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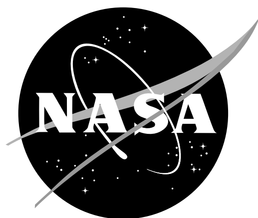

# PEM-INST-001: Instructions for Plastic Encapsulated Microcircuit (PEM) Selection, Screening, and Qualification

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Greenbelt, Maryland 20771

June 2003

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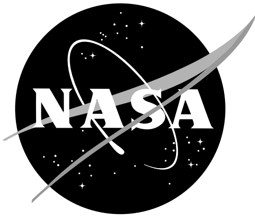


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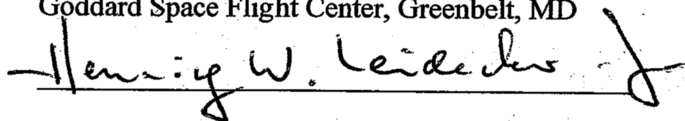

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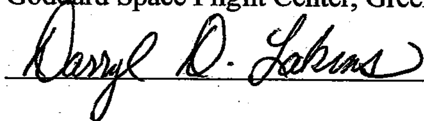

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# PREFACE

Potential users of plastic encapsulated microcircuits (PEMs) need to be reminded that unlike the military system of producing robust high-reliability microcircuits that are designed to perform acceptably in a variety of harsh environments, **PEMs are primarily designed for use in benign environments where equipment is easily accessed for repair or replacement.** The methods of analysis applied to military products to demonstrate high reliability cannot always be applied to PEMs. This makes it difficult for users to characterize PEMs for two reasons:

1. Due to the major differences in design and construction, the standard test practices used to ensure that military devices are robust and have high reliability often cannot be applied to PEMs that have a smaller operating temperature range and are typically more frail and susceptible to moisture absorption. In contrast, high-reliability military microcircuits usually utilize large, robust, high-temperature packages that are hermetically sealed.

2. Unlike the military high-reliability system, users of PEMs have little visibility into commercial manufacturers' proprietary design, materials, die traceability, and production processes and procedures. There is no central authority that monitors PEM commercial product for quality, and there are no controls in place that can be imposed across all commercial manufacturers to provide confidence to high-reliability users that a common acceptable level of quality exists for all PEMs manufacturers. Consequently, there is no guaranteed control over the type of reliability that is built into commercial product, and there is no guarantee that different lots from the same manufacturer are equally acceptable. And regarding application, there is no guarantee that commercial products intended for use in benign environments will provide acceptable performance and reliability in harsh space environments.

   **The qualification and screening processes contained in this document are intended to detect poor-quality lots and screen out early random failures from use in space flight hardware. However, since it cannot be guaranteed that quality was designed and built into PEMs that are appropriate for space applications, users cannot screen in quality that may not exist.** It must be understood that due to the variety of materials, processes, and technologies used to design and produce PEMs, this test process may not accelerate and detect all failure mechanisms. While the tests herein will increase user confidence that PEMs with otherwise unknown reliability can be used in space environments, such **testing may not guarantee the same level of reliability offered by military microcircuits. PEMs should only be used where due to performance needs there are no alternatives in the military high-reliability market, and projects are willing to accept higher risk.**

# 1. NASA/GSFC PEMS POLICY

The use of plastic encapsulated microcircuits (PEMs) is permitted on NASA Goddard Space Flight Center (GSFC) space flight applications, provided each use is thoroughly evaluated for thermal, mechanical, and radiation implications of the specific application and found to meet mission requirements. PEMs shall be selected for their functional advantage and availability, not for cost savings; the steps necessary to ensure reliability usually negate any initial apparent cost advantage. A PEM shall not be substituted for a form, fit, and functional equivalent, high-reliability, hermetic device in space flight applications.

Due to the rapid change in wafer-level designs typical of commercial parts and the unknown traceability between packaging lots and wafer lots, lot-specific testing is required for PEMs, unless specifically excepted by the Mission Assurance Requirements (MAR) for the project. Lot-specific qualification, screening, and radiation hardness assurance analysis and/or testing shall be consistent with the required reliability level as defined in the MAR.

Developers proposing to use PEMs shall address the following items in their Performance Assurance Implementation Plan: source selection (manufacturers and distributors), storage conditions for all stages of use, packing, shipping and handling, electrostatic discharge (ESD), screening and qualification testing, derating, radiation hardness assurance, test house selection and control, and data collection and retention. Use of PEMs outside the manufacturer's rated temperature range requires written approval from GSFC. Specifically, PEMs must be:

- Stored under temperature-controlled, clean conditions, protected from ESD and humidity.
- Traceable to the branded manufacturer.
- Procured from the manufacturer or their approved distributor.
- Tested to verify compliance with the performance requirements of the application environment over the intended mission lifetime.
- Tested using practices and facilities with demonstrated capabilities sufficient to handle and test the technologies involved.

Testing in accordance with EEE-INST-002 shall be performed as necessary to qualify and screen the devices, in order to verify compliance with the application requirements and project risk level defined in the program MAR. Radiation evaluation shall address all threats appropriate for the technology, application, and environment, including Total Ionizing Dose (TID), Single Event Effects (SEE), and displacement damage. Existing radiation data can be used only with the review and approval of the project radiation specialist.

PEMs with manufacture dates older than 3 years before the time of installation shall not be used without GSFC approval. Derating of PEMs must be addressed with consideration of specific material, device construction, device characteristics, and application requirements.

Use of PEMs with pure tin-plated terminations requires special precautions to preclude failures caused by tin whiskers. GSFC approval of mitigation strategies is required.

Exceptions to testing required by EEE-INST-002 may be permitted by GSFC on a case-by-case basis, where it can be demonstrated that either existing lot-specific test data show acceptable results, or the use of high-risk PEMs represents low risk of functional loss should the part fail. All rationale for such exceptions shall be documented.

NASA will use part performance data collected in accordance with this policy to evaluate the policy's effectiveness and to develop recommendations for future improvements and streamlining.

# 2.0 PRODUCT ASSURANCE SYSTEM FOR PEMS

## 2.1 Scope

This document establishes a system of product assurance for PEMs in order to invoke the GSFC PEM policy. It is based partly on existing qualification system for military and aerospace components, experience accumulated by the parts engineering community, and practices or guidelines established by high-reliability electronics industry.

## 2.2 Product Assurance System (Screening, Qualification, and DPA)

Purpose. The purpose of this product assurance system is to mitigate the risk of PEM usage, evaluate long-term reliability of the parts, and prevent failures. Commercial PEMs are primarily designed for benign environments and are considered as high-risk parts when used in space applications. For this reason, **no PEMs are considered acceptable in high-reliability applications "as is" without additional testing and analysis to assure adequate reliability and radiation tolerance.**

Primary Elements of the Product Assurance System

Screening. The purpose of screening is to detect and remove defective parts and reduce infant mortality failures. The screening process proactively evaluates the reliability of the lot.

Qualification. The purpose of qualification testing is to ensure that no wear-out mechanisms would cause premature failures during the part storage, ground phase integration period, and spacecraft mission. The qualification process provides information regarding reliability of the design and the technology.

Radiation Hardness. Radiation effects on the parts (Total Ionization Dose [TID] and Single Event Effects [SEE]) must be assessed on a lot-specific basis according to the project requirements.

Destructive Physical Analysis (DPA). The purpose of DPA is to determine whether the lot has any design, material, workmanship, or process flaws that may not show up during screening and qualification tests and cause degradation or failures during the hardware integration period and spacecraft mission lifetime. When obvious gross defects are revealed during DPA, it is usually an indication that manufacturer's processes are out of control, and a replacement of the lot might be required. Therefore, **it is recommended that DPA should be performed prior to screening and qualification of the lot.** Anomalies revealed by DPA raise concerns regarding quality and reliability of the parts. These concerns may be further addressed by tailoring screening and qualification procedures or by performing additional design evaluation and testing of the parts (refer to Section 6).

A relationship between the major elements of the product assurance system (screening, qualification, and DPA) and reliability of the parts can be illustrated using a classic bathtub-shaped curve of the lifespan failure rate shown in Figure 1. The three elements of the system discussed have been widely used for high-reliability parts and remain the major means to provide high-quality PEMs for space projects.

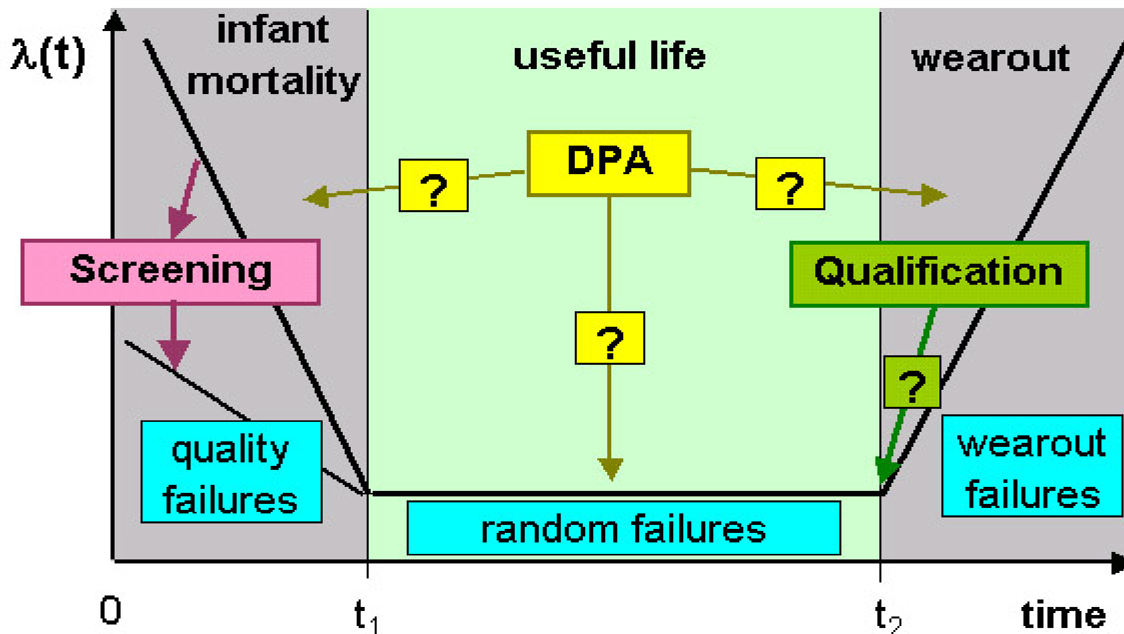


**Figure 1.** Product Assurance System for PEMs and Its Relationship With Reliability During the Part Lifespan

## 2.3 Additional Evaluations

Additional evaluations might be necessary to further mitigate risks associated with the use of PEMs. These assessments shall include:

Design Evaluation. Additional part- and application-specific evaluations performed beyond standard screening, qualification, or DPA may be necessary. Refer to Section 6, which describes capabilities of this element of the product assurance system.

Manufacturer History. The manufacturer's history of ability to produce consistent reliability and quality should be reviewed (refer to Section 9).

Distributor. Use of reputable distributors is essential to avoid procurement of counterfeit parts. Use of brokers is not recommended. Distributor compliance to PEMs handling and storage requirements should be assessed.

Qualification by Flight History. **For all PEMs, qualification by flight history or similarity is not acceptable.** Commercial PEM manufacturers are known to produce the same part number with die sourced from different wafer lots having different die revisions. The same part number may also be made by multiple production plants, processed according to requirements that vary between wafer and assembly

plants. However, the history of parts' application is important and allows addressing specific problems of design and technology of the parts revealed previously.

## 2.4 Requirements for PEMs by Project Risk Levels

Requirements for use of PEMs in GSFC projects are shown in Table 1 for different project risk levels defined in EEE-INST-001.

**Table 1.** GSFC PEM Requirements 1/

| Selection Priority | Screening (See Section 3) | Qualification (See Section 4) | DPA (See Section 5) |
|---|---|---|---|
| Level 1 | X | X | X |
| Level 2 | X | X | X |
| Level 3 | X | X | X |

**Notes:**

1/ PEMs qualified according to this document are intended for operation within the manufacturer's data sheet limits. **Any uprating and use of PEMs outside the manufacturer's specified range, particularly the temperature limits, is not acceptable.**

# 3.0 REQUIREMENTS FOR SCREENING

General. Screening is the only element of the product assurance system, which is applied to all flight parts by testing and inspecting every sample, and proactively affects reliability of the lot. Refer to Tables 2 and 2a for screening requirements of PEMs for projects of different risk levels.

Handling. There are numerous data indicating that improper handling and testing of the parts can introduce more defects than are screened out. Therefore, extreme caution should be taken during handling, storage, and testing to reduce the possibility of electrostatic discharge (ESD), electrical overstress (EOS), contamination, and mechanical damage to the parts. This demands scrupulous attention to the practice and requirements of handling and storage of the flight parts. Guidelines and requirements for handling and storage of PEMs are described in Section 8 of this document. A typical test flow for screening of PEMs is shown in Figure 3.

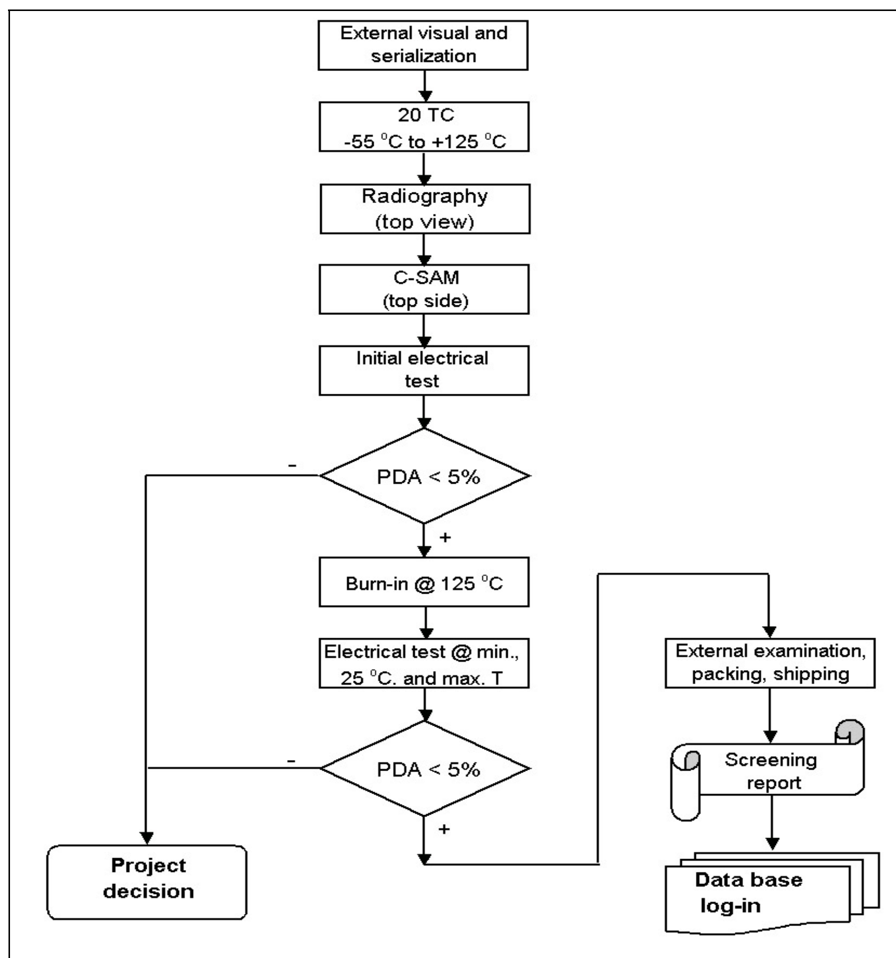


**Figure 2.** A Typical Test Flow for Screening of PEMs
(See Table 2 for details of GSFC screening requirements for PEMs.)

**Table 2.** Screening Requirements for PEMs 1/

| Screen | Test Method and Conditions | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|
| 1. External visual, and serialization 2/ | Per paragraph 5.3.1. | X | X | X |
| 2. Temperature cycling | MIL-STD-883, Method 1010, Condition B (or to the manufacturer's storage temperature range, whichever is less).<br>Temperature cycles, minimum. | 20 | 20 | 20 |
| 3. Radiography 3/ | Per paragraph 5.3.2. | X | X | X |
| 4. C-SAM inspection 4/ | Per paragraph 5.3.3. | X | X | X |
| 5. Initial (pre-burn-in) electrical measurements (EM) 5/ | Per device specification, at 25 °C<br>At min. and max. rated operational temperatures. | X<br>X | X<br>X | X<br>- |
| 6. Engineering review (steps 1 to 5) 6/ | | | | |
| 7. Static (steady-state) burn-in (BI) test at 125 °C or at max. operating temperature 7/ | MIL-STD-883, Method 1015, condition A or B.<br>Hours, minimum depending on the BI temperature. | 240 hrs. at 125 °C<br>445 hrs. at 105 °C<br>885 hrs. at 85 °C<br>1,560 hrs. at 70 °C | 160 hrs. at 125 °C<br>300 hrs. at 105 °C<br>590 hrs. at 85 °C<br>1,040 hrs. at 70 °C | 160 hrs. at 125 °C<br>300 hrs. at 105 °C<br>590 hrs. at 85 °C<br>1,040 hrs. at 70 °C |
| 7a. Post static BI electrical measurements at 25 °C | Per device specification. Calculate Delta when applicable. | X | X | X |
| 9. Dynamic burn-in test at 125 °C or at max. operating temperature 7/ | MIL-STD-883, Method 1015, Cond. D.<br>Hours, minimum. | Same as test step 7. | Same as test step 7. | Same as test step 7. |
| 10. Final parametric and functional tests | Per device specification (at 25 °C, maximum, and minimum rated operating temperatures). | X | X | X |
| 11.Calculate percent defective (steps 7 to 10) 6/ | Maximum acceptable PDA. | 5% | 10% | 10% |
| 12. External visual/packing 2/ | Per paragraph 5.3.1 and Section 8. | X | X | X |

Notes on next page.

## **Notes to Table 2.** Screening Requirements for PEMs

1/ **General**

1.1/ Screening is performed on 100% of flight parts.

1.2/ Historically, only parts with tight lot-specific controls imposed during manufacturing had been allowed for applications in level 1 projects. Such a control is impossible for PEMs, and the suggested screening procedures are not considered as a substitute for manufacturing control, but rather as risk mitigation measures.

1.3/ It is the responsibility of the project parts engineer to submit screening test results to Code 562 for logging into the Code 562 PEM database.

2/ It is recommended to combine the incoming/outgoing visual inspections with the serialization and packaging to reduce handling and possible damage to the parts. Serialization should be performed in such a way to allow a top side C-SAM inspection. Flight parts should be handled and stored in a manner to prevent mechanical and ESD damage, contamination, and moisture absorption (see Section 8).

3/ To minimize handling, only a top view X-ray inspection is required. Focus to inspect for wire sweeping and obvious defects in the part. Depending on the results of the top view X-ray and/or part construction, a side view may be required.

4/ **Acoustic Microscopy (C-SAM)**

4.1/ *General.* Acoustic microscopy is performed to screen out defects at critical die surface and lead tip wire-bond areas of the parts and screening, except for power devices, is performed only at the top side.

4.2/ *Coated Die.* Top side of the internal portion of the leads is inspected in PEMs with polymer die coating. Inspection of the die area is not required, as the die coating has a low acoustic impedance that appears as a false delamination.

4.3/ *Power Devices.* For power parts, the bottom side inspection of die attachment might be replaced with the thermal impedance measurements.

4.4/ *Rejection Criteria.*

- Any measurable amount of delamination between molding compound and the die surface.
- Any delaminations on the leads at wire bond areas.
- Delaminations extending more than 2/3 the length of internal part of the leads.

5/ **Electrical Measurements**

5.1/ *Special Testing.* In addition to parametric and functional measurements per data sheets, supplement and/or innovative testing techniques (e.g. IDDQ leakage currents, thermal impedance, output noise, etc.) can be used to select better quality parts from the lot (cherry pick) as flight candidates. These techniques should be certified and approved by Code 562.

5.2/ Failure modes (parametric or catastrophic) should be recorded for each failed part.

6/ **Engineering Review**

6.1/ More than 10% C-SAM rejects might require additional evaluation of thermo-mechanical integrity of the lot or its replacement.

6.2/ Most established PEMs manufacturers guarantees 3-sigma level process minimum, which means that less than 0.27% of the parts can be out of specification. Excessive fallouts during initial electrical measurements at room temperature might be due to a poor quality of the lot or effect of temperature cycling performed before electrical measurements, or it might be an indication of problems with the testing lab. When excessive rejects are experienced, the project PE decides whether a lot replacement or additional evaluation is needed based on observed failure modes and results of failure analysis. Excessive rejects during initial electrical measurements might be a legitimate cause for lot replacement.

## **Notes to Table 2 (Continued).** Screening Requirements for PEMs

7/ **Burn-in (BI)**

7.1/ *General.* Burn-in is a complex, product-specific test and if possible should be conducted by the manufacturer of the part. If a user performs this test, special care should be taken not to exceed maximum current, voltage, and die temperature limits.

7.2/ *Burn-in Temperature.* The BI temperature is a "stress" temperature used to precipitate failure of defective parts and is typically much higher than the operational temperature of the part, where the characteristics are guaranteed to remain within the data sheet limits. Most PEM manufacturers use temperatures in the range from 125 °C to 150 °C to periodically perform BI to monitor quality of their product. However, if the parts engineer is unable to justify the suitability of burn-in at 125 °C, the burn-in ambient temperature shall be limited to the maximum operating temperature per the device specifications provided by the manufacturer.

7.3/ *Junction Temperature.* The junction temperature during BI testing should not exceed the absolute maximum rated junction temperature for the part.

7.4/ *Molding Material Glass Transition Temperature.* When the die temperature is close to or exceeds the glass transition temperature (Tg) of the molding compound (MC), electrical and mechanical properties of MC may change significantly and new degradation mechanisms may cause failures of the part. For most molding compounds, Tg values exceed 140 to 150 °C, which gives a necessary temperature margin for 125 °C BI. Reliability of the PEMs, which are manufactured with low-Tg molding compounds (Tg < 120 °C), is difficult to assess, and such parts are not recommended for space projects without additional extensive analysis and testing. Glass transition temperature measurements are recommended prior to BI if usage of low-Tg molding compound for the lot is suspected.

7.5/ *Protection.* In some parts the sensitivity of the input/output ESD protection circuits increases with temperature and these circuits can be turned on easily, at lower and/or shorter voltage spikes, than at room temperature. For this reason, special care should be taken to prevent possible power line transients during burn-in testing.

7.6/ Excessive proportion of functional BI failures, even when the total number of failures is within the PDA limits, might be an indication of serious lot reliability problems. In these cases additional testing and analysis of the parts might be required.

7.7/ Steady-state burn-in is performed on all linear and mixed-signal devices (see Table 2A for details on burn-in conditions). The duration of steady-state burn-in can be reduced 50% if the parts are to be subjected to dynamic burn-in testing.

7.8/ Dynamic burn-in is not required for parts operating under steady-state conditions, e.g. voltage references, temperature sensors, etc.

7.9/ Only one type of BI test, either static or dynamic, is required for level 2 and 3 parts.

7.10/ Under special circumstances, when it is technically and economically viable, and for components, which are difficult to assess at the piece part level, alternative testing in lieu of static and/or dynamic BI testing (for example, board-level burn-in) may be permitted. It is the responsibility of the project PE to document and submit a rationale for the technical feasibility and equivalency of the alternative testing to the project and GSFC Code 562 for approval. Board-level burn-in shall not be routinely substituted for piece part burn-in as a convenience.

**Table 2A.** Burn-in and Electrical Measurement Requirements for PEMs

| IC Type | Required Burn-In 1/ Static (Condition C) 2/ | Required Burn-In 1/ Dynamic (Condition D) 2/ | Delta | Electrical Measurements 3/, 4/ |
|---|---|---|---|---|
| **Digital Bipolar & Digital MOS/ BiCMOS:**<br>LOGIC (Gates, Buffers, Flip-Flops, Multiplexers, Registers, and Counters)<br>RAMs<br>FIFOs<br>Microprocessors<br>Interface Peripherals<br>ASICs<br>FPGA, PROM, PAL | Not required for Digital Bipolar Technology.<br><br>Required for Digital MOS Technology.<br><br>$V_{IN}$= $V_{DD}$ across one-half input pins and $V_{SS}$ across the remaining inputs.<br><br>$V_{OUT}$= 0.5 $V_{DD}$ through $R_L$ | Required for both technologies.<br><br>$V_{in}$ = Square wave, 50% duty cycle to input pins and control pins.<br><br>Frequency= 100 Hz to 1 Mhz.<br><br>$V_{OUT}$ = $V_{CC}$ /2 or $V_{DD}$/2 through $R_L$. | $\Delta I_{CC}$<br>or<br>$\Delta I_{DD}$ | **DC:** $V_{IC}$, $V_{OH}$, $V_{OL}$, $I_{CC}(I_{EE})$, $I_{IL}$, $I_{IH}$, $I_{DD}$, $I_{OZL}$, $I_{OZH}$, $I_{OS}$<br><br>**AC:** $T_{PLH}$, $T_{PHL}$, $T_{TLH}$, $T_{THL}$, $T_{PZH}$, $T_{PHZ}$, $T_{PLZ}$, $T_{PZL}$, $T_A$, $T_S$, $T_H$<br><br>**Functional Tests:**<br>a) For simple logic devices, verify truth table.<br><br>b) For complex logic devices such as ASIC, FPGA, and microprocessors, functional testing should include fault coverage calculations.<br><br>c) For PROMs, check fuse map; for RAMs, perform pattern sensitive tests such as March, Galpat, etc. |
| **Linear MOS, Bipolar, and Bi-FET**: 5/<br>Op-Amp, Instrument Amplifiers, S/H, and Comparator | $V_{out}$= Terminated to ground through $R_L$ | $V_{in}$= Square wave or sinewave<br>F= 10Hz to 100 KHz, 50% duty cycle<br>$V_{out}$= Terminated to ground through $R_L$ | $\Delta I_{IB}$<br>$\Delta I_{IO}$<br>$\Delta V_{IO}$ | **DC:** $I_{CC}$, $I_{EE}$, $I_{IO}$, $V_{IO}$, $V_{OPP}$, $A_V$, CMRR, PSRR<br><br>**AC:** Slew rate |

Notes at end of Table 2A.

**Table 2A (Continued).** Burn-in and Electrical Measurement Requirements for PEMs

| IC Type | Required Burn-In 1/ Static (Condition C) 2/ | Required Burn-In 1/ Dynamic (Condition D) 2/ | Delta | Electrical Measurement 3/, 4/ |
|---|---|---|---|---|
| **Linear MOS, Bipolar and JFET**: 5/<br>Line Drivers and Receivers | $V_{in}$= $V_{DD}$ max across one-half input pins and $V_{SS}$ across the remaining inputs. | $V_{in}$= Square wave at a specified frequency and duty cycle<br><br>$V_{out}$= $V_{CC}$ through $R_L$ | $\Delta I_{CC}$<br>$\Delta I_{IH}$ | **DC:** $V_{OH}$, $V_{OL}$, $I_{CC}$, $I_{IL}$, $I_{IH}$, $I_{OS}$<br><br>**AC:** $T_{PLH}$, $T_{PHL}$, $T_{TLH}$, $T_{THL}$<br><br>**Functional Test:** Verify truth table |
| **Linear MOS, Bi-FET, and Bipolar:** 5/<br>Analog Switches and Multiplexers | $V_{in}$= $V_{DD}$ max across one-half of inputs and $V_{SS}$ across the other remaining inputs.<br>$V_{out}$= ± $V_{CC}$ through $R_L$ | $V_{in}$= Square wave<br>F= 100 Khz and 50% duty cycle<br>$V_{out}$= ± $V_{CC}$ through $R_L$ | $\Delta I_{CC}$<br>$\Delta I_{D(OFF)}$<br>$\Delta I_{S(OFF)}$<br>$\Delta R_{(ON)}$ | **DC:** $I_{CC}$, $I_{D(ON)}$, $R_{(ON)}$, $I_{D(OFF)}$, $I_{S(ON)}$, $I_{S(OFF)}$<br><br>**AC:** $T_{(ON)}$ , $T_{(OFF)}$<br>break- before- make- time |
| **Linear Bipolar**:<br>Voltage Regulators | $V_{out}$= Terminated to ground through $R_L$ | Not required | $\Delta I_{SCD}$<br>$\Delta V_{OUT}$ | **DC:** $I_{CC}$, $V_{OUT}$, $I_{OS}$,<br>line/load regulation |
| **Linear Bipolar:**<br>Pulse-width-modulator | Not required | $V_{out}$= Terminated to ground through $R_L$<br>$R_{ext}$, $C_{ext}$ connected if applicable. | $\Delta I_{IO}$<br>$\Delta V_{REF}$ | **DC:** $V_{REF}$, $I_{IB}$, $I_{IO}$, $I_{OS}$, $V_{IO}$, $V_{OL}$, $V_{OH}$, $A_V$, CMRR, PSRR<br><br>**AC:** $T_R$ , $T_F$, $f_{OSC}$ |
| **Linear CMOS**<br>Timers | $T_A \geq 125$ °C<br><br>$V_{out}$= $V_{CC}$ through $R_L$ | Not required | $\Delta I_{CEX}$<br>$\Delta V_{OH}$<br>$\Delta V_{OL}$ | **DC:** $V_{TRIG}$, $V_{TH}$, $V_R$, $V_{OL}$, $V_{OH}$, $V_{SAT}$, $I_{CC}$, $I_{TRIG}$, $I_{TH}$, $I_R$, $I_{CEX}$<br><br>**AC:** $T_{TLH}$, $T_{THL}$ |

Notes at end of Table 2A.

**Table 2A (Continued).** Burn-in and Electrical Measurement Requirements for PEMs

| IC Type | Required Burn-In 1/ Static (Condition C) 2/ | Required Burn-In 1/ Dynamic (Condition D) 2/ | Delta | Electrical Measurement 3/, 4/ |
|---|---|---|---|---|
| **Mixed Signal MOS, Bi-CMOS and Bipolar:** 5/<br>Analog to Digital (A/D) Converters. | $V_{in}$ = Max analog DC input<br>$V_{out} = V_{CC}/2$ through $R_L$ | $V_{in}$= Analog input to generate maximum digital codes.<br>$V_{out} = V_{CC}/2$ through $R_L$ | $\Delta I_{CC}$<br>$\Delta I_{EE}$<br>$\Delta V_{IO}$ | **DC:** $V_{REF}$, $V_{OH}$, $V_{OL}$, $V_{IO}$, $I_{CC}$, $I_{EE}$, $I_{IL}$, $I_{IH}$, $I_{OZL}$, $I_{OZH}$, $I_{OS}$, Zero Error, Gain Error, Linearity Error.<br>**AC:** $T_C$, $T_S$, $T_H$<br>**Functional Test:** Verify codes |
| **Mixed Signal MOS, Bi-CMOS and Bipolar** 5/<br>Digital to Analog (D/A) Converters. | $V_{in} = V_{DD}$ on one-half data inputs and $V_{SS}$ on remaining inputs.<br>$V_{out}$= Terminated to ground through $R_L$ | $V_{in}$ = Apply appropriate digital codes for all inputs and for control signals.<br>$V_{out}$ = Terminated to ground through $R_L$. | $\Delta I_{CC}$<br>$\Delta I_{EE}$ | **DC:** $I_{CC}$, $I_{EE}$, $I_{IL}$, $I_{IH}$, $I_{OZL}$, $I_{OZH}$, $I_{OS}$, Zero Error, Gain Error, Linearity Error, PSRR<br>**AC:** $T_C$, $T_S$, $T_H$<br>**Functional Test:** Verify codes |

**Notes:**

1/ Reference MIL-STD-883, Method 1015. Static and dynamic burn-in shall be performed at maximum recommended operating supply voltage with $V_{in}$ and $R_L$ selected to assure that the junction temperature shall not exceed $T_{jmax}$ specified for the device type.

2/ See Table 2 for BI ambient temperature conditioning.

3/ These are typical recommended electrical parameters. Since electrical parameters are device dependent, refer to detail specifications for actual DC and AC parametric test conditions and limits.

4/ For digital devices, all DC parameters, functional tests, and switching tests shall be performed at 25 °C, at minimum operating temperature and at maximum operating temperature.

For linear devices, all DC parameters shall be tested at 25 °C, at minimum operating temperature and at maximum operating temperature. All AC and switching tests shall be performed at 25 °C.

5/ For level 2 and level 3 parts only one BI test, static or dynamic is required.

# 4.0 REQUIREMENTS FOR QUALIFICATION

Qualification of PEMs is performed to evaluate long-term reliability by accelerating potential degradation processes that might cause wear-out failures of the parts. The major areas of reliability concern for PEMs are:

1. Mechanical Failures due to mechanical stresses in the package (package level wear-out).
2. Contamination Failures caused by moisture and contamination in the molding compound or at the die surface.
3. Wear-Out Failures related to the degradation processes in the die (die level wear-out).
4. Radiation Effects Failures caused by die susceptibility to degradation caused by gamma-irradiation and high-energy charged particles.

Solder Reflow Simulation and Extended Temperature Cycling are intended to demonstrate susceptibility of the parts to thermal stresses. Surface mount technology (SMT) PEMs experience a high temperature shock during solder reflow processes. The reflow temperature exceeds maximum processing temperatures experienced by parts during the curing of molding compounds and the glass transition temperature of the plastic. This can cause significant mechanical stresses, resulting in observable or latent damage to the package and die.

Highly Accelerated Stress Testing (HAST) is used to detect moisture- and contamination-related susceptibility to failures.

High Temperature Operational Life (HTOL) Testing is performed at high temperatures and maximum operation voltage and is intended to accelerate most of the die-related degradation processes.

A typical test flow for qualification of plastic encapsulated microcircuits is shown in Figure 4. Table 3 presents details of the GSFC requirements for the qualification of PEMs for projects of different reliability levels.

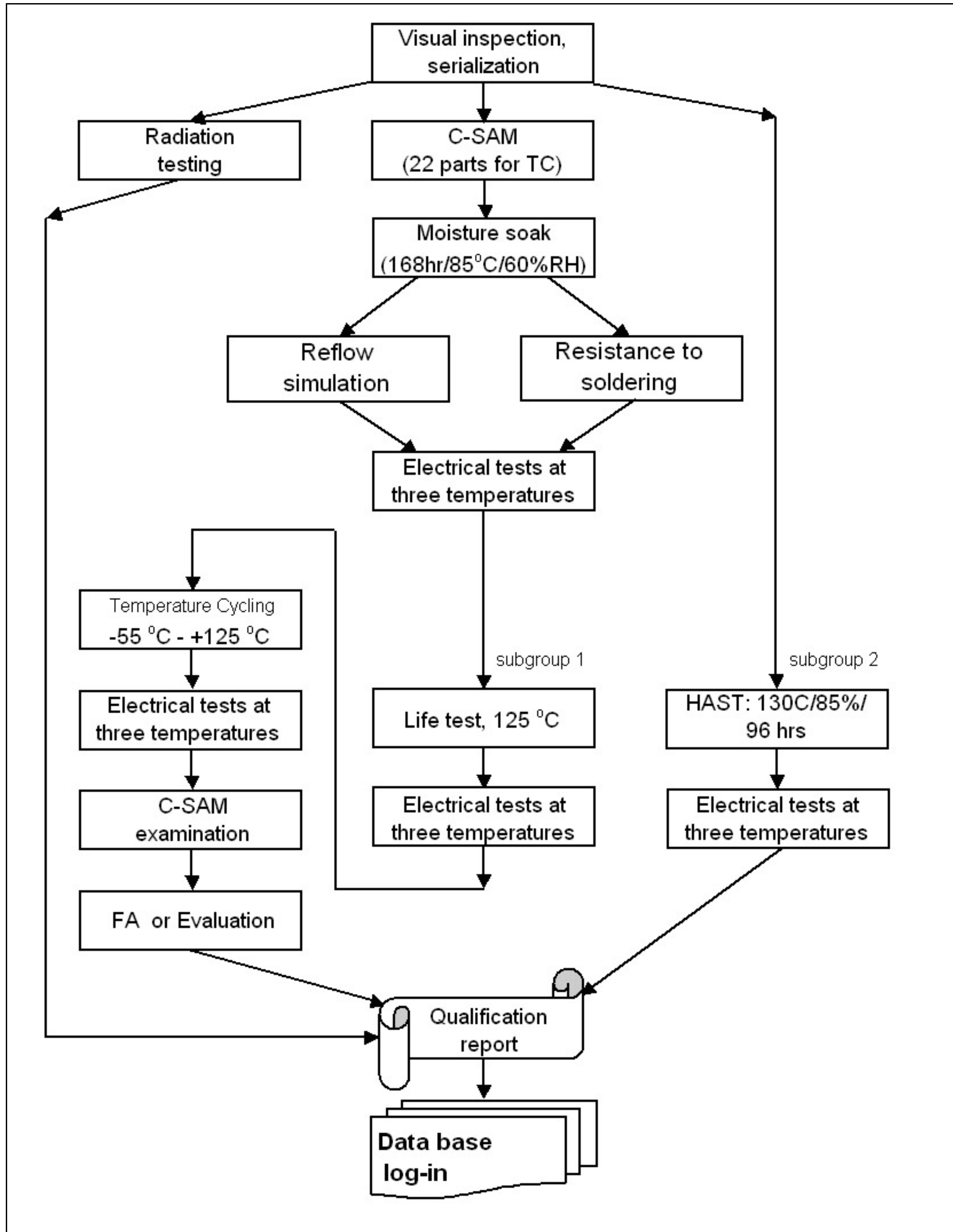


**Figure 3.** A Typical Qualification Test Flow for PEMs
(See Table 3 for GSFC qualification requirements for PEMs.)

**Table 3.** GSFC Qualification Requirements for PEMs 1/

| Process | Sub Test | Test Methods & Conditions | QTY (Failures) | | |
|---|---|---|---|---|---|
| | | | Level 1 | Level 2 | Level 3 |
| **1. Visual inspection & serialization 2/** | | Section 5, paragraph 5.3.1. | 32 | 32 | 17 |
| **2. Radiation analysis** | | TID and SEE | **3/** | **3/** | **3/** |
| **3. Baseline C-SAM** | (Parts in subgroup 1 only) | Section 5, paragraph 5.3.3.1. | 22 | 22 | N/A |
| **5. Preconditioning** | Moisture soak 4/ | JESD22 – A113-B, para. 3.1.5, condition A (168 hours, +85 °C, 60% RH). | 32 | 32 | 17 |
| | **SMT devices**<br>Reflow simulation (with flux application, cleaning, and drying) | JESD22-A113-B, Table 2 and paragraphs 3.1.6 through 3.1.9. Peak solder reflow temperature +235 °C. | 32 | 32 | 17 |
| | **Through-hole devices**<br>Resistance to soldering temperature | JESD22-B106-B. | 32 | 32 | 17 |
| **4. Electrical measurements** | Per device specification | Measure at 25 °C, min. & max. rated temperatures. | 32(0) | 32(0) | 17(0) |
| **6. Life testing**<br>Subgroup 1 | HTOL, 125 °C 5/, 6/ | MIL-STD-883, Method 1005, Cond. D<br>Hours, minimum. | 22<br>1,500 | 22<br>1,000 | 10<br>500 |
| | Electrical measurement (per specification) | Measure at 25 °C, min. & max. rated temperatures. | 22(0) | 22(0) | 10(0) |
| **6a. Temperature cycling**<br>Subgroup 1 | Temperature cycling 5/, 7/ | MIL-STD-883 Method 1010, Cond. B (-55 °C to +125 °C), cycles, minimum. | 22<br>500 | 22<br>200 | 10<br>100 |
| | Electrical measurement (per specification) | Measure at 25 °C, min. & max. rated temperatures. | 22(0) | 22(0) | 10(0) |
| | C-SAM 8/ | Section 5, paragraph 5.3.3. | 22 | 22 | N/A |
| | DPA or FA | 9/ | X | X | N/A |
| **7. Highly accelerated stress test (HAST)** | Biased HAST 5/ | JESD22-A110, with continuous bias (96 hours, +130 °C, 85% RH). | 10 | N/A | N/A |
| Subgroup 2 | Unbiased HAST 5/ | JESD22-A118, Condition A (96 hours, +130 °C, 85% RH). | N/A | 10 | 7 |
| | Electrical measurement (per specification) | Measure at 25 °C, min. & max. rated temperatures. | N/A | 10(0) | 7(0) |

Notes on next page.

## **Notes to Table 3.** GSFC Qualification Requirements for PEMs

1.1/ All parts shall be selected from a screened lot.

1.2/ It is the responsibility of the project parts engineer to submit qualification test results to Code 562 for logging into the Code 562 PEM database.

2.1/ This step is not performed if results of the screening are available.

3/ Radiation hardness of the parts must be assessed on a lot-specific basis according to the project requirements. So that analysis can be completed prior to screening and qualification, unscreened samples can be used for this test. An additional number of samples, depending on radiation requirements, shall be provided by the project to perform this test.

4/ Moisture soak is performed as a part of preconditioning to mimic worst-case moisture absorption conditions of the PEM molding material, which could cause PEMs to be damaged during soldering to boards.

5/ Conditions of the temperature cycling, HAST, and high temperature life testing (HTOL) can be tailored according to specifics of the device application per Code 562 approval. Guidelines for application-tailored qualification testing of PEMs shall be developed by Code 562.

6/ The junction temperature should not exceed the absolute maximum rated junction temperature for the part. If 125 °C ambient causes the maximum rated junction temperature to be exceeded, the ambient temperature should be decreased appropriately.

7/ Temperature cycling is performed after HTOL testing on the same samples only for economic reasons. This test can be also performed on a separate group of parts if additional samples are provided (22, 22, and 10 samples for levels 1, 2, and 3, respectively).

8/ This C-SAM examination is performed to estimate mechanical damage to the part due to temperature cycling and reflow simulation (or resistance to soldering test) by comparing acoustic images with the baseline measurement results.

9/ Failure analysis is performed on any failures during qualification tests to determine whether they are caused by lot-related defects, manufacturing process problems, or improper testing. If no failures are observed, a special evaluation (DPA) should be performed to ensure that no degradation of wire bonding, cratering, and mechanical damage to glassivation and metallization systems occurred (for level 1 and 2 parts only).

**Applicable Standards for Test Methods**

JESD22-A113-B: Preconditioning of Nonhermetic Surface Mount Devices Prior to Reliability Testing.
JESD22-B106-B: Resistance to Soldering Temperature for Through-Hole Mounted Devices.
JESD22-A110-B: Highly Accelerated Temperature and Humidity Stress Test (HAST).
JESD22-A118: Accelerated Moisture Resistance – Unbiased HAST.

# 5.0 DESTRUCTIVE PHYSICAL ANALYSIS (DPA)

This section describes purpose, test flow, and procedures for destructive physical analysis (DPA) of commercial PEMs and is intended to supplement GSFC-S-311-M-70 (Specification for Destructive Physical Analysis).

## 5.1 Purposes of DPA for PEMs

DPA, or construction analysis (CA), provides important information regarding design, workmanship, and process defects related to a PEM manufacturer lot. This information can be used for tailoring of screening and qualification test plans to focus on specific areas of reliability concerns.

DPA for PEMs should focus on three major areas of concern: integrity of the package, quality of assembly, and defects in the die. This analysis should also evaluate package- and die-level homogeneity of the lot. For this purpose, samples for DPA should be selected randomly from different portions of the lot.

An important benefit of DPA is to provide for comparison analysis of design and technology, to identify product change, to provide baseline data in the event of subsequent failures and application problems, and to provide data for physics of failure analysis.

## 5.2 DPA Test Flow

A typical test flow for destructive physical analysis of PEMs is shown in Figure 5.

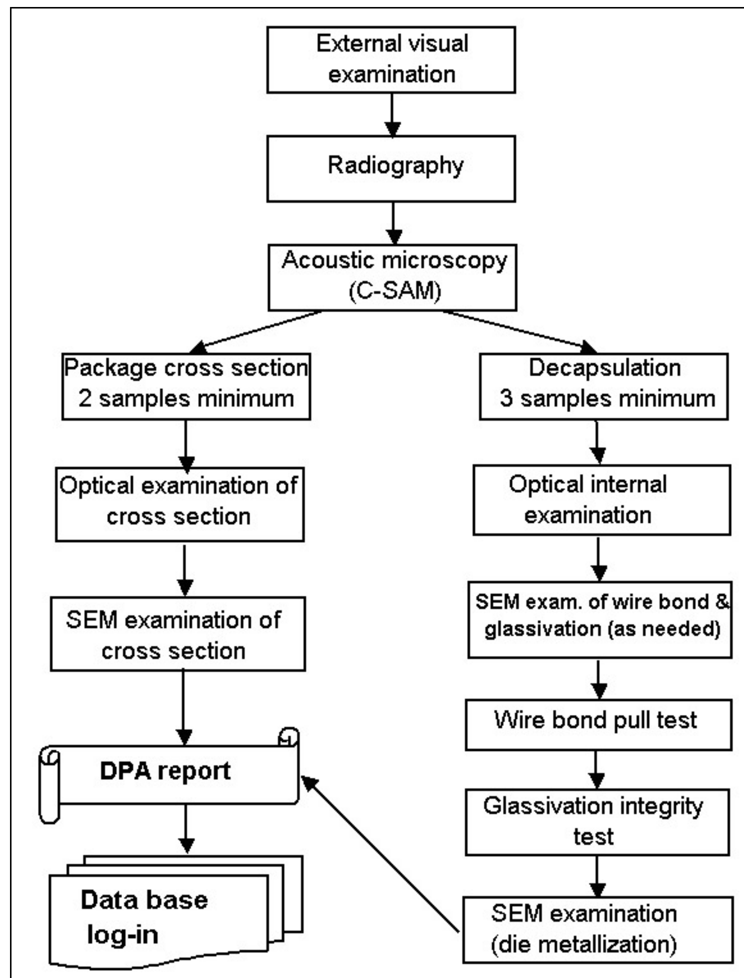


**Figure 4.** A Typical DPA Test Flow for PEMs
(See Section 5.3 for GSFC DPA procedure.)

**Notes:**

1/ Requirements for die-level examinations in PEMs are the same as the requirements for hermetic military- or space-graded parts.

2/ It is the responsibility of the parts lab or project engineer (when DPA is performed by a GSFC contractor) to submit a DPA report to Code 562 for logging into the PEM database.

## 5.3 GSFC DPA Procedure

### 5.3.1 External Visual Examination

Inspect each sample (five samples minimum) at 3X to 10X magnification. One photograph of one typical device showing all markings shall be taken. All anomalies shall be photo-documented. Failure criteria of MIL-STD-883E, Method 2009, "External visual" shall be used as applicable. In addition, inspect for any evidence of lot dissimilarity and the following defects:

- Package deformation (nonplanarity, warping, or bowing).
- Foreign inclusions in the package, voids and cracks in the plastic encapsulant.
- Deformed leads; peeling, blistering, or corrosion of finishing.
- Condition of external leads and plating.
- Legibility and correctness of marking.
- Evaluate homogeneity of the lot (package level).

### 5.3.2 Radiography

The purpose of this examination is to detect internal defects of the package and to determine die and wire placement for future decapsulation. Inspect all submitted samples for the following defects:

- Foreign objects and voids in the encapsulant.
- Voids in the die attach material.
- Misaligned leads.
- Burrs on lead frame (inside the package).
- Poor wire bond geometry (wires that deviate from a straight line from bond to external lead or have no arc from die bonding pad to lead).
- Swept or broken wires.
- Improper die placement.

Radiographs shall be taken of each device in two views 90 degrees apart (top and side views). MIL-STD-883E, Method 2012, "Radiography" is applicable.

Note: When real-time radiography is used for screening, the dose rate that the equipment emits should be estimated. Certain types of radiography can expose microcircuits to unusually high dose rates, such that damage can be introduced to sensitive parts. The Radiation Effects Group should be consulted as necessary.

### 5.3.3 Acoustic Microscopy (C-SAM)

All samples shall be subjected to acoustic micro-imaging analysis. The purpose of this examination is to nondestructively detect the following defects:

- Delamination of the molding compound from the lead frame, die, or paddle (top side and bottom side separately).
- Voids and cracks in molding compound.
- Unbonded regions and voids in the die-attach material (if possible).

5.3.3.1 C-SAM Requirements. The C-SAM procedure for screening should comply with the following requirements:

- A clean bath and deionized water should be used during acoustic examinations of the flight parts.
- The test personnel shall be ESD certified to NASA-STD-8739.7 "ESD control."
- Depending on storage conditions of the parts, a 1-hour bake at 125 °C should be performed to remove moisture from the parts after immersion into the water bath of an acoustic microscope.

5.3.3.2 Package Examination Sites. Examination of the package for voids, cracks, and delaminations shall be performed on each sample at six areas:

1. Interface between the die surface and molding compound (top view).
2. Interface between the lead frame and molding compound (top view).
3. Interface between the die paddle periphery and molding compound (top view).
4. Die-to-paddle attachment interface (if possible).
5. Interface between the die paddle and molding compound (back view).
6. Interface between the lead frame and molding compound (back view).

Notes

- Combined C-mode scans can be performed to investigate more than one area during one scanning run.
- A-scan data (wave form analysis) should be performed to verify any delaminations (if observed).
- Die-attach inspection shall be performed per MIL-STD 883E, Method 2030, "Ultrasonic inspection of die attach" for the parts with the die mounted onto a substrate or heat sink. This standard can also be applicable for other package types provided the resolution is adequate to detect voids in the attachment material.
- Package surface roughness, mold marks, stamped marking, and surface defects create additional ultrasonic wave reflections that hinder analysis results. Labels should be removed from the area to be scanned.
- Anomalies and/or delaminations (if observed) should be verified using A-scan analysis.

5.3.3.3 Evaluation Criteria. The following shall be considered gross defects and the lot shall be rejected:

1. Cracks in plastic package intersecting bond wires.
2. Internal cracks extending from any lead finger to any other internal feature (lead finger, chip, die attach paddle) if the crack length is more than 0.5 of the corresponding distance.
3. Any cracks in the package extending to the surface.
4. Any void in molding compound crossing wire bond.
5. Any measurable amount of delamination between molding compound and die surface or lead frame in the area of wire bond (bonds to lead fingers or to the die paddle).

Note: If rejectable internal cracks or delaminations are suspected, a polished cross section may be required to verify the suspected site.

The following aspects shall be considered as reliability concerns and additional testing and screening of the lot might be necessary:

1. Delamination of more than half of the backside or top peripheral area of the interface between the paddle and molding compound.
2. Delamination of the top tie bar or lead area of more than 0.5 of its length.
3. Delamination at the top of the die paddle of more than 0.5 of the periphery area.

#### 5.3.4 Package Level Cross-Sectioning

Two devices, or 40% of the DPA samples, whichever is larger, shall be subjected to this examination. The purposes of this examination is to evaluate:

- Wire bonding (both to the die and lead frame).
- Die attachment for voiding and delamination.
- Integrity of molding compound/lead frame interface.
- Lead frame plating and external lead finish.
- Lead frame/molding compound interface to ensure that there is no direct path (along the leads) for moisture and contamination to reach the die.

Inspect the following areas of the package and die for defects:

- Defects and cracks in the package.
- Condition of die attachment.
- Lead frame/molding compound delamination.
- Condition of wire bonding at contact pads.
- Contact pad cratering.
- Condition of wire bonding at lead frame.

- Anomalies in molding compound (e.g., red particles might indicate the presence of red phosphorus used as a flame retardant; this type of flame retardant might cause part failure).

SEM examination and X-ray microanalysis at the package level cross section is performed optionally or to get more details of anomalies observed during optical examination. This examination shall be focused on the following areas:

- Lead finish materials.
- Intermetallic formation at wire bond/contact pad interface.
- Composition and structure of molding compound, lead frame, and lead frame plating and finishing.
- Assembly/molding compound integrity.

5.3.4.1 Cross-Sectioning Procedure. Half of the samples shall be sectioned along the leads of one side of the package and half along the leads of the other side of the package. The planes shall cross the package in a mutually perpendicular fashion along the leads in the vicinity of the paddle edge, approximately in the middle of the die. Parts with the paddle tie bars shall be sectioned along the bars. For samples, different planes shall be selected that cross different wire bonds to the die and to the leads. If suitable, a sample can be divided in two parts before potting. Each plane of cross section shall be examined microscopically first at a low power (30X to 60X) magnification and then at a high power magnification (75X to 200X). Optical examination of the bonds inspection shall be performed at up to X1,000 magnification. Pictures of all defective bonds and package faults, as well as at least one picture of a typical bond, die attachment, and overall package layout, should be taken.

5.3.4.2 Evaluation Criteria. The following defects shall be considered as gross defects causing the lot to be rejected:

1. Package cracks and delaminations: Any evidence of external cracks other than between the lead and plastic at the lead entrance; large voids and delamination at the die attachment, die surface, and lead finger tips.
2. Bonding: Lifted and shifted bonds, excessive intermetallic formation at the periphery of the ball bond.
3. Molding compound: Voids and cracks in vicinity of bonding wires, presence of red phosphorus or other corrosive materials.
4. Leads: Pure tin (Sn) finishing of the leads, delamination of finishing.

The following aspects shall be considered as reliability concerns and additional testing and screening of the lot might be necessary:

1. Package cracks and delaminations: Any evidence of delamination or cracking of more than 0.5 of the lead or tie bar length.
2. Bonding: Abnormalities in intermetallic compound formation, cratering.

3. Die attach: Voiding of more than 50%.
4. Molding compound: Foreign intrusions.

### 5.3.5 Internal Visual Inspection

Three samples minimum shall be subjected to this examination.

5.3.5.1 Decapsulation Techniques. Description of different decapsulation techniques including Milling, Manual Wet Etching, Chemical Jet Etching, or Plasma Etching can be viewed at (http://nepp.nasa.gov/DocUploads/E449EBC9-30F5-4400-9F4CD447CF85ED7E/61206_DPA%20for%20PEMs.pdf).

5.3.5.2 Verification of the Decapsulation Quality

1. Confirm acceptance of the specimen for further bonding examination. At least 25% or three wire bonds, whichever is more, should meet the following criteria: be clean, have no damage, and be exposed more than approximately two-thirds of their length.
2. Confirm acceptance of the specimen for further glassivation integrity and SEM examinations. At least 75% of the die area should be clean and have no damage caused by deprocessing.
3. Record any defects induced by the decapsulation that might affect the DPA results.

5.3.5.3 Examination. The decapsulated device shall be examined microscopically, first at low-power magnification (30X to 60X) and then at high-power magnification (75X to 200X) to determine the existence of the die-level and assembly-level defects and to verify the die lot homogeneity and quality of decapsulation.

Pictures of all defects, as well as an overall internal view of the die and die marking, should be presented in the report.

The purpose of this inspection is to evaluate the mechanical condition of die, condition of wire bonds, and condition of glassivation.

When necessary to get more details on observed anomalies, SEM examination of wire bond and glassivation is performed to inspect for anomalies with intermetallic growth at wire bonds, and damage to glassivation.

5.3.5.4. Evaluation Criteria. Evaluation criteria per MIL-STD-883E, Method 2013, “Internal visual inspection for DPA” are applicable. No device shall be acceptable that exhibits the following defects:

- Glassivation pinholes, peeling or cracks (in particular those specific to filler particle-induced damage).
- Metallization voids, corrosion, peeling, or lifting.

- Wire bonds lifting, misplacement, and excessive deformation.
- Additionally, die-level lot homogeneity shall be evaluated.

### 5.3.6 <u>Bond Pull Test</u>

Two devices or 40% of the DPA samples, whichever is larger, shall be subjected to this examination. Each sample which met the requirements per 4.3.5.2 shall be subjected to a destructive bond pull test.

The purpose of this test is to evaluate bond strength, contact pad metallization adherence, and cratering.

The wire bonds shall be pulled to destruction according to MIL-STD-883, Method 2011, “Bond strength (destructive bond pull test),” Condition D.

<u>Note:</u> According to MIL-STD-883, Method 2011, the pull is applied by inserting a hook under the wire approximately in the center of the loop. Normally, decapsulation exposes approximately 75% of the loop (exposure of the wire-to-lead bond would weaken the bond strength due to chemical attack). The wire tension in which the pull force is not applied in the middle of the loop and part of the loop is buried in plastic may differ by a factor of two from the values identified in MIL-STD-883. This means that the rejection criteria per MIL-STD-883, Method 2011, may not be applicable.

Typically, the ball neck is the weakest site of a wire bond because it has been annealed during ball formation. If another site of the wire bond is found to be broken, the site could indicate a problem (especially in the case of a ball lift).

A wire bond strength test may be greatly influenced by the history of the sample. Thermocycling or storage of the sample under high temperature and humidity environments can cause deterioration of the wire bond strength. Enhanced degradation of the intermetallic region of the gold-aluminum wire bonding pad interface occurs in the presence of some flame retardants in epoxy molding compounds (such as those containing bromine or antimony). In some cases, to ensure an adequate quality of the part and its long-term reliability, different types of accelerated tests are recommended before the sample is subjected to the wire pull test.

Results of the bond pull test shall be recorded in the DPA records.

### 5.3.7 <u>Glassivation Layer Integrity</u>

One sample or 20% of the lot, whichever is larger, which meets the requirements per 5.3.5.2 shall be subjected to a glassivation layer integrity test. This test is performed to

evaluate cracks, voids, and pinholes in glassivation. This examination shall be performed per MIL-STD-883E, Method 2021, “Glassivation layer integrity.”

### 5.3.8 Assembly Examination Using Scanning Electron Microscope (SEM)

The purpose of this examination is to verify quality of wire bonding and glassivation integrity. It is performed if optical inspection reveals anomalies that require further analysis. Pictures of worst-case defective bonds and glassivation defects should be presented in the final report.

1. Glassivation shall be examined for delamination, pinholes, and cracks possibly induced by the filler in molding compound or mechanical stresses in the package (which typically occur at the die corners).
2. Wire-to-die bonding shall be examined for the following defects: Cratering of the bond pad on the die; bond liftoff; wire bonds, which are sheared from the die pads; and intermetallic compounds visible more than 0.1 mil beyond the ball attachment periphery.

### 5.3.9 Die Metallization Examination Using SEM

One sample or 20% of the lot, whichever is larger, which passed the requirements of 5.3.5.2 (decapsulation quality) shall be subjected to this test.

The purpose of this examination is to evaluate acceptability of the die interconnect metallization in accordance with MIL-STD-883, Method 2018 and, in particular, look for the following defects:

- Metallization mechanical defects.
- Metallization patterning and alignment.
- Step coverage.

5.3.9.1 Die-Level Cross-Sectioning. SEM examination and X-ray microanalysis at the die-level cross section is performed optionally or when optical examination finds suspected defects. The purpose of this test is to evaluate:

- Quality of planarization (if applicable).
- Condition of vias or step coverage.
- Verification of metallization and passivation systems.
- Metallization defects.
- Passivation defects.

If die cross-sectioning is necessary, the die shall be separated from the plastic package. This can be done in two ways: by etching away the paddle, or by removing most of the

molding compound around the paddle followed by heating the part to a temperature above the eutectic or solder melting point.

Note: It is important to remove all polymer residues from the die before cross-sectioning to achieve good quality polishing. Acid absorbed in the polymer remnants can mix with water during polishing and cause corrosion of metallization.

# 6.0 EVALUATION ANALYSIS

DPA procedures described in Section 5.0 specify minimum requirements for destructive physical analysis of PEMs intended for space applications. In some cases additional research beyond normal screening or DPA examinations may be necessary. In-depth evaluation analysis of the design and materials used in PEMs, custom tailored to analyze the technology as applied to the application, may be necessary. A series of tests and examinations specially designed by a PEM expert may be undertaken to provide a better understanding of part characteristics, materials, and reliability, as necessary. This can include additional destructive and non-destructive physical analysis as well as special electrical testing, mechanical or environmental stresses, and measurements of the parts.

The need for an evaluation analysis usually arises due to a part failure in the system-level testing, insufficient manufacturer data, and/or general concerns about the reliability of the part in specific application conditions. Some examples of these concerns are: effect of reflow conditions on mechanical integrity and reliability of the part; probability of ESD or EOS failures in the part under certain stress conditions; and effect of special environmental (e.g., vacuum) or electrical (e.g., switching transients) conditions on reliability, long-term storage at extreme temperatures, effect of the flame retardant used in molding compound on long-term wire bond integrity, etc.

In some cases, to address special quality or reliability concerns, an extended set of examinations to characterize design and materials used in PEMs may be required. The following list of characteristics gives an example of data that can be required:

1. Package-related characterization: Physical dimensions, weight.
2. Lead-related characterization: Solderability, lead finishing materials (addressing tin whiskers problems), mechanical integrity of leads.
3. Molding compound-related characterization: Outgassing; mechanical characteristics (glass transition temperature [Tg], coefficient of thermal expansion [CTE]); chemical characteristics (impurities [P, Cl, Br, Na]); α-particle emission; types of flame retardant; moisture characteristics (moisture diffusion and hygroscopic expansion coefficients).
4. Die-related characterization (materials and design): Passivation, interlayer dielectric system, metallization system.

# 7.0 DERATING REQUIREMENTS

Reliability of microcircuits encapsulated in plastics depends significantly on the temperature of the part and the level of electrical stress applied during operation. For different degradation mechanisms, an increase in operating voltages increases the failure rate either according to the power law or the exponential law. However, the most critical factor affecting reliability of the parts is the operating temperature, which exponentially accelerates most of the failures. Decreasing temperature and electrical stresses during operation, or derating the part, significantly decreases the probability of failures. Derating can be defined as a method of stress reduction by reducing applied voltages, currents, operating frequency, and power to increase reliability of the part.

Derating is widely used for high-reliability military and space-grade applications. It is even more essential for commercial PEMs. This is partially due to the fact that the thermal resistance for many ceramic or metal packaged parts is much less than for the same style of plastic packaged devices. Correspondingly, the operational temperature of the die in a plastic package at the same dissipation power level will be higher.

General derating requirements are listed in Table 4. Taking a conservative approach, derating requirements for PEMs should be more stringent than the requirements for their high-reliability equivalents. In some cases additional derating may be required based on specific application, design, and technology of the part. All part-specific derating shall be approved by the project and GSFC Code 562.

**Table 4.** Derating Requirements for PEMs

| **Stress Parameter** | **Derating Equation/Factor** | |
|---|---|---|
| | **Digital** | **Linear /Mixed Signal** |
| Maximum Supply Voltage 1/ | $V_{n.r.}+0.5*(V_{max.r.}-V_{n.r.})$ | $V_{n.r.}+0.8*(V_{max.r.}-V_{n.r.})$ |
| Maximum Input Voltage | - | 0.8 |
| Maximum Operating Junction Temperature /2 | 0.8 or 95 °C, whichever is lesser | 0.7 or 85 °C, whichever is lesser |
| Maximum Output Current | 0.8 | 0.7 |
| Maximum Operating Frequency | 0.8 | 0.7 |

**Notes:**

1/ $V_{n.r.}$ is the nominal rated power supply voltage; $V_{max.r.}$ is the maximum rated power supply voltage.

2/ For power devices, do not exceed 110 °C or 40 °C below the manufacturer's rating, whichever is lower.

# 8.0 HANDLING AND STORAGE REQUIREMENTS

Scope. This section describes general guidelines for safe handling of PEMs and assemblies containing PEMs. There are three major areas of concern that should be taken into account when handling and storing PEMs. All are valid up to board-level testing:

1. ESD Sensitivity. Most of the PEMs intended for space applications are advanced low-voltage, low-power microcircuits, which are extremely sensitive to ESD damage. ESD controls to meet NASA-STD-8739 shall be in place.
2. Delicate Piece Part Packages. Many PEMs have tiny leads, which can be easily damaged or contaminated. This can result in poor soldering of the part during installation onto boards and cause failure in the event of mechanical stress applied to the leads during temperature excursions, mechanical shock, or vibration.
3. Moisture Absorption and Contamination. Moisture and contamination can penetrate through plastic packages and cause degradation and failures during testing of the parts, solder reflow process, and operation after integration into the system.

Handling and Storage. Detailed procedures for handling, storing, and maintenance of PEMs and assemblies are to be developed. The IPC/JEDEC standard J-STD-033 can be used when applicable as a guideline for safe handling and packing of PEMs regarding moisture sensitivity. The requirements should follow the entire ground-phase handling of the parts including piece part testing, storage prior to installation, and board/system-level testing and storage after installation and integration into the system. Below are some additional guidelines for measures, which should be undertaken to avoid introduction of latent defects during testing, handling, and storing of the flight parts:

- Reduce handling by reducing the number of screening steps.
- Avoid contamination of the parts by reducing their exposure to humid environments and by using ESD-protective finger cots and ESD-protective bags.
- Use qualified test labs. Periodically check their conformity to proper handling procedures. Ensure that only certified personnel handle flight parts.
- Taking a conservative approach, all parts with a moisture sensitivity level of less than 2 (per IPC/JEDEC J-STD-033) shall be handled as 2a-5a level parts (this typically requires a 24 hr bake at 125°C for parts with thickness of ~2.5 mm or less; and a 48 hr bake at 125°C for parts with thickness ranging from 2.5-4.5 mm).
- Leads damaged during handling or reformed after forming or damage might remain strained and have microcracks. These parts should be marked as such, and are not recommended for use.

Cleaning. Detailed procedures for post installation cleaning and handling of assemblies with installed PEMs can be found in IPC SC-60A, “Post Solder Solvent Cleaning Handbook.” In developing a procedure for safe cleaning of assemblies containing PEMs, use IPC-CH-65A, “Guidelines for Cleaning of Printed Boards and Assemblies.”

# 9.0 INFORMATION FROM MANUFACTURERS

This section describes guidelines for acquiring information from the manufacturer of PEMs, which might be useful to assess quality of the parts.

Table 4 displays questions to be posed and manufacturer data available from Web sites, which would help to evaluate the ability of the manufacturer to produce parts with consistent quality and to provide acceptable customer support. The data are combined in four categories: general information about the part, part design and lifespan assessment, manufacturer assessment, and process assessment.

This information is of mutual interest for the parts engineering community and might be useful for different GSFC projects. For this reason, the project parts engineer should submit a spreadsheet in a standard format according to Table 5 to Code 562 for logging into the PEMs database.

**Table 5.** Manufacturer Information

| # | Category | Information/Question |
|---|---|---|
| 1.1 | | Part number |
| 1.2 | | Function |
| 1.3 | General Information | Date code |
| 1.4 | | Package type |
| 1.5 | | Manufacturer |
| 2.1 | | Die process technology |
| 2.2 | | ESD sensitivity level |
| 2.3 | | Moisture sensitivity level |
| 2.4 | Part | Date of last die revision |
| 2.5 | | Date of introduction to the market |
| 2.6 | | Expected date for obsolescence |
| 2.7 | | Product storing policy (years to keep in stock) |
| 2.8 | | Packing parts for shipment, moisture control |
| 2.9 | | Type of molding compound and characteristics (glassivation temperature, CTE, flame retardant) |

Continued on next page.

**Table 5 (Continued).** Manufacturer Information

| # | Category | Information/Question |
|---|---|---|
| 3.1 | | Vendor facility (location) |
| 3.2 | Manufacturer | Point of contact for quality assurance |
| 3.3 | | Quality certification of the vendor (ISO 9000 or equivalent) |
| 3.4 | | Mask revision control |
| 3.5 | | Application support |
| 3.6 | | Part traceability |
| 4.1 | | Availability of Statistical Process Control (SPC) data |
| 4.2 | | What kind of 100% outgoing inspection and screening is used? |
| 4.3 | | Availability of test flowchart |
| 4.5 | Process | Availability of reliability and quality assurance handbook |
| 4.6 | | Average outgoing quality (AOQ) 1/ |
| 4.7 | | Major process capability indexes for the part (Cpk) 2/ |
| 4.8 | | Acceptable proportion of failures at high temperature measurements |
| 4.9 | | Radiation hardness of the process or of similar parts |
| 4.10 | | Are there any military parts manufactured using same technology? |

**Notes:**

1/ AOQ is the proportion of parts that are outside the manufacturer specification limits. Currently the quality assurance system employed by the most established PEMs manufacturers guarantees a minimum of a 3-sigma level process. This means that AOQ = 2,700 ppm or 0.27% of all shipped parts might have parameters out of the data sheet specification. In some cases this level of failures is below 0.1% and even less than two failures in $10^9$ parts for a 6-sigma manufacturer. However, the parts manufactured by a 6-sigma process have higher quality only when the parts are used and operate at relatively low temperatures. For example, a 6-sigma commercial product, when used in automotive applications, is considered a 3-sigma product.

2/ Cpk is a measure of how well the process fits within the specification limits. It relates process variations to the specification limits using a "natural tolerance", $3\sigma$, and is applicable only for normal distribution.
$Cpk = [\min(HSL - \mu), (\mu - LSL)]/(3\sigma)$, where HSL is the higher specification limit, LSL is the lower specification limit, $\mu$ is the mean value, and $\sigma$ is the standard deviation. Larger Cpk values indicate lesser variations in the process and more consistent quality of the product.

# 10. APPENDIX A. BASIS FOR GSFC POLICY ON THE USE OF PLASTIC ENCAPSULATED MICROCIRCUITS (PEMS)

Prepared by GSFC PEMs Team

**Discussion of Policy Content**

Allowance of the Use of PEMs

Goddard Space Flight Center (GSFC) is adopting the policy to allow the use of plastic encapsulated microcircuits (PEMs) in space flight applications in order to have access to the latest technology advances, which are offered in PEMs and only rarely in hermetic high-temperature packages. The use of PEMs in space applications can bring advantages to the application in terms of performance and part availability, but thorough evaluation of the thermal, mechanical, and radiation environment, together with qualification testing and screening, are generally required to ensure reliability.

Environmental Factors

In space environments, the advantages of PEMs are often accompanied by additional risks of failure. This is especially true in applications where PEMs encounter stresses (temperature extremes, vacuum conditions, radiation, etc.) outside the operating conditions for which they were designed. PEMs are typically designed to operate within two temperature ranges: -40 °C to +85 °C (industrial) or 0 °C to +70 °C (commercial) in contrast to military hermetic styles, which are generally rated from –55 °C to +125 °C. The PEMs manufacturer designs, selects materials, and tests parts to meet the needs of their primary customers (commercial high volume) and principal end-use environments (industrial or commercial), not for high-reliability space flight. PEMs are generally intended for use in benign environments, where failure in service can be mitigated by replacement, maintainability, or repairability.

The variety of materials and fabrication techniques that may be used in making PEMs represents a number of application concerns and reliability risks in space environments. Often, these materials and manufacturing techniques have little or no space flight heritage.

Typical environmental concerns for space flight include:

- Optical components are at risk of contamination from outgassing of the molding material in vacuum environments.
- Molding materials have varying glass transition temperatures that can affect their maximum testing and use temperature.
- Molding material dimensional creepage with respect to temperature and time may place stress on internal bonds and wires.
- Thermal cycling can generate mechanical stresses on bonds, die paddles, etc. as a result of Coefficient of Thermal Expansion (CTE) differences between materials.
- Molding material in PEMs is usually in contact with the die and may contain ions or be the source of secondary emissions that can influence radiation susceptibility of the die. These factors can result in PEMs packaged die having lower radiation tolerance than the same die hermetically packaged.
- Operation outside the device's nominal rated temperature range may result in rapid deterioration of package properties, weakening of bonds, mechanical overstressing of the die, etc.
- PEMs are all susceptible to moisture ingress and absorption but to varying degrees dependent on design, materials, and processing. While not a risk for corrosion or other deterioration in space vacuum, moisture can promote corrosion during storage and ground level processing as well as "popcorning" during soldering, if strict moisture controls are not enacted.

Other PEMs-Specific Reliability and Application Issues

High-volume PEMs parts have steadily decreasing time periods between their introduction and obsolescence. Various reports put the current time to obsolescence in the range of 9 to 18 months. Rapid obsolescence has a number of impacts for space flight applications. Reprocurement to cover shortfalls or test fallout may not occur before the parts are no longer available. Good experience on one project is not useful for another project with similar needs, if the parts are no longer available. Multiple spacecraft programs with builds spaced years apart require a one-time, multi-spacecraft buy or may require different parts for successive spacecraft.

Not only is rapid obsolescence an issue in itself, but it has also led to corresponding reduction in designed operational life of the die design. Reports say that PEMs designers are now operating on as short as a 5-year life expectancy. Design compromises, such as reduced metallization and oxide layer thicknesses, reduce costs but also reliability and life expectancy. It has been reported that mask changes can occur as frequently as once a month. Die shrink changes are known to have dramatically impacted radiation tolerance.

PEMs manufacturers generally utilize continuous improvement philosophies that result in frequent, unannounced changes to designs, materials, and processes. While improving

performance or cost for the target commercial applications, such changes can have unconsidered, negative impacts for space applications.

For high-reliability products, MIL specifications define the assignment of lot date codes and the composition of the corresponding lot. There is no such recognized definition for a PEMs lot; it is up to the manufacturer and the needs of their intended market. This situation results in traceability and lot sample testing concerns for the space flight user. It has been reported that as many as five distinctly different dies of the same function have been found in a single PEMs lot. In addition, a single lot of PEMs can be processed in a number of die fabrication facilities and packaging and test houses throughout the world. PEMs of the same nominal device type, but manufactured through different flows in different facilities, can be intermixed and marked with the same lot identification.

Counterfeit parts are an increasing problem in the semiconductor market, particularly regarding PEMs. Such parts have an identical or near-identical appearance to genuine parts but are known to have substandard quality, reliability, and performance. It is essential to evaluate each lot of parts and to use reputable distributors for PEMs in order to reduce the risk of purchasing counterfeit parts.

Rationale for User-Imposed Qualification Testing and Screening

PEMs are not governed by strict military standards that require inspection of the die for workmanship flaws and the performance of burn-in on each device to remove early random failures. In lieu of piece part testing, PEMs vendors typically employ various sample-based techniques for calculating reliability. Testing may include proprietary testing regimes and employ unique rules governing sample sizes or the exclusion of failures from reliability calculations. These variations can make it difficult to compare PEM reliability data from vendor to vendor, let alone from PEMs to hermetically sealed parts.

For these reasons, it is not prudent to rely solely on unvalidated reliability data from PEM vendors. Screening of PEMs is essential before they are inserted into most flight hardware. The most important element in screening for reduced reliability risk for PEMs is burn-in.

Burn-in at the piece part level addresses infant mortality, which represents a significant problem for space applications and provides some insight into lot reliability and quality. If burn-in at the parts level is not performed, these needs must be addressed by another test approach agreed to by the project, such as board-level burn-in, or board/box-level environmental stress screening.

The argument that burn-in of PEMs should be avoided as it reduces the total ionizing dose (TID) resistance of PEMs should be rejected unless solid evidence is produced to support the claim. Most studies have shown burn-in to have an impact of 500 Rads or

less. To properly evaluate TID of burned-in parts, the TID test samples must be burned-in prior to testing.

Radiation lot acceptance testing (RLAT) of PEMs should be performed independently of any data that may exist for equivalent or similar hermetically sealed devices, and should be performed under the direction of the project radiation specialist. This is necessary as market conditions may drive unannounced process changes, creating differences in radiation response. It may be possible to dispense with single-event qualification of the PEM if data exist for the hermetic device. However, because PEMs are passivated with nitride layers, which are known to be responsible for TID sensitivity to pre-irradiatiation elevated thermal stresses (PETS), TID characterization should always be independently performed.

**Testing and Qualification**

Testing and qualification of EEE parts for space applications are usually performed to requirements specific to the risk level desired for the application. **Three risk levels are currently defined for NASA GSFC Projects.** **Risk Level One** has the lowest inherent risk and is intended for critical applications such as single-string, single-point failure and mission-essential functions. **Risk Level Two** has an increased risk and is intended for general-purpose spaceflight applications, although use in single-string and single-point failure applications may be permissible with project approval. **Risk Level Three** has an unknown risk due to the lack of formalized reliability assessment, screening, and qualification, and due to unreported and frequent changes in design, construction and materials. These inherent risk levels can be modified by additional testing such that level 3 parts can be elevated to level 2, and level 2 to level 2+. Upgrading to level 1 is theoretically impossible due to lot-specific controls imposed during level 1 manufacturing that cannot be imposed once the part has been finished.

Testing of PEMs should be tailored to the application and based on such factors as manufacturer history, analysis of materials, flight history, technology maturity, application criticality, and redundancy.

Basic Screening

Minimum additional testing for PEMs is established in GSFC EEE-INST-002 for mission risk levels 1, 2, and 3. A flow chart of the PEM evaluation process is shown in Figure 5.

Basic process flow:

- External visual inspection for workmanship defects such as bubbles or voids in the plastic package, separation of the package from the terminations, lead corrosion, etc.

- Radiography and C-mode Scanning Acoustic Microscopy (C-SAM) to inspect for swept bond wires, delaminations, voids, damaged or displaced die, mixed die sizes and shapes, etc.
- Functional testing to ensure parts meet requirements over the full application range of temperature, power, frequency, voltage, etc.
- Destructive physical analysis (DPA for PEMs) on samples from each lot to inspect for internal workmanship, bond pull, step coverage, die passivation, metallization voids, corrosion, contamination, etc.
- Radiation testing on samples from each lot. Each lot needs to be characterized for TID, single event effects (SEE), and displacement damage from charged particles.

Qualification

Qualification is required on a lot-by-lot basis unless objective evidence is provided that qualification data for a previous lot of the same or similar devices is applicable to the lot in question. When qualification testing is required, GSFC EEE-INST-002 defines risk-level-specific requirements.

Typical qualification flows include:

- Operational life test to simulate performance under application conditions and duration; may also be used to estimate life failure rate.
- Highly accelerated stress testing (HAST) subjects parts to high levels of temperature and humidity to accelerate destructive processes such as corrosion, delamination, and die attachment failure detectable by post-HAST DPA. Preconditioning of the samples that includes solder exposure is recommended.

Additional Testing to Lower the Risk of PEMs

In addition to the basic process flow described previously, the following additional tests shall be performed as required by GSFC EEE-INST-002 and as tailored to the PEM for its application, based on project requirements:

- Temperature cycling to excite material CTE mismatches and stress wirebonds, die attachment, etc.
- HAST or temperature humidity bias to evaluate package integrity.
- Burn-in for longer duration or at higher stress levels than the basic requirement.
- Post-test analysis consisting of PEMs specific DPA. CSAM may also be required.

Exceptions to Testing

Reductions to the testing listed in EEE-INST-002 may be permitted with project approval on a case-by-case basis, where it can be demonstrated that:

- Existing test data for the delivered lot date code demonstrates acceptable results.
- Use of PEMs represents low risk of functional loss should the part fail. Low risk is defined as low application criticality or low potential for loss based on such things as light duty cycle, benign environment (minimal temperature extremes, radiation exposure, etc.), more than one redundant circuit, short mission life, and low mission cost.

All rationale for such exceptions must be documented.

**Age Control**

Due to molding material creepage, risk of corrosion, material aging, etc., it is necessary to limit the age of PEMs to no more than 3 years from date of manufacture to date of installation, unless otherwise permitted by the project. Exceptions for age control may be granted by the project based on a need for the performance characteristics of older codes, or to use PEMs in inventory that is no longer in production.

**Recommended Processing for Storage and Use of PEMs**

- PEMs must be baked out prior to storage and prior to use in order to drive out absorbed moisture from the plastic molding material. Storage should be in dry environments (Nitrogen purged) at room temperature.
- The developer shall clean and dry boards using solvents and baking methods that will not risk compromising the reliability of parts or boards.
- The terminations of PEMs should be pretinned using tin–lead solder to reduce the risk of tin whisker growth or to remove gold plating. PEMs typically have pure tin-plated terminations, which are a risk for tin whisker growth and subsequent system failure due to shorting or plasma arcs. Alternatively, PEMs may be available with gold-plated terminations, which are at risk for failure due to gold embrittlement.
- After installation and cleaning, the application of conformal coating to the devices is recommended to minimize re-absorption of moisture and to further reduce the risk of tin whisker growth.

**Use of Off-the-Shelf Assemblies Containing PEMs**

Use and function of off-the-shelf units or assemblies that contain PEMs should be analyzed for mission criticality. When loss of off-the-shelf units does not compromise mission success, on a case-by-case basis, these units may be considered exempt from additional PEMs testing requirements, subject to approval by the project. However, additional unit-level testing, such as thermal cycling or thermal vacuum testing, may be directed by the project in lieu of additional part-level screening.

When failure of such units represents significant compromise to mission success, an analysis of the parts used within the units shall be performed. The parts shall be evaluated for screening compliance to GSFC EEE-INST-002, and will include a radiation analysis. Pending the results of this investigation, units may be required to undergo modification for use of higher reliability parts, additional shielding, or replacement with radiation-tolerant parts. When no high-reliability parts are available, additional testing of the unit may be required. All parts upgrading or additional testing shall be subject to project approval.

If a "high-risk" designation is not acceptable for the application, then additional screening must be performed to ensure that the PEMs are consistent with a medium-risk or low-risk level as defined in the project MAR and GSFC EEE-INST-002.

**NASA Reference Documents**

Goddard EEE-INST-002 *Instructions for EEE Parts Selection, Screening, Qualification, and Derating*

Rose, Virmani, and Kadesch (Goddard) *Plastic Encapsulated Microcircuit (PEM) Guidelines for Screening and Qualification for Space Environments*

S-311-M-70 *Specification for Destructive Physical Analysis*

NEPP Document TR04-0600 *PEM Derating, Storage, and Qualification Report*

IPC-SC-60A *Post-Solder Solvent Cleaning Handbook*

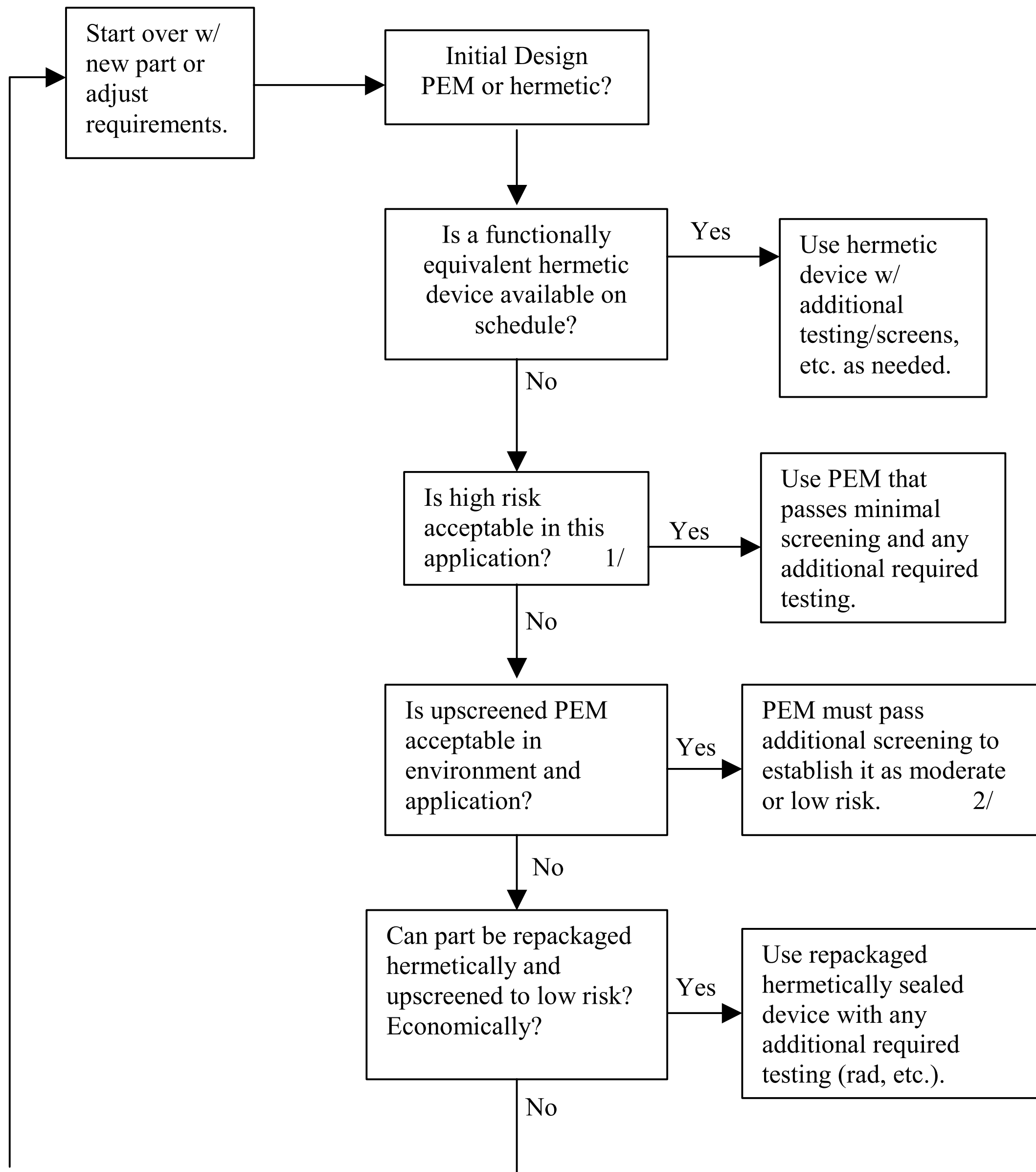


**Figure 5.** PEM Evaluation Process

**Notes:**

1/ High risk may be acceptable if the impact of part failure on achieving mission goals is minimal.

2/ Additional screening performed in accordance with GSFC 311-INST-001, or at project direction for the appropriate risk level.

# 11. APPENDIX B. PRODUCT ASSURANCE METHODOLOGY

Background. The product assurance methodology employed by PEM manufacturers is sufficient to meet most commercial users' needs. However, this system is significantly different compared to military and space-grade parts qualification systems used for providing high confidence in parts quality for high-reliability applications. These differences in approaches result in uncertainty in the reliability of PEMs, and require the end user to perform additional qualification, screening, and analysis of the part to compensate for reduced testing by manufacturer.

General. The classic bathtub curve (see Figure 1, Section 1) consists of three regions: infant mortality, useful life, and wear-out. The infant mortality failures are induced by manufacturing defects and are related to shortcomings in the process control (quality failures). The wear-out failures are inherent to the processes used, materials, and design of the part. For PEMs, these failures could be due to the die-related and package-related limitations. The first group of limitations is similar to the limitations of high reliability parts; e.g., time dependent dielectric breakdown (TDDB), electromigration, hot electron effects, and so on. The second group is specific to PEMs and could be due, for example, to corrosion of metallization in moisture environments, wire bond or die fracture during multiple temperature cycling, and other package-related degradation mechanisms.

The infant mortality period, $t_1$, may last typically for a few months under normal operating conditions and is characterized by decreasing failure rate. The useful life period, $t_2$, lasts normally from 10 to 25+ years and varies significantly depending on the device technology, the level of stress during operation, and the wear-out degradation process.

Manufacturers Methodology. Product assurance methodology of most PEM manufacturers is based on the philosophy that the reliability must be designed or built into the manufacturing process rather than achieved by 100% testing of products. According to this methodology the emphasis is on increasing the yield and reducing the likelihood of defective parts production by tight process control rather than on detection of failures during electrical testing. As a result, for many manufacturers outgoing screening of commercial PEMs usually consists of 100% external visual inspection, and room-temperature functional and parametric electrical measurements. High-temperature measurements are typically performed on a sample basis and allow a certain level of parametric failures. Quality and reliability data provided by most PEM manufacturers are mostly estimates based upon the history of performance of a group of parts manufactured by similar processes and encapsulated in similar packages. Design and manufacturing of commercial PEMs is mostly driven by a faster time-to-market demand, and the product is often released without detailed qualification activities for economical reasons.

Goddard Space Flight Center, Code 562. Recommended product assurance system for PEMs is shown in Figure 2.

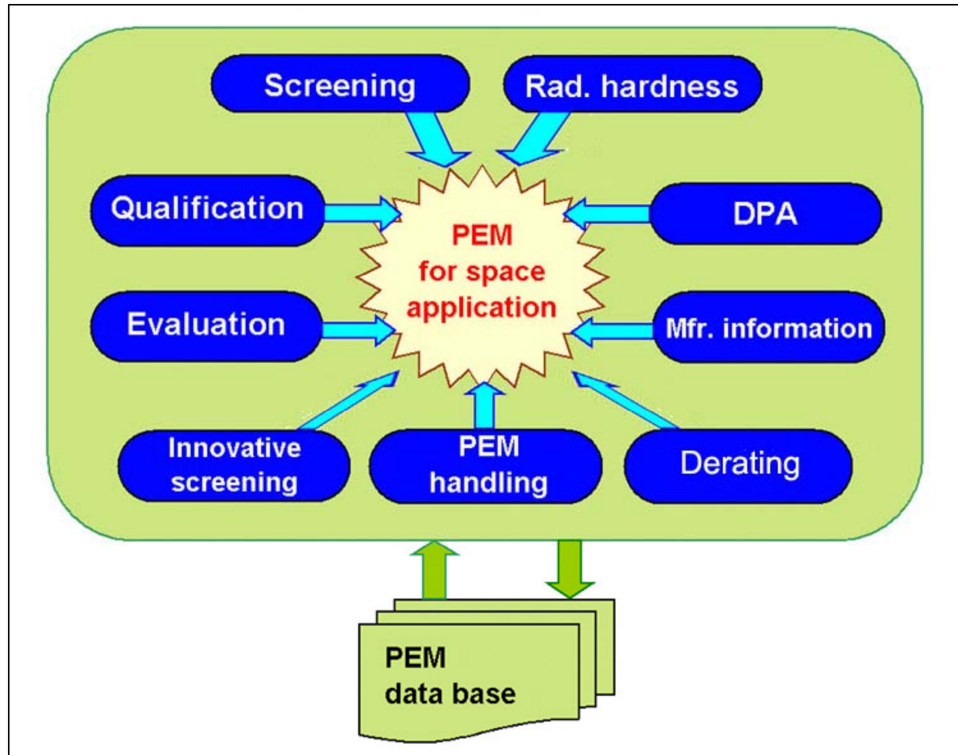


**Figure 6.** GSFC Product Assurance System for PEMs

Every element of the product assurance system has its limitations, and only a combination of all available means can provide cost-effective and comprehensive assessment of the quality of the parts and guarantee high reliability for space applications.

Creating and maintaining a database with the results of PEMs qualification and analysis performed for Goddard Space Flight Center (GSFC) projects is an important element in the development of the knowledge-based system for quality assurance of PEMs. Reports with analysis and summary of the test results, as well as recommendations to improve the qualification system, will be released annually by Code 562.

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**13. ABSTRACT** *(Maximum 200 words)*

Potential users of plastic encapsulated microcircuits (PEMs) need to be reminded that unlike the military system of producing robust high-reliability microcircuits that are designed to perform acceptably in a variety of harsh environments, **PEMs are primarily designed for use in benign environments where equipment is easily accessed for repair or replacement.** The methods of analysis applied to military products to demonstrate high reliability cannot always be applied to PEMs. This makes it difficult for users to characterize PEMs for two reasons:

1. Due to the major differences in design and construction, the standard test practices used to ensure that military devices are robust and have high reliability often cannot be applied to PEMs that have a smaller operating temperature range and are typically more frail and susceptible to moistureabsorption.
2. Unlike the military high-reliability system, users of PEMs have little visibility into commercial manufacturers' proprietary design, materials,procedures. There is no central authority that monitors PEM commercial product for quality, and there are no controls in place that can be imposed across all commercial manufacturers to provide die traceability, and production processes and confidence to high-reliability users that a common acceptable level of quality exists for all PEMsmanufacturers.

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