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Research and Development

Manual of Practice

The Disposal of Combined Municipal/Industrial Wastewater Residues (Metals)

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MANUAL OF PRACTICE: THE DISPOSAL OF COMBINED MUNICIPAL/INDUSTRIAL WASTEWATER RESIDUES (Metals)

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FOREWORD

The Environmental Protection Agency was established to coordinate administration of major Federal programs designed to protect the quality of our environment.

An important part of the agency's effort involves the search for information about environmental problems, management techniques and new technologies through which optimum use of the nation's land and water resources can be assured and the threat pollution poses to the welfare of the American people can be minimized.

EPA's Office of Research and Development conducts this search through a nationwide network of research facilities.

As one of these facilities, the Robert S. Kerr Environmental Research Laboratory is responsible for the management of programs to: (a) investigate the nature, transport, fate and management of pollutants in groundwater; (b) develop and demonstrate methods for treating wastewaters with soil and other natural systems; (c) develop and demonstrate pollution control technologies for irrigation return flows; (d) develop and demonstrate pollution control technologies for animal production wastes; (e) develop and demonstrate technologies to prevent, control or abate pollution from the petroleum refining and petrochemical industries, and (f) develop and demonstrate technologies to manage pollution resulting from combinations of industrial wastewaters or industrial/municipal wastewaters.

This report contributes to the knowledge essential if the EPA is to meet the requirements of environmental laws that it establish and enforce pollution control standards which are reasonable, cost effective, and provide adequate protection for the American public.

W. C. Galegar

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ABSTRACT

The disposal of residues from waste treatment systems treating combined municipal and industrial wastes, quite often, presents some unique problems. The uniqueness derives from the nature or the levels of constituents contributed by industry when combined with municipal wastes. Some of these constituents inhibit treatment processes and/or pose a potential threat to public health if improperly handled.

On a broad scale, environmentally acceptable methods of disposing of residues include incineration, landfilling, landspreading, and a combination of incineration and landfilling. However, no one of these methods is acceptable in all cases because of the diverse nature of the residues. Additionally, with some constituents, none of these methods are free of environmental concern.

This effort is concerned specifically with the disposal of residues from combined treatment systems containing metals and with metal residues in general.

This manual gives the processes and products where different metals are used in order that potential sources of metals in combined wastewater residues may be identified. Potential problems in disposal of these residues are identified. Most metals are toxic to plants or animals at some concentration and, therefore, pose potential environmental or health problems.

Disposal practices, incineration, landspreading, landfilling, and encapsulation are discussed. Limiting concentrations of potential problem metals are given for incineration and landspreading.

This report was submitted in fulfillment of IPA contract by Dr. Hugh M. Jeffus, University of Arkansas, under the partial sponsorship of the U.S. Environmental Protection Agency. This report covers a period from August 15, 1977, through August 15, 1978, and work was completed as of August 15, 1978.

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SECTION 1

INTRODUCTION

The removal of a contaminant from one medium--air, water, land--always produces a contaminant in another medium, although in a more concentrated form. This is a result of the principle that matter cannot be created or destroyed, but can be changed in form and moved to a lower energy level.

The primary problem in wastewater treatment has traditionally been "what to do with the residue." There is a current trend to dispose of this residue on the land as a soil amendment. There is also a trend toward placing the wastewater, either before or after solids separation, on the land. This is not a new idea. In the "Report from the Poor Law Commissioners on an Inquiry Into the Sanitary Conditions of the Labouring Population of Great Britain," 1842, Sir Edwin Chadwick called for "The Rain to the River and the Sewage to the Soil." Since this concept has been applied in many areas of the world for centuries, this evidently was not a novel idea when Sir Edwin set it forth. The municipal sludge of today, particularly from combined systems, is much more complex than in Sir Edwin's day. In fact, many of the constituents of modern combined sewage were used but rarely then. Thus, application today must be made very carefully with consideration given to both short- and long-term effects of the application.

Several recent publications have addressed the sources and effects of heavy metals in sludges on crops (1, 2, 3, 4, 5). It is also interesting to observe how many patents have been issued for recovery of heavy metals from waste streams in the previous 5 years (6). Recovery and reclamation appear absolutely necessary not only for environmental considerations, but for resource management. The United States consumption of the world production of certain metals exceeds the following percentages: aluminum 46%, antimony 21%, cadmium 34%, chromium 16%, cobalt 16%, copper 25%, and zinc 29% (7). There is an insufficient quantity of several metals to raise world consumption to the per capita level of consumption in the United States.

Heavy metals from combined industrial and municipal wastewater are concentrated in the sludge (8). Therefore, very careful monitoring of all industrial waste streams and combined wastewater sludges must be followed.

Sludges applied to pasture and cropland probably have more utility as a soil amendment than as a fertilizer. Currently, less than 0.3 percent of the Nation's croplands receive sewage sludge, and even if the entire municipal sludge production were to be applied at crop nitrogen requirement rates, less than 1 percent of the agricultural land would be involved (3). It has been reported that widespread use of sludge as a fertilizer could potentially satisfy only 2 percent of the current artificial nitrogen and phosphorous fertilizer market (3).

Boron, copper, iron, manganese, molybdenum, and zinc are essential micronutrients for plants (1). However, in high concentrations most metals including boron, copper, manganese, and zinc are toxic to plants.

Copper, chromium, iron, manganese, molybdenum, selenium, and zinc are essential micronutrients for man and animals (4). However, as with plants, high concentrations of some of these metals, molybdenum and selenium, are toxic to man and animals. Cadmium, lead, and mercury are cumulative poisons in man and animals. Most heavy metals are toxic to some degree to both plants and animals.

Another factor which complicates land application of sludge from combined industrial and municipal waste treatment plants is metal mixtures. For example, proper management of soil organic matter and pH will render some metals relatively unavailable to crops and forage, but will render other metals more available. Most metals are relatively insoluble under alkaline soil conditions. Antimony, selenium, and molybdenum are more soluble under alkaline soil conditions.

In the pages that follow, the possible sources of metals which may be found in a residue are stated. This may be of help to those upon whom the responsibility falls for monitoring and reducing the discharge of metals to a waste treatment plant so that the sludge from the wastewater treatment plant may be environmentally acceptable.

SECTION 2

CONCLUSIONS

Some metal residues from combined waste treatment systems pose potential threats to health and the environment. In general, the potential problems most commonly involve cadmium, copper, lead, mercury, molybdenum, and nickel.

Arsenic, barium, cadmium, selenium, and mercury have low boiling temperatures and, therefore, the potential to cause emission problems from sludge incinerators.

Antimony, molybdenum, and selenium are most soluble under alkaline conditions and could, therefore, pose a problem when mixed with other metals in an environment designed to keep other metals immobile, such as a high pH soil system.

Adverse health effects could occur from landfilling high concentrations of arsenic, barium, beryllium, cadmium, chromium, cobalt, lead, mercury, selenium, and vanadium.

Specific information about a landfill site must be obtained before sludge metals concentration limits can be set for that site.

Analyses of soil metal content and sludge metal content must be made before landspreading of sludge is started.

Metal analyses of sludges do not normally reveal the form or compound the metal is in, and almost any metal can exist in some form that is hazardous.

SECTION 3

RECOMMENDATIONS

The following recommendations are offered:

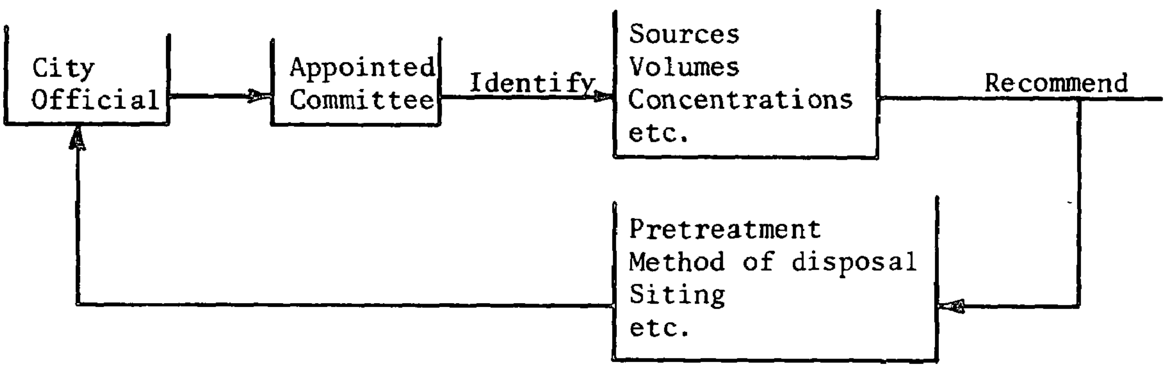
1. The soil chemistry of cadmium and cobalt should be studied in detail.

2. The antimony content of sludges from combined waste treatment systems should be monitored.

3. The toxicity of antimony to plants and animals should be investigated more fully.

4. Stack emission standards for the easily volatilized toxic metals should be set similar to the standard for mercury.

5. City officials in small municipalities (less than 50,000 population) should appoint committees to assist city officials in resolving the problem of residues. The committee might be composed of representatives from industry, utilities, health services, academia, etc., and might involve the disciplines of chemistry, geology, engineering, soil science, and plant science. This committee should contact the appropriate state and federal agencies for help in order to give city officials some background and assistance in the use of their manual of practice as follows:



SECTION 4

POTENTIAL SOURCES AND PROBLEMS OF METALS IN RESIDUES

ALUMINUM

Aluminum metal is used in aircraft, utensils, apparatus, electrical conductors, dental alloys, photography, explosives, fireworks, paints, and the manufacture of steels. Compounds of aluminum are used in medical supplies, fur processing, baking powder, purifying water, dyeing and printing fabrics, artificial gems, paper, vegetable glue, marble and porcelain cements, fireproofing and waterproofing fabrics, glass manufacture, electrolytic copperplating, preserving wood, coating ceramics, organic synthesis, disinfectants, antiperspirants, detergents and soaps, petroleum cracking, lubricants, and in the manufacture of lacquers, filaments, semiconductors, resistors, and rubber.

The primary source of aluminum in combined treatment residues is from water treatment plant discharges where aluminum sulfate is used as a coagulant. The second most prominent use of aluminum sulfate is in the papermaking industry where the product is used for the sizing of paper.

Very little aluminum is discharged to municipal sewers from the manufacture of aluminum sulfate or aluminum chloride (5).

Aluminum toxicity to plants is common where it exists in soils with pH values below 5.0. However, in well-aerated soils with pH values above 5.5, aluminum will not be a major factor in land disposal of aluminum-containing residues (4).

ANTIMONY

Antimony is used in alloys such as babbitt, hard lead, white metal, automobile body solders, bullets, fireworks, and metal coatings. Compounds of antimony are used as catalysts, as pigments, in vulcanizing and coloring rubber, and in the manufacture of matches, fireworks, medical and veterinary supplies, glass, pottery, and porcelain. It is also used in dyeing and printing fabrics, and in the flameproofing of canvas.

Antimony is not known to be essential to the growth of plants but has been reported to be moderately toxic (4). Leaves of plants tend to contain more antimony than do stems (4). Although antimony could be a potential hazard to plants and animals if applied in large amounts, no evidence of hazard is currently available (4). Antimony is most soluble under alkaline soil conditions.

There is not much information as to the antimony content of sludges from combined waste treatment. Investigation of the antimony content of suspected sludges should be made.

ARSENIC

Arsenic originates primarily from the smelting of other nonferrous metals. Arsenic was used in pesticides before 1967 and is used in wood preservatives, as pigments in paints, in fireworks, in the textile and tanning industries, and in making certain bronzes and alloys. Compounds of arsenic are also used in the manufacture of glass, enamels, ceramics, oil cloth, linoleum, and electrical semiconductors, and photoconductors. However, the primary source may be from the food processing industry because arsenic tends to accumulate in the roots and not in the edible portions of most plants (4).

Although arsenic is extremely toxic to man and animals, it is not thought to pose a serious problem in the disposal of residue by landspreading because of the low levels commonly found in most sludges (4). Rates of applications in excess of 90 kilograms (kg) of arsenic per hectare must be applied before toxicity to plants is observed (4). Arsenic tends to revert to the chemical form of arsenate, which is strongly held by the clay fraction in most soils (4).

Arsenic in landfills is a different matter. Serious damage has occured through groundwater contamination from arsenic burial (9).

BARIUM

Barium is used in certain electronic devices and in spark plugs. Compounds of barium are used in printing and dyeing fabrics, tanning and finishing leather, electroplating, synthetic rubber vulcanization, marble substitutes, lubricants, pesticides, rat poisons, corrosion inhibitors, embalming, and pigments. Barium compounds are also used in the manufacture of explosives, paper, glass, paints, enamels, matches, green signal lights, and case hardened steels (1). Barium is also used in diesel fuels as a smoke suppressant, and in some veterinary medical supplies.

All water and acid soluble compounds of barium are poisonous.

Barium in high concentrations can cause yield reductions of crops. Barium concentrations in soils normally range from 200 to 6000 kg per hectare (1). Barium is found in most surface waters. It appears remote that barium would impinge significantly upon sludge disposal from combined waste treatment systems, unless sludge concentrations are in the range of thousands of micrograms per gram ($\mu g/g$).

BERYLLIUM

Beryllium is a source of neutrons when bombarded with alpha particles. It is a neutron reflector and neutron moderator in nuclear reactors. Beryllium oxide is used in rocket propellants. Beryllium has been used in radio tubes, television tubes, and fluorescent tubes.

Beryllium production in the United States is less than 500 tons per year (6). Beryllium is a very expensive metal, and much effort is put forth to recover this metal from smelting operations. It is usually recovered from spent pickle acids deriving from the pickling baths for stainless steel and other alloys in a process for the recovery of copper (6). Beryllium and beryllium salts are toxic to man in extremely low concentrations but should present no problems in combined waste residue disposal because there is limited production and use and efforts are exerted for recovery from waste streams.

BORON

The principal source of boron is from the household use of boron-containing soaps, detergents, and cleaners. Boron is also used in the manufacture of glazes, cements, crockery, porcelain, enamels, glasses, alloys, semiconductors, lubricants, and hardened steels (1). Boron compounds are used in fertilizers, rubber vulcanizers, anesthetics, in fireproofing and weatherproofing fabrics and wood, in the leather and tanning industry, in printing and dyeing, paints, photography, and solder (1).

Boron is an essential micronutrient element for plants and is found in plants and animals. At relatively low levels, boron is toxic to plants and animals. The toxicity level for plants occur at levels greater than 75 μg/g in the soil, and the normal concentration of boron in plants is between 30 and 75 μg/g (1). Therefore, it is unlikely that boron content of most sludges will be a controlling factor in their disposal because of the limited number of high boron content sludges.

CADMIUM

Cadmium is used in electroplating, pigments and chemicals, and alloys. Parts of household appliances (refrigerators, washing machines, etc.), automobiles, airplanes, agricultural implements, and industrial machinery are commonly cadmium coated (1). Additionally, hand tools (pliers, wrenches, screw drivers) and fasteners of all kinds are often cadmium coated (1). Compounds of cadmium are used in the plastic industry, in photography, lithography, process engraving, rubber curing, medical and dental supplies, and as fungicides. Alloys of cadmium are used in the production bearings for internal combustion engines and aircraft, for solder, and bronzing (1). Cadmium is also used in the production of automobile radiators, batteries, the manufacture of super-phosphate fertilizers, and luminescent dials. Approximately 60 percent of the use of cadmium is in the electroplating industry.

Major sources of environmental release of cadmium are metal plating, the manufacture and use of super-phosphate fertilizers, and the vulcanization of rubber. Cadmium is taken up by plants through the roots and leaves and may be quickly translocated to the plant vegetative parts. There is apparently no general rule that may be applied as to the content that will appear in the grain of edible plants. The percentage content of grain to foliar parts of cadmium usually varies from 3 to 15 for corn, but may be from 30 to 100 for soybeans, wheat, oats, and sorghum (4).

Cadmium is toxic to plants and is a cumulative poison to man and animals. Therefore, there is much concern at present about cadmium content of sludges.

Pretreatment ordinances can reduce the cadmium content of sludges as well as other metals of concern (4). However, studies have shown that cadmium is concentrated in biological solids (8). The weight ratio of cadmium in the solids to cadmium in the influent water was 4100 when the influent water concentration was 1 milligram per liter (mg/l).

Additional investigation needs to be performed to learn what is not known about soil chemistry and the interactions of cadmium. The task seems quite formidable. It appears that cadmium is influenced by soil organic matter, clay content and type, hydrous oxide content, soil pH, and redox potential (1). In addition, some metals are antagonistic and some are synergistic to the plant uptake of cadmium.

In view of these things, it would seem that something else could be substituted for the primary use of cadmium (electroplating) that would be more environmentally acceptable. For example, a copper or zinc coated screwdriver would probably function as well as the cadmium coated product, etc.

CHROMIUM

Chromium is used in chrome steels and alloys to increase the resistance and durability of metals. The use of chromium in the electroplating industry is widespread. Chromium is used in making refractory brick to line metallurgical furnaces (1). Compounds of chromium are used in dyeing and tanning, in manufacturing inks, varnishes, glazes of porcelain, and as abrasives. Chromates are used as corrosion inhibitors and rust inhibitors in cooling towers, air conditioners, boilers, and some pipelines. Chromates are also used in primer paints and dips for metals, in paper matches, dry-cell batteries, and some fireworks. Chromium compounds are used as topical antiseptics and astringents, defoliants, and in photographic emulsions (1).

Little soluble chromium is found in soils. Hexavalent chromium applied to soil is soon converted to trivalent chromium and then to a low solubility compound. There is some evidence that chromium is required by humans and animals in minute amounts, and diets are deficient in chromium (4). Excess chromium, in minute amounts, is eliminated. However, chromium and its compounds are extremely toxic to man, especially from ingestion, and with some compounds from dermal exposure. Trivalent chromium is the only form available to plants, and it can be adsorbed through leaves and roots.

Hexavalent chromium can seriously interfere with biological waste treatment at high levels. Trivalent chromium is less inhibitory than hexavalent chromium.

High concentrations of chromium in soils appear to be slightly toxic to plants and reduce yields (1). Chromium is not likely to be a limiting factor in land application of sewage sludge (4). However, care must be taken that water supplies are not contaminated. The allowable chromium concentration in drinking water is very low. Pretreatment of chromium-bearing streams at the source must be practiced.

COBALT

Cobalt is used in the production of high-grade steels and alloys. Cutting and wear-resistant materials are commonly produced from steels and alloys incorporating cobalt (1). Some cobalt compounds are used as a drier in paints, varnishes, enamels and inks, as a pigment, and as a glass decolorizer (1). Cobalt compounds are also used in medical and veterinary supplies, and in radiotherapy.

Cobalt is found in most soils and most sludges. Very little is known about the chemistry of these elements in natural soils. However, it does not appear that cobalt will be a major factor in disposal of residues from most combined waste treatment systems due to the low concentrations found in most sludges. Cobalt content of sludges should be monitored if cobalt is used locally.

COPPER

Copper is used in the production of wire, brass, piping, electrical apparatus, boilers, cooking utensils, automobile radiators, insecticides, fungicides, and fertilizers. Copper is alloyed with tin, lead, zinc, aluminum, nickel, and manganese (1). Compounds of copper are used medical and veterinary supplies, pyrotechnics, paints, pigments, catalyst, manufacturing rayon, and printing and dyeing fabrics.

Copper is found in most soils at a concentration normally ranging from 10 to 80 parts per million (ppm) (4). Copper is an essential micronutrient for plants, but copper toxicity can occur at high concentrations. The copper accumulates in the roots with very little being translocated to the foliage. Copper appears to be about twice as toxic as zinc to plants.

Copper is toxic to animals in high concentrations, especially if the molybdenum intake is very low (4). The copper concentrates in animal livers under this circumstance and can be mitigated by controlling the molybdenum in the diet, especially for ruminant animals. Sheep are most susceptable to copper toxicity, followed by cattle, swine, and poultry, in that order (4). Swine crave copper, and swine and poultry are fed beneficial amounts of copper. The copper seems to be a substitute for antibiotics. The concentrations fed to swine in their diet have been as high as 250 ppm; however, lower concentrations are now fed. The copper accumulates in the swine liver but causes no apparent harm to the swine if the diet also contains adequate amounts of zinc and iron (4).

Copper is a problem in waste treatment where concentrations of 100 mg/1 can "poison" anaerobic digesters. This is about 1/5 of the concentration of chromium or nickel required to cause toxicity in anaerobic digesters.

The concern over copper is that it may build up in the soil over a period of years and produce toxicity to plants.

There appears little reason not to control high concentrations at the source. There are numerous recovery schemes for reclaiming copper (6). There is little waste from the production of copper sulfate. None of the major United States producers of copper sulfate discharge to a municipal sewer system (5).

LEAD

The two principal uses of lead are in the production of storage batteries and gasoline additives (1). Lead is also used in alloys, ammunition, construction, in pigments, as a caulking compound in plumbing, in solder, in exterior paints, and in the production of insecticides. Compounds of lead are used in matches, explosives, printing and dyeing fabrics, organic synthesis, photography, and veterinary supplies.

Lead is very toxic to animals. Doses are cumulative. Very small amounts of lead are adsorbed through plant leaves; the primary entry of lead to plants is through the roots. If the pH of the soil is above 5.5 and there is adequate labile phosphorous in the soil, there will be very little translocation by lead from roots to plant foliage and seeds (4). It appears that the primary entry of lead into the animal food chain is from animals grazing on forage that contains residues from exhaust gas sources such as automobile exhausts and blast furnace emissions.

If lead is adequately controlled at the source, it is unlikely that lead will control sludge application to land surfaces; however, it must be rigorously monitored as some sludges have very high lead contents (4). High lead concentrations in sludge will inhibit sludge digestion.

MANGANESE

The major use of manganese is in the iron and steel industry. Manganese is also used in alkaline batteries, glass, paints, and as driers for paints and varnishes. Other uses of manganese are in fertilizers, disinfectants, as an antiknock compound for internal combustion engines, as a drier for varnishes and oils, and in dye manufacturing.

Manganese is an essential micronutrient for plants and animals. It may enter plants through roots and leaves. High levels of manganese in the soil may cause toxic conditions in plants under reducing conditions. However, if the pH of the soil is maintained above 5.5, the manganese exists as the relatively insoluble oxides and hydroxides and plant uptake is restricted.

Manganese content of potable waters is restricted due to the taste imparted to certain beverages and the "black water" problems that arise from the domestic use of manganese-bearing waters.

Manganese should pose relatively little hazard in sludge disposal; however, care must be exercised to prevent contamination of surface and groundwater supplies with manganese where it would create the aforementioned problems.

MERCURY

Mercury is used for many purposes. The largest uses are in the electrolytic production of chlorine and caustic soda and in the electrical and electronics industry. Mercury is also used in paints, industrial and control instruments, dental preparation, as catalysts, in agriculture and in general laboratory instruments and experiments. Smaller users of mercury are the pharmaceuticals-cosmetics industry, pulp and paper industry, the production of floor waxes, furniture polishes, fabric softeners, fireworks, and laundry preparations. Mercury is used in neon, fluorescent, and mercury-arc lights, in measuring instruments such as thermometers, barometers, manometers, hydrometers, etc., and in batteries, rectifiers, switches, and oscillators. It is also used in the plastics industry, especially in the production of vinyl chloride and urethane. Low concentrations of mercury may appear in wastewaters from mercury contamination of commercial bleach.

Mercury is present in most soils as a result of the weathering of cinnabar. Mercury is taken up by plants through the roots or leaves and is readily translocated throughout the plant. A typical soil might have a natural mercury content of 0.01 to 0.5 ppm (4). Mercury and soil solid surfaces have affinity for each other, and mercury applied to soil surfaces normally is not a threat to groundwater. Most natural waters have concentrations of mercury less than .001 microgram/milliliter (μg/ml) (1).

Mercury ingested in food by animals and man tends to accumulate. It is excreted at a much slower rate than it is ingested. Mercury is toxic to man and animals, and has been reported to be toxic to plants. However, most municipal sludges do not contain sufficient mercury to create a major problem when sludge is applied to land. In combined systems mercury must be monitored, and high mercury sources must be pretreated at the source. Many relatively new recovery processes have been patented for recovery of mercury (6). Mercury is concentrated many times in the sludge from activated sludge systems relative to the influent stream (8).

MOLYBDENUM

The largest use of molybdenum is in the production of molybdenum steels and alloys (1). Other uses are in pigments, lamp filaments, electrical contacts, spark plugs, fertilizers, dyes, and as catalysts. Molybdenum disulfide is used as a lubricant.

Molybdenum enters plants through roots and leaves. It is an essential micronutrient for plants. The maximum sorption of molybdenum in soils occurs at pH 4.2, and the availability of molybdenum to plants increases as the soil pH increases. This is the reverse behavior to that observed with copper, nickel, and zinc (4). This will create problems with landspread sludge that contain mixtures of metals with molybdenum.

Animals are susceptible to a toxicity produced by too much molybdenum called molybdenosis. The amount of molybdenum necessary to produce the condition varies with animal species and age (4). Cattle and sheep are more susceptible than horses and pigs. Forages containing more than 10 to 20 ppm may produce molybdenosis in ruminants (4). The condition is affected by other metals intake, such as copper, zinc, and iron, and by the sulfate intake. Molybdenum in excessive concentration produces a copper and phosphorous deficiency in the animals.

It is doubtful that molybdenum in sludge would present a serious hazard to the health of grazing animals except where forages from sites treated with sludges high in molybdenum form a major part of the animal diet (4). However, from the foregoing it is apparent that molybdenum could be a problem in combined waste treatment sludge that is to be disposed of on land. Molybdenum is one of the elements that must be controlled at the source to prevent excessive concentrations in the sludge from combined municipal and industrial waste treatment plants.

NICKEL

Nickel is used in the production of stainless steels, in nickel alloys, in electroplating, in batteries and in magnets, electrodes, electrical contacts, spark plugs, machinery parts, and as a catalyst. Compounds of nickel are used in paints, lacquers, cellulose compounds, and cosmetics (1).

Nickel is commonly found in soils, plants, and waters. The common concentration range in soils is from 10 to 100 ppm, with higher concentrations found in weathered serpentine soils.

Nickel has been claimed to be an essential micronutrient for some plants, but generally is regarded as having no essential known function. Nickel becomes toxic to plants when the nickel concentration reaches 50 ppm (4). The toxicity has been observed on acid soils. Most nickel is eliminated by animals and should provide no problems in diets; however, most metals have some highly toxic compound such as nickel carbonyl.

Nickel is toxic to anaerobic digesters at a concentration of 500 mg/l. For this reason, and those stated above, nickel must be controlled at the source.

SELENIUM

Most of the selenium consumed in the United States is used in the glass and electronics industry (1). Selenium is used in rectifiers and photoelectric cells. The rectifiers are used in electroplating, welding, battery chargers, magnetic coils, arc lamps, and voltage regulators. Photoelectric cells are used in light exposure meters, electric eyes, detectors, colorimeters, and pyrometers. Selenium is used to produce pigments to color materials such as plastics, paints, enamels, inks, and rubber. It is also used in stainless steel and photocopiers, and compounds of selenium are used in pharmaceuticals, deodorants, pesticides, plastics, inks, oils, fireproofing agents, glue, insect repellants, lubricants, and paint removers. In addition, selenium compounds are used in the production of rubber and as catalysts in the production of soaps, waxes, and edible fats.

Little evidence exists to suggest that selenium is an essential element for plants, but it is definitely required by certain animals (4). It is an essential element in trace quantities for vitamin E production, and large quantities can be toxic to animals. Selenium and its compounds can be inhaled, ingested, and adsorbed through the skin to cause poisoning in man. The symptoms are much the same as arsenic poisoning. Selenium is taken up by plants, which serves as a transfer mechanism from soil to animals. At levels of 0.05 ppm in the diet degeneration of muscle tissue results; when the diet contains more than 4 ppm, selenium toxicity may occur (4). Selenium, like antimony and molybdenum, is most soluble under alkaline conditions. This complicates the management of sludges on land where these metals are mixed with other metals that are least soluble under alkaline conditons.

There are processes for recovery of selenium (6). Although selenium is not likely to be a limiting factor in the disposal of most sludges, there seems little reason for selenium wastes not to be pretreated at the source to insure that selenium is not a problem.

SILVER

Most silver that enters waste treatment systems probably comes from source silver used in photographic materials. Silver is also used in electronics manufacture, jewelry, electroplated ware, storage batteries, the production of mirrors, dental and medical supplies, gas masks, explosives, and some bearings and solders. Silver is also used as a catalyst in some industrial operations. There are no known discharges of silver from the manufacture of silver nitrate (5).

It is unlikely that silver will be a problem in the disposal of most residues from combined municipal and industrial wastewater treatment.

SODIUM

Sodium, as salt, is an essential part of the diet of man and animals. It is found in municipal waste primarily due to the excretions of man and as waste from food preparation. Sodium compounds have many uses, and the compounds of sodium are many. It is used in baking powders, medical supplies, soaps, paper sizing, water softeners, printing fabrics, fire extinguishers, cleaning compounds, food preservatives, disinfectants, bleaches, and in manufacturing glazes and enamels. Sodium is also used in sodium arc lamps, in photography, in fumigants, in oxidants, in organic synthesis, and for other purposes. It is toxic to plants in high concentrations. However, the effect of concern where sludge is to be applied to land, is the drastic effect salt has on the soil. When the sodium concentration is high in ratio to the calcium and magnesium, the soil becomes plastic and sticky. This destroys the permeability of the soil and ruins its fertility.

Sodium is not likely to be a major problem in sludge disposal from the majority of systems. It is toxic to anaerobic digesters at high concentrations.

STRONTIUM

Strontium is used in the production of pyrotechnics to impart a crimson color. Strontium compounds are used in electronics, glass, grease, paints, plastics, and pharmaceutical supplies. The radioactive isotope, strontium-90, is often a waste product of fissionable material. Strontium-90 could be a major problem if it were a constituent of the residue because plant and animal systems do not discriminate between calcium and strontium. Strontium is not likely to be a problem in sludge disposal because most sludges have low strontium contents. Some combined sludges do have relatively high strontium levels, however.

THALLIUM

Thallium is used in electronics, alloys, glass, and agriculture, and as a rat poison. Thallium compounds are used in the manufacture of artificial gems, ant bait, and green fire for signaling at sea.

There is only one United States producer of thallium. Therefore, there is unlikely to be a problem with thallium in combined waste treatment residue due to the limited production and use of thallium.

TIN

The primary use of tin is in the production of tin cans. Tin is also used in the production of many alloys, babbitt, brass, bronze, and galvanizing materials. It is used in roofing materials, pipe and tubing, solder and in collapsible tubes, and foil (1). Compounds of tin are used in glass manufacture, dyeing and printing fabrics, toothpaste, fingernail polish, and in decorating porcelain and china. Tin is thought to be quite inert in soils and is, therefore, unlikely to be a major problem in waste disposal.

TITANIUM

Titanium is used in the production of certain steels, in electrodes, welding rod coatings, shoe whiteners, paper coating, acetate rayon, water paints, exterior paints, inks, plastics, and as pigments. Compounds of titanium are used in dyeing, stain removers, reducing agents, and medical supplies.

Titanium is present in any soil that contains layer lattice clay. Titanium has no recognized essential biological function. It can enter plants through roots or leaves. Titanium can be toxic to animals if ingested in large quantities. The toxicity symptoms for humans resemble Parkinson's Disease. The primary source of titanium in the human diet is black pepper.

Titanium is unlikely to be a major factor in combined waste sludge disposal except from steel mills or where titanium recovery is a segment of the secondary nonferrous metal industry.

TUNGSTEN

Tungsten is used in the production of steels, cutting tools, and in the electrical industry as filaments and conductors. Little is known of the tungsten content of soils and sludges. However, it is unlikely that tungsten will be a problem in the disposal of combined waste treatment residue because tungsten is not used by many industries.

VANADIUM

The major uses of vanadium are in vanadium steels and nonferrous alloys (1). Vanadium compounds are used as a catalyst in several processes, as driers in paints and varnishes, in photography, in drying and printing fabrics, and in the production of colored glass and glasses (1). The most likely source of vanadium in waste streams is from crude oil and coal.

Vanadium has no recognized function in biological systems. Plants adsorb vanadium through roots or leaves. Vanadium is suspected to be toxic to animals. However, in the absence of steel mills or coal conversion facilities, vanadium is unlikely to be a limiting factor in combined waste treatment sludge disposal.

ZINC

Zinc is used extensively as a protective coating of metals to prevent corrosion and in alloys such as brass and bronze (1). Galvanized pipes are commonly used in domestic water systems, and zinc solubilized by corrosion is thought to contribute substantially to the zinc concentrations in wastewaters (1).

Zinc and its compounds are constituents of many household items including utensils, cosmetic and pharmaceutical powders and ointments, antiseptics, astringents, insecticides, fungicides, glues, matches, inks, porcelain, paints, varnishes, oil colors, linoleum, and rubber. Zinc and zinc compounds are used in dyes, phosphors for fluorescent lights, and electrical apparatus. Zinc is also used in the manufacture of glass, castings, printing plates, building materials, railroad car linings, automobile tires, dry-cell batteries, television screens, reducing agents, and parchment paper. Zinc compounds are used in hardeners of cement, weighting textiles, agricultural fertilizers, wood preservatives, and in paper bleaching.

Zinc is an essential nutritional trace element, and some diets may be deficient in zinc. It can cause plant toxicity and animal toxicity at high concentrations. Zinc has been used as a standard for plant toxicity. Zinc is most soluble in soils under acidic conditions; and, when zinc toxicity does occur, the plant concentrations will be several hundred ppm (4). Several hundred ppm of zinc in the diet of animals causes reduced weight gain and lower feed efficiency.

Zinc is not likely to be a major factor in the disposal of the residue from combined waste treatment unless the zinc concentration is in the order of thousands of mg/l.

Table 1 gives toxicity and solubility conditions of some common metals.

OTHER METALS

The following metals are given limited coverage herein because they are

TABLE 1. GENERALIZED METAL TOXICITY AND SOLUBILITY CONDITIONS

Metal	Phytotoxin	Toxic to man or animals	Highest solubility conditions	Toxic conditions
Aluminum (Al)	X pH <5.0		Acid	
Antimony (Sb)		X	Alkaline	
Arsenic (As)	X	X	Acid	High concentration for plants Low concentration for animals
Barium (Ba)	X	X	Acid	High concentration
Beryllium (Be)		X		Low concentration
Boron (B)	X	X		Medium concentration
Cadmium (Cd)	X	X	Acid	Cumulative
Chromium (Cr)	X slight	X	Acid	
Cobalt (Co)			Acid	
Copper (Cu)	X	X	Acid	
Lead (Pb)		X	Acid	Cumulative
Manganese (Mn)	X pH <5.5			
Mercury (Hg)	X slight	X		Cumulative
Molybdenum (Mo)		X	Alkaline	Low concentration

(continued)

TABLE 1. (continued)

Metal	Phytotoxin	Toxic to man or animals	Highest solubility conditions	Toxic conditions
Nickel (Ni)	X		Acid	Low concentration
Selenium (Se)		X	Alkaline	Low concentration
Silver (Ag)			Acid	
Sodium (Na)				
Strontium (Sr)				
Thallium (Tl)		X		
Tin (Sn)			Acid	
Titanium (Ti)		X		High concentration
Tungsten (W)				
Vanadium (V)		Suspected		
Zinc (Zn)	X		Acid	High concentration

not produced in large quantities or have very limited usage and, therefore, will not occur in significant quantities in most sludges.

Bismuth is used in pharmaceuticals, cosmetics, and in the manufacture of other chemicals as a catalyst.

Cerium is used in manufacturing spark metals for lighters, as a catalyst, and in the manufacture of glass.

Cesium is used in pharmaceuticals and in electronics manufacture.

Columbium is used to produce high-strength alloys, stainless steel, and super alloys.

Gadolinium is used in control rods in nuclear reactors.

Gallium is used in the electronics industry primarily in light-emitting diodes for watches, calculators, and fluorescent light for xerography.

Germanium is used in electronics and dentistry.

Hafnium is used as a neutron absorber.

Indium is used in alloys for bearings, for dentistry, and for the manufacture of glass and semiconductors.

Lanthanum is used in glass to improve optical properties.

Lithium is used in chemical manufacture, ceramics, greases, alloys, swimming pool sanitation, and organic synthesis.

Platinum group metals (platinum, palladium, iridium, osmium, rhodium, and ruthenium) are used as catalysts in the petroleum refining industry and in automobile exhaust emission control systems.

Radium is used in medical treatment.

Rubidium is used in research.

Scandium is used in high intensity mercury lamps.

Tantalum is used primarily for capacitors in the electronics industry and as pressure vessels for the manufacture of chlorine.

Tellurium is alloyed with steel and copper and is used in the manufacture of rubber, electronics, and chemicals.

Yttrium is used as a phosphor in color television receivers and in lasers.

Zirconium is used in flash bulbs, explosives, in vacuum tubes, and in metallurgy.

SECTION 5

DISPOSAL

The ideal disposal alternative is to have no disposal but to practice recovery and recycle. Industrial pretreatment must be practiced, and recovery is only one step removed from pretreatment and, in some cases, may be a part of pretreatment. Pretreatment complies with the spirit of the Resource Conservation and Recovery Act of 1976 (Public Law 94-580) in two ways. First, it conserves our natural resources. Second, it reduces the amount of pollutants discharged to the environment. The depletion of our metal resources has previously been alluded to. However, the most compelling reason to pretreat industrial wastes is to prevent the dispersal of the pollutants into the environment. Pretreatment at the source catches the wastes at the most advantageous point insofar as the ability to treat or recover is concerned. At that point, the waste is in the most concentrated form, has not been diluted or mixed with other wastes, and is therefore more easily handled.

Disposal alternatives which may be considered are incineration, landspreading, landfill, and encapsulation. Incineration for heat recovery and landspreading for nutrient usage are disposal processes that conform to resource conservation and recovery. Encapsulation might be used as a method of storage for some constituents that are not economically recoverable now, but may be more valuable at some future time. It is difficult to see how landfilling would be either conservation or recovery. In any situation, there may be factors that will dominate and override conservation and recovery considerations. Incineration, landspreading, and landfill are not acceptable with all materials, but one of these alternatives will usually apply. The limitations and possible pitfalls of these alternatives are hereinafter discussed.

INCINERATORS

The two most common types of sewage sludge incinerators are the multiple hearth and the fluidized bed. The multiple hearth incinerator is used in more disposal installations than any other type of incinerator. The cyclone furnace is another type of incinerator that is designed for sludge disposal in smaller installations.

Other sludge reduction processes are wet air oxidation, pyrolysis, and sludge drying units.

INCINERATION

Sewage sludge incinerators normally operate at a temperature in the range of 900 to 1100°C. The melting and boiling temperatures of the metals discussed in the previous section are given in Table 2. From this table, it is obvious that many of the metals of concern are likely to be volatilized at incinerator temperatures.

TABLE 2. MELTING AND BOILING POINTS OF VARIOUS METALS (°C)

Metal	Melting temperature	Boiling temperature	Metal	Melting temperature	Boiling temperature
Aluminum	660	1800	Molybdenum	2622	≈4510
Antimony	631	1380	Nickel	1455	3075
Arsenic	*	*	Selenium	+144	+685
Barium	850	1440	Silver	960.5	≈2000
Beryllium	≈1300	2970	Sodium	97.7	883
Boron	2150		Strontium	757	1366
Cadmium	321	767	Thallium	303.5	1457
Chromium	1900	2480	Tin	231.9	2260
Cobalt	1493	3550	Titanium	≈1725	
Copper	1083	2595	Tungsten	3410	5900
Lead	327.4	1740	Vanadium	1717	3000
Manganese	1247	≈2032	Zinc	419.4	907
Mercury	-39	356.9			

* Sublimes at 615°C without melting
\+ Red form
≈ Approximately

In addition, the testing procedures for metal content do not determine the nature or type of compound in which the metal exists. Since different compounds of a particular metal have different boiling temperatures, some metals may vent from the incinerator at lower temperatures than those given for the pure metal in Table 2. The exact nature of the metal could only be determined by going to the source of the metal discharge and ascertaining the exact compound containing the metal.

Therefore, if significant concentrations of arsenic, barium, cadmium, lead, mercury, selenium, or thallium exist in the waste treatment residue, it should not be incinerated. Emission standards have been established for mercury from sludge incineration at 3200 grams per day (10). This limit is based upon 1 microgram of mercury per cubic meter of emitted gas. Similar standards should be promulgated for the other toxic, easily volatized metals.

A recent study has shown that the major portion of the metals in anaerobic digesters is within the cell mass (11). Thus, the metals will be released in the incineration process.

The ash remaining after incineration will have a higher concentration of the more heat-stable metals than the sludge that was incinerated. Assuming a normal range of 65 to 75 percent volatile solids in the sludge, the ash will contain three to four times the concentration of these heat-stable metals than the sludge. Care must be exercised in the disposal of this ash. The ash may be deposited in a secure landfill; however, if the more toxic metals exist, the ash should be encapsulated. The metals in the ash will probably be in the form of oxides and hydroxides. Under the reducing conditions existing in a landfill, the metals can be solubilized.

The concentration of material allowable in the dry sludge may be computed as follows:

> Assume 23.75 pounds of air per pound of solids is required for combustion (12) (50% excess air). The volume of required air is $\frac{23.75}{.0708}$ = 335 cubic feet per pound.
>
> If the ash remaining is 14% of the dry solids, then $\frac{335}{.86}$ = 390 cubic feet of air per pound of volatile solids. This value is consistent with values from operating incinerators.
>
> 390 x .0283 = 11 cubic meters of air per pound of volatile solids which is 41 micrograms of combustion products per cubic meter of air.
>
> Therefore, $41 \times 10^6 \times a$ = gas stream concentrations where a is the allowable concentration of metals in the sludge in parts per million.

From previous data (13) it appears that it is difficult to predict how much chromium, copper, cobalt, etc. will appear in the exhaust gas stream. However, it has been pointed out that some metals will appear in the gas stream (13). The following limiting concentrations of selected metals in combined residue from municipal and industrial wastes are based upon a limit of 1.5

micrograms per cubic meter of stack gas, except for mercury which is limited to 1 microgram per cubic meter:

Element	μg/g
Arsenic	60
Cadmium	60
Selenium	60
Mercury	40

These concentrations are on a dry weight basis per pound of volatile solids; therefore, an analysis on a wet basis must be corrected for moisture content and percent volatile solids.

LANDSPREADING

Landspreading of municipal sludges is becoming more common in the United States. Before landspreading is begun on a given plot, a complete metal analysis should be made of the soil. Then semiannual analyses should be continued to prevent excessive buildup of the metals. An analysis of the residue to be spread should be made periodically. This periodic analysis would alert operators to any significant changes and would allow computation of theoretical loading that might be applied without excessive buildup of metals in the soil. Obviously, the soil, the sludge, and the vegetative cover must all be managed. Edible root crops, for example, should not be grown on soil amended with high arsenic content sludges. Certain grain crops, rather than edible vegetative crops, should be grown on land that has been amended by sludges containing relatively high cadmium or mercury contents, etc.

Landspreading should not be practiced in certain areas such as on thin soils over carbonate rock or in regions of karstic topography. Such a practice would contaminate groundwater with heavy metals, nitrates, and organic material from the sludge.

Assistance in soil analysis, crop recommendations, and other pertinent local factors may be obtained from the Soil Conservation Service and the County Extension Service.

Application of residue to soil may be made until the metal content in the soil approaches the levels given in Column 3 of Table 3. These values were established for average metal content soils with carbon exchange capacity of 5 to 15 milliequivalents per 100 grams of soil. Local factors may require reducing the limiting concentrations. In no case should the soil metal content be allowed to exceed those values given in Column 2 of Table 3. The following factors may be used to calculate application loadings.

One μg/g in the soil is approximately two pounds per acre. (This assumes the weight of the soil in the top 15 centimeters is two million pounds per acre).

TABLE 3. METAL CONCENTRATION LIMITS IN SLUDGES FOR LANDSPREADING

	Common level µg/g*	Maximum level µg/g†	Limiting concentrations per 100 tons µg/g
Aluminum	Varies		20,000
Antimony			25
Arsenic	6	40	25
Barium	500	3000	3000
Beryllium			25
Boron	10	100	350
Cadmium	.06	7.0	45π
Chromium	100	3000	1000
Cobalt	8	40	100
Copper	20	100	1000
Lead	10	500	4400π
Lithium			10
Manganese	850	4000	1000
Mercury	.03	0.6	10
Molybdenum	2	5	25
Nickel	40	1000	450
Selenium	0.5	2	10
Silver	0.1	5	40
Sodium			10% of Calcium
Strontium			150
Thallium			5
Tin	10	400	100
Titanium			200
Tungsten			100
Vanadium	100	500	500
Zinc	50	300	2000

*Most values from (1)
†Some values from (15)
πTaken from (16) with cation exchange capacity of 5-15 (meq/100g)

One hundred short tons at 100 μg/g equals 10 mg/l when incorporated in the top 15 cm of soil.

The limiting concentrations given in Column 3 of Table 3 assumes that the 100 tons will be applied over an extended period of time that will exceed a minimum of 10 years. If the concentration of metals is higher, the amount of sludge that may be applied to the soil is reduced. If more than 100 tons of sludge is to be applied, the concentration must be reduced. Example calculations follow.

EXAMPLE 1. Suppose a sludge with the following metal content is to be spread on pasture land: Boron 300 mg/l, Cadmium 60 mg/l, Chromium 700 mg/l, Copper 600 mg/l, Nickel 300 mg/l. No other metals are present.

These concentrations are checked against Column 3 of Table 3, and it is observed that cadmium exceeds the allowable concentration. Therefore, the cadmium content governs the application, and thus,

$$\frac{45 \text{ mg/l (allowable)}}{60 \text{ mg/l (existing)}} \times 100 \text{ tons per acre} = 75 \text{ ton.}$$

Thus, only 75 tons of this sludge may be applied per acre.

EXAMPLE 2. If more than 100 tons is to be spread per acre, say 125 tons, the limiting concentrations are computed thusly:

$$\frac{100}{125} \times \text{limiting concentration} = \text{allowable concentration of metal in the sludge.}$$

This allowable concentration would then be 36 mg/l for cadmium, 800 mg/l for chromium, etc.

LANDFILL

The placing of sludges in landfills is practiced in many communities (3); however, this practice is not always satisfactory to all parties concerned. A recent study of industrial waste disposal landfills showed 49 to 50 sites studied had migration of metals (14). These were old sites, but it would appear that the difference between old and new sites would be time.

The integrity of a landfill is extremely site specific. The type of soil, annual rainfall and annual runoff, depth to groundwater, depth to bedrock, impermeable substrata, etc., all impinge upon the suitability of a site for a landfill. Assistance in evaluation of these factors may be obtained from State Pollution Control Agencies, the Soil Conservation Service, State Geological Commission, County Extension Service, the United States Geological Survey, and the Environmental Protection Agency.

There have been numerous cases of contamination of groundwater with metals from the disposal of industrial wastes (9, 17). One notable, recent case in Minnesota involved contamination of groundwater with arsenic from a grasshopper poison buried in the mid 1930's. The arsenic appeared almost 40 years later (9). Additionally, there recently have been several fires and explosions with injury to personnel at landfills where organic matter had been buried. Thus, if an impermeable cap is placed on a landfill to prevent leaching of metals, another problem is created by allowing methane to accumulate in large, potentially explosive quantities.

Therefore, the conclusion must be that a landfill to dispose of toxic metal wastes must be sealed at the bottom to prevent excessive leaching of the potentially toxic metals to groundwater.

Sludges containing the following metals should not be placed in landfills without encapsulation if the concentrations exceeds the limits set by local and Federal authorities: Arsenic, Barium, Beryllium, Cadmium, Chromium, Cobalt, Lead, Mercury, Selenium, and Vanadium. The limiting concentration will be site specific due to the variability of the parameters that affect leaching, such as annual rainfall, soil type, depth to groundwater, organic matter, structural integrity of underlying strata, etc.

If local authorities determine that concentrations of metals exceed safe concentrations for landfill, the waste may be encapsulated.

ENCAPSULATION

Encapsulation (18) involves the surrounding of the waste with an impermeable, durable material that will prevent leaching of the undesirable constituents. Chemical fixation, as commonly practiced, is not encapsulation and generally has been unsatisfactory (19).

The reason for this unsatisfactory performance appears to be that fixation involves mixing the residue with a media that holds the residue but does not prevent water from coming in contact with the residue. The residue and its metal content is leached when the water does contact it (19). In fact, some fixation processes allow the leaching of a typical metal, copper, from a fixed sludge at a much faster rate than it is leached from the raw sludge (19). This, of course, is directly opposite to the desired effect.

Encapsulation provides an impermeable boundary between the residue and the environment, and therefore the residue is not leached because rainwater and groundwater never come into contact with the residue (18).

REFERENCES

1. Page, A. L. Fate and Effects of Trace Elements is Sewage Sludges When Applied to Agricultural Lands. EPA 670/2-74-005, U.S. Environmental Protection Agency, Cincinnati, Ohio, Jan. 1974. 98 pp.

2. Carroll, Thomas E. et al. Review of Landspreading of Liquid Municipal Sewage Sludge. EPA 670/2-75-049, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio, June 1975. 106 pp.

3. Bastian, Robert K. Municipal Sludge Management: An Overview of the Sludge Management Situation. EPA 430/9-76-009, EPA Construction Grants Program, U.S. Environmental Protection Agency, Washington, D.C., April 1976. 64 pp.

4. Council for Agricultural Science and Technology. Application of Sewage Sludge to Cropland; Appraisal of Potential Hazards of the Heavy Metals to Plants and Animals. EPA 430/9-76-013, Office of Water Program Operations, U.S. Environmental Protection Agency, Washington, D.C., Nov. 1976. 63 pp.

5. Martin, Elwood E. Supplement for Pretreatment to the Development Document for the Inorganic Chemical Manufacturing Point Source Category. EPA 400/1-77-087A, Office of Water and Hazardous Materials, U.S. Environmental Protection Agency, Washington, D.C., July 1977. 282 pp.

6. Sittig, Marshall. Resource Recovery and Recycling Handbook of Industrial Wastes. Noyes Data Corporation, Park Ridge, New Jersey, 1975. 427 pp.

7. Bureau of Mines. Minerals Yearbook: Volume I, Metals, Minerals, and Fuels; Volume II: Area Reports-International. U.S. Department of the Interior, 1972. 1103 pp.

8. Neufeld, Ronald D. Utilization of Biological Sludges for the Removal and Possible Reclamation of Heavy Metals from Wastewater. In: Proceedings of the National Conference on Management and Disposal of Residues from the Treatment of Industrial Wastewaters. Information Transfer, Inc., Washington, D.C., Feb. 1975. pp. 73-77.

9. Office of Solid Waste Management Programs. Hazardous Waste Disposal Damage Reports. EPA/530/SW-151, U.S. Environmental Protection Agency, Washington, D.C., June 1975. pp. 1-2.

10. Environmental Protection Agency. National Emission Standards for Hazardous Air Pollutants; Subpart E-National Emission Standard for Mercury, 40 CFR 61.52, Federal Register 48302, Oct. 14, 1975.

11. Hayes, Thomas D. and Thomas L. Theis. The Distribution of Heavy Metals in Anaerobic Digestion. Journal Water and Pollution Control Federation, Jan. 1978. pp. 61-72.

12. Technology Transfer. Process Design Manual for Sludge Treatment and Disposal. U.S. Environmental Protection Agency, Washington, D.C., Oct. 1974. pp. 8-10.

13. Task Force on Sewage Incineration. Sewage Sludge Incineration. EPA/R2-72-040, Washington, D.C., August 1972. 89 pp.

14. Geraghty and Miller, Inc. The Prevalence of Subsurface Migration of Hazardous Chemical Substances at Selected Industrial Waste Land Disposal Sites. EPA 625/77-1-008, U.S. Environmental Protection Agency, Washington, D.C., 1977.

15. Technology Transfer. Process Design Manual for the Disposal of Wastewaters and Sludges on Land. U.S. Environmental Protection Agency, Washington, D.C., 1977. pp. 5-10.

16. The Office of Water Program Operations. Municipal Sludge Management: Environmental Factors. EPA 430/9-77-004, U.S. Environmental Protection Agency, Municipal Construction Division, Washington, D.C., Sept. 1977. 31 pp.

17. Lazar, Emery C. Summary of Damage Incidents from Improper Land Disposal. In: Proceedings of the National Conference on Management and Disposal of Residues from the Treatment of Industrial Wastewaters, Washington, D.C., Feb. 1975. pp. 253-257.

18. Lubowitz, H. R. et al. Development of a Polymeric Cementing and Encapsulating Process for Managing Hazardous Wastes. EPA 600/2-77-045, U.S. Environmental Protection Agency, Cincinnati, Ohio, August 1977. 167 pp.

19. Mahlock, J. L. et al. Pollutant Potential of Raw and Chemically Fixed Hazardous Industrial Wastes and Flue Gas Desulfruization Sludges. EPA 600/2-76-182, Interim Report, U.S. Environmental Protection Agency, Cincinnati, Ohio, July 1976. 117 pp.

20. Settlement Agreement. Natural Resources Defense Council, Inc., et al. versus Russell E. Train. United States District Court for the District of Columbia, Washington, D.C., June 1976.

APPENDIX A

INDUSTRIAL WASTE SURVEY

An industrial waste survey is necessary to determine source, quantity, etc. of materials discharged to the sewer system. The procedure for the waste survey is given in "Handbook for Monitoring Industrial Wastewater" and the analysis of the waste in "Manual of Methods for Chemical Analysis of Water and Wastes." Both manuals are available form the Office of Technology Transfer, Cincinnati, Ohio 45268.

The first section of this manual, along with Appendix B, will provide information on what metals would be expected in the waste streams.

APPENDIX B
METALS FROM POINT SOURCE CATEGORY

TABLE B-1. METALS IN SETTLEMENT AGREEMENT

Point Source Categories (20)	As	Ag	Be	Cd	Cr	Cu	Hg	Ni	Pb	Se	Sb	Tl	Zn
1. Timber Products Processing	X					X		X					X
2. Steam Electric Power Plants					X	X	X	X					X
3. Leather Tanning and Finishing	X				X								
4. Iron and Steel Manufacturing					X	X		X					
5. Petroleum Refining					X	X			X				
6. Inorganic Chemicals Manufacturing			X	X	X		X		X		X		X
7. Textile Mills	X				X	X			X		X		X
8. Organic Chemicals Manufacturing		X				X	X	X	X	X	X		
9. Nonferrous Metals Manufacturing	X	X	X	X	X	X		X	X	X	X		X
10. Paving and Roofing Materials													
11. Paint and Ink Formulation and Painting	X			X	X	X	X	X	X	X			X
12. Soap and Detergent Manufacturing							X						
13. Auto and Other Laundries													
14. Plastic and Synthetic Materials Manufacturing				X		X	X	X		X	X		X
15. Pulp and Paper Mills and Converted Paper Products						X	X						X
16. Rubber Processing				X						X	X		X
17. Miscellaneous Chemicals	X	X		X	X	X	X	X		X	X	X	X
18. Machinery and Mechanical Products Manufacturing	X	X	X	X	X	X	X	X	X	X	X	X	X
19. Electroplating		X		X	X	X		X					X
20. Ore Mining and Dressing	X	X	X	X	X	X	X	X	X		X		X
21. Coal Mining						X	X		X				X

TABLE B-2. OTHER METALS OF CONCERN

Point Source Categories (20)	Al	B	Ba	Co	Li	Mn	Mo	Na	Pl	Sn	Sr	Ti	V	W
1. Timber Products Processing	X	X						X						
2. Steam Electric Power Plants						X								
3. Leather Tanning and Finishing		X	X											
4. Iron and Steel Manufacturing	X	X	X	X		X	X			X		X	X	X
5. Petroleum Refining	X		X			X	X						X	
6. Inorganic Chemicals Manufacturing	X							X				X		
7. Textile Mills	X		X					X		X		X		
8. Organic Chemicals Manufacturing	X				X		X	X						
9. Nonferrous Metals Manufacturing	X	X		X			X	X	X	X		X	X	X
10. Paving and Roofing Material														
11. Paint and Ink Formulation and Painting	X	X	X	X		X	X				X	X		
12. Soap and Detergent Manufacturing	X	X						X						
13. Auto and Other Laundries								X						
14. Plastic and Synthetic Materials Manufacturing	X						X				X		X	
15. Pulp and Paper Mills and Converted Paper Products	X		X					X						
16. Rubber Processing	X	X	X											
17. Miscellaneous Chemicals	X	X	X	X				X			X	X		
18. Machinery and Mechanical Products Manufacturing	X		X		X	X	X		X	X	X	X		X
19. Electroplating	X		X							X				
20. Ore Mining and Dressing	X	X	X	X		X	X		X	X		X	X	X
21. Coal Mining								X					X	

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

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16. ABSTRACT

This manual gives the processes and products where different metals are used in order that potential sources of metals in combined wastewater residues may be identified. Potential problems in disposal of these residues are identified. Most metals are toxic to plants or animals at some concentration and, therefore, pose potential environmental or health problems.

Disposal practices, incineration, landspreading, landfilling, and encapsulation are discussed. Limiting concentrations of potential problem metals are given for incineration and landspreading.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Sludge Disposal Metals Residues-Wastes Incinerators Encapsulating	Metals - Sources Landspreading Landfill	68C

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