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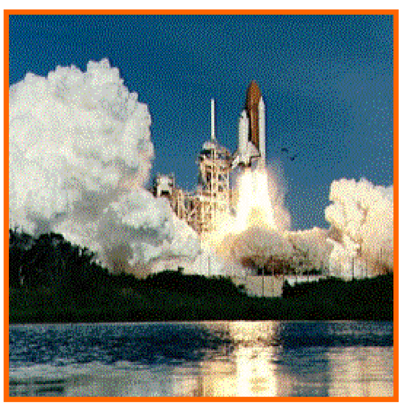
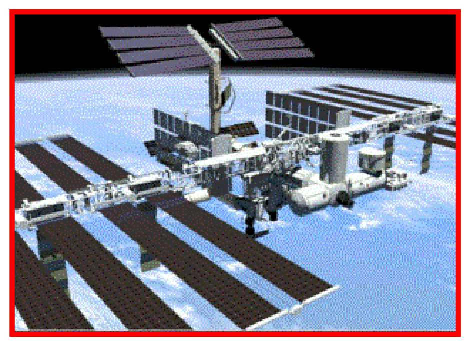
NASA Commissioned Guideline Report on the Use of COTS Plastic Microcircuits in NASA Space Flight Hardware





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EXECUTIVE SUMMARY

Commercial Off-The-Shelf Plastic Encapsulated Microcircuits (COTS PEMs) are now being evaluated by the US DOD agencies, European Space Agency, and the National Aeronautical Space Agency, among others. For many years these agencies would not use COTS PEMs in their military and space hardware because of their reliability risk and even safety concerns. Today this is all changing and these same agencies are attempting to find ways to reduce the risk and at the same time reduce some of the development costs. The main drivers to use COTS are the lower procurement cost, more performance and functionality, and reduced size and weight.

To this end NASA has also embarked on an ambitious path to gather real time data and evidence on COTS PEMs that will lead to more understanding and knowledge of COTS quality and reliability. NASA has spent three years of planning, testing, and analyzing COTS PEMs, under the NEPP Program, and has identified many of the quality and reliability risks associated with COTS PEMs if used in a demanding reliability application and in a radiation hostile environment.

The nature of COTS is, of course, ongoing change to meet the needs of a demanding and competitive commercial market. Therefore, to stay abreast, the work must continue by NASA to refine all the information gathered and add new information as it becomes available.

This NASA guideline and report shares NASA's recent experiences with COTS PEMs reliability (non-radiation), gives examples of risk based on the data gathered and analysis, and makes recommendations that NASA believes will help steer the NASA design community and Project Managers to use COTS PEMs with confidence and minimum risk.

PREFACE

This task was accomplished with the cooperation and support of the seven NASA Centers, Sypris Test and Measurement, General Test Laboratories, and other military and aerospace agencies including: SAF, USA, USN, ESA, JAXA, and CSA.

Special acknowledgement goes to the following individuals who were major contributors to the COTS PEMS evaluation task and final report: M. Sandor, D. Peters, S. Agarwal, D. Vu, D. Gerke, P. Miranda, and M. Borzage.

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INTRODUCTION

This guideline is predicated on actual NASA experiences and test evaluations conducted on circuits and packages that would be used in NASA applications. Data was collected, evaluated, and analyzed by multiple NASA Centers and multiple Governmental Agencies for the sole purpose of determining which tests should be conducted on PEMs (and were shown to have high value in reducing potential risks associated with such parts when used in NASA flight hardware), and which tests were valueless. In some cases, sound engineering judgment and recommendations may override actual test results collected (tests were based on small sample sizes). It has been established that adhering to industry test standards, conferring with the PEMs manufacturers, and review of industry data can also improve reliability for NASA applications. NASA believes that, based on its designed tests and the data collected on PEMs, a strong testimonial is evident for adhering to the recommendations as given. However, each NASA application and the associated mission requirements (when using PEMs) must be evaluated before pursuing any course of action to attain optimum reliability results.

SECTION 1

NASA EXPERIENCES AND PROCESSES

A plastic encapsulated microcircuit is a microcircuit made in Silicon Valley, or elsewhere, that meets the commercial temperature range (0-70^{o}C) and satisfies the commercial marketplace needs. Industrial temperature range (~ -40C to 85C), and Enhanced Plastic products are all considered in this guideline as PEMs being that are plastic, and are not fully electrically screened over temperature. Being that the commercial marketplace is in a constant state of change, the reliability, radiation tolerance, and electrical performance of PEMs, so too, is in a constant state of change.

The commercial marketplace for PEMs over the last few years has evolved from the automobile environment, which was the major commercial business segment – to the laptop computer environment, the next major commercial business segment – to the cell phone market environment, what has now evolved to be the major commercial business segment.

The PEMs manufacturers in Silicon Valley will quickly adjust their processes to fulfill the performance needs of the major commercial business segment environment as it changes. We in the NASA community are not aware of when they change from one business segment to the next. Therefore, we are forced to characterize the lots that we procure to assure us that they will work over the intended NASA environment (i.e., temperature, radiation, vibration, etc.). An old Silicon Valley anthology was: "If you don't test it, it won't fail…" And so too, NASA believes: If you don't test it, you have no physical proof that the very part that you have purchased even works in the intended environment. NASA has yet to see consistent 100% yields for any Semiconductor company. The Silicon Valley companies take no liabilities/consequential damages if their PEMs part does not work. Their warranty is: it is guaranteed to work, if it does not work, simply bring it back, and a new (also untested) PEMs part will be supplied. And so on. This is fine for the commercial world (which is repairable), but clearly is unacceptable for NASA. We cannot take such a risk, we cannot go and get the non-functioning PEMs part and return it for a replacement. Reliability of "each part" is paramount to NASA missions.

1.1 SUPPLY CHAIN

Original equipment manufacturer (OEM) Semiconductor companies take direct orders from their strategic customers. Strategic customers are customers who buy millions of parts per day (different companies have different minimums, and different definitions of a strategic customer). NASA is not a strategic customer. NASA is directed by the OEM Semiconductor companies to procure through authorized distributors throughout the United States. Authorized distributors many times do not control lot homogeneity. Further, distributors many times re-tape-and-reel, or reload rails, or in other ways mix lots prior to selling through distribution. This further complicates matters. (OEM Semiconductor companies, as a matter of course, will put marginally performing parts out to the marketplace through their distribution channel to assure that they are not directly shipped to their large strategic customers.)

1.2 INFORMATION FROM DISTRIBUTORS

Many space customers over the last 30 years have had the luxury of immediate communication from the OEM Semiconductor companies when there were questions or problems. Strategic commercial customers still receive instant communication. As NASA is not a strategic customer, and is requested to use only the distribution channel, one major difficulty today is getting quick and thorough information. Distributors are very slow at getting information back to NASA. OEMs do not want to interface with NASA if the procurement came through distribution. OEM Semiconductor companies direct customers who procured via the distribution channel, to get questions answered via the distribution channel. Many OEMs also direct NASA to their web page on the Internet and claim that all information is accurate and available on the web site. Based on NASA's experience (that will follow in this guideline), however, web sites are not kept current and do not always reflect accurate or complete information on the PEMs parts that we procure.

On the web site of each OEM, there is a cautionary note to not utilize their PEMs products in high reliability, life support, or space flight applications. The second cautionary note is never to exceed the data sheet parameters, which includes temperature, electrical parametrics, and heat temperatures for soldering. It should be stated here that most NASA applications (1) are for space flight environments; (2) exceed the commercial data sheets; (3) are flown in missions that are longer than the OEM warranty period for PEMs parts; (4) are being used in a radiation environment. (Extrapolation of radiation hardness from a military radiation hardness designator to PEMs is unscientific.) Thus, it is crystal clear that the NASA PEM application is totally outside the PEMs recommendations and application notes of the OEM Semiconductor company, and usage "as is" without full redundancy would be irresponsible, to some degree risky, and incredibly naïve.

Because we exceed the data sheet, good engineering judgment directs us that to ascertain PEMs part reliability there is no other option other than to characterize the lot, and measure each individual PEMs part we have procured using the following guideline:

1.3 CONCURRENT ENGINEERING

Concurrent Engineering between the "EEE Parts component engineer" and the "system designer" should occur prior to parts selection, and design finalization. All efforts should be made to design "within specification" and use radiation-hard hermetic space quality parts when available. Use Space Quality Parts from the NASA Parts Selection List (NPSL). When this cannot occur, the component engineer can offer risk rating and explain the elements of risk of using PEMs to the designer. Elements of risk might include: unknown radiation hardness; unknown electrical temperature performance; unknown plastic glass transition; unknown materials; unknown chip qualities; unknown assembly qualities such as bonding; unknown lead and lead finish materials; unknown qualification since the last change, etc., etc.

A designer might quote FIT numbers from the web site of the OEM; however, the NASA component engineer may question and request to see the data from which the website FIT numbers came from. Many of the OEM web site FITS today are generalizations and combinations of results, and are not supported by technical justification and scientific data. The temperature measurement of FITS is typically 25°C. NASA typically needs measurements at the "temperature of the application", and it is frequently not 25°C. NASA has never flown a spacecraft at 25°C. The NPSL space quality parts are measured over full operating temperature. The COTS FITS are tested go-no-go at 25°C only. FITS do not include AC tests, nor functional tests at room temperature, or overall operating temperature ranges. Space quality parts always show DC, AC, and functional tests over all temperature ranges (as applicable). Commercial FIT numbers reflect only periodic monitoring of criteria and not "reliability data on the specific lot NASA has purchased".

The NASA component engineer should make every effort to understand the supply chain and understand the Semiconductor company. However, as the attached sticker shows, many of these companies have worldwide manufacturing capability, worldwide assembly capability, and ship from numerous locations throughout the world via direct and distribution channels to the end customer. Therefore, understanding the constantly changing supply chain can be a full time job. To most commercial customers, this supply chain works because they view the PEMs parts as a commodity that is repairable when there is a problem. However, NASA has non-reparable missions where performance is paramount! PEMs should be selected for their functional and/or size advantage, not for cost savings (…because the characterization and screening steps necessary to ensure reliability usually negate any perceived cost advantage). Before a design is agreed upon, and finalized, the NASA component engineer should assure that the functional advantage is truly an advantage after being submitted to Program radiation levels, and Program thermal and mechanical requirements. Many times, the very parameter that draws the design engineer to the PEMs part, is the first parameter to degrade in the Program radiation and/or thermal environment.

1.4 SUPPLY CHAIN PROCUREMENT

In that PEMs parts are constantly changing, the time of procurement is the opportunity to buy all of the flight quantities needed, plus all of the engineering model units, all radiation samples, and all screening samples that are from the precise lot, and therefore truly represent the lot. (If one was to buy the same part a day, or a week, or a month later, it may be from a different wafer foundry, it may have been assembled in a different assembly facility, it may have different epoxy, materials, etc., etc.) Therefore, NASA suggests large quantities be procured up-front all at one time. [NASA Projects should be aware that rapid obsolescence is common in the PEMs community, the time until obsolescence is often nine to eighteen months. OEM semiconductor manufacturers have reported making die mask changes as frequently as once a month, and fully qualified to an "internal company qualification" – but are unqualified to the historical model. Obtaining all lot specimens up-front, at one time is paramount to the known reliability of the PEMs lot.]

As an example, when a NASA project needs 20 flight model parts; it is recommended that at the same moment the project should buy 20 engineering model (EM) parts; along with 22 DPA samples (if the project desires a 90% confidence level in sampling); along with 22 radiation samples for TID; along with 22 radiation samples for SEE; plus a 200 pieces quantity for screening yield loss; plus 100 additional spare samples for additional engineering evaluation. Therefore, to buy 20 flight models, one really needs 406 parts to ensure the lot reliability, and all to be procured – at one time, at the beginning of the project. As PEMs parts are usually very inexpensive, this is not cost prohibitive. The benefit of buying these all at once is that they are more likely to be of the same homogeneity as the flight lot. The sample quantities for very expensive PEMs should be looked at by the NASA component engineer on a case-by-case basis, and confidence level/risks clearly explained in writing to the Project for approval.

It is also suggested that PEMs with date codes older than one year, not be candidates for NASA Programs (– as little is known about shelf life, tin whisker growth, inter-metallic formation, storage life, corrosion/oxidation of PEMs) without NASA component engineer, and Program approval.

1.5 SCHEDULE, BUDGET, AND CHOOSING A CUSTOMER SOURCE INSPECTOR

A sufficient schedule and budget should be planned by the Project to allow the NASA component engineer to fully understand the supply line, the OEM PEMs manufacturer, and approving a PEMs screening laboratory, when necessary. This in-depth activity does not happen using a mouse and looking at a web page on a computer. Sometimes contacting the OEM semiconductor company, arranging for a visit (if there is any interest on their behalf), trying to convince the OEM semiconductor company to screen the PEMs parts to assure the part reliability in the NASA environment is the natural preference. Using the OEM Semiconductor company to do all electrical testing over the NASA temperature extremes is the natural choice (as the OEM Semiconductor company already has experience with their part, the automatic test equipment, the electrical test programs [which may have to further modified], and the burn-in ovens/burn-in circuits to screen the parts.) However, it should be noted here that most OEM Semiconductor companies are interested in making money, and not interested in this activity. Therefore, a schedule and budget needs to be planned for a screening laboratory with a NASA customer source inspector (CSI) in attendance. [Federal Acquisition Regulations often require a competitive bid, which means multiple laboratories…] Assurance that the Laboratory is experienced in testing the PEMs part technology, assuring that proper automatic test equipment, and test programs exists, assuring that the unique package style can be handled and tested by the laboratory, and that the laboratory can complete the exact screening flow on time are very important concerns. NASA has found that weekly monitoring and constant vigilance by a NASA CSI is necessary for on-budget and on-schedule performance. These screening laboratory "surveys" to assure and accumulate data on testing, burning in, conducting qualification, etc. are required to assure the reliability of "the exact part's performance in the intended environment."

1.6 NASA EXPERIENCES WITH 5 PEMS PART TYPES

NASA selected five PEMs part types from a list of over 100 candidate parts to be used in NASA flight Programs. NASA requested multi-Center usage to down-select to a manageable 5 PEM candidates.

NASA has been told at many conferences by numerous intellectual sources that "all COTS have changed for the better". NASA has also been told that: "the new semiconductors utilize strong continuous improvement techniques with strong statistical process controls, and there are no longer outliers, drifters, or out-of-spec parts at usage conditions"; "even in Spaceflight usage conditions." The following sections reflect NASA's recent experience on five PEMs parts chosen by all NASA Centers for this evaluation.

This evaluation overlays a copy of similar technical problems and concerns found in microelectronics from the 1970's through the 1990's. Semiconductor physics today remains consistent, and measurement for exactness in microelectronic parts is as necessary now as it was in the past.

1.7 TECHNICAL PLANNING

The planning undertaken by the NASA team was extensive to insure that all essential issues and concerns for PEM quality and reliability would be addressed or at least considered. The planning included developing proposed PEM screening and qualification tests that would then be reviewed by the NASA team for their completeness and effectiveness after their implementation and execution on COTS PEMs. The planning also solicited the technical expertise from the test houses that would conduct the testing. It was imperative that a synergistic plan be developed and which also took into account the cost and schedule restraints. Without such careful planning, the outcome and execution would have undoubtedly been less desirable as there were obstacles (technical and programmatic) that needed resolution and review by the NASA team. A good plan, at any level of effort, is essential for the success of the COTS PEM evaluation.

1.8 VENDOR VISITS/AUDITS

Vendor visits including onsite audits were conducted on the certified test houses candidates. Two test houses were seriously considered. One test house was located on the east coast and the other was located on the west coast. It was decided that no more than two test houses would be used to allow careful review and comparison of the different methods being used according to what was standard operating procedure for each test house. The audits focused on technical capability, configuration controls used, data collection methods used, the data reports that would be submitted to NASA, the electrical test parameters and test conditions, the burn-in and life test circuit review, adherence/reporting on NASA schedule requirements, and flexibility to make plan changes if necessary. Visits to any test house before final selection is imperative to establishing a good working relationship, open cooperation, and to mutually insure NASA's expectations. It is also important to make periodic visits for NASA programs that are long in duration and involve complex requirements.

1.9 RFQ/QUOTATIONS

In an effort to assure program back-up, NASA selected a minimum of five certified laboratories. Per the Federal Acquisition Regulations (FAR), a single Request for Quotation was submitted to all laboratories on the same date, and due on the same date. Two laboratories were non-responsive. Of the three remaining laboratories, NASA selected the most cost-effective, with the best screening proposal, and with the ability to meet the NASA schedule/requirements.

1.10 CUSTOMER SOURCE INSPECTOR (CSI)

CSI was justified by NASA for the following reasons. The use of a CSI is strongly encouraged for upscreening of COTS. The upscreening of COTS at a test house should be treated much like the build of a system or subsystem where QA presence is required. Even when a process flow is agreed upon, there can be misinterpretations of the intended test and procedures. Laboratories tend to take more seriously a project which has a consistent, on-going visits by a NASA CSI. The CSI should provide on-going weekly progress to assure that the laboratory has communicated actual test completed, and to assure there were no system or individual errors at the test lab. The CSI should work close enough with the test house to offer technical solutions when appropriate. Finally, the CSI should provide weekly written reports to satisfy NASA's need to maintain documentation of the upscreening process for the project.

1.11 PROGRAM MANAGEMENT

NASA's approach to program management for this evaluation task was to insure all aspects of the performance to plan and implement were carefully monitored, reviewed, and approved. To this end, verbal and written communications were extensively used on a weekly basis. Communication links were set up with the NASA Centers, contractor screening laboratories, as well as all responsible technical peers, managers, and CSI. Weekly schedules were provided by the screening laboratories. All required changes, with approval signatures, were documented either by e-mail or via the actual documents sent in the mail. Telecons were used extensively to keep all responsible parties current on status and problems.

1.12 RATIONALE FOR DEVICE SCREENING AND QUALIFICATION

NASA has developed a trial screening flow for plastic encapsulated microcircuits to investigate the best methodologies to insure some minimum quality/reliability by eliminating product with defects. Since every OEM Semiconductor manufacturer has a different flow for his commercial product, there is no way a user can be sure the product received is uniform in quality. Hence, there are no standards for commercial products between manufacturers for NASA to compare the reliability of one vendor to the reliability of the next. Workmanship, flaws, and outliers need to be captured and focused upon if they exist. NASA chose to screen select parts to find out which screens are necessary and which screens are valueless. If there are variations in products, they need to be highlighted to the NASA projects so risk assessments can be determined. NASA believes that screening is an important element to assure that each part in a procured lot is reliable. In addition, NASA acknowledges that screening of parts adds to the lot reliability, but does not add to individual part reliability. Screening is used to mitigate risks by identifying products that may be potentially unreliable prior to installation in the system.

SECTION 2

NASA TEST RESULTS

2.1 DPA PEM LOT SUMMARY

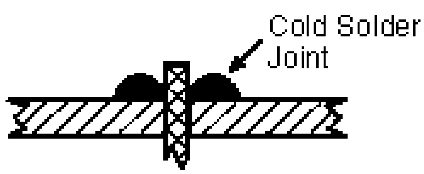
Part Type	Vendor	Ex-Visual	Int Visual	X-Ray	Outgassing	Ld Finish	Die Attach	Tg	Bond Pull	Metallization
A/D	A	Pass	Pass	Pass	Pass	Pure Sn	Pass	Low	Pass	Pass
Multiplexer	B	Pass	Pass	Pass	Pass	Pb-Sn	Pass	High	Pass	Pass Marginally
Op Amp	C	Pass	Pass	Pass	Pass	Pb-Sn	Pass	Lo	Pass	Pass
Reference	D	Pass	Pass	Pass	Pass	Pure Sn	Pass	High	Pass	Pass
Amplifier	E	Pass	Pass	Pass	Pass	Pb-Sn	Pass	High	Pass	Pass

TABLE 2-1

The purpose of Destructive Physical Analysis (DPA) is to verify and document the quality of device processing and assembly steps to avoid defects that will adversely affect performance and reliability. By deprocessing a device, a complete profile can be created to determine how well a device conforms to design and process requirements. In some cases defects revealed in a device can result in rejection of an entire lot of devices. The bottom line of a DPA is to make certain the materials and components one purchases really meets ones needs.

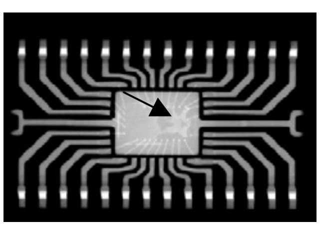
NASA completed DPA on five different part types from five different vendors. The summary for some of the findings are shown in Table 2-1. No lot was completely rejected. However some issues and concerns shown below require further evaluation, testing, and or processing.

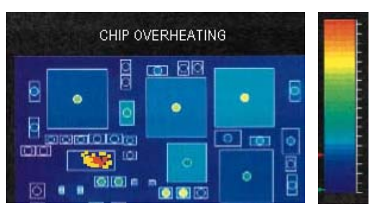
Example 1 shows bare metal exposed on the leads of the device. This can cause faulty soldering and or



intermittent problems. It is therefore recommended that all leads be tin plated and inspected for complete coverage.

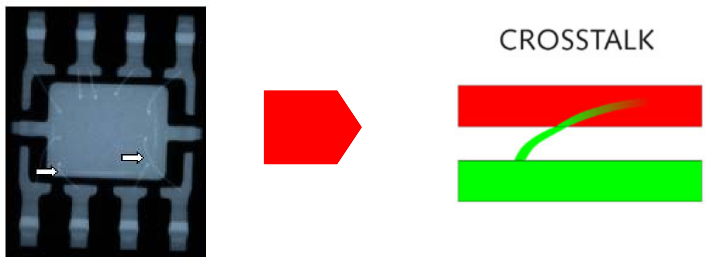
Example 2 shows incomplete die attach (voids). Lots experiencing this problem need to be 100%





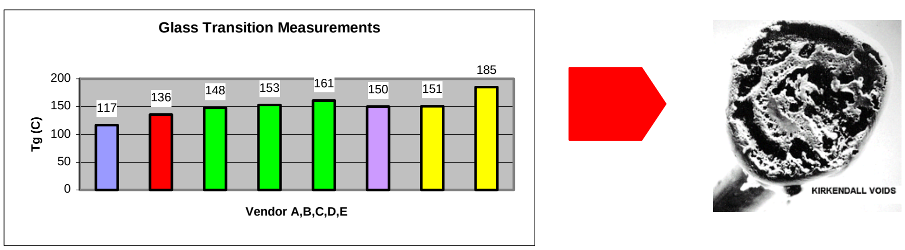
inspected. This can be a serious problem for parts requiring high power dissipation. Limited die attach area for PEMs can allow excessive heat buildup (hot spot) due to increase in the thermal resistance and thereby reduce part life. In the vacuum of Space, there is no path for heat dissipation other than through the die attach and the leads.

Example 3 is an example of wire sweep (closeness of wires). Lots experiencing this type of problem



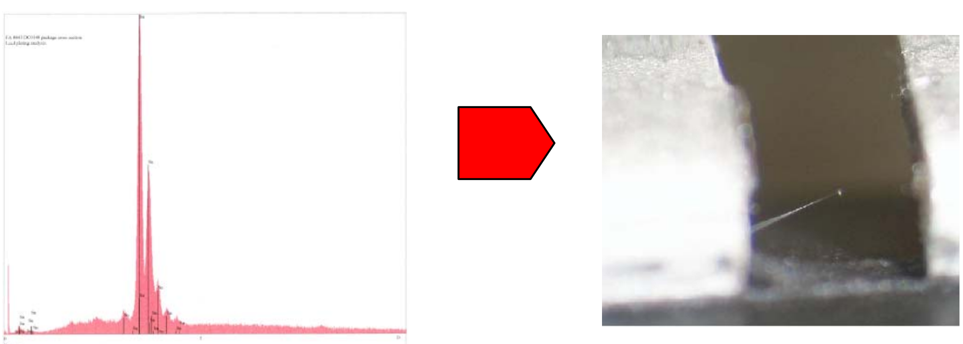
need to be 100% screened (X-ray). This type of problem can lead to shorts, intermittents, crosstalk, and or leakage during application.

Example 4 shows the variation in the glass temperature temperature (Tg) among the five vendors tested.



Molding compounds that exhibit an extremely low Tg at incoming need to be evaluated for stability during subsequent processing and including any burn-in or storage. Environment and or processing temperatures can alter the stability of the Tg and possibly lead to the formation of intermetallics that would affect wire bonding integrity.

Example 5 shows an X-ray energy dispersive spectrum of the tin coat (no lead) on the leads for one



device. Lots that exhibit no lead need to be reprocessed with tin-lead finish. Pure tin can cause tin whisker growth, which can cause shorts and intermittents. The use of pure tin is prohibited by NASA.

The value of doing DPA is threefold. First it can identify deviations in supplier process or design of component. From this information recommendations can be made on lot disposition and corrective actions. Second it can be performed after any process step during screening, qualification, and or assembly to determine any changes that may adversely affect reliability. Individual DPA tests can be selected as needed or their importance to the user. Third it is used to establish a data baseline for a supplier's current and future shipments of parts. The only way to be sure of what you are buying is to analyze it. Once DPA has successfully passed, it is encouraged to proceed with all radiation testing (total ionizing dose, and single event effects) to qualify the PEMs lot for the program environment.

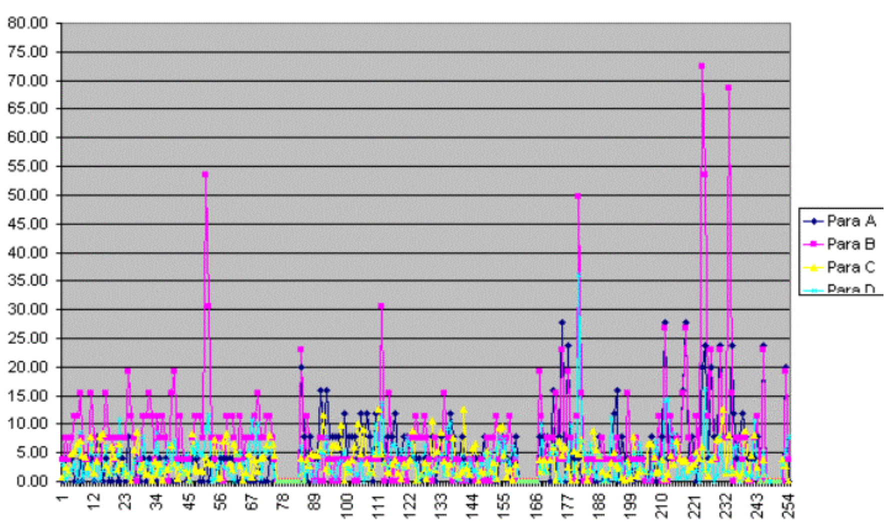
2.2 NASA BURN-IN SUMMARY

Part Type	Sample Size	Vendor	Hours	Burn-In Temp	Rejects (25°C)	Functional	Parametric	Critical Parameters
A/D	254	A	440	+85°C	1	0	1	ICCD
Multiplexer	250	B	168	+125°C	7	0	7	Ron,I+VEN, IAL,IAH
Op Amp	253	C	400	+105°C	1	0	1	VOS
Reference	252	D	168	+125°C	37	0	37	Vout
Amplifier	230	E	168	+125°C	1	1	0	Gain ERR, VOO

TABLE 2-2

The purpose of performing burn-in is to eliminate marginal devices from a lot of devices. Marginal devices are those with inherent defects or defects resulting from manufacturing aberrations which are evidenced as time and stress dependent failures. In the absence of burn-in, these defective devices would be expected to result in infant mortality or early lifetime failures under normal use conditions. The burn-in method of screening out defective devices is only as effective as the testing conducted following burn-in. Such testing must be thorough and include measurement of all device electrical parameters specified in the manufactures specifications including parametric degradations.

The results of the 100% burn-in screen are shown in Table 2-2. The burn-in temperature and times were adjusted as needed to insure the device junction temperatures remained below the glass transition temperature. The majority of the rejects failed parametric or parametric degradation as defined (>10%). “Critical Parameters” listed are the predominate failing parameters for a given part type. The total percent failures for all devices is 3.8%. The average percent failures per lot is 0.8%. The graph shown below is an example of some parameter changes after burn-in for Vendor D devices. The y-axis is the % change between pre and post burn-in and the x-axis are the device serial numbers. The serial numbers represent three different date codes. This is an example of the sensitivity and stability or lack of for different parameters under the same burn-in conditions. Vendor A, B, C, and E product demonstrate relatively consistent failure rates that would be expected with COTS as shipped by the vendor (+25C test only). Vendor D product is suspect and not to be used without thorough reliability evaluation.



2.3 NASA OPERATING LIFE SUMMARY

Part Type	Sample Size	Vendor	Hours	Burn-In Temp	Rejects (25°C)	Functional	Parametric	Critical Parameters
A/D	45	A	1000	+85°C	0	0	0	Offset
Multiplexer	45	B	1000	+125°C	0	0	0	Ron
Op Amp	45	C	1500	+105°C	1	0	1	VOS
Reference	45	D	1000	+125°C	3	0	3	Vout
Amplifier	45	E	1000	+125°C	0	0	0	Gain ERR, VOO

TABLE 2-3

The purpose of this test is to evaluate the reliability of the die and to generate defects resulting from manufacturing aberrations that are manifested as long-term and stress-dependent failures. The burn-in temperature and time chosen were predicated on the vendor's glass transistion temperature and the calculated junction temperature. Guidelines were imposed to insure some margin of safety from the manufactures application recommendations. Data was taken across temperature but only ambient (25°C) results are recorded in Table 2-3. This is done so that results could be compared to the vendor's published data at ambient (25°C). Reject parts recorded are defined as a hard functional and or parts that fail a data sheet parametric limit. Critical parameters shown by part type either failed the vendors specification or showed > 10% degradation. NASA considers parametric degradation as a failure unless the part application and design can tolerate the change. Below is a case where the parametic degradation are beyond nominal drift tolerances.

Example at +125°C

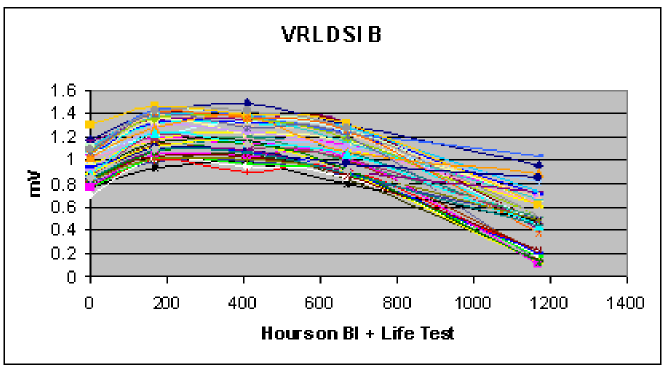


FIGURE 2-3

This example, in Fig.2-3, demonstrates that during the life test on samples that were burned-in, parametric degradation approaches and exceeds the allowable limit of 1.5 millivolts. This occurs near 200 hours of operation. With continued time and stress the parameter improves significantly at 800 hours for some parts. This was a commercial part that was specified at +125°C. It is an example of why a part should be evaluated at all the vendor's specified temperatures as well as the intended space application temperature requirements. Some designs cannot tolerate excessive degradation. This behavior could be a reliability issue for sensitive designs.

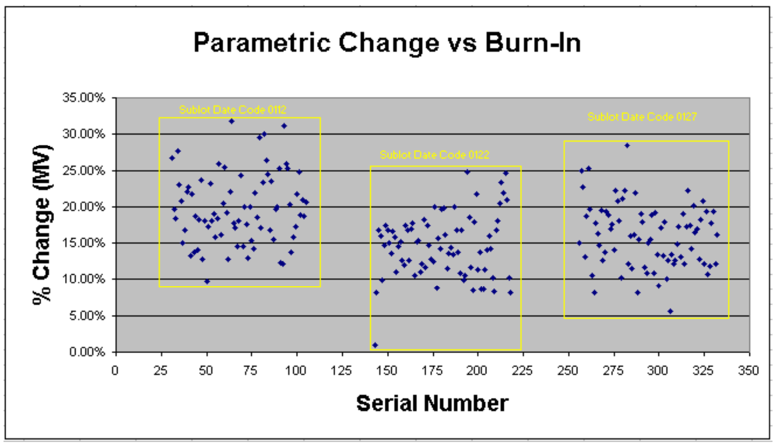
Worst-case analysis for critical design parameters is recommended using actual life test characterization data from the procured lot.

2.4 VENDOR LOT VARIATIONS

One of the important influences on COTS product reliability is lot to lot manufacturing variation. It is evitable that some processes and products will have different quality and reliability because of nonuniformity at the basic elements of construction such as individual wafers, individual die/location from the center of the wafer during the metallization process. Statistical Process Control (SPC) is used by the manufacturer to sample the uniformity at the lowest element of construction (different process steps), however it is still a sampling method, and not a one hundred percent guarantee. From SPC the final product quality is predicted. It is then inferred by some that the product reliability should also be predicted. In fact this logic does work fairly well for commercial product solely because of the COTS users acceptance standards. Users who impose a higher quality and reliability standard (HiRel) against COTS product will find some limitations and constraints. Some of these limitations are only addressed by extensive screening and qualification of the final product since nothing can actually be done on how the manufacture manufacturers the product.

Below is a figure that shows that some manufacturing variations have influence on the final product performance behavior after burn-in. Three different date codes for the same product from the same vendor were evaluated by NASA for this purpose. The first issue is the amount of degradation seen on all three date codes. Depending on the acceptable parametric degradation limit imposed by design, some lots may not yield any usable product. Only in a high reliability application would variations such as shown become a major obstacle. This is why a thorough product and design evaluation is critical to mission success when using COTS.

This variation problem is further compounded if some radiation tolerance/specification is to be imposed. Radiation tolerance and product performance behavior are also very sensitive to manufacturing variations within the process and or any changes in the design implemented with just a single mask change.



2.5 NASA CSAM SUMMARY

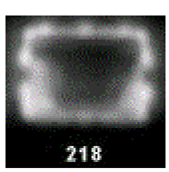
CSAM Incoming Totals

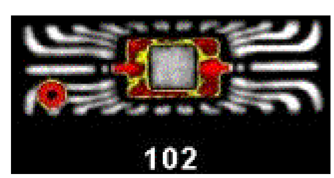
		TOPSIDE									BACKSIDE						THRUSCAN		
		(top of lf)			(top of die)			(space around die)			(die paddle area)			(back of lf)			(die attach area)		
Package	Vendor	LR	MR	HR	LR	MR	HR	LR	MR	HR	LR	MR	HR	LR	MR	HR	LR	MR	HR
24 Ld SOIC	A	250	0	0	250	0	0	0	35	215	109	126	15	237	8	5	11	74	165
28 Ld SOIC	B	251	0	0	247	4	0	11	240	0	244	7	0	251	0	0	237	2	12
8 Ld SOIC	C	226	0	0	220	6	0	225	1	0	225	1	0	226	0	0	223	2	1
8 Ld SOIC	D	203	24	1	NA1	NA1	NA1	34	120	74	224	2	2	153	0	0	NA1	NA1	NA1
8 ld SOIC	E	62	96	70	NA2	NA2	NA2	NA2	NA2	NA2	228	0	0	159	67	2	114	69	45
Total		992	120	71	717	10	0	270	396	289	1030	136	17	1026	75	7	585	147	223

Incoming CSAM inspection for delamination was conducted on each and every part. Each was part was viewed at the topside with specific areas including the top of the leadframe, the top of the die, and the area adjacent to the die or space around the die. Specific areas of each part were then classified as LR, MR, or HR. LR (low risk) was assigned for specific areas having ≤ to 10% total area of delamination (shown as red in color) , MR (medium risk) was assigned for specific areas having 10 to 50% of delamination, and HR (high risk) was assigned for specific areas have 50 to 100% of delamination. From the data the each vendor and or package type can be evaluated for typical delamination expected at incoming without further processing. Vendor C demonstrates best assembly process control (less than 10% for all 6 areas) while vendor A demonstrates worst process control (greater than 50% for 2 out of 6 areas). Vendors B, D, and E demonstrates marginally acceptable (some room for improvement) process control. What is not known is what process controls if any are imposed by any of the vendors or what outgoing monitors are in place to insure minimum delamination in final product delivered. From a users point of view, clearly Vendor C products would be the first choice. This data demonstrates that using product without inspection clearly puts the user at a disadvantage if material/assembly quality and reliability requirements are to be met. Also note that the areas of inspection that record NA2 and NA1 indicate that delamination could not be clearly demonstrated and therefore were not included in the statistics. From this analysis it is not clear if delamination correlates to the number of leads and or package size. The most serious concern from this evaluation is the amount of delamination observed by thruscan on three vendors products which indicates inadequate die attach. This raises reliability concerns especially for any high power consumption parts where it is necessary to remove the heat from the plastic package via the die attach and leads to insure high reliability.

In summary the incoming inspections and evaluations have shown that delamination does exist with many vendors products as shipped and without process controls the delamination variation can change for the better or worst with each subsequent production lot.

CSAM Delamination Examples:





2.6 NASA X-RAY SUMMARY (Wire Sweep)

Part Type	Vendor	LR	MR	HR
A/D	A	249	1	0
Multiplexer	B	250	0	0
Op Amp	C	349	1	0
Reference	D	223	1	0
Amplifier	E	226	1	1
	Total	**1297**	**4**	**1**

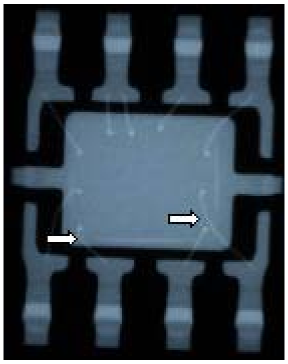
Wire Sweep is a common molding problem encountered in microchip encapsulation. The resin melt flow will exert drag force on wires and hence causes deformation of wires leading to reliability problems.

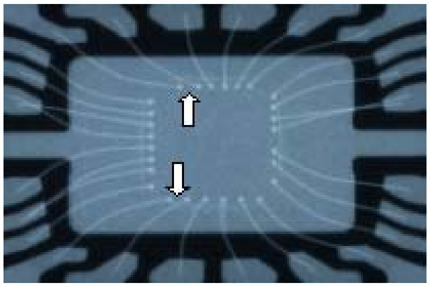
During the wiring process and more often after encapsulation, X-ray is used to inspect the bond wire sweep to ensure there is no risk of shorting. To accurately identify wire sweeps with repeatable results, an X-ray system must have both a high lateral resolution or small focal spot and high geometric magnification so even the smallest diameter of wires can be inspected. This ensures proper identification of the beginning and ending of each bond wire as well as the curve of the sweep.

With too little magnification, shorted adjacent wires could be seen as a single wire sweep and not a failure, resulting in bad components being used. In addition, the system should provide software that enables the quantification of wire sweep by the use of on-screen measurement tools.

NASA has found little evidence of wire sweep on the small packages and low lead counts inspected. It is more of an issue for fine pitch devices as wires become closer and closer to each other.

Wire Sweep Examples:





SECTION 3

RECOMMENDATIONS / LESSONS LEARNED

3.1 UPSCREENING

NASA considers the upscreening a vital process to the success of using COTS PEMs in Space applications. It becomes more apparent as the application demands more reliability and lower risk. Its sole purpose is to eliminate products with defects that can affect their reliability. Table 3.1 lists the NASA recommended steps to follow in order. First, a Destructive Physical Analysis (DPA) is performed. This is done as the first step so that any quality issues (materials/construction) can be addressed early. Some issues discovered may even alter the sequence of events that would normally take place. For example components that show totally unacceptable metallization step coverage may be replaced with new components from another lot before any other steps of the flow are implemented. DPA will be examined in the next subsection (3.2). The next recommended step is submitting representative samples from this lot to radiation testing (total ionizing dose and single event effects) to qualify this lot of PEMs to the Project radiation environment. Upon radiation test completion all components that will be subjected to upscreening and additional processing are individually serialized. Typically components are marked using a NASA approved ink or in some case laser marking can be used. However laser marking can destroy packages if it is not properly done. If it is used components should be inspected after marking to insure the integrity of the package is not violated. Serialization is used primarily to keep traceability of components during all subsequent processing and for correlating individual component with data review, analysis and selection. Serialization allows each component to be accounted for. Next the parts are electrically tested using approved test programs with agreed upon test parameters to be measured. The purpose of the first test is to determine if procured components meet the advertised manufacturer's data sheet performance over temperature. Test temperatures can be one up to four ranges: commercial range, industrial range, military range, or per special application range. If components cannot pass the intended temperature use they would be flagged for review. Components that meet minimum yield can then be further processed. Components are then subjected to a small number of temperature cycles to insure no package to die construction problems precipitate including wire bonding and die attach. Components are then examined using x-ray. PEMs can have a problem known as wire sweep, which occurs during mold injection. As a result wires become to close and violate the normal wire pitch allowed. This can lead to reliability problems later on such as shorting and leakage. Wire sweep in more acute as lead counts increase since wire pitch is greatly reduced with higher pin count packages. CSAM is then performed to inspect for any package delamination that is inherent with components as received from the manufacturer. The delamination can occur in different locations within the package including on top or below the lead frame and around the die. The severity is an indication of how well the package assembly process is controlled. Delamination at this stage can be altered by further processing and lead to reliability problems. Lots that exhibit severe delamination may be subject to review and or replacement. Components are then electrically tested to insure that there was no effect by the temperature cycling. Test conditions are the same as during the first electrical test to maintain data integrity and continuity for the remaining processing. Components are then put on burn-in to induce infant mortality failures. A dynamic condition is generally considered the best for this although a static condition is sometimes necessary for some component designs and technologies. It is extremely important this step be implemented correctly and monitored. NASA prefers the burn-in condition simulate the application as close as possible. After burn-in the components are then electrically tested to the same conditions as previously. It is imperative that this step and the prior electrical tests are done with read and record data to allow proper data review and analysis including delta if they are selected. At the end of the upscreening process all data collected and recorded is reviewed and analyzed according to the accept and reject criteria established. At this point, components are not subjected to further processing without data acceptance.

Table 3-1

NASA Guideline
104-07-01-1

Recommended COTS PEMs Screening Flow

	Steps	Sample Size	Option(s)	Cautions	Required
1	DPA/Radiation	22	Can be reduced with Project approval		
2	Serialization	100%		Laser Marking can damage parts	
3	Electrical At Temperature	100%	This step is optional with Project approval		Min & Max Application Temp
4	Temperature Cycling	100%			
5	X-Ray	100%	Not necessary if package lead count < 28		No Wire Sweep Allowed
6	C-SAM	100%		Delamination risk is subjective	
7	Electrical At Temperature	100%			Min & Max Application Temp
8	Dynamic Burn-In	100%	Static is allowed for some part types		Tj is 20C below Tg
9	Electrical At Temperature	100%			Min & Max Application Temp
10	Data Review	100%		Data review requires Electrical R&R	Delta Analysis

3.2 DESTRUCTIVE PHYSICAL ANALYSIS (DPA)

NASA recommends the DPA be completed before any upscreening is done to insure the quality of the product procured. Table 3-1 lists the recommended DPA elements to be performed on PEMs. DPA quickly notifies the perspective user of quality issues that may need remedy before upscreening. The steps used by NASA are external and internal visual, which examines the package for anomalies and checks all package markings for correctness and legibility. X-ray is performed in the x and y directions and also looks for violations of wire sweep and die attach. SEM analysis is extensive and identifies package and die construction issues including metallization, gold wirebond, and lead surface. Package cross sections identify the epoxy package, silicon die, die topcoat if present, lead frame and surface, and die attach. Die cross sections are used to view the metallization especially the contacts and vias as well as others areas such as field oxides, polysilicon layers, and silicon nitride layers. The volatile condensable material test (package out gassing) measures the volatiles as a percent. Additional measurements include the package weight loss and water vapor. Outgassing of components can introduce problems when mirrors and sensors are nearby. Energy dispersive spectrum is a method to identify different elements as they appear on the component lead surface. In particular it is used to detect the presence or lack of lead (Pb) in association with tin (Sn) plating. Glass transition temperature (Tg) test is used to determine the glass transition temperature of the package epoxy material. Different equipment can be used for this test. NASA recommends TMA as the more reliable and consistent method to be used. The internal wire construction looks at the gold wire ball bond and in conjunction with the cross section of the gold ball bond to see if there is any evidence of intermetallics or voids. The external lead construction identifies the lead base material and the uniformity of the lead/tin plating as well as the percent of coverage. The top and bottom marking are recorded and check for proper identification against the manufacturers standard marking conventions. CSAM is used to determine the incoming quality of the manufacturers lot. If it is deemed to be excellent, CSAM may be omitted as part of the upscreening process with Project approval. However it may still be required after package QCI processing. The final DPA report provides a complete description of all tests and their results along with a pass or fail condition for the lot(s).

NASA Guideline
104-07-01-1

Recommended COTS PEMs DPA Evaluations

	Evaluation	Sample Size	Option(s)	Cautions	Required
1	External & Internal Visual	22			
2	Radiographic	22			Inspect for Wire Sweep
3	SEM Analysis	22			Glassivation and Metal
4	Package Cross Section	2			
5	Die Cross Section	22			Contacts/vias for 2 or more metal layers
6	Volatile Condensable Materials	2/date code			NASA Acceptance Levels
7	Energy Dispersive Spectrum	2/date code			Lead Coating Material
8	Package Glass Transition Temperature	2/date code	Thermal-Mechanical Analysis Preferred	Residual stresses affect final measurement	Two Consecutive Runs
9	Internal Wire Construction	2/date code			Minimum Pull Strength
10	External Lead Construction	22			Plating Coverage
11	Top & Bottom Marking	22			
12	CSAM	22		Use Approved Lab	
13	DPA Report	-			Complete Documentation

Table 3-2

3.3 QUALITY CONFORMANCE INSPECTION (QCI)

NASA recommends the following QCI tests to be performed on PEMs as a minimum. They are listed in Table 3-3. First, an acceleated steady state life test is performed to stress the die. The conditions are the same as those used in the upscreening burn-in in order to compare results. The major difference for the life test is the duration which should equate to the application duty cycle times the mission life. If more margin is required the duration can be extended. If the application(s) duration is very short an industry standared of 1000 hr will demonstrate die reliability. Temperature cycle is performed to identify failure mechanisms with PEMs such as cracked die, wire breaks, wire lifts, interface delamination, and voids in die attach. Conditions are the same as those used in the upscreening however the number of cylces is increased to equate to the application cycles with margin added as necessary. HAST is performed to evaluate the non-hermetic packaging of solid state components in humid environments. HAST accelerates the penetration of moisture through the external package material or at the egress around the package leads. NASA believes this test has value since many times PEMs may be in a long-term storage, which can have moisture consequences before any launch. Conditions used should follow industry methods unless otherwise dictated by design or application. Moisture sensitivity level (MSL) testing should follow industry methods that are required to satisfy the manufactures MSL rating. In some cases it has been found that components have not met the manufacturers MSL published rating. Post CSAM and DPA are performed after life test, temperature cycle, and HAST to identify any anomalies caused by these tests.

Table 3-3

NASA Guideline
104-07-01-1

Recommended COTS PEMs QCI Evaluations

	Evaluation	Sample Size	Option(s)	Cautions	Required
1	Life Test	45		Tj is 20C below Tg	Pre/Post Electricals
2	Temperature Cycle	22	Can use manufacturer's temp rating		Pre/Post Electricals
3	HAST	22			Pre/Post Electricals
4	Moisture Sensitivity Level	2/date code			Pre/Post Electricals
5	Post CSAM	2 per each evaluation(1-4)			
6	Post DPA	5 after life test			Inspect for bonding intermetallics

3.4 ELEMENTS IMPACTED WITH SCREENING

NASA has found that the screening results can have major repercussions to the mission program and how components are used in the design and or even replaced with new components. Table 3.4 shows what elements may be impacted upon careful review of the data. Test results can lead component engineers to make decisions that will lead to further investigations, other evaluations, or analysis that may disqualify a component or compromise its reliability. NASA recommends that component engineers do not disregard or dismiss any data without careful review upon completion of all testing.

Table 3-4

NASA Guideline
104-07-01-1

ELEMENTS LIKELY TO BE IMPACTED WITH COTS PEMs SCREENING RESULTS

Test Step/Flow	Destructive Physical Analysis	Part Serialization	1st Electricals Over Temp	Temperature Cycling	X-Ray	C-SAM	2nd Electricalsn Over Temp	Monitored Dynamic Burn-In	3rd Electricals Over Temp with Deltas	Test Data Review + Analysis
Samples	22	100%	100%	100%	100%	100%	100%	100%	100%	100%
Critical Element										
Design Change										NASA
Worst Case/Stress Analysis									NASA	
Parts List Review/Acceptance	NASA					NASA				NASA
Application	NASA								NASA	
Part Risk Rating	NASA					NASA	NASA		NASA	NASA
Physics of Failure				NASA				NASA		
Vendor Quality	NASA		NASA		NASA		NASA		NASA	NASA
Part Procurement	NASA					NASA				NASA
Configuration Control		NASA						NASA		
Product Reliability	NASA		NASA	NASA	NASA	NASA	NASA	NASA	NASA	NASA
Failure Analysis		NASA				NASA			NASA	
Data Acceptance	NASA	NASA	NASA		NASA	NASA	NASA		NASA	NASA

3.5 LESSONS LEARNED

3.5.1 Program

Program Management must be aware that PEMs should not be used in spaceflight applications as a cost savings activity. The facts are that by the time PEMs are characterized for reliability, quality, and radiation tolerance, they are often more expensive than space quality parts. They need to apply constrains on project design teams who design-in unknown, un-characterized, PEMs parts into critical NASA applications, without full redundancy. It is important to allocate funding for large one-time procurements, and screening/characterizations efforts to get a real-time reliability view of of the actual lot that was procured. Program managers need to understand that the data supplied in the commercial world is often different than the lot sold to NASA. It is essential that concurrent engineering of PEMs starts with good component engineers. No project can be successful without knowledge of the procured lot.

3.5.2 Technical

NASA engineers found that it was not ennough to rely soley on the technical expertise of the test laboratories. Technical issues and problems that arose required judgement and guidance by NASA specialists. In some cases special engineering tests were developed in order to get required data for decisions making before proceeding with the planned flow. Changes in technical scope affect the scheduling but are often necessay to keep the integrity of the objectives, that is, to collect accurate and meaningful data

3.5.3 Implementation

Implementation and execution requires a team approach to ensure all issues and problems arising are addressed thoroughly. Even the smallest issues should have peer review before proceeding. Mistakes will happen especially when little attention is given to the possible problem senarios. NASA has found that proceeding slowly enables more time to assess a situation and sometimes more than one assessment is necessay by different personell other than those directly responsible. Disciplined personel/leaders keep you on tract.

3.5.4 Scheduling

NASA found it extremely valuable to have weekly schedules sent from both test labs. Schedules included PO#, Customer Part Number, Generic Part Number, Job Number, Quantity, Operation, Notes, Scheduled Date, and Actual Date Completed.

3.5.5 Budgets

An important aspect to being succesful is to adequately plan the budget necessary to complete the job and allow for some contingenices. NASA contingencies experienced and planned for included additional engineering tests outside the planned flow, data analysis methodology development, and visits to candidate test labs with follow-up peer reviews. Upscreening and QCI budget planning needs to focus on the size of the job and how much effort is required by support functions. All the budget elements should be estimated ahead of time and reviewed for adequacy of unforeseen contingencies. This requires engineering as well as project review.

3.5.6 Resources

Resource planning requires understanding the necessary steps to complete the entire job. NASA found it necessary to have the following resources available for its immediate use: Software and data analysis engineer, failure analysis engineers, component specialists, program managers/supervisors, inventory specialist, secretary, packaging specialist, budgetary specialist, and purchasing specialist.

3.5.7 Reviews

Scheduled weekly reviews with the test labs is imperative to maintain open communications. NASA employed weekly telecons with operations, production, engineering, and sales as necessary. Many issues and problems do not get immediate attention without setting responsibility and commitments with time of completion. Weekly telecons among the key players keeps the responsiblities of individuals visible and open. Conflicts and technical obstacles can be aired and allowances can be made for schedule changes.

3.5.8 CSI

On site customer source inspection was found to be extremely valuable to NASA when there are complex and numerous process steps to be implemented in upscreening and quality conformance inspections. CSI provides timely technical inputs needing resolution, ongoing weekly review and reports, independent assesments and guidance, and continual communication on overall schedules and prevents slippage. NASA found that when CSI was formally used the overall project was handled more professionally and effectively.Contractor Laboratories tent to take more seriously a project which has a consistent, on-going visits by a NASA CSI. A contract technical manager can perform some of the role played by a customer source inspector.

3.5.9 RADIATION OF COTS

The work conducted for this guideline did not include any radiation evaluations. However, it is extremely imporatant that COTS PEMs are evaluated for the Space radiation environment for which they are intended as early as possible preferably after DPA. It is necessary to assess the suitability of epoxy-encapsulated COTS components under conditions similar to the final application. It is imperative to test all relevant parameters. One approach to this is to develop application specific test boards. In order to establish the inhernent reliability, parametric drift (shift) should be measured and calculated together with any burn-in and or life test drift measured. In this way a truly worst case analysis can be performed by the designer for the application under evaluation.

Sample sizes are critical to establishing confidence. Sampling plans based on Lot Tolerance Percent Defective (LTPD) provide the minimum sample size needed to assure, with a given risk, that a lot with a percent defective equal to or more than the specificed LTPD would be rejected. The standard confidence for lot rejection is 90%. For example, a lot size of 50 devices and no errors at a given dose level, to achieve a LTPD of 3%, the sample size must be 40. With a LTPD test plan high survival probabilities cannot be obtained in practice for a small lot. NASA recommends a minimum of 22 units per lot with equal representation of different date codes with 99% proability of detection . See figure below.

Radiation Effects on Microelectronics

Effect	Source	Circuit Impact
Total Ionizing Dose (TID)	Trapped electrons Trapped protons Solar Flares Nuclear Weapons	Parametric shifts Gain Degradation Leakage Current Speed Reduction
Single Event Effects (SEE)	Cosmic particles Trapped protons Solar flares	Single Event Upset (SEU) Single Event Latchup (SEL) Single Event Gate Rupture (SEGR)
Prompt Dose	Nuclear Weapon	Rail span collapse Transient Upset Latchup Transient Burn-Out
Neutrons	Nuclear Weapon	Gain degradation Leakage Current

Table 3-5

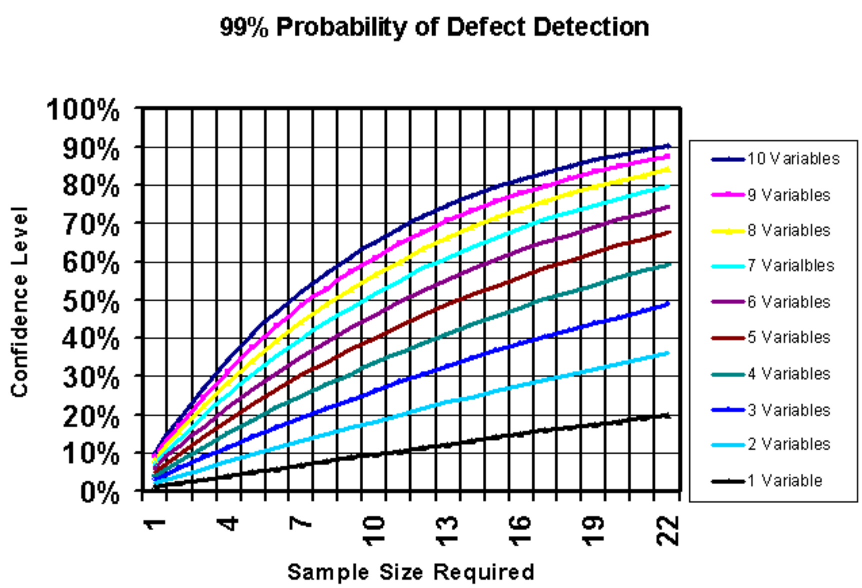


Fig 3-5

ATTACHMENT 1

NASA COTS PEMs Evaluation Upscreening Flow Followed

Step	Screen	Required	Reject Criteria	
1	DPA	1. SEM / Cross section of steps,via, contacts 2. Xray Fien Focus 3. Glass transition temperature for plastic package(2 ea/date code). Ref: Mil-Std-1580B	Any abnormal processing especially with metalization. Thinning, voids, notches, or apparent abberations will be recorded.	**22 pcs**
2	Serialization	Laser Serialization or other means for traceability	N/A	All Devices
3	1st Electricals	Test to data sheet @ +25C, 70C, 0C, (with functional sub groups)	Data to be read & recorded	All Devices
	Subgroup 3A - FIT Verification			
3A	FITS Verification Sample Static Burn-In	BI @ 125C with interim readout 168 hrs, 500hrs and 1000hrs.	Data to be recorded @ +25C, 70C, 0C (with functional sub groups)	**22 pcs**
4	Temp Cycle	Ta = -65C to +150C	10 cycles ; Mil-Std-883 method 1010 Cond C	All Devices
5	X-Ray	Mil-Std-883 method 2012, Inspect for wire sweep (top view)		All Devices
6	C-SAM	Inspect for delamination and or cracks between LF & MC, die surface to MC, die attach to die pad, die pad to MC.	Delamination, voids, or cracks: >10% of area. Rejects will be identified and recorded. Photographs will be reviewed by the Specialist	All Devices
7	Electricals	Test to data sheet @+85C, +125C, -40C,-55C, (with functionality)	Any part failing to meet data sheet parametrics at the temperatures specified. Data to be recorded/reviewed for outliers.	All Devices
8	Dynamic Burn-In	Circuit used is per application (168hrs at +125C);Vcc= max rating	N/A	All Devices
9	Electricals	Test to data sheet @ **+25C, 0C, -40C, -55C,+70C,+85C+125C** (with functionality)	Any part failing to meet data sheet parametrics at the temperatures specified. Data to be recorded/reviewed for outliers/drifters	All Devices
10a	Screening Data Analysis & Formatting			All Devices
10b	Screening Data Engr Review/QCI Sample Selection			All Devices