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An Update: Elimination of Lead from Electronics

Lead is commonly used in solders and finishes required for the manufacture of printed wiring assemblies for electronics. Lead is a neurotoxin, a haematotoxin, a teratogen, and is possibly carcinogenic. According to Leslie Byster, communications director for the Silicon Valley Toxics Coalition (SVTC), discarded electronic products comprise “the most rapidly growing waste problem in the world.” Disposal of electronic waste in landfills is undesirable due to the potential for the leaching of lead into groundwater. Recycling is an option for dealing with this electronic waste but the collection and recycling of such waste in a responsible way is expensive. Recycling programs are themselves controversial since (at least in the U.S.) much of the waste is shipped overseas and disposed of under conditions that pose a threat to workers and the environment.

These concerns have led to voluntary efforts in Japan to totally eliminate lead from new commercial electronics by 2003 with total elimination of lead solders by 2010. In Europe, the European Union (EU) will pass legislation at the end of 2002 that governs the use of lead (and other toxic materials) in electronics. One measure is called the Waste from Electrical and Electronic Equipment (WEEE) Directive and it will require manufacturers to take full responsibility for discarded electronic products in 2005 (i.e., the manufacturer must pay all recycling expenses). A second measure is called the RoHS (Restriction on Hazardous Substances). This legislation requires the phase out of lead and other toxic materials from electronic products over a fixed time schedule beginning in July 2006. In addition, the EU has banned the export of hazardous electronic waste from any European country to any developing countries.

It appears that the U.S. commercial electronic OEM’s that sell overseas will be forced to switch to lead-free production to remain competitive. For now, military applications are not covered by the pending EU legislation. However, as military electronics production becomes more linked with commercial electronics production, the effects of this legislation will begin to be felt. For example:

1. Component vendors are switching component finishes from tin/lead to pure tin to satisfy the needs of their European and Asian customers. Pure tin finishes are well known for growing tin whiskers (Figure 1) that can short out electronics. As more and more tin-plated parts flood the market, the military will need to recoat these parts or develop strategies for mitigating the risks associated with pure tin plating. The pressure on the U.S. military and on avionics OEM’s to use more commercial-off-the-shelf (COTS) components in order to reduce costs compounds this problem.

2. The current trend is for commercial avionics and military electronics production to be outsourced to vendors that service many markets. These vendors in turn will be under pressure to switch to lead-free manufacturing processes to satisfy the lead-free demands of Asia, Europe and the commercial U.S. market. The cost of maintaining separate production lines for lead and lead-free production will be prohibitive and the U.S. military will be forced to accept lead-free electronics. The costs associated with tracking and repairing both lead-containing and lead-free electronics will also prove to be prohibitive and will eventually force the U.S. military to totally adopt lead-free.

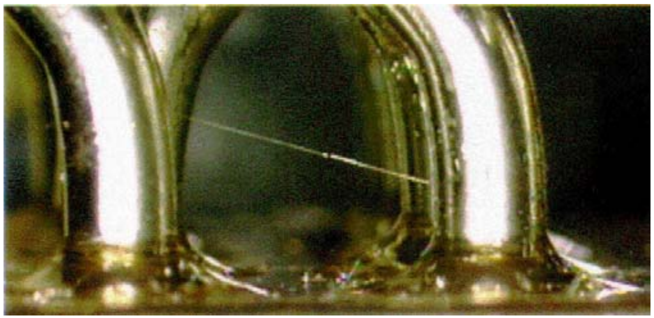
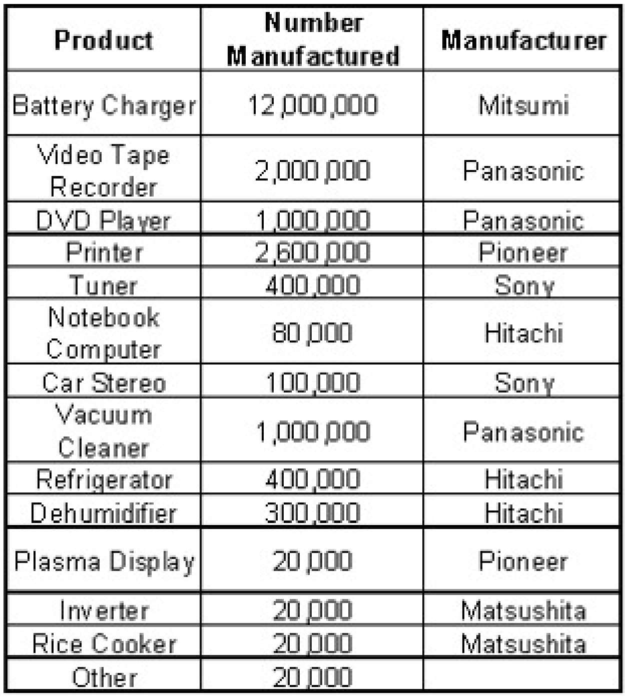


Photo Courtesy of NASA Goddard Space Flight Center http://nepp.nasa.gov/whisker

Figure 1. A Tin Whisker on a Tin-Plated Relay

Production of lead-free electronics is already a reality. In Japan, millions of lead-free commercial electronic products have been produced (see Table 1). Obviously, it is technically feasible to produce lead-free electronics for the commercial market. The real conundrum for avionics and military electronics manufacturers are whether lead-free electronics can be produced that meets the current requirements for high reliability electronics.

Unfortunately, there are still many technical questions surrounding the use of lead-free materials in high reliability electronics. Some of the unanswered questions are:



Product	Number Manufactured	Manufacturer
Battery Charger	12,000,000	Mitsumi
Video Tape Recorder	2,000,000	Panasonic
DVD Player	1,000,000	Panasonic
Printer	2,600,000	Pioneer
Tuner	400,000	Sony
Notebook Computer	80,000	Hitachi
Car Stereo	100,000	Sony
Vacuum Cleaner	1,000,000	Panasonic
Refrigerator	400,000	Hitachi
Dehumidifier	300,000	Hitachi
Plasma Display	20,000	Pioneer
Inverter	20,000	Matsushita
Rice Cooker	20,000	Matsushita
Other	20,000	

Courtesy of Mitsui Comtek Corp.

Table 1. Lead-Free Products Already Produced in Japan

1. Will the fact that component vendors are switching to lead-free finishes (mainly pure tin) result in an increase in failures due to tin whisker formation?

2. Are lead-free solders as reliable as tin/lead solder?

3. What are the effects of small amounts of lead (from intentional or accidental mixing of solders) upon the reliability of lead-free solders?

4. What effects will the higher processing temperatures required by lead-free solders have on the moisture sensitivity levels of electronic components?

5. What effect will the higher processing temperatures have on plated-through-hole reliability?

6. Are the replacement materials environmentally safe?

7. Will tin pest become a problem?

It has been known for many years that pure tin plating can grow tiny filaments or whiskers that are typically 1 to 3 microns in diameter and up to 10 millimeters in length (Figure 2). These whiskers can cause short circuits and have been the cause of many documented electronic failures (missiles, aircraft, satellites, pacemakers, etc.). These whiskers can be especially damaging in a space environment (i.e., a vacuum) because they can vaporize to form a tin plasma, which can conduct currents of over 200 amps. NASA Goddard has an excellent web site (http://nepp.nasa.gov/whisker) that shows many examples of tin whisker growth that they have documented from non-NASA sources. In addition, NASA Goddard has demonstrated that tin whiskers can grow through very thin layers of a polyurethane conformal coating (Figure 3). Why these whiskers grow is still not well understood. The generally accepted cause is stress in the tin-plating that can come from many sources (e.g., the plating process; intermetallic growth; scratches or nicks; bending of the plating; CTE mismatches, etc.).

The recent trend for component vendors to switch to pure tin plating has led to the formation of several industry consortia which are working to determine the cause of tin whisker growth and to develop strategies for mitigating the risks from tin whiskers. The National Electronics Manufacturing Initiative (NEMI; http://www.nemi.org/) has a large program that is exploring the causes of tin whisker growth. Another group (the CALCE Tin Whisker Alert Group; http://www.calce.umd.edu/lead-free/tin-whiskers) is exploring the use of conformal coatings for preventing tin whisker growth and should have preliminary test results by the end of 2002. In addition, this group (of which Boeing is a member) is surveying 111 component vendors to determine their immediate and future plans for switching to pure tin plating. Boeing is doing much of the testing for the Tin Whisker Alert Group and has established a tin whisker website (http://pw-web-01/mp&p/Tin_Whiskers/web_page.html) for dissemination of information.

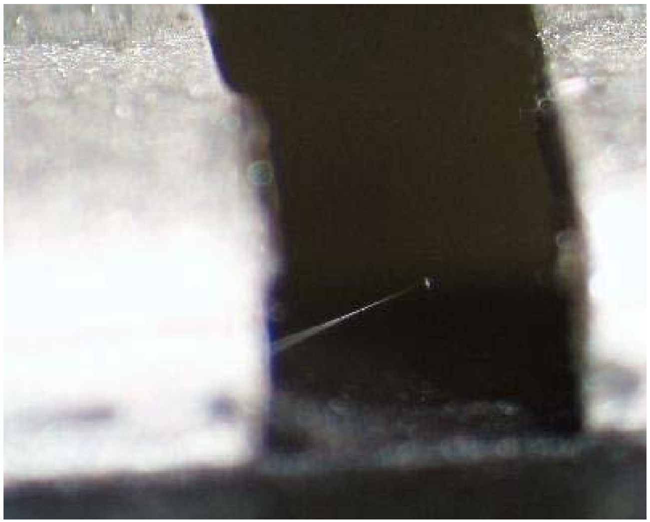


Photo Courtesy of NASA Goddard Space Flight Center http://nepp.nasa.gov/whisker

Figure 2. A Tin Whisker Growing On a Tin-Plated DIP Lead

The question of whether lead-free solders are as reliable as tin/lead solder is still being explored. A tremendous amount of research is being focused on this area and several large consortia have been formed to address this question. NCMS (the National Center for Manufacturing

Sciences) and NEMI have been producing valuable data on solder joint reliability. This data is usually produced by the accelerated thermal cycle testing of solder joints. Another consortia, the No-Lead Solder Joint Group on Pollution Prevention (JG-PP; http://www.jgpp.com/) was recently formed to verify the feasibility of using lead-free materials for the production of high reliability electronics for the U.S. Armed Services. The JG-PP (of which Boeing is a member) will begin their test program in early 2003 with all testing complete in 2004.

A survey of the available test data suggests that the leading lead-free solder candidate (tin/silver/copper) is more reliable than tin/lead when used with compliant component types (e.g., plastic ball grid arrays) but is less reliable with components whose coefficient of thermal expansion differs greatly from that of the circuit board (e.g., chip resistors and other ceramic parts). This means that tin/silver/copper may not be suitable for use in high reliability electronics unless strategies can be found for increasing its reliability with certain component types. One strategy might be staking or under filling the component with an adhesive to decrease the stress on the solder joints and increase their reliability.

To complicate matters further, the reliability of tin/silver/copper (compared to tin/lead) is also strongly dependent upon use temperature. These findings emphasize that great care must be taken when choosing a lead-free solder since its long-term reliability (compared to tin/lead) is highly dependent upon package type and use environment.

Recently, Boeing and others have been exploring the effects of small amounts of lead upon the reliability of lead-free solders. Mixing of lead-free solders and tin/lead solder will occur (accidentally or intentionally) during the manufacture and repair of electronics. A review of the available literature shows that, in general, small amounts of lead decrease the reliability of lead-free solders. However, small amounts of lead can actually increase the reliability of some lead-free solders (such as tin/silver/copper) when they are used with noncompliant (ceramic) components. In some cases, small amounts of lead can cause catastrophic failure of the solders. A good example is 58%bismuth/42%tin, which turns to a powder during thermal cycling if contaminated with a small amount of lead. Again, these findings emphasize that the properties of lead-free solders (compared to tin/lead) can vary widely depending on the package type they are used with and their sensitivity to trace contaminants.

The higher processing temperatures required by lead-free solders will have a negative impact on the moisture sensitivity levels (MSL) of components. When components are removed from their hermetic packaging they begin to absorb moisture from the air. If they absorb too much moisture, they can explode during reflow soldering due to the rapid formation of steam inside the component. The MSL tells assembly houses how long a component can sit before it must be used. If this time limit is exceeded, the component must be baked which adds cost to the assembly process. Higher processing temperatures have been shown to greatly reduce the MSL of components (i.e., a drop of 1 to 3 MSL levels). Many component manufacturers are working this problem and are developing components that are less sensitive to the temperatures required for lead-free assembly.

The higher processing temperatures required by lead-free solders may also have a negative impact on the reliability of plated-through holes. It is not unusual for a printed wiring board to see five thermal cycles during assembly. These include two reflow passes, a wave solder pass and a rework cycle that includes both a removal and a replacement thermal cycle. The effects of lead-free processing temperatures on plated-through holes are relatively unexplored but preliminary results from NEMI and Alcatel (a world-wide supplier of high tech systems in the telecommunications, electronics & electro-mechanics fields) suggest that higher reflow temperatures do have a significant negative impact. More work definitely needs to be done in this area.

Before OEM's switch to lead-free technology, they must be sure that the lead-free materials are not an environmental hazard. Data on whether lead-free solders can leach toxic metals is scarce but a study by Boeing showed that tin/silver/copper has limited potential for leaching silver (which is very toxic to marine life). A large leachate study will be conducted by the University of Tennessee as part of the US EPA Design for the Environment (DfE) Project that is comparing the life cycle environmental impact of tin/lead vs. lead free solders. The DfE Project is a cooperative effort between EPA and participating industry partners, including IPC (formerly the Institute of Interconnecting and Packaging Electronic Circuits) and EIA (Electronics Industries Alliance).

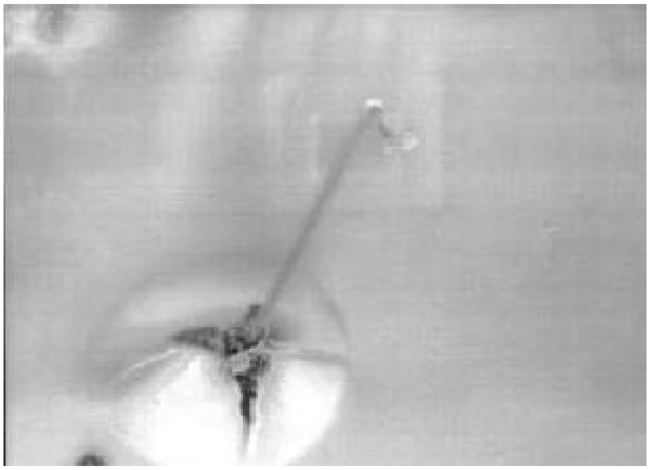


Photo Courtesy of NASA Goddard Space Flight Center http://nepp.nasa.gov/whisker

Figure 3. A Tin Whisker Growing Through 0.25 Mils of Conformal Coating

Another potential problem with some lead-free solders has only recently appeared (i.e., tin pest). White tin (the beta phase) is the stable phase above 13°C and grey tin (the alpha phase) is the stable phase below 13°C. Under certain conditions, a phase transition from beta to alpha can occur accompanied by a 26% volume increase that causes cracking of the solder. Alloying of the tin with another metal can slow or prevent the transition. A study from the UK has shown that tin/0.5%copper can transform from white tin into grey tin upon prolonged storage at –18°C with severe consequences (see Figure 4). A related alloy (tin/0.7%copper) is a leading candidate for lead-free wave soldering operations but no data exits on whether it is more resistant to this phenomenon. A study by Hewlett Packard suggests that tin/silver/copper is resistant to the formation of tin pest. Researchers there exposed tin/silver/copper solder joints to -50°C for 6 months and no tin pest was observed.

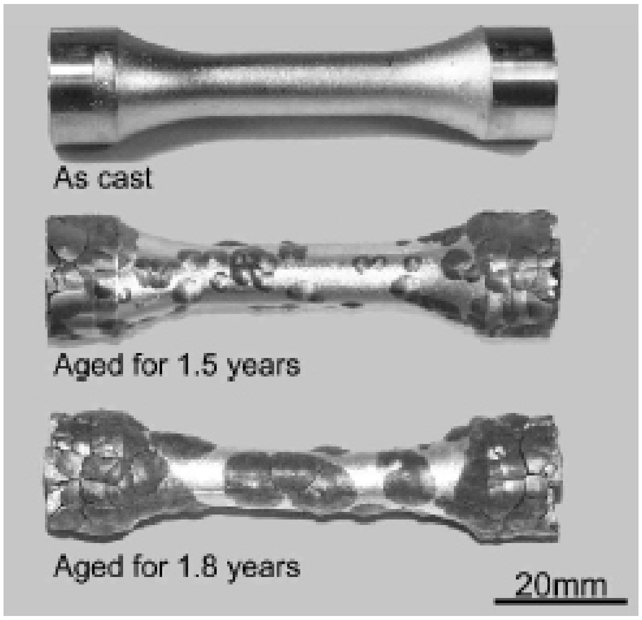


Photo Courtesy of the Open University, Milton Keynes, UK

Figure 4. Tin Pest On a Tin/0.5%Copper Ingot

Before manufacturers of high reliability electronics can switch from lead-containing materials to lead-free solders and finishes, many questions remain to be answered. Reliability concerns must be addressed and the long-term environmental impacts of the alternative materials must be characterized to ensure that they are indeed less hazardous than the materials they are replacing. Large test programs will need to be conducted and electronics manufacturers must form consortia so that the tremendous costs involved can be shared.

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Archived TechNotes Now Available Via Boeing External Website

The current TechNotes (in living color) as well as earlier issues (back to Feb. 1999) are now available to ALL Boeing suppliers/subcontractors and customers by accessing the Boeing External Web. The Boeing Commercial Airplane (BCA) Supplier Management & Procurement SHEA Team made this possible by recently transitioning their Supplier Management Environmental Website to the External Web Go to: http://www.boeing.com/companyoffices/doingbiz/environmental/TechNotes.html to see current and past issues of Boeing Environmental TechNotes.

In addition to TechNotes, you can also see what BCA's Supplier Management Environmental Program has to offer in pollution prevention options for suppliers/subcontractors. The Program's website mission is to provide suppliers with information and support on regulatory compliant and environmentally-preferred materials and processes

You will find sections on the following: Service Information, Low VOC Coatings, Non-Chromated Coatings, Solvent Cleaning, Tankline Processes & Regulations/Environmental Management Systems (EMS) Information. Obviously, these sections are tailored for BCA's supplier network. Suggestions have been made to expand the Supplier Environmental Program to include Integrated Defense Systems (IDS) suppliers/subcontractors. However, any effort to turn BCA's supplier environmental site into an enterprise-wide site will depend on feedback received from you, our military/space & communication supplier/customer readership.

After reviewing the BCA website, especially the Service Information section's Contract Requirements and Specification (Process & Specification Support Standard Departures Accountability) pages, if you feel similar information tailored for IDS readership would be helpful, please let us know.

Send your comments about an expanded enterprise website to Paul Rempes at Boeing-St. Louis Environmental Assurance, mailto:paul.e.rempes@boeing.com. How might your company/organization use this site? What other information would be useful? We look forward to hearing from you.