Critical Review of US Military Environmental Stress Screening (ESS) Handbook

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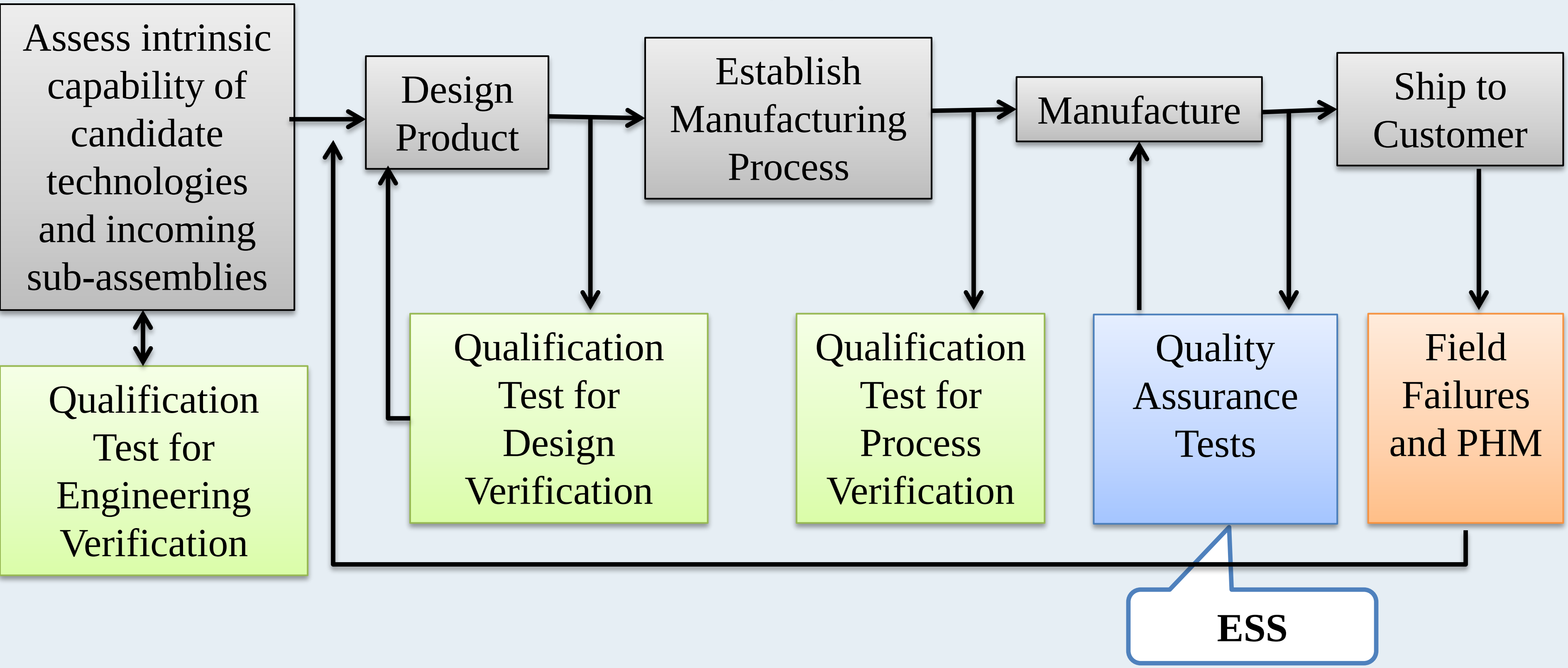
Environmental Stress Screening in a Product Development Process



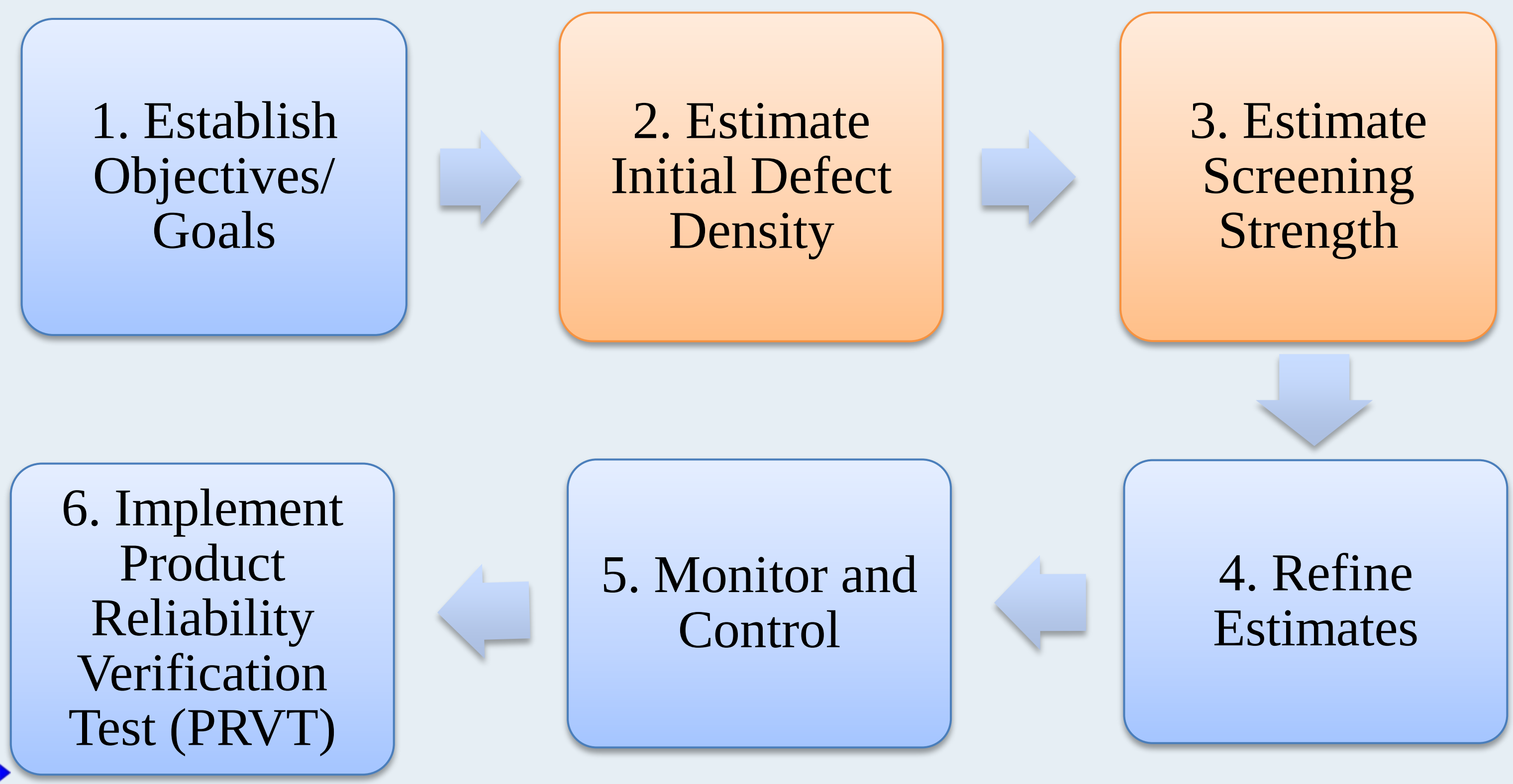
ESS is a process to eliminate defects due to manufacturing variations in electronics devices by a 100% screening.

Motivation for MIL-HDBK 344A Evaluation

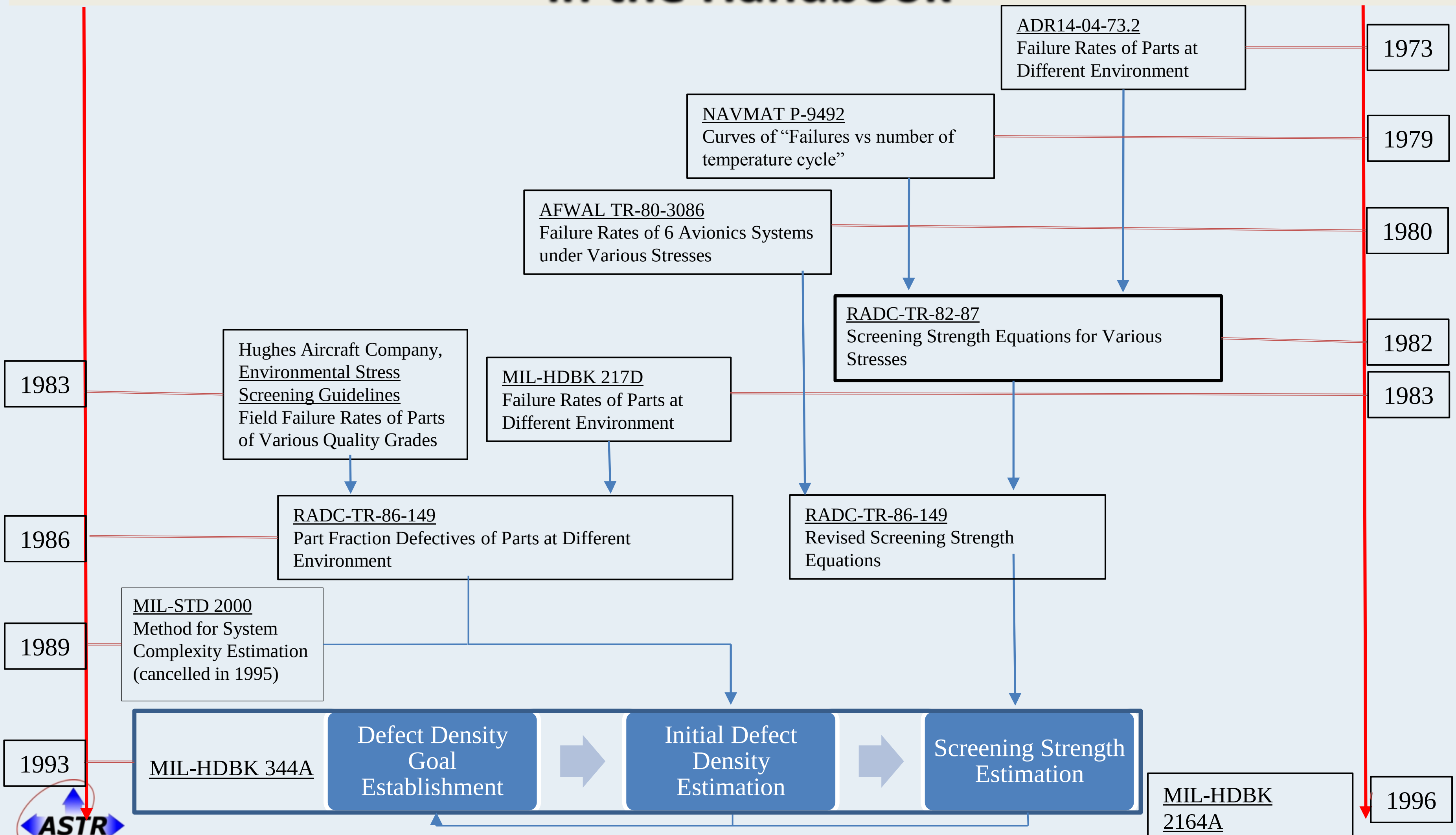
- MIL-HDBK 344A- Environmental Stress Screening (ESS) of Electronic Equipment describes a quantitative approach for planning, monitoring and controlling ESS process.
- It was last updated in 1993, but it is still widely adopted within and beyond military and aerospace industries today.
- 344A is still widely used for ESS effectiveness studies and even for reliability assessment.
- Significant similarities with 344A are found in the approach discussed in a Chinese ESS Standard- GJB/Z34.

Steps in ESS Implementation as per MIL-HDBK 344A

- Six essential steps involved in quantitative approach in MIL-HDBK344A
- Purpose: Monitor and control ESS process statistically.



Sources for Values/ Equations/ Methods Used in the Handbook



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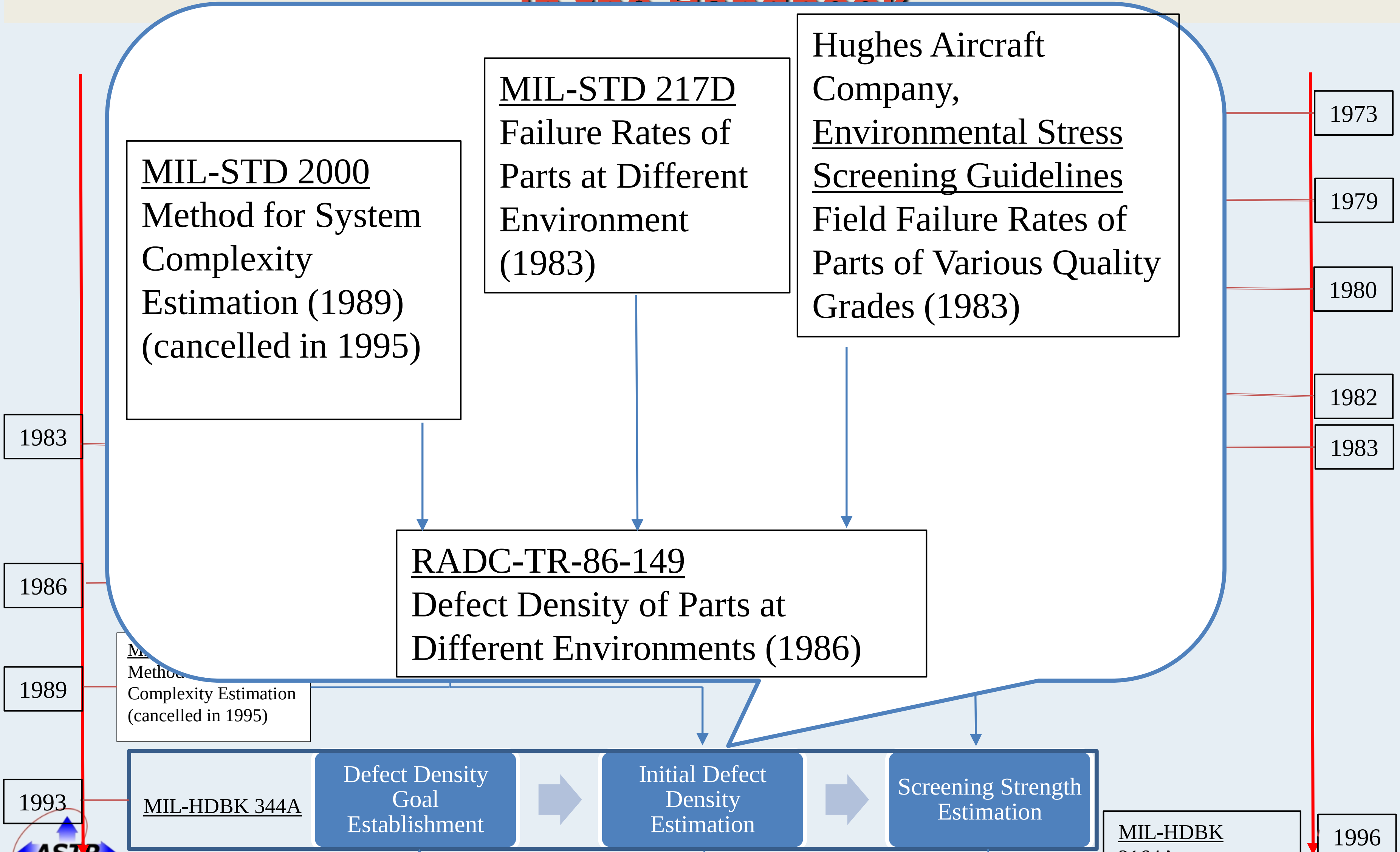

Sources for Values/ Equations/ Methods Used

ADR14-04-73.2
Failure Rates of Parts at Different Environment (1973)

NAVMAT P-9492
Curves of "Failures vs number of temperature cycle" (1979)

AFWAL TR-80-3086
Failure Rates of 6 Avionics Systems under Various Stresses (1980)

RADC-TR-82-87
Screening Strength Equations for Various Stresses (1983)

RADC-TR-86-149
Revised Screening Strength Equations (1986)

1983

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1986

1989

MIL-STD 2000
Method for System Complexity Estimation (cancelled in 1995)

1993

MIL-HDBK 344A

Defect Density Goal Establishment → Initial Defect Density Estimation → Screening Strength Estimation

MIL-HDBK 2164A

1996

ASTR

Defect Density Estimation in MIL-HDBK 344A

- Initial Defect Density (D_{IN}) of a system is estimated using the following relationship in MIL-HDBK 344A

$$\text{Initial Defect Density} = \{\text{System Complexity Matrix}\} \bullet \{\text{Defect Density Vectors}\}$$

- Defect Density Vectors: Estimated initial defect density values at anticipated stress level of parts and interconnections used in a system.
- Defect Density Values of different parts for various environments from field data are included in this handbook.

Defect Densities of Microelectronic Devices in Various Environments in MIL-HDBK 344A

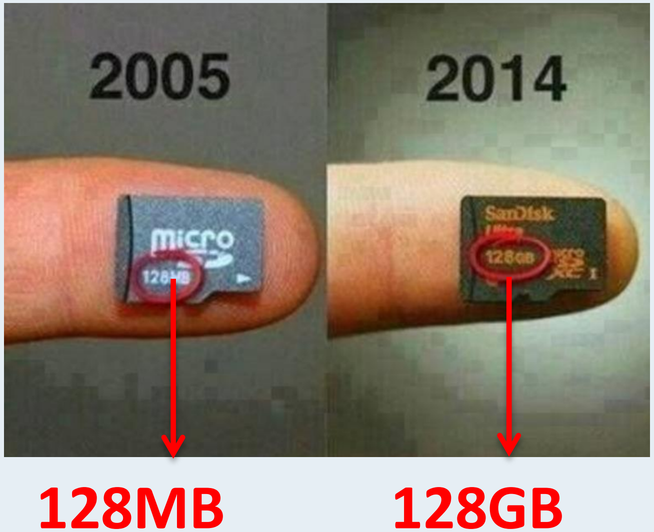
12 tables similar to the one below for different devices (e.g., microelectronic devices, capacitors, resistors) are included in the handbook for defect density estimation

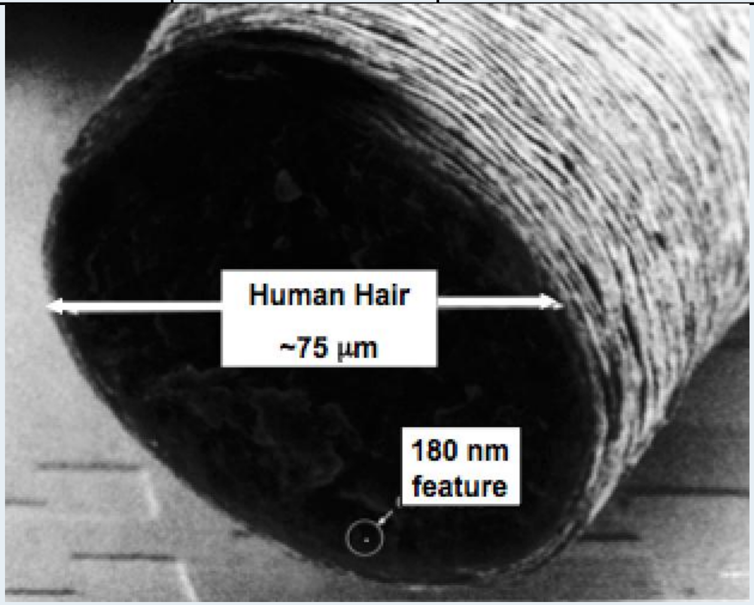
Table 5.2: Microelectronic Devices Defect Density (in PPM) for Various Environments

	QUALITY LEVEL		
ENVIRONMENT	S	B	B-1
GB	9.2	18.3	36.2
GF	19.4	38.7	77.4
GM	26.6	53.2	106.3
NS	26.6	53.1	106.3
NU	36.0	72.1	144.1
AIC	24.2	48.3	96.6
AIF	31.4	62.8	125.6
AUC	30.6	61.1	122.3
AUF	43.4	86.9	173.7
ARW	48.2	96.4	192.9
SF	11.7	23.3	46.6
MF	29.7	59.4	118.8
ML	65.1	130.2	260.3
CL	1,065.9	2,131.8	4,263.7

Evolution of Microelectronics in 30 years

	1980s	Today
Smallest Microelectronic Feature Size	1 µm	22-35nm
Maximum Microprocessor Clock Speed	25 MHz	>4.2 GHz
Maximum Size of Available Commercial Memory	1MB	256GB





[1] Keast, C. Fermilab Colloqium Presentation on *3D Integration for Integrated Circuits and Advanced Focal Planes, 2007*

Main Problems of Defect Density Estimation in MIL-HDBK 344A

- The method of counting number of parts/ leads/ interconnections over the system for complexity is not a valid method.
- Limited data on factory defect rates and field failure rates for parts of various quality grades [2] was used by Hughes Aircraft Company [3] to derive the defect density values for several part types.
- The defect densities given for different quality of parts/ interconnects were developed over 20 years ago with, which are likely invalid today with the changes in quality of parts and assembly technologies.
- Defect density values for COTS parts are not available in handbooks or from manufacturers

[2] Hughes Aircraft Company, "Environmental Stress Screening Guidelines", 1983.
[3] U.S. Air Force, *Environmental Stress Screening*, RADC-TR-86-149, 1986

Screening Strength Estimation in MIL-HDBK 344A

- Screening Strength (SS) is the ratio of number of fallouts during the screen to number of initial latent defects.
- With the estimation of D_{IN} and $D_{REMAINING}$ from previous steps, required SS can be calculated from this equation to achieve the desired $D_{REMAINING}$ goal.

$$SS = \frac{D_{IN} - D_{REMAINING}}{D_{IN}}$$

- Screening Strength (SS) can be seen as the probability that a specific screen will precipitate a latent defect to a patent defect (Precipitation Efficiency, PE) and detect the patent defect by test (Detection Efficiency, DE).

$$SS = PE * DE$$

Precipitation Efficiency Calculation: MIL-HDBK 344A

Precipitation Efficiency (PE) is defined as a measure of the capability of a screen to precipitate latent defects to patent defects, given by:

$$PE = 1 - e^{-kt}$$

Where:

t: duration of screen

k: stress precipitation constant

- For Temperature Cycling: $k=0.0017\,(\Delta T+0.6)^{0.6}[\ln(RATE+2.718)]^{3}$
- For Constant Temperature: $k=0.0017t(\Delta T+0.6)^{0.6}$
- For Random Vibration: $k=0.0046G^{1.71}$
- For Swept Sine Vibration: $k=0.000727G^{0.863}$
- For Fixed Sine Vibration: $k=0.00047G^{0.49}$

(Formulae from RADC-TR-86-149 [3])

[3] U.S. Air Force, *Environmental Stress Screening,* RADC-TR-86-149, 1986

Main Problem of Screening Strength Estimation in MIL-HDBK 344A

- Mathematical expressions for Precipitation Efficiency were derived by Hughes Aircraft Company in 1982 [4] by data collected by McDonnel Aircraft Company in 1980 [5] and by Grumman Aerospace Corporation in 1973 [6] respectively.
  - Not universally applicable since the coefficients in these models are from regression analysis of specific screening results of selected products
  - With several decades of changes in technology in the electronics industry, these models and model coefficients are completely out of date.

[4] Saari, A.E., Schafer. R. E., and VanDenBerg, S.J., "Stress Screening of Electronic Hardware", Hughes Aircraft Company, Ground Systems Group, Fullerton, CA., RADC-TR-82-87, May 1982.
[5] Anderson, J.R., "Environmental Burn-in Effectiveness", McDonnell Aircraft Company, St. Louis, NO., Report No. AFWAL TR-80-3086, August 1980.
[6] Kube, F., Hlrschberger, G., "An Investigation to Determine Effective Equipment Environmental Acceptance Test Methods", Grumman Aerospace Corporation, Report No., ADR14-04-73.2, April 1973.

Case Study of Defect Density Estimation Based on a Current Design

- Users of MIL-HDBK 344A from the industry can be using different possible methods to estimate initial defect density of their systems today.
- A modern electronic system designed in 2015, to be used an industrial building, is used for this case study to compare defect density values result for the system with different methods.

Calculation of Defect Density from Field/ Factory Data from the Original Data Source

- Most defect density values in MIL-HDBK 344A were derived by extrapolating values from a few parts of certain quality grades.
- The defect density values for those parts were calculated from the equation below:

$$Defect\ Density = Factory\ Defect\ Rate + \frac{Field\ Failure\ Rate \times Field\ Part\ Hours}{Part\ Type\ Quantity}$$

- Summation of defects detected in the factory and defects detected in the field and divided by the total quantity, with the assumption of all failures detected are due to defects.

Common Defect/ Failure Related Terminologies

- Intrinsic Failure Rate (IFR): Failure rate (in FIT) during random failure period of a device.
- Early Failure Rate (EFR): Number of failures (in ppm) during early failure period of a device.
- Average Outgoing Quality (AOQ): Total number of products per million (ppm) that are outside manufacturer specification limits during the final quality control inspection (Ackerman and Fabia 1993).

Possible Defect Density Values Today for ESS by MIL-HDBK 344A approach

- Ideal case:
  - Defect density can be the summation of defects detected in factory by all means provided by the manufacturer and defects detected in the field of the parts obtained by the user divided by the total number of parts tested.
- More practical case:
  - Defect density can be the summation of defects from the data available provided by the manufacturer adjusted by an acceleration factor for field environment when applicable. (For example, AOQ, EFR, IFR):
- Other cases:
  - Use of defect density values from tables in MIL-HDBK 344A
  - Use of one of the available data provided by the manufacturer

Possible Defect Density Calculation Method

- AOQ values have not been found for any parts.
- Parts with enough data for defect density calculation are included below:
- Defect Density Calculation Method from available data:

$$Defect\ Density = EFR\ (ppm) + \left(\frac{IFR(FIT) \times Billion\ Part\ Hours}{Part\ Type\ Quantity}\right) \times million\ parts\ (in\ ppm)$$

- Original Defect Density Calculation Method:

$$Defect\ Density = Factory\ Defect\ Rate + \frac{Field\ Failure\ Rate \times Field\ Part\ Hours}{Part\ Type\ Quantity}$$

Defect Density Values Using Different Methods

	From available data (ppm)	From values of two consecutive grades under same environment from handbook (ppm)		# of devices
Zener Diode	126.74	86 (JAN)	17.12 (JANTX)	1
Dual Diode	295.24	86 (JAN)	17.12 (JANTX)	1
Rectifier Diode	21.872	86 (JAN)	17.12 (JANTX)	1
Bipolar Junction Transistor	161.76	346 (JAN)	69.2 (JANTX)	4
Ceramic Capacitor	3.31	61.5 (M)	18.4 (P)	2
Metal Strip Capacitor	10.97	61.5 (M)	18.4 (P)	1
Thick film chip Resistor 1	0.00003	20.3 (M)	6.1 (P)	6
Thick film chip Resistor 2	0.00012	20.3 (M)	6.1 (P)	4
Total	**1108.48**	**2029.5**	**444.36**	**20**

Conclusions from Case Study

- Current electronics part manufacturers do not provide information on defect densities.
  - Quality data required for the calculation is not available for most parts in the actual system
- Unrealistic assumptions had to be made to make defect density estimation possible
  - testing conditions for the parts are same as field conditions
  - all the defects or failures detected are included in the quality data provided by the manufacturer.
- Since assuming an inherent failure rate itself for any part types is a wrong concept, we do not encourage any attempts to estimate defect density today for the use of MIL-HDBK 344A.

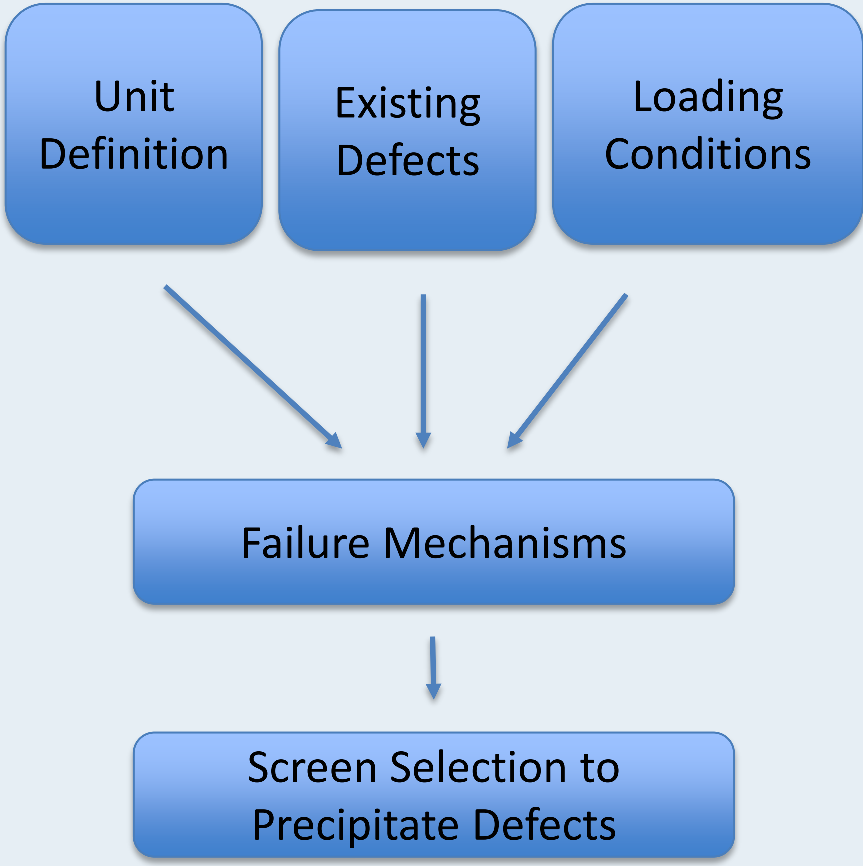
Problems with the Existing Methods for Initial ESS Profile Set Up

- Stress Types
  - Random vibration and thermal cycling/ shock are the only stresses being recommended to eliminate defects in electronic systems for screening (ESS) purposes by all common standards and handbooks including MIL-HDBK 344A
- For stress profile determination
  - Apart from 344A, most handbooks in effect describe a standardized stress profile based on stress limits, or assembly levels of electronic systems without identifying the critical defects and their effects in the field, and understanding defect-stress relationships
  - ESS profiles determined by these methods can be redundant or ineffective

Therefore, the choice of stress types and stress profile determination should be defect and use-condition specific.

PoF Centered Defect-based Approach for Stress Screening

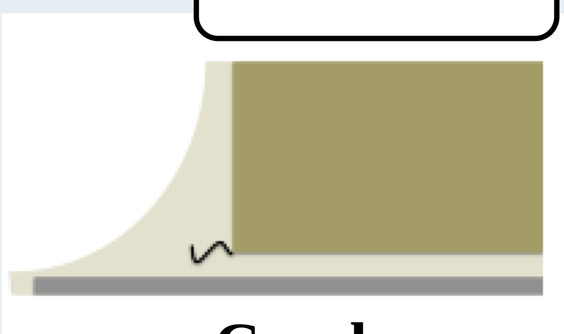
- Physics of Failure (PoF) is widely used for reliability assessment and prognostics and health management (PHM) for electronics systems.
- Yet, the application of PoF concept for screening seems to lag behind.
- A defect-based approach based on PoF is proposed for initial ESS profile set up.

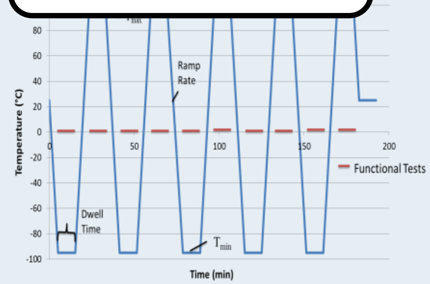


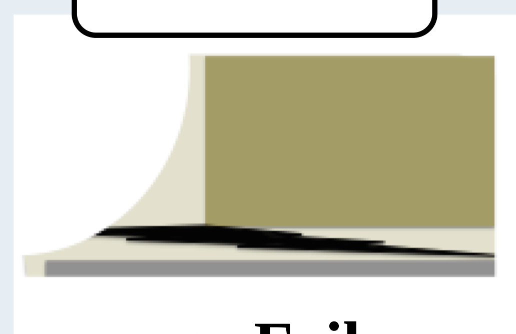
Defect-Based Approach

- ESS should be planned based on physics-of-failure. A defect-based approach is proposed as an alternative to the existing approaches to set up an initial ESS profile.
- Based on the defects' failure mechanism under different stresses, an appropriate stress test should be selected to precipitate the defect.

Defects → Failure Mechanisms → Stress Tests







Crack → Thermal Shock → Failure

Defect vs Stress Table for Board Layer Defects

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Uncovering Defects in Electronic Systems

Home Board Level/Above Component Level Feedback

Component Type - Board Layer

Defect Type	Cold Step Stress	Hot Step Stress	Thermal Shock	Random Vibration (RS)	Random Vibration (ED)	Combined Environment (TS +RS)	Combined Environment (TS +ED)	Power Cycling	Torque	Temperature, Humidity, Bias
Board Warpage	✗	✗	✓	✗	✗	✓	✓	✗	✗	✗
Hollow Fiber	✗	☹	☹	✗	✗	☹	☹	✗	✗	✓
Separation of Fiber/Resin Interface	✗	☹	☹	✗	✗	☹	☹	✗	✗	✓
Blistering/ Delamination	✗	✗	✓	☹	☹	✓	✓	✗	☹	☹

Example of Defect Page- Hollow Fiber

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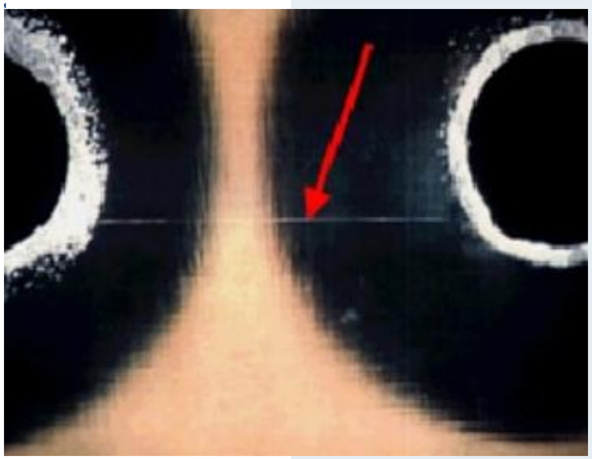
- **Defect Description**

  Long, hollow capillaries in glass filaments that provide pathway for conductive filament formation.

- **Defect Formation Process(s)**

  Air bubbles in molten glass are drawn into long capillaries in glass filaments during the processing of E-glass (most common fiberglass used in the electronics industry).



g of E-glass (most common

Example of Defect Page – Hollow Fiber

List of Tests to Precipitate this Defect	Failure Acceleration	Likelihood to Precipitate Defect	Failure Mechanism
Temperature, Humidity and Bias	Humidity and high temperature increases moisture absorption by the laminate materials that accelerates filament growth [7] Voltage gradient accelerates filament growth [7]	✔	Conductive Filament Formation
Hot Step Stress	High temperature increases the moisture absorbed by the laminate materials given a threshold moisture content [7]	Δ (The presence of threshold moisture content in the laminate materials)	
Thermal Shock	Same as Hot Step Stress	Δ	
Combined Environment	Same as Hot Step Stress	Δ	

[7] Rudra B., Pecht,M., Jennings, D., "Assessing Time-to-Failure Due to Conductive Filament Formation in Multi-Layer Organic Laminates." *IEEE Transactions on Components, Packaging, and Manufacturing Techniques- Part B*, vol. 17, no. 3, 1994.

Other Recommendations

- We urge the Department of Defense to discard MIL-HDBK 344A, so as to prevent more investments and efforts from wasted into performing ESS as required by MIL-HDBK 344A.
- Before the proposed defect-based approach matures, we encourage the industry to create a methodology in parallel that reflects today's needs.
- For example, the up-to-date methodology should include the methods to acquire and estimate values instead of providing generalized values and models.