NASA Acquisitions Pollution Prevention Office
Kennedy Space Center, FL 32899

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Assessment of NASA Solder Operations and Risks Associated with Lead-Free Solders

Matthew J. Rothgeb

Final Report
17 April 2003

NASA Contract: NAS10-99034(B) / DO-14

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1308 Research Park Drive
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ABSTRACT

A study was performed to determine the types and severity of risk relating to electronics manufacturing with lead-free solders to National Aeronautics and Space Administration (NASA) programs both present and future. Because of recent legislation overseas and the electronics manufacturing industries recent interest in converting to lead-free electronics systems as opposed to currently manufactured lead based systems, a risk to high-reliability electronics such as aerospace equipment has become evident. Several site visits were performed within NASA Center shops that used the highest volume of lead based solders in previous years. If site visits could not be arranged, telephone interviews were performed with shop owners and personnel within the five NASA Centers that were assessed.

Kennedy Space Center, Johnson Space Center, Jet Propulsion Laboratories, Goddard Space Flight Center and Marshall Space Flight Center were assessed for solder usage, procurement, quality assurance, quality control and programs each supported. Risk was assessed on two levels, quantitative and qualitative. Quantitative risk was determined by calculating the number of solder joints accomplished annually at the Centers assessed and estimating the total number of joints that NASA accomplishes annually. Through this estimation, it was determined that NASA accomplished between 8 and 12 million solder joints in 2002. Qualitatively, each Centers programs were reviewed for the risk of intrusion of lead-free systems into their process lines and/or the risk to NASA of obsolescence should the electronics industry shift to lead-free systems in the near future.

NASA's highest risk exists in future programs should the industry convert to lead-free systems. There are not enough resources within NASA to support the construction of a next generation reusable launch vehicles or to maintain those systems without the involvement of outside electronics manufacturers. Should the industry discontinue support of conventional lead solders and an alternative to conventional lead-based systems is not qualified for aerospace (manned and non-manned systems), all of NASA's high-reliability systems currently under construction and all future systems will be compromised.

Engineers involved with construction of existing aerospace systems and the planning of future space transport systems need to be involved in the research, demonstration and validation of lead-free solders and electronics components. Mission preparedness and success depend upon this if foreign and domestic electronics manufacturers continue to aim toward the goal of conversion to lead-free systems as the norm of the industry.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

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1.0 Summary

1.1 Problems Under Investigation

Soldered assemblies pervade many forms of electronic platforms used by the National Aeronautics and Space Administration (NASA). Any change in soldering technology therefore would have major implications for aerospace operations. Such a challenge is now facing NASA in the push towards lead-free solder fuelled by impending legislative restrictions on the use of lead and increasingly, by commercial and marketing activities overseas.

While lead free solders are purported to reduce their environmental and health risks, these new solders present certain technical risks. First, the reliability of most lead-free solders is not known for high-reliability applications. Electroplated tin is more prone to the phenomena of whiskering, which can lead to electrical shorting. Lead free solders also require different processing conditions, such as higher melting temperatures.

Whatever the driver, it is probable that lead-free soldering will become the norm for commercial applications before 2006-2007, and will shortly thereafter push for a similar switch to lead-free solder for high-reliability electronics (as is seen in most NASA applications), which commands less than 1% of the total electronics market and therefore has little say over the direction of the overall industry. Because of these pending changes and short timeframe, an assessment was conducted considering the current usage of solder across NASA's Centers in order to determine the nature and magnitude of the risk to NASA today and should the electronics industry follow through with a complete changeover to lead-free solder.

1.2 Purpose, Scope and Limitations

The purpose of the assessment was to determine the areas of risk within NASA by reviewing solder usage at several centers that are representative of the work NASA performs in the world of electronics fabrication, rework and repair. It was determined early during this process that a full assessment of every NASA Center was not feasible within the time constraints of the contract and would not be necessary to identify key areas of risk within NASA. Five NASA Centers were reviewed during the assessment for the type, frequency, purpose and function of soldering activities they were involved with. Additionally the types of projects supported and the aspects of flight versus non-flight were observed during this process.

It has already been proven by numerous health organizations, the deleterious effects that lead has on the human body. NASA has always pushed for environmental excellence among its Centers, and has set goals for itself to reduce pollution according to and beyond that which is required by Executive Orders and other legislation. While it is likely that the EPA Toxic Release Inventory (TRI) limit of lead will again be decreased in the future, it is unlikely that it will be banned for use in the United States (US) in the near future. While the hazards of any toxic substance to human health are always of great concern to NASA, it remains that if a substance has not been banned and its use is required for critical aerospace functions its use will be continued until an alternative is approved or until such time as it is banned from use and no exemptions are permitted. Because the threat to NASA programs is not driven as much by US environmental regulatory actions as it is driven by overseas legislation and industry conversion to lead-free, the environmental risks will not be covered in detail in this report. It remains to be said that NASA welcomes the opportunity to reduce pollution wherever possible as long as mission preparedness is not compromised.

Certain limitations were evident from the beginning of the assessment process. Because each NASA Center is different in operational procedure, there was no clear starting point from which to assure all areas of each facility were accounted for in our assessment of their soldering processes. In some cases, a facility may have a very accurate tracking system in place that assures the data is accurate. Other facilities have no means to track usage, procurement or workload that soldering operations account for at their Center or within each program. Because of this, estimations were necessary to give as broad a picture of NASA's overall risk as possible.

The AP2 Office assessment team defines two areas of risk that should be considered to determine NASA's position. The first area is the risk that lead-free solder ends up on a NASA system by accident. The second area is the risk of electrical failure do to the lead-free solder. For the purpose of this report, only the first area is considered. The second area is being addressed through the Joint Group for Pollution Prevention (JG-PP) lead-free solder project. The first area of risk was both quantitatively and qualitatively assessed by the AP2 Office. The goal was to determine the likelihood of lead-free solder accidentally being used (*intrusion*), the overall risk to NASA programs if the industry shifts (*obsolescence)* to all lead-free and the number of solder joints (possible points of failure) that were completed annually within all NASA Centers.

1.3 Nature and Method of Investigation

Written surveys were sent to NASA's Kennedy Space Center (KSC), Johnson Space Center (JSC), Jet Propulsion Laboratory (JPL), Marshall Space Flight Center (MSFC) and Goddard Space Flight Center (GSFC). After responses were received from these surveys, it was determined that KSC, JPL, and MSFC would be sufficient to determine overall risk to NASA because of the encompassing nature of the soldering operations they perform and their relatively large volume of solder work. Data was still collected from the other Centers and was analyzed, but could not be analyzed in as great of detail. Detailed follow-up surveys were sent to the three selected Centers and site visits were arranged at each where possible to gain an accurate picture of activities performed.

Where tracking of the amount of soldering occurring at each Center was not found, estimations were made to determine with high confidence, the number of solder joints that were newly made, repaired, or reworked annually at each shop within a Center. A qualitative determination of risk was also made through interviews of personnel. Risk was determined in two areas: overall risks to future programs should lead-free solder become the industry norm and the risk of lead-free components being introduced in error during fabrication, rework or repair.

1.4 Results and Conclusions

The results of the assessment process brought to light several areas and degrees of risk to NASA concerning lead based electrical components and manufacturing. Because of the nature of the programs NASA works with, the level of risk is more critical to that of flight hardware as opposed to ground service equipment and other non-flight articles. Another area of division is found with the type of equipment that is being fabricated, reworked or repaired within the realm of flight hardware. Three categories were derived: existing hardware (Shuttle, SRB, ISS), existing new construction (Satellites, ET, ISS), next generation Reusable Launch Vehicles (RLVs) and other future aerospace programs. These areas need to be considered in different lights because of the way each program is set up and developed.

Risk within existing hardware rework and repair is low to moderate. Specifically, the risk of intrusion of lead-free components or solders is low in flight hardware but slightly higher in ground service equipment because QA/QC is not as strict for most of those applications. Risk within the area of new construction varies from low to high depending on the Center's methods of procurement, the quality assurance and quality control (QA/QC) programs and the trend in the market toward lead-free electronics fabrication. Lastly, the risk within any future space transport systems is the highest area of risk for NASA.

Overall the points of possible risk for NASA can be determined by estimating the number of solder joints that are completed annually within the Agency. It was determined that over 6 million joints were soldered in 2002 at the six facilities that were assessed. It can then be derived that the overall risk for all NASA facilities is in the range of 8 to 12 million solder joints annually.

NASA should ensure that procurement and QA/QC is regulated for electronics to the highest point possible to assure that lead-free electronics components are least likely to be introduced into research and development and flight articles inadvertently. Personnel involved in existing hardware rework and repair should be properly trained to identify components that are lead free versus lead bearing electronic components. Personnel within these programs should also be involved in lead solder alternative projects concerning repair work because of the unique characteristics and risks involved in repairing leaded solder equipment with non-leaded solders. Lastly, it is imperative to involve engineers that are involved with future construction of RLVs and other space systems with a leaded solder alternative project as to maintain mission preparedness for the future of NASA.

2.0 Introduction

2.1 History

Tin-lead alloys have been used in electronics manufacturing since the early development of electrical circuitry. Lead is a very important material in the industry because it meets high technical standards and performance requirements and is very cheap compared to other compatible metals. It has been estimated that approximately 90 percent of all electronic components contain some amount of lead.

The negative health effects of lead on the human body, as well as the environment, have been understood for some time. Lead accumulating in the body affects brain development, neuron signaling and hemoglobin production. Lead is considered a neurotoxin and is listed by the EPA as one of the top 17 most toxic substances imposing the greatest threat to human health. The knowledge of these dangers brought increased regulation of the use of lead in household paints and in gasoline in the late 20th Century.

In 1972 the EPA began the phase out of lead found in gasoline. Since the main method of transport for lead is through the lungs, this greatly impacted human health and the results of the changeover from leaded to non-leaded gasoline was dramatic. Between 1978 and 1991 the lead level in human blood in the US dropped 78%.

Regulatory pressures have caused electronics manufactures in the United States and overseas to look for alternatives to lead in electronic components as well as in the manufacturing process. This pressure is coming from several different levels and regions throughout the world.

Effective January 17, 2001 the EPA lowered the Toxic Chemical Release (TRI) reporting threshold to 100 pounds. Executive Order 13148 requires a 50% reduction in the use of lead in the US within government agencies by December 31st, 2006. Overseas, environmental regulations and practices have led to political and financial obstacles for the electronics industry. The European Union (EU) recently created the "Restriction of Hazardous Substances" (RoHS) directive. This directive prohibits sales of some lead-containing products beginning in July of 2006. The EU also drafted legislation related to recycling entitled the "Waste Electrical and Electronic Equipment " directive (WEEE). The goal of WEEE is to increase recycling of electrical and electronic equipment in order to reduce the total quantity of waste that is disposed of in landfills. The directive calls for produces to take back and recycle electronic equipment, providing incentives to design electrical and electronic equipment in an environmentally more efficient way. Other activities, such as a pact between the US National Electronics Manufacturing Initiative Inc. (NEMI), Europe's Soldertec at Tin Technology Ltd. and the Japan Electronics and Information Technology Industries Association (JEITA) agreeing on a lead-free solder road map which would result in eliminating lead solder from manufacturing processes by 2005 is another example of world-wide activities that will impact the electronics industry.

These directives not only impact those in the EU, but anyone selling electronic products to Europe and anyone receiving electronics components from Europe. This and other directives also require manufacturers to make end products recyclable. Since working with lead is considered hazardous, recycling other metals used in solders is seen as preferred. Japan is also working on plans with the Ministry of International Trade to phase out lead within its manufacturing processes.

Additionally to legislation, market pressures exist. Consumer awareness of environmental impact has been proven to be an effective marketing point. Consumers prefer products that are perceived to be environmentally sound. This has caused manufactures in Japan and other locations overseas to move toward lead-free products despite any strict legislation banning its use.

2.2 Significance

The significance to the Aerospace community, namely NASA, of pending regulations and market pressures is very high. The aerospace and military communities as a whole represent less than 1% of the electronics fabrication worldwide and therefore have little say as to how the market and industry should conduct their business. Not being integrally involved with the conversion to lead-free electronics could hold disastrous consequences for nearly all aerospace and military electronics applications and most certainly will effect mission preparedness on numerous levels.

While lead-free solders are purported to reduce environmental and health risks, these new solders present certain technical risks. First, the reliability of most lead-free solders is not known for high-reliability applications. Electroplated tin is more prone to the phenomena of whiskering, which can lead to electrical shorting. Lead free solders also require different processing conditions, such as higher melting temperatures. While the push toward lead-free solders was likely to occur in the future at some point in time, recent interest and regulatory activity overseas has the high probability of shifting the phase-out of lead solder to the extent that NASA programs will be affected sooner than anticipated previously.

2.3 Purpose

It has been determined that there is not currently a highly reliable lead-free alternative to tin-lead solder and leaded components that is qualified to be used on mission critical hardware within the Aerospace community. Nearly all applications where solder is used within NASA require high reliability electronics. The programs within NASA require high reliability electronic components, however, because NASA's share of the electronics market is so small, they are dependant upon the use of commercially available parts and assemblies. Even if the Aerospace and Military communities can gain exemption from any legislation that bans the use of lead-bearing electronics components, any regulations on commercial manufacturing or industry shifts that eliminate lead-bearing components would prohibit NASA and other agencies from attaining needed high reliability electrical components.

Concern is amplified by the fact that supposed high reliability components bearing pure tin (lead-free) finishes have been observed on purchased parts in the Aerospace and Military communities despite contractual prohibitions and strict performance and procurement standards. Additionally, failures of military and aerospace equipment attributed to the use of lead-free solders have been documented.

These concerns led experts within the Agency to conclude that an investigation of NASA's current lead solder usage and applications that are at risk was necessary in order to understand the importance of NASA's involvement in the movement toward lead-free electronics manufacturing.

2.4 Scope

The scope of the assessment includes detailing the solder usage at several NASA Centers that are representative of the overall types of electronics soldering activities ongoing throughout the Agency. Since little was known previous to this activity about the soldering activities occurring at the various NASA Centers a survey was developed and sent to the most probable representatives of NASA's soldering activities. After initial surveys were returned, the Centers to be assessed were down selected to three. The Centers most likely to represent NASA's overall solder usage that can be assessed adequately were chosen as the candidates for this down selection. Any useful information gained from the preliminary survey was also considered in the results of this assessment.

Identification of the types and quantity of risk to NASA in the area of electronics workmanship is a second area of the scope. To quantify risk it was determined that the number of components and ultimately the number of joints soldered annually would be an indicator of risk. This is justified by the fact that each joint is susceptible to failure in several dimensions, and failure of a component is the end result of that risk. Additionally, the type of risk (qualitative) needs to be identified and the severity of that risk determined.

Three general categories of risk are covered in this assessment. The first category is currently ongoing program (Ground Service Equipment (GSE), Space Transport Systems (STS)) risk due to the unintentional introduction of lead-free components or solders and the risk should leaded components not be available for those current program applications. The second category is current new fabrication and rework (Satellites, Research and Development (R&D), GSE) risk due to the unintentional introduction of lead-free components or solders and the risk to this work should leaded components not be available for that fabrication. The third area of risk is "future programs" (STSs, Satellites, GSE) should lead-free components or solders be introduced or should leaded components or solders not be available in the future for those programs.

2.5 Author Development

This report will describe the current situation and considerations related to lead bearing solders and components and the movement within the industry and regulatory bodies to convert modern and future electronics to lead-free systems. The methods and procedures used to collect the information presented in the report will be detailed, along with the results. Along with the information derived during the assessment process each facility that was reviewed will be discussed. Centers relations and ongoing activities related to electronics fabrication, research and maintenance would also be discussed as well as how they relate to other Agency centers or programs. Data gathered and calculated during the assessment as well as observations made through interviews and site visits and how those observations relate to relative risk of each program or center will likewise be presented. Lastly, conclusions and recommendations to NASA stakeholders based on the results will be covered.

3.0 Methods, Assumptions, and Procedures

3.1 Description of Study

The NASA solder assessment covers two main areas of interest necessary to determine risks related to the recent movement towards lead-free electronics systems. In order to determine the overall level of risk quantitatively, some number detailing the risk to NASA must be derived. The assessment team determined that the number of components and ultimately the number of electrical joints soldered would give a picture of this risk. Second to this, risk must also be qualitatively determined. All qualitatively determined risk is attained through interviews or observations made during site visits. In order to determine risk in this way, the types of risk and areas where risk may be present need to be identified. It was determined early in the process that two main types of risk are critical to understand for risk to be assessed within NASA, *intrusion* and *obsolescence*.

The first area of qualitative risk is *intrusion*. Intrusion can be defined as lead-free components, solder or systems being integrated into high reliability systems inadvertently. Since high reliability systems have technical and performance standards that no lead-free solders have yet been qualified for, and since occurrences of intrusion have already occurred, this was considered as the first area of risk to be reviewed qualitatively. The second area of qualitative risk is *obsolescence*. Obsolescence for the purpose of this report is the concept that some high-level changes are already occurring within the electronics manufacturing industry overseas as well as in the United States that will ultimately shift the electronics industry to lead-free within a short timeframe. It is estimated that as early as 2006 the use of lead in some electronics may be banned. Should the industry continue to shift in this direction there is a serious risk to all high reliability electronics. Since NASA and the DoD only represent a small portion of the electronics consumer base, there is little that can be done to sway these electronics manufacturing leaders or those creating such legislation banning lead based electronics overseas.

3.2 Methods and Procedures

Initially, five NASA Centers were selected to review for the possibility of site visits and/or detailed telephone interviews with personnel to determine which Centers would best represent the overall use of lead solder and other lead-bearing components throughout NASA. The five Centers selected were Goddard Space Flight Center (GSFC), Jet Propulsion Laboratory (JPL), Johnson Space Center (JSC), Kennedy Space Center (KSC) and Marshal Space Flight Center (MSFC). These Centers were chosen based on the assessment team's personal observations of each facility and/or preliminary research performed to determine the work done at each center involving lead soldering. Personal observations were made during the NASA AP2 Offices Pollution Prevention Opportunity Needs Assessments (PPONAs). That exercise resulted in site visits at each Center and reviewed all major industrial and manufacturing operations that involved hazardous materials.

The first stage of the process was a preliminary survey that was sent to each of the five centers. The preliminary survey can be found in *Appendix A* of this report. At this time in the process, personnel at KSC forwarded the survey to Boeing personnel located in Palmdale, CA. where some Space Shuttle related soldering work is performed. Because the estimations received from this shop showed evidence of significant solder work being performed, it was at this time that "KSC-Palmdale" was added to the list of assessment locations, bringing the total to six locations reviewed by the team. Upon receipt of the initial surveys, the largest users of lead solder were identified along with the type of work performed (new, repair, rework), kind of operations (manual, wave, reflow, vapor-phase) and what type of programs that work supported.

It was determined that a more detailed survey was necessary to gather all of the information required for the site visits and for the report. The detailed survey can be found in *Appendix A* of this report. The surveys were distributed to each shop that performs any soldering operations. The detailed surveys returned along with interviews allowed the assessment team to build tables to better understand the data gathered and to calculate the number of risk points associated with each shop and each Center, these tables can be found in *Appendix B and C*. The level of risk for each Center was determined through interviews with personnel involved with programs at each Center that perform soldering operations. A brief outline of questions asked during the interview process can be found in *Appendix A* of this report.

3.3 Travel, Interviews and Site Visits

From the information gathered during initial surveys and the AP2 Office's personal experience with each location taken into account, three Centers were initially chosen for site visits, KSC, JPL and GSFC. Limited funding for travel to each center necessitated the initial down selection and further defined what site visits were to be performed and how we would proceed with any future data gathering. After further travel funding consideration and some telephone interviews with GSFC, it was determined that there would be very little value added to a site visit to GSFC. It was felt by the team that observations made in late 2002 during the PPONA performed at GSFC would be sufficient for the purposes of this assessment and that telephone interviews would prove sufficient for gathering the remaining information from their Center. Because ITB Inc. has personnel located at MSFC capable of performing an assessment it was added to the list of sites to visit. Despite the fact that only one shop at MSFC performs soldering operations, the assessment team felt this site visit would prove valuable as an example of small scale soldering operations that occur at nearly every NASA Center.

Because of funding and time constraints it was determined at this point in the process that most of the information would need to be gathered digitally or during telephone interviews. Site visits were performed at four shops within KSC, one shop at MSFC and one major shop at JPL. Although site visits were only possible at three Centers, detailed follow-up surveys were sent to each center and interviews were conducted with personnel at JPL, KSC, GSFC, MSFC and KSC-Palmdale. JSC and KSC-Palmdale only returned a preliminary survey outlining overall usage of solder annually. While KSC-Palmdale was available for interview, JSC did not return any further request for information. The initial data gathered was still rolled into the overall summary of total risk points calculated for NASA.

Generally, site visits answered all questions needed to complete the report for those areas, however sometimes follow up phone interviews were conducted. Interviews were performed after the secondary detailed surveys were returned and typically several follow up interviews were made to the same shops to answer any further questions that arose from the assessment process or in studying the data.

3.4 Assumptions

Several assumptions were made in order to estimate the quantitative risk to NASA. To estimate risk quantitatively, it was necessary to calculate the number of solder applications (joints) that could be accomplished per solder roll used. It was determined by the assessment team that approximately 16,939 joints could be completed per 1 lb roll of solder. The methods and support for this calculation are given in *Appendix D* of this report.

Because intrusion of lead-free components had already occurred within aerospace systems and organizations (Boeing), the DoD (Army, Navy, Air Force) and other high-reliability electronics manufacturers, it was assumed that the methods by which that intrusion occurred could also occur within NASA as long as the errors causing that intrusion were found within the vendor and not the agency in question. In most documented cases of intrusion, the agency involved ordered components according to specifications, but non-qualified parts were delivered to the agency. Because parts were ordered to specification it may have been assumed that they were acceptable and thus used on high-reliability equipment.

For future risk, it was assumed that the all manufacturers would move to lead-free systems, but that lead solder and components could still be used (i.e. exemptions are given to NASA to allow the use of lead based components and systems, but the industry makes a switch to lead-free.). While this would allow NASA to support operations of current systems and systems that components were already ordered for or could be constructed by NASA, it still leaves risk in that many components and vital systems are procured from the industry manufactures and it is not feasible for NASA to manufacture all of their own electronics systems.

3.5 Standards

NASA uses several universal standards for electronics manufacturing and workmanship of electronics equipment. These standards must be met at all NASA Centers. Some Centers have authored their own standards but they must at a minimum meet the NASA wide standards. NASA HQ owns the workmanship standards for all electronics related processes. These standards are generated, maintained and updated by the NASA Workmanship Standards Technical Committee that consists of technical representatives from the NASA field Centers. Generally, each project (Shuttle, ISS, satellites, etc.) has its own specifications and quality plans and they may or may not reference the HQ level standards, nonetheless these standards must be met. A list of standards that NASA follows for soldering activities is found in *Appendix E* of this report.

4.0 Results and Discussion

4.1 Results

Site visits were performed at three NASA Centers, and telephone interviews were performed at two additional Centers. Overall there were several major differences in the procurement and Quality Assurance / Quality Control (QA/QC) systems between the Centers assessed. While some Centers have very strong confidence that intrusion of lead-free solders is a very remote possibility other Centers admittedly do not test every component that arrives at the facility. The concern exists because lead-free components have been integrated into other systems within the DoD and aerospace industries even though strict standards exist for those high-reliability applications. Centers with centralized QA/QC and procurement departments within their electronics branches are more likely to catch an error in procurement and are better equipped to make changes to their procurement and QA/QC systems to ensure that this risk is minimized. Some Centers interviewed or visited had multiple methods for attaining components and solder other Centers ordered components through different contractors or vendors depending on the program that was supported. Each Center interviewed stated that the standard for electronics was met through procurement, and that QA/QC is present to test for reliability, but not every component is tested.

4.2 Surveys, Site Visits and Interviews Performed at KSC

The assessment team visited four shops at KSC and interviewed several others in addition to those visited. Twenty-six shops sent surveys to the AP2 Office. Shops using the highest amount of solder were targeted for site visits. Building K6-1247 rooms 2, 3, 4, and 14B Building K6-1094 room 10, Building M7-505 room 1220 and the NSLD 1 room 300 (NASA Shuttle Logistics Depot) were chosen for these site visits. Additionally, the QA/QC for K6-1094 was contacted as well as the procurement office in charge of obtaining components for repairs performed in that shop. While obtaining solder usage information at KSC, the AP2 Assessment Team was informed that the Shuttle Orbiter program in Palmdale, California (CA) was also using lead solders for repair and modification work to the Shuttle. This location is covered separately in Section 4.3 "*Surveys, Site Visits and Interviews Performed at KSC-Palmdale"*.

4.2.1 <u>Building K6-1247: Rooms 2, 3, 4 and 14B</u>

4.2.1.1 <u>Description of Work Performed</u>

Within Building K6-1247 at KSC, United Space Alliance (USA) performs soldering in support of Shuttle ground operations; including the Mobile Launch Platform (MLP), Shuttle Processing Systems, Logistics, NASA funded modifications, Consolidated Space Operations Center Communications and Operational Television systems. Ground support equipment is the primary focus of work, with the exception of wiring cables and equipment related to the pyrotechnics for Solid Rocket Booster (SRB) hold-downs and heater cables for the O-rings. While some work is new fabrication (as all cables associated with pyrotechnics are replaced after each launch) a majority of work performed here is to replace older worn-out or failed cables or repair those cables if possible. Manual soldering and some reflow soldering is performed within K6-1247. Nearly all work performed is on cables, cable harnesses and associated sub-assemblies. Half of the cables produced are crimped, and half are soldered. Approximately 20 lbs of solder was procured for use within K6-1247 in 2002.

4.2.1.2 <u>Details of Work Performed</u>

In 2002, this shop prepared over 900 electrical cables, 26 wiring harnesses and associated sub-assemblies. Cables vary in size from 2-200+ feet and the number of wires within each cable can vary from 2-100+ per cable. Cables are manufactured to specification and designs for each job are incorporated with the resources (wires, solder, connectors) needed to build the cable in a kit. Procurement orders lead solder according to the specifications.

Work varies within K6-1247 and work and materials are not quantitatively tracked. Only a small portion of the work performed is repeated during the processing phase of a shuttle launch and because of this, estimation of the amount of solder that actually is on-cables is difficult to determine. The Acquisitions Pollution Prevention (AP2) Office estimated that if 20 lbs of solder were used annually, this represents the equivalent of 300,000 typical solder joints. Some cables manufactured require much larger amounts of solder than would be used on a typical component soldering operation and many cables have hundreds of wire connectors that require both tinning and soldering on each end.

4.2.1.3 How Work is Accomplished

Most of the work performed within K6-1247 is on an as needed basis. When a cable needs to be replaced it is identified, specifications and drawings are made or pulled from the archives and the shop receives the proper materials to assemble the cable. Aside from this work, there are routine jobs performed after each launch and during the shuttle processing operations for the MLP and the SRBs. Once cables are finished, they are checked for quality on site, certified and sent to the proper end user.

4.2.1.4 Risks

Risks for the shop within K6-1247 vary from low to moderate. Much of the equipment that cables are fabricated for are used on ground service equipment. While much of this work is at risk for failure should lead-free solders intrude into those systems, many are not flight critical, and this would only represent a risk of increased costs and not necessarily flight risks. However, some cables are manufactured for the purpose of warming the O-rings on the SRBs and for detonating the pyrotechnic hold-downs for the SRBs. Either of these systems inherently holds a higher level of risk to flight should lead-free solder cause a failure of those cables. Risk for the shop is limited, however because only half of the cables within the shop are soldered, while the other half are crimped. Another limitation of this risk can be found in procurement and the QA/QC process in place. Currently, materials are procured and each cable is tested before it is certified and sent to its final destination. This minimizes risk, but does not eliminate it completely. Additionally, personnel within the facility should easily recognize the difference between lead-free and lead based solders, and this will further limit the risk for this area of KSC. Moderate to high risks of obsolescence do exist should lead-based solders be effectively banned. While it is not likely that this would occur without the shop preparing in advance for such a change, it does pose a risk to future space transport systems and infrastructure that are dependant upon similar ground support equipment cabling.

4.2.2 Building K6-1094: Room 10

4.2.2.1 Description of Work Performed

Within Building K6-1094 at KSC, USA performs soldering operations on ground support equipment (CCMS, Firing Room, Hardware Interface Modules on MLP, Launch Room Consoles, Monitors, etc.). Work at this location consists of new fabrication (10%), rework (10%) and repair (80%) operations. Typically, manual soldering and lead tinning is performed while fabricating or repairing cables and connectors. Performing soldering operations, the shop used approximately 4 lbs of solder in 2002.

4.2.2.2 Details of Work Performed

Work performed within the shop consists of the replacement of faulty equipment or components used within the Firing Room or other ground support equipment. The shop possesses a reflow soldering machine but has not used it yet. In 2002, approximately 400 plated through hole components, 150 surface mount components and 50 cable/wire connectors were worked on within K6-1094 at KSC.

4.2.2.3 How Work is Accomplished

Equipment that needs to be repaired is sent to K6-1094. Within the shop, the faults are identified, repaired and tested for quality assurance. Once a faulty component is identified, procurement is notified and the part is ordered. While most components are available within the store stock at KSC, some are required to be ordered from outside vendors. If new components are ordered, QA/QC is tasked to identify that the product received is the one ordered based on the labeling of the received item. QA/QC work on the actual components may not be performed, but equipment is tested thoroughly before it is certified as repaired and sent back to the customer.

4.2.2.4 Risks

Risks within K6-1094 at KSC are low to moderate. Only limited numbers of components are required to be ordered annually, those components represent the highest risk to this shop of intrusion. Because most work within the shop supports ground service equipment, the risks may be cost related but not as critical to flight safety. The risk of intrusion is greatest within this shop because not all components are fully tested to determine that they do meet specification. Further risk of obsolescence exists for all future programs that may be developed at KSC. Flight support operations, including flight control operations could be affected by industry shift. If lead-free solders are involved with future space flight GSE, it can represent a large area of risk if the reliability of those replacements is not fully realized.

4.2.3 Building M7-505: Room 1220 (Carmen Moore)

4.2.3.1 Description of Work Performed

Within Building M7-505 at KSC, Boeing performs soldering operations that support both space flight (ISS, Shuttle, Checkout Assembly and Payload Processing Services) and ground service equipment (Mobile Launch Platform). Work at this location consists of new fabrication (80%), rework (10%) and repair (10%) operations. Typically, manual soldering and lead tinning is performed while fabricating or repairing cables and connectors. Approximately 15 lbs of solder were used in 2002 for manual soldering, and 12 lbs was used in solder pots for tinning leads for cables. Personnel within this shop stated that less than 20% of all work performed at that shop used solder because most space flight cables are crimped, not soldered. Crimping is preferred because it is easier to qualify for flight.

4.2.3.2 Details of Work Performed

Cables manufactured within M7-505 range in size from 0.5 - 2+ inches in diameter and vary in connections from 2 - 100+ individual wire connectors per cable. Cables are manufactured to specification and designs for each job are incorporated with the resources (wires, solder, connectors) needed to build the cable in a kit. Cable designs and kits are created and assembled by design engineers not located in the shop.

Because of the programs that are supported for which cables are fabricated within M7-505, each cable manufactured here is unique. There are no common cables repeatedly constructed, and the amount of work performed, with or without solders, is not tracked. Personnel estimated the number of cables manufactured within their shop as less than 1000 in 2002. Of those cables, only 50-100 involved soldering. Personnel who were asked to estimate the amount of solder that is applied per connection stated they could not because soldering is performed to visual standards and not by weight or quantity. It is believed that more solder is procured for the shop than is required annually. For each cable that is fabricated, if solder is required, a roll of solder is included in the kit with the direction to 'solder as required.' If solder remains after work, it is stored within the shop for later use.

4.2.3.3 How Work is Accomplished

Workflow is as follows for M7-505: It begins when design engineers that work for Boeing receive drawings for cables that are needed. Upon receipt, a document outlining the construction is written, designs are modified, if necessary, and it is sent to a materials specialist. The materials specialist assembles the parts required for the job and performs some QA / QC is performed here prior to assembly. The kit is next sent to the shop where it is put together according to the drawings. After completion, QA / QC is performed and upon passing, it is sent to customer. No work within this cable fabrication shop is outsourced.

4.2.3.4 Risks

Risk within M7-505 at KSC is low. Most cables manufactured are crimped, not soldered on-site, less than 15 lbs a year of solder is actually used. Most of the solder procured is disposed of as waste. Personnel stated the reason given for this low usage is that crimping is easier to qualify for flight than soldering. Risk of intrusion is very low since only cables are fabricated within the shop, the likelihood that a lead-free solder would be procured and not noticed is extremely low. Lead-free solders look and perform noticeably different than lead-based solders. Industry shift does present an obsolescence risk to this shop if lead-based solders are banned, but only to < 20% of the work performed within the shop.

4.2.4 Building NSLD 1: Room 300

4.2.4.1 Description of Work Performed

Within the NSLD 1, Room 300, United Space Alliance (USA) performs numerous soldering operations annually in support of the space shuttle orbiter. The NSLD is qualified to repair over 300 pieces of shuttle equipment, including avionics boxes, computer assemblies, cables, displays, antennas, hand controls and other various electronic assemblies. Additionally, the NSLD performs a minimal amount of new fabrication in building pyrotechnic cables and bolts used as hold-downs on the Solid Rocket Boosters (SRBs). Within the shop, reflow, wave and manual soldering operations are performed. There is also a solder pot on-site for tinning leads and components prior to soldering them to a piece of equipment. A total of 25 lbs of solder was procured in 2002 for NSLD 1, a majority of that solder is used in the solder pot on site and a majority of it is disposed of as waste. It was estimated that only 4 lbs of solder wire is used annually within the facility. Work at this location consists of new fabrication (4%), rework (48%) and repair (48%) operations. Manual soldering is performed most often to repair Shuttle equipment. Components that are required to support the repair operations at the NSLD are commonly tinned prior to being soldered. All repair work is performed as needed. The NSLD shop consists of a large room filled with work areas, benches, test equipment (antenna, electronics shock and heat testing equipment, etc) and soldering stations. The entire shop is a clean area; only authorized personnel may enter work areas and touch equipment that is to be worked on. There are approximately 9 workstations within the shop, each possessing one or more rolls of solder. It was estimated by personnel that a roll of solder would last one workstation 2-5 years.

4.2.4.2 Details of Work Performed

The NSLD primarily supports the Space Shuttle Orbiter program and performs nearly all repair work to any components that have failed prior to or during flight of a mission. Since most avionics boxes and other electrical equipment within the shuttle were originally designed in the 1970's, components needed for repair are rare and sometimes irreplaceable. The shuttle operates on a triple redundant system, to ensure that should a device or component fail, backups will allow for a safe mission and return to earth. Additionally, avionics systems and other electrical devices on the shuttle have numerous back-ups on the ground. When an article fails either while testing or during flight, it is returned to the NSLD for repairs. When repair is not possible because components do not exist, the backup units are used.

The NSLD supports the ongoing space shuttle program. Repairs of equipment are necessary to keep the fleet operational for the duration of the program. Nearly all components necessary to repair these components are already procured and are in store stock. The NSLD is planning on purchasing all of the solder that will be required for the lifetime of the program to ensure that intrusion of a lead-free solder is not a risk. It was estimated by the assessment team that in 2002, over 60,000 solder joints were worked on within the NSLD. Personnel at the facility were aware of the possibility of a changeover to lead-free solders and were preparing appropriately to ensure readiness and reduce the chance of materials obsolescence.

4.2.4.3 How Work is Accomplished

When a component aboard the shuttle fails, it is removed at the Orbiter Processing Facility (OPF) during normal maintenance for the turnaround to launch. If an identical component exists and is flight tested, it replaces the faulty component while the original is being repaired at the NSLD. All repair work is performed on an as needed basis. Components may fly aboard a shuttle numerous times before they are sent to NSLD for any work. Once the component is checked into the NSLD it is tested, torn down and evaluated to determine the fault. Once this is determined, a plan for the repair work is written. The component is repaired accordingly if possible and is next tested for flight readiness. All components are thermo-chamber tested and vibration tested to assure they are ready for flight. If failure occurs during this testing it is sent back for rework or more repair. This process is repeated until the component is certified for flight. The components are then sent back to the OPF for integration to the shuttle or storage.

4.2.4.4 Risks

Very little risk exists within the NSLD shop of lead-free solders or components being accidentally introduced into critical flight systems. Only very minimal risk exists to the new fabrication that exists should the industry changeover to lead-free systems. Currently, only small amounts of solder are used annually, and the work that is supported is thoroughly tested before it is certified as ready for flight. All components are tested prior to integration into a system; they are tinned on-site and incorporated into the item in need of repair. After repairs are made, it is again tested. It is very unlikely that a lead-free solder or component would survive all the QA/QC present here. The main risk within the NSLD, and the shuttle program overall is if the potential for obsolescence is not properly understood. It appears that the personnel at the facility understand the potential for this and are preparing accordingly.

4.2.5 KSC Overall:

According to data gathered by the AP2 Office, KSC used approximately 110 lbs of lead solder in 2002. Of that, over 30 lbs were disposed of as waste. The remaining 80 lbs is on finished products or repair work. This shows that KSC performs over 1.3 million solder applications (joints) that year. A table detailing the data collected from each KSC location is found in *Appendix B & C* of this report.

During site visits, telephone interviews and through the two surveys sent to each shop using solder at KSC, several areas that possess possible risk to NASA exist at KSC. The first area of risk is that of intrusion of lead-free components or solders into high-reliability systems. Numerous pieces of flight hardware, flight critical ground service equipment and other logistics equipment is repaired and maintained annually at KSC. Most systems at KSC have low risk of intrusion either because all components have been ordered and exist in current stocks, or because work only utilizes solder (cable fabrication) where identification of lead-free solders would be easily accomplished. Risk still exists of intrusion in several areas where components are ordered from vendors for repairs to equipment used in the Launch Control Room, Firing Room and on the MLP. The QA/QC procedures could not clearly be identified for all locations during the assessment, but these procedures should be reviewed to minimize the risk of intrusion. The more likely area of risk to KSC exists in future programs. Should the industry shift to lead-free systems and components, any future space transport systems (RLVs and satellites) and all related logistics equipment necessary to accomplish processing and launch of that system will be affected. If lead-free alternatives are not considered during the planning stages of next generation RLVs high risks exist that will adversely affect costs, mission preparedness and safety.

4.3 Surveys, Site Visits and Interviews Performed at KSC - Palmdale:

The AP2 Office was notified of the Palmdale, CA operations while sending surveys to KSC. Boeing sent a response to the survey to the AP2 Office, and follow up interviews were performed for this location. Work performed in Palmdale is similar to that performed at the NSLD at KSC. All work here supports the Space Shuttle program. It is estimated that thousands of pounds of lead-bearing solder are incorporated into the space shuttle systems. Solder usage and programs supported by KSC-Palmdale are detailed in *Appendix B* of this report.

4.3.1 Boeing Operations in Palmdale, CA

4.3.1.1 Description of Work Performed

Annually, over 100 lbs of solder are procured for use in programs related to the shuttle at Palmdale. The Shuttle relies upon a variety of soldering processes, including manual, wave, reflow, vapor phase and perform soldering.

4.3.1.2 Risks

The Boeing team located in Palmdale is currently performing a self-assessment concerning the potential for lead-solder obsolescence. Risks have been determined to be a "tremendous processing impact if potential obsolescence of leaded solder is not understood." The overall objective of their assessment is to determine all of the obsolescence concerns, to define the Shuttle's reliance on leaded solder, to define the status of lead-free solder replacements and to look into the military and industry replacement plans. Upon completion of the assessment recommendations will be made for the future of the Shuttle program concerning lead based solders. Boeing has estimated that an obsolescence issue may potentially affect the shuttle program as early as 2004.

4.4 Surveys, Site Visits and Interviews Performed at JPL:

Only one area of JPL was reviewed during a site assessment due to time constraints. However, the members of the assessment team recently visited JPL for pollution prevention assessment and were familiar with operations at the facility. Additionally, JPL has a remarkable tracking system for materials, work performed and hazardous materials usage. These resources allowed the assessment team to identify more clearly than at any other center, the amount of solder usage that exists within JPL.

Overall, six locations were reviewed for solder usage. Surveys were sent to each area and were returned with detailed information. Follow up surveys clarified much of this information and answered more detailed questions.

In 2002, JPL used over 200 lbs of solder. Of the approximate 200 lbs, only 64lbs were incorporated into equipment while fabricating. Much of the solder was disposed of as waste from solder pots and reflow machines. JPL performs soldering operations for flight hardware, ground support equipment and research and development. Solder usage at JPL consists of new fabrication, rework and repair operations. Nearly all equipment is new fabrication and rework or repair related to that fabrication. Many articles are in the R&D stages (proof of concept, etc.) before they are considered for flight. In 2002, JPL procured just over 200,000 components for use in projects on-site. This represents over $4 million dollars in components for use in those projects.

4.4.1 Building 103A, Room 108: Surface Mount Technology Laboratory (SMT):

4.4.1.1 Description of Work Performed

A walk-through was performed by a member of the assessment team at the SMT laboratory within JPL. During the assessment, personnel notified the assessment team that the SMT lab and the Micro-Devices Laboratory (MDL) were the top two solder users on-site. Nearly all work performed within the SMT is flight critical, and the operations that are ongoing at both labs are very unique. JPL performs reflow soldering for surface mount technology within the microelectronics laboratory on-site. Additionally, a large amount of the solder necessary to perform this activity is disposed of as waste. Solder in pots and in reflow machines can only be used a limited number of times before its purity is compromised and must be replaced. Because of this, and because some solder pots were decommissioned, over 100 lbs of solder was disposed of in 2002.

4.4.2 All Other Locations within JPL

4.4.2.1 Programs Supported

Programs that JPL support are numerous. Approximately thirty major projects are currently ongoing at JPL. These programs include CLOUDSAT, Deep Impact, Laser Mapping (LAMP), Herschel, CNES07 Orbiter, Electronic Nose, Microwave Limb Sounder, Mars Rovers, Kepler, etc. Soldering processes include manual, tinning and reflow soldering. Solder usage and programs supported by areas at JPL are detailed in *Appendix B* of this report.

4.4.2.2 Record Keeping and QA/QC

JPL has very detailed record keeping systems that allowed the assessment team to determine the amount of solder to a close approximation that is applied to components Center wide. Additionally, it could be determined through their records the number of components and the cost associated with those components. In order to keep their procurement and materials tracking systems as reliable as possible, JPL has centralized all component purchasing and the QA/QC associated with those components. This allows for JPL to minimize the risk of faulty components or unknown vendor's components from being incorporated into high-reliability systems without their knowledge. While every component is not tested before it is sent to the end destination, many of them are tested for quality, all are checked into the facility and part numbers are cross referenced to assure the proper components are received. Even though the operations and programs were very diverse and no common repetitive activities were ongoing at JPL, the information that is continuously tracked by the Center allowed the assessment team to determine that approximately 1.8 million solder joints were processed in 2002.

4.4.2.3 Risks

Risk at JPL ranges from low to moderate. Risk of intrusion at JPL is very low, QA/QC is closely monitored and there is only one location that performs these duties. This allows for tight restrictions on components that are permitted and affords the Center more control over components for high-reliability systems. Because all components are tracked and checked prior to getting to the shop, this greatly reduces the risk. Risk to future programs is the highest risk factor for JPL. If the industry converts to lead-free systems, JPL programs are at higher risk of obsolescence than programs such as the Shuttle, which have the possibility of stockpiling the required solder and components necessary for the life of the program. Programs at JPL are constantly changing and new projects are started all the time. New components must be acquired to support these programs. If the major electronics manufactures shift to lead-free systems, this puts soldering operations at JPL at risk. If lead-free systems and solders are not considered now, the risk of a failure due to lead-free intrusion increases. Personnel at JPL have already started testing alternatives to lead based solders used at JPL. It is recommended that personnel continue to be involved so that their expertise can assist manufactures in providing an alternative to currently use lead-based systems.

4.5 Surveys, Site Visits and Interviews Performed at MSFC:

The AP2 assessment team requested the assistance of ITB, Inc. personnel working at MSFC in providing a site-visit to the one location that returned a survey from MSFC. It is believed with strong confidence that this location represents the majority if not all of the soldering activities that are performed within the Center. Solder usage and programs supported by areas at MSFC are detailed in *Appendix B* of this report.

4.5.1 The Manufacturing Services Building, B4705, Room 120

4.5.1.1 Description of Work Performed

The assessment team visited the one location at MSFC that reported solder usage, Building B4705, Room 120. The site was chosen to represent the level of activity a small lead solder use NASA Center might encounter. The shop performs manual soldering and tinning to support several programs within NASA.

4.5.1.2 Details of Work Performed

Work performed within Building B4705 consists of new fabrication (80%), rework (10%) and repair (10%) operations. MSFC estimates about 10,000 manual solder joints are completed annually using approximately 0.0112 oz (0.0007 lbs) per joint. This estimate is higher than the amount estimated by the assessment team on the order of magnitude of 10. Personnel estimated that annually, approximately 50 plated through hole boards, 50 surface mount boards and 25 cables are manufactured within the shop. Soldering pots used for tinning and manual soldering use approximately 10 lbs of solder annually (on-component). Approximately 35 lbs of solder are procured annually and 25 lbs are disposed of when fresh solder is needed in pots. One contractor procures both solder and components and performs QA/QC reviews of procured items. All items are procured to NASA specifications according to personnel on-site. When orders are received, the QA/QC technician checks the requisition and the paperwork to assure the proper materials were received. It was not determined if components were checked visually or otherwise that they were indeed lead-bearing as opposed to lead-free components.

4.5.1.3 Programs Supported

Personnel at this shop perform tinning and solder operations primarily for research experiments that fly aboard the ISS and Shuttle. Projects vary from month to month and year to year. Projects supported include, Environmental Control and Life Support System (ECLSS), Space Station Urine Recovery System, Micro Gravity Science Research Rack (MSRR), g-LIMIT (micro gravity experiment), Micro gravity Science Glove Box, DELTA-L (ISS experiment - mostly cables), PROSEDS (Tethering system, ISS experiment), SUBSA, and Quench Module (QMI - insert into MSRR). Each of the above projects has been supported by MSFC in development and flight article construction.

4.5.1.4 Risk

The overall risk to MSFC is low to moderate. The risk of intrusion of lead-free components in new fabrication is moderate due to the QA procedures and assumptions made by personnel within the shop. If the QA process consists of only checking requisitions and paperwork, then a lead-free component could intrude the system, as has happened to other DoD agencies. Ongoing work typically consists of repair and rework during development. Since this would more than likely consist of components already purchased, the risk is lower. Additionally, most experiments worked on are not generally repaired after 2-3 months. Experiments will fly aboard the Shuttle once and generally have replacement boards in case problems occur.

However, high levels of risk are present in future constructions and construction of equipment in coordination with the European Space Agency (ESA). As the industry has already begun a shift to lead-free components, personnel within the DoD and other high-reliability electronics manufacturing applications are seeing components arrive that are suppose to be lead-bearing and are not. This increasing possibility of intrusion will gradually increase the possible affects on each new project. High levels of risk are also present should the industry convert to completely lead-free. Personnel at MSFC felt that as long as the NASA specification was being met, they would not be impacted by a change to lead-free solder. While this is true, no lead-free solder has been approved for any operations performed for flight within MSFC or any NASA Center.

Additional risks for MSFC exist in their efforts with the ESA on current and future projects. Because the European Union and the electronics manufacturing industry within Europe are moving toward lead-free systems, a compatibility issue may soon be present within such current projects. Personnel at MSFC stated that NASA was coordinating with the ESA on some experiments to fly on the ISS, including ECLSS, MSRR and QMI. This is an area where possible compatibility issues may arise if the ESA includes lead-free components or systems in their portions of those projects.

4.6 Surveys and Interviews performed at GSFC:

The assessment team did not perform a site-visit to GSFC, but were able to collect some valuable information with the two surveys sent to each Center and with follow-up interviews concerning solder usage, procurement and QA/QC. Solder usage and programs supported by areas at GSFC are detailed in *Appendix B & C* of this report.

GSFC soldering activities support numerous project and facility operations. A majority of the work is manual soldering, but some reflow soldering is also performed on-site. From the initial survey sent to GSFC, thirty shops within the facility responded. Only one shop reported that they generated more than one pound of solder annually. This shop was located in Building 16W, Room S010.

Personnel within this shop were contacted for interview to better understand the work performed within their shop and within GSFC as a whole.

4.6.1 Building 16W, Room S010

Work performed within this area supports various projects such as IRAC, EO-1, TRIANA, ST-5, Leonardo, Wide Field Camera and SWIFT. Annually, 8.2 lbs of solder paste and 3 lbs of solder core are used to support these and other programs. While primarily new fabrication occurs within the shop, some repair and rework is performed as well. According to personnel within the shop, there are several other areas within the facility that use similar amounts of solder, but did not send surveys back to the AP2 Office. According to calculations made by the assessment team, it is estimated that this shop completes over 100,000 solder joints annually.

4.6.2 Other Shops

Other areas with GSFC use solder, but in much lower quantities. Similar projects are supported as well as facilities and institutional functions. Work performed at GSFC includes cable fabrication, instrument testing and maintenance, testing, coupon qualification, surface mount technology, plated through hole, and other types of related electronics manufacturing and maintenance work. Much of the work performed is research and development for future flight projects. Additionally, Hubble Space Telescope (HST) upgrades are also developed and constructed within GSFC. Manual, reflow and wave soldering processes all occur within the Center. Combining all the shops that returned surveys, GSFC used approximately 34 lbs of solder in 2002. Of that amount, 8 lbs were disposed of as waste, leaving 26 lbs used on components or hardware. According to calculations made by the assessment team, it is estimated that GSFC completes over 400,000 solder joints annually.

4.6.2.1 Risk

Upon receiving surveys and interviewing several personnel at GSFC, including personnel involved with procurement of components and other materials associated with several different projects, it was assessed that GSFC has moderate to high level of risk in soldering applications. During interviews with shop personnel it was determined that there are numerous methods for procuring components within the facility and numerous contractors that procured components for electronics workmanship applications. As it was understood, each project has the possibility of different vendors, contractors and methods for procuring the materials necessary to build the final article. Additionally there appears to be no centralized QA/QC function within GSFC for all high-reliability applications, but several areas where QA/QC of components ordered is performed. Personnel were not aware of how components were checked for quality or reliability upon receipt, but were sure that all components were ordered to specification. This leads to higher risks because there is a higher probability of errors within a multi-faceted system of QA/QC as opposed to a singular source for all component QA/QC checks after procurement and before it is sent to the end user.

The non-centralized nature of GSFC's procurement system and QA/QC procedures for procured components are contributing factors that lead to higher risk of intrusion for ongoing projects as well as any future projects started. While many of the ongoing programs are short term and the risk of intrusion is lower, as more of the industry shifts to lead-free, the risk of intrusion increases. Because GSFC manufactures high-reliability flight hardware all future flight hardware is at a high level of risk of obsolescence should the industry shift to lead-free systems and components. While GSE and institutional equipment is also at risk if the industry shifts, those applications will generally be less affected by the changeover because they are not high-reliability electronics applications.

Personnel within the Center need to be aware of the possibility of the industry changeover to lead-free systems and be involved in the development of lead-free alternatives for high-reliability electronic systems.

4.7 Surveys Received from JSC:

Surveys were sent to personnel at JSC, and only one response was returned for the entire facility. While this did not allow the assessment team to detail the information, the overall usage of solder could be used to estimate the number of solder joints completed annually. Personnel at JSC estimated that 100 lbs of solder are used annually for various activities including space flight hardware (ISS, Shuttle), aircraft, and ground service equipment. JCS estimated that approximately 25% of their lead solder was collected as waste, leaving 75 lbs of solder used on equipment annually. The assessment team calculated that this represents over 1.2 million solder joints completed in 2002. Solder usage and programs supported by areas at JSC are detailed in *Appendix B* of this report.

4.7.1.1 Risk

Further information was requested from JSC, but the AP2 Office received no responses to those queries. Because of this the procurement system as well as the QA/QC procedures were not assessed for JSC. Ongoing programs could not be assessed because of this; however, personnel within JSC should determine risk to those systems. It was assumed that future programs would hold similar risks as other NASA Centers if the industry shifts to lead-free systems. This shift would represent a high risk to all flight and high-reliability systems manufactured or repaired at JSC.

4.8 Overall Discussion and Summary of Results:

4.8.1 Quantitative:

Electronics manufacturing and purchasing of electronic components within NASA represents a very small portion of the total industry. Even compared to other branches NASA uses far less solder and performs less soldering activities than most Agencies within the DoD. Recently, the DoD solder usage was estimated by the JG-PP Working Group for its lead-free solder project. The Air Force estimated 1,700 lbs/yr, Navy estimated 780 lbs/yr, Army estimated 550 lbs/yr and the Marine Corps estimated 198 lbs/yr. It was determined through the assessment process that the six locations reviewed by the assessment team used only 326 lbs of solder in 2002. It is estimated that this represents 75% of all of NASA's solder usage, and the overall total solder used within the Agency is below 500 lbs. It was estimated by the assessment team that throughout NASA's Centers 8 - 12 million solder joints are completed annually.

Table 1: "*Solder Use and Points of Risk (Joints) at Centers Reviewed*" shows the overall usage within the six NASA areas reviewed and the estimated number of solder joints that were completed in 2002. This table is compiled from all the data gathered during site-visits and through surveys.

Table 1 - Solder Use and Point of Risk (Joints) at Centers Reviewed

TOTALS									
Company/Location	**All Locations Reviewed**								
POC									
Components	**Number of Components**	**Number of Joints**	**Solder Used**	**Amount of Solder Used Per**			**Amount of Solder Used Per Joint**		
			pounds	pounds	ounces	grams	pounds	ounces	grams
Cables / Connectors / Leads	255,615	1,627,001	88	0.000345	0.005514	0.156314	0.000054	0.000866	0.024558
Plated thru hole Printed Wiring Boards	153,535	769,097	67	0.000439	0.007030	0.199299	0.000088	0.001403	0.039786
Surface Mount Technology	398,016	3,041,282	134	0.000337	0.005398	0.153030	0.000044	0.000706	0.020027
Other=harnesses including the wiring of components in Panels, Racks, annually	113,214	561,090	36	0.000318	0.005089	0.144268	0.000064	0.001027	0.029110
Total	920,382	5,998,469	326	0.00036	0.00576	0.16323	0.00006	0.00100	0.02837
Comments:	*Average for amounts per component/joint.								

4.8.2 Qualitative:

Qualitative analysis of the risk involved within NASA was also determined. The Table in *Appendix F* of this report shows examples of the levels of risk quantitatively throughout NASA. Table 2: "*Qualitative (Relative) Risks to NASA*" below shows this risk as observed by the assessment team.

Table 2 - Qualitative (Relative) Risks to NASA

Relative Risk						
Center	**Intrusion Risk**			**Industry Shift Risk**		
	Ongoing Programs	**New Fabrication**	**Future Programs**	**Ongoing Programs**	**New Fabrication**	**Future Programs**
KSC	Low to Moderate	High	High	Low	Low	High
KSC - Palmdale	Low to Moderate	Low	Unknown	Low	Unknown	Unknown
JPL	Low	Low to Moderate	Low to Moderate	Low	Moderate	Moderate
JSC	Unknown	Unknown	High	Unknown	Unknown	High
GSFC	Moderate	Moderate	High	Low to Moderate	Moderate	High
MSFC	Low	Moderate to High	High	Moderate to High	Moderate	High
Overall Risk	***Moderate***	***Moderate***	***Moderate to High***	***Moderate***	***Moderate***	***High***

Ongoing Programs	Programs that have already completed initial construction. Provide maintenance (repair, upgrades) and support for programs. (Shuttle, ISS, GSE)
New Fabrication	New fabrication currently ongoing or already schedule to begin (Satellites, ISS, R&D, GSE)
Future Programs	Programs that have not started construction yet and may only be in initial planning stanges (Shuttle replacements, Future ISS constructions, Satellites.)

4.8.2.1 Existing Hardware:

The push for lead-free solder presents a low to moderate risk for existing hardware. Most areas where flight is a concern are controlled to the extent that an accidental introduction of a lead-free solder is highly unlikely. The Space Shuttle Orbiter NSLD for example has made progress and is planning on performing a buyout of solder for the lifetime of the program. Any avionics equipment worked on at the NSLD is thoroughly heat and shock tested prior to being accepted as a repaired item. Components repaired at the NSLD are already present in store stock and the shop does not believe that any new components will need to be purchased for the remainder of the shuttle program. Components for flight are usually not tinned upon purchase or they are re-tinned on-site to ensure that the component meets the requirements of space flight.

Cable shops at KSC and other Centers typically use solder only on GSE cables. Most ISS and Shuttle cables that are constructed at KSC by USA and Boeing are crimped, not soldered. GSE equipment at risk at KSC includes the MLP, SRB hold down pyrotechnic bolts, tracking and data relay systems and Firing Room equipment. Firing room equipment is repaired as needed but may present a risk because new components procured are not as strictly reviewed before being sent to the shop where repairs are made. There are QA/QC controls in place for this area of procurement at each NASA Center, but the methods used vary from Center to Center. Examples of the qualitative risk levels are given in *Appendix F* of this report.

4.8.2.2 New Construction:

Low to moderate to high risk is present for new manufacturing of spacecraft and test articles. Procurement of electrical components at each Center varies and because of this there are areas of risk present. JPL has a much lower risk than other Centers because all procurement of electrical components is centralized and there is one source for QA/QC. There is still risk present because not every component is reviewed prior to being sent to shops. GSFC however has no centralized procurement office for electrical components and each program at the facility may have multiple vendors. This type of non-centralization leaves questions as to how the QA/QC might also vary. It was determined through interviews that not every component is tested, but in most cases a sample of each is reviewed. While these areas have higher risk in procurement, they are also subject to several levels of testing before a flight article is produced. Often times five or more systems are made for testing where any errors in procurement might be made evident before a flight article is constructed.

The other area is the risk of obsolescence for new construction is the industry shift to lead-free solders is made without NASA having been involved in the testing of alternatives that would meet the requirements of their systems. For all new construction, as is seen at GSFC and JPL, the risk would be significant should this changeover occur.

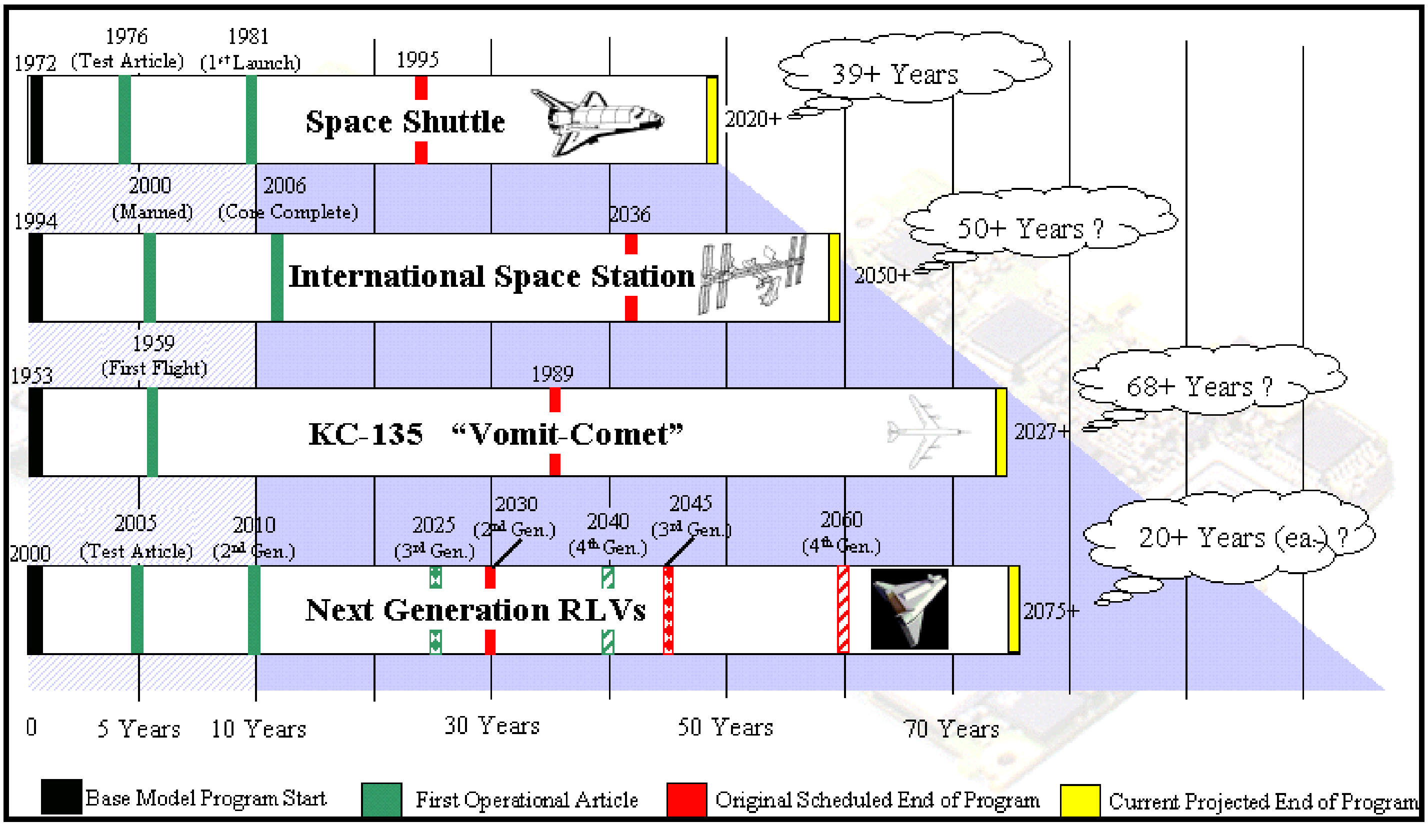
4.8.2.3 Future Systems:

One of the highest areas of risk for NASA currently is in that of future programs. Should the industry move toward lead-free electronics even on a longer timeline that is expected, any future space transport systems would be a high area of risk for NASA. This risk is that of mission preparedness, materials obsolescence and high cost of buy-out if lead based solders are eliminated in common electronics production. It is imperative to involve the engineers that are planning future construction of such programs with a leaded solder alternative project in order to maintain mission preparedness for the future.

5.0 Conclusions

Aerospace and flight equipment built by the government is historically known for exceeding predicted lifespans (still operating within safety margins) before the end of the program is offical. According to the April, 2001 Space Launch Initiative and predicted schedules, before 2050 NASA will have built 2nd, 3rd and 4th generation RLV's. This means the possiblity that several fleets of high-reliability aerospace craft will need to be built and maintained during that timeframe. While the push toward lead-free solders was likely to occur in the future at some point in time, recent interest and regulatory activity overseas has the high probability of shifting the phase-out of lead solder to the extent that these future as well as current NASA programs will be affected sooner than anticipated previously. Figure 1, "*NASA Program Lifecycles*", below shows some examples of NASA program lifecycles. Figure 2, "*Solder Sustainment Through Program Lifecycles*", shows an example of how the push toward lead-free solders might affect these NASA programs.

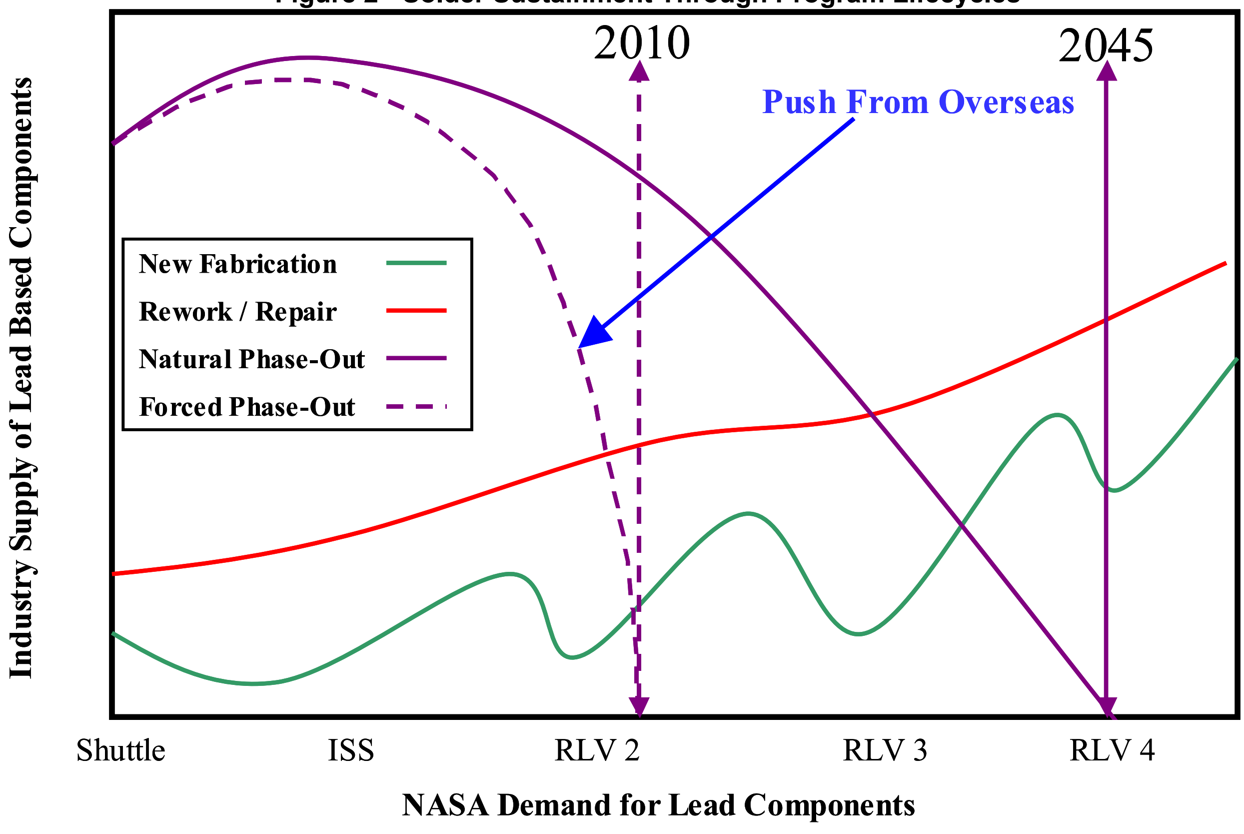
Figure 1 - NASA Program Lifecycles



Several types of risk exist within NASA operations associated with the recent movement of electronics manufacturers to lead-free solders and systems. This risk can be divided into two main areas of risk, each with three categories of risk within them. The first area of risk is intrusion. Within this area, the categories of ongoing programs, new fabrication and future programs exist. Intrusion poses a moderate to high risk for all categories within NASA. Future programs pose the greatest risk of intrusion because the industry has just begun converting to lead-free solders and systems and while it is possible now to minimize the risk by tightening procurement controls and QA/QC procedures, as the market shifts it will become increasingly difficult to find components and vendors carrying lead-based systems. Because of the variation between Centers and their methods for tracking information, the risk of intrusion varies currently from Center to Center. Centers that have centralized procurement and QA/QC will be better prepared to reduce the risk of intrusion. Centers that allow each individual program or contractor to procure materials and perform QA/QC functions will have increased effort and decreased ability to reduce the risk of intrusion.

The second area of risk is tied to the first, but is moreover the direct risk of obsolescence associated with NASA's programs if the electronics industry converts completely to lead-free systems. Within this area of obsolescence, the categories of ongoing programs, new fabrication and future programs also exist. While most ongoing programs, such as the Shuttle, that are currently active within NASA have the resources available to them to accomplish mission success through the program lifetime, any new fabrications scheduled are at a higher level of risk. The Shuttle likely has most, if not all components and solders already in stock to maintain and repair any equipment necessary for the remainder of the program. Any new fabrication, however, such as satellites constructed at JPL and GSFC that require vendors to supply components, circuit cards or other electronic materials are at a higher risk because although QA/QC is performed to some extent, it has been proven by other organizations that even with standards not allowing for it and QA/QC in place to prevent it, parts and components have arrived at facilities with lead-free finishes. This puts new fabrications at a higher level of risk. Additionally, any high-reliability ground service equipment is also at risk, but because of the environment in which it operates and that the industry is taking ground-based systems into account while converting to lead-free, it is at a much lower level of risk. Once again, the most critical systems at risk are future programs. Any future programs planned are at an increased risk because as those programs get closer to the time when construction will occur, more vendors and industry leaders will have shifted to lead-free systems. If a lead-free alternative is not qualified for these high-reliability systems, these programs will be in jeopardy of increased cost, and the lifetime and safety of the programs could be compromised.

Figure 2 - Solder Sustainment Through Program Lifecycles



Risk of failure, materials obsolescence and lack of mission preparedness will only increase with time for any and all areas within NASA due to intrusion and obsolescence of lead-free solders, components and systems. Critical systems and programs, both flight and GSE will have an increased chance of being adversely affected by an industry shift to lead-free solder and electronics systems.

6.0 Recommendations

Several recommendations can be given to NASA concerning the current and future risk to electronic systems and the programs reliant on them. Currently, there are standards that exist to prevent non-qualified materials from being introduced into high-reliability systems. In light of recent failures attributed to non-qualified lead-free components being integrated into high-reliability systems within other organizations, the controls in place to prevent such intrusion need to be assessed and strengthened where necessary to minimize the risk of intrusion and failure. The QA/QC systems in place for electronics components should be universal within NASA, and dedicated to the goal of preventing non-qualified components and systems from being accidentally delivered to shops within the prospective Centers. All electronics should be sent through detailed QA/QC prior to being delivered to the end users. Because the need to identify lead-free solders may be new to such departments, training may be necessary and new procedures put into place within those areas to ensure that non-qualified components are not inadvertently integrated into high-reliability systems during construction.

When dealing with the possibility of industry shift, the largest area of concern for NASA is future programs, most notably the next generation RLVs that are already proposed, one of which could be scheduled to fly as early as 2008. While smaller programs within NASA, such as any individual un-manned missions are more flexible to changes in the industry and have less stringent safety standards, manned space flight is not afforded this luxury. If NASA engineers that will be designing future space transport systems do not take the possibility of industry shift to lead-free into account, these future programs could be in jeopardy before they have a first flight. A replacement for currently used lead-based solders needs to be identified, tested, validated and approved for use in manned space flight as well as any other high-reliability electronics systems that NASA designs and maintains. The AP2 Office formally recommends that NASA involve top-level engineers in the demonstration, validation and acceptance of lead-free replacements for currently used lead-based solders throughout NASA. Actions that can be taken immediately by NASA and future actions that need to be taken are summarized in Table 3: "*Recommendations to NASA Concerning Lead-Free Solders*" below.

Table 3 - Recommendations to NASA Concerning Lead-Free Solders

Recommendations to NASA Concerning Lead-Free Solders	
Now	**Future**
Develop lead-free solder project that focuses on use of lead-free solder for two main areas: Flight and Ground Service Equipment	Following the completion of the JG-PP Lead-Free Solder Project (Project Number J-01-EM-026), testing results should be used to determine if a follow on project is required for NASA or if the current lead-free solder alloys tested are suitable for either ground service equipment or flight equipment.
Assess current QA/QC systems at all NASA Centers (New Fabrication of un-manned craft and GSE are of greatest concern)	Make appropriate changes to ensure that inadvertent exposures to lead-free solder containing components is prevented.
Account for any risk present in Shuttle Program (Boeing is currently performing a risk assessment concerning this)	Build appropriate controls to prevent intrusion of lead-free solder within the Shuttle Program
If engineers are already planning new space transport systems (Next Generation Shuttle, Orbital Space Plane, ISS Crew Transport System), they need to be informed of the risk of material obsolescence in lead-based electronics.	Any new space transport systems should be designed with lead-free solders in mind and if possible incorporated into the original designs and specifications where possible. For the current shuttle, a buyout of solder and components may be more cost effective, however, this may not be the case for shuttle replacements and this needs to be addressed as those programs are beginning.

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APPENDIX

TABLE OF APPENDIXES

APPENDIX A

Surveys and Interviews

1. Initial Survey

Survey Instrument for Soldering Processes Performed at NASA Centers

1. **Name of the Person Completing the Survey:**

2. **Location of Soldering Processes;** *Building Name or Building Number, and Room Number if Available:*

3. **Type of Soldering Operation(s);** *Please Check All of the Following that Apply:*

   __Reflow Soldering __Wave Soldering __ Manual Soldering

   __Other, Please Explain

4. **Solder Alloy(s) Currently Being Used;** *Example, Tin-Lead, Tin-Copper, Tin-Silver-Copper, Tin-Silver-Copper-Bismuth, or Other, please list:*

5. **Purpose of Soldering Operation(s);** *Please Check All of the Following that Apply:*

   __New Fabrication __Rework Operations (Note 1) __Repair Operations (Note 2)

   __Other, Please Explain

6. **Type of Component(s) or Equipment Being Processed, Please Include the Quantity of Each Type of Component Being Processed;** *Example, Plated Through Hole, Surface Mount, Area Arrays, Cable or Wire Connectors, Other, Please List:*

7. **Customer(s);** *Specific Program, Project, Institutional Function, External Agency, Other, Please List:*

8. **Total Quantity (approximate), in Pounds, of Solder that Contains Lead Being Used Annually:**

9. **Total Quantity (approximate), in Pounds, of Solder that Contains Lead Collected as Waste:**

Footnote:

(1) Rework Operations: The act of reprocessing non-complying articles, through the use of original or equivalent processing, in a manner that assumes full compliance of the article with applicable drawings or specifications.

(2) Repair Operations: The act of restoring the functional capability of a defective article in a manner that precludes compliance of the article with applicable drawings or specifications.

Page 1

APPENDIX A

Surveys and Interviews

2. Follow-Up Survey

Survey Instrument for Soldering Processes Performed at NASA Centers

1. **Point of Contact for Each Area where Soldering Activities Occur:**

2. **Location of Soldering Processes;** *Building Name, Building Number, and Room Number if Available:*

3. **Type of Soldering Operation(s);** *Please Check All of the Following that Apply and Answer Follow-Up Questions for those Operations:*

   A. __ Reflow Soldering
   - i. Please estimate amount of solder used for this process (weight)
   - ii. Please estimate the number of components processed annually
   - iii. Estimate the number of solder joints completed annually
   - iv. Estimate the amount of solder used per solder joint

   B. __Wave Soldering
   - i. Please estimate amount of solder used for this process (weight)
   - ii. Please estimate the number of components processed annually
   - iii. Estimate the number of solder joints completed annually
   - iv. Estimate the amount of solder used per solder joint

   C. __ Manual Soldering
   - i. Please estimate amount of solder used for this process (weight)
   - ii. Please estimate the number of components processed annually
   - iii. Estimate the number of solder joints completed annually
   - iv. Estimate the amount of solder used per solder joint

   D. __Other, Please Explain
   - i. Please estimate amount of solder used for this process (weight)
   - ii. Please estimate the number of components processed annually
   - iii. Estimate the number of solder joints completed annually
   - iv. Estimate the amount of solder used per solder joint

4. **Solder Alloy(s) Currently Being Used for Each Operation;** *Example, Tin-Lead, Tin-Copper, Tin-Silver-Copper, Tin-Silver-Copper-Bismuth, or Other, please list:*

5. **Purpose of Soldering Operation(s);** *Please Check All of the Following that Apply and Answer Follow-Up Questions for those Operations:*

   A. __New Fabrication
   - i. Please estimate amount of solder used for New Fabrication

   B. __Rework Operations *(Note 1)*
   - i. Please estimate amount of solder used for Rework Operations

   C. __Repair Operations *(Note 2)*
   - i. Please estimate amount of solder used for Repair Operations

   D. __Other, Please Explain
   - i. Please estimate amount of solder used for Other Operations

Page 1

APPENDIX A

Surveys and Interviews

2. Follow-Up Survey (Cont.)

6. **Type of Component(s) or Equipment Being Processed, Please Include the Quantity of Each Type of Component Being Processed;** *Example, Plated Through Hole, Surface Mount, Area Arrays, Cable or Wire Connectors, Other, Please List:*

7. **Customer(s);** *Specific Program, Project, Institutional Function, External Agency, Other, Please List:*

8. **Total Quantity (approximate), in Pounds, of Solder that Contains Lead Being Used Annually at This Location:**

9. **Total Quantity (approximate), in Pounds, of Solder that Contains Lead Collected as Waste Annually at This Location:**

10. **Total Quantity (approximate), in Pounds, of Solder that Contains Lead Procured Annually for This Location:**

11. **Is there any Outsourcing of Work Off-Site for Components that are Worked On at this Location? If so, What and Where?**

Footnote:

(1) Rework Operations: The act of reprocessing non-complying articles, through the use of original or equivalent processing, in a manner that assumes full compliance of the article with applicable drawings or specifications.

(2) Repair Operations: The act of restoring the functional capability of a defective article in a manner that precludes compliance of the article with applicable drawings or specifications.

Page 2

APPENDIX A

Surveys and Interviews

3. Interview Questions*

1. What types of solder processes are performed within your shop?

2. How is the amount of work tracked within your shop, if at all?

3. Is it possible to estimate the number of components or joints that are soldered within your shop in a typical year?

4. Explain the flow of work at your shop? Where does the process start (trouble shoot, design acceptance, etc.) and what steps does it flow through until it is certified for use? What tests must the finished article pass to be certified for use?

5. How are components and solder procured at your shop? Who orders the components?

6. Where and how is quality assurance and quality control performed for components procured?

7. Are components tinned after they arrive or do they arrive in the shop pre-tinned?

8. What projects does the work performed in your shop support?

9. Can you estimate the percentage of work that supports flight versus non-flight?

10. Can you estimate the percentage of work performed that uses lead-bearing solders?

11. What standards (NASA or otherwise) are used for soldering activities within your shop?

**Note: Not every interview consisted of only these above questions. Some of these questions were answered on the surveys sent to each area. Other questions may have been asked after these questions were answered in order to clarify the level and type of work performed and the procedures that are followed for that work. This is not a comprehensive list of questions, only the first tier of questions asked during the interview process.*

APPENDIX B

Solder Survey Summary Tables

Company/Location	JPL - Building 168-337								
POC	Fred Soltis - 818 354-2478			Fred.S.Soltis-104194@jpl.nasa.gov					
Components	Number of Components	Number of Joints	Solder Used	Amount of Solder Used Per Component			Amount of Solder Used Per Joint		
			in pounds	in pounds	in ounces	in grams	in pounds	in ounces	in grams
Cables / Connectors / Leads	500	1,000	1.000000	0.00200	0.03200	0.907185	0.00100	0.01600	0.453592
Plated thru hole Printed Wiring Boards									
Surface Mount Technology									
Other=harnesses including the wiring of components in Panels, Racks, annually									
Total	500	1,000	1	0.002	0.032	0.90718474	0.001	0.016	0.45359237
Supported Programs	Microwave Limb Sounder (MLS), Herschel Planck								
Comments:	none								

Company/Location	JPL - Building 189: Room: 101								
POC	Adam Kisor - 818 354-9370			akisor@mailhost4.jpl.nasa.gov					
Components	Number of Components	Number of Joints	Solder Used	Amount of Solder Used Per Component			Amount of Solder Used Per Joint		
			in pounds	in pounds	in ounces	in grams	in pounds	in ounces	in grams
Cables / Connectors / Leads	25	100	0.333333	0.01333	0.21333	6.047898	0.00333	0.05333	1.511975
Plated thru hole Printed Wiring Boards	25	100	0.333333	0.01333	0.21333	6.047898	0.00333	0.05333	1.511975
Surface Mount Technology	25	100	0.333333	0.01333	0.21333	6.047898	0.00333	0.05333	1.511975
Other=harnesses including the wiring of components in Panels, Racks, annually									
Total	75	300	1	0.04	0.64	18.1436948	0.01	0.16	4.5359237
Supported Programs	Electronic Nose Development (NASA Code U), Microarray Sensors (NASA Code R)								
Comments:	none								

Company/Location	JPL - Building 303: Room 207								
POC	Jose Pantaleon - 818 354-1949			jpantale@mailhost4.jpl.nasa.gov					
Components	Number of Components	Number of Joints	Solder Used	Amount of Solder Used Per Component			Amount of Solder Used Per Joint		
			in pounds	in pounds	in ounces	in grams	in pounds	in ounces	in grams
Cables / Connectors / Leads									
Plated thru hole Printed Wiring Boards									
Surface Mount Technology	1,639	8,197	0.500000	0.00031	0.00488	0.138349	0.00006	0.00098	0.027670
Other=harnesses including the wiring of components in Panels, Racks, annually									
Total	1,639	8,197	0.5	0.0003050	0.0048801	0.1383494	0.0000610	0.0009760	0.0276699
Supported Programs	LAMP								
Comments:	* Back calculated number of joints assuming .25 inches of solder core used for each joint soldered on-site.								

APPENDIX B

Solder Survey Summary Tables

Company/Location	JPL - Building 103: Rooms 108A, 108C, 108E&F, 110, 120								
POC	Dr. J.K. Bonner - 818 354-1320			jkbonner@mailhost4.jpl.nasa.gov					
Components	Number of Components	Number of Joints	Solder Used	Amount of Solder Used Per			Amount of Solder Used Per Joint		
			in pounds	in pounds	in ounces	in grams	in pounds	in ounces	in grams
Cables / Connectors / Leads	10,000	400,000	10.0	0.001000	0.016000	0.453592	0.000025	0.000400	0.011340
Plated thru hole Printed Wiring Boards									
Surface Mount Technology	70,000	1,400,000	30.0	0.000429	0.006857	0.194397	0.000021	0.000343	0.009720
Other=harnesses including the wiring of components in Panels, Racks, annually									
Total	80,000	1,800,000	40	0.0014286	0.0228571	0.6479891	0.0000464	0.0007429	0.0210596
Supported Programs	Mars Exploratory Rover, Microwave Limb Sounder (MLS), Tropospheric Emission Spectrometer (TES), Cloudsat								
Comments:	none								

Company/Location	JPL - Building 84 Rm: 1; Building 83 Rm: 208								
POC	Alan Young - 818 354-4531			afyoung@mail1.jpl.nasa.gov					
Components	Number of Components	Number of Joints	Solder Used	Amount of Solder Used Per			Amount of Solder Used Per Joint		
			in pounds	in pounds	in ounces	in grams	in pounds	in ounces	in grams
Cables / Connectors / Leads	72	434	0.03	0.00042	0.00667	0.188997	0.00007	0.00111	0.031354
Plated thru hole Printed Wiring Boards	4,320	24,480	18.00	0.00417	0.06667	1.889968	0.00074	0.01176	0.333524
Surface Mount Technology	2,576	15,541	1.07	0.00042	0.00665	0.188410	0.00007	0.00110	0.031230
Other=harnesses including the wiring of components in Panels, Racks, annually	20	121	0.0083	0.00042	0.00664	0.188241	0.00007	0.00110	0.031114
Total	6,988	40,576	19.1083	0.0054137	0.0866193	2.4556157	0.0009419	0.0150698	0.4272222
Supported Programs	NASA Contractors, DCMA, JPL Employees								
Comments:	none								

Company/Location	JPL - Building 198-302								
POC	Johnny Duong - 818 354-8571			jduong@mailhost4.jpl.nasa.gov					
Components	Number of Components	Number of Joints	Solder Used	Amount of Solder Used Per			Amount of Solder Used Per Joint		
			in pounds	in pounds	in ounces	in grams	in pounds	in ounces	in grams
Cables / Connectors / Leads									
Plated thru hole Printed Wiring Boards									
Surface Mount Technology									
Other=harnesses including the wiring of components in Panels, Racks, annually	5,000	20,000	3.0000	0.00060	0.00960	0.272155	0.00015	0.00240	0.068039
Total	5,000	20,000	3	0.0006	0.0096	0.2721554	0.00015	0.0024	0.0680389
Supported Programs	Projects								
Comments:	none								

APPENDIX B

Solder Survey Summary Tables

Company/Location	KSC - Building K6-1247 Rooms 2, 3, 4 and 14B								
POC	Clifford R. Johnson - 321 861-0075 Clifford.Johnson-1@ksc.nasa.gov								
Components	Number of Components	Number of Joints	Solder Used in pounds	Amount of Solder Used Per			Amount of Solder Used Per Joint		
				in pounds	in ounces	in grams	in pounds	in ounces	in grams
Cables / Connectors / Leads	64,670	323,352	19.725	0.00031	0.00488	0.138349	0.00006	0.00098	0.027670
Plated thru hole Printed Wiring Boards	820	4,098	0.25	0.00031	0.00488	0.138349	0.00006	0.00098	0.027670
Surface Mount Technology									
Other=harnesses including the wiring of components in Panels, Racks, annually									
Total	65,490	327,450	19.975	0.0006100	0.0097603	0.2766988	0.0001220	0.0019521	0.0553398
Supported Programs	Various Ground Support Processing Systems, Logistics Spares, NASA Funded Modifications and CSOC Communications and								
Comments:	* Back calculated number of joints assuming .25 inches of solder core used for each joint soldered on-site.								

Company/Location	KSC - NSLD 1 Room 300								
POC	Marion Sees - 321 799-5598								
Components	Number of Components	Number of Joints	Solder Used in pounds	Amount of Solder Used Per			Amount of Solder Used Per Joint		
				in pounds	in ounces	in grams	in pounds	in ounces	in grams
Cables / Connectors / Leads	6,557	32,786	2.000000	0.00031	0.00488	0.138349	0.00006	0.00098	0.027670
Plated thru hole Printed Wiring Boards	3,279	16,393	1.000000	0.00031	0.00488	0.138349	0.00006	0.00098	0.027670
Surface Mount Technology	3,279	16,393	1.000000	0.00031	0.00488	0.138349	0.00006	0.00098	0.027670
Other=harnesses including the wiring of components in Panels, Racks, annually	68,851	344,253	21.000000	0.00031	0.00488	0.138349	0.00006	0.00098	0.027670
Total	81,965	409,825	25	0.0012200	0.0195205	0.5533976	0.0002440	0.0039041	0.1106795
Supported Programs	Space Shuttle Logistics Depot, Avionics and other equipment for Shuttle								
Comments:	* Back calculated number of joints assuming .25 inches of solder core used for each joint soldered on-site.								

Company/Location	KSC - Building K6-1094, Room 1030								
POC	Romie L. Grant - 321 861-5620 Romie.Grant-1@ksc.nasa.gov								
Components	Number of Components	Number of Joints	Solder Used in pounds	Amount of Solder Used Per			Amount of Solder Used Per Joint		
				in pounds	in ounces	in grams	in pounds	in ounces	in grams
Cables / Connectors / Leads	1,639	8,197	0.5	0.000305	0.004880	0.138349	0.000061	0.000976	0.027670
Plated thru hole Printed Wiring Boards	3,279	16,393	1.0	0.000305	0.004880	0.138349	0.000061	0.000976	0.027670
Surface Mount Technology	6,557	32,786	2.0	0.000305	0.004880	0.138349	0.000061	0.000976	0.027670
Other=harnesses including the wiring of components in Panels, Racks, annually									
Total	11,475	57,376	3.5	0.0009150	0.0146404	0.4150482	0.0001830	0.0029281	0.0830096
Supported Programs	Space Flight Operations Contract								
Comments:	* Back calculated number of joints assuming .25 inches of solder core used for each joint soldered on-site.								

APPENDIX B

Solder Survey Summary Tables

Company/Location	**KSC - Building M7-505 Room 1220**								
POC	**Carmen Moore - 321 867-2638**	Carmen.Moore-1@ksc.nasa.gov							
Components	**Number of Components**	**Number of Joints**	**Solder Used**	**Amount of Solder Used Per**			**Amount of Solder Used Per Joint**		
			in pounds	in pounds	in ounces	in grams	in pounds	in ounces	in grams
Cables / Connectors / Leads	49,179	245,895	15.00	0.00031	0.00488	0.138349	0.00006	0.00098	0.027670
Plated thru hole Printed Wiring Boards									
Surface Mount Technology									
Other=harnesses including the wiring of components in Panels, Racks, annually	39,343	196,716	12.0000	0.00031	0.00488	0.138349	0.00006	0.00098	0.027670
Total	88,522	442,611	27	0.0006100	0.0097603	0.2766988	0.0001220	0.0019521	0.0553398
Supported Programs	CAPPS (Checkout Assembly and Payload Processing Sevices) and ISS								
Comments:	* Back calculated number of joints assuming .25 inches of solder core used for each joint soldered on-site.								

Company/Location	**MSFC - Sierra Lobo, Inc. - Manufacturing Services, Bldg. 4705, Rm. 120**								
POC	**"Mickey" Stewart - 256 544-1062**	Mickey.G.Stewart@msfc.nasa.gov							
Components	**Number of Components**	**Number of Joints**	**Solder Used**	**Amount of Solder Used Per**			**Amount of Solder Used Per Joint**		
			in pounds	in pounds	in ounces	in grams	in pounds	in ounces	in grams
Cables / Connectors / Leads	25	500	2.00	0.08000	1.28000	36.287390	0.00400	0.06400	1.814369
Plated thru hole Printed Wiring Boards	1,237	4,750	4.00	0.00323	0.05174	1.466750	0.00084	0.01347	0.381973
Surface Mount Technology	1,237	4,750	4.00	0.00323	0.05174	1.466750	0.00084	0.01347	0.381973
Other=harnesses including the wiring of components in Panels, Racks, annually									
Total	2,500	10,000	10	0.02882	0.46116	13.07363	0.00189	0.03032	0.85944
Supported Programs	Note: MSFC estimated: 0.0112 oz. Per joint: Work Supports: ECLSS, MSRR, g-LIMIT, MSG, DELTA-L, PROSEDS, SUBSA and QMI.								
Comments:	Use: 10lbs, Dispose: 25lbs, Total: 35lbs Note: 80% New Fabrication, 10% Re-Work, 10% Repair								

Company/Location	**JSC - Various Buildings: 4, 9, 56**								
POC	**Geoffrey Yoder - 281 483-8698**	geoffrey.l.yoder@nasa.gov							
Components	**Number of Components**	**Number of Joints**	**Solder Used**	**Amount of Solder Used Per**			**Amount of Solder Used Per Joint**		
			in pounds	in pounds	in ounces	in grams	in pounds	in ounces	in grams
Cables / Connectors / Leads	122,948	614,738	37.5	0.00031	0.00488	0.138349	0.00006	0.00098	0.027670
Plated thru hole Printed Wiring Boards	98,358	491,790	30.0	0.00031	0.00488	0.138349	0.00006	0.00098	0.027670
Surface Mount Technology	24,590	122,948	7.5	0.00031	0.00488	0.138349	0.00006	0.00098	0.027670
Other=harnesses including the wiring of components in Panels, Racks, annually									
Total	245,895	1,229,475	75	0.00031	0.00488	0.13835	0.00006	0.00098	0.02767
Supported Programs	ISS, Shuttle, GFE projects (R&D)								
Comments:	* Back calculated number of joints assuming .25 inches of solder core used for each joint soldered on-site.								

APPENDIX B

Solder Survey Summary Tables

Company/Location	Palmdale, CA. - SEA/Orbiter								
POC	Eric Eichinger - 714 372-5197 eric.c.eichinger@boeing.com								
Components	Number of Components	Number of Joints	Solder Used	Amount of Solder Used Per			Amount of Solder Used Per Joint		
			in pounds	in pounds	in ounces	in grams	in pounds	in ounces	in grams
Cables / Connectors / Leads									
Plated thru hole Printed Wiring Boards									
Surface Mount Technology	245,895	1,229,475	75.0	0.00031	0.00488	0.138349	0.00006	0.00098	0.027670
Other=harnesses including the wiring of components in Panels, Racks, annually									
Total	245,895	1,229,475	75	0.00031	0.00488	0.13835	0.00006	0.00098	0.02767
Supported Programs	Shuttle Avionics Equipment								
Comments:	* Back calculated number of joints assuming .25 inches of solder core used for each joint soldered on-site.								

Company/Location	GSFC - Buildings 4, 5, 7, 11, 15, 19, 20, 22, 28, 30, 16W, Area 200								
POC	Greg Vuocolo - 301 286-9233 gvuocolo@pop200.gsfc.nasa.gov								
Components	Number of Components	Number of Joints	Solder Used	Amount of Solder Used Per			Amount of Solder Used Per Joint		
			in pounds	in pounds	in ounces	in grams	in pounds	in ounces	in grams
Cables / Connectors / Leads									
Plated thru hole Printed Wiring Boards	42,219	211,093	12.88	0.00031	0.00488	0.138349	0.00006	0.00098	0.027670
Surface Mount Technology	42,219	211,093	12.88	0.00031	0.00488	0.138349	0.00006	0.00098	0.027670
Other=harnesses including the wiring of components in Panels, Racks, annually									
Total	84,437	422,185	25.754	0.00031	0.00488	0.13835	0.00006	0.00098	0.02767
Supported Programs									
Comments:	* Back calculated number of joints assuming .25 inches of solder core used for each joint soldered on-site.								

TOTALS

Company/Location	All Locations								
POC									
Components	Number of Components	Number of Joints	Solder Used	Amount of Solder Used Per			Amount of Solder Used Per Joint		
			in pounds	in pounds	in ounces	in grams	in pounds	in ounces	in grams
Cables / Connectors / Leads	255,615	1,627,001	88	0.00034	0.00551	0.156314	0.00005	0.00087	0.024558
Plated thru hole Printed Wiring Boards	153,535	769,097	67	0.00044	0.00703	0.199299	0.00009	0.00140	0.039786
Surface Mount Technology	398,016	3,041,282	134	0.00034	0.00540	0.153030	0.00004	0.00071	0.020027
Other=harnesses including the wiring of components in Panels, Racks, annually	113,214	561,090	36	0.00032	0.00509	0.144268	0.00006	0.00103	0.029110
Total	920,382	5,998,469	326	0.00036	0.00576	0.16323	0.00006	0.00100	0.02837
Supported Programs									
Comments:	*Average for amounts per component/joint.								

APPENDIX C

Survey Overviews for KSC and GSFC

GSFC NASA Lead Solder Survey Overview

Building	Room	Point of Contact	Type of Soldering	Soldering Operation	Lead Solder Used per year (pounds)	Waste Lead Solder per year (pounds)
4	181	James Dye	Manual	New Fabrication, Rework, Repair	1	0.125
5	W6	Steven Wood	Reflow, Manual	New Fabrication, Rework, Repair	1	0.05
5	E70	Jeff Gum	Manual	New Fabrication, Repair	1	0
5	W6E	Dwight Roberts	Manual	New Fabrication, Rework, Repair	1	1
7	39	Tom Hait	Manual	New Fabrication, Rework, Repair	0.2	0.25
7	A-Mezz2	Jack Bauernschmidt	Manual	Repair	0.1	0
7	194	Larry Dumonchelle	Manual	New Fabrication, Rework, Repair	1	0.22
7	39	John Zahniser	Manual	New Fabrication	0.25	0
7	N100	John Bichell	Manual	Cable Fabrication	0.5	0
7	39	Jason Behr	Manual	New Fabrication, Rework, Repair	0.5	0
7	19	Shari Jarvis	Manual	New Fabrication	1	0
7	8C	Vaughn Nelson	Manual	New Fabrication, Rework, Repair	1	0.01
11	S126	Michael Wilks	Manual	New Fabrication, Rework, Repair	1	0.25
15	103	Paul Trahan	Manual	New Fabrication, Rework, Repair	1	1
15	107B	Robert Rosenberry	Manual	New Fabrication, Rework, Repair	0.01	0.001
15	104	Ram Ramrattan	Manual	New Fabrication, Rework, Repair	0.25	0
19	S47	Steve Seufert	Manual	New Fabrication, Rework, Repair	1	0
19	S31	William Schaefer	Manual	New Fabrication, Rework, Repair	5	0
19	S37	Lamonte Poole	Wave	Rework	2	1
20	80	Charlie Stone	Manual	New Fabrication, Rework, Repair	0.5	0.5
20	C40	Robert Lussier	Manual	New Fabrication, Rework, Repair	0.25	0.25
22	G70	Steve Brown	Manual	Repair	1	0.5
28	W117	Jeff Lentz	Manual	Rework	1	0
30	111	Carl Taylor	Manual	Repair	0.1	0
30	177	Diane Kolos	**Other	**Coupn Qualification	0.2	0.1
16W	S010	Sherry Warner	Reflow, Manual	New Fabrication, Rework, Repair	11.2	3
Area 200	NA	Michael Perry	Manual	New Fabrication, Repair	1	0.05
				Total Used / Wasted	***34.06***	***8.306***
				Total Amount of Solder Used		34.06
				Total Amount of Solder Wasted		8.306
				Total Amount of Solder Used on Joints		25.754
				Total Number of Solder Joints		422185

APPENDIX C

Survey Overviews for KSC and GSFC

KSC NASA Lead Solder Survey Overview						
Building	**Room**	**Point of Contact**	**Type of Soldering**	**Soldering Operation**	**Lead Solder Used per year (pounds)**	**Waste Lead Solder per year (pounds)**
VAB K6-848	2M4	Roy Heini	Reflow, Manual	New Fabrication, Rework, Repair	0.25	0.0625
1045 Gemini Room	120	Billy Crocker	Manual	New Fabrication, Rework, Repair	5	1.5
5	150	Joseph Vaiming	Manual	New Fabrication, Repair	0.1875	0.0625
5	1007	James Edwards	Manual	New Fabrication, Rework, Repair	0.1875	0.0625
M6-342	Numerous	Michael Maxwell	Manual	New Fabrication, Rework, Repair	1	0.5
5 South	3100	Bruce Bohnert	Manual	New Fabrication, Repair	0.5	0.125
PTCR	208 (Pads A & B)	Robert Waln	Reflow, Manual	New Fabrication, Rework, Repair	1	0.5
Logistics Support Facility	139, 136	N/A	Manual	New Fabrication, Rework	7	5
1045 Gemini Room	100	Wayne Grider	Manual	New Fabrication, Rework, Repair	5	1.5
16850 Buccaneer	295	Wayne Grider	Manual	New Fabrication, Rework, Repair	0.1	0.25
VAB	MM5, 2M4, 2M6	Michael Newbeck	Manual	New Fabrication, Repair	1	0.5
SLF	J6-2465	Steven Lloyd	Manual	Repair	2	0.125
K6-1247	2, 3, 4, 14B	Clifford R. Johnson	Reflow, Manual	New Fabrication, Rework, Repair	20	2
K6-1094	1030	Romie L. Grant	Manual	New Fabrication, Rework, Repair	10	0.0625
K6-1298	115, 117	William Gaviria	Manual	Repair	0.5	0.0625
NSLD 1	328	William Gaviria	Manual	Repair	0.5	0.0625
NSLD 1	300	Marion Sees	Reflow, Wave, Manual, Tinning	New Fabrication, Rework, Repair	25	10
K6-1446D	1107	Mark Reagan	Manual	Repair	0.5	N/A
K6-1446A	1009	Dale Cicirelli	Manual	Repair	0.5	N/A
O&C	5216, 5217	Mark Edwards	Training	Training	1	1
M7-505	1214A	Andrew Salaka	Manual	Repair	0.1	0.1
M6-336	N/A	Bob Churnell	Manual	New Fabrication, Rework	0.5	0.05
M7-505	120	Carmen Moore	Manual, Tinning	New Fabrication, Rework, Repair	27	8
60680	Hgr AE	Marvin Hearndon	Reflow, Manual	New Fabrication, Rework, Repair	3	1
M7-505	1247, 1247D, 1248A, 1220	Luis A. Ramos	Reflow, Manual	New Fabrication, Rework, Repair	1	N/A
				Totals	***112.825***	***32.525***
				Total Amount of Solder Used		112.825
				Total Amount of Solder Wasted		32.525
				Total Amount of Solder Used on Joints		80.3
				Total Number of Solder Joints		1316358

APPENDIX D

Estimations and Calculations

Note:
For the purposes of identifying a level of risk, it was determined that a way to view risk in soldering electronics (new fabrication, rework or repair) is to identify how many solder joints are created annually. Each joint would represent an area of possible risk should a lead-free component or lead-free solders be used.

Known:

- Typical solder wire core is 1/32 inch in diameter.
- Typical solder core weighs 1 pound.

Assumption 1:
It can be safely assumed that a single (1) typical solder joint will use less than 1/4 inch of solder from a 1/32 diameter solder core spool.

Justification 1:
Volume of 0.03125 diameter x 0.25 inch length solder = π x radius$^{2(\text{squared})}$ x height

$$3.14 \times .016 \text{ in.}^2 \times 0.25 \text{ in} = 0.000201 \text{ in}^{3(\text{cubed})} \text{ (Answer A)}$$

If the volume (0.000201 in^3) of 0.25 inches of solder is then converted to determine the size of a sphere (approximating the same shape of a solder joint) the size of this solder sphere would be approximately 0.072 inches in diameter.

For reference, a typical BB has a diameter of 0.18, or approximately twice that of the proposed solder joint. It can be inferred from this that a typical electronics component being soldered would have significantly less than 0.25 inches of solder wire we are assuming is applied to each joint.

It could possibly be assumed that only 0.125 inches of solder would be necessary for each joint, but in order to derive numbers of solder joints produced annually with confidence that the numbers are low rather than high, 0.25 was assumed.

Assumption 2:
If 1/4 inch of 1/32 diameter solder core is used the total weight of that solder would equal .000061 pounds of solder.

Justification:
The specific gravity of 63% Sn - 37% Pb solder is 8.42.

Weight of one cubic foot of solder = 62.35 lbs/ft^3(constant) x 8.42 (specific gravity) = 525 lbs/ft^3

So the weight of one cubic inch of solder would = 0.304 lbs/in^3 (Answer B)

Thus, the weight of a 0.25 in slice of 0.032 in diameter wire solder = (Answer A) x (Answer B)

0.000201 in^3 x 0.304 lbs/in^3 = **0.000061 lbs (per solder joint)**

Assumption 3:
Each solder core (roll) contains 16,393 quarter inch solder applications.

Justification:
If each wire core weighs one pound, and 0.25 in of that wire weighs 0.000061 lbs, it can be calculated simply that a solder wire core contains 16,393 soldering applications which equates to 4,092 inches of solder wire per core, or 341 feet of solder wire per core.

APPENDIX E

List of Standards

Soldering

- NASA-STD-8739.2 *Surface Mount Technology* - Aug. 1999
- NASA-STD-8739.3 *Soldered Electrical Connections* - Jan. 2001
- J-STD-004 *Requirements for Soldering Fluxes Amndmt.1* - Apr. 1996
- J-STD-005 *Requirements for Soldering Paste Amndmt.1* - Jan. 1995
- J-STD-006 *Requirements for Electronic Grade Solder Alloys and Fluxed and Non-Fluxed Solid Solders for Electronic Soldering Applications Amndmt.1* - Jun. 1996

Printed Wiring Boards

- IPC-2221 *Generic Standard on Printed Wiring Board Design* - February 1998
- IPC-2222 *Sectional Standard on Rigid Printed Wiring Board Design* - February 1998
- IPC-6011 *Generic Performance Specifications for Printed Boards* - July 1996
- IPC-6012 *Qualification and Performance Specification for Rigid Printed Boards A* -October 1999
- IPC-A-600 *Guidelines for Acceptability of Printed Boards F* - November 1999

Wiring/Harnessing

- NASA-STD-8739.4 *Crimping, Interconnecting Cables, Harnesses, and Wiring* - Feb. 1998

Fiber Optics

- NASA-STD-8739.5 *Fiber Optics Terminations, Cable Assemblies, and Installation* - Feb. 1998

Polymerics

- NASA-STD-8739.1 *Workmanship Standard for Staking and Conformal Coating of Printed Wiring Boards and Electronic Assemblies* - Aug. 1999

Electrostatic Discharge Control

- NASA-STD-8739.7 *Electrostatic Discharge Control (Excluding Electrically Initiated Explosive Devices)* - Dec. 1997

Other Standards

- JPL D-8208, Rev.H *Spacecraft Design and Fabrication Requirements for Electronic Packaging and Cabling*
- FP513414, Rev.H *Assembling and Wiring of Electronic Equipment*
- IPC-SM-785 *Guidelines for Accelerated Reliability Testing of Surface Mount Solder Attachments* - Nov. 1992
- MIL-STD-810 *DoD Test Method Standard for Environmental Engineering Considerations and Laboratory Tests* - Aug. 2002

MIL-STD-202 *Electronic and Electrical Component Parts* - Feb. 2002

APPENDIX F

Qualitative Risk Definitions

Risk	Description/ Example
High	• Critical flight hardware • Non centralized procurement system and limited QA procedures • Probably need to buy out parts • Relatively large number of soldering operations and high solder usage • Known components imported from overseas • No testing of procured components to assure the specification is met • Replacement components will be required to maintain system • No planning for lead replacement and no other solder qualified
Moderate	• Critical or non critical flight hardware • Centralized procurement system OR limited QA procedures • Moderate number of soldering operations and moderate solder usage • Replacement components MAY be required to maintain system • Components / systems tested in simulated environmental conditions prior to use or
Low	• Non critical flight hardware • Centralized procurement system and comprehensive QA procedures • No need to buy out parts • Relatively small number of soldering operations and low solder usage • No replacement components necessary to maintain system (one time launch) • Space system already being constructed (present risk is low)
Unknown	Not enough information to assess risk

ACRONYMS

AP2	Acquisitions Pollution Prevention
CSOC	Consolidated Space Operations Center
DoD	Department of Defense
EPA	Environmental Protection Agency
ESA	European Space Agency
ET	External Tank
EU	European Union
GSE	Ground Service Equipment
GSFC	Goddard Space Flight Center
HQ	Headquarters
HST	Hubble Space Telescope
ISS	International Space Station
ITB	International Trade Bridge
JG-PP	Joint Group for Pollution Prevention
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
KSC	Kennedy Space Center
MDL	Micro-Devices Laboratory
MLP	Mobile Launch Platform
MLS	Microwave Limb Sounder
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
OPF	Orbiter Processing Facility
OTV	Operational Television Systems
PPONA	Pollution Prevention Opportunity Needs Assessment
PTH	Plated Trough Hole
QA	Quality Assurance
QC	Quality Control
R&D	Research and Development
RLV	Reusable Launch Vehicle
RoHS	Restriction of Certain Hazardous Substances
SMT	Surface Mount Technology
SRB	Solid Rocket Boosters
STS	Space Transport System
US	United States
USA	United Space Alliance

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