IPMI

International Precious Metals Institute
4400 Bayou Blvd., Suite 18
Pensacola, FL 32503-1908 USA
Phone 1-850-476-1156
Fax 1-850-476-1548
Email: mail@ipmi.org

ENVIRONMENTALLY SOUND MANAGEMENT
USED MOBILE TELEPHONES

INTRODUCTION

Mobile telephones have, within two decades of their introduction, become a familiar tool of modern life, filling a societal need for communication among billions of people in every country on the planet. They serve not just as a personal luxury, or an addition to traditional wired telephones, but also as a primary means of communication in areas of the world where a wired communication infrastructure is not in place. The ability of ordinary people throughout the world to easily communicate with each other by mobile phones is a revolutionary change in the way we live. They have improved private, business, industrial and governmental infrastructures, to the benefit of sound environmental management and regulation. Wireless phones are a keystone of sustainable development.

Of course, it is also inescapable that billions of mobile phones, now and in the future, will be disposed, as they reach the end of their useful lives and are replaced. The size of an individual mobile phone is small – the average weight of a mobile phone has been reduced from 10 kg in the 1980s to 0.5 kg in the 1990s to less than 0.1 kg – but their cumulative size is substantial. Annual production of 400 million mobile phones, when disposed, will have a total mass of 40,000 tonnes, perhaps twice that with batteries, chargers and accessories. And mobile phones contain plastics, halogens, and a wide range of metals. While these substances present no environmental or human health hazard in ordinary use, if their disposal is not properly managed, it may involve processes and conditions that could lead to release of these substances or toxic by-products. The disposal of mobile phones thus needs to be managed in an environmentally sound way, to minimize releases into the environment and threats to human health.

The mobile phone manufacturing industry has responded to that need. In December 2002 the leading manufacturers – Nokia, Motorola, LG, Matsushita (Panasonic), Mitsubishi, NEC, Philips, Samsung, Siemens and Sony Ericsson – undertook in partnership with the Basel Convention to develop and promote the environmentally sound management of end-of-life mobile phones, to include a guidance on environmentally sound practices for recycling and recovery.

IPMI GUIDANCE – ESM FOR USED MOBILE PHONES

The International Precious Metals Institute, whose members include recyclers, smelters and refiners of precious metal-bearing materials, has produced this guidance to assist its members, mobile phone manufacturers, and others in these same efforts. This guidance identifies and describes a set of methods and practices that can be used for reuse and recovery of used mobile phones, with the intent of saving natural resources and protecting human health and the environment against adverse effects. Furthermore, while this guidance does not directly address the design of mobile phones, including choice of materials, these issues are closely related, because the identification of materials of concern in disposal management can be considered for reduction or substitution.

CHARACTERIZATION OF MOBILE PHONES

This guidance is intended to encompass only mobile phones. There are other devices with similar characteristics, some of which are both portable, i.e. battery-powered, and capable of communication, such as by 802.11 wireless technology. These devices include personal digital assistants, e-mail devices, pagers, and pocket PCs. Some or all of this guidance might have applicability to such devices, but it is not intended to encompass them. There are also non-typical devices that are both mobile and capable of communication, that might have quite different components, and that are not within the scope of this guidance. For example, this guidance does not encompass military mobile communication devices that might require special attention, or devices that communicate with earth satellites. While it is difficult to precisely define such devices, the reader of this guidance should be able to recognize that a particular device is either a typical mobile phone, or seems to be unusual, and should seek additional information and other sources of guidance.

A mobile phone typically consists of the following components:
a) electronic circuitry – a printed circuit board containing a microprocessor, digital signal processor, read-only-memory and flash memory chips, to which are attached connectors, a small microphone and a small speaker,
b) an antenna, sometimes contained inside with the circuitry,
c) a screen – liquid crystal display (LCD) technology and glass,
d) a battery – sealed within its own case, using one of three technologies: nickel-cadmium, nickel metal hydride or lithium ion/polymer,
e) a case – plastic, holding the components described above, sometimes with a metal coating or liner,
f) a charging base or connector – a small transformer to low-voltage direct current, wire, plastic, with copper connecting points, used for recharging the battery, and
g) accessories, such as an earphone or connecting cable to a computer.

ENVIRONMENTAL CONCERNS

A mobile phone is a solid state device, and its contained substances are never released into the environment over a wide range of operating conditions. Normal use and handling creates no exposure to substances of concern for human health.[1] Nor does normal use result in any physical or chemical change in a mobile phone; a used phone is, in all relevant physical and chemical characteristics, identical to the same phone when it was new. There are, however, components and substances in a mobile phone that, under conditions of land disposal, waste incineration and some destructive recycling processes, may be of concern. These substances are understood and capable of sound control with modern equipment and processes, but require attention and appropriate management. Some substances will require active control, while others may need only to be routinely monitored.

The paragraphs that follow list these substances and some aspects of their toxicity or characteristics of concern. The list includes certain United States regulatory exposure limits, established by the Environmental Protection Agency (U.S. EPA) and Occupational Safety and Health Administration (U.S. OSHA). These limits are not included as mandatory, at least not for operations outside of the United States. A recycling operation must comply with its national regulations, and each nation makes its own determinations of reasonable risks for exposed workers and populations. The United States' determinations may, however, be a useful reference for comparison.

Substances of Concern:

Lead (CASRN 7439-92-1): The electronic circuitry of a mobile phone typically contains a small amount of tin-lead solder, now less than one half gram per phone. Lead is not contained in the display screen, and lead-acid batteries have not been used in mobile phones. Lead is a cumulative neurological poison and a probable human carcinogen (U.S. EPA B2). It has been a public health problem because of its past use in old paint, which has been ingested by children, and in gasoline, from which lead is released to the atmosphere in automotive engine emissions. The U.S. EPA requires lead in outside ambient air not to exceed 1.5 micrograms per cubic meter (1.5 $\mu g/m^3$) averaged over 3 months. The U.S. EPA limits lead in drinking water to 15 µg per liter (15 ppb). The U.S. OSHA limits workplace exposure to airborne lead to 50 $\mu g/m^3$, and requires increased surveillance when workers are exposed to airborne lead above 30 $\mu g/m^3$.

Cadmium (CASRN 7440-43-9): Some mobile phones use a nickel cadmium battery, which contains cadmium and cadmium hydroxide, typically less than 25% of the weight of the battery. There may also be a small amount of cadmium in plated contacts and switches in the electronic circuitry of a mobile phone. Cadmium is toxic, particularly by inhalation, to the respiratory tract, and to the kidney and liver, and is a probable human carcinogen (U.S. EPA B1). Nickel cadmium battery technology is still used in mobile phones, but has been largely replaced, beginning in the mid-1990s, with nickel metal hydride and, more recently, with lithium ion/polymer batteries. The U.S. EPA has set a limit of 5 ppb cadmium in drinking water. The U.S. OSHA limits cadmium in workplace air to 100 $\mu g/m^3$ as fume and 200 $\mu g/m^3$ as dust.

Beryllium (CASRN 7440-41-7): A mobile phone may contain beryllium in a copper-beryllium alloy (98% copper, ≤2% beryllium) used at connecting points with external wires and devices, in an amount typically less than 0.1 gram per phone. Inhalation of beryllium-containing dust, mist or fume may cause a serious lung disorder called chronic beryllium disease in susceptible persons, and beryllium is a probable human carcinogen (U.S. EPA B1). The U.S. EPA restricts the amount of beryllium that industries may release into the atmosphere to 0.01 $\mu g/m^3$, averaged over a 30-day period. The U.S. OSHA sets a limit of 2 $\mu g/m^3$ of workplace air for an 8-hour work workday. This is under regulatory review and is widely considered to be inadequately protective for very small particulate, such as fume.

Cobalt (CASRN 7440-48-4): A mobile phone may contain cobalt in a lithium ion battery. Cobalt is beneficial for humans, and is part of vitamin B12. Cobalt fume and dust is an irritant to lungs if inhaled, and cobalt is a possible human carcinogen (IARC 2B). The U.S. OSHA has set a limit of 0.1 mg/m^3 for cobalt in workplace air for an 8-hour workday and 40-hour work week.

Nickel (7440-02-0): A mobile phone battery may contain nickel in a nickel cadmium or nickel metal hydride battery, in the form of nickel hydroxide (12054-48-7). A mobile phone may also contain nickel in a steel alloy. Nickel refinery dust in refineries and smelters is classified as a human carcinogen (U.S. EPA A). The U.S. OSHA has set a workplace limit of l mg/m^3 for nickel for an 8-hour workday, 40-hour workweek.

Mercury (CASRN 7439-97-6): A small percentage of older mobile phones contain a mercury vapour lamp, i.e. a small screen illumination unit using mercury vapour, typically with about 0.01 g of mercury for each such phone. Mercury is a neurological poison, and is not classifiable as to human carcinogenicity. The U.S. EPA has set a limit of 2 ppb for mercury in drinking water. The U.S. OSHA has set a limit of 0.05 mg/m^3 of metallic mercury vapor for an 8-hour workday and 40-hour work week.

Silver (CASRN 7440-22-4): A mobile phone typically contains several grams of silver in the electronics and keypad contacts, in elemental form. Silver is not toxic to humans, and is not classified as to carcinogenicity (D), but, if bioavailable in ionic form, can be toxic to some animal species. The U.S. OSHA limits silver in workplace air to 0.01 mg/m^3 for an 8-hour workday, 40-hour work week.

Arsenic (CASRN 7440-38-2): A mobile phone typically contains a minute amount of gallium arsenide in its microelectronic circuitry, of which the arsenic content is less than a milligram. Arsenic is classified as a carcinogen (U.S. EPA A). The U.S. EPA has set a limit of 0.01 ppm for arsenic in drinking water. The U.S. OSHA limits arsenic in workplace air to 10 µg/m^3 for an 8 hour workday and 40 hour work week.

Tin (CASRN 7440-31-5): A mobile phone typically contains a small amount of tin in tin-lead solder used in its printed wiring board. Inorganic tin is not a significant health concern, and is not classifiable as a carcinogen. The U.S. OSHA has set a workplace limit of 2.0 mg/m^3 for tin and inorganic tin compounds.

Zinc (CASRN 7440-66-6): Zinc may be contained in a mobile phone in a battery or in electronic circuitry. Zinc is a required human nutrient, is not a significant health concern, and is not classifiable as a carcinogen. The U.S. OSHA has set a limit of 5 mg/m^3 for zinc oxide fume in workplace air for an 8-hour workday and 40-hour work week.

Copper (CASRN 7440-50-8): Copper is the most commonly used metal in a mobile phone's electronic circuitry. Copper is a required human nutrient, is not a significant health concern, and is not classifiable as a carcinogen. In high doses it can cause respiratory and intestinal irritation, and in very high doses it can cause liver and kidney damage. The U.S. EPA has set a drinking water limit of 1.3 ppm. The U.S. OSHA has set limits of 0.1 mg/m^3 for copper fume and 1 mg/m^3 of copper dust and mist in workplace air for an 8-hour workday and 40-hour work week.

Concerns with Combustion of Organic Content

Because mobile phones may be burned or incinerated in disposal or may be smelted in metal recovery operations, their organic and halogen content is of significance. These substances can be properly controlled by combustion techniques and emission control systems, but require attention because uncontrolled burning or smelting conditions might be inadequate to ensure complete destruction or capture of toxic emissions.

Plastics: The case of a mobile phone is typically made of PC/ABS plastic, a mix of polycarbonate (PC) and acrylonitrile butadiene styrene (ABS). The case of the charging station is typically made of PC. While these plastics are not of concern as such, they contribute hydrocarbons to a combustion process, and require complete oxidation. The printed wiring board is typically epoxy resin or fiberglass. Both the cases and wiring board are likely to contain bromine in organic compounds used as a fire retardant, which may contribute to the formation of brominated hydrocarbons in poorly combusted and controlled exhaust gas streams.

Liquid Crystal: The display screen in a mobile phone uses “liquid crystal” (LCD) technology. “Liquid crystal” is not liquid in the normal or scientific sense of that word, because it does not flow or deviate from a fixed shape. It is a solid form of polycyclic aromatic hydrocarbon (PAH, CASRN 130498-29-2) in which internal molecules have a limited mobility to twist under electrical stimulation. A typical mobile phone contains several milligrams of “liquid crystal” between thin glass panels. Burning or smelting of an LCD screen raises concerns with products of incomplete combustion, in which PAHs may be released, and in the presence of halogens, dioxins and furans may be produced. PAHs have caused cancer in laboratory animals. The U.S. OSHA has set a limit of 0.2 mg/m^3 of PAHs in workplace air.

Halogens: The electronic circuitry of a mobile phone, and the plastic of the printed wiring board and case, may contain compounds of chlorine and/or bromine in flame retardants. Fluorine compounds are used in lithium ion batteries. These substances are of concern because of the possibility that halogenated organic compounds may be created and released in burning or smelting, such as dioxins and furans that might be formed in exhaust gasses and thus require special treatment.

Concerns with Corrosives

Shredding or breakage of a mobile phone may raise concerns for corrosive constituents contained in batteries.

Potassium hydroxide (CASRN 1310-58-3): A mobile phone battery may use potassium hydroxide paste as an electrolyte. Potassium hydroxide is reactive with water and is a strong caustic, causing chemical burns on contact with skin.

Lithium ion (CASRN 12190-79-3): Most mobile phone batteries now use lithium ion batteries. Lithium ion is typically a lithium cobaltite compound. It is very corrosive, causing chemical burns on contact with skin. Lithium ion is not as reactive as elemental lithium, but there is also a potential for fire during shredding, producing toxic fumes.

EXPOSURE TO SUBSTANCES OF CONCERN

No substances will be released from a mobile phone through normal operation, normal handling or other contact. Similarly, manual disassembly of a mobile phone, such as proper opening of its case and careful removal of circuitry or other components, should not release substances. The corrosive substances in batteries will ordinarily not be released during disassembly, because the batteries are sealed units. Human health and environmental concerns may arise if mobile phones are land disposed, or incinerated as waste, or processed destructively, such as in shredding, smelting and other metal recovery operations.

Exposure in Reuse

Reuse of a used mobile phone does not itself create any exposure to substances of concern. It will simply extend the number of years that the phone is used, and postpone disposal. However that later disposal may be different than it would have otherwise been, and thus may create different exposures to substances of concern. Mobile phones are often reused in poor areas, and are therefore more likely to be disposed without environmental attention, such as in uncontrolled land disposal or incineration.[2]

Such concerns and risks are exacerbated if a used mobile phone is not fully operative before resale and reuse in a poor area, because such a phone will have a shorter useful life. Its eventual disposal, still in a poor area without an infrastructure of sound environmental management, will be accelerated. Thus inadequate or improper refurbishment of a mobile phone will have an adverse environmental impact.

Refurbishment itself, if it involves the opening of a mobile phone case and electrical work, perhaps including tin-lead soldering, may expose workers to lead fume. And mobile phones and components that can not be properly refurbished will require disposal, with possible exposures described below.

Exposure in Land Disposal

Land disposal of mobile phones may place them in contact with co-disposed acids, and, over an extended period of time, the substances that are soluble in those acids may leach out. If the landfill is not bound by an impermeable barrier, these substances may migrate into ground waters, and eventually to lakes, streams, or wells, and raise a potential exposure to humans and other species. The route of exposure will be almost entirely by ingestion, either directly through drinking water or through food that has previously absorbed or ingested substances of concern.

Exposure in Waste Incineration

Waste incineration of mobile phones, in the absence of proper control of combustion and emissions, can release substances of concern in air emissions, and to other environmental media in subsequent management of fly ash and bottom ash.[3] Some metals, including cadmium and lead, have relatively low melting temperatures and may melt at high incineration temperatures and form fume or minute metal oxide particles, that will be carried into the exhaust with the air emissions. If these metals, and other metals contained in mobile phones, do not melt at the temperatures of incineration, they will remain in bottom ash that, if disposed on land, may raise the concerns described above. And leaching from ash may be substantially faster than leaching from solid objects. In addition, if incineration is not at a sufficiently high temperature, sustained for a sufficient time, the plastics and other hydrocarbons contained in a mobile phone may not be completely oxidized to carbon dioxide and water, and may combine with halogens to form new halogenated hydrocarbons, including dioxins and furans.

Exposure in Metal Recovery

The primary step in metal recovery from mobile phones is smelting, usually beginning in a copper smelter. It may be possible and advantageous to further recover additional metals in lead, tin and nickel smelting. Smelting is a process that separates metals and other materials, increasing recoverable metal concentrations while collecting precious metals. It is typically a high volume, high temperature operation, and metal fume and metal oxide particulate may be released, exposing workers and communities unless controlled. If hydrocarbons are present in materials being smelted, the process may release particles of incomplete combustion and, if halogens are also present, dioxins and furans.[2] These releases can be controlled through properly engineered processes and emission control systems, but require attention and sound management.

Metal recovery from separated batteries will, like smelting, involve high volume, high temperature processes, and metal fume and metal oxide particulate may be released, exposing workers and communities. Cadmium is a component of NiCd batteries, has a low melting temperature, and will be easily emitted in furnace exhaust, most likely as cadmium oxide particulate. As with smelting, these releases can be controlled through properly engineered processes and emission control systems, but require attention and sound management. Smelting will be preceded by shredding, a necessary preparation step, that will release some small particles containing one or more substances of concern. These particles may be of concern for worker safety, but should not be of concern beyond the workplace unless the shredding is done out of doors.

Smelting will be followed by a number of metal-specific electro-refining, dissolution and precipitation processes, in which individual metals are upgraded and refined to market grade. These steps may result in waste water that may contain high toxic metal concentrations and that, if not completely reused within the refining facility, will require attention and sound management.

The slag that is produced in the smelting process will also contain substances of concern. If it still contains relatively high concentrations of metals of economic interest, it should be reintroduced into the smelter, or into other smelting processes to recover these metals. Such continued smelting will have potential releases of fume and particulate, but will increase metal recovery and avoid landfill disposal. Slag may also be ground to a powder as a preparation for further meal recovery by selective leaching and precipitation of desired metals. These further processing steps may create potential exposures of workers to metal-containing dust, and waste water with high toxic metal concentrations, and should be controlled through properly engineered processes and sound management.

Slag is typically a silicate glass, and when it has been stabilized and made insoluble in high temperature processing it will not leach substances of concern, and may be safely used as a building or road construction aggregate. If slag has not been rendered stable and insoluble, its use on land or ultimate disposal in a landfill has the same potential for release of substances of concern described above.

ENVIRONMENTALLY SOUND RECYCLING AND RECOVERY PRACTICES

Reuse

A used mobile phone will normally be in essentially the same condition as when it was new, because it has no moving parts to wear out, and its electronic components should not have deteriorated. It may need cleaning, or a new case, or a new battery, but these are routine maintenance tasks. Sale of a used mobile phone and its reuse by another person is therefore a logical and reasonable practice, and permits more people, particularly poorer people, to enjoy the benefits of telephone service.

Because a used mobile phone is likely to be sold in an area with a less developed environmental infrastructure, it is important that it be in good condition, so that it does not quickly become a solid waste burden and raise environmental and human health concerns associated with inappropriate disposal. Therefore a used mobile phone should be evaluated before resale, and, if necessary, properly refurbished to bring it back to an operating condition equivalent to new. A used mobile phone that can not be returned to that operating condition should be disposed in an environmentally sound way, as described below.

Refurbishing working conditions should be controlled to ensure that lead soldering of mobile phones' electronic circuitry is performed under protective conditions, with lead fume evacuated away from workers, and proper disposal of residues and unrepairable phones.

Metal Recovery

End-of-life mobile phones are, when collected in sufficient volume, a useful source of metals, including copper, gold, silver and palladium. And from an environmental pint of view, the recovery of these metals has the greatest positive impact.[4]

Dismantling – Charging Base Station and Accessories

The metals of interest and of environmental concern are primarily located in the electronic circuitry in the handset. However the charging base station will contain a small amount of copper, at contact points with the handset, and a transformer with copper wire. Accessories such as earphones and connecting cables will contain a small amount of copper. These devices should be checked for potential continued use with a useable mobile phone, but if they are not suitable for such use, they should be processed in an appropriately controlled copper smelter for the economic and environmental benefit of recovered metal.

Metal recovery from the handset, where metals of economic and environmental interest are located, involves a series of steps to separate and upgrade individual metals and which result in production of market grade metals.

Dismantling – Battery Removal

Batteries used in mobile phones include rechargeable nickel cadmium (Ni-Cd), nickel metal hydride (NiMH) and lithium ion (Li-ion) batteries. These batteries are all removable by hand, and should be removed by the consumer, by a collection center, or in a subsequent dismantling process. If removed manually in a dedicated dismantling process, care should be taken to avoid repetitive strain injury.

Once removed, batteries should be managed with care to avoid breakage. While they are not fragile, they may break in rough handling, and leak caustic electrolyte or other substance. It is particularly important that batteries be managed as if they still contain an electrical charge, and they should be isolated, or their electrical contacts should be covered with an insulating tape, to prevent short circuits and current flows, which can cause fire.

All of the three battery types can be recycled, including by processing for reuse as reconditioned batteries with a great deal of remaining electric charge capacity. Reconditioning and reuse of a battery should be considered as the best method of recycling, provided that a market for the battery must exist.

Ni-Cd batteries that are intended for disposal will be classified as hazardous waste in many countries and should be recycled through metal recovery to avoid final disposal, particularly by incineration. Recovery of nickel and cadmium from such batteries is achieved through heating in a furnace, where the cadmium is evaporated at a relatively low temperature, sometimes under vacuum, is removed in the furnace exhaust stream, and is then condensed in a concentrated form. The separated cadmium and nickel are then purified in additional refining steps to market grades. This operation requires a pollution control system that will capture metal fume and particulate, particularly the cadmium and cadmium oxide that is being intentionally driven into a volatile state in furnace exhaust.

NiMH and Li-ion batteries are considered suitable in some countries for land disposal in municipal waste, and such disposal may be appropriate if there is no economically feasible metal recovery process. But nickel can be recovered from NiMH batteries, and cobalt can be recovered from Li-ion batteries, through metal-specific smelting. There are no current economically feasible technologies for recovery of the Li-ion polymer itself, as a separate substance, but new technologies may be developed.

Dismantling – Other Parts

A mobile phone can be further disassembled after battery removal, using manual labor, and some components can be recovered for potential reuse. Disassembly of small devices, however, is very labor-intensive, and the value that might be recovered may be exceeded by the cost, even in low labor cost countries.[5] The speaker and microphone, microprocessor, ROM and flash memory chips are of virtually no economic value other than in another communication device, and no manufacturer of mobile phones will purchase used, recovered parts.

Furthermore there is no environmental reason to attempt recovery through further dismantling and separation of any component. For example, recovery of LCD screens has been found to make no sense either ecologically or economically,[6] and LCD materials of concern will be safely destroyed in metal smelting conditions that are described below. The same is true for plastic cases from mobile phones. A mobile phone case will typically contain a metal coating on the inside, applied to provide electromagnetic radiation shielding, that will make it virtually impossible to recover as clean PC/ABS.[7] There is little if any market for recovered mixed plastics, and the ecological benefit of energy recovery is higher than for recovery of mixed plastics.[8] The presence of brominated fire retardants, which would further limit any market for recovered plastic cases, will require that copper smelting be performed with appropriate controls, as described below, but the plastic will provide heat energy to the smelting operation, and will not interfere with the process.

Shredding

Shredding is a necessary preliminary step before smelting, for size reduction and mechanical handling purposes. Even if mobile phones have been manually disassembled to remove the electronic circuit boards, which contain the recoverable metals of economic interest, those boards may require shredding before smelting. After battery removal a mobile phone should be shredded into small pieces – 2-3 cm – that can be efficiently packaged, transported and managed by equipment that feeds a copper smelter.

The shredded product could be further separated by eddy current processing into a non-ferrous metal fraction, intended for smelting, and a plastic fraction. However the inevitable loss of non-ferrous metal into the plastic fraction will contaminate the plastic, and such loss, particularly of the precious metals, will reduce the important environmental benefits of metal recovery (see above), and its economic benefits as well. And, as described above, the plastic fraction would probably be recoverable only as a mixed plastic, because of coated metal linings in handset cases, with limited uses that are less environmentally beneficial than energy recovery in the smelting process.

Worker safety becomes particularly important in shredding and further operations to recover metals from mobile phones, and these operations require attention to the following areas[9]:

- Eye Protection. Face shields or protective glasses may be required from pieces of metal and plastic ejected from shredders or other processes.
- Head Protection. Some facilities will present overhead hazards from material handling and storage, and hard hats are appropriate or required.
- Hand Protection. The potential for lacerations, thermal or chemical burns and chemical contamination may require a program for use and maintenance of appropriate gloves.
- Skin Protection. The potential for lacerations, thermal or chemical burns, or chemical irritations on arms or legs may require uniforms or long-sleeved shirts and pants of a suitable protective material.
- Foot Protection. The potential for loose weight falling upon a worker's feet may require clip-on steel toe protectors or steel toe shoes. In copper smelting operations, the potential for a chemical or molten metal spill may require more specialized footwear.
- Hearing Protection. High noise levels, such as in shredding operations[10], should be controlled by engineered enclosures or noise barriers, but workers may also need personal hearing protection. The U.S. OSHA permitted exposure limit for workplace noise is 90 db over an eight hour workday, with additional surveillance required at 85 db.

- Respiratory Protection. Substances of concern that are released in metal recovery operations should be controlled by engineered capture systems, but workers should also be provided with appropriate personal respiratory protective equipment to avoid exposure in unexpected releases and process upset conditions. Regular monitoring of potential worker exposure should be conducted.

Attention also is needed to protect against fires caused by shredding. Although the batteries will have been removed, small capacitors may have a retained electrical charge and can burn when shredded, possibly igniting the plastics. Special measures are necessary to control this.

Magnets in speakers tend to stick to the sides of the shredder, possible leading to blockage of the shredder, and it may be necessary to use anti-magnetic liners (manganese or stainless steel).

Copper Smelting

The primary step in metal recovery is copper smelting, which upgrades recoverable non-ferrous metal concentrations. Smelting is a process in which metals and/or metal-bearing materials are melted at high temperature, and then, while molten, separated through oxidation and/or reduction. Copper, when in a molten state, dissolves the precious metals – gold, silver and palladium – while other metals, such as lead, cadmium and beryllium, are oxidized in the process. These metal oxides have limited solubility in molten copper, and are of lower mass density, so they float to the top – forming the slag – where they are mechanically removed. Slag may be reprocessed in the copper smelter, or processed in other smelters, such as lead, tin and nickel, for further metal recovery. Some of these other metals, i.e. other than copper and precious metals, have a high vapour pressure at smelting temperatures and are emitted as fume or stack particulate, which can be captured and processed for further metal recovery. The molten copper is poured from the smelter into shaped molds, and harden into thin flat ingots that are suitable for use as copper anodes in the next metal recovery step – electro-refining.

A copper smelter processes substances of concerns at very high temperatures, and could present risks to human health and the environment. Emission of combustion gases and metal particulate at a number of points, including charging doors, slag tap, casting molds, and furnace stack, can be controlled, and must be captured and routed to a control system consisting of one or more devices such as an acid gas scrubber, venturi, cyclone, electrostatic precipitator and fabric filter (baghouse). Worker safety is particularly important, and the areas of concern listed above for shredders must be followed at copper smelters as well, with still greater attention.[11]

The detailed control of pollution from a copper smelter is beyond the scope of this guidance, and reference should be made to more detailed papers. The World Bank and U.S. Environmental Protection Agency have produced papers describing the copper smelting process in somewhat greater detail, giving specific pollution control guidance, and providing additional references.[12]

However one point of specific guidance regarding copper smelting of mobile phones is appropriate here. Pollution control of copper smelting of primary copper ores and ore concentrates requires modification specifically for electronic scrap and mobile phones. From a metallurgical point of view, mobile phones can be smelted with no prior separation of components or contained substances. All of the metals can be recovered or managed, and are not particularly different from the mix of metals contained in copper ore and primary concentrates. However the management and control of plastics require special attention in a smelter. Plastics and other hydrocarbons can serve as fuel, similar to coal, oil or natural gas, and thus are useful in copper smelting and provide an environmental benefit through energy recovery. Unlike smelting primary copper feedstocks, however, smelting of mobile phones, particularly with the presence of halogens – chlorine and bromine – raises concerns with the possible creation of furans and dioxins. The oxidation of hydrocarbons should be at a temperature of 850 deg.C. (1600 deg.F.) or higher, with a residence time of 2 seconds, with excess oxygen. These smelting furnace conditions will assure thermal destruction of hydrocarbons and will substantially reduce the possibility of formation of furans and dioxins in the furnace emission stream. Halogens will be converted to acids, and then to salts in an acid gas scrubber. In addition, the smelter exhaust gas should be reduced to a temperature of 200 deg.C. (400 deg.F.) or less at the inlet to a baghouse or electrostatic precipitator.

Refining

In the first electro-refining step, a copper anode from the smelter is dissolved in sulphuric acid, and the copper is simultaneously electroplated onto a copper cathode. The resulting copper cathode, at a purity level of 99.5% or greater, is suitable for sale in international copper markets as the complete equivalent of copper from primary sources. The sulphuric acid bath can be reused, but must eventually be replaced. Used sulphuric acid can be used in other metallurgical operations, or can be neutralized and cleaned through precipitation and settlement or filtering, and discharged at high standards for purity.

The precious metals that were dissolved in the copper anode – gold, silver, palladium – are not carried over into the copper cathode. They remain instead in the electrolytic cell, as insoluble precipitants known as cell slimes. Slimes are periodically collected and processed for recovery of desired metals. This processing may include a variety of steps, including additional melting and selective dissolution and precipitation, that upgrade and/or selectively remove specific metals to market standards, completely equivalent to products from primary sources. All of these metal-specific operations may create air emissions or waste waters, and require individual attention to appropriate control systems.

Slag Management

The slag that is removed in the smelting process may still contain copper and precious metals, and may be reintroduced into the smelting process, subject to the same control systems as before, or into other smelting processes. Slag may also be ground to a powder, from which a desired substance can be leached. Slag from the copper smelting of mobile phones will contain, among other substances, lead, cadmium and beryllium oxide, which may concentrate in smelter slag. Therefore reprocessing of smelter slag, particularly by grinding it to a fine powder, requires a very high degree of attention to the potential presence these metals in workers' breathing zones.

If the smelter slag does not contain metal concentrations of interest, it may be suitable for use as building or road construction aggregate. Slag is essentially a silicate glass, and to be appropriate for such use, it must be stable and insoluble from high temperature processing so that it will not leach its constituents. Periodic testing for solubility should be conducted. As an alternative to use as a construction aggregate, smelter slag may be disposed in a controlled industrial landfill, with similar appropriate attention to the possibility of release of substances of concern.

REGULATION BY COMPETENT AUTHORITIES

While environmentally sound management of mobile phones will be undertaken by private facilities, these facilities will need to operate within a regulated environment, to ensure that competitive pressures do not encourage cost saving steps that inappropriately or illegally sacrifice protections. Accordingly there must be an adequate regulatory infrastructure and enforcement by competent environmental authorities.

There is no single set of regulations that is appropriate for all facilities, because there are a series of operations and potential exposures involved in collection, battery removal and sorting, dismantling, shredding, copper smelting, refining, and slag management. Collection facilities, particularly those that maintain little storage of used mobile phones, for example, might be of very little concern, and regulatory oversight might be limited to careful management of removed batteries. Copper smelters, on the other hand, will require substantially more oversight.
Each facility must, of course, be legally authorized within its regulatory infrastructure. Each facility should be regulated under national law as appropriate for its activities, addressing facility operation, worker health and safety, control of emissions to air, land and water and waste management. At the level of least concern, such as collection, this may not require a facility-specific license or permit, but may instead be a general authority with broadly applicable operating conditions. At greater levels of concern, such as at copper smelters, a facility-specific license or permit should be required.

Such a license or permit should closely describe and authorize specific facility capacities, processes and potential exposures. While recognizing that there are competing technologies and innovations, it should require best available technology that is economically achievable.
A facility-specific permit should also require equipment and procedures that are appropriate and adequate for controlling normal environmental releases, and for monitoring, reporting and responding to unexpected pollutant releases and other emergencies, such as process upsets and fires.

Unless worker safety is regulated and controlled by different agency than the permitting authority, such as the U.S. OSHA, this area of concern should also be addressed in a facility-specific license or permit.

A facility-specific licence or permit should include schedules for monitoring, reporting and auditing, to be performed by both the competent authority and by the facility.

A facility-specific license or permit should include provisions for closure of the facility at the end of its useful life, and for financial preparation for such closure.

THIRD PARTY MANAGEMENT SYSTEMS – ISO and EMAS

While third party management systems do not themselves impose limits upon exposures to substances of concern for workers, the public and the environment, they do require that facility management include these matters in a cycle of close review, careful management and constant improvement. The environmentally sound management of the largest and most complex metal recovery facilities, i.e. copper smelters, should be certified by an independent verifier/third party certifier under an applicable environmental management system, including European Eco-Management and Audit Scheme (EMAS) or ISO 14000, or under an equivalent system, such as a complex operating program licensed and overseen by a competent authority.

These third party management systems may, however, create an undue burden and impose excessive costs on small enterprises, such as collectors, shredders and other processing facilities prior to copper smelting. These facilities should be audited by less complicated and less frequent procedures, such as by representatives of the mobile phone manufacturers or copper smelters with which they deal.

GUIDELINES FOR TRANSBOUNDARY MOVEMENTS

As described above, the most environmentally sound final disposal of mobile phones is through metal recovery by a copper smelter, followed by metal-specific refining. While there are copper smelters in many countries that can process ores and ore concentrates, there are only a few copper smelters in the world that have the specialized material handling equipment and pollution control systems that are appropriate for metal recovery from mobile telephones. And because annual disposal of mobile phones is unlikely to provide more than 40,000 tonnes of feedstock worldwide, it is not likely that new copper smelters will be built for this source material. Therefore transboundary movement of mobile phones to these few facilities will be necessary. Such transboundary movement has been recognized by OECD Council Decision C(83)180 as efficient and environmentally sound and by the Basel Convention, Article 4.9, as appropriate for “raw material for recycling or recovery industries in the State of import.”

Transboundary movement of used mobile phones intended for metal recovery should be made pursuant to specific contracts that detail the responsibilities and rights of the parties, the materials to be shipped and processed, metals to be recovered and the anticipated metal recoveries, the costs to be incurred, and assignment of the risk of loss and the risk of environmental damage,.

Used mobile phone handsets and accessories intended for smelting do not require special packaging if batteries have been removed. The packaging should minimize releases to the environment if unintentional breakage does occur during transport, such as containment in sacks or closed shipping containers.

Mobile phones with batteries removed, that are properly packaged, and that are transported to a proper licensed copper smelter, pursuant to a specific contract, under the guidance of the Mobile Phone Partnership Initiative, should not require additional consent of competent authorities.

Issued: 14 July 2003

REFERENCES

[1] Mueller, J., Griese, H., Hagelüken, M., Middendorf, A., and Reichl, H., *X-Free Mobile Electronics – Strategy for Sustainable Development*, IEEE Symposium on Electronics and the Environment, 2003, p. 15

[2] Skerlos, S.J., Morrow, W.R., Chan, K.Y., Zhao, F., Hula, A., Seliger, G., Basdere, B., and Prasitnarit, A., *Economic and Environmental Characteristics of Global Cellular Telephone Remanufacturing*, IEEE Symposium on Electronics and the Environment, 2003, pp. 99-104: "At present the majority of remanufactured phones are distributed to EMs [emerging markets] in South America and Europe. .. It can also be expected that, especially at first, LDCs will have less ability to handle toxic battery and circuit board materials after the phone is discarded." (pp.102-103)

[3] Stewart, E. and Lemieux, P., *Emissions from the Incineration of Electronic Industry Waste*, IEEE Symposium on Electronics and the Environment, 2003, pp. 271-275. This paper describes experiments by the U.S. EPA using controlled combustion but with inadequate afterburner capacity and no other emission controls, and is thus not representative of either uncontrolled burning or appropriately controlled copper smelting.

[4] Stevels, A., *Is the WEEE Directive EcoEfficient*, IEEE Symposium on Electronics and the Environment, 2003, pp. 7-12: "[T]he environmental impact of the gold and palladium makes that it is top priority to have it all recycled." (p. 9)

[5] Huisman, J. and Stevels, A., *Eco-efficiency of take-back and recycling, a comprehensive approach*, IEEE Symposium on Electronics and the Environment, 2003, pp. 265-270.

[6] Hermann, F., Klotz, G., and Urbach, H., *Guidance Document on Substances under Special Attention*, IEEE Symposium on Electronics and the Environment, 2000, p. 217

[7] discussion with Dr. Michael Biddle, CEO, MBA Polymers, Richardson, California, USA. Separation of any coating from plastic is difficult, and separation of a metal coating from a very thin plastic case is prohibitively expensive.

[8] Stevels, A., *Is the WEEE Directive EcoEfficient*, IEEE Symposium on Electronics and the Environment, 2003, pp. 7-12: "For plastics the high-energy content of the materials make that energy recovery in many cases is to be preferred (from an environmental perspective) over mechanical mixed plastics recycling." (p. 10)

[9] Dambeck, P. and Gardner, J., *Health & Safety Issues for a U.S. Electronics Recycling Facility*, 2003

[10] Peters-Michaud, N., Katers, J., and Barry, J., *Occupational Risks Associated with Electronics Demanufacturing and CRT Glass Processing Operations and the Impact of Mitigation Activities on Employee Safety and Health*, IEEE Symposium on Electronics and the Environment, 2003, pp. 323-328.

[11] Lehner, T., *E&HS Aspects on Metal Recovery from Electronic Scrap*, IEEE Symposium on Electronics and the Environment, 2003, pp. 318-322.

[12] Copper Smelting, Pollution Prevention and Abatement Handbook, World Bank Group, July 1998; Secondary Copper Smelting, AP-42 Emission Factors 12.9, U.S. EPA, 1994; Primary Copper Smelting, AP-42 Emission Factors 12.3, U.S. EPA, 1986