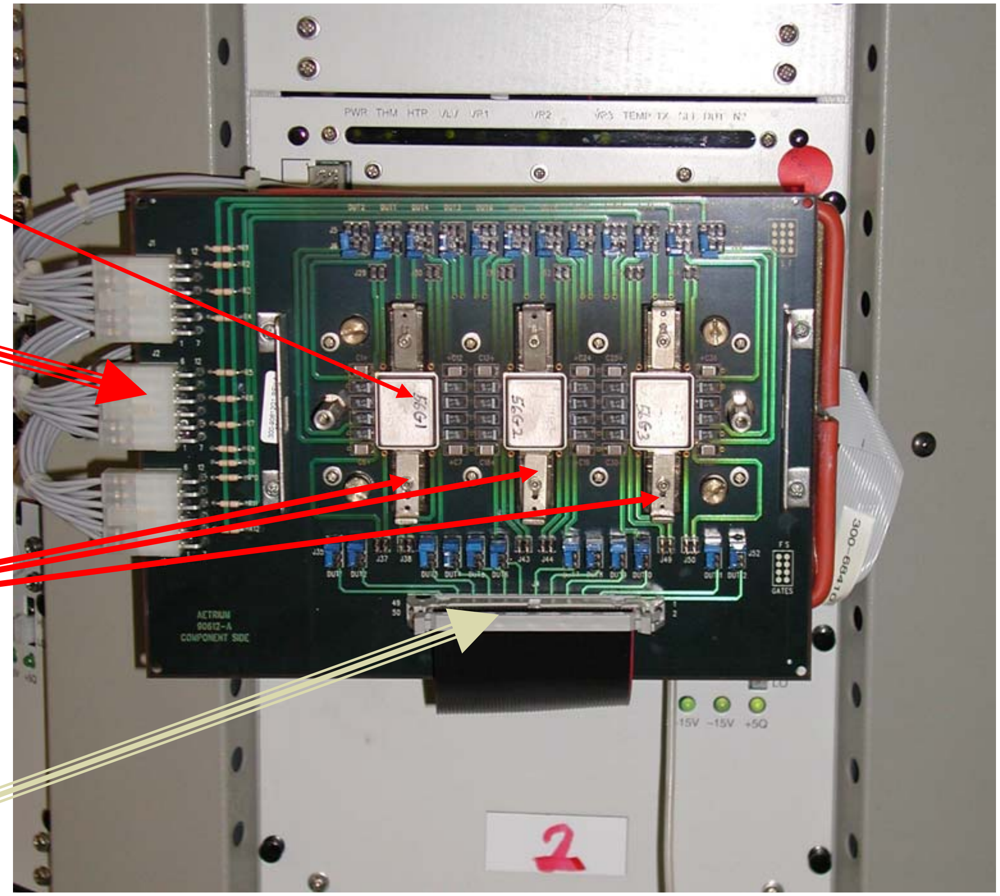
Device Package
4 DUTs Inside

Drain Bias

Heater Stage

Gate Bias



The Equipment Uses a Servo Feedback Loop Which Adjusts the Gate Voltage to Keep Constant Drain Current

The 2nd Key Stress in the application of microwave devices - Voltage/Electric field

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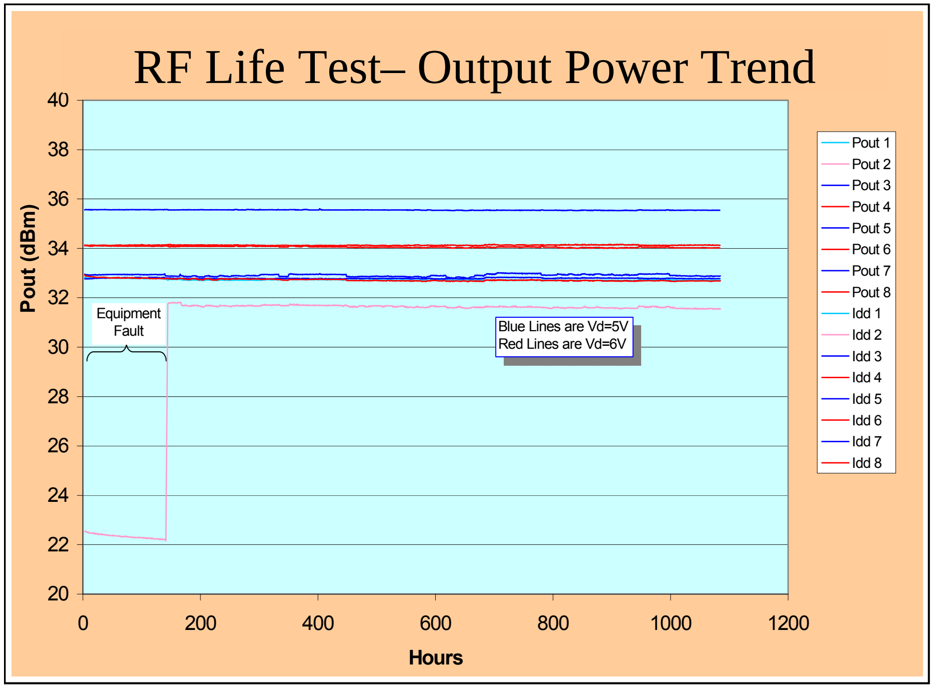
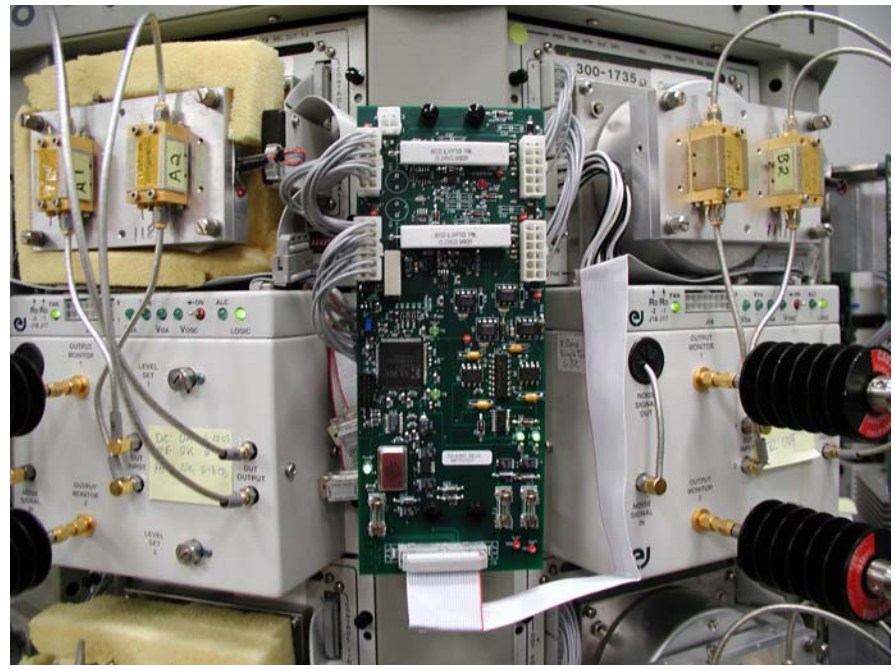


Stable Po during RF Life Test

RF Life Test Equipment



RF Operational Life Tests Are Used to Mitigate High Field Effects Also Known as Hot Electron Effect

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