Restriction of Hazardous Substances Directive

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The **Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment** 2002/95/EC (Pronunciation / commonly referred to as the **Restriction of Hazardous Substances Directive** or **RoHS**) was adopted in February 2003 by the European Union.[1] The RoHS directive took effect on 1 July 2006, and is required to be enforced and become law in each member state. This directive restricts the use of six hazardous materials in the manufacture of various types of electronic and electrical equipment. It is closely linked with the Waste Electrical and Electronic Equipment Directive (WEEE) 2002/96/EC which sets collection, recycling and recovery targets for electrical goods and is part of a legislative initiative to solve the problem of huge amounts of toxic e-waste. In speech, it is often spelled out or pronounced /ɹɑs/, /ɹɑʃ/, /ɹoʊz/, or /ɹoʊ hɑz/.

European Union directive:	
Directive 2002/95/EC	
Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment	
Made by	Council & Parliament
Made under	Art. 95 EC
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History	
Made	27 January 2003
Came into force	13 February 2003
Implementation date	13 August 2004
Preparative texts	
Commission proposal	C365E, 19 December 2000, p. 195, C240E, 28 August 2001, p. 303.
EESC opinion	C116, 20 April 2001, p. 38.
CR opinion	C148, 18 May 2001, p. 1.
EP opinion	C34E, 7 February 2002, p. 109.
Other legislation	
Amended by	Dir. 2008/35/EC; Dec. 2005/618/EC, Dec. 2005/717/EC, Dec. 2005/747/EC, Dec. 2006/310/EC, Dec. 2006/690/EC, Dec. 2006/691/EC,

Contents

Details

Dec. 2006/692/EC, Dec. 2008/385/EC.
Status: Current legislation

Each European Union member state will adopt its own enforcement and implementation policies using the directive as a guide.

RoHS is often referred to as the lead-free directive, but it restricts the use of the following six substances:

1. Lead
2. Mercury
3. Cadmium
4. Hexavalent chromium (Cr^{6+})
5. Polybrominated biphenyls (PBB)
6. Polybrominated diphenyl ether (PBDE)

PBB and PBDE are flame retardants used in several plastics.

The maximum permitted concentrations are 0.1% or 1000 ppm (except for cadmium, which is limited to 0.01% or 100 ppm) by weight of *homogeneous material*. This means that the limits do not apply to the weight of the finished product, or even to a component, but to any single substance that could (theoretically) be separated mechanically—for example, the sheath on a cable or the tinning on a component lead.

As an example, a radio comprises a case, screws, washers, a circuit board, speakers, etc. The screws, washers, and case may each be made of homogenous materials, but the other components comprise multiple sub-components of many different types of material. For instance, a circuit board comprises a bare PCB, ICs, resistors, capacitors, switches, etc. A switch comprises a case, a lever, a spring, contacts, pins, etc, each of which may be made of different materials. A contact might comprise a copper strip with a surface coating. A speaker comprises a permanent magnet, copper wire, paper, etc.

Everything that can be identified as a homogeneous material must meet the limit. So if it turns out that the case was made of plastic with 2,300 ppm (0.23%) PBB used as a flame retardant, then the entire radio would fail the requirements of the directive.

In an effort to close RoHS loopholes, in May 2006 the European Commission was asked to review two currently excluded product categories (monitoring and control equipment, and medical devices) for future inclusion in the products that must fall into RoHS compliance.[2] In addition the commission entertains requests for deadline extensions or for exclusions by substance categories, substance location or weight.[3]

Note that batteries are not included within the scope of RoHS. However, in Europe, batteries are under the European Commission's 1991 Battery Directive (91/157/EEC[4]), which was recently increased in scope and approved in the form of the new battery directive, version 2003/0282 COD,[5] which will be official when submitted to and published in the EU's Official Journal. While the first Battery Directive addressed possible trade barrier issues brought about by disparate European member states' implementation, the new directive more explicitly highlights improving and protecting the environment from the negative effects of the waste contained in batteries. It also contains a program for more ambitious recycling of industrial, automotive, and consumer batteries, gradually increasing the rate of manufacturer-provided collection sites to 45% by 2016. It also sets limits of 5 ppm mercury and 20 ppm cadmium to batteries except those used in medical, emergency, or portable power-tool devices.[6] Though not setting quantitative limits on quantities of lead, lead-acid, nickel, and nickel-cadmium in batteries, it cites a need to restrict these substances and provide for recycling up to 75% of batteries with these substances. There are also provisions for marking the batteries with symbols in regard to metal content and recycling collection information.

The directive applies to equipment as defined by a section of the WEEE directive. The following numeric categories apply:

1. Large and small household appliances.
2. IT equipment.
3. Telecommunications equipment (although infrastructure equipment is exempt in some countries)
4. Consumer equipment.
5. Lighting equipment—including light bulbs.
6. Electronic and electrical tools.
7. Toys, leisure, and sports equipment.
8. Medical devices (currently exempt)
9. Monitoring and control instruments (currently exempt)
10. Automatic dispensers.

It does not apply to fixed industrial plant and tools. Compliance is the responsibility of the company that puts the product on the market, as defined in the Directive; components and sub-assemblies are not responsible for product compliance. Of course, given the fact that the regulation is applied at the homogeneous material level, data on substance concentrations needs to be transferred through the supply chain to the final producer. An IPC standard has recently been developed and published to facilitate this data exchange, IPC-1752.[7] It is enabled through two PDF forms that are free to use.

RoHS applies to these products in the EU whether made within the EU or imported. Certain exemptions apply, and these are updated on occasion by the EU.

Product category 8 and 9 exclusions

Medical devices, and monitoring and control instruments comprise RoHS Category 8 and Category 9 products respectively. The EU recognizes that these products are manufactured in small numbers and generally have a long product life. Further, these products are often used in mission-critical applications where their failure can reasonably be expected to be extremely disruptive, if not catastrophic. Since the long term effects of lead-free solder, a primary RoHS objective, cannot be known for a period of at least five years following the directive’s application to the remaining eight categories, the EU has established at least a temporary moratorium for Category 8 and 9 products.

In an effort to gain more insight the EU commissioned a study to assess when and if the RoHS directive should be applied to Category 8 and 9 products. Released in July 2006, the *Review of Directive 2002/95/EC (RoHS) Categories 8 and 9 – Final Report* recommended that Category 8 and 9 products remain exempt from the RoHS directive until 2012 or 2018 depending upon specific product sub-categories and applications.[8] Since the EU has not yet adopted this recommendation, the exact timing of RoHS application to Category 8 and 9 products remains uncertain.

Hazardous Materials and The High-Tech Trash Problem

RoHS and other efforts to reduce hazardous materials in electronics are motivated in part to address the global issue of consumer electronics waste. As newer technology arrives at an ever increasing rate, consumers are discarding their obsolete products sooner than ever. This waste ends up in landfills and in countries like China to be "recycled."[9]

> "*In the fashion-conscious mobile market, 98 million U.S. cell phones took their last call in 2005. All told, the EPA estimates that in the U.S. that year, between 1.5 and 1.9 million tons of computers, TVs, VCRs, monitors, cell phones, and other equipment were discarded. If all sources of electronic waste are tallied, it could total 50 million tons a year worldwide, according to the UN Environment Programme.*"[10]

Recycling efforts may be doing more harm than good. Not only are adult and child workers in these jobs being poisoned by heavy metals, but these metals are returning to the U.S. "*The U.S. right now is shipping large quantities of leaded materials to China, and China is the world's major manufacturing center,*" Jeffrey Weidenhamer says, a chemist at Ashland University in Ohio. "*It's not all that surprising things are coming full circle and now we're getting contaminated products back.*"[11][12]

Changing Toxicity Perceptions

In addition to the high-tech trash problem, RoHS reflects contemporary research over the past 50 years in biological toxicology that acknowledges the long-term effects of low-level chemical exposure on populations. New testing is capable of detecting much smaller concentrations of environmental toxins. Researchers are associating these exposures with neurological, developmental, and reproductive changes.

RoHS and other environmental laws are in contrast to historical and contemporary law that seek to address only acute toxicology, that is direct exposure to large amounts of toxins causing severe injury or death.[13]

Life-cycle impact assessment of lead-free solder

The United States Environmental Protection Agency (EPA) has published a life-cycle assessment (LCA) of the environmental impacts of lead-free and tin-lead solder, as used in electronic products.[14] For bar solders, when only lead-free solders were considered, the tin/copper alternative had the lowest (best) scores. For paste solders, bismuth/tin/silver had the lowest impact scores among the lead-free alternatives in every category except non-renewable resource consumption. For both paste and bar solders, all of the lead-free solder alternatives had a lower (better) LCA score in toxicity categories than tin/lead solder. This is primarily due to the toxicity of lead, and the amount of lead that leaches from printed wiring board assemblies, as determined by the leachability study conducted by the partnership. The study results are providing the industry with an objective analysis of the life-cycle environmental impacts of leading candidate alternative lead-free solders, allowing industry to consider environmental concerns along with the traditionally evaluated parameters of cost and performance. This assessment is also allowing industry to redirect efforts toward products and processes that reduce solders' environmental footprint, including energy consumption, releases of toxic chemicals, and potential risks to human health and the environment. Another life-cycle assessment by IKP, University of Stuttgart, shows similar results to those of the EPA study.[15]

Life-cycle impact assessment of BFR-free plastics

The ban on concentrations of brominated flame retardants (BFR) above 0.1% in plastics has had an impact on plastics recycling. As more and more products include recycled plastics, it has become critical to know the BFR concentration in these plastics, either by tracing the origins of the recycled plastics to establish the BFR concentrations, or by measuring the BFR concentrations from samples. Plastics with high BFR concentrations are costly to handle or to discard, whereas plastics with levels below 0.1% have value as recyclable materials.

There are a number of analytical techniques for the rapid measurement of BFR concentrations. X-ray fluorescence spectroscopy can confirm the presence of bromine (Br), but it does not indicate the BFR concentration or specific molecule. Ion attachment mass spectrometry (IAMS) can be used to measure BFR concentrations in plastics. The BFR ban has had significant impacts both upstream — plastic material selection — and downstream — plastic material recycling.

Labeling

RoHS does not require any specific product labeling, however many manufacturers have adopted their own compliance marks to reduce confusion. Visual indicators in use today include explicit "RoHS compliant" labels, green leaves, check marks, and "PB-Free" markings. In addition, the closely related WEEE (Waste Electrical and Electronic Equipment Directive) trash-can logo with an "X" through it is an indicator that the product may be compliant. Chinese RoHS labels, a lower case "e" within a circle with arrows, can also designate compliance.

The WEEE directive logo

The proposed RoHS2 attempts to address this issue by requiring the CE mark, introducing an additional enforcement agency, Trading Standards.[16]

RoHS in other regions

Please note that world wide standards and certification are available under the QC 080000 standard, governed by the NSAI (National Standards Authority of Ireland), to ensure the control of RoHs in industrial applications.

Asia / Pacific

China Order No. 39: Final Measures for the Administration of the Pollution Control and Electronic Information Products(often referred to as *China RoHS*[17]) has the stated intent to establish similar restrictions, but in fact takes a very different approach. Unlike EU RoHS, where products in specified categories are included unless specifically excluded, there will be a list of included products, known as the *catalogue* — see Article 18 of the regulation — which will be a subset of the total scope of Electronic Information Products, or EIPs, to which the regulations apply. Initially, products that fall under the covered scope must provide markings and disclosure as to the presence of certain substances, while the substances themselves are not (yet) prohibited. There are some products that are EIPs, which are not in scope for EU RoHS, *e.g.* radar systems, semiconductor-manufacturing equipment, photomasks, etc. The list of EIPs is available in Chinese and English.[18] The marking and disclosure aspects of the regulation were intended to take effect on July 1, 2006, but were postponed twice to March 1, 2007. There is no timeline for the catalogue yet.

Japan does not have any direct legislation dealing with the RoHS substances, but its recycling laws have spurred Japanese manufacturers to move to a lead-free process in accordance with RoHS guidelines. A ministerial ordinance *Japanese industrial standard for Marking Of Specific Chemical Substances* (J-MOSS), effective from July 1, 2006, directs that some electronic products exceeding a specified amount of the nominated toxic substances must carry a warning label.[19]

South Korea promulgated the *Act for Resource Recycling of Electrical and Electronic Equipment and Vehicles* on April 2, 2007. This regulation has aspects of RoHS, WEEE, and ELV.[20]

Turkey announced the implementation of their Restriction of Hazardous Substances (RoHS) legislation effective June 2009.[21]

North America

California has passed SB 20: Electronic Waste Recycling Act of 2003, or EWRA. This law prohibits the sale of electronic devices after January 1, 2007, that are prohibited from being sold under the EU RoHS directive, but across a much narrower scope that includes LCDs, CRTs, and the like and only covers the four heavy metals restricted by RoHS. EWRA also has a restricted material disclosure requirement.

Other US states and cities are debating whether to adopt similar laws, and there are several states that have mercury and PBDE bans already. Federal RoHS-like regulation in the US is unlikely in the near to medium term.

Other standards

RoHS is not the only environmental standard of which electronic product developers should be aware. Manufacturers will find that it is cheaper to have only a single bill of materials for a product that is distributed worldwide, instead of customizing the product to fit each country's specific environmental laws. Therefore, they develop their own standards, which allow only the strictest of all allowable substances.

For example, IBM forces each of their suppliers to complete a Product Content Declaration form to document compliance to their environmental standard Baseline Environmental Requirements for Materials, Parts and Products for IBM Logo Hardware Products. So for example, IBM bans DecaBDE, even though there is a RoHS exception for this material[1], this exemption was lifted on 1 April 2008 [2].

Similarly, here is Hewlett-Packard's environmental standard: General specification for the environment (GSE).

Criticism

Adverse effects on product quality and reliability, plus high cost of compliance (especially to small business) are cited as criticisms of the directive, as well as research indicating that the life cycle effect of lead-free solder is more significant than that of traditional solder materials.[22]

One criticism of RoHS is that the restriction of lead and cadmium does not address some of their most prolific applications, while being costly for the electronics industry to comply with. Specifically, the total lead used in electronics makes up only 2% of world lead consumption, while 90% of lead is used for batteries (covered by the battery directive, as mentioned above, which requires recycling and limits the use of mercury and cadmium, but does not restrict lead). Another criticism is that less than 4% of lead in landfills is due to electronic components or circuit boards, while approximately 36% is due to leaded glass in monitors and televisions, which can contain up to 2 kg per screen.[23]

Restricting lead content in solder for electronics requires expensive retooling of assembly lines and different coatings for the leads of the electronic parts. Lead-free solders have a higher melting point requiring higher process temperatures (e.g., a 30°C typical difference for tin-silver-copper alloys), driving changes to materials for chip packages, for some printed circuit boards and components containing plastics.[24] The higher temperature also precludes the use of components designed for lower temperatures. Interestingly, because these lead-free solders are less susceptible to high temperature failures, the automobile industry has used them to their advantage for years now, see the pros section.

Lead-free solders are significantly harder, which can increase the likelihood of cracks instead of plastic deformation, which is typical for lead-containing solders.[24] Such cracks occur due to thermal or mechanical forces acting on components or the circuit board, the former being more common during manufacturing and the latter in the field.[25]

The editor of Conformity Magazine wonders if the transition to lead-free solder will not affect long-term reliability of electronic devices and systems, especially in applications more mission-critical than in consumer products, citing possible breaches due to other environmental factors like oxidation.[26] This article refers to the Newark InOne "*RoHS Legislation and Technical Manual*",[27] which cites these and other "lead-free" solder issues, such as:

1. Warping or delamination of printed circuit boards;
2. Damage to through-holes, ICs and components on circuit boards; and,
3. Added moisture sensitivity, all of which may compromise quality and reliability.

Effect on reliability

Admission of reliability problems is found in Annex, item #7, of the RoHS directive itself, granting servers exemption from regulation until 2010. It should be noted that these issues were raised when the directive was first implemented in 2003 and reliability effects were less known.[28]

Another problem that lead-free solders face is the growth of tin whiskers. These thin strands of tin can grow and make contact with an adjacent trace, developing a short circuit. Research has also identified a particular failure mode for tin whiskers, where in high power components a short circuiting tin whisker is ionized into a plasma that is capable of conducting hundreds of amps of current, massively increasing the damaging effect of the short circuit.[29] Tin whiskers have already been responsible for at least one failure at a nuclear power plant.[30] Other documented failures include satellites in orbit,[31] aircraft in flight,[32] and implanted medical pacemakers.[33] It should be noted that these failures pre-date RoHS and do not involve consumer electronics, and therefore would be exempt. To help mitigate potential problems, lead-free manufacturers are using a variety of approaches such as tin-zinc formulations that produce non-conducting whiskers.[34] Fortunately, experience thus far suggests deployed instances of RoHS products are not failing due to whisker growth. Dr. Ronald Lasky of Dartmouth College reports: "*RoHS has been in force for more than 15 months now, and ~$400B RoHS-compliant products have been produced. With all of these products in the field, no significant numbers of tin whisker-related failures have been reported.*"[35] Whisker growth can occur slowly over time, is unpredictable, and not fully understood, so time may be the only true test of these efforts.

Reliability decay of low-lead materials may be economically desirable for some consumer product companies because it provides a mechanism to enforce planned obsolescence and replacement. Ironically, this is the opposite of the claimed intent of RoHS legislation.

Some countries have exempted medical and telecommunication infrastructure products from the legislation.[36] However, this may be a moot point, as electronic component manufacturers convert their production lines to producing only lead-free parts, conventional parts with eutectic tin-lead solder will simply not be available, even for military, aerospace and industrial users. To the extent that only solder is involved, this is at least partially mitigated by many lead-free components' compatibility with lead-containing solder processes. Leadframe based components, such as QFPs, SOICs, and SOPs with gull wing leads, are generally compatible since the finish on the part leads contributes a small amount of material to the finished joint. However, components such as BGAs which come with lead-free solder balls and leadless parts are often not compatible with lead-containing processes.[37]

Economic effect

There are no *de minimus* exemptions, e.g., for micro-businesses, meaning that some small businesses have closed down, citing the cost of compliance.[38] This economic effect was anticipated and at least some attempts at mitigating the effect were made.[39]

Another form of economic effect is the cost of product failures attributed to RoHS compliance. For example, tin whiskers were responsible for a 5% failure rate in certain components of Swiss Swatch watches in 2006, reportedly triggering a $1 Billion recall.[40] Swatch responded to this by applying for exemptions to RoHS compliance for two components. One of these exemptions was effectively approved, with the other still pending after an initial denial. For the denied part Swatch has stated to be using a replacement solder that is almost pure lead, and its application was for permission to switch to a solder with a lower lead content.[41][42][43]

Tin phase transformation

In an article published in Advanced Packaging, November/December 2006, Glenn A. Rinne of Unitive Electronics, Inc. (an Amkor Company) describes the allotropic phase transformation of tin, also known as tin pest, which begins at temperatures below 13°C (about 55°F)[44]. Tin pest causes solder joints affected by it to crumble. The effect is difficult to predict and control, because the transformation is slow. Interestingly, the effect was already known more than 100 years ago, as it has at various times been cited as a factor in the failure of Napoleon's Russian campaign, and Robert Scott's South Pole expedition.[45][46]

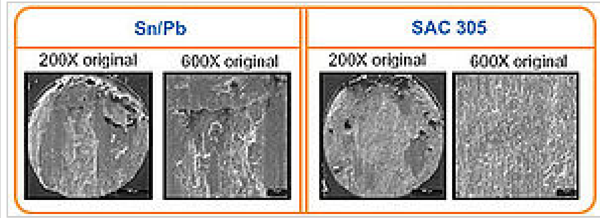
Pros

Health benefits

RoHS helps reduce damage to people and the environment in third-world countries where much of today's "high-tech trash" ends up.[47][48][49] The use of lead-free solders and components has provided immediate health benefits to electronics industry workers in prototype and manufacturing operations. Contact with solder paste no longer represents the same health-hazard it did before.[50]

Reliability concerns

Contrary to the predictions of widespread component failure and reduced reliability, RoHS's first anniversary (July 2007) passed with little fanfare.[51] Today, millions of compliant products are in use worldwide. Some of the most popular consumer electronics are now RoHS compliant, examples include Apple's iPod portable music players, Dell and HP home computers and servers, and Motorola's RAZR wireless phones.



An illustration of solder joint reliability, demonstrating AlphaSTAR's reliability versus traditional joints. AlphaSTAR is a RoHS immersion silver PWB assembly process from Cookson Electronics. Copyright 2007 © Enthone Inc.

Many electronics companies keep "RoHS status" pages on their corporate websites. For example, the AMD website states:

> "*Although lead containing solder cannot be completely eliminated from all applications today, AMD engineers have developed effective technical solutions to reduce lead content in microprocessors and chipsets to ensure RoHS compliance while minimizing costs and maintaining product features. There is no change to fit, functional, electrical or performance specifications. Quality and reliability standards for RoHS compliant products are expected to be identical compared to current packages.*"[52]

RoHS printed circuit board finishing technologies are surpassing traditional formulations in fabrication thermal shock, solder paste printability, contact resistance, and aluminum wire bonding performance and nearing their performance in other attributes.[53] One of these finishing products, known as immersion silver, is depicted here.

The properties of lead-free solder, such as its high temperature resilience, has been used to prevent failures under harsh field conditions. These conditions include 150°C operating temperatures with test cycles in the range of -40°C - 150°C with severe vibration and shock requirements. Automobile manufacturers are turning to RoHS solutions now as electronics move into the engine bay.[54]

Flow properties and assembly

One of the major differences between lead-containing and lead-free solder pastes is the "*flow*" of the solder in its liquid state. Lead-containing solder has higher surface tension, and tends to move slightly to attach itself to exposed metal surfaces that touch any part of the liquid solder. Lead-free solder conversely tends to stay in place where it is in its liquid state, and attaches itself to exposed metal surfaces only where the liquid solder touches it.

This lack of "*flow*" -- while typically seen as a disadvantage because it can lead to lesser quality electrical contacts -- can be used to place components tighter than they normally could be placed due to the properties of lead-containing solders.

For example, Motorola reports that their new RoHS wireless device assembly techniques are "*...enabling a smaller, thinner, lighter unit.*" Their Motorola Q phone would not have been possible without the new solder. The lead-free solder allows for tighter pad spacing.[55]

Some exempt products achieve compliance

Research into new alloys and technologies is allowing companies to release RoHS products that are currently exempt from compliance, *e.g.* computer servers.[56] IBM has announced a RoHS solution for high lead solder joints once thought to remain a permanent exemption. The lead-free packaging technology "*...offers economical advantages in relation to traditional bumping processes, such as solder waste reduction, use of bulk alloys, quicker time-to-market for products and a much lower chemical usage rate.*"[57][58]

Test and measurement vendors, such as National Instruments, have also started to produce RoHS-compliant products, despite devices in this category being exempt from the RoHS directive.[59]

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See also

- Battery Directive
- Electronic waste
- Green computing
- Ion attachment mass spectrometry - used to enforce RoHS limits on banned substances
- List of European Union directives
- Waste Electrical and Electronic Equipment Directive

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57. ^ IBM Launches Production of Lead-free Packaging Technology
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External links

- RoHS compliance guidance for businesses on NetRegs.gov.uk
- RoHS Compliance in the EU - www.rohs.eu
- RoHS Compliance Definition & Guidelines
- EU Regulations compliance (WEEE, RoHS, Batteries, REACH)
- RoHS directive official text
- Official United Kingdom site on RoHS
- Free RoHS regulatory bulletin updates - Bureau Veritas
- Pushback is seeking to reverse the lead in solders ban
- Silicon Valley Toxics Coalition
- Understanding RoHS (PDF) Shimadzu Scientific Instruments
- Lead-free RoHS Compliance Material Comparison from Sunstone Circuits
- RoHS Explained: includes overview and links to related resources?
- RoHS News
- Electronic Components and RoHS Compliance News
- EIATRACK information on RoHS and WEEE Directives
- RoHS 101
- China RoHS
- Intertek RoHS Blog
- Cleaner products at lower cost (1/3; Hermann Strass; Open Systems Publishing; May 2003
- EU RoHS Enforcement Guidance Document, V.1; EU RoHS Enforcement Authorities Informal Network; May 2006
- NASA Tin Whiskers Photo Collection
- Lead-Free Medical Devices Article from 2005