Restricted Substances in Materials: Testing and Reporting Procedures Workshop October 5-7, 2005 Summary Report

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The Restricted Substances in Materials workshop was hosted by, and held at, the National Institute of Standards and Technology (NIST) on October 5-7, 2005. Ninety-six people attended, from seven different countries. The workshop included 22 separate presentations and panel discussions. Each of these is summarized below.

Background Information

The European Union (EU) Restriction of Hazardous Substances (RoHS) Directive, which will go into effect on July 1, 2006, mandates that electrical and electronic equipment (EEE) sold in the EU will contain restricted levels of the following six substances:

- Lead (Pb)
- Cadmium (Cd)
- Mercury (Hg)
- Hexavalent Chromium (Cr^{6+})
- Polybrominated Biphenyls (PBB)
- Polybrominated Diphenyl Ethers (PBDE).

The RoHS Directive, which aims to protect human health and the environment, applies to EEE sold in the EU. Aerospace, military, and medical devices, which do not have consumer purposes, are exempt from RoHS. The Peoples Republic of China will implement a similar regulatory structure to coincide with the EU regulations. In addition, Canada and individual states in the United States (US) are planning or implementing related legislation. In Japan, the Japan Electronics and Information Technology Industries Association issued guidelines on declarations of substances linked to the Joint Industry Guide under the jurisdiction of the Electronics Industry Association based in the US.

Goals of the Workshop

The goals of the workshop were (1) to assess the measurement and standards needs of industry and (2) to collaboratively produce a plan that addresses international standards issues to help U.S. manufacturers access the global market.

Conference-Related Material

The following materials were made available at the workshop:

- Conference Program
- Participants List

- Compact Disc containing complete presentations (three presentations were not included)
- *Notify U.S.* handout.

During the workshop, a number of invited speakers discussed key aspects of the development and impacts of RoHS. There talks are summarized below. The complete presentations and other workshop materials are available on the internet at the following address: http://www.cstl.nist.gov/nist839/RoHS/RoHS_Meeting.htm

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***The Role of NIST in Support of U.S. Industry and Global Comparability*, presented by Willie May, NIST, Chemical Science and Technology Laboratory**

Dr. May presented an overview of NIST and NIST's role with RoHS. In this overview, Dr. May discussed NIST's mission, history, assets, role, standing within the international community, and RoHS-related services and products.

Regarding NIST's role with RoHS, Dr. May posed the following four rhetorical questions to the audience:

- Is there a problem?
- Is there a role for NIST in solving the problem?
- Does NIST have the resources to assist with the problem?
- How can NIST assist with RoHS?

***Impact of Regulated Substances and Environmental Legislation on the Electronics Industry*, presented by Joe Johnson, Cisco Systems**

Mr. Johnson discussed the impact of regulated substances and environmental legislation on the electronics industry. In his presentation, Mr. Johnson discussed the legislative history, issues, and challenges as they pertain to RoHS.

Mr. Johnson noted that the EU has been the leader with respect to environmental regulations and he presented a short legislative history that has led to RoHS. The history included a brief discussion of the EU directives on Waste Electrical and Electronic Equipment (WEEE), Energy Using Products (EuP), and Registration, Evaluation, and Authorization of Chemicals (REACH).

- WEEE Directive requires producers to manage post-consumer recycling and disposal of electronic products (August 2005)
- EuP Directive requires producers to design products to meet specific eco-design criteria over the entire life-cycle of certain products (~2007)
- REACH Directive requires the registration and risk assessment of chemical substances, possibly including "downstream use" in products (~2007).

The issue, as articulated by Mr. Johnson, is, “How can an electronics manufacturer be in compliance with all of the various international rules?”

The solution, according to Mr. Johnson, involves the following:

- Promote worldwide requirements and appropriate exemptions
- Develop cost-efficient compliance strategies for multi-tiered global supply chain
- Develop Certified Reference Materials (CRMs) for analytical compliance testing
- Educate and train industry by developing compliance documentation
- Develop a management information system
- Develop auditing and testing tools.

***RoHS Implementation - A View from an Engineering Polymers Supplier,* presented by Eric Beyeler, DuPont Engineering Polymers**

Mr. Beyeler presented a discussion of RoHS implementation issues from an engineering polymers supplier point of view. Mr. Beyeler discussed the background and challenges that organizations, such as his, must face.

Mr. Beyeler noted that the issues related to RoHS are global issues, that there are many products and many marketplaces, and all of this is complicated by a long and international supply chain. With all of these factors, manufacturers must be able to demonstrate that their products are compliant with RoHS.

Mr. Beyeler presented three questions to electronic manufacturers:

- How do you test for compliance?
- How do you certify compliance?
- What are the standards of acceptability?

Mr. Beyeler presented his ideas to facilitate full compliance:

- Standardized specification, including limits and test methods
- Standardized test methods, which should address expectations on variability and interpretation of results
- Standardized proof of compliance, which must be compatible with extensive and highly diverse product lines.

***The Restriction of Hazardous Substances (RoHS) Directive - Enforcement in the UK and Across Europe*, presented by Steve Andrews, Department of Trade and Industry, United Kingdom (UK)**

Mr. Andrews presented a discussion of the RoHS Directive. In his presentation, Mr. Andrews discussed the background, compliance approach, and UK enforcement tools.

Mr. Andrews discussed the organization of the UK Department of Trade and Industry (DTI) and the Sustainable Development Directorate within DTI. DTI is responsible for policies that protect the environment. Mr. Andrews noted that, under the RoHS directive, the agreed permitted levels by weight in homogeneous materials are 0.1% for Pb, Cr^{6+}, and Hg; 0.01% for Cd; and 0.1% for PBBs and PBDEs.

Mr. Andrews discussed approaches for compliance with regard to the RoHS Directive:

- Self certify by manufacturers, which can be enforced by market surveillance
- Establish standards for RoHS compliance testing, where several suitable analysis standards currently exist
- Develop standards on reporting formats, which can lead to standardized markings and part numbering
- Exchange information among EU member states regarding analysis expertise and market intelligence, which will save costs and help avoid conflicts.

Mr. Andrews also discussed enforcement and outreach tools available to the UK to enforce RoHS:

- Web site
- Enforcement powers
- Inspection processes
- Compliance notices
- Prosecution powers with fines.

***The Impact of Emerging Substance Regulations - Strategies for Product Environmental Compliance*, presented by E. Karofsky, AMR Research**

Mr. Karofsky discussed the impact of emerging restricted substance regulations. In his presentation, Mr. Karofsky discussed background, questions, issues, and solutions.

As background, Mr. Karofsky discussed the negative impact of not complying with RoHS. Mr. Karofsky offered three examples to the audience, including Sony's $160 million lost opportunity when Cd was found in Sony PlayStation® cables; Abacus's $6 million lost inventory because of noncompliant goods; and the organization's responsibility to report losses on SEC 10(k)

financial reports.

A major question Mr. Karofsky asked is, “How do you talk to your supplier to ensure compliance with RoHS?” Mr. Karofsky emphasized that companies need standards to drive strategies; otherwise, it is difficult to communicate with suppliers, difficult to manage diverse global regulations, and difficult to control legal exposure of a company. Mr. Karofsky added that material declarations are central to developing a strategy to allow companies to ensure product design readiness, technology adoption, process readiness, and content verification.

Mr. Karofsky also articulated the need for standards so that an organization can develop a methodology for the exchange of information. As a solution, Mr. Karofsky proposed a master database in one central location where all component products information can be stored and accessed.

***Materials Declaration*, presented by Fern Abrams, IPC- Association Connecting Electronics Industries**

Ms. Abrams discussed the IPC approach to materials declaration and the issues related to developing standards. With regard to the RoHS Directive, these issues are as follows:

- Several countries are currently working on RoHS-related legislation
- Until finalized, RoHS-related issues are a moving target for industry
- Material declaration statement (MDS) formats and custom software are proliferating
- Many players are developing standards
- Disjointed standards are being developed by various organizations.

Ms. Abrams suggested that any solution requires the following:

- Solution needs complete supply chain solution
- Solution needs national and international recognition
- Solution needs to include a business-to-business data exchange
- Solution needs flexibility to accommodate manual data entry.

Ms. Abrams proposed an Adobe PDF implementation for material declaration for the following reasons:

- One format for Extensible Markup Language (XML) data
- The Adobe® Reader® for PDF files is free; there is an estimated 500 million installations worldwide
- Large number of independent software vendors who support PDF
- Platform supports manual entry
- Provides XML import/export to integrate with data management systems.

Ms. Abrams concluded with a discussion of the IPC 1750 family of supplier declaration standards and forms. IPC 1751, General Requirements, establishes necessary declaration

between members of a supply chain and contains general information about a supplier. IPC 1752, Material and Substance Declaration, allows for the reporting of RoHS compliance and manufacturing process information. Ms. Abrams emphasized that IPC would support the development and maintenance of standard forms.

***Supplier Declarations Under EU's RoHS Directive*, presented by Chris Bell, Austin, Brown and Wood, LLP**

Mr. Bell discussed supplier declarations under the RoHS Directive. In his presentation, Mr. Bell described the following major issues as they relate to RoHS:

- Only products, not suppliers, must comply with RoHS
- RoHS does not address compliance
- MSDSs are not required by RoHS
- No legally mandated format has been developed
- Legal effect of such declaration, as yet, unclear; if a supplier's declaration is wrong, who pays?
- Not everything (i.e., paper, packaging) sold in EU is covered by RoHS; RoHS covers only electrical and electronic equipment (EEE)
- RoHS only covers six substances
- RoHS does not require a total ban
- RoHS covers product content, not a production issue
- Need to know clearly the basis for making a declaration (i.e., by a supplier's declaration or by reviewing Material Safety Data Sheets)
- Compliance will depend on supply-chain contract relations.

***Collaborative Automotive Industry Initiatives, Material Declaration - A Working Example*, presented by Michael M. Fisher, American Plastics Council/American Chemistry Council**

Mr. Fisher discussed automotive industry initiatives with respect to material declaration. Within his presentation, Mr. Fisher provided an automobile industry background, discussed the issues as they relate to RoHS, and described the requirements.

Mr. Fisher noted that the automobile industry has been working with restricted substances issues in automobiles for a long time. He went on to describe the Global Automobile Declarable Substance List (GADSL). The GADSL is used by the automotive industry to comply with environmental and health regulations worldwide and affects automotive OEMs, automotive parts manufacturers, and chemicals/plastics manufacturers.

Mr. Fisher made it clear that, for RoHS to be effective, a single set of rules would be required. Mr. Fisher emphasized that any material declaration solution must be a cooperative, vertical, and collaborative effort.

***Supply Chain Material Disclosure*, presented by Jim Dills, The Goodbye Chain Group**

Mr. Dills presented a discussion of supply chain issues, small- to medium-sized enterprise (SME) issues, and material declaration issues.

Mr. Dills discussed the fact that the entire supply chain needs to be RoHS compliant. As an example, Mr. Dills described the problem faced by Sony when one of its 4,200 suppliers provided noncompliant parts, which subsequently cost Sony $160 million.

Mr. Dills discussed the issues faced by SMEs, which include the following:

- Thin operating margins
- Lack of resources
- Inability to accurately provide substance information
- Lack of awareness
- Part numbering.

Mr. Dills also discussed material declaration management. Mr. Dills provided a short history of material declaration statements that have led to the IPC 1752. Mr. Dills discussed the time it takes to complete the material declaration forms, especially if every company has its own forms. Mr. Dills felt that a standard materials declaration form would speed up compliance, cut costs, and reduce supply chain stress.

Mr. Dills summarized his presentation by stating that data management presents the greatest challenge to SMEs and that standard forms, tools, and business processes are the best hope for SMEs and that NIST's support for standards is critically important.

***Issues in Material Composition Reporting*, presented by Frank Rossman, Jabil Circuit/Environmental Initiatives**

Mr. Rossman addressed three issues as they related to the electronics industry. First, Mr. Rossman discussed the benefit of requiring "full disclosure", not just the minimum disclosure. By requiring full disclosure, an organization meets current and future reporting needs.

Second, Mr. Rossman described material declarations he has received and reviewed. Mr. Rossman reported that 50% of these documents were in error. Mr. Rossman emphasized the need to establish an industry-accepted data-gathering software tool to allow for one-time data reporting and for simplifying data exchange.

Third, Mr. Rossman described the benefit of part number changes and the trends in industry. Material composition changes should drive manufacturers to change part numbers to ensure that

compliant products are designed and manufactured. However, Mr. Rossman said that some manufacturers will change the part number of RoHS compliant parts while others will use the same part number for both compliant and noncompliant parts.

Finally, Mr. Rossman asked, "What is standard component testing?" The strategy is for component composition to be verified against material composition reports by using standardized testing methods. However, standards are not available; therefore, manufacturers have nothing to test against.

***Restricted Substances Data Exchange: Large and Small Company Perspectives*, presented by Jennifer Shepherd, Canyon Snow Engineering**

Ms. Shepherd presented a series of relationships between large and small companies - large Original Equipment Manufacturers (OEMs) may work with small suppliers or small OEMs may work with large suppliers. Ms. Shepherd noted that the imbalances in company size and leverage creates unexpected dynamics and that it is this complexity of the industry supply chain that is driving a need for standardization. Ms. Shepherd emphasized the need for substance-level data for RoHS, which will be driven by legislation and regulations, voluntary programs, and large OEM commitments and programs.

***International Electrotechnical Commission's Technical Committee 111 (IEC TC111) Working Group 3*, Procedures for the Determination of Six Regulated Substances in Electrotechnical Products, presented by Joe Johnson, Cisco Systems**

Mr. Johnson provided a description of the IEC TC111 Working Group 3. The mission of this working group is to develop a standard that will define test procedures that will allow the electrotechnical industry to determine the concentration of RoHS-restricted substances in electrotechnical products on a consistent basis. He felt that any testing scheme must be consistent, reliable, harmonized, and facilitate international trade. Mr. Johnson further explained that testing may be performed as an alternative to supply-chain material declarations, as a supplement to a material declaration, as a "spot check" to confirm supplier compliance, or as a basis to assess compliance.

Mr. Johnson continued by detailing the standard, which included sample preparation, screening by X-ray fluorescence (XRF) spectroscopy, and specific tests to measure the six RoHS-restricted substances in polymer materials, metallic materials, or electronics. Mr. Johnson noted that a Committee Draft of the standard will be voted on by the end of 2005 and that the standard is expected to become final by October 2006.

***ASTM International Committee F40 on Declarable Substances in Materials*, presented by**

Timothy McGrady, IMR Test Labs

Mr. McGrady presented an overview of ASTM International (formerly American Society for Testing and Materials), ASTM's Committee F40, an analysis of the supply chain model, and a series of recommendations.

Mr. McGrady described ASTM's methods for developing standards, types of documentation, how the ASTM standards are used by industry, and the standards and conformity assessment model. Mr. McGrady explained that with the standards and conformity model, the model is applicable to regulations as well as purchase orders, that the government becomes the "buyer" or "assessor" and the manufacturer becomes the "seller" or the "complier", and where any supporting data must be legally defensible.

Mr. McGrady presented an overview of ASTM International Committee F40 on Declarable Substances in Materials. This Committee addresses issues related to the development of standards for the evaluation of materials/products relative to RoHS requirements. The goals of the Committee are to reduce costs, to educate, and to build/modify infrastructures in order to help companies achieve legally defensible positions through established standards.

Mr. McGrady presented an analysis of the supply chain model, which included raw materials, manufactured materials, parts/components, sub-assemblies, and finished products. Mr. McGrady noted that as the supply chain grows in complexity, the numbers of items to be tested increases, testing difficulty increases, and costs increase.

Finally, Mr. McGrady presented a series of recommendations to include:

- Efforts to educate government about industry needs concerning standards
- Chemical/material/supplier/trade associations must be involved in risk assessment
- Need for CRMs, RMs, and research
- Long-term commitment from everyone involved.

***Contributing Work to the XRF Screening Method*, presented by Bob Wopperer, Oxford Instruments**

Mr. Wopperer stated that there is no one single technique that will test for all substances restricted by the RoHS directive, but that if one single technique is to be used, X-ray fluorescence (XRF) is the most comprehensive, nondestructive, and user-friendly option. Mr. Wopperer emphasized that most samples can be easily determined to be compliant or noncompliant with a quick XRF measurement and that only a small percentage of samples will require further testing.

***Flame Retardants - Issues of Relevance to Environmental Regulations*, presented by David**

L. Edenburn, Edenburn Consulting International

Mr. Edenburn discussed the use of flame-retardants in electronic products as they related to RoHS. Flame-retardants are deliberately added to plastics to pass required fire tests. RoHS only restricts one type of flame-retardants (halogen-based flame retardants containing bromine). Because plastic manufacturers know exactly what flame retardant is being used and the quantity added to their products, future products will comply with RoHS. Mr. Edenburn warned that the real issue is for the recycler who may be receiving pre-RoHS, noncompliant material. Proposed methods for determining flame-retardant type and level include gas chromatography/mass spectra, FTIR scan, or XRF scan; however, Mr. Edenburn emphasized that there is currently no test to determine if a recycled material is RoHS compliant or not. In addition to other suggestions, Mr. Edenburn suggested that a library of spectra be prepared for all likely plastic/flame retardant combinations.

***The Hexavalent Chromium Challenge*, presented by Sophia Lau, IBM Systems and Technology Group**

Chromium is used on screws, bolts, and heat sinks within electronic products. Chromium is used because of its three properties: it is anti-corrosive, self-healing, and inexpensive. The only type of chromium that is restricted by RoHS is Cr^{6+} because it is a carcinogen. There is no substitute for Cr^{6+} that is as inexpensive and available around the world.

Ms. Lau emphasized that there is a strong need in the U.S. electronics industry to accurately and reliably determine RoHS-compliancy in chromium coating. If the EU can be persuaded to adopt the well-established industry unit for expressing quantities of Cr^{6+} in units of mass per unit surface area, it will eliminate the need to develop a new, accurate, and environmental-friendly method of measuring Cr^{6+}. Ms. Lau added that X-ray absorption spectroscopy studies for measuring Cr^{6+} may also lead to a set of potential reference materials, thereby enabling the development of economical testing methods. Raman spectroscopy may also be useful for Cr speciation.

Following the presentation, Ms. Lau and Dr. Winchester of NIST discussed the potential uses of glow-discharge optical emission spectrometry for depth profiling and determination of total coating mass.

***Analysis of Mercury in Materials*, presented by Timothy McGrady, IMR Test Labs**

Mr. McGrady indicated that there are no existing test procedures for Hg in plastics or metals. While EPA and ASTM list many Hg test methods, none of the methods test for Hg in plastics nor metals. However, Mr. McGrady explained that EPA Method 7473 Mercury in Solids and Solutions by Thermal Decomposition, Amalgamation, and Atomic Absorption Spectrophotometry may be adapted to test for Hg in plastics and solids and is known as Direct Mercury Analysis (DMA). DMA is a quick and easy method, is basically cold-vapor atomic absorption spectrophotometry, can analyze solid samples, and is very sensitive (0.01 ng instrument detection limit). Mr. McGrady noted that Hg is hardly being used in the electronics industry, except for switches (which may be exempted) and button-cell batteries.

***RoHS-related CRM activities of IRMM*, presented by Thomas Linsinger, EC Joint Research Center, Institute for Reference Materials and Measurements (IRMM)**

Similar to NIST, the goal of IRMM is to standardize materials and measurements to support trade and competition. According to Dr. Linsinger, to reach the goal of developing internationally accepted measurement tools, CRMs that are available include Pb and Cd in metal alloys, Pb in ceramic matrices, Cd, Pb, and Hg in polymers, and Cr^{6+} in welding dust. Those CRMs that are needed include flame-retardants in polymers. In an effort to develop PBB and PBDE CRMs in polymers, the IRMM's timetable is material processing by early 2006, interlaboratory comparisons by 2006, and measurements for homogeneity, stability, and characterization by 2007.

***Report from Declaration Standards Session*, moderated by Eric Simmon, NIST Electronics and Electrical Engineering Laboratory**

During this session, which was moderated by Eric Simmons and opened to general discussion, the attendees of the workshop discussed RoHS-related requirements and how NIST could be helpful with these requirements. The industry requirements were identified as the following:

- Need for a data management and a data exchange methodology
- Need for standardized forms
- Need for Certified Reference Materials (CRMs)
- Need for part numbering/labeling standards
- Need for standard practices for sample preparation.

After a discussion of industry needs, the attendees of the workshop discussed ways that NIST, as an expert consultant, could assist industry. The following recommendations were made:

- NIST should continue to support IPC 175x
- NIST should continue to participate in IEC TC111
- NIST should continue to assist with the development of data management/exchange approaches
- NIST should participate in the development of labeling standards
- NIST should investigate cross-industry (i.e., automotive) standards.

***Report from Test Method and Reference Materials Section*, moderated by John Sieber, NIST Chemical Science and Technology Laboratory**

The major issues involving the RoHS Directive are (1) the need for standard test methods for raw materials, (2) the need for standard test methods for electrical and electronic products, and that (3) RoHS-affected substances are everywhere.

To begin to address the above issues, the electronic industry needs to:

- Develop standards by participating in IEC TC111, especially Working Group 3; participating in ASTM International; and seeking assistance with interlaboratory studies
- Develop standard guides for risk assessment, interpretation of test results against a set of action limits, and selection of test methods
- Develop standard practices for sample preparation
- Implement standard test methods in laboratories
- Develop educational/outreach efforts through additional conferences, especially on specific subtopics
- Identify needs of the recyclers.

Issues regarding test methods for brominated flame-retardants (BFRs):

- Test methods under investigation include:
  - GC-MS and HPLC-UV for PBB and PBDE
  - XRF for total Br
- Need to develop spectral library for BFRs
- Need to focus on vicinity of maximum concentration values for each compound
- Examine stability issues with candidate CRM materials
- Determine the effects of UV light on BFRs in polymers
- Determine what CRMs are needed; highest priority appears to be BFRs in acrylonitrile butadiene styrene and polycarbonate
- Need to address BFRs in recycled materials.

Issues regarding test methods for Cr^{6+}:

- Test methods under investigation include:
  - XRF for total Cr and layer thickness
  - XAS/XRF/XPS for Cr speciation and layer thickness
  - Raman spectroscopy

    - GD-OES, which allows for depth profiling for total Cr and total mass of coating
- Focus on 10- to 500-nm layers containing Cr, Cr3+, and Cr6+
- Understand stability issues with samples and potential CRM materials in coating form
- Determine if there is a need to test Cr6+ and total Cr in polymers
- Determine if a dichromate solution CRM has any application
- Determine if coating CRMs are possible
- Examine use of Cr plating layer as blank for spot and thickness tests.

Issues regarding test methods for Cd:

- Test methods under investigation include:
    - ICP-OES, ICP-MS, and AAS
- Determine if test methods exist using SS-OES or GD-OES
- Focus on testing for Cd in ferrous and non-ferrous alloys, polymers, paints, ceramics, tin/copper/bronze/aluminum solder, and glass
- Concern exists that NIST aluminum and copper SRMs are in short supply.

Issues regarding test methods for Pb:

- Test methods under investigation include:
    - ICP-OES, ICP-MS, and AAS
- Determine if test methods exist using SS-OES or GD-OES
- Focus on testing for Pb in ferrous and non-ferrous alloys, polymers, ceramics, tin/copper/bronze/aluminum solder, and glass
- Concern exists that NIST aluminum and copper SRMs are in short supply.

Issues regarding test methods for Hg:

- Test methods under investigation include:
    - CV-AAS, AFS, ICP-OES, and ICP-MS
- Focus on testing Hg in polymers and ceramics
- Determine if DMA is covered by IEC
- Determine if ASTM methods can be modified for use on polymers
- Determine if carbonaceous materials such as coal and oil can be used as reference materials.

Issues regarding the use of test method XRF:

- Need a general screening method that can work with all designs of XRF spectrometers, work with all materials, and be able to quantify in 10 ppm to percent levels
- Need to determine if micro-XRF can be used for certain applications in certain products
- Need to determine appropriate CRMs
- Need standards to improve performance of fundamental parameters methods.

Issues regarding organizational leadership:

- Does the EEE industry need an international body to identify and review higher-order reference materials and test methods?

- Does the EEE industry need to involve other organizations such as additional National Measurement Institutes or the Laboratory of the Government Chemist or the International Laboratory Accreditation Conference?

Action items:

- List all potentially useful NIST SRMs
- Explore options to use such test methods as Raman, GD-OES, and XAS/XES
- Recruit expert laboratories to help with reference materials and test methods
- Develop document containing state-of-the-art data on testing to determine substance requirements.

What should be done about SRMs and research at NIST? -- Attendees listed perceived needs.

Brominated Flame Retardants in polymer CRM

Solder – Pb-free solders

1. Sn-Ag-Cu SAC305 published specs for surface mount applications, Elements: Pb, Cd, Ag, Cu, Ni
2. SnNiCu Sn100C – wave soldering alloy, same elements

Glass filler fibers and ceramics – elements are Pb, Cd, Sb, As

PVC – used in many parts – power cords, wire coverings/coatings; Elements: Pb, Sb, Cd, Sn, possibly add hex Cr colorant?; To evaluate extraction methods, possibly Br concern about specificity for halogens; can HgS or other stable Hg source be added?

Hg in polyurethane – lower priority

Cr conversion coatings – to distinguish oxidation states; to study extraction methods
See research topics under Cr heading above

Research – see presentation by S. Lau, IBM and listings above for Cr^{+6}
Can research help change the EU hex Cr units decision?
Changing composition/sol-gel water content makes layers.