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# Environmental Impacts and Toxicity of Lead Free Solders

Including Japanese and European Union Regulations

**ABSTRACT**

It is clear that lead free soldering is a foregone conclusion. There are several alternatives under investigation, some of which are already in use. These investigations of the various lead free solder alloy candidates have been in progress for the past few years. Researchers have been determining the solder alloys' physical and mechanical properties, environmental impacts, and occupational toxicity. This paper seeks to continue the research into the environmental impacts of lead free alloys. Comparisons are made between seven lead free solder alloys: Tin/Silver/Copper, Tin/Silver, Tin/Copper, Tin/Antimony, Tin/Indium, Tin/Silver/Bismuth, and Tin/Bismuth. These alloys were tested in the various physical forms most likely to occur from PCB fabrication, assembly, and finished product disposal to determine the environmental impact from each alloy. The goal of this research is not to say "no" to lead free solders, but to assist the industry in selecting the best alloy from the many available alternatives.

## Waste Regulation Worldwide

Management of waste in industrialized countries ranges from highly regulated, specific, government controlled operations to practical non-existence. Within this range falls most industrialized countries which significantly regulate industrial/commercial hazardous waste, with or without also regulating household hazardous waste disposal. Hazardous waste is defined as any waste that may "pose a substantial present or potential threat to human health and the environment when improperly treated, stored, transported, or otherwise managed". When waste is disposed it is weathered by rainfall and reactions with other wastes, which allows metal elements and their salts to be leached from the metal surfaces of the waste. If the metal bearing leachate is allowed to contact stormwater, groundwater, or to migrate into groundwater, local drinking water supplies are threatened with contamination.

## Deionized Water Leach Methods

Many members of the European Community, including France and Germany, as well as Japan utilize deionized (demineralized) water leaching tests. A draft European Community test method also specifies deionized water leaching. The State of Texas also publishes a seven day deionized water leach method. These methods are used to demonstrate the contamination potential to drinking water and groundwater from a waste that comes into contact with drinkable water. A portion of the material under study is mixed with some multiple of its weight in deionized water, shaken or tumbled for a specified time, then allowed to leach while being shaken, tumbled, or undisturbed. Table one highlights each leach method. After the appropriate leach time the liquid leachate is then filtered and analyzed for the constituents of interest. If the leachate shows contaminants higher than the local drinking water standards or other regulatory limits, the waste material is considered to have failed the test.

**Table one. Summary of the Various Leach Methods Employed**

| Jurisdiction | Method Name | Leach Media | pH of Leach Media | Dilution Factor |
|---|---|---|---|---|
| United States | TCLP | Acetic acid, buffered | 4.88 | 20 |
| United States | SPLP | Nitric + Sulfuric Acids | 5.00 | 20 |
| California (USA) | STLC | Citric acid, buffered | 5.00 | 10 |
| European Community | PrEN | Deionized water | Neutral | 10 |
| Japan | JST-13 | Deionized water | neutral | 10 |

## More Aggressive Leach Methods

Aside from the deionized water leaching methods there are methods which utilize leaching fluids containing various acids. These methods are used both to simulate acid rain and to simulate improper waste disposal- mixing household waste with industrial waste in the same disposal unit. The Synthetic Precipitation Leaching Procedure (SPLP) developed by the USEPA is one such test. The leaching fluid in this test contains nitric and sulfuric acids, diluted to a pH of 5.00. Some European environmental authorities use a similar leaching fluid. These fluids contain either sulfuric acid or sodium nitrate. The Toxicity Characteristic Leaching Procedure (TCLP) was developed by USEPA for determining whether a waste was hazardous by virtue of its toxicity. TCLP fluid contains dilute (pH 5.0) acetic acid, which mimics the organic acids typically found in landfill leachate where household waste is disposed in the landfill. Consumers typically dispose of their used electronic products by "throwing them in the trash", so this scenario of electronics being disposed with food and other household waste is highly plausible. The State of

California promulgates a Soluble Threshold Leaching Concentration (STLC) test, which utilizes citric acid to mimic the landfill disposal scenario and its effects on waste leaching.

**Metal Toxicity and Regulatory Agency Impacts** [3]

There are existing environmental and toxicological regulations on both lead and lead free solder alloying elements. Among these are the following:

Silver and silver compounds can cause biological effects such as digestive tract irritation and agryria, which is characterized by a permanent blue-gray pigmentation of the skin, eyes, and mucous membranes. Ecotoxicity, reproductive effects, and mutagenicity have been observed in laboratory studies; however, toxicological data has not been fully investigated.

Antimony and antimony compounds can cause biological effects such as severe digestive tract irritation with abdominal pain, nausea, vomiting, and diarrhea. Toxicological data has not been fully investigated; however, antimony carries one of the lowest allowable concentration limits in drinking water.

Copper and copper compounds can cause biological effects such as severe digestive tract irritation with abdominal pain, nausea, vomiting, and diarrhea. Ecotoxicity has been observed in laboratory studies; however, toxicological data has not been fully investigated.

Indium and indium compounds have shown developmental toxicity in rats and mice. Particular symptoms of this developmental toxicity include fetal mortality, fetal malformation, reduced fetal weight, and malformations in the tail, ribs, digits, and kidneys. Ecotoxicity and mutagenicity have been observed in laboratory studies; however, more toxicological studies are needed.

Bismuth and/or bismuth compounds have been suggested to be a carcinogen or a co-carcinogen in rats. Also, some studies have shown that bismuth can cause chromosomal aberrations in rats. More epidemiological studies are required for a more complete determination. Little has been studied as to the potential toxic effects of bismuth.

There are regulatory concerns for the lead replacement metals regarding environmental impact and use in the workplace. PCB manufacturers and PCBA assemblers moving to lead free solder materials will need to evaluate these new materials in the workplace for environmental permitting, management, and industrial hygiene issues.

Silver and silver compounds - regulated under Superfund, SARA 313, RCRA, Clean Water Act Toxic Pollutant, California State Superfund Hazardous Substances, CAL-OSHA Director's List of Hazardous Substances, and California HWCL Hazardous Wastes.

Antimony and antimony compounds - regulated under Superfund, SARA 313, Clean Air Act Hazardous Air Pollutant, Clean Water Act Toxic Pollutant, California State Superfund Hazardous Substances, CAL-OSHA Director's List of Hazardous Substances, and California HWCL Hazardous Wastes.

Copper and copper compounds - regulated under Superfund, SARA 313, Clean Water Act Toxic Pollutant, California State Superfund Hazardous Substances, CAL-OSHA Director's List of Hazardous Substances, and California HWCL Hazardous Wastes.

Except for the bismuth and indium radionuclides, bismuth and indium and their compounds are not heavily regulated by federal and state authorities. If bismuth and indium alloys are selected by the industry, their use will dramatically increase. Regulation may follow as environmental agencies deem them an adverse impact to the environment, and as the electronics industry solidifies a commitment to a given alloy or a few alloys.

The State of California, in addition to its use of the STLC and the USEPA TCLP test, also provides regulations for the Total Threshold Limit Concentration (TTLC). The TTLC is simply a measure of the physical composition of the substance under study, with no regard for its leachability. Substances containing regulated elements or compounds over the TTLC value are deemed hazardous by the State of California. Table one shows the current STLC and

TTLC values, along with the associated maximum percentages a solder alloy can contain without failing the TTLC value.

**Table Two. California STLC and TTLC Values for Common Solder Metal Alloys**

| Substance | STLC, mg/l | TTLC, mg/kg | Allowable Percent in Alloys (per TTLC value) |
|---|---|---|---|
| Antimony & cmpds | 15 | 500 | 0.05 |
| Cadmium & cmpds | 1.0 | 100 | 0.010 |
| Copper & cmpds | 25 | 2,500 | 0.25 |
| Lead & cmpds | 5.0 | 1,000 | 0.10 |
| Nickel & cmpds | 20 | 2,000 | 0.20 |
| Silver & cmpds | 5.0 | 500 | 0.05 |
| Zinc & cmpds | 250 | 5,000 | 0.50 |

These element allowances are much smaller than alloys currently under investigation as lead free alternatives. In fact, they are much less than amounts which would be expected to materially change the properties of any tin based solder. This provides a significant issue for California based assemblers and fabricators. There is nor will there likely be a lead free alloy which will prove to pass TTLC values and thus be non-hazardous under California law.

The Surface Mount Council in its report[4] earlier this year gives a table showing the relative toxicity of the various lead free soldering elements. The table is reproduced here as Table three:

**Table Three. Surface Mount Council Toxicity Data**

| Metal Element | OSHA PEL or ACGIH TLV ($mg/m^3$) |
|---|---|
| Bismuth | None |
| Zinc Oxide Fume | 5 |
| Tin (inorganic) | 2 |
| Tin (organic) | 0.1 |
| Antimony | 0.5 |
| Copper (dust) | 1 |
| Copper (fume) | 0.1 |
| Indium | 0.1 |
| Silver (metal dust and fume) | 0.1 a |
| Silver (and soluble compounds) | 0.01 b |
| Lead (inorganic) | 0.05 c |

Note a: OSHA PEL Note b: ACGIH TLV Note c: ACGIH TLV is 0.15 $mg/m^3$

Based on this data and other data cited in its report, the Surface Mount Council assigns this toxicity ranking to the common lead free solder alloying elements:

$$Bi < Zn < In < Sn < Cu < Sb < Ag < Pb$$

**Experimental Methods**

Experiments with eight lead free alloys were undertaken to show their toxicity relative to each other and to conventional tin-lead solders. Wire solder, solder solids, -325, +500 solder paste (with flux) and solder dross were the physical forms of solder tested. These physical forms of solder mimic the waste streams from PCB fabrication and assembly operations. The eight alloys chosen are:

96.3 Tin, 3.2 Silver, 0.5 Copper
96.5 Tin, 3.5 Silver
98 Tin, 2 Silver
99.3 Tin, 0.7 Copper
95 Tin, 5 Antimony
80 Tin, 20 Indium
90 Tin, 5 Bismuth, 5 Silver
43 Tin, 57 Bismuth

Each of the chosen alloys is commercially available today; and several are already in use. Several Japanese manufacturers are utilizing Tin-Bismuth-Silver and/or Tin-Copper alloys[5]. The National Center for Manufacturing Sciences has studied lead free solder alloys and narrowed the field to alloys of tin-bismuth, tin-bismuth-silver, and tin-silver. Nortel has manufactured wireless telephones using tin-copper solder, with the same composition as alloy four. Zinc is reported widely as giving poor solder wetting action; and it is not typically used for either PWB surface finishes or component lead finishes. Alloys of zinc have thus been excluded from this research. Various Japanese concerns are promoting tin-zinc alloys and are working to overcome the wetting and oxidation limitations of these alloys; thus, the tin-zinc eutectic will be studied in future experiments.

**Sample Preparation, Leaching, and Analysis**

Each metal was procured in an elemental state, then alloyed under oxygen free conditions. Solder wire was 0.032 inch diameter. Solder solids were bar stock, milled to pieces no larger than 0.375 inch by 0.375 inch. This maximum particle size is mandated by the USEPA leaching methods. Solder dross was produced by heating the alloyed solder solids in an ambient atmosphere while occasionally removing the dross from the surface of the solder melt using a titanium bar. An analysis of the oxide content of the dross produced in this manner showed it contained approximately ninety percent entrapped metal, and ten percent metal oxide.

Samples of solderpaste were prepared by alloying the appropriate elements, then blowing them into spheres under an inert atmosphere. The spheres were then sieved to give a -325 to +500 sieve size powder, which is suitable for fine pitch solder paste printing. A flux paste consisting of reagent grade rosin gum (20 percent), glycerol (ten percent), and ethanol (seventy percent) was prepared. The solder spheres and flux paste were mixed to give a ninety percent solids paste. Typical viscosity of the pastes was in the 350 to 400 Kcps range. The above ingredients were selected to provide a uniform paste chemistry, which would eliminate all variables except the metal constituents from influencing the results. Synthetic activators were not used as they might cause metallic leaching reactions. The powder sphere size was selected to give a worst case scenario (maximum leachability). Leaching is a surface phenomenon. Smaller spheres give a higher surface area to volume ratio than larger spheres and thus higher opportunity for metal leaching.

After preparation of the “waste” samples, each was leached according to USEPA, Japanese, or European protocols, and the leachate analyzed using USEPA metals analysis methods.

**Results and Conclusions**

A review of tables four through eight shows that lead free solders display several elements leaching at levels above USEPA and other regulatory limits in different leaching media. Most striking in its apparent toxicity is the 95Tin: 5Antimony alloy. The leachable levels found are approximately 10,000 times the maximum allowable in drinking water. The 95Tin-5Antimony alloy studied leached above regulatory limits in every physical form and in all leach methods. All lead free alloys containing silver leached above regulatory limits for the TCLP leach, except for the Tin-Bismuth-Silver, which did show some silver leaching. Silver bearing lead free alloys were close to the USEPA limit of 0.1 mg/L in drinking water for leach tests using deionized water. When groundwater was used as the leaching media, the silver levels went above the regulatory limit. Copper was leached above the STLC (California) regulatory limit in the 99.3Tin: 0.7Copper alloy. Bismuth showed little leachability regardless of leachate method or media. It was leachable using the STLC (California) test. Similarly, Tin did not leach significantly in most of the tests. Salts of tin tend to be insoluble in water at room temperature. Indium leached at 0.1 to 1.0 mg/L in all tests except for the SPLP (synthetic precipitation).

The data may also be reviewed by leaching method rather than by metal alloy element. The SPLP test was in general, ineffective at leaching all elements except for antimony. This demonstrates that acid rain poses little potential to release lead free solder metals into the environment. Deionized water test methods, such as those proposed or used in both Japan (JST-13) and the European Community (preliminary) also tend not to leach lead free solder alloys, except for antimony. The more aggressive TCLP test, which simulates disposal in a municipal landfill leaches measurable amounts of tin, silver, copper, antimony, indium, and bismuth. This demonstrates that co-disposal of electronic wastes with municipal wastes is undesirable. The STLC test used for regulatory purposes in California, leaches measurable amounts of tin, silver, copper, antimony, indium, and bismuth, with much higher levels of both copper and bismuth than the TCLP. The STLC, like the TCLP, simulates co-disposal of wastes.

Lead free solders are not a panacea for solving the potentially toxic effects from tin-lead solder alloys. The data from these experiments shows that most lead free solders leach at levels that would cause them to be classified as a hazardous waste, failing both silver and antimony levels. If lead free solders containing silver or antimony are improperly disposed and contacted groundwater, the solders could render that groundwater unsafe to drink per USEPA standards. Solder dross from these alloys carries much the same risks, as the dross behaved similarly to the parent alloys in these experiments. Bismuth and indium are not currently regulated and their toxicity has not been widely studied, thus they pose unknown challenges for adopters of lead free solders.

Reviewing the experimental leaching results above, coupled with available toxicity data, the alloys studied can be ranked as follows in order of increasing environmental and occupational impacts:

| | |
|---|---|
| 43 Tin, 57 Bismuth | least impacts |
| 80 Tin, 20 Indium | |
| 99.3 Tin, 0.7 Copper | |
| 90 Tin, 5 Bismuth, 5 Silver | |
| 98 Tin, 2 Silver | |
| 96.5 Tin, 3.5 Silver | |
| 96.3 Tin, 3.2 Silver, 0.5 Copper | |
| 95 Tin, 5 Antimony | greater impacts |

**References**

[1] Surface Mount Technology, Volume 12 Number 12 (December 1998), Page 40.

[2] IPC Review, October 1998, Page 1

[3] Sources for this and the next section include:
Registry of Toxic Effects of Chemical Substances (RTECS) published by National Institutes of Safety and Health (NIOSH); material safety data sheets for the metal elements; 29 and 40 CFR; and Waste Classification Regulation Guidance Manual, California Environmental Protection Agency, August 1994.

[4] Allenby, B. R. et al. An Assessment of the Use of Lead in Electronic Assembly; Surface Mount Council, 1999

[5] Material from this section taken from the papers presented at the lead free soldering forum at IPC PCEXPO'99, Long Beach, California; March 1999. Papers were authored by Smith, Felty, Shibata, and Tanner

**Acknowledgements**

Special thanks to Dr. Smith and the staff at EFEH & Associates laboratories for their assistance with the analytical work. The laboratory may be reached at 281-996-5031.

**Table Four. Complete Results of the TCLP Leach**

| 3/8 inch solder spheres | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Alloy** | Sn, mg/L | Ag, mg/L | Cu, mg/L | Sb mg/L | Pb, mg/L | In, mg/L | Bi, mg/L |
| **Sn-Ag-Cu** | 0.00 | 9.32 | 43.7 | NA | NA | NA | NA |
| **Sn96.5-Ag3.5** | 0.00 | 11.5 | NA | NA | NA | NA | NA |
| **Sn98-Ag2** | 0.00 | 8.46 | NA | NA | NA | NA | NA |
| **Sn-Cu** | 0.00 | NA | 44.5 | NA | NA | NA | NA |
| **Sn-Sb** | 0.00 | NA | NA | 55.5 | NA | NA | NA |
| **Sn-In** | 0.22 | NA | NA | NA | NA | 0.39 | NA |
| **Sn-Ag-Bi** | 0.13 | NA | NA | NA | NA | NA | 1.24 |
| **Sn-Bi** | 0.35 | NA | NA | NA | NA | NA | 1.61 |
| **Sn/Pb wire** | 0.08 | NA | NA | NA | 1002 | NA | NA |
| -325, +500 solder paste | | | | | | | |
| **Alloy** | Sn, mg/L | Ag, mg/L | Cu, mg/L | Sb mg/L | Pb, mg/L | In, mg/L | Bi, mg/L |
| **Sn-Ag-Cu** | 0.00 | 0.00 | 28.2 | NA | NA | NA | NA |
| **Sn96.5-Ag3.5** | 0.00 | 0.00 | NA | NA | NA | NA | NA |
| **Sn98-Ag2** | 0.00 | 0.00 | NA | NA | NA | NA | NA |
| **Sn-Cu** | 0.00 | NA | 28.1 | NA | NA | NA | NA |
| **Sn-Sb** | 0.00 | NA | NA | 33.0 | NA | NA | NA |
| **Sn-Bi** | 0.51 | NA | NA | NA | NA | NA | 3.78 |
| **Sn/Pb** | 11.3 | NA | NA | NA | 1800 | NA | NA |

**Table Five. Complete Results of the Deionized Water Leach -** *3/8 inch size solder solids*

| **Alloy** | Sn, mg/L | Ag, mg/L | Cu, mg/L | Sb mg/L | Pb, mg/L | In, mg/L | Bi, mg/L |
|---|---|---|---|---|---|---|---|
| **Sn-Ag-Cu** | 12.00 | 0.04 | 0.11 | NA | NA | NA | NA |
| **Sn96.5-Ag3.5** | 2.11 | 0.09 | NA | NA | NA | NA | NA |
| **Sn98-Ag2** | 5.38 | 0.04 | NA | NA | NA | NA | NA |
| **Sn-Cu** | 0.57 | NA | 0.199 | NA | NA | NA | NA |
| **Sn-Sb** | 0.61 | NA | NA | 32.12 | NA | NA | NA |
| **Sn-In** | 2.07 | NA | NA | NA | | 0.08 | NA |
| **Sn-Ag-Bi** | 0.08 | Trace | NA | NA | NA | NA | 0.14 |
| **Sn-Bi** | 0.38 | NA | NA | NA | NA | NA | Not found |

**Complete Results of the Deionized Water Leach -** *3/8 inch size solder dross*

| **Alloy** | Sn, mg/L | Ag, mg/L | Cu, mg/L | Sb mg/L | Pb, mg/L |
|---|---|---|---|---|---|
| **Sn-Ag-Cu** | 5.44 | 0.085 | 0.089 | NA | NA |
| **Sn96.5-Ag3.5** | 5.31 | 0.066 | NA | NA | NA |
| **Sn98-Ag2** | 4.38 | 0.093 | NA | NA | NA |
| **Sn-Cu** | 0.853 | NA | 0.146 | NA | NA |
| **Sn-Sb** | 0.399 | NA | NA | 27.71 | NA |

These deionized water results will be comparable to the JST-13 Japanese leaching method, the EN pr method (European Community draft method), and various other deionized/demineralized water leach methods.

**Table Six. Complete Results of the Groundwater Leach -** *3/8 inch size solder solids*

| **Alloy** | Sn, mg/L | Ag, mg/L | Cu, mg/L | Sb mg/L | Pb, mg/L | In, mg/L | Bi, mg/L |
|---|---|---|---|---|---|---|---|
| **Sn-Ag-Cu** | 17.335 | 0.313 | 0.152 | NA | NA | NA | NA |
| **Sn96.5-Ag3.5** | 20.459 | 0.365 | NA | NA | NA | NA | NA |
| **Sn98-Ag2** | 0.187 | 0 | NA | NA | NA | NA | NA |
| **Sn-Cu** | 2.238 | NA | 0.078 | NA | NA | NA | NA |
| **Sn-Sb** | 2.003 | NA | NA | 68.445 | NA | NA | NA |
| **Sn-In** | 0.16 | NA | NA | NA | | 0.11 | NA |
| **Sn-Ag-Bi** | 0.18 | Not found | NA | NA | NA | NA | Not found |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Sn-Bi** | 0.12 | NA | NA | NA | NA | NA | 0.14 |

**Complete Results of the Seven Day Leach using Groundwater -** *3/8 inch size solder dross*

| **Alloy** | Sn, mg/L | Ag, mg/L | Cu, mg/L | Sb mg/L | Pb, mg/L |
|---|---|---|---|---|---|
| **Sn-Ag-Cu** | 9.220 | 0.259 | 0.181 | NA | NA |
| **Sn96.5-Ag3.5** | 9.803 | 0.303 | NA | NA | NA |
| **Sn98-Ag2** | 2.502 | 0.370 | NA | NA | NA |
| **Sn-Cu** | 1.158 | NA | 0.064 | NA | NA |
| **Sn-Sb** | 1.912 | NA | NA | 53.47 | NA |

**Table Seven. Complete Results of the Synthetic Precipitation Leaching Procedure (SPLP) -** *3/8 inch size solder solids*

| **Alloy** | Sn, mg/L | Ag, mg/L | Cu, mg/L | Sb mg/L | Pb, mg/L | In, mg/L | Bi, mg/L |
|---|---|---|---|---|---|---|---|
| **Sn-Ag-Cu** | 0.17 | Not found | 0.08 | NA | NA | NA | NA |
| **Sn96.5-Ag3.5** | 0.21 | Trace | NA | NA | NA | NA | NA |
| **Sn98-Ag2** | 0.46 | Trace | NA | NA | NA | NA | NA |
| **Sn-Cu** | 0.39 | NA | 0.12 | NA | NA | NA | NA |
| **Sn-Sb** | 0.22 | NA | NA | 43.4 | NA | NA | NA |
| **Sn-In** | 0.78 | NA | NA | NA | NA | Not found | NA |
| **Sn-Ag-Bi** | 0.22 | Not found | NA | NA | NA | NA | Not found |
| **Sn-Bi** | 0.99 | NA | NA | NA | NA | NA | Not found |

**Table Eight. Complete Results of the Soluble Threshold Leaching Concentration (STLC) -** *3/8 inch size solder solids*

| **Alloy** | Sn, mg/L | Ag, mg/L | Cu, mg/L | Sb mg/L | Pb, mg/L | In, mg/L | Bi, mg/L |
|---|---|---|---|---|---|---|---|
| **Sn-Ag-Cu** | 1.73 | Not found | 87.4 | NA | NA | NA | NA |
| **Sn96.5-Ag3.5** | 63.2 | Trace | NA | NA | NA | NA | NA |
| **Sn98-Ag2** | 29.3 | Trace | NA | NA | NA | NA | NA |
| **Sn-Cu** | 5.77 | NA | 86.0 | NA | NA | NA | NA |
| **Sn-Sb** | 2.11 | NA | NA | 11.1 | NA | NA | NA |
| **Sn-In** | 1.20 | NA | NA | NA | NA | 0.09 | NA |
| **Sn-Ag-Bi** | 0.98 | 0.50 | NA | NA | NA | NA | 46.1 |
| **Sn-Bi** | 0.99 | NA | NA | NA | NA | NA | 29.4 |

**Table Nine. Regulatory Limits for evaluating TCLP and Deionized Water Leaching Tests [a]**

| **Element** | **Media** | **Limit, mg/L** | **Source** |
|---|---|---|---|
| Indium | All | None found | |
| Bismuth | All | None found | |
| Tin | All | None found | |
| | | | |
| Silver | TCLP Leachate | 5.0 | USEPA 40 CFR 261 |
| Silver | Drinking Water | 0.10 | USEPA 40 CFR 141 |
| | | | |
| Antimony | TCLP Leachate | 1.0 | TNRCC 30 TAC 335[b] |
| Antimony | Drinking Water | 0.006 | USEPA 40 CFR 141 |
| Antimony | Drinking Water | 0.002 | Japanese legislation |
| Antimony | Drinking Water | 0.005 | 98/83/EEC |
| | | | |
| Copper | TCLP Leachate | 500 | various State (USA) regulations |
| Copper | Drinking Water | 1.0 | USEPA 40 CFR 141; Japanese legislation; Thai legislation |
| Copper | Drinking Water | 2.0 | 98/83/EEC |
| | | | |
| Lead | TCLP Leachate | 5.0 | USEPA 40 CFR 261[c] |
| Lead | Drinking Water | 0.015 | USEPA 40 CFR 141 |
| Lead | Drinking Water | 0.05 | Japanese legislation; Thai legislation |
| Lead | Drinking Water | 0.010 | 98/83/EEC |
| | | | |

| | | | |
|---|---|---|---|
| Zinc | Drinking Water | 1.0 | Japanese Legislation |
| Zinc | Drinking Water | 5.0 | Thai Legislation |

Notes for Table Nine:
a- TCLP leachate tests were evaluated only against TCLP limits shown in this table; groundwater and deionized water leachate tests were evaluated only against the drinking water limits shown in this table
b- TNRCC 30 TAC 335 refers to State of Texas statutes
c- some jurisdictions observe a 1.5 mg/L limit, based on a multiple of the 0.015 mg/L drinking water limit

## Appendix I – Details of the various Leaching Methods Employed in this Research

**Seven-Day Distilled Water Leachate Test - State of Texas (USA) Method**
This test is intended only for dry, solid wastes, i.e., waste materials without any free liquids.
1. Place a 250 gm. (dry weight) representative sample of the waste material in a 1,500 ml. Erlenmayer flask.
2. Add one liter of deionized or distilled water into the flask and mechanically stir the material at a low speed for five minutes.
3. Stopper the flask and allow to stand for seven days.
4. At the end of seven days, filter the supernatant solution through a .45-micron filter, collecting the supernatant into a separate flask.
5. Subject the filtered leachate to the appropriate analysis.
**Source:** The provisions of this **§** 335.521 adopted to be effective May 30, 1995, 20 TexReg 3722.
**Cross Reference:** This Section cited in 30 TAC **§**335.503 (relating to Waste Classification and Waste Coding Required); 30 TAC **§**335.505 (relating to Class 1 Waste Determination); 30 TAC **§**335.507 (relating to Class 3 Waste Determination). Results from this leachate are compared directly against the jurisdiction's drinking water standards.

**TCLP - Toxicity Characteristic Leaching Procedure – United States EPA Method**

This analysis determines the soluble portion of the analytes. This is a Federal guideline and differs from the State in several ways. The alkalinity of the sample must first be determined in order to know which of two different extraction fluids should be used. Samples with a low alkalinity use extraction fluid #1 which is a sodium acetate solution with a pH of 4.93. Samples with a high alkalinity use extraction fluid #2 which is a dilute acetic acid solution with a pH of 2.8. The sample is then tumbled in the appropriate extraction fluid for 18 hours. However the choice of extraction fluids does not apply to volatiles. When analyzing for volatiles, fluid #1 is always used and a Zero Headspace Extraction (ZHE) apparatus is required. Results from this leachate are compared against TCLP regulatory limits for the analyte.

**California Waste Analysis Methods**

TTLC and STLC are used when determining the hazardous waste characterization under California State regulations as outlined in Title 26 of the California Code of Regulations (CCR).

**TTLC - Total Threshold Limit Concentration**

This analysis determines the total concentration of each target analyte in a sample. Samples are analyzed using published EPA methods. When any target analyte exceeds the TTLC limits the waste is classified as hazardous and its waste code is determined by the compound(s) that failed TTLC. The results of this analysis can be used to determine if analysis for STLC level is necessary by comparing 10 times the STLC limit to the TTLC results. A factor of ten is necessary to compensate for a 1:10 dilution factor that is present in one analysis but not the other. If the TTLC results do not exceed 10 times the STLC limit then normally no further analysis is required.

**STLC - Soluble Threshold Limit Concentration**

This analysis determines the amount of each analyte that is soluble in the "Waste Extraction Test", (W.E.T.) leachate. This W.E.T. leachate procedure is used for solid samples or for samples containing > 0.5% solids. The sample is tumbled in 10 times its weight of a 0.2M sodium citrate buffer for 48 hours. This leachate is then analyzed to determine the soluble concentrations.

The concentration of analyte in the leachate is compared against the STLC and TTLC regulatory values.