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Summary of Conclusions from the State-of-the-Market Survey

for

Navy Contract N00140-95-Z-0231

Electronic Miniaturization for Missile Applications (EMMA)

G-12 Technical Forum

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May 18, 2000

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Challenges in Using COTS ICs in High-Rel Applications, Results from the EMMA Study

- Background: Collins is part of Navy contract (with Raytheon) to evaluate use of commercial IC parts in Navy missiles
  - EMMA = Electronic Miniaturization of Missile Assemblies
  - Phase 1: State-of-the-Market-Survey: Study of COTS use in high-rel environments and applications
  - Collins report documented in 5 Technical Papers
- This Presentation Summarizes the Conclusions of the Study
  - Issues involved in use of COTS ICs: design, materials, controls, etc.
  - Part type by part type characteristics and vulnerabilities
  - Methods for discerning suitable from unsuitable COTS ICs
  - Industry experience with COTS ICs in high-rel applications
  - Industry approaches for qualification, ruggedizing, cocooning, etc.

Caveats

The Following Should Be Kept In Mind About This Presentation

- No Generalization is Worth A Damn (including this one)
- Sometimes You Can't Build A Square Circle (What you can say in words cannot always be implemented in fact)
- Presentation Content is Based Upon:
  - Phase 1 Study Just Completed for the EMMA Contract
  - Tradition at Collins of Passion for High Reliability
  - Recent Packaging Work in pursuit of Hermetic-Equivalence (ChipSeal Program with WPAFB/Dow Corning)
  - Current ROBOCOTS™ Project (Robust COTS Packaging)
  - Author's Opinions (Sometimes unbiased by facts)

Outline

- **Introduction (WP 99-2025)**
- IC Packaging Technologies (WP 99-2026)
- Published Reliability Data on Commercial Packaging Technologies (WP 99-2029)

copies of reports my be requested from ACI

Emma Summary

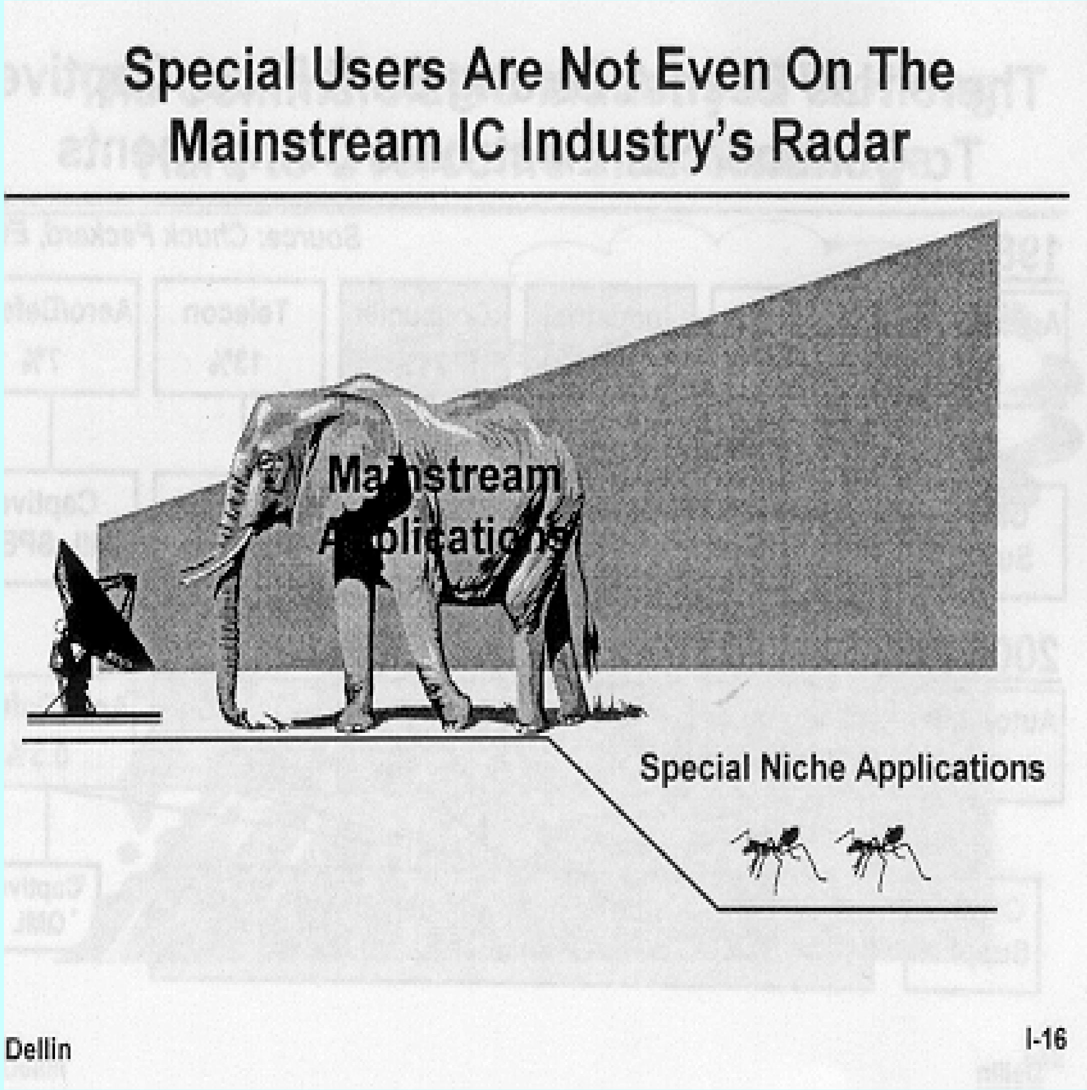
- Today's Goals:
  - Industry today is filled with lots of data and lots of confusion. People make good decisions when they have good data. One goal is to get the good data to stand out from the smoke and mirrors
  - Continue to work together to Learn How to Dance With The Elephants

Learn How the Elephants Dance

Volume commercial IC users are like the elephants on the savannah of electronics products

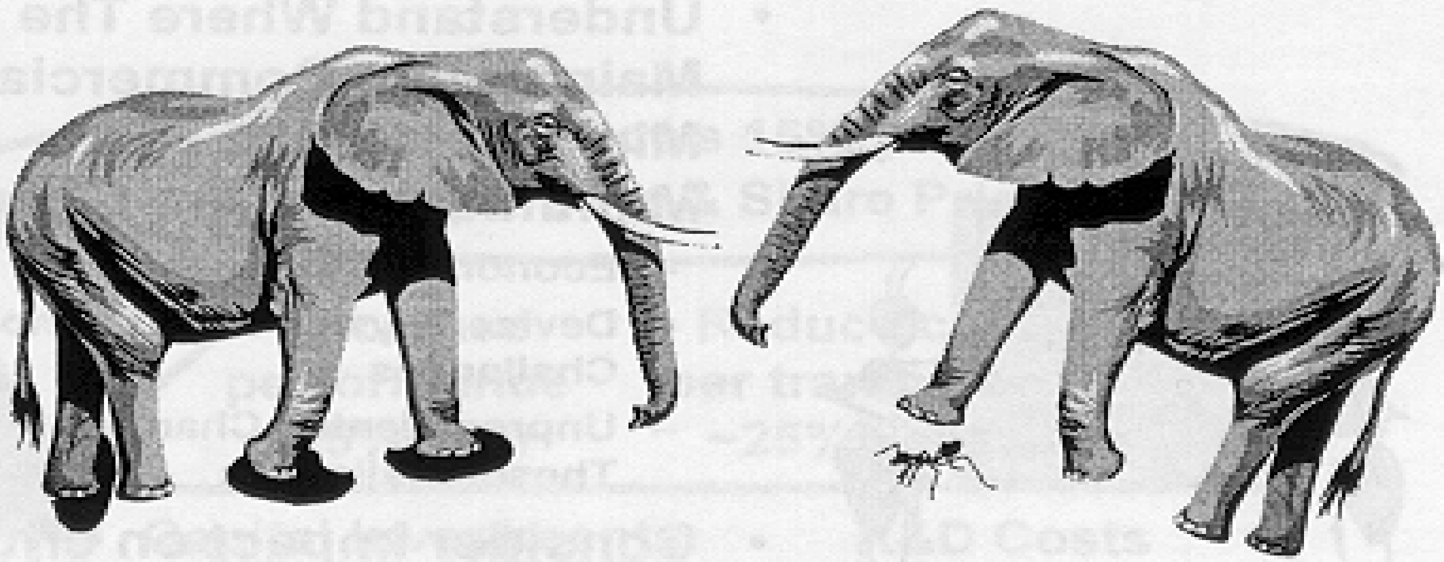
Avionics IC users are niche applications like ants trying to feed on the same savannah

credits to Dr. Dellin, Sandia Labs



Learn How the Elephants Dance

When Elephants Dance
Ants Get Squashed



Dellin

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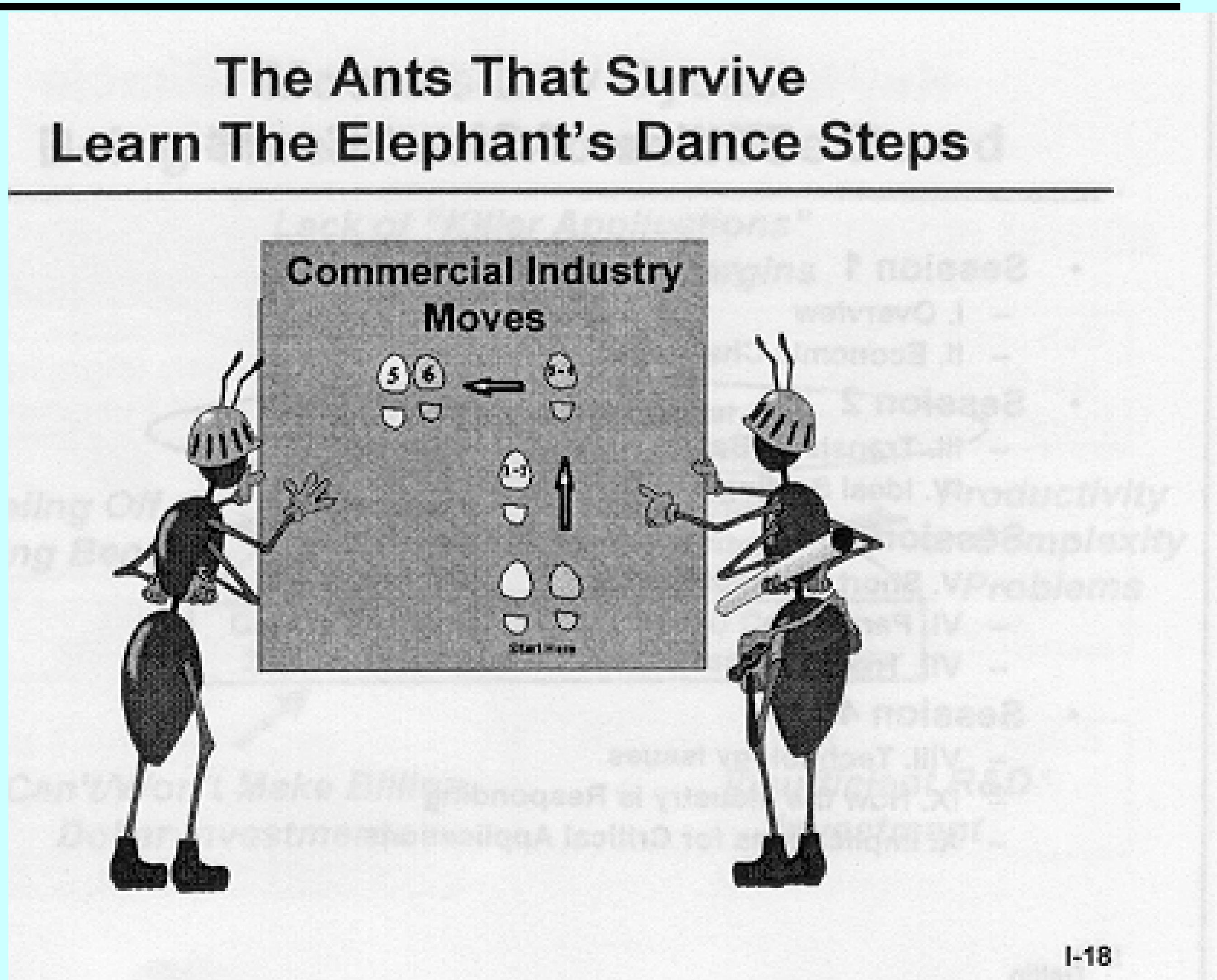
Learn How the Elephant Dance

Survival depends on learning how the elephants dance*

* even then you can get dumped on



Current Situations in Defense Electronics & Commercial High-Rel Electronics

- Declining Number of Sources for High-Rel Components
- Increasing Parts Obsolescence Problems
- “Political” Pressure to Use COTS Parts
- Pressure to Reduce Costs
- Pressure to Reduce Size But Increase Function
  - Continuing Needs for More Device Integration
  - New Needs to Integrate Digital & RF Functions in Modules
  - New Needs to Integrate MEMS Devices Into Modules
  - New Needs to Integrate Optoelectronic Devices in Modules

New Robust Plastic Packaging Approaches

Can Address all these Concerns

- Incentives for Considering COTS ICs
  - Cost Reduction
  - Wider Availability
  - Lighter Weight, Smaller Size
  - Latest Chips Available First as COTS Parts
  - Lower Power Consumption
  - COTS Quality & Reliability Steadily Improving
  - Hermetic Choices are Rapidly Diminishing
  - Pentagon Brass Thinks It's A Good Idea
  - Company Management Thinks It's A Good Idea

Challenges in Using COTS ICs in High-Rel Applications, Results from the EMMA Study

- Concerns About Using COTS ICs
  - Limited Temperature Range (0 to 70C, or -40 to 85C), Unknown Performance and Reliability (Outside of Data Sheet Temperature Range)
  - Unknown Durability in Harsh Vibration, Thermal Cycling
  - Potential Legal Liability in high-rel use
  - Eventual Vulnerability to Moisture, Unknown Long Term Life Characteristics
  - New Die-Level Vulnerabilities with Smaller Features and Lower Voltages
  - Rapid Obsolescence (Moore's Law) vs 20-year Products
  - Unannounced Changes by COTS Vendors
  - Thermal Issues (Poor thermal paths, self-heating popcorn failures)

Using COTS in Extended Environments

This is what you <u>do</u> hear about:

- Most Studies of COTS Plastic Encapsulated Microcircuits (PEMS) Packaging show Some <u>Are Suitable</u> for Extended Environments

- ***This is what you <u>do not</u> hear about:***
- Those Same Studies of COTS PEMS Packaging show Some Are <u>Not Suitable</u> for Extended Environments
- Contractor evaluations of COTS PWB Assemblies often show them fragile in Shock, Vibration, Thermal Cycling Environments

- ***<u>Lesson from the Challenger Mission:</u>*** *Don't Use Parts in Temperature Ranges That Were Not Designed For!!!*
- ***<u>Lesson from the Iran Rescue Mission:</u>*** *Don't Use Parts in Environments That Were Not Designed For*

Outline

- Introduction (WP 99-2025)
- **IC Packaging Technologies (WP 99-2026)**
- Published Reliability Data on Commercial Packaging Technologies (WP 99-2029)

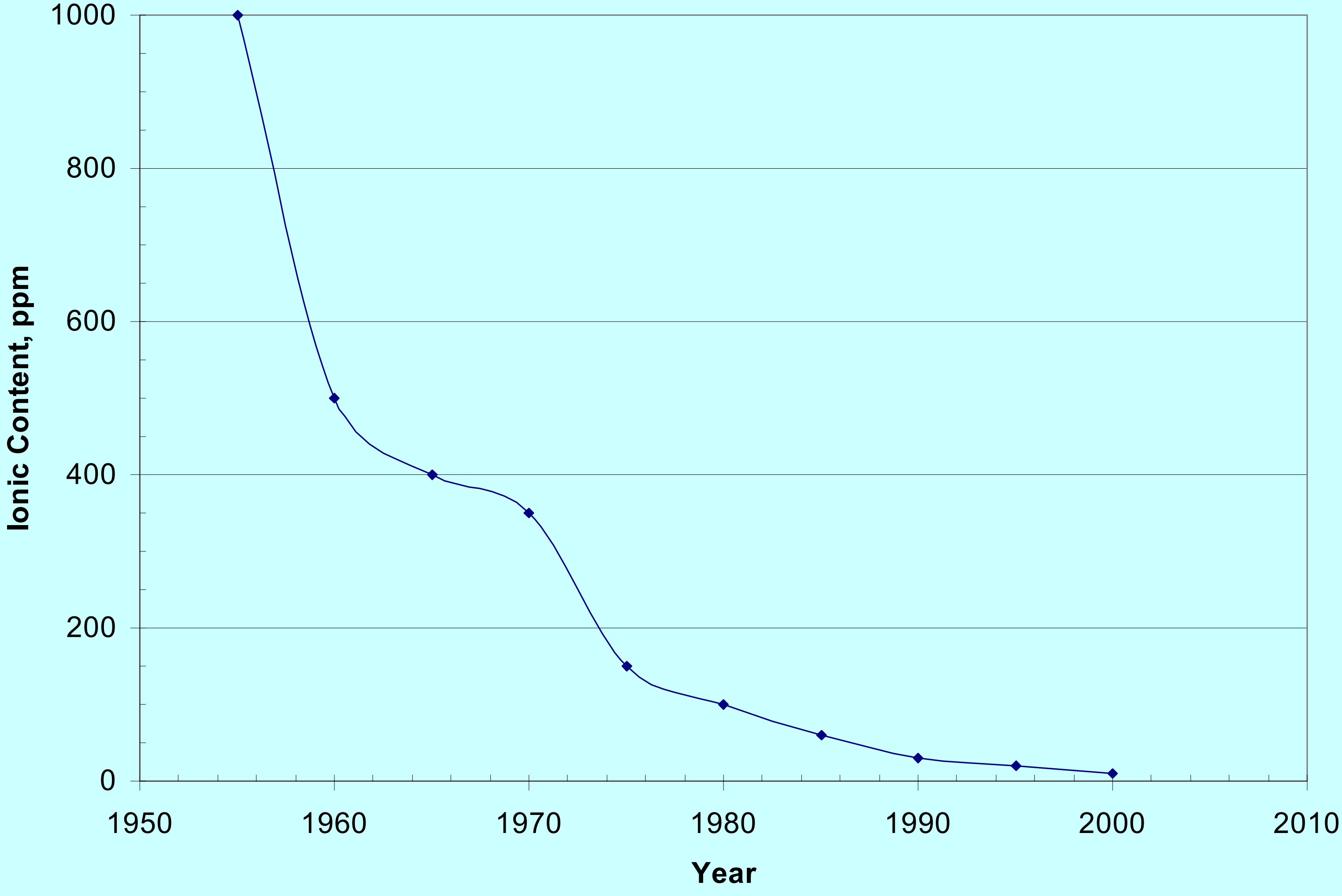
Important Encapsulating Material Properties for High Reliability

- Epoxy Family Type
  - Epoxy Cresol Novolac (traditional molded plastic IC packages)
  - Bi-phenyl Epoxy (new anti-popcorn formulations)
  - Multifunctional Epoxy (new special application formulations)
  - Anhydride Cured Epoxy (liquid encapsulants)
- Glass Transition Temperature (Tg)
  - Need Tg at least 20C higher than maximum field temperature
- Coefficient of Thermal Expansion (CTE)
  - Need CTE close to PWB to avoid premature solder joint failures
  - Need CTE balanced between silicon and I/O (leadframe) to avoid plastic or silicon cracks or other failures
- Similar Requirements for Die Adhesive Used In Plastic Packages

Important Encapsulating Material Properties for High Reliability (cont.)

- Elastic Modulus
  - Need modulus high enough to provide durable protection, but low enough to accommodate CTE mismatch strains
- Ionic Content
  - Mobile ions within epoxies are a major driver of corrosion (in humidity)
  - Ionic content in some IC epoxies is a function of both curing chemistry and process controls used during preparation, encapsulation, and curing
  - Ionic content can also be driven by contaminants in encapsulant fillers, and by contaminants from the assembly process
  - Ion mobility (and ionics degrading effects) increases dramatically as temperatures rise to near and above the glass transition temperature
  - The excellent work done to control ionic content in molded ICs does not appear to be widely implemented or understood for over-molded BGAs or for liquid-encapsulated BGAs
  - Whether laminates, die adhesives, & solder masks contribute is unclear

Improvements in Molded Plastic Package ICS Directly Related to Ionic Content Reduction



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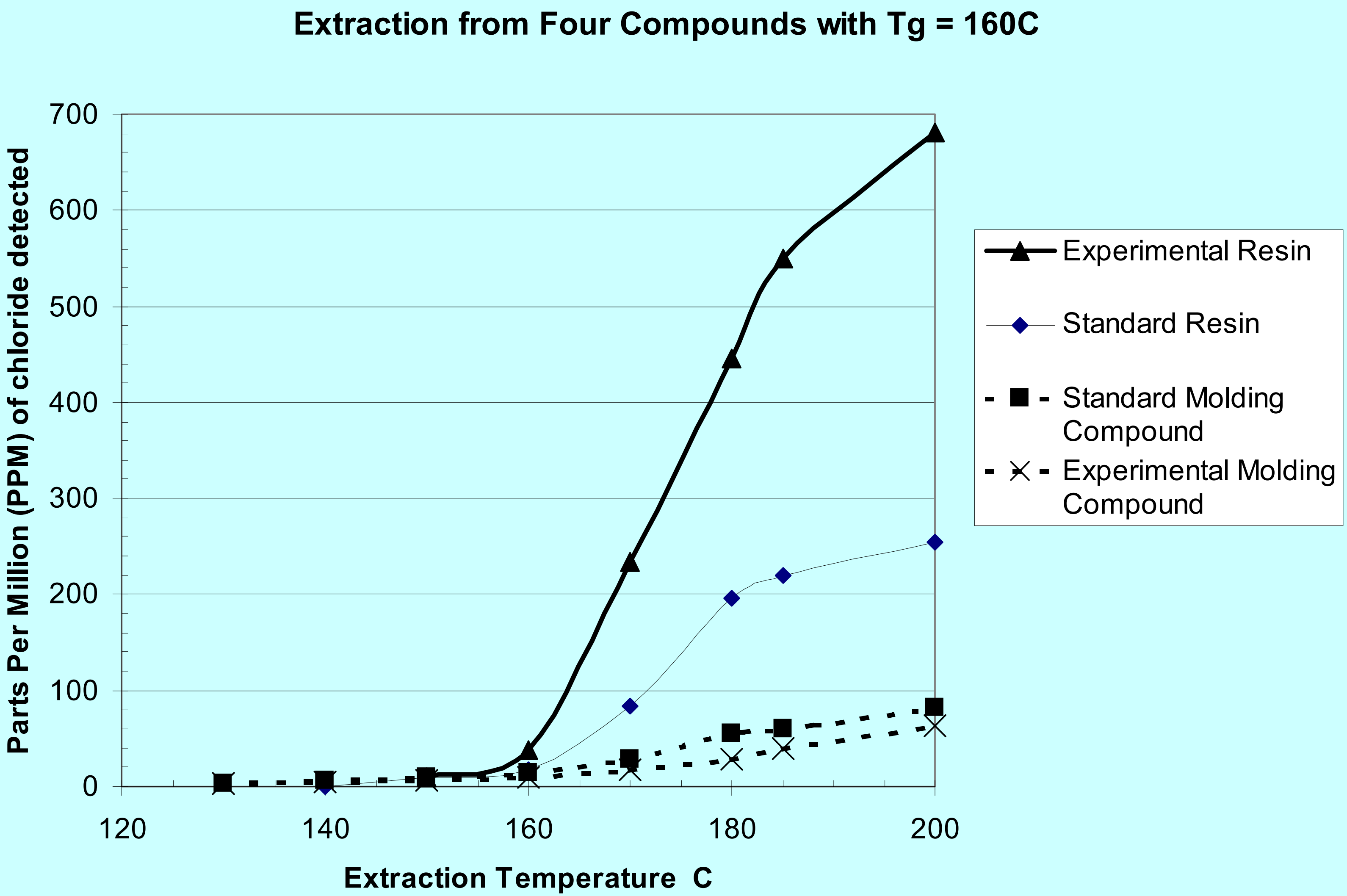
Improvements in Molded Plastic Package ICS Are Directly Related to Ionic Content Reduction

Molded Plastic Package ICs:

- Early Emphasis: void-free molding (not reliability)
- Reliability Improvements 1950s - 1970s
  - Mostly from reductions of ionics in fillers and resins
- Reliability Improvements 1980s - 1990s
  - Mostly from reductions of ionics in process assembly (chloride-free manufacturing)
    - cleaning solvents
    - leadframe and die residues
    - die-attach adhesives

Dramatic Effect of Extraction Temperature on Chlorides Detected



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Variability in Epoxy Molding Compounds

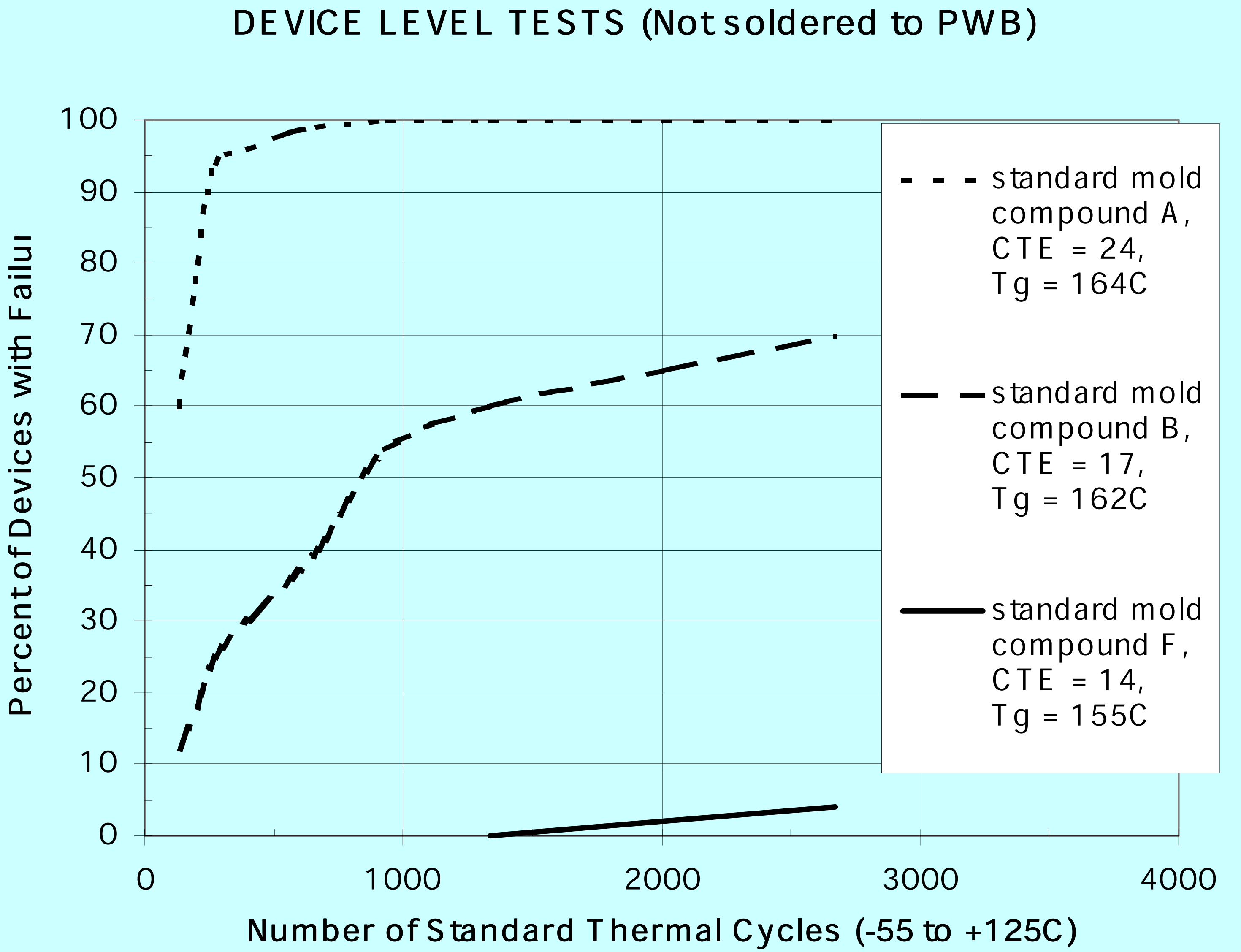
- Nitto website lists 27 different ortho cresol novolac epoxy molding compounds and 15 bi-phenyl epoxy molding compounds currently in production
- Sumitomo, Plaskon, and Dexter offer similar variety
- Sinnaduarai & Pecht state over 400 compounds are fielded
- wide variation in properties
  - Tg varies from 110C to 200C
  - CTE varies from 7 ppm/C to 30 ppm/C
  - Elastic Modulus varies from 10 to 30 GPa
  - Ionic Content varies from less than 1 to over 100 (if measured by the same 160C extraction method)

Conclusions: 1) Not All Epoxies Are The Same

2) Don't Believe the Data Sheets on Ionics

Does Molding Compound Make A Difference?

(source: L. Nguyen, National Semiconductor, ECTC, 1994, pp. 210-217)



Not All Epoxies Are The Same!!!

Company	Compound	Tg degrees C	CTE ppm/C	Ionic ppm	Modulus GPa
Nitto	MP-8000AHP	158	18	30	13
Nitto	HC-30-2	169	28	6	15
Nitto	MP-7410TA	120	8	11	27
Nitto	MP-3000F3S	195	21	40	14
Nitto	MP-7100H	125	13	0	19
Nitto	MP-180BV	166	14	14	11
Dexter	MG15F	190	25	40 est.	18
Dexter	MG65F	150	10	40 est.	20
Plaskon	3400-2	155	20	30 est.	15
Plaskon	PPF-165	130	21	6 est.	15
Plaskon	AMC2	147	14	6 est.	17

What About All Those New Miniature COTS Package Types

How Do New COTS Packages Do In Thermal Cycling?

- Did We Learn Our Lessons with Leadless SMT Technology? (Low Expansion Parts Break Solder Joints to PWBs)
- Many New Packages are “Near-Die-Size”. The Silicon Occupies a High Percentage of the Volume and Dominates the Expansion Rate of the Entire Package.
- Many New COTS Packages Have Low Expansion Rates (6 to 10 PPM/C) like TSOPs

New COTS ICs Are Great for Commercial Environments, But Not as Good as We are Used to for Robust Durability in High-Rel Use

What About All Those New Miniature COTS Package Types

- ***In Dry Environments Plastic Package Parts Have a Long Life, As Evidenced By Success in Computers***
- ***What About Moist Environments?***
  - "In order to support an electrochemical corrosion process a continuous moisture path must exist between electrodes. This adsorbed moisture film must be sufficiently thick as to exhibit the behavior of bulk water. This only happens above a threshold relative humidity RH_c for external or internal surfaces. Ionic contamination lowers the value of RH_c."

    -Seraphim, Lasky, & Li, Principles of Electronic Packaging, McGraw-Hill, 1989, p. 279
  - Another Book Suggests That 65% at Room Temperature is the Corrosion Initiation Threshold -Robock & Nguyen, Chapter8, Microelectronic Packaging Handbook, Tummala & Rymaszewski, editors

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What About All Those New Miniature COTS Package Types

Temperature	21C	40C	60C	90C
Threshold Relative Humidity (at constant Humidity Mass Ratio)	65%	23%	8%	3%

- All Plastic Parts Absorb Moisture from Humid Ambients in a Short Time, and are Vulnerable to Failures Due to Moisture-Degradation Mechanisms When RH Levels Exceed The Values in the above Table.
- Plastic Package ICs With Inherently High Ionic Content and/or Environment-Induced Cracks are Particularly Vulnerable
- Plastic Package ICs Destined for Use in High-Rel Environments Must be Qualified for Appropriate High Humidity Environments

So With All These Challenges to Using COTS ICs, Why Are We Doing This?

(As Adam said to Eve: There aren't many other choices)

- We Have to Build Things from the Parts Available and the Parts Affordable (Affordable Hermetic Parts are Increasingly Hard to Get)
- The World Situation Has Changed and We Have to Adapt to the New Conditions
- Some COTS Parts are Suitable, Some Are Not
- We Need Rapid Methods of Discerning Which ICs are Suitable
- We need Rapid Production Paths for When the COTS ICs are Found Unsuitable and for When We Need to Build Custom Ruggedized Parts
- The New Focus Must be on Developing Flexible Ways to Respond to Rapid Technology Changes, and to Adapting Commercial Technology for High-Rel Use

Comparative Performance Needed for Various Environments

Field Conditions	Test Conditions				
	85C/85%RH	95C/95%RH	HAST 108C/90%RH	HAST 125C/90%RH	HAST* 130C/85%RH
General 12C/72%RH	500 hrs	130 hrs	100 hrs	50 hrs	55 hrs
Tropical (99% coverage) 29C/86%RH	5100 hrs	1300 hrs	1000 hrs	500 hrs	560 hrs
Severe 35C/90%RH	10,000 hrs	2600 hrs	2000 hrs	950 hrs	1100 hrs

* values in this column calculated from S-H equation presented in reference [E6], all other values quoted from reference [E6]

E6. Sinnadurai, N., "Plastic Packaging is Highly Reliable", IEEE Trans. on Reliability, Vol. 45, No. 2, June 1996, pp. 184-193.

Industry Approaches to Managing Risks of Using Plastic Package ICs in High-Rel

1. Use QPL Parts
2. Qualify the COTS Parts for Use
   - Qualify “Nurtured” COTS Supplier once, and Buy from them forever
   - Qualify COTS Parts from Selected Suppliers, Re-qualify Periodically
   - Buy from any COTS Supplier, Qualify Every Lot (every IC?)
3. Use the COTS Part “As-Is”, Change the Boundary Conditions
   - Plan and budget to Replace Equipment Every 2-3 Years
   - Design-In Sufficient Redundancy for Fault-Tolerance / Fault Monitoring
   - Deploy Massive Replacements to Replace Failures as Needed
   - “Cocoon” the Equipment to See Only COTS Environments

The “right” approach is probably a combination of the above depending upon part availability

Outline

- Introduction (WP 99-2025)
- IC Packaging Technologies (WP 99-2026)
- **Published Reliability Data on Commercial Packaging Technologies (WP 99-2029)**

Summary of Published Reliability Data

Questions on Suitability of COTS ICs for High-Rel Applications Usually Involve 5 Questions Needing Satisfactory Answers:

① What Range of Environmental Conditions Are Really Involved?

② Does the IC Function Satisfactorily over the Required Temperature Range?

③ When Assembled on the PWB, Does the COTS IC survive an adequate number of Thermal Cycles for the Application?

④ Will the COTS IC Survive for an Adequate Lifetime in the High Humidity Environment of the Intended Application?

⑤ Will the COTS IC be Satisfactorily Available with the Needed Quality & Reliability Over the Required Life of the Application?

Summary of Published Reliability Data

This Report Proposes that all Published Reliability Data Be Normalized to "Standard" Conditions Which are Relevant to the High-Rel Community

- Thermal Cycling: -55 to +125C, (the report only used data which had at least a ten minute dwell at each temperature extreme)
- High Humidity:
  - 85/85 test data is insufficient for high-rel, unless tested beyond 5000 hrs
  - HAST Testing should be the standard measure for corrosion susceptibility (Standard Conditions per EIA/JEDEC JESD22-A110-A, 130C and 85%RH, with Bias)

    (The definition of standard bias conditions still needs further work!!)
- All Published Data in this report Re-calculated to Standard Conditions Using EIA SSB-1.003 Acceleration Equations

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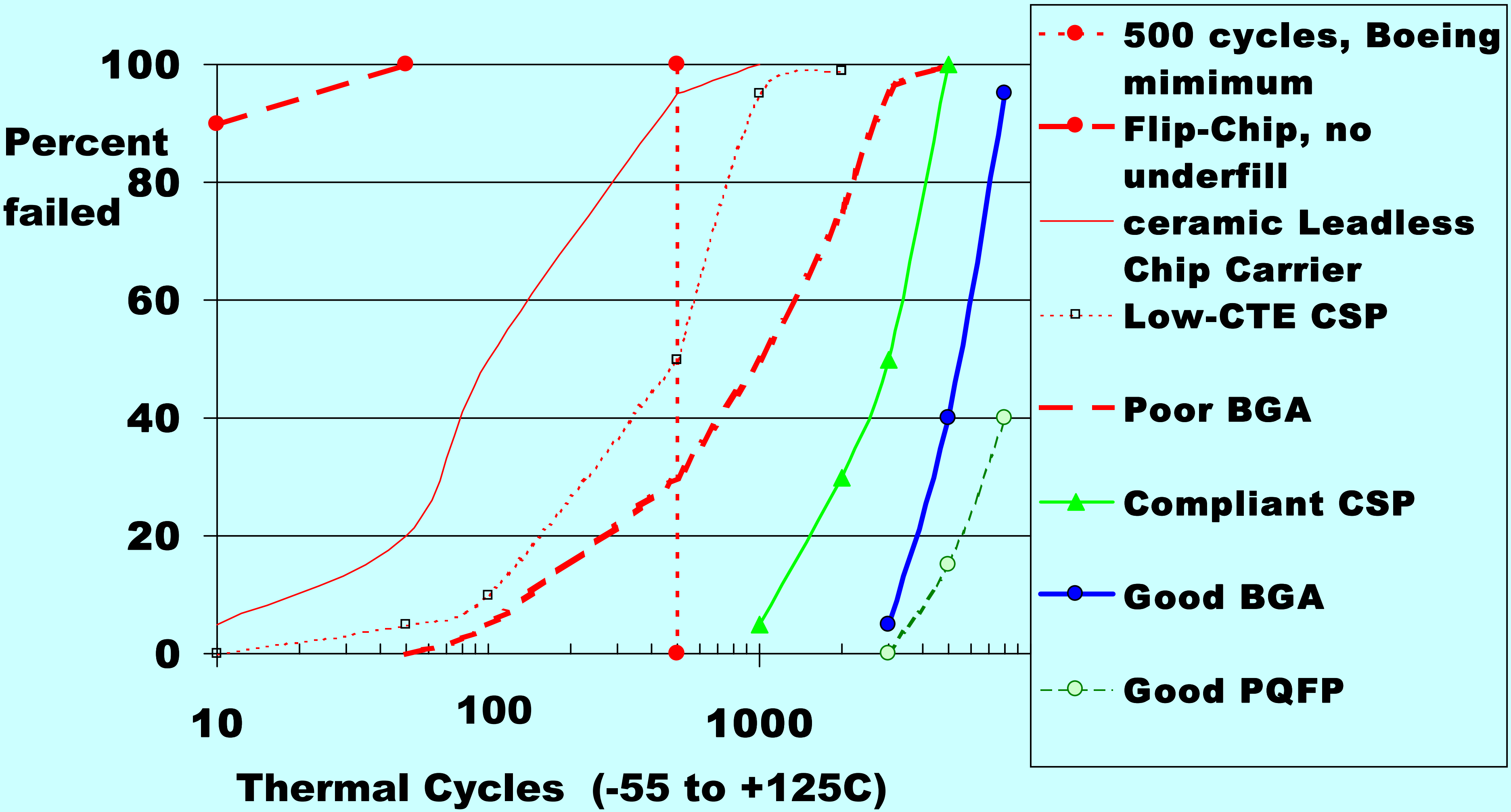
Summary of Published Reliability Data

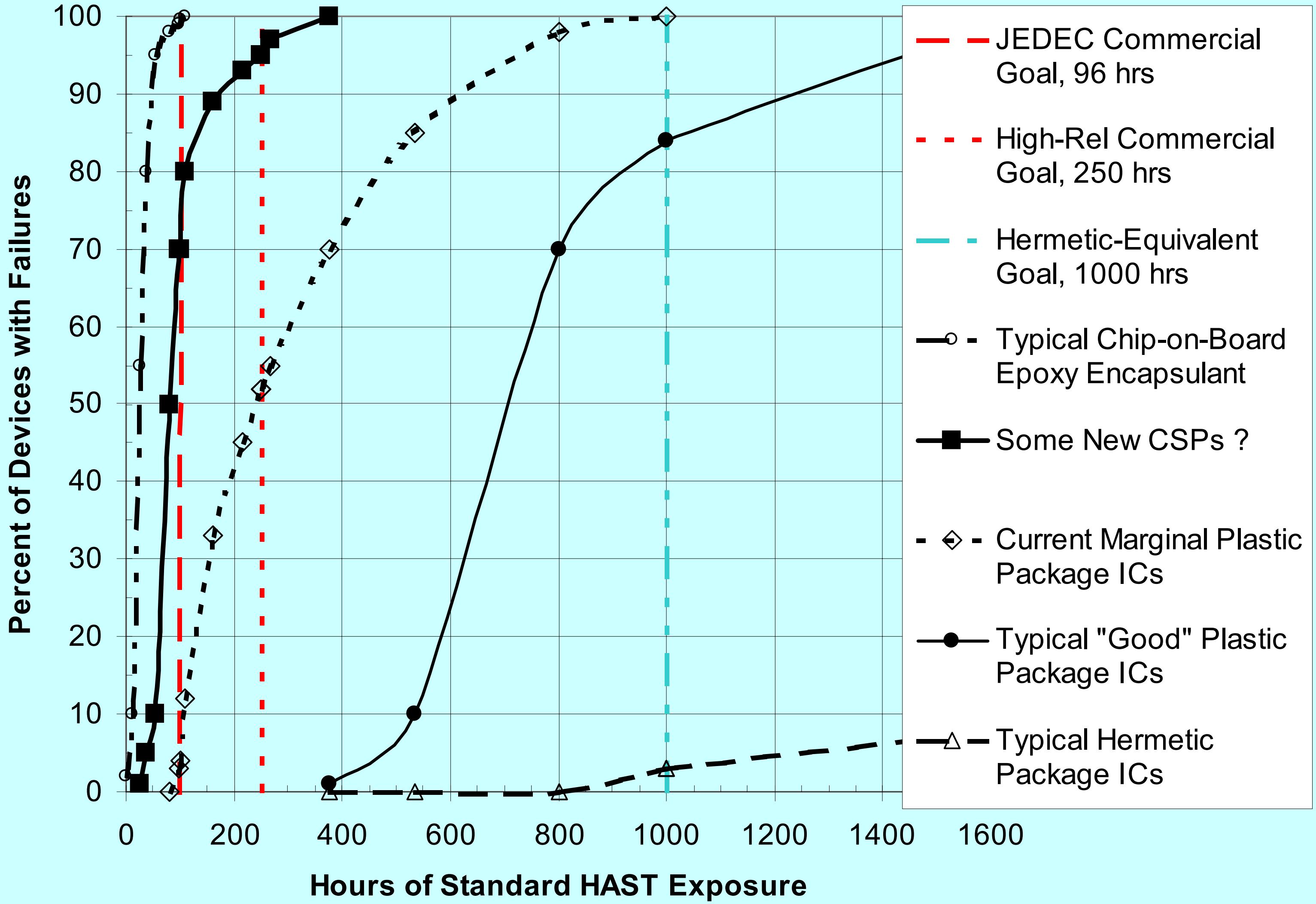
Comments About Accelerated Testing and "Standard Test Conditions"

- Criticisms about introducing new failure mechanisms seldom apply to high-rel applications with harsh environments
  - -55 and +125 are real environments in harsh military applications
  - 130 C at 85% in HAST is not far from real 125C 99%RH conditions
- Transformation to Standard Conditions gives the most optimistic estimate. If there are new failure mechanisms introduced, performance will be even worse than predicted in this report, and the parts should probably not be used in high-rel applications anyway

Lessons Learned in Related Projects
(EMMA Summary, WP 99-2029)



HAST Performance of Various Packages



Comments on High Humidity Performance of COTS ICs

- Concerns with the New Smaller COTS Package Types:
  - The Extensive Learning from Improving PEM Molding Compounds is not being Effectively Transferred to Smaller COTS Package Types
  - Some Packages are Being Introduced with Little Homework Done on Control of CTE, Tg, or Ionics in the Encapsulating Materials
  - Effects on Reliability of Types of Epoxies Used in Die Adhesives, Laminate Substrate, and Solder Masks Seem to be Unknown
  - Liquid Encapsulant Epoxy and Over-molding Epoxy, in General, Seem to Have Very Poor HAST Performance. Of Concern is that these Same Materials are used in Chip-On-Board, Flip-Chip Underfills, BGAs, and Some CSPs!!

Recommendations
(Things we need to get done)

- Exploit Opportunities for Cost Savings with COTS ICs <u>Where They Are Suitable</u>
- Develop Better Ways of Assessing Suitability (Qualification Costs Can Exceed Procurement Cost Savings, Qualification Times Can Negate Availability Advantages of COTS)
  - Need Rapid Assessment Method for Life in Thermal Cycling
  - Need Rapid Assessment Method for Life in High Humidity
- Develop Better Specifications on “Real” Environments
- Acquire Better History on Field Reliability

Demand Better Data on Field Reliability History

- Questionable Conclusions on Field History Are Being Reached By Mixing Apples and Oranges
  - e.g.: Plastic Package ICs (properly built) are more reliable than Hermetic Package ICs (improperly built)
  - e.g.: Plastic Package ICs (die built in modern IC fabs) are more reliable than Hermetic Package ICs (die built 20 years ago)
- Any Hypothesis Can Be Proven By Manipulation Of Data
  - Use Only The Data That Supports the Hypothesis, Ignore the Rest
  - Obscure the Real Trends by Reporting Averaged Data
  - Half of all American……….
  - The Average Person in America…………
- New Initiative Needed: Good Feedback Data (No more NTFs)

  (Accurate life predictions require identification of failure mechanisms)

Develop Faster, Easier, Verified Methods for Accelerated Testing

- Better Predictions Require Better Methods of Accelerated Testing (better accuracy)
- The Availability of Very Fast Test Methods Would Greatly Simplify the COTS Dilemma

The ability to measure is the beginning of all knowledge

……Lord Kelvin

- New Project To Address These Issues: *ROBOCOTS™*

(Robust Packaging Of COTS ICs)

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ROBOCOTS™

A New Program
for
Robust Packaging of Commercial-Off-The-Shelf ICS

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May 18, 2000

Common Challenges for COTS ICs in High-Rel Applications

- Discerning Which COTS Parts are Suitable for High-Rel Use
  - Some Plastic Parts are Quite Robust
  - Some Plastic Parts are Very Wimpy
  - They all Look alike!
  - Current Qualification Methods are Long and Costly
- What to do When No Suitable COTS Part is Available
  - Need a low-cost Commercial Path for Ruggedized Custom Plastic Packaging

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ROBOCOTS™ Project Goal #1:

Develop Fast (few-days), easy test Methods capable of Discerning Robust Plastic Packaged ICs from Wimpy Ones

- Develop New *Fast (few-day)* Measurement Capabilities
  - Impedance Spectroscopy in HAST to Identify Corrosion Vulnerabilities (possibly also useful to measure Tg, dielectric constant, and to monitor compound changes, etc.)
  - Ion Chromotography to Quantify Trace Ionics (need standard method with 160C extraction, to be useful)
  - Rapid Thermal Shock test method
  - DSC to Identify Tg, TMA to Identify Tg, plastic CTE, package CTE
  - X-ray to Identify Die Size and I/O Configuration
  - Force Gage to Identify Lead Compliancy Spring Rate
  - Encapsulant Modulus Measured by method TBD
- Get Samples of Known-Good & Known-Poor COTS for Callibrating the Test Methods
- Establish Test Result Values Needed for High-Rel

ROBOCOTS™ Project Strategy

- If COTS ICs Pass the *ROBOCOTS™* Packaging Tests, Use Them
- If COTS ICs Don't Pass the *ROBOCOTS™* Tests, Obtain Same Die in Ruggedized Package Versions

ROBOCOTS™ Project Goal #2

- Develop Robust Custom Plastic Packaging Options Suitable for Use in Severe Environments:
  - General High Reliability Commercial Avionics
  - Full Military-Specification Electronics
  - Harsh Applications (wings & tails, 130C ambient)
- Solutions Needed for PEMs, BGAs, CSPs, COB, TAB, Flip-Chip
- Solutions Needed for Single-Chip and Multi-Chip Packages
- Demonstrate Fully Qualified Ruggedized Plastic Package
  - Analog Devices 846B used as Demonstration Vehicle for BGA
- Develop Production Paths for Ruggedized ICs
  - Exploit contract BGA Capabilities and Interest in DoD-Quantities Business

Ruggedizing COTS Bare Die