AEROSPACE REPORT NO.
TOR-2013-00296

Preventive Measures Based on Hybrid and Integrated Circuit Lessons Learned

June 3, 2013

Lawrence I. Harzstark
Electronics Engineering Subdivision
Electronics and Sensors Division Office

Prepared for:

Space and Missile Systems Center
Air Force Space Command
483 N. Aviation Blvd.
El Segundo, CA 90245-2808

Contract No. FA8802-09-C-0001

Authorized by: Engineering and Technology Group

Developed in conjunction with Government and Industry contributions as part of the U.S. Space Programs Mission Assurance Improvement workshop.

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Approved by:

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Acknowledgments

This document has been produced as a collaborative effort of the Mission Assurance Improvement Workshop (MAIW). The forum was organized to enhance Mission Assurance processes and supporting disciplines through collaboration between industry and government across the US Space Program community utilizing an issues-based approach. The approach is to engage the appropriate subject matter experts to share best practices across the community in order to produce valuable Mission Assurance guidance documentation.

The document was created by multiple authors throughout the government and the aerospace industry. We thank the following contributing authors for making this collaborative effort possible:

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Marie Pelvay	The Boeing Company
Andrew Moor	Johns Hopkins University Applied Physics Laboratory
James Heckman	Ball Aerospace and Technologies Corporation
Louis D'Angelo	Lockheed Martin Corporation
Robert Beeston	Northrop Grumman Aerospace Systems
Yaana Allen	Orbital Sciences Corporation
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Abstract

During the development and manufacturing production of space systems, programs have experienced electronic device anomalies and failures that have impacted program execution and represent risk to mission success. Many of these issues and concerns have been observed in complex microelectronic devices identified as hybrids and monolithic integrated circuits (IC).

The analysis to determine root cause can reach into layers of the supply chain and may not be evident to the IC/Hybrid suppliers throughout their design and production lifecycle. Prime contractors and unit suppliers frequently lack insight into IC/Hybrid product design and verification details prior to an anomaly. Insufficient root cause and corrective action (or sharing of this information) inhibits the proliferation of lessons learned and effective industry wide corrective action.

This document summarizes the activities of the Mission Assurance Improvement Workshop (MAIW) team to review and analyze the industry National Security Space Advisory Forum (NSSAF) Alert System (which is sponsored by the Space Quality Improvement Council (SQIC)) for root cause and corrective actions relative to hybrid and monolithic integrated circuits and develop lessons learned that could provide information across the industry to decrease the amount and frequency of anomalies and failures observed with these commodity types.

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Executive Summary

Based on the concerns and observations by government and management of industry contractors of hybrid and integrated circuit anomalies and problems identified during programs, the Mission Assurance Improvement Workshop team was tasked with performing an independent assessment/peer review of the most recent hybrid and integrated circuit entry submittals to the National Security Space Advisory Forum (NSSAF) Alert database and evaluating the root cause and corrective actions to determine potential trends for lessons learned.

Issues from NSSAF Alert Database

The NSSAF database was selected as the scope of data since all information included in that database has been pre-approved for discussion by all industry partners through the signature approvals of non-disclosure agreements from the Space Quality Improvement Council member companies.

- **Time frame of Issues**: NSSAF Alerts from approximately the last four years were selected so that the most recent issues are assessed.
- **Quantity of NSSAF Issues**: Thirty-two NSSAF alerts from this time frame were identified as relating to hybrids or ICs.

The industry partner responsible for the entry presented the information to the team with detailed discussion. A matrix was developed to capture and document the information including any deficiencies in the original write-up and potential lessons learned.

Issues from non-NSSAF Database Sources

As information was reviewed, it became clear that a greater volume of data was needed in order to determine if trends existed and be able to identify lessons learned. Each team partner was requested to review their in-house databases, sanitize the information, and present to the team.

Overall Conclusions and Lessons Learned

Based on the total list of observed issues, the final matrix includes 76 issues from all sources (see appendix D). The data did not identify any specific issue that would decrease failures and anomalies but significant lessons learned were able to be developed in the form of 7 checklists (see Appendix E) for use during design reviews, manufacturing readiness reviews, test reviews, Worst Case Circuit Analyses, new technology and general engineering principles. They can also be used for detailed audits of the manufacturing floor. The team believed that with complex electronic devices, there will always be issues, but they can be minimized with the implementation of the checklists and other recommendations.

Based on the total items of issues reviewed, evaluated for cause/corrective action, the following conclusions are reached with the applicable lessons learned defined and incorporated into several checklists to be utilized as supplements to the standard documents/questionnaires and checklists used by the contractors.

- **Conclusion**: Of the seventy-six anomalies reviewed by the team, forty-one (57%) were categorized as manufacturing anomalies.
  - **Lessons Learned**: The single most important manufacturing lessons learned item is the importance of performing manufacturing and/or design-for-manufacturing reviews with

the Prime at the hybrid and IC supplier to validate that the parts, materials and processes being used have been properly selected, qualified, and evaluated for manufacturing methods and all methodology and approaches are appropriate.

- **Conclusion**: The two most significant design issues observed were related to incomplete characterization of devices and not performing adequate design reviews.
  - **Lessons Learned**: A more thorough design review would have detected the relevant issues that arose. Additional information added to the checklists would be useful.
- **Conclusion**: The two most significant test issues observed were electrical overstress induced during test and failures due to out-of-test limits.
  - **Lessons Learned**: Perform a test readiness review and include evaluation of test procedures including test stimulus and test fixtures and re-evaluate criteria used for Destructive Physical Analysis.
- **Conclusion**: In general, radiation issues manifested themselves during acceptance radiation testing including over-exposure during real time x-ray.
  - **Lessons Learned**: Having SMEs with the right expertise be involved with the supplier analyses as well as the design process ensuring that lessons previously learned are folded back into the design review process.
- **Conclusion**: Better communication across the industry is needed concerning sharing issues, corrective actions, and lessons learned to improve the quality and reliability of procured microelectronic devices.
  - **Lessons Learned**: A semi-annual Hybrid/IC Failure Summit meeting should be convened to share information and should include manufacturers, first-tier (typically subcontractors) and second-tier (typically primes) customers.

The remainder of this report describes the details of the issues reviewed from the NSSAF and other databases and presents the recommended lessons learned. It also presents a summary of the NSSAF process and some shortcomings observed and potential recommendations for improvement identified by the team.

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1. Introduction

The Government Industry Data Exchange Program (GIDEP) has been in place since 1959 and is used by government and industry to share issues, problems, corrective actions, and lessons learned. As the GIDEP system comprises formally documented, reviewed, and vetted issues and recommendations, notification of an issue is not immediate. And due to their broad distribution well beyond the national space community, alerts may contain only conservative detail. In order to facilitate earliest possible industry awareness of a potential risk, a separate system was developed and deployed by GIDEP and the SQIC in 2005 to allow contractors to share information between them with tightly-controlled distribution. The system is controlled by a non-disclosure agreement and allows the quick dissemination of information between the NSSAF Prime contractors. Since its inception, this system has improved the quick dissemination of information regarding issues with potentially industry-wide impact, but it has been noted that modifications could lead to a more effective system with greater long-term impact, particularly in the area of complex electronic assemblies.

Management and program managers (both government and contractors) have experienced cost and schedule delays due to apparent problems caused by electronic parts. Specifically, hybrids and integrated circuits have been identified as one of the leading causes of part anomalies observed. The steering committee of the Mission Assurance Improvement Workshop (MAIW) discussed various ways and means for general issues of hybrids and integrated circuits to be communicated between prime contractors to allow the industry to improve and provide a better and more reliable product to the customer. The Steering committee first wanted to understand if the hypothesis is correct that there are many issues associated with hybrids and integrated circuits and if issues are being shared so that cause and corrective actions can be implemented globally. Secondly, the concept of how to share the information to reduce issues needed to be addressed. Based on this perceived problem, an MAIW task was developed to validate the premise and provide lessons learned and potential recommendations for future implementation.

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2. Purpose and Scope

The purpose of this task group is to better understand recent global issues being observed by government and industry in hybrids and integrated circuit devices, determine the best means of communicating these issues, and improve the benefits of corrective/preventive action. In addition, the development of checklists which allow the experiences and lessons learned to be documented and utilized to the full advantage for the benefit of the customer base.

2.1 Objectives:

The objectives of this MAIW task are to:

- Utilize the approved NSSAF/SQIC Alert database to validate/peer review the existing root cause and corrective actions for the set of most critical recent hybrid/IC issues
- Identify root cause and corrective action, if any, and the reason for any information deficiencies (single program, proprietary constraint, etc.)
- Formulate key, broadly applicable, lessons learned
- Make recommendations for additional part standard requirements as appropriate
- Propose method for continuous revisit and update of released Alerts so that root cause and corrective action results for future IC/Hybrid issues are effectively shared across the industry
- Develop checklist(s) that incorporate lessons learned and can be utilized by industry to minimize problems observed with hybrids and integrated circuits

2.2 Team Formation

The MAIW steering committee identified representatives from each of the participating industry partners. Weekly telecons and periodic face-to-face meetings were convened to share experiences between contractors.

Table 1. “Hybrid/IC Lessons Learned and Corrective Action” Team Composition

Aerospace Corporation	Larry Harzstark, Gary Schipper
John Hopkins University Applied Physics Lab	Andrew Moor
Boeing Space & Intelligence Systems	Joan Lum
Boeing Research & Technology (BR&T)	Marie Pelvay
Ball Aerospace & Technologies Corp.	James Heckman
Lockheed Martin Space Systems Company	Louis D’Angelo
Orbital Sciences Corp.	Yaana Allen
Northrop Grumman Aerospace Systems	Robert Beeston
Raytheon Space and Airborne Systems	Bill Rowe

Photo 1 Team Members
Left to Right: Pelvay, Lum, Moor, Harzstark, Rowe, D’Angelo, Beeston (not shown Allen, Schipper, Heckman)

3. Assessment of Issues in NSSAF Database and Other Sources

In order to capture and evaluate the current issues, the NSSAF Alerts released from the 4Q08 to 2Q12 were selected as the reference time frame. Team members were briefed and operated under the non-disclosure agreements necessary to share information in the NSSAF database. Additional sources (listed below) of industry Hybrid/IC issues were also reviewed in an effort to identify all significant issues of the past four years. These other sources are discussed in 3.1.2.

- Released NSSAF Alerts
- Other Published Industry Alerts (NASA/MDA/PUMP)
- Participant Prime Contractor Unpublished Sources

3.1 NSSAF Alert Review Process

Thirty-two NSSAF Alerts pertaining to hybrids/ICs with sufficient information to evaluate were released between 4Q08 and 2Q12. These were originally submitted by SQIC member Primes as follows:

Table 2. NSSAF Alert Submittals Pertaining to Hybrids/ICs 4Q08 – 2Q12.

NSSAF-member Prime	# Hybrid/IC Alerts Submitted
Lockheed Martin	15
Boeing	6
Northrop Grumman	5
Raytheon	2
Orbital	2
Ball Aerospace	1
The Aerospace Corp.	1

Each identified hybrid/IC Alert was discussed with the MAIW topic team based on the research performed by the representative from the submitting Prime. Brief discussion of the issue was followed by the team consensus classifying each issue into the following areas to facilitate determining commonality between issues.

- Issue Category
  - Manufacturing
  - Design
  - Test
  - Other
- Level where failure occurred
  - At supplier before shipping
  - By end user at Receipt
  - After assembly into next level
- Root cause reflected in latest alert

- Final root cause assessment (if different than reported in Alert)
- Corrective action (and was corrective action effective?)
- Is the item a standard product or is it a custom device?
- Did Prime procure hybrid/IC or did subcontractor procure?
- Is the item a hybrid or an IC?
- Is the item RF or not?

Since NSSAF Alerts are published to notify multiple user companies of issues, they generally include supplier names and usually offer at least preliminary root cause and corrective action. The team members were generally able to share reasonable detail since NSSAF Alerts are under a pre-existing proprietary agreement between all the members. After reviewing and classifying all the NSSAF Alerts, it was determined that additional hybrid/IC issues should be sought out to ensure that important and representative issues are captured.

3.1.1 Review of NSSAF Alerts for Common Issues

Figure 1 shows some of the trends from review of the data performed by the team. Half of the issues were identified as primarily manufacturing-related. The data was examined for other trends in the identified categories and no significant trends were found.

The number of Hybrid Alerts vs IC Alerts in the NSSAF database was approximately equal.

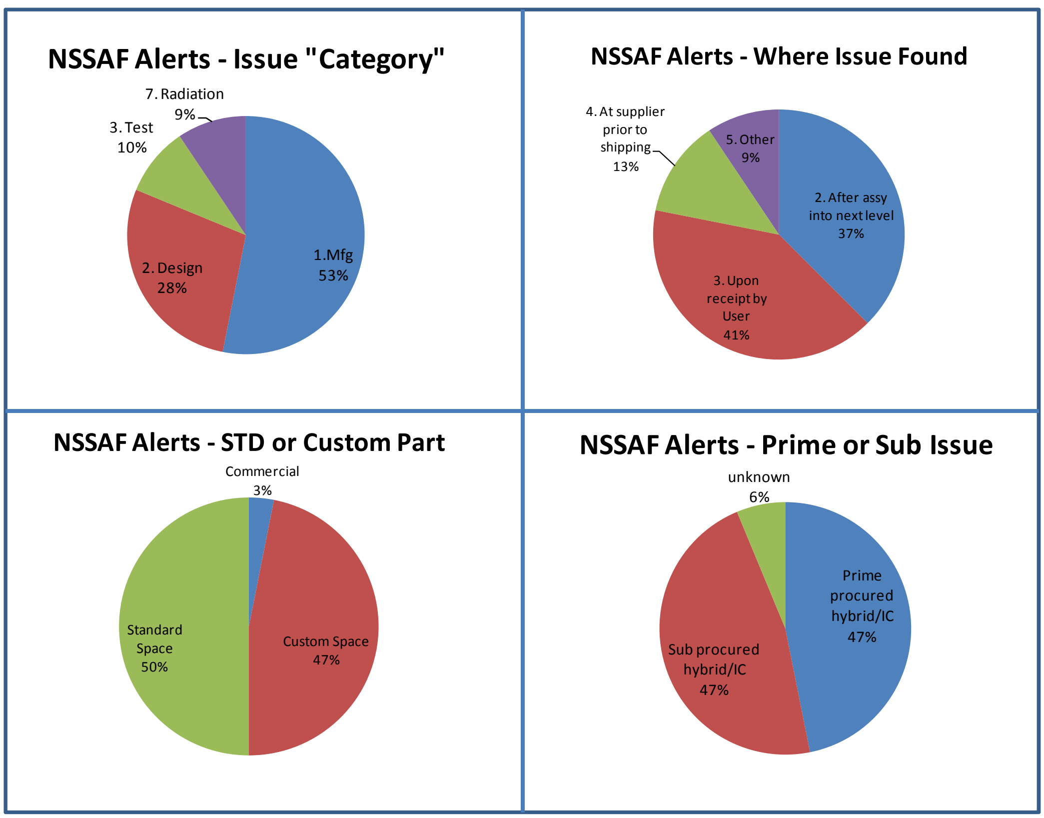

Figure 1. Analyses of the 32 NSSAF alerts regarding hybrids and ICs.

3.1.1.1 Most Frequently Named Suppliers

Of the 32 NSSAF Alerts applicable to hybrids and ICs, 23 different suppliers were identified. Of these 23 suppliers, the most frequently named supplier was indicated in 5 Alerts. Another supplier was named in 4 Alerts, 3 suppliers named in 2 Alerts, and the remainder of the suppliers were named in only 1 Alert each.

Table 3. Most Frequent Suppliers from Hybrid/IC NSSAF Alerts (4Q08 – 2Q12)

Suppliers Named in 32 hybrid/IC NSSAF Alerts	# NSSAF Alerts	# Mfg – related	#Design – related	# Test – related
Supplier #1	5	1	3	1
Supplier #2	4	4	0	0
Suppliers #3, #4, #5	2 ea.	4	2	0

The nine Alerts from the two most frequently named suppliers were all Hybrid issues (as opposed to ICs). The products manufactured by the top two suppliers are complex.

Regarding Supplier #1, the supplier was mentioned five times but nothing was really common between the five alerts. They ranged from omission of a hydrogen getter, to an overstress during electrical test that was not detected. Three of the five problems were classified as design issues with the other two being test and manufacturing. This possibly points to a weakness of the design reviews by this supplier. But given these are RF hybrids and RF performance tends to be sensitive to smaller variations than low frequency hybrids, this may be the real issue rather than a specific problem with the design reviews.

Regarding Supplier #2, three of the four items are all associated with rework processes used on DC-DC converters. These are all basically manifestations of the same problem. The root cause for the fourth problem (not realizing the issue mentioned could impact more parts than specified in the original notice) is more of a user problem than a manufacturer problem.

There does not appear to be evidence in the 32 alerts reviewed to support a claim one supplier requires significantly more attention than another.

3.1.1.2 Root Cause and Corrective Action Review for NSSAF Alerts

Of the 32 NSSAF Alerts applicable to hybrids and ICs, only 15 included at least a preliminary root cause in the Alert. Ten of those without root cause in the original Alerts had a root cause reported by the team member representing the originating Prime (i.e., a root cause was eventually found though Alert was not updated to include it).

Of these 25 with root cause captured, corrective action was reviewed. In 11 cases, the stated corrective action either involved implementing a test to screen out parts with the offending issue or the parts are no longer used. This is not a true corrective action as it indicates true root cause may not have been found. In the 14 remaining Alerts with root cause identified, 1 had unknown corrective action and 13 described process change, specification change or test procedure change to correct the root cause. See Figure 2 for more detail.

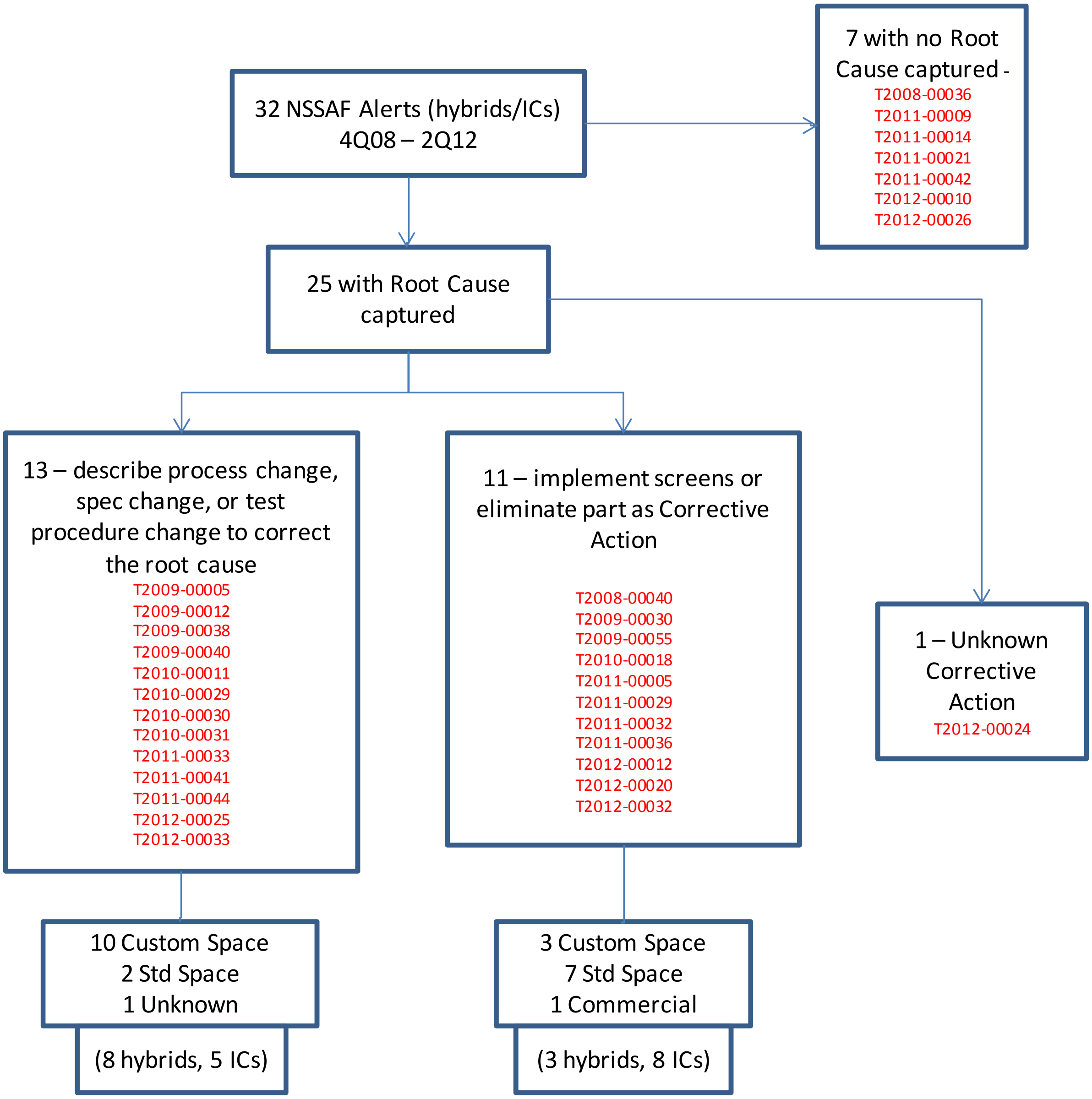

Figure 2. NSSAF alerts with root cause identified were reviewed for corrective action. (T2XXX numbers indicate ID# of NSSAF Alerts)

In the case of the 11 Alerts where "Corrective Action" was a test to screen out the offending parts from the lot or eliminating/replacing the part – there was discussion amongst the team whether root cause had been truly identified. Some barriers to getting to true root cause included the following:

- Supplier does not agree with Prime's assessment of root cause and is unwilling to invest resources in further testing or process changes
- Supplier and/or Prime is unable to invest the time necessary to determine true root cause so test is specified to screen out suspect product
- Supplier is actively working the issue with Prime - sometimes it does take time to come to root cause and the supplier wants to avoid broadcasting the issue prior to having a full understanding of the problem.

- Program schedule does not allow comprehensive root cause analysis and screening adequately mitigates program risk

After reviewing and classifying all the NSSAF Alerts, it was determined that a larger population of hybrid/IC issues may illuminate common root causes and contributing factors. The following paragraphs describe other sources sought out to ensure that the most important issues were captured.

3.1.2 Other Published Industry Alerts

To scope additional issues, team members reviewed and classified MDA Alerts, NASA Alerts and PUMP Industry Alerts in the same manner as NSSAF Alerts. For the purposes of this review, issues regarding counterfeit hybrid/ICs were not considered of interest. GIDEP Alerts were not included since they are primarily submitted by suppliers, and this review was focused on contractor/government perceived issues.

Table 4. Hybrid/IC Issues from Industry Alerts

Agency Originating Alert	Alert Type	Total Alerts released 4Q08-2012	# Hybrid/IC Alerts Released	# Hybrid/IC Alerts reviewed in this report	% of Alerts that were Hybrid/IC
Space Quality Improvement Council (SQIC)	NSSAF 1/	200	34	32	16%
Missile Defense Agency (MDA)	MDA 2/	48	5	2	4.1%
Aerospace Corp.	PUMP 3/	128	6	4	3.1%
NASA	NASA 4/	18	0	0	0%

1/ of 34 NSSAF alerts released on hybrid/ICs, one was withheld by the originator, and one was a repeated issue
2/ of five alerts that were for hybrid/ICs, three were either for non-hermetic devices, or were too general to include
3/ of six PUMP Alerts released relating to hybrid/ICs, two were same issue as NSSAF Alerts.
4/ NASA Alerts released 4Q08 to 2Q12 were reviewed and none pertained to hybrids/ICs.

These alerts are created, ledgered, and tracked to closure within MDA and NASA and The Aerospace Corporation for the purpose of ensuring that potentially systemic problems are identified, shared, and acted upon to mitigate program risk.

3.1.3 Unpublished Prime Issue Databases

After consulting with the MAIW steering committee, additional input was requested from participating Primes to uncover any significant issues that may not have been “common” enough to publish as industry NSSAF Alerts. As noted in Table 5, two SQIC member contractors (Boeing and Raytheon) provided additional issues from their internal failure analysis databases that were not previously reported as NSSAF Alerts. Since APL is not a contractor, they do not participate in SQIC, but they also provided failure data from incoming inspection anomalies as well as failure analysis. These issues provided by the two contractors did not meet their internal guidelines for being released as NSSAF Alerts for one of the following reasons:

- Root cause does not relate to process/test for supplier's industry standard product line (applicable to contractor specification only),
- Anomaly was a “one of” and/or low probability event (as defined by internal CAB or FRB, as applicable)

- There was no non-conformance – issue was due to a parameter not specified in the SMD that was later added by DLA as corrective action
- Issue was found on an airborne program, and based on the issue not deemed globally applicable to space community

Though each Prime was asked to share, there were some proprietary concerns which resulted in supplier names and in some cases corrective action being WITHHELD. Though still useful, this reduced the ability to analyze the data.

Table 5. Hybrid/IC issues from Participants' Internal Databases (4Q08 – 2Q12)

Prime	Participant's internal issue Source	# Hybrid/IC issues shared
Applied Physics Lab (APL)	Incoming inspection (DPA rejects) and also Failure Analysis	17
Boeing	Failure Analysis database – only failures discovered at unit test and above. Primary failures only.	11
Raytheon	Failure Analysis database – only failures discovered at unit test and above. Primary failures only.	4 Space 6 Airborne

Note: Hybrid/IC issues found during DEVELOPMENT are generally not in the population due to unavailability of this information based on being tracked apart from flight issues (especially when unit has not yet been delivered to Prime). There are also programmatic barriers that don't present themselves as actual part problems in built hardware, but may still cause a perception of part problems by the program.

Combining all sources there are 76 hybrid/IC issues that were reviewed. Items grouped under Manufacturing Issues, Design Issues, Test Issues and Other were analyzed by SMEs to determine common root causes, lessons learned, and where appropriate checklist items were generated to address noted deficiencies.

3.1.4 Manufacturing Issues – SME Review Results

Of the seventy-six hybrid anomalies reviewed by the team, forty-three (57%) were categorized as manufacturing anomalies. Of the forty-three, 17 were found in the NSSAF database, 25 were from company-internal information (approximately eight from each of two major primes and APL), and 1 was from MDA.

3.1.4.1 Manufacturing – Most Significant Actionable Issue

The single most important manufacturing lessons learned item is the importance of performing manufacturing and/or design-for-manufacturing reviews with the Prime at the hybrid and IC supplier to validate that the parts, materials and processes being used have been properly selected, qualified, and evaluated for manufacturing methods and all methodology and approaches are appropriate.

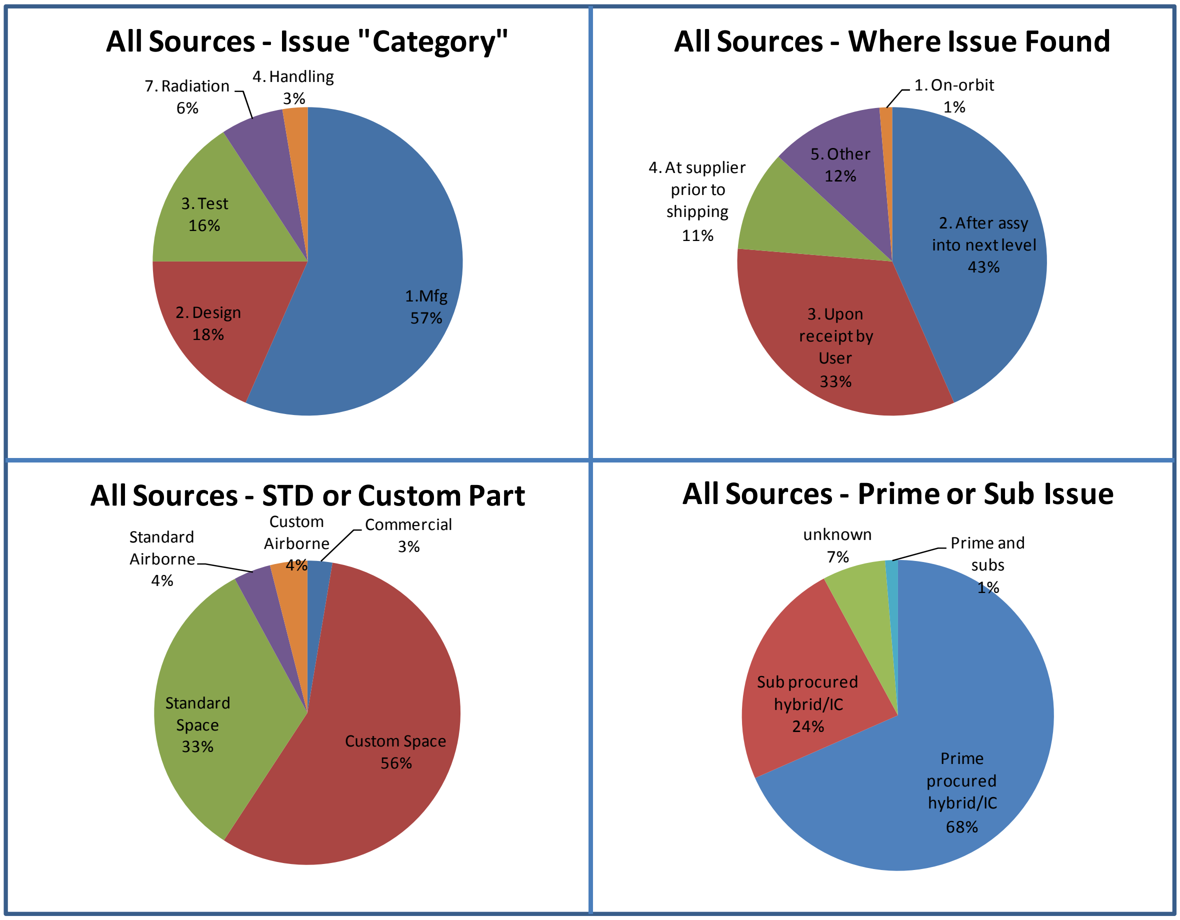

Figure 3. Analyses of the 76 issues from all sources regarding hybrids and ICs.

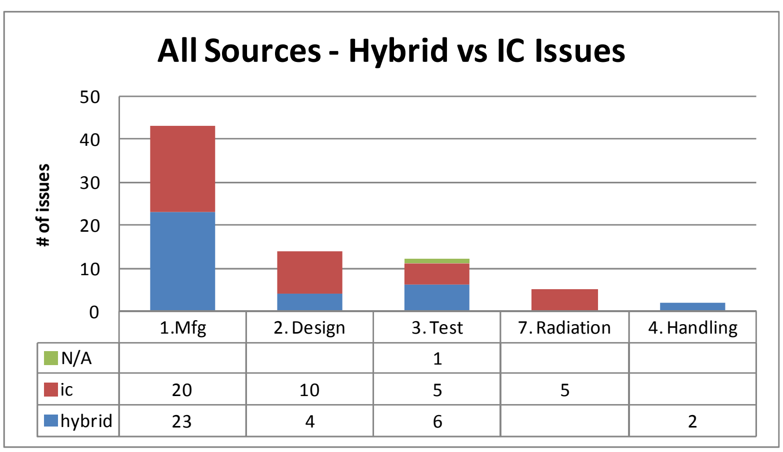

Figure 4. Quantity of Hybrid vs IC issues 4Q08 – 2Q12.

3.1.4.2 Manufacturing – Most Common Root Causes

The most common root cause of the manufacturing issues can be summarized as attention to detail for processes performed on a manual basis such as low volume hybrid die attach, sealing, etc. In the integrated circuit realm it would be process controls that have not been trended or corrective actions not implemented for trends observed.

The 43 manufacturing items were further categorized into ‘subclassifications’ – which are loosely correlated to process steps such as die attach, wire bond, PIND, lid seal, lead braze, soldering, resistor trim, etc. There were 21 different sub-classifications identified, and 9 line items did not have a sub-classification identified. No trending is able to be derived from sub-classifications, as they are defined. However; wire bonding, lid seal, and die attach epoxy related processes are approximately equal contributors to the most common root cause.

When separated into where the anomalies were found, the data showed:

- After assembly into next higher level hardware – 20 (46%)
- Upon receipt by user – 14
- Other – 6
- At supplier prior to shipping – 3

When the forty-three are sorted by custom vs. standard, the data showed:

- Custom space – 26 (60%)
- Standard space – 11
- Custom airborne – 2
- Standard airborne – 3
- Not defined/commercial – 1

When sorted by manufacturer, the data showed:

- 18 of 43 (42%) had a manufacturer listed, and only one manufacturer was listed more than three times; 25 (58%) had no manufacturer listed (information was withheld)

3.1.4.2.1 Minimize Manual Labor Content

The manufacturing lessons learned, which may be gleaned from the data and information available, are rather high level and generic. Hybrids are typically custom, small-volume, and highly specialized assemblies, comprised of equally specialized parts, materials and processes. They are predominantly produced by hand, using purely manual or semi-automated processes in small batches, often numbering only several to possibly dozens at a time, depending on the process. Fully automated processes are rare, though with proper qualification can be accepted by Prime contractors. Because of this fact, human error is frequently a leading proximate or contributing cause of a defect. Rework sometimes causes other issues not related to the process being reworked. Subject matter expert assessment of what is required and the potential risk could mitigate collateral damage.

The most actionable manufacturing issue to address is achieving better control of these manual processes, especially those which involve the use of epoxies, or where placement accuracy (i.e., wire bonding to very small areas) is critical. Integrated Circuit die are manufactured on highly automated lines and typically issues are not observed unless a major problem is uncovered and will usually affect the entire lot. The Integrated Circuit assembly process though can create similar issues as to the hybrid manufacturing process (i.e., wire bonding, die attach, package sealing, etc).

3.1.4.2.2 Early Detection

The best place to discover anomalies is obviously before the hybrids are shipped from the manufacturer, but this is certainly not possible in many cases, as many anomalies are latent. Methods to discover issues earlier in the cycle especially prior to assembly into the next higher assembly must be developed. One recommendation is to hold interim device (peer) review with SMEs before too far in process (i.e., before formal design review). Another approach is to test the design out on a surrogate like part, using materials from the same lot as production.

While from the data, only 10% of the manufacturing anomalies addressed herein were found at the manufacturer, it should be noted that the source databases for the reviewed information did not uniformly include vendor-identified anomalies, some only included failures at unit-level or above.

3.1.5 Design Issues – SME Review Results

Fourteen items from the database were identified by the team as being primarily design related. These items were discussed by SMEs from all the Primes who submitted them to discern the most impactful issues, root causes, and lessons learned in this area.

Data sources for the items identified as design issues were:

- NSSAF 9 items
- PUMPS 2 items
- MDA Alerts 1 item
- Contractor data bases 2 items

These design issues were grouped as follows

- Parts which were not adequately characterized for the application (5 examples)
- Custom parts (typically hybrids) which didn't get an adequate design review (4 examples)
- Problems with assembly of part (3 examples)

Two items were not included in the grouping above. In one case, the investigation had been halted before completely establishing root cause. Since root cause was not determined there is nothing to mine from this specific item as a "lesson learned."

The other item not included in the groupings above described a solderability issue specific to LCC packages. Studies have shown a combination of factors resulting from steam-aged LCC packages with gold finish failing the solderability test requirements of MIL-STD-883 Method 2026. DLA has proposed changing Method 2026 to allow for usage of an activated flux when performing solderability testing on these LCC packages. Since there are no reported failures of parts after installation due to this issue, there isn't a "lesson learned" here. However, it seems reasonable to add solderability to checklists as something to be considered when using LCC packages.

3.1.5.1 Inadequately Characterized for the Application (examples)

The five items considered not adequately characterized consisted of:

- Latch-up of a single pole double throw switch integrated circuit. The IC experienced latch-up when the switch input voltage was brought to within 1V of the negative supply rail. Maximum ratings specified for this IC allowed the input voltage to be as much as 1.5V more negative than the negative supply rail. The IC manufacturer confirmed the latch-up behavior and is re-designing the IC to avoid this problem. Meanwhile, a note has been added to the specification for this IC indicating the latch-up behavior.
- A GaAs MMIC was found to be more sensitive to ESD effects than realized. The solution was to handle all MMICs of that technology type as ESD Class 0.
- A voltage reference integrated circuit was found to oscillate with a shunt capacitance of 1 nF to 3 uF. Performance of this IC was tested with a 10 uF capacitive load. No restriction on capacitance was included in the specification. The specification has since been revised to state capacitance values from 1 nF to 3 uF should be avoided.
- The package lid of a hybrid amplifier package was changed from kovar to nickel. Usage of nickel lids required higher welding temperatures to achieve hermetic seals. This resulted in cracked substrates. The corrective action taken was to use kovar lids and lower welding temperatures.
- A die shrink of an integrated circuit created faster transistors in the IC resulting in logic gates being more sensitive to input noise both internal and external. This resulted in errors in the using assembly. Additionally, one lot was observed to have faulty performance when tested from 30°C to 60°C due to a race condition but correct performance outside of this temperature range. Corrective actions included revised screening at the manufacturer to prevent shipment of parts with the temperature sensitivity and improvements of the using assembly to reduce noise at the part inputs. This type of problem should have been detected if a complete characterization by the manufacturer had been performed.

The common thread in the items above is a difference between performance in parts as designed/built and performance indicated by specifications. In each case, this difference could have been found by more complete testing at the manufacturer prior to shipment or by the user prior to using in assemblies.

3.1.5.2 Inadequate Design Review (examples)

The four items considered not getting an adequate design review:

- Some voltage controlled oscillator hybrids built with GaAs devices known to be sensitive to hydrogen were built without a hydrogen getter. The requirement to have a hydrogen getter was flowed down to the manufacturer but not implemented by the manufacturer. This issue was found during a subsequent review by the user.
- Review of RGA data for several hybrids found high levels of hydrogen present in hybrids susceptible to hydrogen effects. It was determined that the hydrogen getters installed were not effective. Issue corrected by installing hydrogen getters known to be effective.
- Some voltage controlled oscillator hybrids were found to have excessive phase noise eventually leading to loss of lock. Investigation revealed normal operation caused the emitter-base junction

of some transistors to be in breakdown. This produces a gain degradation of the transistor (MacDonald effect) resulting in the degraded phase noise performance noted. The excessive voltage applied to the emitter-base junction of these transistors was missed during design reviews.

- Some hybrids intended for usage in space applications were built using ceramic capacitors with base metal electrodes. Capacitors built using base metal electrodes generally have thinner dielectrics than capacitors built using precious metal electrodes. Additionally, the base metals can oxidize during firing of the capacitors leading to failure mechanisms not found in capacitors built with precious metal electrodes. Consequently, usage of base metal electrode capacitors is not normally allowed in space applications.

There is an industry/supplier (JEDEC/G-11/) team addressing the requirements (design, construction, screening, qualification and quality conformance inspection) for space utilization of BME capacitors with the intent of developing a military specification for these capacitors.

In each case above, there was a known issue that could have been found by a more complete design review. Adding items to checklists used during design reviews should prevent occurrence of similar problems.

3.1.5.3 Design Issues Created During Assembly (examples)

The three items with issues created during assembly were:

- Cracks in solder balls of BGA packages after assembly. Investigation into the failures found a mismatch in thermal expansion coefficient between the underfill material and the BGA package. This led to excessive stress on the solder balls producing the cracks observed. The issue was corrected by using a different underfill material with a better matched thermal expansion coefficient.
- Pins on a stacked IC configuration came loose during assembly testing. Investigation found an inadequate process at the manufacturer for pin attachment and mismatch between the thermal expansion coefficient of the staking material used and board leading to excessive stress on the pin attachment.
- Low output power was found in some hybrid RF amplifiers. Testing revealed the saturation voltage of some bipolar transistors was 300-600mV rather than the expected 40-50 mV. Further investigation attributed the high saturation voltage to the die attach. The transistors were assembled using a gold-tin eutectic rather than a gold-silicon eutectic as recommended by the transistor manufacturer. Changing the die attach to gold-silicon corrected the problem. The precise mechanism that produced the higher saturation voltage when a gold-tin eutectic die attach was used is unknown.

The common thread in the items above is a deviation in assembly process from the recommended processes. In two cases, a review of materials used in the assembly process should have found the thermal coefficient mismatch and prevented occurrence of the problem. In the third case, a better review should have found the difference between the assembly process used and the manufacturer's recommendation. However, since a gold-tin eutectic is generally considered equivalent to a gold-silicon eutectic and often preferred due to the lower eutectic temperature for gold-tin, it is not clear a better design review would have flagged this as a problem to be addressed.

3.1.5.4 Design – RF vs Microcircuit Issue

Of the fourteen design-related issues identified, six of them (43%) were RF components. Since the overall number of RF components out of the 76 issues from all sources was only 15 (20%), this would seem to suggest there are disproportionally more design issues associated with RF parts than other hybrid/ICs. Review of the specifics regarding the six RF design-related issues show problems that are common with non-RF designs, and underscore the importance of ensuring the proper experts are involved in design reviews in general. Checklist items have been proposed to help mitigate issues in future designs.

Table 6. Though RF Parts Accounted for a Disproportionately High Percentage of Design-Related Issues, the Specifics have little to do with RF Performance or RF Design

RF Alert #	Design-related Issue
T2009-00012	ESD rating not adequate
PUMPS -12-0053P	Material selection issue which should have been caught at design review
T2010-00031	Critical material missed at Design Review even though Prime flowed requirement
T2011-00033	Prior analysis did not identify the derating exceedance nor was life tested under most stressing conditions
T2009-00038	Process/material change not adequately qualified
T2011-00044	Hybrid supplier did not follow process for transistor from transistor mfr

3.1.5.5 Design – Most Significant Actionable Issues

The two most significant design issues observed were related to incomplete characterization of devices and not performing adequate design reviews.

3.1.5.6 Design – Most Common Root Cause

The most common root cause attributable to these design issues was lack of thoroughness by the manufacturer and/or contractor in not pursuing fundamental good engineering practices.

3.1.5.7 Design – Other Lessons Learned

3.1.5.7.1 Hybrids Designed by Subtiers

Not necessarily discernible by the examples of issues above, is the question of how well do Primes get insight into hybrids that are designed/procured by subcontractors and subtiers. Based on team discussion, contract language emphasizing an expectation that contractors be proactive in hybrid and IC insight at subcontractors would help to prioritize this activity. Hybrid design review participation is sometimes left to the unit engineer who may not have adequate depth. There was general concurrence that Prime's hybrid SME may not be sufficiently involved in design reviews, or even have access to parts lists internal to these hybrids. What would trigger a Prime-attended design review at a hybrid supplier?

3.1.5.7.2 Design Changes to Legacy Parts

Similarly, existing designs used on new programs are not always allocated the resources or expertise to ensure that the same part procured several years prior remains unchanged in design, materials, processes and facilities. Though Product Change Notices (PCNs) may be reviewed on a continuing basis, validation that the design, material and processes have remained unchanged should be accounted for prior to re-procurement.

3.1.6 Test Issues – SME Review Results

Twelve items from the database were identified by the team as being primarily test related. These items were discussed by SMEs from all the Primes who submitted them to discern the most impactful issues, root causes, and lessons learned in this area.

Of the twelve items, the data sources were the following:

- three were found in the NSSAF database
- one was identified in PUMPS
- eight more were contributed from prime-internal information.

3.1.6.1 Test – Most Actionable Lessons Learned

The most significant actionable lessons learned in the "test" classification were:

- Awareness of the relevance of rejection criteria
- Prevention of electrical overstress induced during test by checking for out-of-spec stimulus during Test Readiness Reviews (TRR)

3.1.6.1.1 Relevance of Rejection Criteria

Rejection criteria that are repeatedly dismissed with a "use-as-is" disposition should be assessed for relevancy. The reviewed data revealed many instances of "use-as-is" dispositions, notably within Destructive Physical Analyses (DPA). Additionally, discussion with subject matter experts (SME) revealed sentiment that DPA criteria in place may not be the most appropriate criteria for all parts and part types subject to these standards. If reject criteria exists which is continually accepted use-as-is for a specific part or part type, it may make sense to modify the rejection criteria to more accurately reflect the true threshold for a reliability risk. This would result in a reduced number of individual reviews and associated paperwork required for "failing" evaluations. This would in turn lead to reduced cost and schedule impact caused by review and processing of out of specification results.

As this MAIW data review included a limited number of DPA reports, it is suggested that a more in-depth review may identify a list of items repeatedly dispositioned "use-as-is" for further consideration. It is recommended that this be discussed at an upcoming JEDEC/G12 member meeting. Case studies that potentially would have benefited from adjusted failure criteria are included below.

Case Study #1 – Rejection Criteria Relevance – Internal Water Vapor Testing Failures

The Internal Water Vapor Testing failures have revealed inconsistency in the test results. Two examples existed in the data where a sample of devices failed the moisture requirement when tested at the first test house. In each case, a second set of samples from the original lots were then provided to alternative test houses and both sets of samples passed the moisture requirement with margin. The lots were subsequently accepted via waiver. If this test is commonly resubmitted, reviewed, and accepted, addition of criteria to adjudicate resubmissions may help to reduce waiver paperwork and therefore cost and schedule (in the absence of an available improvement of the methods to make the results more consistent).

It should be noted that the requirements of MIL-PRF-38535 differ from those of MIL-PRF-38534 in that the latter explicitly allows submission of a second set of test samples to an alternate test lab for Internal Water Vapor Testing followed by engineering review. This allows the relevant subject matter experts to review the data and determine whether the devices are acceptable for use (i.e., an "accepted" disposition for DPA, no additional documentation required).

Unlike MIL-PRF-38534, MIL-PRF-38535 does not allow alternate testing on a second set of samples. Internal Water Vapor Testing results indicating above maximum moisture limit are listed immediately as failures and require "reject-use-as-is" disposition for use. This may result in additional cost for further processing of paperwork and schedule delay resulting from formal reviews. It may be advantageous to coordinate the failure criteria of MIL-PRF-38535 with MIL-PRF-38534.

Of note, a revision to MIL-STD-883, Method 1018 for Internal Gas Analysis has been proposed to require accept/reject criteria for other gases in addition to moisture, but will require additional time to analyze and come to agreement (likely at least a year from May 2013). This modification to the test methods in MIL-STD-883 may help to resolve the issues identified by adjusting the acceptance criteria to better address applicable reject criteria.

Case Study #2 – Rejection Criteria Relevance – Real Time X-Ray (RTXR) – identified seal voiding failures.

Another possible candidate for rejection criteria review is X-ray-identified seal voiding. An example was included wherein out-of-specification seal voiding was identified during RTXR. The devices passed hermeticity testing and were accepted for use as-is. It may be useful to discuss the specific/common situations wherein reliability risk is considered low and rejection criteria may be adjusted to account for such situations, again avoiding additional paperwork, time, and money to reach approval for use in situations that are consistently determined to be low risk.

Anecdotally, similar issues were noted for out-of-spec CSAM results, step coverage, and plating thickness.

3.1.6.1.2 Prevention of Electrical Overstress Induced During Test

Three examples were noted in the available data of electrical overstress/out-of-specification stimulus applied to flight product. Two resulted in device failure. Full test setup verification is essential to confirm not only that all expected signals are present but also that no unexpected/out-of-specification stimulus exist. It is recommended that an evaluation be included during Test Readiness Review (TRR) for out-of-spec stimulus applied to the device under test by the tester.

TRR checklist items relevant to this topic are included in Appendix E herein and relevant case studies are included below.

Case Study #1 – Electrical Overstress – Test Fixture Suspect

One example of electrical overstress manifested itself as an electrical anomaly post installation. The test fixture resulted in arc-overs within the flight devices. No evidence of damage to the test fixture or improper usage of the test setup exists and the damage to devices tested on this fixture was repeatable. If a TRR including oscilloscope or similar review of all signals for both expected and out-of-spec stimulus had been performed, it is believed that the overstress could have been identified and prevented prior to test of flight product.

Based on the complexity and new technology aspects of devices, it has been discussed with DLA about modifications to the mil-spec for hybrids and integrated circuits to impose additional ESD requirements such as the Machine Model and Charge Device Model characterization and testing.

Case Study #2 – Electrical Overstress – Stimulus Outside Max Ratings

Another example of anomalous tester stimulus to a device under test was noted in which the stimulus applied was outside of the device maximum ratings. The test setup did provide expected results for each parameter. The issue was in the unexpected signals during test step transitions that resulted in out-of-specification stimulus at the device. This situation could have been detected prior to use given an appropriate verification review. Test setup review should include checks not only for intended signals but also for any stimulus that goes beyond the device's maximum ratings at any time during the test sequence including power sequencing. Signal verification in this manner is recommended for all test setups.

3.1.6.2 Test – Most Common Root Cause

Within the "test" classification, the most common root cause appeared to be human error/process escapes. Relevant issues include manual data review escapes resulting in shipment of out-of-spec product, internal visual escapes, and one instance of test fixture use prior to formal release. Escapes related to processes that may be automated would benefit from automation (providing the automation is thoroughly proven out). Risk of human error exists in all manual processes.

3.1.6.2.1 TRR Checklist Item

It is recommended that a review for out-of-spec stimulus applied by the tester to the device under test be included during Test Readiness Review (TRR). Expanding this review to include out-of-family should also be considered.

3.1.6.3 Test – Other Lessons Learned

One MAIW participant requires a small sample of parts be tested and a pilot burn-in for 24 hours, before subjecting the entire part lot to test to avoid any chance of electrical or mechanical overstress. Initial setup verification is essential, but continued functionality/safety to the DUT should not be overlooked. Practices should be put in place to address socket reuse and wear-out concerns and to have an independent SME review board designs and software. Additionally, incorporating out-of-family analysis of flight data should be considered to help flag unexpected effects of the tester on the part and any other abnormal conditions.

3.1.7 SME Review Results – Other

Of the 76 issues reviewed by the team, 7 were categorized as "other." These are anomalies that did not fall into the other major classifications of Manufacturing, Design, or Test. These anomalies were identified as Handling and Radiation.

Table 7. "Other" Issue Categories

Category	Quantity
Radiation	5
Handling	2

Radiation related issues consisted of the majority of the "other" issues. Radiation was the only category in which an on-orbit failure/anomaly was reported. In general, radiation issues manifested themselves during acceptance radiation testing. However, in one instance failure was induced by real time X-ray inspection of the assembly on which a radiation sensitive device was mounted. Real time X-ray can contain far more radiation than a conventional 2D film style X-ray. When using real time X-ray equipment, an evaluation of the device technology and sensitivity of the devices to X-ray need to be performed to determine the dose accumulation the devices will be exposed to during test and whether or not the devices will be impacted.

3.1.7.1 Most Significant Actionable "Other" Issue

Radiation Lessons Learned – End users need to verify supplier analysis and measurements. All aspects of handling and assembly of a radiation sensitive device, and assemblies containing radiation sensitive devices, need to be considered to prevent inadvertent exposure. Recommend contractors add this to checklists so that this exposure can be avoided.

Handling Lessons Learned – Not enough information was available to glean a lesson learned, but possible visual inspection escapes could be evaluated.

3.1.7.2 Most significant Actionable "Other" Issues

Ensure all requirements are identified up front in the specification so the appropriate jeopardy and responsibilities can be defined for both the supplier and procurer.

3.1.7.3 Most Common Root Cause – "Other"

Of the five Radiation issues identified, four of them can generally be grouped into two areas, though they are already well-known and point to the importance of having SMEs with the right expertise be involved with the supplier analyses as well as the design process ensuring that lessons previously learned are folded back into the design review process.

- Enhanced Low Dose Rate Sensitivity (ELDRS) – Two of the five radiation issues were regarding ELDRS sensitivity, and in both cases it was discovered after receipt of a part by the user, and in neither case was a root cause identified.
- Supplier Knowledge/Contractor insight of Radiation Issues – Two issues relating to inaccurate supplier analysis prediction and need for end user to validate manufacturer data for SEE and make sure system can tolerate.

3.1.8 Improved Communication

In order to enhance communication related to known issues and share information among the industry, it is recommended that semi-annual Hybrid/IC Failure Summit meetings be convened including manufacturers, first-tier (typically subcontractors) and second-tier (typically primes) customers. All concerned parties likely have valuable and significant information that for many reasons is not currently shared – but must be if improvements are to be realized across the industry. In many cases, the supplier is not aware the users have observed issues nor are they aware of the NSSAF database. This activity could be part of the Space Parts Working Group meetings, and the top several hybrid and IC suppliers could be scheduled to individually present 30-60 minutes on their corrective actions and process improvements related to any recent issues they have encountered that may have affected the industry. This forum would provide the necessary isolation from competitors, but provide the primes with a wide view of their supplier partners' perspectives/issues on a face-to-face basis. Suppliers would change on a meeting-by meeting basis to allow for a necessary variety of products and issues. In order to encourage participation, a key ground rule of the meeting would be to have a non-retribution environment so that industry and suppliers would feel comfortable in sharing information.

3.2 Overall Conclusions and Lessons Learned

Based on the above discussions of review, evaluation, and cause/corrective action of all the issues, the following conclusions are reached with the applicable lessons learned defined and incorporated into several checklists to be utilized as supplements to the standard checklists used by the contractors.

- **Conclusion**: Of the seventy-six hybrid anomalies reviewed by the team, forty-three (57%) were categorized as manufacturing anomalies.
- **Lessons Learned**: The single most important manufacturing lessons learned item is the importance of performing manufacturing and/or design-for-manufacturing reviews with the Prime at the hybrid and IC supplier to validate that the parts, materials, and processes being used have been properly selected, qualified, and evaluated for manufacturing methods and all methodology and approaches are appropriate.
- **Conclusion**: The two most significant design issues observed were related to incomplete characterization of devices and not performing adequate design reviews.
- **Lessons Learned**: A more thorough design review would have detected the relevant issues that arose. Additional information added to the checklists would be useful.
- **Conclusion**: The two most significant test issues observed were electrical overstress induced during test and failures due to out-of-test limits.
- **Lessons Learned**: Perform a test readiness review and include evaluation of test procedures including test stimulus and test fixtures and re-evaluate criteria used for Destructive Physical Analysis.
- **Conclusion**: In general, radiation issues manifested themselves during acceptance radiation testing including over-exposure during real time X-ray.
- **Lessons Learned**: Having SMEs with the right expertise be involved with the supplier analyses as well as the design process ensuring that lessons previously learned are folded back into the design review process.
- **Conclusion**: Better communication across the industry is needed related to sharing issues, corrective actions, and lessons learned to improve the quality and reliability of procured microelectronic devices.
- **Lessons Learned:** A semi-annual Hybrid/IC Failure Summit meeting should be convened to share information among manufacturers, first-tier (typically subcontractors) and second-tier (typically primes) customers.

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4. Discussion of SQIC/GIDEP National Security Space Advisory Forum (NSSAF)

The NSSAF was launched in September, 2005 as a fully operational alert system specifically for the national space prime contractor community to supplement existing enterprise-wide problem alert resources, such as the Government-Industry Data Exchange Program (GIDEP) Alert System as an early warning anomaly and alert system for parts, materials, and system-level problems uniquely affecting spacecraft, payload, launch, and ground systems.

4.1 Observations from NSSAF Database Process

As designed, the NSSAF Alert process is effective in quickly communicating issues across Primes to identify potential issues with specific manufacturing lots of products from specific manufacturers. The NSSAF database has shortfalls relative to defining the scope of product potentially affected and identifying root cause and providing corrective actions to prevent recurring issues. Another improvement would be broadening the outreach to government and other agencies as proposed by the Tier 2 process. See Appendix F for an overview of how the NSSAF process functions.

4.1.1 Areas where NSSAF has been Effective

The primary area in which the NSSAF system has been effective is in the early identification of issues and problems observed by contractors. It provides the notification of an issue to allow other interested contractors to gain insight by working with the identified contractor to obtain data, etc., to help ascertain whether they are also impacted by the issue.

4.1.2 Metrics

Though no formal metrics are tracked, it was noted by the NSSAF participants that the streamlined Alert distribution is generally effective in providing communication of issues as compared to the GIDEP process. Review of periodic metrics to evaluate the effectiveness of the system can be facilitated through incorporating searchable database fields so information can be mined and reported as discussed later in this report.

4.1.3 Shortfalls in using NSSAF to Reduce Hybrid/IC Issues

Even though the NSSAF system has been functioning and providing the early warning of issues to contractors, users including contractor management, government, and Aerospace have identified shortfalls within the current NSSAF system. The following describes some of the shortfalls with some proposed recommendations for solutions.

4.1.3.1 Exclusion of Government

In its current state the NSSAF is still an industry-only system due to its hosting of preliminary and non-vetted content; thus key government PMP and mission assurance personnel do not have access to the detailed anomaly information. Government participation will broaden the database input and SME oversight. The impact of the exclusion could be mitigated by putting more emphasis on eventually migrating appropriate NSSAF Alerts to mainstream GIDEP Alerts by the part manufacturer or contractor once any sensitive issues are resolved.

4.1.3.2 Uniformity of Participation by Contractors

Though use of NSSAF content has been incorporated into the PMP and risk management processes of all SQIC industry members, there is inconsistency in the contributions of anomaly data among the users into the database as indicated in Table 2. The criterion for an issue to be elevated to an NSSAF Alert varies across the prime contractors (see Table 8 below for summary). This may account for why there is an impression by some that only an apparent subset of known issues is actually being input to NSSAF. Reviewing the guidelines used by the participating contractors as well as analysis of non-NSSAF issues submitted for review by two contractors for this investigation (see para 3.3.1), shows there is a deliberate balance between issuing notification quickly and issuing notifications that give the SQIC community actionable information. There was no evidence that participating contractors are not reporting significant issues that have industry-applicable root causes. The ability to quickly ascertain root cause of issues initially reported in NSSAF could be a stepping stone to using the information to drive industry improvements.

Table 8. Processes Used by Several Contractors to Assess Whether Issues Should Be Shared as NSSAF Alerts

ConOps #1	Company Bulletins are submitted as NSSAF Alerts via a centralized internal organization (with few exceptions).
ConOps #2	Issues elevated to corrective action boards or are submitted to NSSAF if they meet internally-established criteria including existence of preliminary root cause.
ConOps #3	Issues elevated to a centralized company alert review board, or developed into a Mission Assurance Bulletin are submitted to NSSAF if they meet internally-established criteria including whether enough is known about the issue to determine whether it represents significant risk and mitigating actions can be identified.
ConOps #4	Component engineering focal point submits potential issues to contractor SQIC representative and programs for concurrence. If any program objects to having the data published then it simply isn't published.
ConOps #5	A NSSAF draft is submitted to senior management of the impacted division for review and approval when the root cause of a non-conformance is identified as a discrepant part number.

4.1.3.3 Lack of Updated Root Cause and Corrective Action (RCCA)

The NSSAF was designed to provide early data-exchange, but not to ledger and track problems to closure. Thus NSSAF Advisories in most cases are not updated with the latest RCCA information. While it is not the current purpose of the NSSAF Alert system to track RCCA, lack of this information is a barrier for other Primes to address issues on similar devices, since Primes who have not had the issue do not know what root cause to address and cannot query the supplier for further information unless authorized by the Alert author. Due to level of sensitivity, significant time can elapse before the author is clear to allow another Prime to dialog with the supplier.

4.2 Proposed changes to NSSAF Process to Facilitate Problem Non-recurrence

4.2.1 NSSAF Recommended to Evolve to Beyond Early Warning System

The MAIW IC/Hybrids team recommended a number of enhancements and changes to the NSSAF user interface and operations that would improve the effectiveness and efficiency of the NSSAF for data-sharing, risk assessment, and mitigation. Though the NSSAF was designed and deployed for earliest awareness and data-sharing of potentially systemic space system anomalies, as it has become incorporated into the PMP operations and problem tracking processes of the SQIC member companies, it has also become a central resource for problem-tracking, analysis, root cause investigation, and decision support for corrective action. As such, the IC/Hybrids team made recommendations that will be vetted and coordinated with GIDEP for incorporation into the NSSAF interface and system.

4.2.2 Tier 2 Enhancements to Improve Corrective Action and Lessons Learned

Presently the NSSAF is still in its original operations model, an industry-only system with data controls and database operations able to share unvetted and preliminary information in a secure environment. SQIC and GIDEP have been working towards completion and deployment of an Evolved NSSAF to include government participation, and improved operations for sharing *mature* problem data across industry, programs, and government customers. Several of the IC/Hybrids team's recommendations such as a lessons learned section and additional controls have already been incorporated into the beta test version of this next-generation version of the NSSAF.

In addition to all current operations and interface elements of the NSSAF, the IC/Hybrids Team is recommending the following enhancements:

4.2.3 NSSAF Communication/Closure Enhancements

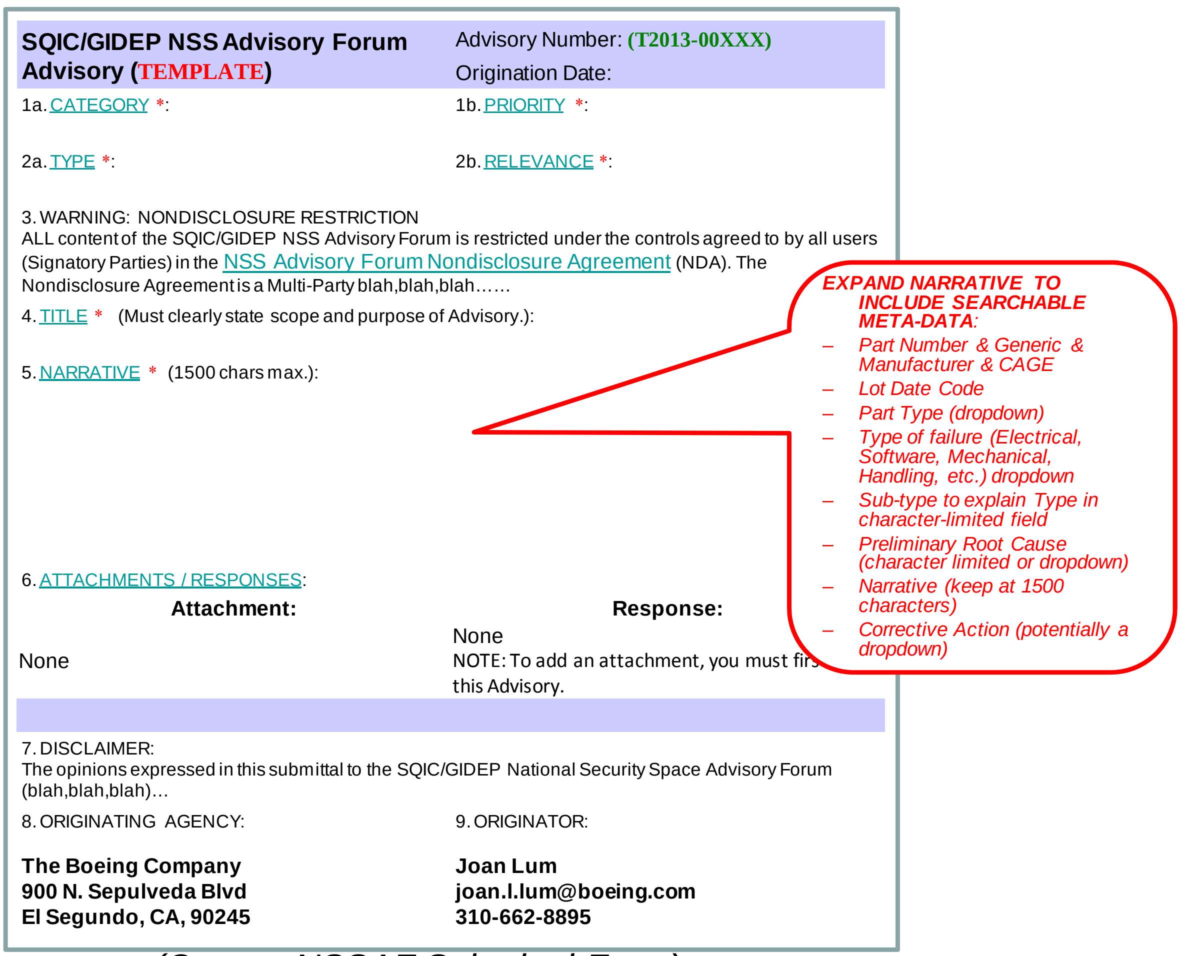
- User List; at the main ledger page, a pop-up listing of all NSSAF registered users with their contact information.
- A check-box for each Advisory indicating that users/readers are permitted to contact the indicated supplier, vendor, or other third parties directly.
- "Closure" fields for each Advisory:
  - *Closure Type* – a menu selection indicating status of the issue; Closed, Under Investigation, Anomaly Confirmed, GIDEP Released, etc.
  - *Closure Date* – to quickly alert NSSAF users to Advisories that are either still active and should be reviewed, vs. those that have been investigated to identify root cause or otherwise concluded their investigation.
  - *Closure Notes* – A searchable text field with hyperlinks to documented closure records; GIDEP Alerts, white papers of findings, conference proceedings with investigation results, Aerospace TORs, etc.
- Change to the operation of the NSSAF such that any response, update, or addition to an existing Advisory triggers release of an e-mail notification to all users, so that they are aware at all times of the latest data for every issue.

4.2.4 Data-Mining Enhancements

- Expanded *Type, Relevance, Category*, and *Priority* details for each Advisory.
- Expand and compartmentalize the current *Narrative* field to expand number meta-data fields, creating meaningful drop down fields for data as indicated below. Although it will add key strokes for the originator to enter an Alert into the system, the data improvements would make it worthwhile.
  - Part Number and generic
  - Manufacturer and CAGE

- Lot date code
- Part type (drop down)
- Type of failure (electrical, software, mechanical, handling, etc.) drop down
- Sub-type to explain type in character-limited field
- Preliminary root cause (character limited or drop down)
- Narrative (keep at 1500 characters)
- Corrective action (potentially a drop down)

• Incorporate customizable report-generation into the NSSAF, enabling users to incorporate searches, downselects, and sorts into reports specifically relevant to a particular organization, program, or issue.



(Current NSSAF Submittal Form)

4.2.5 SQIC-Community Peer Network to Facilitate Alert Closure Info-Share

• The MAIW team is recommending that a feature be incorporated into the NSSAF that would permit a user to select one or more Advisories to "Follow" – and that NSSAF would keep that user apprised of changes in status, updated content, addition of closure information, and any other key data fields that the user would like to stay informed of.

- The NSSAF would allow a setting to, at given intervals – every 10 days, 30 days, etc. – or triggered by changes to content or status, to release an e-mail notification to all NSSAF users "following" that particular Advisory.
- And though by rule of the NSSAF NDA and Ops Concept, all NSSAF content is available to all users without exception, this feature would allow users to stay closely on top of particular issues relevant to their programs with immediate, up-to-date, customized snapshot views.

4.3 Other Forums for Discussion of Issues

Besides the NSSAF and GIDEP systems, there are many forums available to the government and industry to discuss and share issues and problems with suppliers and among themselves and work to resolve them. The following is a brief list and description of the forums:

JEDEC is an independent semiconductor engineering trade organization and standardization body that meets three times per year with the charter to discuss military and space level electronic parts. The meetings are working sessions with representatives of the government agencies controlling the specifications and standards (Defense Logistics Agency Land and Maritime), the user groups from the contractors and the suppliers and other government agencies such as NASA, US Air Force, Army, European Space Agency, JAXA, etc.

US Air Force Space Parts Working Group is a yearly workshop hosted by The Aerospace Corporation with the sole function of gathering parts suppliers together with space systems manufacturers and users to share technology roadmaps, requirements, and government program updates, acquisition strategies, issues and lessons in parts, materials, and processes.

NRO and SMC Sharing Forums held on a monthly basis consisting of the government SPOs and representatives from Aerospace to discuss general parts, materials, and processes issues from across the industry.

DLA Supplier Audits are performed to certify manufacturer's processes, facilities, and test approaches and capabilities to meet the requirements of the military specifications and standards. Organizations such as Aerospace and NASA/JPL participate in the audits to determine supplier's capabilities and ensure product is in compliance with the requirements. Many changes to specifications are generated based on results of the audits and lessons learned. Contractors are encouraged to participate in these audits to gain a better understanding of the supplier information. Cross functional teams make for a more in-depth audit and help to improve working relationships.

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5. Lessons Learned from Other Sources

Based on the historical and technical expertise of the subject matter experts from Aerospace, NASA and the contractor base and field usage of hybrids and integrated circuits, the following additional generic lessons learned have been identified and incorporated into the applicable checklists.

5.1 Integrated Circuits

- Contractors must perform their own validation of test methodology for their product since DLA only reviews military/space requirements and not per contractor specifications
- Contractors must ensure their applications are enveloped by the environmental/electrical test requirements in the specification
- Contractors must ensure the supplier is actually testing to the contractor specification requirements and not their standard product requirements
- Contractors must ensure that complete characterization (electrical, temperature, environmental, reliability and radiation) are performed
- Contractors must ensure that new technology insertion requirements (including a physics of failure approach) are implemented
- Contractors must ensure that qualification invokes lessons learned from the characterization and new technology insertion evaluations
- Contractors must ensure the burn-ins performed are adequate to eliminate marginal devices (i.e., adequate temperature, voltage, and frequency)
- Contractors must ensure that screening, qualification, and quality conformance inspection tests are defined in sufficient detail to adequately represent mission applications
- For custom monolithic integrated circuits, contractors should ensure they implement adequate design reviews, manufacturing readiness reviews, and test readiness reviews to mitigate potential problems

5.2 Hybrids

- Contractors must perform their own validation of test methodology for their hybrids since DLA only reviews military/space requirements and not per contractor specifications
- Contractors must understand what devices and from what source(s) the elements are being procured from to ensure they meet the program requirements
- Contractors must ensure all elements are procured from the OEM or their authorized/franchised distributors – MIL-PRF-38534 requires element traceability to the OCM – the effectiveness of the manufacturer's traceability system needs to be evaluated during audits
- Contractors must ensure all the processes the supplier is using have been qualified for space applications
- Contractors must ensure all third parties utilized by the supplier have been evaluated
- Most issues arise due to workmanship anomalies and a good checklist identifying the items to be evaluated will aid in mitigating these types of issues.

- Contractors must ensure that new technology insertion requirements (including a physics of failure approach) are implemented
- Contractors must ensure that qualification invokes lessons learned from the characterization and new technology insertion evaluations
- Contractors must ensure the burn-ins performed are adequate to eliminate marginal devices (i.e., adequate temperature, voltage, and frequency)
- Contractors must ensure the seal tests and internal water vapor requirements are adequate to support mission requirements
- Contractors should ensure they implement adequate design reviews, manufacturing readiness reviews, and test readiness reviews to mitigate potential problems
- For subcontractors procuring hybrids: develop supplier SOW; consider First Article Inspection for complex assemblies; hold table top reviews
- Contractors must ensure that adequate bake-out of packages is performed
- Due to poor soldering or solder/glass cracking, contractors must ensure that leaks in feed-throughs are adequately safeguarded
- Contractors must ensure that the use of getters include proper H2/moisture getter activation and/or maintenance
- Contractors must ensure that packages have the correct plating materials and thicknesses

> The goal of screening is to eliminate defective parts where defective would mean non-compliance with specification requirements. Screening really isn't designed around mission or application requirements.
>
> The goal of QCI is to validate/verify lot quality is consistent with standard requirements. Like screening, QCI is not designed around mission or application requirements.
>
> Qualification should definitely address mission and application requirements. Since drawings are written to standard requirements such as those in MIL-PRF-38535 or MIL-PRF-38534, it really isn't feasible to put specific mission/application qualification requirements in the drawing. Some contractors will define a worst-case-application and use that in their drawing requirements.

6. Lessons Learned Checklists

As a result of this MAIW task activity, a set of lessons learned was developed based on the review of the NSSAF database and other databases (Aerospace PUMPS, MDA, NASA, contractor failure information/Destructive Physical Analysis, incoming, and source inspection records, etc.).

The team utilized a series of existing contractor checklists as a starting point and enhanced them to include the lessons learned from the databases review specifically for hybrids and integrated circuits. These checklists are not intended to eliminate the checklists currently utilized by the contractors but as a supplemental enhancement. These checklists are included in Appendix E.

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Appendix A. Definitions

The following represents unique definitions of terms used in this report:

Term	Definition
Custom part	Any part not defined as a Standard Part (includes additional screening, performance selection, changes to parametrics, changes to elements, materials or processes, etc.)
Design Issue	Performance anomaly found with parts built as intended with no manufacturing defects. These include design deficiencies in the part which limit reliability or usage in a manner not documented by data sheet/specification and design deficiencies in the using assembly that cause stresses on the part to be other than intended.
Manufacturing Issue	An anomaly that is confirmed to have occurred as part of the hybrid/IC manufacturing process, and is directly attributable to non-compliant parts, material(s), and/or process(es) used in the manufacturing of the component. Processes include all documentation, equipment, tools, personnel, and other intrinsic aspects of the manufacturing cycle.
Standard Part	Part built by vendor to the military/space requirements or their own data sheet that is made available to anyone and is not modified by the user.
Supplier	In the context of this report, refers to the Original Equipment Manufacturer (OEM).
Test Issue	Anomaly either induced as a result of testing (i.e., electrical overstress, mechanical damage) or that should have been screened out by a required test (i.e., incorrect performance of required test allowed escape). Additional consideration, any anomalies that were caught during a required test or screen and were then listed as “use-as-is”.

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Appendix B. Acronyms

The following are a list of acronyms utilized throughout this report:

DLA	Defense Logistics Agency
DPA	Destructive Physical Analysis
MAIW	Mission Assurance Improvement Workshop
GIDEP	Government Industry Data Exchange Program
JEDEC	Joint Electron Devices Engineering Council
IB	Industrial Base
IC	Integrated Circuit
LM	Lockheed Martin
MDA	Missile Defense Agency
MSB	Mission Success Bulletin (from Lockheed Martin)
NASA	National Aeronautics and Space Administration
NRO	National Reconnaissance Office
NSSAF	National Security Space Advisory Forum
SMC	Space and Missiles System Center
SME	Subject Matter Expert
SQIC	Space Quality Improvement Council
TOR	Technical Operating Report

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Appendix C. Reference Documents

The following documents are identified as reference documents for information and detailed descriptions of items identified in this report:

MIL-PRF-38534	Hybrid Microcircuits, General Specification for
MIL-PRF-38535	Integrated Circuits (Microcircuits) Manufacturing, General Specification for
MIL-STD-883	Test Method Standard Microcircuits

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Appendix D. Matrix of NSSAF and Other Database Items Reviewed

The complete matrix identifying all the pertinent Alert numbers and information reviewed, evaluated and categorized is available only to those briefed to the NSSAF Proprietary agreements. It is currently available on the MAIW portal, but we are considering eventually releasing the matrix into the NSSAF as a document to be accessed from the same database as the Alerts.

Link: https://opmis.xsp.org/member/libraryV3/main.cfm?action=9&returnAction=32&libid=854794

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Appendix E. Checklists

The team utilized a series of existing contractor checklists as a starting point and enhanced them to include the lessons learned from the databases review specifically for hybrids and integrated circuits. These checklists are defined below:

General Information Checklist

	General
1	Does the supplier understand all the specified requirements? Consider requirement for a kickoff meeting/requirements walkthrough post contract award at the supplier facility.
2	Are all documents/specs released and of intended revision?
3	Do all travelers include traceability for action date, operator, and specific piece of equipment, equipment cal date, and conditions/methods/requirement documents as relevant?
4	Is buyer notified of all deviations/waivers including those at any subtier suppliers?
5	Is a change notification process in place?
6	Has the contractor validated that all third parties utilized by the supplier have been evaluated and approved?
7	Has the contractor implemented adequate design reviews, manufacturing readiness reviews and test readiness reviews to mitigate potential problems?
8	For QML devices, has the contractor reviewed the SMD document for both new and recurring orders (as initial review and then for any changes)?
9	Are photographs (pre-seal digital photographs) of both the cavity and lid, taken preseal with appropriate resolution to support post-seal risk evaluation activities? Verify traceability of pictures to device serial number is maintained.

New Technology Insertion

	New Technology Insertion
1	Has the buyer validated that new technology insertion requirements (including a physics of failure approach) are implemented?
2	Has the buyer validated that the qualification invokes lessons learned from the characterization and new technology insertion evaluations to ensure ability to meet mission requirements?

Materials – Design – Manufacturing

	Materials – Design – Manufacturing Checklist
1	Are all previous peer and other reviews action items closed?
2	Have all materials and processes used in the hybrid/integrated circuit been reviewed, qualified and approved by the PMPCB?
3	Have thermal, stress, and WCCA been completed and reviewed by the buyer?
4	For custom monolithic integrated circuits, did the buyer perform design reviews, manufacturing readiness reviews, and test readiness reviews to mitigate potential problems.
5	Are all processes (including rework) qualified, properly documented, and adequately controlled?
6	Are all traceability, quality verification, and special handling processes finalized and approved?
7	Is there a system for controlling non-conforming material? Explain the customer involvement in the non-conformance process.
8	Are all operators/technicians adequately trained and certified for the operations being performed and are records available for review?

	Materials – Design – Manufacturing Checklist
9	Does the buyer understand what devices and from what source(s) the elements are being procured from to ensure they meet the program requirements? (OEM/authorized distributor versus broker/unauthorized distributor)
10	Does the supplier have a qualification checklist or document that shows the incorporation of lessons learned from characterization and new technology insertion?
11	Does the supplier utilize process control tools when evaluating workmanship anomalies?
12	Has the ESDS approach used by the hybrid manufacturer been reviewed and evaluated? Is it adequate for the types of die elements and overall hybrid sensitivity?
13	Have all process documents, specs, and travelers been finalized and approved by the supplier and buyer?
14	Have ESD, humidity and contamination control processes and equipment been reviewed and approved? Has the change control process been reviewed and verified by the buyer?
15	Was a Reliability analysis performed including a determination of Mean-Time-To-Failure (MTTF), Failures-in-Time (FIT) and activation energy levels and approved by buyer?
16	Were all parts (standard and custom) evaluated for GIDEP and other industry/government ALERTS?
17	Have all active device foundries been approved by the buyer?
18	Are parts appropriately packed and labeled for shipment?

MRR Related Items

	MRR Related Items
1	Is the supplier following the manufacturer recommendations (i.e., die attach material cures, etc.)?
2	Has the thermal profile been reviewed against material limits?
3	Is all equipment properly calibrated and is an acceptable cal schedule maintained?
4	Is the physical layout producible?
5	Are all manual processes independently verified? By who and how?
6	Are all processing steps completed prior to the last set of parametric data taken?
7	Has the manufacturing yield been evaluated to identify potential issues?
8	Has the sealing process been reviewed and is it qualified?
9	Have the test procedures for all tests been reviewed and approved by the buyer?
10	Does the type of wire bonds being used meet industry best practices?
11	Is plasma clean performed prior to wirebonding?
12	Is the Die attach process consistent with the die backside metal? (e.g., die with no backside barrier metal should not use a gold-tin eutectic due to possible device degradation)
13	Were the die elements within the hybrid evaluated in accordance with MIL-PRF-38534 for Class K? If not, what evaluation criteria were used? Were additional evaluations performed for any elements such as transistors employing gold top side metal?
14	Has training/certifications been completed/validated?
15	Has the manufacturing traveler been reviewed and each process, inspection, or test step traceable to a released command media procedure? Does it include mandatory CSI points?
16	Is the packaging/handling clearly defined?
17	Is the bake-out time of the packages adequate to ensure all moisture and contaminants are eliminated?
18	Are feed-throughs in the package adequately safeguarded against poor soldering or solder/ glass cracking to prevent leakage?
19	Are the use of getters adequately controlled to include proper H2/moisture getter activation and/or maintenance?
20	Do the packages have the correct plating materials and thicknesses?

CDR Related Checklist Items

	CDR Related Items
1	Have all design requirements been met? If not explain.
2	Has the thermal gradient across sensitive devices been considered?
3	Are devices susceptible to walk out or power slump characteristics?
4	Are nichrome resistors used in the hybrid? If used, what mitigation was used?
5	Are devices susceptible to hydrogen poisoning? If they are susceptible to hydrogen poisoning, was a mitigation plan submitted to the buyer and approved?
6	What mitigation techniques are being used to ensure the bi-metallic bonds will meet mission requirements? Explain. Of particular concern are bi-metallic bonds at the die.
7	Has complete characterization (electrical, thermal, environmental, reliability and radiation) been completed and validated?
8	How has any non-compliances with the design and/or requirements been captured and adjudicated?

WCCA Related Checklist Items

	WCCA Related Items
1	Are all bias conditions within the part ratings? If not, has the buyer approved a waiver?
2	What derating criteria was used – buyer or supplier and if it was the supplier criteria did the buyer review and approve its use?

Test Related Checklist Items

	Test Related Items
1	Are screening, qualification, and quality conformance inspection tests and conditions defined in sufficient detail to adequately represent mission applications?
2	Are all tests included per the procurement specification and are the appropriate test limits and methodologies in place?
3	Has the element evaluation data/process been reviewed and approved by the supplier and the buyer?
4	If real-time X-ray is used, is a process, which has been approved by the buyer, in place to control exposure times and rates to maintain a safe level of radiation exposure?
5	Have all PIND test conditions been evaluated to ensure they are proper for the type of device being tested (i.e., dual cavity or other package)?
6	Has the buyer validated that the burn-in performed is adequate to eliminate marginal devices (i.e., adequate temperature, voltage and frequency)?
7	Have all hardware schematics and layouts and all software been reviewed and approved (i.e., electrical setup, burn-in, etc.)?
8	Are all data processing equations correct?
9	When multiple devices are tested on the same setup (i.e., burn-in loadboard, electrical DUT board, etc.), is each device receiving appropriate stimulus (electrical, thermal, etc), including the situation with setup at full capacity and the situation with only one device in the setup?
10	Is the test equipment properly calibrated/certified and is traceability of these certifications maintained?
11	Is the test equipment rated to the environment that it is exposed (temp, moisture, etc.)?
12	Is the device interface to the test equipment appropriate?
13	Is equipment accuracy acceptable for the test performed?
14	Is a process in place (golden units, equipment check, DUT board/socket check) to verify equipment functionality prior to each test time including socket re-use and wear-out concerns?
15	Are adequate precautions in place to prevent:
15a	incorrect DUT board use?

	Test Related Items
15b	incorrect device placement/orientation?
15c	use of incorrect test programs/revisions?
15d	incorrect temperature/environments?
15e	stimulus beyond absolute max (overstress) applied conditions? Oscilloscope-aided check for above max stimulus is recommended for initial verification of all tests with electrical stimulus (electrical test, burn-in, including validation of power dissipation calculations, etc.)
16	Have all test stimuli been verified to be as-expected? (all required conditions are correctly applied)
17	Has training/certifications been completed/validated?
18	Have the routers/planning documents been reviewed and approved with adequate inspection steps?
19	Is the packaging/handling clearly defined?
20	Are all operator notes, test/power glitches, device reseating and failures recorded and maintained?
21	If Enhanced Low Dose Rate Sensitivity (ELDRS) is a requirement, ensure testing is performed and all test programs have been updated based on lessons learned?

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Appendix F. Overview of SQIC/GIDEP National Security Space Advisory Forum (NSSAF)

A key initiative of the Space Quality Improvement Council (SQIC) has been the creation and operations of the SQIC/GIDEP National Security Space Advisory Forum (NSSAF) alert system. The NSSAF, launched in September, 2005 as a fully operational alert system specifically for the national space prime contractor community, was formulated as SQIC members identified the critical need for an early warning anomaly and alert system for parts, materials, and system-level problems uniquely affecting spacecraft, payload, launch, and ground systems. To supplement existing enterprise-wide problem alert resources, such as the Government-Industry Data Exchange Program (GIDEP) Alert System, the NSSAF accommodates the highly-specialized technical nature, controls, and timeliness required to identify and remedy potentially systemic problems early in a space system's development lifecycle, averting costly late-term fixes or irrecoverable post-deployment anomalies.

Developed by the SQIC in conjunction with GIDEP, the SQIC industry members collaboratively created and implemented the NSSAF as a secure, Web-based resource specifically developed for industry-sharing of critical space system anomaly data and problem reports. The NSSAF allows industry to share parts problems, test results and data, anomaly investigation results, recommended mitigative actions, and lessons learned in a secure and controlled environment. In providing this capability the NSSAF facilitates the national space contractor community working cooperatively to investigate, assess risk, and resolve potentially mission-impacting problems early in the space system development lifecycle.

The Aerospace Corporation administers operations of the NSSAF, and assists the space contractor community in resolving technical and operational anomalies as they are identified. Presently the NSSAF hosts entries including:

1. counterfeit parts
2. prohibited materials
3. electronic parts failures
4. test process errors
5. hardware and software problems
6. design, manufacturing, and packaging anomalies affecting space system quality and mission risk

NSSAF Advisories provide:

1. technical assessments
2. photographs
3. test data
4. white papers
5. internal contractor bulletins
6. lot and date codes
7. usage and version discriminators enabling rapid, effective program risk assessment, investigation, and mitigative action

The NSSAF is currently an industry-only data-exchange resource, for the purpose of enabling earliest-possible sharing of potential systemic problems, even if unvetted and not yet matured to the point of release to government customers; in this way the contractors can share and seek technical feedback as problems arise, while root-cause investigation, or additional testing and analysis, is ongoing. The prime contractor community has embraced the utility of sharing critical early-lifecycle anomaly information, and the NSSAF has been instrumental in numerous instances enabling critical data-sharing and mission-impacting collaborative investigations. As a result, SQIC member companies have integrated the NSSAF into their anomaly and escape management processes and command media.

SQIC government customer leadership – Air Force Space and Missile Systems Center (SMC), Missile Defense Agency (MDA), National Aeronautics and Space Administration (NASA), and the National Reconnaissance Office (NRO) – have recognized the value of this collaborative data-sharing in the interest of enterprise mission assurance, and encouraged its broad use, even without access to the early anomaly notices themselves. The Aerospace Corporation, as a SQIC member, participates in the NSSAF and is able to assess potential acquisition or program risks as they are submitted, and encourage SQIC industry members to notify their government customers when an identified anomaly poses a threat or program risk that should be mitigated or addressed.

In 2009, with the NSSAF having become well institutionalized, the SQIC industry members and government customer leadership collectively considered evolving the NSSAF to broaden its usage, and devising a secure, tiered-access architecture enabling government visibility to mature, vetted NSSAF content, while still facilitating the industry-only sharing of earliest, unvetted anomalies as in the current NSSAF. The Aerospace Corporation, SQIC industry members, and GIDEP, in coordination with government customer leadership, have begun this evolution of the NSSAF, and an initial operational concept (IOC) for the two-tiered NSSAF was presented and agreed-to in December, 2010. Presently the operational, organizational, and technical details of that system are being resolved. SQIC government leadership SMC, NRO, MDA, and NASA may at some point include contractual language *directing* use of the NSSAF for NSS acquisition contracts, subject to mutual agreement of the contracting parties and commensurate adjustment of relevant contracting terms and conditions.

The following two figures depict: 1) the content and usage model of the NSSAF, and 2) the two-tiered architecture of the NSSAF as it is being developed and deployed.

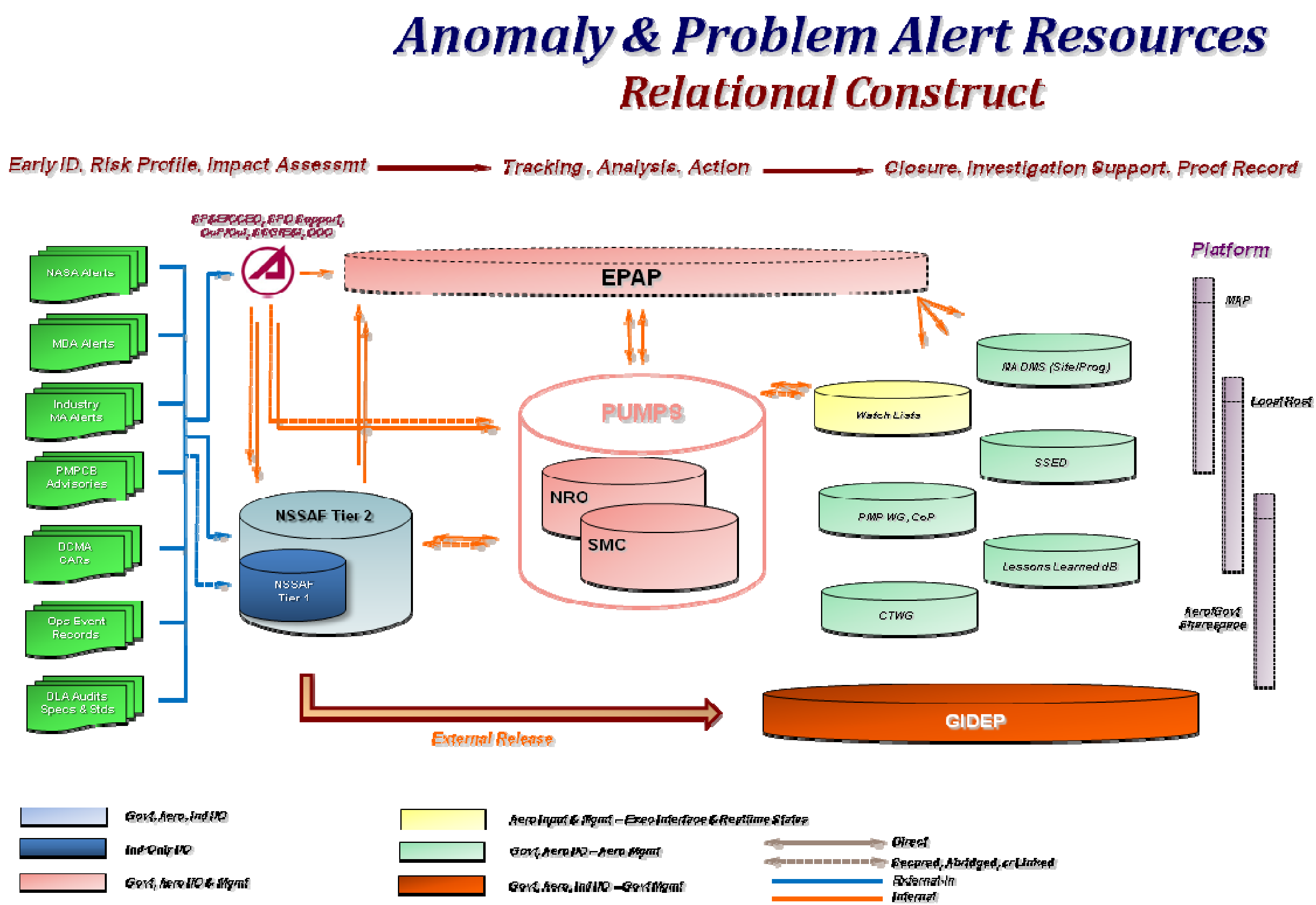

Figure F-1. Anomaly and problem alert resources.

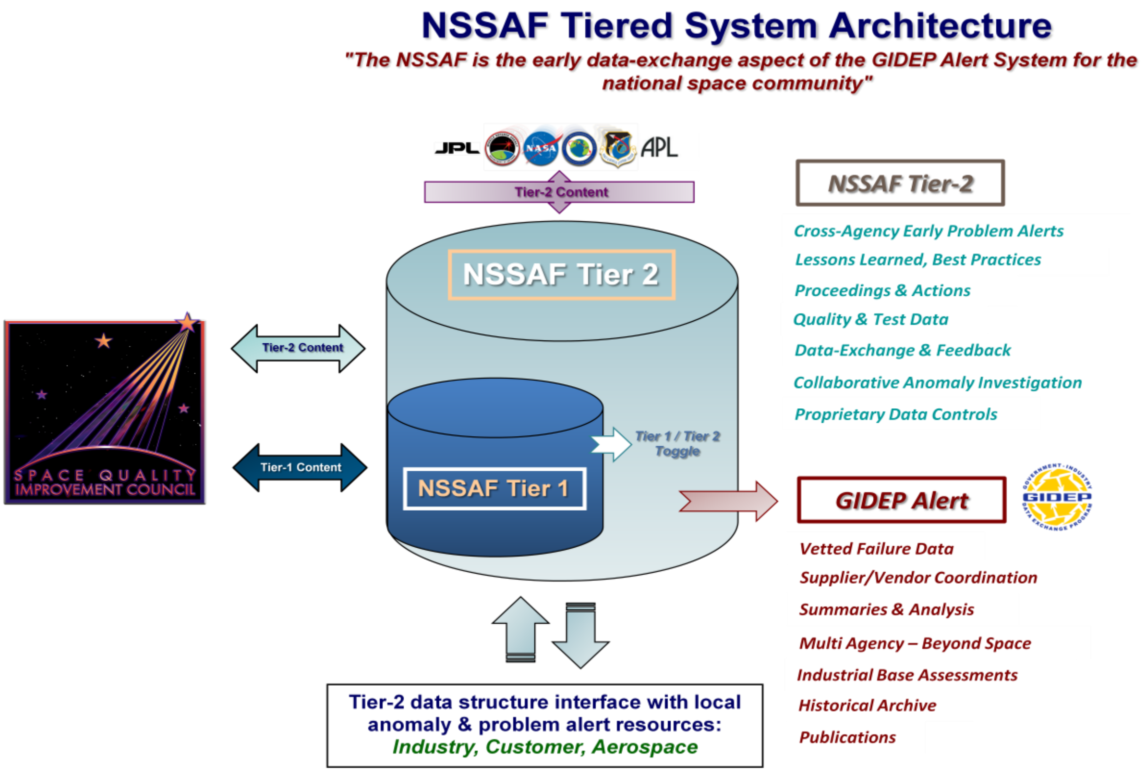

Figure F-2. NSSAF tiered system architecture.

Notes on Data Usage and Processes – Prime Contractor Usage of SQICs

1. For NSSAF Alerts at most SQIC member companies, internal processes have been established for the documentation, configuration control, tracking, and closure of these records to definitively determine whether or not they present an impact or risk to their products or programs.
2. In conducting the activities associated with the above note, processes have been formally and informally established for obtaining and handling proprietary or other sensitive data.
3. In some organizations, the processing of anomalies is independent from gated systems such as engineering processes, including test and evaluation.
4. Some companies require specific confirmation that anomalies have been evaluated in order for a program or product milestone to be cleared or consummated.
5. Some companies tie the closure of anomalies with the documentation of lessons learned, while in other organizations these activities are unrelated and often organizationally distinct.
6. Access and "organizational proximity" of the IC/Hybrids SMEs to the anomaly data resources increases the efficiency and confidence of exploiting the anomaly data towards risk profiling and mitigation.