7. METAL SMELTING AND REFINING SOURCES OF CDD/CDF

7.1. PRIMARY NONFERROUS METAL SMELTING/REFINING

Little information has been published on the potential for the formation and environmental release of CDD/CDFs from primary nonferrous metal manufacturing facilities. Norwegian investigators (Oehme et al., 1989) have reported the presence of CDD/CDFs in the wastewater of a magnesium refining facility and in the receiving water sediments downstream of a nickel refining facility in Norway. Insufficient information is available from this study for evaluating CDD/CDF emissions, if any, from the smelting/refining of magnesium and nickel in the United States. The potential for formation and release of CDD/CDFs by primary copper smelters in the United States has been reported by Environmental Risk Sciences (1995) to be negligible. Lexen et al. (1993) reported finding few or no CDD/CDFs in solid wastes from a primary aluminum smelter. Bramley (1998) indicated that the smelting/refining of titanium may be a source of CDD/CDFs. The findings of these studies are discussed in the following subsections.

7.1.1. Primary Copper Smelting and Refining

Environmental Risk Sciences (1995) prepared an analysis for the National Mining Association on the potential for CDD/CDF emissions from the primary copper smelting industry. The analysis included reviewing the process chemistry and technology of primary copper smelting, identifying operating conditions, and comparing process stream compositions from seven of the eight U.S. primary copper smelters that are members of the National Mining Association. The analysis also included stack testing for CDD/CDFs at two facilities. The stack testing (Secor International Inc., 1995a and 1995b) involved the principal off-gas streams for copper smelters: main stack, plant tail gas stack, and the vent fume exhaust. The two facilities that were tested (Phelps Dodge Mining Co. in Playas, New Mexico, and Cyprus Miami Mining Co. in Claypool, Arizona) were selected as representative of the other facilities in the industry because of their similarity to the other facilities in terms of process chemistry, process stream composition, and process stream temperatures.

The results of the assessment of the process chemistry and technology and the operating conditions and process stream compositions indicate that although there is some

potential for CDD/CDF formation in this industry, several factors lessen the probability of CDD/CDF formation. These factors include (a) most of the energy used to melt copper is derived from oxidation of copper sulfide ore minerals (i.e., $CuFeS_2$) rather than carbon (i.e., fossil fuels); (b) low concentrations of organic carbon and chloride are present in raw materials and reagents; (c) high concentrations of sulfur dioxide are present in process gases (6 to 40 percent SO_2 by volume); (d) high temperatures are maintained in the furnaces and converters (1,100 to 1,500°C); and (e) copper (II) chloride is apparently absent in process emissions.

The results of this assessment were supported by the stack test data from the two tested facilities. CDD/CDFs were not detected in the air emissions from either facility. In 1995, eight primary smelters were in operation in the United States, one of which closed at the end of the year (Edelstein, 1995). Total refinery production was 1.60 million metric tons in 1995, including 0.36 million metric tons from scrap material (Edelstein, 1995) and 1.13 million metric tons in 1987 (USGS, 1997c). Conservatively assuming that all nondetected values were present at one-half the detection limits, Environmental Risk Sciences (1995) calculated the annual TEQ emission to air to be less than 0.5 g I-TEQ$_{DF}$ in 1995 for the seven facilities (out of a total of eight) belonging to the National Mining Association. Assuming that feed and processing materials were similar in 1987, 1987 releases can be estimated at less than 0.5 g I-TEQ$_{DF}$ as well. The activity level estimates are assigned a high confidence rating and the emission factor estimate a medium rating.

7.1.2. Primary Magnesium Smelting and Refining

Oehme et al. (1989) reported that the production of magnesium can lead to the formation of CDDs and CDFs. Oehme et al. (1989) estimated that 500 g of I-TEQ$_{DF}$ were released in wastewater to the environment and 6 g I-TEQ$_{DF}$ were released to air annually from a magnesium production facility studied in Norway; CDFs predominated with a CDF to CDD concentration ratio of 10:1. At the time of sampling, the magnesium production process involved formation of MgO (magnesium oxide) from calcinated dolomite followed by a step in which $MgCl_2$ was produced by heating MgO/coke pellets in a shaft furnace in a pure chlorine atmosphere to about 700 to 800°C. The $MgCl_2$ was then electrolyzed to form metallic magnesium and Cl_2. The Cl_2 excess from the $MgCl_2$ process and the Cl_2 formed during electrolysis were collected by water scrubbers and directly discharged to

the environment. The discharged wastewater contained 200–500 ppm of suspended particulate matter. All but trace quantities of the hexa- through octa- congeners were associated with the particulates; up to 10 percent of the tetra- and penta- congeners were present in the water phase.

A recent study by the firm operating the facility (Musdalslien et al., 1998) indicates that installation of a water treatment system has reduced annual emissions to water to less than 1 g Nordic TEQ and emissions to air have been reduced to less than 2 g Nordic TEQ. This study also presented results demonstrating that the carbon reducing agent used in the $MgCl_2$ production step and the operating conditions of the shaft furnace greatly affect the formation of CDD/CDFs. Gases from the furnace were measured nine times over sampling periods of 6 to 8 hours. The calculated emission factor to air (i.e., before any APCD controls) ranged from 468 to 3,860 ng Nordic TEQ per kg of $MgCl_2$ produced. The APCD controls consist of three water scrubbers, a wet ESP, and an incinerator.

U.S. production of primary magnesium was 142,000 metric tons in 1995. This production was about 98 percent of the rated capacity of the three U.S. magnesium production facilities. The United States has been the world's largest producer of metallic magnesium for the past five decades (Kramer, 1996). Similar to the Norwegian plant, an electrolytic process (i.e., electrolysis of magnesium chloride) is used at the plants in Texas (capacity of 65,000 kkg/yr) and Utah (capacity of 40,000 kkg/yr) to recover metallic magnesium from $MgCl_2$. However, these two facilities reportedly use seawater and lake brines as the source of magnesium, and the procedures to obtain and purify $MgCl_2$ do not involve chlorinating furnaces and carbonized pellets (Lockwood et al., 1981). A thermic process is used to recover magnesium from dolomite at the facility in Washington (capacity of 40,000 kkg/yr) (Kramer, 1995). In thermic processes, magnesium oxide (MgO), a component of calcinated dolomite, is reacted with a metal such as silicon (usually alloyed with iron) to produce metallic magnesium.

Monitoring of wastewater discharges for CDD/CDF content from U.S. magnesium production facilities has not been reported. Wastewater discharge of CDD/CDF reported for the Norwegian facility, discussed in the previous paragraphs, are not adequate to support development of wastewater emission factors for U.S. facilities because of

possible differences in the processes used to manufacture $MgCl_2$ and pollution control equipment.

Monitoring of air emissions for CDD/CDF content has recently been reported for one of the three U.S. primary magnesium production facilities, the Magnesium Corporation of America facility near Rowley, Utah. The average emission rates (for three tests) reported for the melt reactor stack and the cathode stack were 0.31 mg I-TEQ$_{DF}$/hr and 0.16 mg I-TEQ$_{DF}$/hr, respectively (Western Environmental Services and Testing, Inc., 2000). The confidence in the degree to which the one tested facility represents the emissions from the other two U.S. facilities is currently very low. Therefore, the emissions data were judged inadequate for developing at this time national emission estimates that could be included in the national inventory. However, a preliminary estimate of potential TEQ annual emissions from U.S. primary magnesium production facilities can be made by assuming that the average total emission factor for the Utah facility (i.e., 0.47 mg I-TEQ$_{DF}$/hr) measured in May of 2000 is representative of the other two facilities on a magnesium production basis. Specifically, if it is assumed that this facility operated for 24 hours per day and 365 days in 1995, then the annual release in 1995 would have been 4.1 g I-TEQ$_{DF}$. If it is further assumed that this facility operated at 98 percent of it's rated capacity of 40,000 kkg/yr, then the production-based emission factor is 105 ng I-TEQ$_{DF}$/kg of magnesium produced. Applying this emission factor to 98 percent of the industry's production capacity in 1995 (i.e., 142,000 kkg) yields an annual emission estimate of 14.6 g I-TEQ$_{DF}$ in 1995. This estimate should be regarded as a preliminary indication of possible emissions from this source category; further testing is needed to confirm the magnitude of these emissions.

7.1.3. Primary Nickel Smelting and Refining

Oehme et al. (1989) reported that certain primary nickel refining processes generate CDDs and CDFs, primarily CDFs. Although the current low-temperature process used at the Norwegian facility is estimated to result in releases to water of only 1 g I-TEQ$_{DF}$ per year, a high temperature (i.e., 800°C) $NiCl_2$ to NiO conversion process that had been used for 17 years at the facility is believed to have resulted in significant releases in earlier years based on the ppb levels of CDFs detected in aquatic sediments downstream of the facility (Oehme et al., 1989).

The only nickel mining and smelting complex in the United States is located in Oregon. This facility restarted operations in April 1995 and produced 8,290 metric tons of nickel that year. The facility had been on standby since August 1993 and had no production in 1994. The smelter has a capacity of 16,000 metric tons per year (Kuck, 1995).

Monitoring of discharges for CDD/CDF content at this one U.S. facility has not been reported. Emissions of CDD/CDF were reported for a Norwegian facility in the late 1980s, as discussed in Section 7.1.4. The emissions information contained in the Norwegian study, Oehme et al. (1989), is not adequate to support development of emission factors for the U.S. facility.

7.1.4. Primary Aluminum Smelting and Refining

No sampling of air emissions from this industry for the presence of CDD/CDFs has been reported. Lexen et al. (1993) reported that samples of filter powder and sludge from a lagoon at the only primary aluminum production plant in Sweden showed no or little CDD/CDF. A brief summary of the processes involved in primary aluminum smelting is presented in the following paragraphs.

Bauxite ore, a hydrated oxide of aluminum consisting of 30 to 56 percent alumina (Al_2O_3), is refined into alumina by the Bayer Process and the alumina is then shipped to a primary aluminum smelter for electrolytic reduction to aluminum. Electrolytic reduction of alumina occurs in shallow rectangular cells, or "pots," which are steel shells lined with carbon. Carbon electrodes (petroleum coke mixed with a pitch binder) extending into the pot serve as the anodes, and the carbon lining serves as the cathode. Three types of pots are used: prebaked anode cell, horizontal stud Soderberg anode cell, and vertical stud Soderberg anode cell. Most of the aluminum produced in the United States is produced using the prebaked cells. Molten cryolite (Na_3AlF_6) functions as both the electrolyte and the solvent for the aluminum. Aluminum is deposited at the cathode as molten metal (U.S. EPA, 1998a).

Prior to casting, the molten aluminum may be batch treated in reverberatory furnaces (like those used in secondary aluminum smelting) to remove oxides, gaseous impurities, and active metals such as sodium and magnesium. One process consists of

adding a flux of chloride and fluoride salts and then bubbling chlorine gas through the molten mixture (U.S. EPA, 1998a).

U.S. production of primary aluminum was 3.343 million metric tons in 1987 and 3.375 million metric tons in 1995. In 1995, 13 companies operated 22 primary aluminum reduction plants (USGS, 1997d, 1997e).

7.1.5. Primary Titanium Smelting and Refining

No sampling of emissions or products from this industry for CDD/CDF content has been reported. However, Bramley (1998) and the Peer Review Panel (Eastern Research Group, 1998) suggested that carbochlorination processes used in this industry may be a source of CDD/CDFs. A brief summary of the processes used in this industry is presented in the following paragraphs.

Titanium oxide ores and concentrates are chlorinated in fluidized-bed reactors in the presence of coke at 925 to 1,010°C to form titanium tetrachloride ($TiCl_4$). The $TiCl_4$ is separated from other chlorides by double distillation. The $TiCl_4$ is then either oxidized at 985°C to form pigment-grade titanium dioxide or is reduced using sodium or magnesium to form titanium sponge (i.e., metallic titanium) (Knittel, 1983). Titanium ingot is produced by melting titanium sponge or scrap or a combination of both using electron beam, plasma, and vacuum arc methods. Scrap currently supplies about 50 percent of ingot feedstock (Gambogi, 1996).

Titanium sponge is currently produced at two facilities in the United States, one in Albany, Oregon, and the other in Henderson, Nevada. In 1995, the U.S. production volume of titanium sponge was withheld to avoid disclosing company proprietary data; domestic sponge capacity was 29,500 metric tons per year. In 1987, U.S. production of titanium sponge was 17,849 metric tons. The majority of titanium dioxide (i.e., greater than 90 percent) is produced using the process described above. Titanium dioxide is produced at nine facilities in the United States. Production volumes in 1987 and 1995 were 821,000 and 1,180,000 metric tons, respectively (Gambogi, 1996; USGS, 1997f).

7.2. SECONDARY NONFERROUS METAL SMELTING

Secondary smelters primarily engage in the recovery of nonferrous metals and alloys from new and used scrap and dross. The principal metals of this industry both in

terms of volume and value of product shipments are aluminum, copper, lead, zinc, and precious metals (U.S. DOC, 1990a). Scrap metal and metal wastes may contain organic impurities such as plastics, paints, and solvents. Secondary smelting/refining processes for some metals (e.g., aluminum, copper, and magnesium) use chemicals such as NaCl, KCl, and other salts. The combustion of these impurities and chlorine salts in the presence of various types of metal during reclamation processes can result in the formation of CDDs and CDFs, as evidenced by the detection of CDDs and CDFs in the stack emissions of secondary aluminum, copper, and lead smelters (Aittola et al., 1992; U.S. EPA, 1987a, 1997b).

7.2.1. Secondary Aluminum Smelters

Secondary aluminum smelters reclaim aluminum from scrap. This recycling involves two processes—precleaning and smelting. Both processes may produce CDD/CDF emissions.

Precleaning processes involve sorting and cleaning scrap to prepare it for smelting. Cleaning processes that may produce CDD/CDF emissions use heat to separate aluminum from contaminates and other metals; these techniques are "roasting" and "sweating." Roasting uses rotary dryers with a temperature high enough to vaporize organic contaminants, but not high enough to melt aluminum. An example of roasting is the delacquering and processing of used beverage cans. Sweating involves heating aluminum-containing scrap metal to a temperature above the melting point of aluminum, but below the melting temperature of other metals such as iron and brass. The melted aluminum trickles down and accumulates in the bottom of the sweat furnace and is periodically removed (U.S. EPA, 1997b).

After precleaning, the treated aluminum scrap is smelted and refined. This usually takes place in a reverberatory furnace. Once smelted, flux is added to remove impurities. The melt is "demagged" to reduce the magnesium content of the molten aluminum by the addition of chlorine gas. The molten aluminum is then transferred to a holding furnace and alloyed to final specifications (U.S. EPA, 1997b).

CDD/CDF emissions to air have been measured at six U.S. secondary aluminum operations. Four facilities were tested in 1995 and two facilities were tested in 1992. Three of the four 1995 tests were conducted by EPA in conjunction with The Aluminum

Association for the purpose of identifying emission rates from facilities with potentially MACT-grade operations and APCD equipment; the other test performed in 1995 (U.S. EPA, 1995h) was performed by EPA. Two facilities tested by the California Air Resources Board in 1992 were reported in two confidential reports.

The first facility tested in 1995 was a top-charge melt furnace (Advanced Technology Systems, Inc., 1995). During testing, the charge material to the furnace was specially formulated to contain no oil, paint, coatings, rubber, or plastics (other than incidental amounts). The CDD/CDF emissions from such a clean charge, 0.26 ng I-TEQ$_{DF}$/kg charge material (0.27 ng TEQ$_{DF}$-WHO$_{98}$/kg), would be expected to represent the low end of the normal industry range.

The second facility operated a sweat furnace to preclean the scrap and a reverberatory furnace to smelt the precleaned aluminum (U.S. EPA, 1995h). Stack emissions were controlled by an afterburner operated at 1,450° F. The TEQ emission factor for this facility was 3.22 ng I-TEQ$_{DF}$/kg aluminum produced (3.37 ng TEQ$_{DF}$-WHO$_{98}$/kg).

The third facility employed a crusher/roasting dryer as a precleaning step, followed by a reverberatory furnace (Galson Corporation, 1995). The emissions from the two units were vented separately. The exhaust from the crusher/dryer was treated with an afterburner and a baghouse. The exhaust from the furnace passed through a baghouse with lime injection. Both stack exhausts were tested and the combined TEQ emission factor was 12.95 ng I-TEQ$_{DF}$/kg aluminum produced (13.55 ng TEQ$_{DF}$-WHO$_{98}$/kg). Because the activity level of the facility at the time of sampling was treated as confidential business information, the calculated emission factor was based on the reported typical production rates of the two operations, 26,000 lbs/hr for the crusher/dryer and 6,700 lbs/hr for the furnace.

The fourth facility operated a scrap roasting dryer followed by a sidewell reverberatory furnace (Envisage Environmental Inc., 1995). The emissions from the two units were vented separately. Exhaust from the dryer passed through an afterburner and a lime-coated baghouse. The exhaust from the furnace passed through a lime-coated baghouse. Both stack exhausts were tested and the combined TEQ emission factor was 36.03 ng I-TEQ$_{DF}$/kg of charge material (37.94 ng TEQ$_{DF}$-WHO$_{98}$/kg). Problems with the

scrap dryer were discovered after the testing was completed. Also, operating conditions during testing were reported to represent more worst-case than typical operations.

Two facilities tested by CARB in 1992 and reported in two confidential reports (CARB, 1992a, as reported in U.S. EPA, 1997b; CARB, 1992b, as reported in U.S. EPA, 1997b) were reported to have TEQ emission factors of 52.21 and 21.67 ng I-TEQ$_{DF}$/kg of scrap aluminum consumed (55.68- and 23.44-ng TEQ$_{DF}$-WHO$_{98}$/kg). One facility was equipped with a venturi scrubber; the other was assumed in U.S. EPA (1997b) to be uncontrolled.

The congener and congener group emission factors derived from these stack tests are presented in Table 7-1. The average congener and congener group profiles are presented in Figure 7-1. The average of the TEQ emission factors measured at the six tested facilities (including the facility at which a specially formatted clean charge was used) is 21.1 ng I-TEQ$_{DF}$/kg of scrap feed (22.4 ng TEQ$_{DF}$-WHO$_{98}$/kg). [Note: Although the emission factors at two of the facilities tested in 1995 are based on the output rather than input rate, the two rates are assumed, for purposes of this report, to be roughly equivalent.] Although the testing was recently conducted at U.S. facilities, a low confidence rating is assigned to this average emission factor because it is based on the results of testing at only six facilities, several of which may have more effective APCD than the other facilities in the industry.

For comparison purposes, The European Commission uses 22 ng I-TEQ$_{DF}$/kg scrap aluminum as the "typical" emission factor for the European Dioxin Inventory (Quab and Fermann, 1997). Umweltbundesamt (1996) reported stack testing results for 25 aluminum smelters/foundries in Germany. Sufficient data were provided in Umweltbundesamt (1996) to enable calculation of TEQ emission factors for 11 of the tested facilities. The calculated emission factors ranged from 0.01 to 167 ng I-TEQ$_{DF}$/kg of scrap feed. Three facilities had emission factors exceeding 100 ng I-TEQ$_{DF}$/kg, and two facilities had emission factors less than 1 ng I-TEQ$_{DF}$/kg. The mean emission factor for the 11 facilities was 42 ng I-TEQ$_{DF}$/kg.

An approximate total of 727,000 metric tons of scrap aluminum were consumed by 67 secondary aluminum smelters in 1987 (U.S. DOC, 1995c). In 1995, consumption of scrap aluminum by the 76 facilities that compose the secondary aluminum smelting industry had nearly doubled to 1.3 million metric tons (USGS, 1997a; The Aluminum

Association, 1997). A high confidence rating is assigned to these production estimates, because they are based on government survey data. Applying the I-TEQ$_{DF}$ emission factor of 21.1 ng TEQ/kg of scrap feed to these consumption values yields estimated annual emissions of 15.3 g I-TEQ$_{DF}$ in 1987 and 27.4 g I-TEQ$_{DF}$ in 1995. Applying the TEQ$_{DF}$-WHO$_{98}$ emission factor of 22.4 ng TEQ/kg to the consumption values yields estimated annual emissions of 16.3 g TEQ$_{DF}$-WHO$_{98}$ in 1987 and 29.1 g TEQ$_{DF}$-WHO$_{98}$ in 1995.

It should be noted that a significant amount of scrap aluminum is also consumed by other segments of the aluminum industry. However, this scrap is generally scrap from metal manufacturing processes, including metal and alloy production (e.g., borings, turnings, and dross), rather than old scrap that results from consumer products (e.g., cans, radiators, auto shredders). Integrated aluminum companies consumed 1.4 million metric tons of scrap aluminum in 1995, and independent mill fabricators consumed 0.68 million metric tons (USGS, 1997a).

7.2.2. Secondary Copper Smelters

Secondary copper smelting is part of the scrap copper, brass, and bronze reprocessing industry. Brass is an alloy of copper and zinc; bronze is an alloy of copper and tin. Facilities in this industry fall into three general classifications: secondary smelting, ingot making, and remelting. Similar process equipment may be used at all three types of facilities, so the distinguishing features are not immediately apparent (U.S. EPA, 1994g).

The feature that distinguishes secondary smelters from ingot makers and remelters is the extent to which pyrometallurgical purification is performed. A typical charge at a secondary smelter may contain from 30 to 98 percent copper. The secondary smelter upgrades the material by reducing the quantity of impurities and alloying materials, thereby increasing the relative concentration of copper. This degree of purification and separation of the alloying constituents does not occur at ingot makers and remelters. Feed material to a secondary copper smelter is a mixture of copper-bearing scrap such as tubing, valves, motors, windings, wire, radiators, turnings, mill scrap, printed circuit boards, telephone switching gear, and ammunition casings. Nonscrap items like blast furnace slags and drosses from ingot makers or remelters may represent a portion of the charge. The secondary smelter operator uses a variety of processes to separate the

alloying constituents. Some purify the scrap in the reductive atmosphere of a blast furnace. The charge may be subsequently purified in the oxidizing atmosphere of a converter. Other secondary smelters perform all purification by oxidation in top-blown rotary converters or in reverberatory furnaces (U.S. EPA, 1994g).

The ingot makers blend and melt scrap copper, brass, and bronze of various compositions to produce a specification brass or bronze ingot. When necessary, the ingot makers add ingots of other metals (e.g., zinc or tin) to adjust the metallurgy of the final product. The feed materials for ingot makers contain relatively high amounts of copper. Examples of feed materials include copper tubing, valves, brass and bronze castings, ammunition shell casings, and automobile radiators. "Fire-refined" anode copper or cathode copper may also be charged. Items such as motors, telephone switchboard scrap, circuit board scrap, and purchased slags are not used by ingot makers. The reductive step (melting in a reducing atmosphere, as in a blast furnace) that some secondary smelters employ is not used by ingot makers. Ingot makers do, however, use some of the other types of furnaces used by secondary smelters, including direct-fired converters, reverberatory furnaces, and electric induction furnaces (U.S. EPA, 1994g).

Remelting facilities do not conduct any substantial purification of the incoming feeds. These facilities typically just melt the charge and cast or extrude a product. The feeds to a remelter are generally alloy material of approximately the desired composition of the product (U.S. EPA, 1994g).

Emissions Data

Stack emissions of CDD/CDFs from a secondary copper smelter were measured by EPA during 1984–1985 as part of the National Dioxin Tier 4 Study (U.S. EPA, 1987a). The facility chosen for testing was estimated to have high potential for CDD/CDF emissions because of the abundance of chlorinated plastics in the feed. This facility ceased operations in 1986. The tested facility was chosen for testing by EPA because the process technology and air pollution control equipment in place were considered typical for the source category. Copper and iron-bearing scrap were fed in batches to a cupola blast furnace, which produced a mixture of slag and black copper. Four to 5 tons of metal-bearing scrap were fed to the furnace per charge, with materials typically being charged 10 to 12 times per hour. Coke fueled the furnace and represented approximately

14 percent by weight of the total feed. During the stack tests, the feed consisted of electronic telephone scrap and other plastic scrap, brass and copper shot, iron-bearing copper scrap, precious metals, copper-bearing residues, refinery by-products, converter furnace slag, anode furnace slag, and metallic floor-cleaning material. The telephone scrap made up 22 percent by weight of the feed and was the only scrap component that contained plastic materials. Oxygen-enriched combustion air for combustion of the coke was blown through tuyeres (nozzles) at the bottom of the furnace. At the top of the blast furnace were four natural gas–fired afterburners to aid in completing combustion of the exhaust gases. Fabric filters controlled particulate emissions, and the flue gas then was discharged into a common stack. The estimated emission factors derived for this site are presented in Table 7-2. The emission factors are based on the total weight of scrap fed to the furnace. The TEQ emission factor, based on the measured congener and congener group emission factors, is 779 ng I-TEQ$_{DF}$/kg of scrap metal smelted (810 ng TEQ$_{DF}$WHO$_{98}$/kg). Figure 7-2a presents the congener group profile based on these emission factors.

In 1992, stack testing of the blast furnace emissions of a secondary smelter located in Philadelphia, Pennsylvania (Franklin Smelting and Refining Co.), was conducted by Applied Geotechnical & Environmental Services Corporation (AGES, 1992). Similar to the facility tested by EPA in 1984–1985, this facility processed low-purity copper-bearing scrap, telephone switch gear, and slags, as well as higher copper content materials (U.S. EPA, 1994g). The facility used a blast (cupola-type) furnace coupled with a pair of rotary converters to produce blister copper. The blast furnace used coke as both the fuel and the agent to maintain a reducing atmosphere. The black copper/slag mixture from the blast furnace was charged to the rotary converters for further refining with the aid of oxygen, sand, and oak logs (AGES, 1992; U.S. EPA, 1994g). The APCD equipment installed on the blast furnace included an afterburner, cooling tower, and baghouse. During testing, the afterburner was reported to be operating erratically and was particularly low during one of the two sampling episodes. Stack gas flow was also low during both sampling episodes because one or more baghouse compartments were inoperable (AGES, 1992). The estimated emission factors derived for this site from the AGES results are presented in Table 7-2. The emission factors are based on the total weight of scrap fed to the blast furnace. The TEQ emission factor was 16,618 ng I-

TEQ$_{DF}$/kg of scrap (16,917 ng TEQ$_{DF}$-WHO$_{98}$/kg). Figure 7-2b presents the congener and congener group profiles based on these emission factors.

In 1991, stack testing of the rotary furnace stack emissions of a secondary smelter located in Alton, Illinois (Chemetco, Inc.) was conducted by Sverdrup Corp. (1991). The Chemetco facility used four tap down rotary (i.e., oxidizing) furnaces. Furnace process gas emissions were controlled by a primary quencher and a venturi scrubber. The feed was relatively high-purity copper scrap containing minimal, if any, plastics. The same manufacturing process and APCD equipment were in place in 1987 and 1995 (U.S. EPA, 1994g). Because this facility operated under oxidizing rather than reducing conditions and processed relatively high-purity scrap, the potential for CDD/CDF formation and release was expected to be dramatically different than that of the two tested facilities reported above. The estimated emission factors derived for this site from the results of Sverdrup Corp. (1991) are presented in Table 7-2. The emission factors are based on the total weight of scrap feed to the furnace. The TEQ emission factor was 3.60 ng I-TEQ$_{DF}$/kg of scrap (3.66 ng TEQ$_{DF}$-WHO$_{98}$/kg).

Only limited data on emissions from secondary copper smelters are reported in the European Dioxin Inventory (LUA, 1997). I-TEQ$_{DF}$ emission factors reported for German shaft furnaces/converters and reverberatory furnaces range from 5.6 to 110 ng I-TEQ$_{DF}$/kg and from 0.005 to 1.56 ng I-TEQ$_{DF}$/kg. Emission factors reported for two "smelter and casting furnaces" in Sweden in which "relatively clean scrap is used as input" are 0.024 and 0.04 ng I-TEQ$_{DF}$/kg. A smelter in Austria is reported to have an I-TEQ emission factor of 4 ng I-TEQ$_{DF}$/kg. The minimum, typical, and maximum default emission factors selected in LUA (1997) are 5, 50, and 400 ng I-TEQ$_{DF}$/kg, respectively.

Activity Level Information

In 1987, four secondary copper smelters were in operation: Franklin Smelting and Refining Co. (Philadelphia, PA), Chemetco (Alton, IL), Southwire Co. (Carrollton, GA), and a facility located in Gaston, SC, that was owned by American Telephone and Telegraph (AT&T) until 1990 when it was purchased by Southwire Co. In 1987, estimated smelter capacities were 13,600 kkg for the Franklin Smelting and Refining Co. facility, 120,000 kkg for the Chemetco facility, 48,000 kkg for the Southwire Co. facility, and 85,000 kkg for the AT&T facility (Edelstein, 1999). In 1995, only three of these four facilities were in

operation. The Southwire facility in Gaston (previously owned by AT&T) was closed in January 1995. The Franklin facility subsequently ceased operations in August 1997. Estimated smelter capacities in 1995 were 16,000 kkg for the Franklin Smelting and Refining Co. facility, 135,000 kkg for the Chemetco facility, and 92,000 kkg for the Southwire Co. facility (Edelstein, 1999).

Emission Estimates

Although little research has been performed to define the CDD/CDF formation mechanism(s) in secondary copper smelting operations, two general observations have been made (Buekens et al., 1997). The presence of chlorinated plastics in copper scraps used as feed to the smelters is believed to increase the CDD/CDF formation. Second, the reducing or pyrolytic conditions in blast furnaces can lead to high CDD/CDF concentrations in the furnace process gases. As noted in "Emission Data," above, two of the U.S. facilities that have been tested (i.e., U.S. EPA, 1987a; AGES, 1992) each had the following characteristics. Both processed low-purity scrap containing significant quantities of plastics, and both facilities used blast furnaces. The APCD equipment at both facilities consisted of an afterburner, cooling tower (Franklin facility only), and a baghouse (U.S. EPA, 1994g). The other tested U.S. facility (i.e., Sverdrup, 1991) used oxidizing rather than reducing conditions and processed relatively high purity scrap.

For purposes of this report, the TEQ emission factor measured at the Franklin Smelting and Refining Co. facility in 1992 is considered to be representative of the TEQ emission factor in 1987 and 1995. Combining this emission factor (16,618 ng I-TEQ$_{DF}$/kg scrap feed, or 16,917 ng TEQ$_{DF}$-WHO$_{98}$/kg) with the estimated smelter capacities (data are not available on the amount of scrap processed) for this facility in 1987 (13,600 kkg) and 1995 (16,000 kkg) yields I-TEQ$_{DF}$ emission estimates of 226 g (230 g TEQ$_{DF}$-WHO$_{98}$) in 1987 and 266 g (271 g TEQ$_{DF}$-WHO$_{98}$) in 1995. This facility ceased operations in 1997.

Similarly, for purposes of this report, the TEQ emission factor for the Chemetco, Inc., facility is considered to be representative of the TEQ emission factor in 1987 and 1995. Combining this emission factor (3.60 ng I-TEQ$_{DF}$/kg scrap feed or 3.66 ng TEQ$_{DF}$-WHO$_{98}$/kg) with the estimated smelter capacities (data are not available on the amount of scrap processed) for this facility in 1987 (120,000 kkg) and 1995 (135,000 kkg) yields I-

TEQ$_{DF}$ estimates of 0.43 g (0.44 g TEQ$_{DF}$-WHO$_{98}$) in 1987 and 0.49 g (0.49 g TEQ$_{DF}$-WHO$_{98}$) in 1995.

The facility in Gaston, South Carolina, was in operation during 1987, but not in 1995. Prior to 1990, when this facility was owned by AT&T, the plant processed a great deal of high-plastics-content scrap (such as whole telephones). This scrap was fed to a pyrolysis unit prior to entering the blast furnace. In addition to a blast furnace, the facility also had an oxidizing reverberatory furnace for processing higher purity scrap. The facility had separate baghouses for the blast furnace, the converters, and the reverberatory furnace (U.S. EPA, 1994g). Because this facility processed low-purity, high-plastics-content scrap in 1987, and presumably processed much of this in the reducing atmosphere of a pyrolysis unit and blast furnace, the average of the TEQ emission factors for the Tier 4 (U.S. EPA, 1987a) and Franklin facilities (8,700 ng I-TEQ$_{DF}$/kg, or 8,860 ng TEQ$_{DF}$-WHO$_{98}$/kg) was used to estimate potential emissions in 1987 of 740 g I-TEQ$_{DF}$ or 753 g TEQ$_{DF}$-WHO$_{98}$ (assuming an activity level of 85,000 kkg). This activity level is the estimated capacity of the facility; data are not available on the amount of scrap processed.

The Southwire facility in Carrollton, Georgia, had both a blast furnace and a reverberatory furnace. In 1992, approximately 50 percent of incoming scrap was processed in each furnace (U.S. EPA, 1994g). Unlike the two tested facilities and the Gaston facility, the Southwire facility stopped processing plastic-coated scrap in the 1970s. In addition, this facility had a more complex APCD system, which may have reduced the formation and release of CDD/CDFs. The blast furnace process gases passed through an afterburner (1,600°F), U-tube coolers, and an evaporative spray system before entering the baghouse at a temperature of 225 to 375°F. For these reasons, EPA has determined that the existing emissions data for secondary smelters cannot reliably be used to generate a quantitative estimate of potential emissions during 1987 and 1995 for this facility.

A high confidence rating is assigned to the production estimates, because they are based on government survey data. A low confidence rating is assigned to the TEQ emission estimates because they are based on limited measurements made at three smelters, one of which was not in operation in 1987 or 1995.

It should be noted that a significant amount of scrap copper is consumed by other segments of the copper industry. In 1995, brass mills and wire-rod mills consumed 886,000 metric tons of copper-based scrap; foundries and miscellaneous manufacturers consumed 71,500 metric tons (USGS, 1997a). As noted above, however, these facilities generally do not conduct any significant purification of the scrap. Rather, the scrap consumed is already of alloy quality and processes employed typically involve only melting, casting and extruding. Thus, the potential for formation of CDD/CDFs is expected to be much less than the potential during secondary smelting operations.

7.2.3. Secondary Lead Smelters

The secondary lead smelting industry produces elemental lead through the chemical reduction of lead compounds in a high-temperature furnace (1,200 to 1,260° C). Smelting is performed in reverberatory, blast, rotary, or electric furnaces. Blast and reverberatory furnaces are the most common types of smelting furnaces used by the 23 facilities that make up the current secondary lead smelting industry in the United States. Of the 45 furnaces at these 23 facilities, 15 are reverberatory furnaces, 24 are blast furnaces, 5 are rotary furnaces, and 1 is an electric furnace. The one electric furnace and 11 of the 24 blast furnaces are co-located with reverberatory furnaces, and most share a common exhaust and emissions control system (U.S. EPA, 1994h).

Furnace charge materials consist of lead-bearing raw materials, lead-bearing slag and drosses, fluxing agents (blast and rotary furnaces only), and coke. Scrap motor vehicle lead-acid batteries represent about 90 percent of the lead-bearing raw materials at a typical lead smelter. Fluxing agents consist of iron, silica sand, and limestone or soda ash. Coke is used as fuel in blast furnaces and as a reducing agent in reverberatory and rotary furnaces. Organic emissions from co-located blast and reverberatory furnaces are more similar to the emissions of a reverberatory furnace than the emissions of a blast furnace (U.S. EPA, 1994h).

The total annual production capacity of the 23 companies that make up the U.S. lead smelting industry is 1.36 million metric tons. Blast furnaces not co-located with reverberatory furnaces account for 21 percent of capacity (or 0.28 million metric tons). Reverberatory furnaces and blast and electric furnaces co-located with reverberatory furnaces account for 74 percent of capacity, or 1.01 million metric tons. Rotary furnaces

account for the remaining 5 percent of capacity, or 0.07 million metric tons (U.S. EPA, 1994h). Actual production volume statistics by furnace type are not available. However, if it is assumed that the total actual production volume of the industry, 0.97 million metric tons in 1995 (USGS, 1997a) and 0.72 million metric tons in 1987 (U.S. EPA, 1994h), reflect the production capacity breakdown by furnace type, then the estimated actual production volumes of blast furnaces (not co-located), reverberatory and co-located blast/ electric and reverberatory furnaces, and rotary furnaces were 0.20, 0.72, and 0.05million metric tons, respectively, in 1995, and 0.15, 0.53, and 0.04 million metric tons, respectively, in 1987. In 1987, the industry consisted of 24 facilities.

CDD/CDF emission factors can be estimated for lead smelters using the results of emission tests recently performed by EPA at three smelters (a blast furnace, a co-located blast/reverberatory furnace, and a rotary kiln furnace) (U.S. EPA, 1992e, 1995d, 1995e). The air pollution control systems at the three tested facilities consisted of both baghouses and scrubbers. Congener-specific measurements were made at both APCD exit points at each facility. Table 7-3 presents the congener and congener group emission factors from the baghouse and the scrubber for each site. Figure 7-3 presents the corresponding profiles for the baghouse emissions from the tested blast furnace and reverberatory furnace. Although all 23 smelters employ baghouses, only 9 employ scrubber technology. Facilities that employ scrubbers account for 14 percent of the blast furnace (not co-located) production capacity, 52 percent of the reverberatory and co-located furnace production capacity, and 57 percent of the rotary furnace production capacity. TEQ emission factors (ng TEQ/kg lead processed) from the reported data for each of the three furnace configurations are presented below as a range reflecting the presence or absence of a scrubber.

Emission factors when nondetected values are set equal to zero:
- Blast furnace:
    - 0.63 to 8.31 ng I-TEQ$_{DF}$/kg lead produced
    - 0.64 to 8.81 ng TEQ$_{DF}$-WHO$_{98}$/kg lead produced
- Reverberatory/co-located furnace:
    - 0.05 to 0.41 ng I-TEQ$_{DF}$/kg lead produced
    - 0.05 to 0.42 ng TEQ$_{DF}$-WHO$_{98}$/kg lead produced

- Rotary furnace:
  - 0.24 to 0.66 ng I-TEQ$_{DF}$/kg lead produced
  - 0.24 to 0.66 ng TEQ$_{DF}$-WHO$_{98}$/kg lead produced

If it is assumed that these ranges of emission rates are representative of those at nontested facilities with the same basic furnace configuration and presence or absence of scrubbers, then combining these emission rate ranges with the estimated volume of secondary lead production derived above and the percentage of each configuration type that have scrubbers, yields the following estimated air emissions in units of grams TEQ per year:

Configuration	Estimated Annual TEQ Emissions (g TEQ)*			
	Ref. Year 1995		Ref. Year 1987	
	I-TEQ$_{DF}$	TEQ$_{DF}$-WHO$_{98}$	I-TEQ$_{DF}$	TEQ$_{DF}$-WHO$_{98}$
Blast furnaces w/scrubbers	0.018	0.018	0.013	0.013
Blast furnaces w/o scrubbers	1.429	1.515	1.072	1.136
Reverberatory furnaces w/ scrubbers	0.019	0.019	0.014	0.014
Reverberatory furnaces w/o scrubbers	0.142	0.145	0.104	0.106
Rotary furnaces w/ scrubbers	0.019	0.019	0.015	0.015
Rotary furnaces w/o scrubbers	0.005	0.005	0.004	0.004
	1.632	1.721	1.223	1.288

* Calculated using emission factors based on nondetected values set equal to zero.

A medium confidence rating is assigned to the emission factors derived above because stack test data were available for 3 of the 23 smelters in the United States (of which only 16 were in operation as of December 1993), and the stack test data used represent the three major furnace configurations. The activity level estimate has been assigned a medium confidence rating because, although it is based on a U.S. Department of Commerce estimate of total U.S. production, no production data were available on a furnace type or furnace configuration basis.

7.3. PRIMARY FERROUS METAL SMELTING/REFINING

Iron is manufactured from its ores (i.e., magnetic pyrites, magnetite, hematite, and carbonates of iron) in a blast furnace, and the iron obtained from this process is further refined in steel plants to make steel. The primary production of iron and steel involves two operations identified by European researchers as potential emission sources of CDD/CDFs: iron ore sinter production and coke production. Each of these potential sources is discussed in the following subsections.

7.3.1. Sinter Production

At some iron manufacturing facilities, iron ores and waste iron-bearing materials undergo sintering to convert the materials to usable feed for the blast furnace. In the sintering process, iron ore fines and waste materials are mixed with coke fines, and the mixture is placed on a grate, which is then heated to a temperature of 1,000–1,400°C. The heat generated during combustion sinters the small particles. Iron-bearing dusts and slags from processes in the steel plant are the types of iron-bearing waste materials used as a feed mix for the sinter plant (Knepper, 1981; Capes, 1983; U.S. EPA, 1995b).

Several European investigators have reported that iron ore sinter plants are major sources of airborne emissions CDD/CDFs (Rappe, 1992b; Lexen et al., 1993; Lahl, 1993, 1994). Lahl (1993, 1994) reports that the management practice of recycling dusts and scraps from other processes in the steel plant into the sintering plant introduces traces of chlorine and organic compounds that generate the CDD/CDFs found in these plants.

Organic compounds that are potential precursors to CDD/CDF formation come primarily from the oil, which is found in mill scale, as well as some blast furnace sludges that are used as part of the sinter feed mixture. Most U.S. plants limit the amount of oil because it increases emissions of volatile organic compounds (VOCs) and may create a fire hazard. In addition, plants with baghouses must limit the oil content because the oil tends to blind the fabric filters. Typical oil contents of the feed at U.S. sinter plants range from 0.1 to 0.75 percent (Calcagni et al., 1998).

Sinter plants in Sweden were reported to emit up to 3 ng I-TEQ$_{DF}$/Nm^3 stack gas or 2 to 4 g I-TEQ$_{DF}$/yr per plant to the air (Rappe, 1992b; Lexen et al., 1993). Bremmer et al. (1994) reported the results of stack testing at three iron ore sintering plants in The Netherlands. One facility equipped with wet scrubbers had an emission factor of 1.8 ng

I-TEQ$_{DF}$/dscm (at 11 percent O$_2$). The other two facilities, both equipped with cyclones, had emission factors of 6.3 and 9.6 ng I-TEQ$_{DF}$/dscm (at 7 percent O$_2$). Lahl (1993, 1994) reports stack emissions for sintering plants in Germany (after passage through mechanical filters and electrostatic precipitators) ranging from 3 to 10 ng I-TEQ$_{DF}$/Nm^3. A recent compilation of emission measurements by the German Federal Environmental Agency indicates stack emission concentrations ranging from 1.2 to 60.6 ng I-TEQ$_{DF}$/m^3 (at 7 percent O$_2$); the majority of emissions in 1996 were around 3 ng I-TEQ$_{DF}$/m^3 (Umweltbundesamt, 1996).

EPA conducted tests at two of the nine U.S. sinter plants operating in 1997 in order to quantify emissions of CDD/CDFs (Calcagni et al., 1998). In choosing representative plants for testing, EPA considered a variety of issues, including the types and quantities of feed materials, types of emission controls, and the oil content of the sinter feed. EPA decided to test a plant with a baghouse and a plant with a venturi (or wet) scrubber. Baghouses and wet scrubbers are the principal air pollution control devices employed to control emissions from the sinter plant windbox. Four plants used a baghouse and five plants used a wet scrubber. The types of feed materials and oil content at the two selected plants were determined to be representative of other plants in the industry. Sampling was performed over 3 days (4 hours per day) at each plant.

The average CDD/CDF TEQ concentrations measured in the stack emissions were 0.19 ng I-TEQ$_{DF}$/Nm^3 and 0.81 ng I-TEQ$_{DF}$/Nm^3 for the wet scrubber and baghouse, respectively. The corresponding TEQ emission factors are 0.55 ng I-TEQ$_{DF}$/kg sinter (0.62 ng TEQ$_{DF}$-WHO$_{98}$/kg) and 4.14 ng I-TEQ$_{DF}$/kg sinter (4.61 ng TEQ$_{DF}$-WHO$_{98}$/kg), respectively, for wet scrubbers and baghouses. These emission factors are assigned a high rating because they are based on recent EPA testing at two facilities considered by EPA to be representative of both current and 1995 standard industry practices. Congener-specific emission factors for these two facilities are presented in Table 7-4. Figure 7-4 presents the congener profiles for these facilities. Although concentrations were higher from the baghouse than from the scrubber, both concentrations are low relative to what had been reported from testing at German, Dutch, and Swedish sinter plants. These differences may be due to differences between the operation or APCD of U.S. sinter plants and the tested European plants. Most of the U.S. integrated iron and steel plants, including those with sinter plants, have eliminated the purchase and use of

chlorinated organics in their facilities. Their rolling mill oils (lubricants and hydraulic fluids) do not contain chlorinated compounds. In addition, routine analysis of waste materials going to the sinter plant have not detected any chlorinated solvents. Finally, none of the U.S. plants currently use an electrostatic precipitator to control emissions from the sinter windbox (Calcagni et al., 1998).

In 1996 (data were not readily available for 1995), 11 sintering plants were operating in the United States, with a total annual production capacity of about 17.6 million metric tons (Metal Producing, 1996). Over the past two decades, the size of this industry has decreased dramatically. In 1982, 33 facilities operated with a combined total capacity of 48.3 million metric tons (U.S. EPA, 1982b). The nine currently operating U.S. sinter plants have a combined capacity of 15.6 million metric tons (Calcagni et al., 1998). In 1987, sinter consumption by iron and steel plants was 14.5 million metric tons (AISI, 1990); in 1995, consumption was 12.4 million metric tons (Fenton, 1995), or approximately 70 percent of production capacity, assuming that production capacity in 1995 was the same as in 1996. These activity level estimates are assigned a confidence rating of medium.

As shown in Table 7-5, 59 percent of current (i.e., 1998) sinter production capacity is at facilities with wet scrubbers and 41 percent is at facilities with baghouses. If it is assumed that these same relative proportions of APCD to production capacity existed in 1995, and it is assumed that actual production in 1995 was equal to sinter consumption at iron and steel plants (i.e., 12.4 million metric tons), then estimated TEQ emissions from wet scrubber-equipped facilities were 4.0 g I-TEQ$_{DF}$ (4.5 g TEQ$_{DF}$-WHO$_{98}$) and emissions from baghouse-equipped facilities were 21.0 g I-TEQ$_{DF}$ (23.4 g TEQ$_{DF}$-WHO$_{98}$), for a total of 25.1 g I-TEQ$_{DF}$ (28.0 g TEQ$_{DF}$-WHO$_{98}$). These emission estimates are assigned an overall medium confidence rating on the basis of the medium rating for the activity level estimates.

If these same assumptions are applied to the 1987 sinter consumption rate of 14.5 million metric tons, then estimated TEQ emissions from wet scrubber-equipped facilities were 4.7 g I-TEQ$_{DF}$ (5.3 g TEQ$_{DF}$-WHO$_{98}$) and emissions from baghouse-equipped facilities were 24.6 g I-TEQ$_{DF}$ (27.4 g TEQ$_{DF}$-WHO$_{98}$), for a total of 29.3 g I-TEQ$_{DF}$ (32.7 g TEQ$_{DF}$-WHO$_{98}$). These emission estimates are less certain than the estimates for 1995 because of uncertainties concerning actual APCD in place in 1987 and content of waste feed (i.e.,

oil content and presence of chlorinated organics in the oil) at that time. Consequently, a low confidence rating is assigned to the emission factor.

7.3.2. Coke Production

Coke is the principal fuel used in the manufacture of iron and steel. Coke is the solid carbonaceous material produced by the destructive distillation of coal in high-temperature ovens. No testing of CDD/CDF emissions from U.S. coke facilities has been reported. However, at a facility in The Netherlands, Bremmer et al. (1994) measured a CDD/CDF emission rate to air during the water quenching of hot coke of 0.23 ng I-TEQ_{DF}/kg of coal consumed. Minimal CDD/CDF air emissions, 0.002 ng I-TEQ_{DF}/kg of coal, were estimated by Bremmer et al. (1994) for flue gases generated during the charging and emptying of the coke ovens.

In 1995, an estimated 30 million metric tons of coal were consumed by coke plants in the United States (EIA, 1997b). No testing of CDD/CDF emissions from U.S. coke plants has been reported upon which to base an estimate of national emissions. The limited data available were thus judged inadequate for developing national emission estimates that could be included in the national inventory. However, a preliminary estimate of potential TEQ annual emissions from U.S. coke plants can be made by combining the consumption value of 30 million metric tons and the emission factor reported by Bremmer et al. (1994) for a Dutch coke plant (0.23 ng I-TEQ_{DF}/kg of coal consumed). This calculation yields an annual emission of 6.9 g I-TEQ_{DF} in 1995. This estimate should be regarded as a preliminary indication of possible emissions from this source category; further testing is needed to confirm the true magnitude of these emissions.

7.4 SECONDARY FERROUS METAL SMELTING/REFINING

Electric arc furnaces (EAFs) have been reported to be sources of CDD/CDF emissions in Europe; no testing has been reported at U.S. facilities. EAFs are used to produce carbon and steel alloys primarily from scrap material. The production of steel in an EAF is a batch process, and the input material is typically 100 percent scrap. Scrap, alloying agents, and fluxing materials are loaded into the cylindrical, refractory-lined EAF, and then carbon electrodes are lowered into the EAF. The current of the opposite polarity

electrodes generates heat between the electrodes and through the scrap. Processing time of a batch ranges from about 1.5 to 5 hours to produce carbon steel and from 5 to 10 hours to produce alloy steel (U.S. EPA, 1995b).

The melting of scrap ferrous material contaminated with metalworking fluids and plastics that contain chlorine provides the conditions conducive to formation of CDD/CDFs. Tysklind et al. (1989) studied the formation and releases of CDD/CDFs at a pilot 10 ton electric furnace in Sweden. Scrap ferrous metal feedstocks containing varying amounts of chlorinated compounds (i.e., PVC plastics, cutting oils, or $CaCl_2$) were charged into the furnace under different operating conditions (i.e., continuous feed, batch feed into the open furnace, or batch feed through the furnace lid). During continuous charging operations, the highest emissions, 1.5 ng Nordic TEQ/dry Nm^3 (i.e., after a baghouse filter), were observed with a feedstock consisting of scrap metal with PVC plastics (1.3 g of chlorine per kg of feedstock). This emission equates to 7.7 ng Nordic TEQ/kg of feedstock. The highest emissions during batch charging also occurred when the scrap metal with PVC plastic was combusted (0.3 ng Nordic TEQ/dry Nm^3 or 1.7 ng Nordic TEQ/kg of feedstock). Much lower emissions (0.1 ng Nordic TEQ/dry Nm^3 or 0.6 ng Nordic TEQ/kg of feedstock) were observed when scrap metal with cutting oils that contained chlorinated additives (0.4 g of chlorine per kg of feedstock) was melted. Although these cutting oil-related emissions were not significantly different than the emissions observed from the melting of no-chlorine scrap metal, relatively high levels of CDD/CDF (i.e., 110-ng Nordic TEQ/dry Nm^3) were detected in flue gases prior to the baghouse. The congener profiles of raw flue gas samples (i.e., prior to APCD) showed that CDFs, rather than CDDs, were predominant in all three feedstock types. The congener profile from the test burn with PVC-containing feedstock showed a higher chlorinated congener content than was observed with the other feedstocks.

Eduljee and Dyke (1996) used a range of 0.7 to 10 ng I-TEQ$_{DF}$/kg of scrap feed to estimate national emissions for the United Kingdom. The range was assumed to be representative of no-chlorine and high-chlorine operations. However, Eduljee and Dyke (1996) provided little information on the supporting emission test studies (i.e., tested facility operational materials, feed rates, congener-specific emission rates).

Umweltbundesamt (1996) reported stack testing results for a variety of EAFs in Germany. Sufficient data were provided in Umweltbundesamt (1996) to enable

calculation of TEQ emission factors for six of the tested facilities. Two facilities had emission factors exceeding 1 ng I-TEQ$_{DF}$/kg of scrap processed, and two facilities had emission factors less than 0.1 ng I-TEQ$_{DF}$/kg of scrap. The mean emission factor was 1.15 ng I-TEQ$_{DF}$/kg of scrap. The TEQ concentrations in the stack gases at these facilities (corrected to 7 percent O$_2$) ranged from less than 0.1 to 1.3 ng I-TEQ$_{DF}$/m^3.

In 1995, electric arc furnaces accounted for 40.4 percent of U.S. steel production (or 38.4 of the total 95.2 million metric tons of raw steel produced) (Fenton, 1996). No testing of CDD/CDF emissions from U.S. electric arc furnaces has been reported upon which to base an estimate of national emissions, and the limited European data available were thus judged inadequate for developing national emission estimates that could be included in the national inventory. However, a preliminary estimate of potential TEQ annual emissions from U.S. electric arc furnaces can be made by combining the production estimate of 38.4 million metric tons and the average emission factor derived from the data reported in Umweltbundesamt (1996) for six EAFs (i.e., 1.15 ng I-TEQ$_{DF}$/kg scrap). This calculation yields an annual emission estimate of 44.3 g I-TEQ$_{DF}$ in 1995. This estimate should be regarded as a preliminary indication of possible emissions from this source category; further testing is needed to confirm the true magnitude of these emissions.

7.5. FERROUS FOUNDRIES

Ferrous foundries produce high-strength iron and steel castings used in industrial machinery, pipes, and heavy transportation equipment. Iron and steel castings are solid solutions of iron, carbon, and various alloying materials. Castings are produced by injecting or pouring molten metal into cavities of a mold made of sand, metal, or ceramic material. Metallic raw materials are pig iron, iron and steel scrap, foundry returns, and metal turnings (U.S. EPA, 1995b, 1997b).

The melting process takes place primarily in cupola (or blast) furnaces and to a lesser extent in electric arc furnaces. About 70 percent of all iron castings are produced using cupolas, although steel foundries rely almost exclusively on EAFs or induction furnaces for melting. The cupola is typically a vertical, cylindrical steel shell with either a refractory-lined or water-cooled inner wall. Charges are loaded at the top of the unit; the iron is melted as it flows down the cupola, and is removed at the bottom. (EAFs are

discussed in Section 7.4.3.) Electric induction furnaces are batch-type furnaces in which the charge is melted by a fluctuating electromagnetic charge produced by electrical coils surrounding the unit (U.S. EPA, 1995b, 1997b).

Iron and steel foundries, particularly those using EAFs, are highly dependent on iron and steel scrap. Of the estimated 72 million metric tons of iron and steel scrap consumed by the iron and steel industry in 1995, 25 percent (or 18 million metric tons) were used by ferrous foundries. The other 75 percent were used by primary ferrous metal smelters (principally those using EAFs) (USGS, 1997b). Thus, foundries face the same potential for CDD/CDF emissions as EAFs because of their use of scrap that contains chlorinated solvents, plastics, and cutting oils. (See Section 7.4.3.) The potential for formation and release of CDD/CDFs during the casting process (i.e., pouring of molten metal into molds and cores made of sand and various organic binders and polymers) is not known.

The results of emissions testing have been reported for only one U.S. ferrous foundry (CARB, 1993a, as reported in U.S. EPA, 1997b). The tested facility consisted of a batch-operated, coke-fired cupola furnace charged with pig iron, scrap iron, scrap steel, coke, and limestone. Emission control devices operating during the testing were an oil-fired afterburner and a baghouse. The congener and congener group emission factors derived from the testing are presented in Table 7-6. The calculated TEQ emission factor for this set of tests is 0.37 ng I-TEQ$_{DF}$/kg of metal charged to the furnace (0.42 ng TEQ$_{DF}$-WHO$_{98}$).

Umweltbundesamt (1996) reported stack testing results for a variety of ferrous foundries in Germany. Sufficient data were provided in Umweltbundesamt (1996) to enable calculation of TEQ emission factors for eight of the tested facilities. Three facilities had emission factors exceeding 1 ng I-TEQ$_{DF}$/kg of metal charge, and four facilities had emission factors less than 0.1 ng I-TEQ$_{DF}$/kg of metal charge. The emission factors span more than four orders of magnitude. The mean emission factor was 1.26 ng I-TEQ$_{DF}$/kg of metal feed.

Because of the wide range of emissions for the tested German foundries reported in Umweltbundesamt (1996), the confidence in the degree to which the one tested U.S. facility represents the mean emission factor for the approximate 1,000 U.S. foundries is considered very low. Therefore, the limited data available were judged inadequate for developing national emission estimates that could be included in the national inventory.

However, a preliminary estimate of potential TEQ annual emissions from U.S. ferrous foundries can be made by combining the mean emission factor derived from the data reported in Umweltbundesamt (1996) for eight foundries (1.26 ng I-TEQ$_{DF}$/kg of metal feed) with an activity level for U.S. foundries. In 1995, U.S. shipments from the approximate 1,000 U.S. ferrous foundries were 13.9 million metric tons, of which about 90 percent were iron castings and 10 percent were steel castings (Fenton, 1996). This calculation yields an annual emission estimate of 17.5 g I-TEQ$_{DF}$ in 1995. This estimate should be regarded as a preliminary indication of possible emissions from this source category; further testing is needed to confirm the true magnitude of these emissions.

7.6.   SCRAP ELECTRIC WIRE RECOVERY

The objective of wire recovery is to remove the insulating material and reclaim the metal (e.g., copper, lead, silver, and gold) in the electric wire. The recovery facility then sells the reclaimed metal to a secondary metal smelter. Wire insulation commonly consists of a variety of plastics, asphalt-impregnated fabrics, or burlap. Chlorinated organics are used to preserve the cable casing in ground cables. The combustion of chlorinated organic compounds in the cable insulation, catalyzed by the presence of wire metals such as copper and iron, can lead to the formation of CDDs and CDFs (Van Wijnen et al., 1992).

Although in the past, scrap electric wire was commonly recovered using thermal processing to burn off the insulating material, current recovery operations no longer typically involve thermal treatment according to industry and trade association representatives. Instead, scrap electric wire is mechanically chopped into fine particles. The insulating material is then removed by air blowing and, followed by gravitational settling of the heavier metal (telephone conversations between T. Leighton, Versar, Inc., R. Garino, Institute of Scrap Recycling Industries, March 2, 1993; and J. Sullivan, Triple F. Dynamics, March 8, 1993).

EPA measured dioxin-like compounds emitted to the air from a scrap wire reclamation incinerator during its 1986 National Dioxin Study of combustion sources (U.S. EPA, 1987a). Testing determined that the facility was typical of this industrial source category at that time. Insulated wire and other metal-bearing scrap material were fed to the incinerator on a steel pallet. The incinerator operated in a batch mode, with the

combustion cycles for each batch of scrap feed lasting between 1 and 3 hours. Natural gas was used to incinerate the material. Although most of the wire had a tar-based insulation, PVC-coated wire was also fed to the incinerator. Temperatures during combustion in the primary chamber furnace were about 570°C. The tested facility was equipped with a high-temperature natural gas-fired afterburner (980 to 1,090°C). Emission factors estimated for this facility are presented in Table 7-7. The estimated TEQ emission factor (based only on 2,3,7,8-TCDD, 2,3,7,8-TCDF, OCDD, and OCDF) is 16.9 ng I-TEQ$_{DF}$/kg scrap feed (15.8 ng TEQ$_{DF}$-WHO$_{98}$). Figure 7-5 presents a congener group profile based on these emission factors.

Bremmer et al. (1994) reported emission factors for three facilities in The Netherlands, which have subsequently ceased operations. Emission rates at a facility burning underground cables and cables containing PVC ranged from 3.7 ng I-TEQ$_{DF}$/kg to 14 ng I-TEQ$_{DF}$/kg. The emission rate at a second facility ranged from 21 ng I-TEQ$_{DF}$/kg of scrap (when burning copper core coated with greasy paper) to 2,280 ng I-TEQ$_{DF}$/kg of scrap (when burning lead cable). The third facility, which burned motors, was reported to have an emission rate of 3,300 ng I-TEQ$_{DF}$/kg of scrap. On the basis of these measurements, Bremmer et al. (1994) used emission rates of 40 ng I-TEQ$_{DF}$/kg of scrap and 3,300 ng I-TEQ$_{DF}$/kg of scrap for estimating national emissions in The Netherlands for facilities burning wires and cables and those burning motors.

Although limited emission testing has been conducted at one U.S. facility, the activity level for this industry sector in reference years 1987 and 1995 is unknown; therefore, an estimate of national emissions cannot be made. It is uncertain how many facilities still combust scrap wire in the United States. Trade association and industry representatives state that U.S. scrap wire recovery facilities now burn only minimal quantities of scrap wire. However, a recent inventory of CDD/CDF sources in the San Francisco Bay area noted that two facilities in the Bay area thermally treat electric motors to recover electrical windings (BAAQMD, 1996).

In addition to releases from regulated recovery facilities, CDD/CDF releases from small-scale burning of wire at unregulated facilities and open air sites have occurred; however, the current magnitude of small-scale, unregulated burning of scrap wire in the United States is not known. For example, Harnly et al. (1995) analyzed soil/ash mixtures from three closed metal recovery facilities and from three closed sites of open burning for

copper recovery near a California desert town. The geometric mean of the total CDD/CDF concentrations at the facility sites and the open burning sites was 86,000 and 48,500 ng/kg, respectively. The geometric mean TEQ concentrations were 2,900 and 1,300 ng I-TEQ$_{DF}$/kg, respectively. A significantly higher geometric mean concentration (19,000 ng I-TEQ$_{DF}$/kg) was found in fly ash located at two of the facility sites. The congener-specific and congener group results from this study are presented in Table 7-8. The results show that the four dominant congeners in the soil samples at both the facility and open burning sites were OCDF, 1,2,3,4,6,7,8-HpCDF, 1,2,3,4,7,8-HxCDF, and 2,3,7,8-TCDF. A slightly different profile was observed in the fly ash samples, with 1,2,3,7,8-PeCDF and 1,2,3,4,7,8,9-HpCDF replacing OCDD and 2,3,7,8-TCDF as dominant congeners.

Van Wijnen et al. (1992) reported similar results for soil samples collected from unpermitted incineration sites of former scrap wire and cars in The Netherlands. Total CDD/CDF concentrations in the soil ranged from 60 to 98,000 ng/kg, with 9 of the 15 soil samples having levels above 1,000 ng/kg. Chen et al. (1986) reported finding high levels of CDD/CDFs in residues from open air burning of wire in Taiwan, and Huang et al. (1992) reported elevated levels in soil near wire scrap recovery operations in Japan. Bremmer et al. (1994) estimated an emission rate to air of 500 ng I-TEQ$_{DF}$/kg of scrap for illegal, unregulated burning of cables in The Netherlands.

7.7.   DRUM AND BARREL RECLAMATION FURNACES

Hutzinger and Fiedler (1991b) reported detecting CDD/CDFs in stack gas emissions from drum and barrel reclamation facilities at levels ranging from 5 to 27 ng/m^3. EPA measured dioxin-like compounds in the stack gas emissions of a drum and barrel reclamation furnace as part of the National Dioxin Study (U.S. EPA, 1987a).

Drum and barrel reclamation furnaces operate a burning furnace to thermally clean used 55-gallon steel drums of residues and coatings. The drums processed at these facilities come from a variety of sources in the petroleum and chemical industries. The thermally cleaned drums are then repaired, repainted, relined, and sold for reuse. The drum-burning process subjects used drums to an elevated temperature in a tunnel furnace for a sufficient time so that the paint, interior linings, and previous contents are burned or disintegrated. The furnace is fired by auxiliary fuel. Used drums are loaded onto a conveyor that moves at a fixed speed. As the drums pass through the preheat and

ignition zone of the furnace, additional contents of the drums drain into the furnace ash trough. A drag conveyor moves these sludges and ashes to a collection pit. The drums are air cooled as they exit the furnace. Exhaust gases from the burning furnace are typically drawn through a breeching fan to a high-temperature afterburner.

The afterburner at the facility tested by EPA operated at an average of 827°C during testing and achieved a 95 percent reduction in CDD/CDF emissions (U.S. EPA, 1987a). Emission factors estimated for this facility are presented in Table 7-9. On the basis of the measured congener and congener group emissions, the average TEQ emission factor is estimated to be 16.5 ng I-TEQ$_{DF}$ per drum (17.5 ng TEQ$_{DF}$-WHO$_{98}$/drum). The congener group profile is presented in Figure 7-6.

Approximately 2.8 to 6.4 million 55-gallon drums are incinerated annually in the United States (telephone conversation between C. D'Ruiz, Versar, Inc., and P. Rankin, Association of Container Reconditioners, December 21, 1992). This estimate is based on the following assumptions: (1) 23 to 26 incinerators are currently in operation; (2) each incinerator, on average, handles 500 to 1,000 drums per day; and (3) on average, each incinerator operates 5 days per week, with 14 days downtime per year for maintenance activities. The weight of 55-gallon drums varies considerably; however, on average, a drum weighs 38 lbs (or 17 kg); therefore, an estimated 48 to 109 million kg of drums are incinerated annually. Assuming that 4.6 million drums are burned each year (i.e., the midpoint of the range) and applying the emission factors developed above, the estimated annual emission of TEQ is 0.08 g I-TEQ$_{DF}$ (0.08 g TEQ$_{DF}$-WHO$_{98}$). No activity level data are available that would enable annual emission estimates to be made specifically for reference years 1987 and 1995.

A low confidence rating is assigned to the activity level estimate because it is based on expert judgment rather than a published reference. A low confidence rating is also assigned to the emission factor, because it was developed from stack tests conducted at just one U.S. drum and barrel furnace and thus may not represent average emissions from current operations in the United States.

7.8.   SOLID WASTE FROM PRIMARY/SECONDARY IRON/STEEL MILLS/FOUNDRIES

Literature on the Identification of Relevant Industrial Sources of Dioxins and Furans in Europe (Quab, 1997), Table 17, contains summary data on the typical annual quantities

and ranges of TEQ (Norwegian-TEQ [NTEQ] and I-TEQ) from various solid residuals from the metallurgical industries in Europe. No support information accompanies the tabular data. Specific congeners are not discussed. However, the summary data for annual TEQ generation in grams are as follows:

Grey Iron Foundries: baghouse dust and scrubber sludge	0.817 NTEQ
Steel Mill Coke Oven Door Leakage Dust	0.31 NTEQ
Steel Mill Coke Oven Door Leakage Dust	0.04 I-TEQ
Pig Iron Tapping Slag	0.041 NTEQ
Basic Oxygen Furnace Scrubber Sludge	1.53 NTEQ (range of 0.30 - 7.81)
Electric Furnace Baghouse Dust	3.1 I-TEQ (range of 0.4 - 2.4)
Electric Furnace Slag or Baghouse Dust	19.2 NTEQ

Table 7-1. CDD/CDF Emission Factors for Secondary Aluminum Smelters

Congener/Congener Group	Mean Facility Emission Factor (ng/kg scrap feed) (Ref. 1)	Mean Facility Emission Factor (ng/kg scrap feed) (Ref. 2)	Mean Facility Emission Factor (ng/kg scrap feed) (Ref. 3)	Mean Facility Emission Factor (ng/kg scrap feed) (Ref. 4)	Mean Facility Emission Factor (ng/kg scrap feed) (Ref. 5)	Mean Facility Emission factor (ng/kg scrap feed) (Ref. 5)
2,3,7,8-TCDD	ND (0.01)	0.13	0.51	2.17	1.97	0.845
1,2,3,7,8-PeCDD	0.02	0.39	1.19	3.84	7.10	3.64
1,2,3,4,7,8-HxCDD	0.05	0.24	1.35	2.88	4.26	2.82
1,2,3,6,7,8-HxCDD	0.13	0.86	1.52	5.39	5.30	4.12
1,2,3,7,8,9-HxCDD	0.15	1.26	2.51	7.22	5.30	2.02
1,2,3,4,6,7,8-HpCDD	0.51	7.67	2.60	18.01	28.9	19.3
OCDD	0.42	14.97	1.01	NR	33.2	24.3
2,3,7,8-TCDF	0.44	0.74	14.20	47.12	23.2	4.84
1,2,3,7,8-PeCDF	0.06	1.51	10.47	20.01	33.8	1.18
2,3,4,7,8-PeCDF	0.17	2.44	11.06	29.60	48.0	23.3
1,2,3,4,7,8-HxCDF	0.32	2.44	21.84	52.32	46.1	17.6
1,2,3,6,7,8-HxCDF	0.11	2.69	7.10	16.31	46.1	16.9
1,2,3,7,8,9-HxCDF	0.02	1.02	0.47	1.20	22.0	1.35
2,3,4,6,7,8-HxCDF	0.30	3.82	7.09	22.96	39.0	16.0
1,2,3,4,6,7,8-HpCDF	0.07	11.39	14.61	35.29	122	42.6
1,2,3,4,7,8,9-HpCDF	0.03	5.50	1.21	5.17	27.1	6.20
OCDF	0.30	30.40	3.15	18.77	60.5	29.5
*Total I-TEQ$_{DF}$	0.26	3.22	12.95	36.03	52.21	21.67
*Total TEQ$_{DF}$-WHO$_{98}$	0.27	3.37	13.55	37.94	55.68	23.44
Total TCDD	NR	3.30	46.03	NR	47.8	0.845
Total PeCDD	NR	4.91	28.07	NR	64.0	3.64
Total HxCDD	NR	11.45	35.51	NR	78.0	8.95
Total HpCDD	NR	14.71	6.01	NR	58.5	19.3
Total OCDD	0.42	14.97	1.01	NR	33.2	24.3
Total TCDF	NR	29.67	161.80	NR	620	4.84
Total PeCDF	NR	28.73	222.75	NR	585	35.1
Total HxCDF	NR	32.23	115.32	NR	515	52.0
Total HpCDF	NR	39.44	39.94	NR	247	48.8
Total OCDF	0.30	30.40	3.15	18.77	60.5	29.5
Total CDD/CDF	NR	209.81	659.60	NR	2,309	227

* TEQ calculations assume not-detected values are zero.

NR = Not reported.

ND = Not detected (value in parenthesis is the emission at the detection limit).

Sources: Ref. 1: Advanced Technology Systems, Inc. (1995)

Ref. 2: U.S. EPA (1995h)

Ref. 3: Galson Corporation (1995)

Ref. 4: Envisage Environmental, Inc. (1995)

Ref. 5: CARB (1992a, 1992b), as reported in U.S. EPA (1997b)

Table 7-2. CDD/CDF Emission Factors for Secondary Copper Smelters

Congener/Congener Group	Mean EPA Tier 4 Emission Factor[a,b] (ng/kg scrap feed)	Franklin Smelting Facility Mean Emission Factor[d] (ng/kg scrap feed)	Chemetco Smelting Facility Mean Emission Factor[e] (ng/kg scrap feed)
2,3,7,8-TCDD	127	227	ND (0.05)
1,2,3,7,8-PeCDD	NR	846	0.21
1,2,3,4,7,8-HxCDD	NR	1,476	0.39
1,2,3,6,7,8-HxCDD	NR	1,746	0.70
1,2,3,7,8,9-HxCDD	NR	2,132	1.26
1,2,3,4,6,7,8-HpCDD	NR	17,065	8.95
OCDD	1,350	55,668	22.45
2,3,7,8-TCDF	2,720	4,457	2.11
1,2,3,7,8-PeCDF	NR	9,455	1.47
2,3,4,7,8-PeCDF	NR	5,773	2.63
1,2,3,4,7,8-HxCDF	NR	70,742	7.30
1,2,3,6,7,8-HxCDF	NR	20,524	2.15
1,2,3,7,8,9-HxCDF	NR	5,362	4.06
2,3,4,6,7,8-HxCDF	NR	12,082	0.27
1,2,3,4,6,7,8-HpCDF	NR	37,251	11.48
1,2,3,4,7,8,9-HpCDF	NR	7,570	2.74
OCDF	2,520	82,192	21.61
*Total I-TEQ$_{DF}$	779[c]	16,618	3.60
*Total TEQ$_{DF}$-WHO$_{98}$	810[c]	16,917	3.66
Total TCDD	736	14,503	3.05
Total PeCDD	970	30,248	5.19
Total HxCDD	1,260	55,765	9.62
Total HpCDD	2,080	38,994	16.71
Total OCDD	1,350	55,668	22.45
Total TCDF	13,720	108,546	46.42
Total PeCDF	8,640	71,136	27.99
Total HxCDF	4,240	164,834	27.96
Total HpCDF	3,420	66,253	23.38
Total OCDF	2,520	82,192	21.61
Total CDD/CDF	38,890	688,139	204.33

* TEQ calculations assume not-detected values are zero.

NR = Not reported.

ND = Not detected (value in parenthesis is the emission at the detection limit).

a   No nondetected values were reported for 2,3,7,8-TCDD, 2,3,7,8-TCDF, or any congener group in the
        three test runs.
b   Source: U.S. EPA (1987a).
c   Estimated using the measured data for 2,3,7,8-TCDD, 2,3,7,8-TCDF, OCDD, and OCDF and congener
        group emissions (i.e., for the penta-, hexa-, and hepta-CDDs and CDFs, it was assumed that the
        measured emission factor within a congener group was the sum of equal emission factors for all
        congeners in that group, including non-2,3,7,8-substituted congeners).
d   Source: AGES (1992).
e   Source: Sverdrup Corp. (1991).

Table 7-3. CDD/CDF Emission Factors for Secondary Lead Smelters

Congener/Congener Group	Blast Furnace (Ref. A) (ng/kg lead produced)		Blast/reverb (Ref. B) (ng/kg lead produced)		Rotary kiln (Ref. C) (ng/kg lead produced)	
	Before Scrubber	After Scrubber	Before Scrubber	After Scrubber	Before Scrubber	After Scrubber
2,3,7,8-TCDD	2.11	0.25	0.00	0.00	0.10	0.24
1,2,3,7,8-PeCDD	0.99	0.03	0.00	0.00	0.01	0.00
1,2,3,4,7,8-HxCDD	0.43	0.00	0.00	0.00	0.00	0.00
1,2,3,6,7,8-HxCDD	0.99	0.03	0.00	0.00	0.00	0.00
1,2,3,7,8,9-HxCDD	1.55	0.03	0.00	0.00	0.00	0.00
1,2,3,4,6,7,8-HpCDD	2.06	0.08	0.10	0.06	0.00	0.22
OCDD	1.40	0.39	0.57	0.55	0.24	2.41
2,3,7,8-TCDF	8.73	0.93	1.46	0.49	0.40	1.20
1,2,3,7,8-PeCDF	3.88	0.43	0.24	0.02	0.14	0.40
2,3,4,7,8-PeCDF	6.65	0.36	0.31	0.00	0.14	0.46
1,2,3,4,7,8-HxCDF	5.83	0.37	0.63	0.00	0.11	0.27
1,2,3,6,7,8-HxCDF	1.67	0.11	0.19	0.00	0.02	0.10
1,2,3,7,8,9-HxCDF	0.11	0.00	0.00	0.00	0.04	0.13
2,3,4,6,7,8-HxCDF	2.06	0.11	0.15	0.00	0.00	0.00
1,2,3,4,6,7,8-HpCDF	2.34	0.19	0.48	0.00	0.03	0.13
1,2,3,4,7,8,9-HpCDF	0.63	0.06	0.00	0.00	0.00	0.00
OCDF	1.39	0.18	0.29	0.00	0.00	0.00
Total 2,3,7,8-CDD	9.52	0.82	0.68	0.61	0.35	2.87
Total 2,3,7,8-CDF	33.28	2.74	3.75	0.51	0.88	2.68
Total I-TEQ$_{DF}$ (nondetects = 0)	8.31	0.63	0.41	0.05	0.24	0.66
Total TEQ$_{DF}$-WHO$_{98}$ (nondetects = 0)	8.81	0.64	0.42	0.05	0.24	0.66
Total TCDD	74.33	7.39	0.97	1.58	3.40	7.90
Total PeCDD	39.29	1.73	0.15	0.16	0.29	0.27
Total HxCDD	20.05	0.81	0.14	0.02	0.10	0.23
Total HpCDD	4.20	9.72	0.09	0.09	0.01	0.29
Total OCDD	1.39	0.18	0.57	0.55	0.24	2.41
Total TCDF	145.71	17.34	8.21	4.71	10.82	28.57
Total PeCDF	69.59	3.45	3.07	0.36	1.69	5.04
Total HxCDF	19.73	1.02	1.14	0.19	0.15	0.73
Total HpCDF	4.74	0.11	0.72	0.01	0.05	0.14
Total OCDF	1.39	0.18	0.29	0.00	0.00	0.00
Total CDD/CDF (nondetects = 0)	380.43	41.92	15.36	7.66	16.76	45.57
Total CDD/CDF (nondetects = ½ DL)	380.44	42.27	15.36	7.74	16.80	45.62

Note: Except where noted, emission factors were calculated assuming nondetected values are zero.

Sources: Ref. A: U.S. EPA (1995e)
        Ref. B: U.S. EPA (1992e)
        Ref. C: U.S. EPA (1995d)

Table 7-4. CDD/CDF Emission Factors for Sinter Plants

Congener/Congener Group	Wet Scrubber APCD (ng/kg sinter)		Baghouse APCD (ng/kg sinter)	
	ND = 0	ND = 1/2DL	ND = 0	ND = 1/2DL
2,3,7,8-TCDD	0.049	0.049	0.406	0.406
1,2,3,7,8-PeCDD	0.138	0.138	0.937	0.937
1,2,3,4,7,8-HxCDD	0.030	0.030	0.135	0.135
1,2,3,6,7,8-HxCDD	0.612	0.612	1.469	1.469
1,2,3,7,8,9-HxCDD	0.288	0.288	0.609	0.609
1,2,3,4,6,7,8-HpCDD	0.696	0.696	0.698	0.698
OCDD	0.496	0.496	0.695	0.695
2,3,7,8-TCDF	0.602	0.602	10.232	10.232
1,2,3,7,8-PeCDF	0.343	0.343	3.518	3.518
2,3,4,7,8-PeCDF	0.349	0.349	3.228	3.228
1,2,3,4,7,8-HxCDF	0.421	0.421	1.382	1.382
1,2,3,6,7,8-HxCDF	0.164	0.164	0.495	0.495
1,2,3,7,8,9-HxCDF	0.011	0.014	0.029	0.057
2,3,4,6,7,8-HxCDF	0.142	0.142	0.285	0.285
1,2,3,4,6,7,8-HpCDF	0.247	0.247	0.316	0.316
1,2,3,4,7,8,9-HpCDF	0.036	0.036	0.000	0.115
OCDF	0.103	0.103	0.050	0.192
Total 2,3,7,8-CDD	2.309	2.309	4.949	4.949
Total 2,3,7,8-CDF	2.418	2.421	19.535	19.820
Total I-TEQ$_{DF}$	0.55	0.55	4.14	4.14
Total TEQ$_{DF}$-WHO$_{98}$	0.62	0.62	4.61	4.61
Total TCDD	NR	NR	NR	NR
Total PeCDD	NR	NR	NR	NR
Total HxCDD	NR	NR	NR	NR
Total HpCDD	NR	NR	NR	NR
Total OCDD	0.496	0.496	0.695	0.695
Total TCDF	NR	NR	NR	NR
Total PeCDF	NR	NR	NR	NR
Total HxCDF	NR	NR	NR	NR
Total HpCDF	NR	NR	NR	NR
Total OCDF	0.103	0.103	0.050	0.192
Total CDD/CDF[a]	4.73	4.73	24.48	24.77

a The listed values for total CDD/CDF include only the 17 toxic congeners.

Source: Calcagni et al. (1998)

Table 7-5. Operating Parameters for U.S. Iron Ore Sinter Plants

Company	Location	1998 Capacity (1,000 kkg/yr)	Current APCD
A.K. Steel Corp.	Middleton, OH	907	WS
A.K. Steel Corp.*	Ashland, KY	816*	NA
Bethlehem Steel	Burns Harbor, IN	2,676	WS
Bethlehem Steel	Sparrows Point, MD	3,856	WS
Geneva Steel	Provo, UT	816	BH
Inland Steel	East Chicago, IN	1,089	BH
LTV Steel	East Chicago, IN	1,270	WS
U.S. Steel	Gary, IN	3,992	BH
Weirton Steel*	Weirton, WV	1,179*	NA
Wheeling-Pittsburgh Steel	East Steubenville, WV	519	WS
WCI Steel	Warren, OH	477	BH
TOTALS		17,597**	

NA = Not available.
WS = Wet scrubber.
BH = Baghouse.

*   Not in operation during 1998 (Calcagni et al., 1998)
**   Total 1998 capacity was 15,600 thousand metric tons (i.e., excluding the Ashland, KY, and Weirton, WV, facilities).

Sources: Metal Producing (1991, 1996); Calcagni et al. (1998)

Table 7-6. CDD/CDF Emission Factors for a Ferrous Foundry

Congener/Congener Group	Mean Facility Emission Factor (ng/kg scrap feed) (CARB, 1993a)
2,3,7,8-TCDD	0.033
1,2,3,7,8-PeCDD	0.086
1,2,3,4,7,8-HxCDD	NR
1,2,3,6,7,8-HxCDD	0.051
1,2,3,7,8,9-HxCDD	NR
1,2,3,4,6,7,8-HpCDD	0.093
OCDD	NR
2,3,7,8-TCDF	0.520
1,2,3,7,8-PeCDF	0.305
2,3,4,7,8-PeCDF	0.350
1,2,3,4,7,8-HxCDF	0.190
1,2,3,6,7,8-HxCDF	0.170
1,2,3,7,8,9-HxCDF	NR
2,3,4,6,7,8-HxCDF	0.101
1,2,3,4,6,7,8-HpCDF	0.193
1,2,3,4,7,8,9-HpCDF	NR
OCDF	0.059
Total 2,3,7,8-CDD	0.262
Total 2,3,7,8-CDF	1.888
Total I-TEQ$_{DF}$ (for reported congeners)	0.372
Total TEQ$_{DF}$-WHO$_{98}$	0.415
Total TCDD	3.96
Total PeCDD	1.76
Total HxCDD	0.55
Total HpCDD	0.19
Total OCDD	NR
Total TCDF	25.8
Total PeCDF	850
Total HxCDF	1.74
Total HpCDF	0.24
Total OCDF	0.06
Total CDD/CDF (not including OCDD)	884.3

NR = Not reported.

Source: CARB (1993a), as reported in U.S. EPA, 1997b

Table 7-7. CDD/CDF Emission Factors for a Scrap Wire Incinerator

Congener/Congener Group	Mean Facility Emission Factor [a] (ng/kg scrap feed)
2,3,7,8-TCDD	0.374
1,2,3,7,8-PeCDD	NR
1,2,3,4,7,8-HxCDD	NR
1,2,3,6,7,8-HxCDD	NR
1,2,3,7,8,9-HxCDD	NR
1,2,3,4,6,7,8-HpCDD	NR
OCDD	1,000
2,3,7,8-TCDF	2.67
1,2,3,7,8-PeCDF	NR
2,3,4,7,8-PeCDF	NR
1,2,3,4,7,8-HxCDF	NR
1,2,3,6,7,8-HxCDF	NR
1,2,3,7,8,9-HxCDF	NR
2,3,4,6,7,8-HxCDF	NR
1,2,3,4,6,7,8-HpCDF	NR
1,2,3,4,7,8,9-HpCDF	NR
OCDF	807
Total 2,3,7,8-CDD	NR
Total 2,3,7,8-CDF	NR
Total I-TEQ$_{DF}$	16.9[b]
Total TEQ$_{DF}$-WHO$_{98}$	15.8
Total TCDD	4.42
Total PeCDD	13.7
Total HxCDD	71.1
Total HpCDD	347
Total OCDD	1,000
Total TCDF	107
Total PeCDF	97.4
Total HxCDF	203
Total HpCDF	623
Total OCDF	807
Total CDD/CDF	3,273

NR = Not reported.

a   No nondetected values were reported for 2,3,7,8-TCDD, 2,3,7,8-TCDF, or any congener group in the three test runs.

b   Estimated based on the measured data for 2,3,7,8-TCDD, 2,3,7,8-TCDF, OCDD, and OCDF and congener group emissions (i.e., for the penta-, hexa-, and hepta-CDDs and CDFs, it was assumed that the measured emission factor within a congener group was the sum of equal emission factors for all congeners in that group, including non-2,3,7,8-substituted congeners).

Source: U.S. EPA (1987a)

Table 7-8. Geometric Mean CDD/CDF Concentrations in Fly Ash and Ash/Soil at Metal Recovery Sites

| Congener/Congener Group | Metal Recovery Facilities | | | | Open Burn Sites | |
| | Fly ash (2 sites) | | Ash/Soil (3 sites) | | Ash/Soil (3 sites) | |
	Geom. mean (µg/kg)	Relative % of Total CDD/CDF	Geom. mean (µg/kg)	Relative % of Total CDD/CDF	Geom. mean (µg/kg)	Relative % of Total CDD/CDF
2,3,7,8-TCDD	*		*		*	
1,2,3,7,8-PeCDD	400	0.1%	0.24	0.3%	0.24	0.5%
1,2,3,4,7,8-HxCDD	1,200	0.2%	0.25	0.3%	0.13	0.3%
1,2,3,6,7,8-HxCDD	2,300	0.5%	0.49	0.6%	0.33	0.7%
1,2,3,7,8,9-HxCDD	1,700	0.3%	1.3	1.5%	0.39	0.8%
1,2,3,4,6,7,8-HpCDD	12,000	2.4%	2.6	3.1%	1.2	2.5%
OCDD	18,000	3.5%	7.2	8.5%	3.4	7.0%
2,3,7,8-TCDF	15,000	2.9%	6.4	7.5%	1.7	3.5%
1,2,3,7,8-PeCDF	35,000	6.9%	2.9	3.4%	0.58	1.2%
2,3,4,7,8-PeCDF	10,000	2.0%	1.4	1.6%	0.66	1.4%
1,2,3,4,7,8-HxCDF	46,000	9.0%	5.9	6.9%	2.7	5.6%
1,2,3,6,7,8-HxCDF	12,000	2.4%	1.8	2.1%	0.76	1.6%
1,2,3,7,8,9-HxCDF	5,000	1.0%	0.92	1.1%	0.66	1.4%
2,3,4,6,7,8-HxCDF	5,000	1.0%	1.6	1.9%	0.49	1.0%
1,2,3,4,6,7,8-HpCDF	71,000	13.9%	12	14.1%	4.3	8.9%
1,2,3,4,7,8,9-HpCDF	25,000	4.9%	3	3.5%	0.71	1.5%
OCDF	100,000	19.6%	14	16.5%	6.6	13.6%
Total TCDD	*	*	*	*	*	*
Total PeCDD	2,000	0.4%	1.4	1.6%	2.8	5.8%
Total HxCDD	4,000	0.8%	2.7	3.2%	0.98	2.0%
Total HpCDD	24,000	4.7%	4.1	4.8%	2.0	4.1%
Total OCDD	18,000	3.5%	7.2	8.5%	3.4	7.0%
Total TCDF	23,000	4.5%	14	16.5%	5.6	11.5%
Total PeCDF	110,000	21.6%	12	14.1%	7.0	14.4%
Total HxCDF	88,000	17.3%	12	14.1%	7.6	15.7%
Total HpCDF	110,000	21.6%	17	20.0%	7.4	15.3%
Total OCDF	100,000	19.6%	14	16.5%	6.6	13.6%
Total I-TEQ$_{DF}$	19,000		2.9		1.3	
Total CDD/CDF	510,000		85		48.5	

* Analytical method used had low sensitivity for TCDDs; results were not reported.
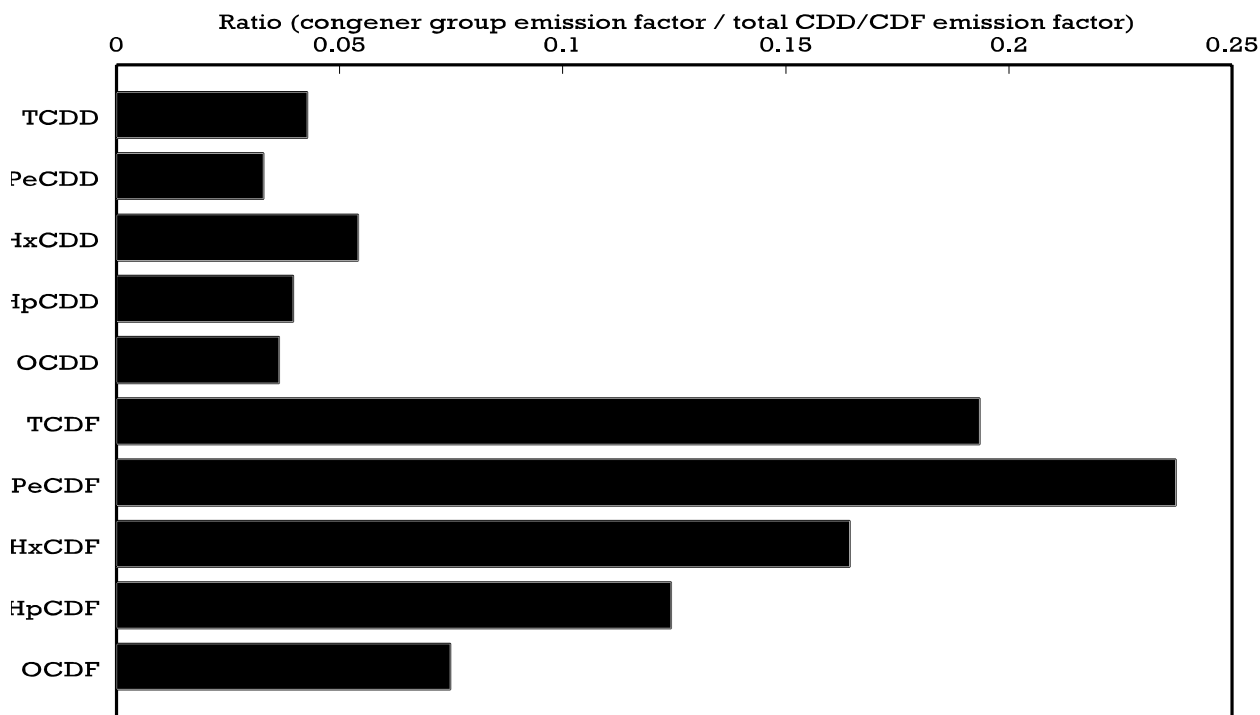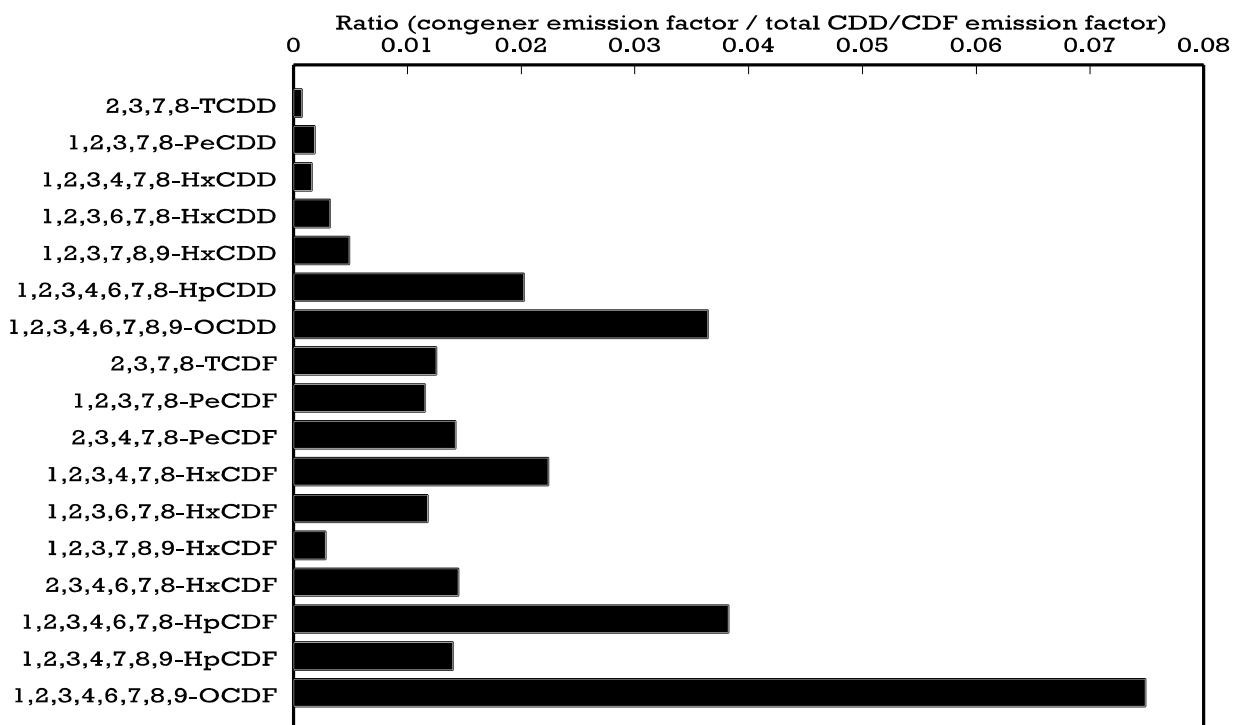
Source: Harnly et al. (1995)

Table 7-9. CDD/CDF Emission Factors for a Drum and Barrel Reclamation Furnace

| Congener/Congener Group	Mean Facility Emission Factor[a] (ng/drum)
2,3,7,8-TCDD	2.09
1,2,3,7,8-PeCDD	NR
1,2,3,4,7,8-HxCDD	NR
1,2,3,6,7,8-HxCDD	NR
1,2,3,7,8,9-HxCDD	NR
1,2,3,4,6,7,8-HpCDD	NR
OCDD	37.5
2,3,7,8-TCDF	36.5
1,2,3,7,8-PeCDF	NR
2,3,4,7,8-PeCDF	NR
1,2,3,4,7,8-HxCDF	NR
1,2,3,6,7,8-HxCDF	NR
1,2,3,7,8,9-HxCDF	NR
2,3,4,6,7,8-HxCDF	NR
1,2,3,4,6,7,8-HpCDF	NR
1,2,3,4,7,8,9-HpCDF	NR
OCDF	22.4
Total 2,3,7,8-CDD	NR
Total 2,3,7,8-CDF	NR
Total I-TEQ$_{DF}$	16.5[b]
Total TEQ$_{DF}$-WHO$_{98}$	17.5
Total TCDD	50.29
Total PeCDD	29.2
Total HxCDD	32.2
Total HpCDD	53.4
Total OCDD	37.5
Total TCDF	623
Total PeCDF	253
Total HxCDF	122
Total HpCDF	82.2
Total OCDF	22.4
Total CDD/CDF	1,303

NR = Not reported.

a No nondetected values were reported for 2,3,7,8-TCDD, 2,3,7,8-TCDF, or any congener group in the three test runs.

b Estimated based on the measured data for 2,3,7,8-TCDD, 2,3,7,8-TCDF, OCDD, and OCDF and congener group emissions (i.e., for the penta-, hexa-, and hepta-CDDs and CDFs, it was assumed that the measured emission factor within a congener group was the sum of equal emission factors for all congeners in that group, including non-2,3,7,8-substituted congeners).

Source: U.S. EPA (1987a)

Ratio (congener emission factor / total CDD/CDF emission factor)

2,3,7,8-TCDD	
1,2,3,7,8-PeCDD	
1,2,3,4,7,8-HxCDD	
1,2,3,6,7,8-HxCDD	
1,2,3,7,8,9-HxCDD	
1,2,3,4,6,7,8-HpCDD	
1,2,3,4,6,7,8,9-OCDD	
2,3,7,8-TCDF	
1,2,3,7,8-PeCDF	
2,3,4,7,8-PeCDF	
1,2,3,4,7,8-HxCDF	
1,2,3,6,7,8-HxCDF	
1,2,3,7,8,9-HxCDF	
2,3,4,6,7,8-HxCDF	
1,2,3,4,6,7,8-HpCDF	
1,2,3,4,7,8,9-HpCDF	
1,2,3,4,6,7,8,9-OCDF	

Ratio (congener group emission factor / total CDD/CDF emission factor)

Sources: U.S. EPA (1995h); Galson Corporation (1995)

Figure 7-1. Congener and Congener Group Profiles for Air Emissions
from Secondary Aluminum Smelters

Ratio (congener group emission factor / total CDD/CDF emission factor)
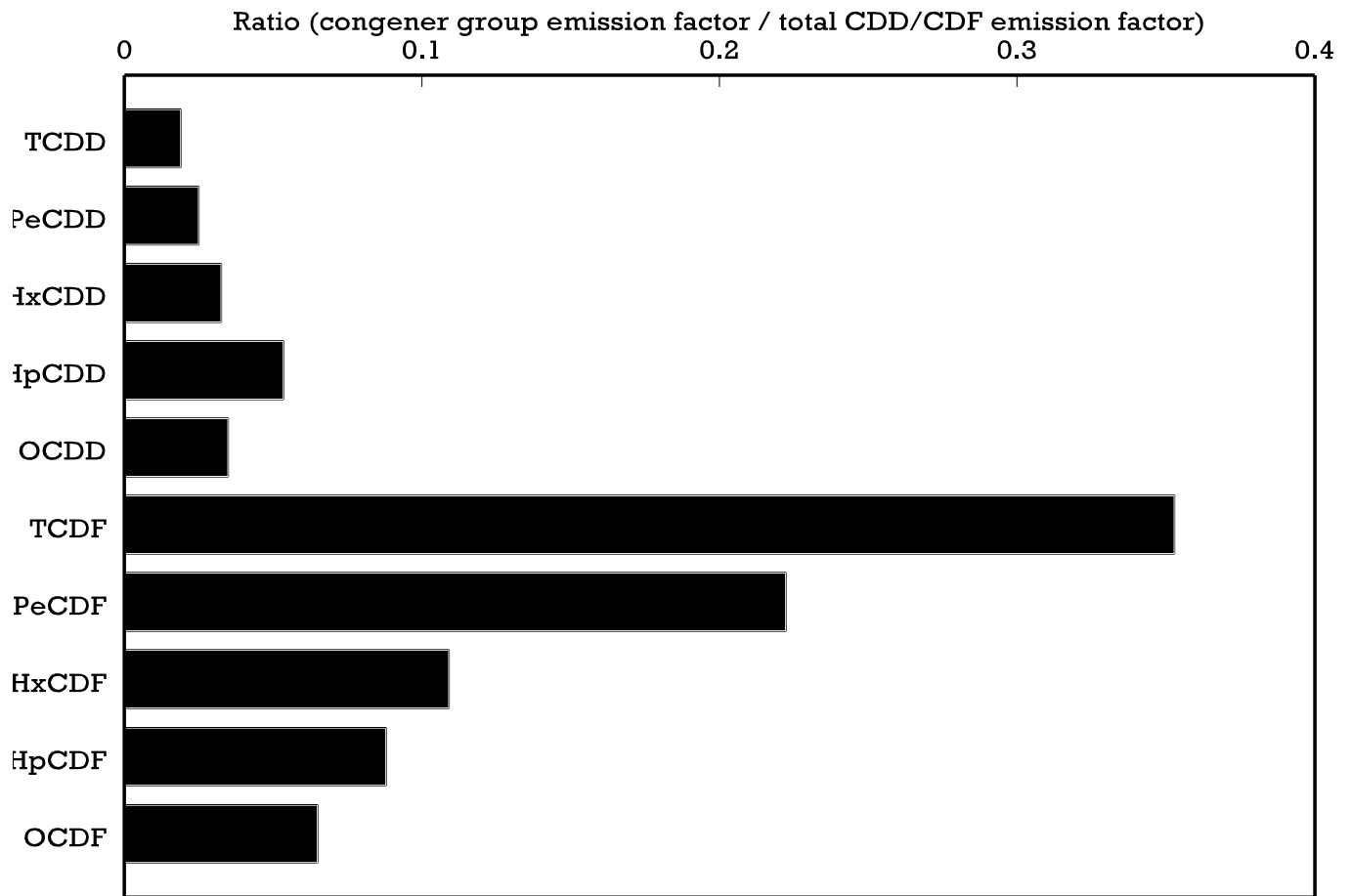
Source: U.S. EPA (1987c)

Figure 7-2a. Congener Group Profile for Air Emissions from a Secondary Copper Smelter

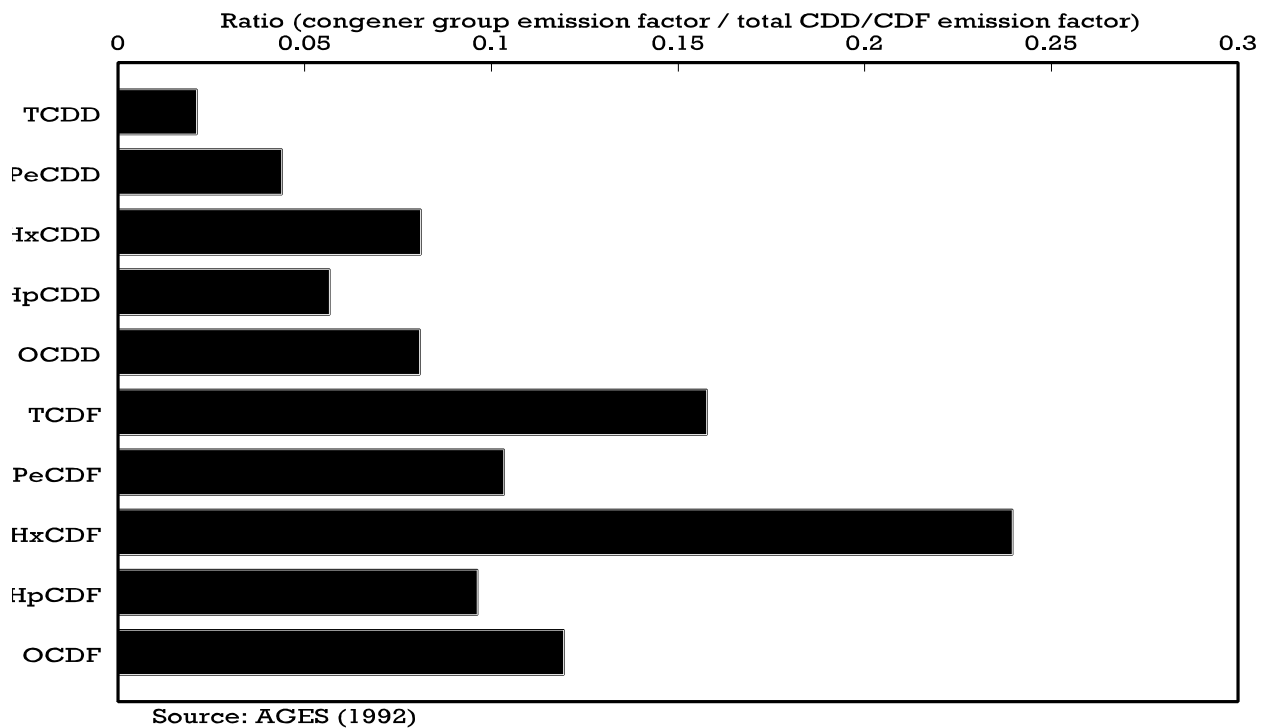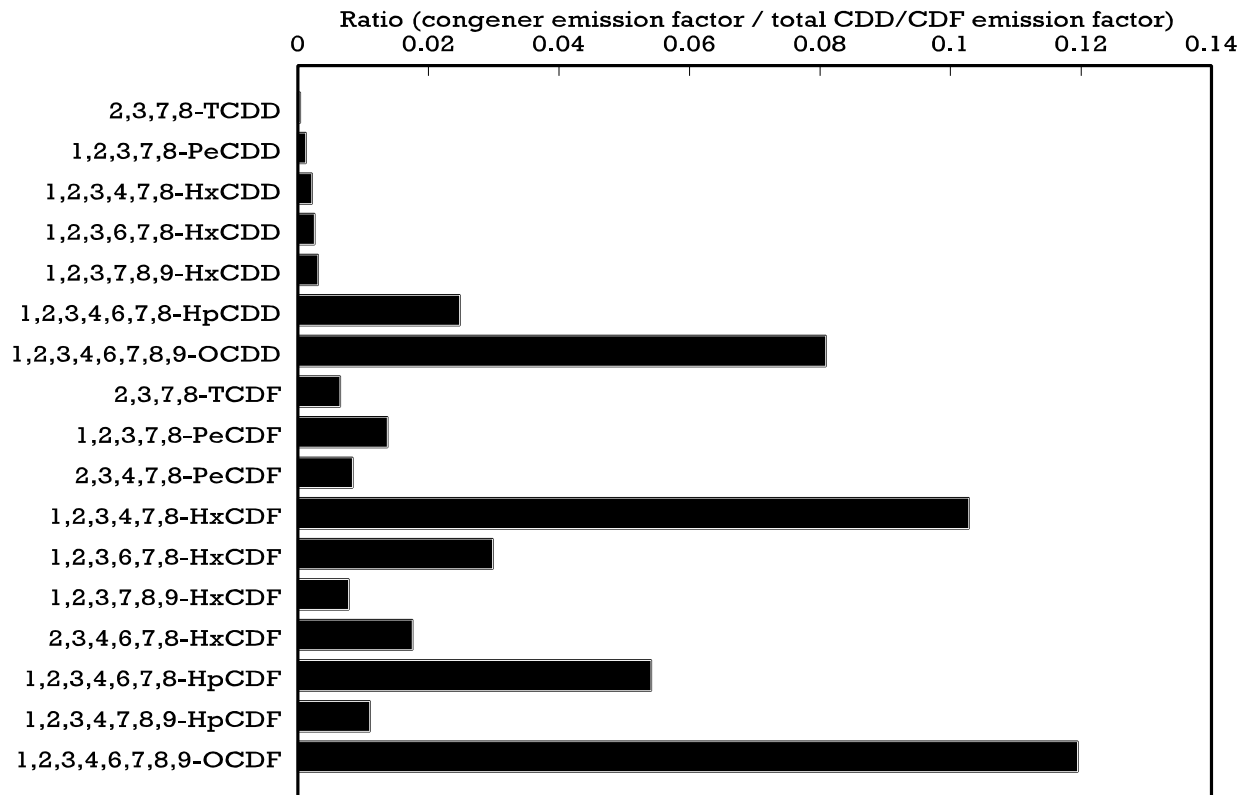Ratio (congener emission factor / total CDD/CDF emission factor)

0   0.02   0.04   0.06   0.08   0.1   0.12   0.14

2,3,7,8-TCDD
1,2,3,7,8-PeCDD
1,2,3,4,7,8-HxCDD
1,2,3,6,7,8-HxCDD
1,2,3,7,8,9-HxCDD
1,2,3,4,6,7,8-HpCDD
1,2,3,4,6,7,8,9-OCDD
2,3,7,8-TCDF
1,2,3,7,8-PeCDF
2,3,4,7,8-PeCDF
1,2,3,4,7,8-HxCDF
1,2,3,6,7,8-HxCDF
1,2,3,7,8,9-HxCDF
2,3,4,6,7,8-HxCDF
1,2,3,4,6,7,8-HpCDF
1,2,3,4,7,8,9-HpCDF
1,2,3,4,6,7,8,9-OCDF

Ratio (congener group emission factor / total CDD/CDF emission factor)

0   0.05   0.1   0.15   0.2   0.25   0.3

TCDD
PeCDD
HxCDD
HpCDD
OCDD
TCDF
PeCDF
HxCDF
HpCDF
OCDF

Source: AGES (1992)

Figure 7-2b. Congener and Congener Group Profiles for a Closed Secondary Copper Smelter
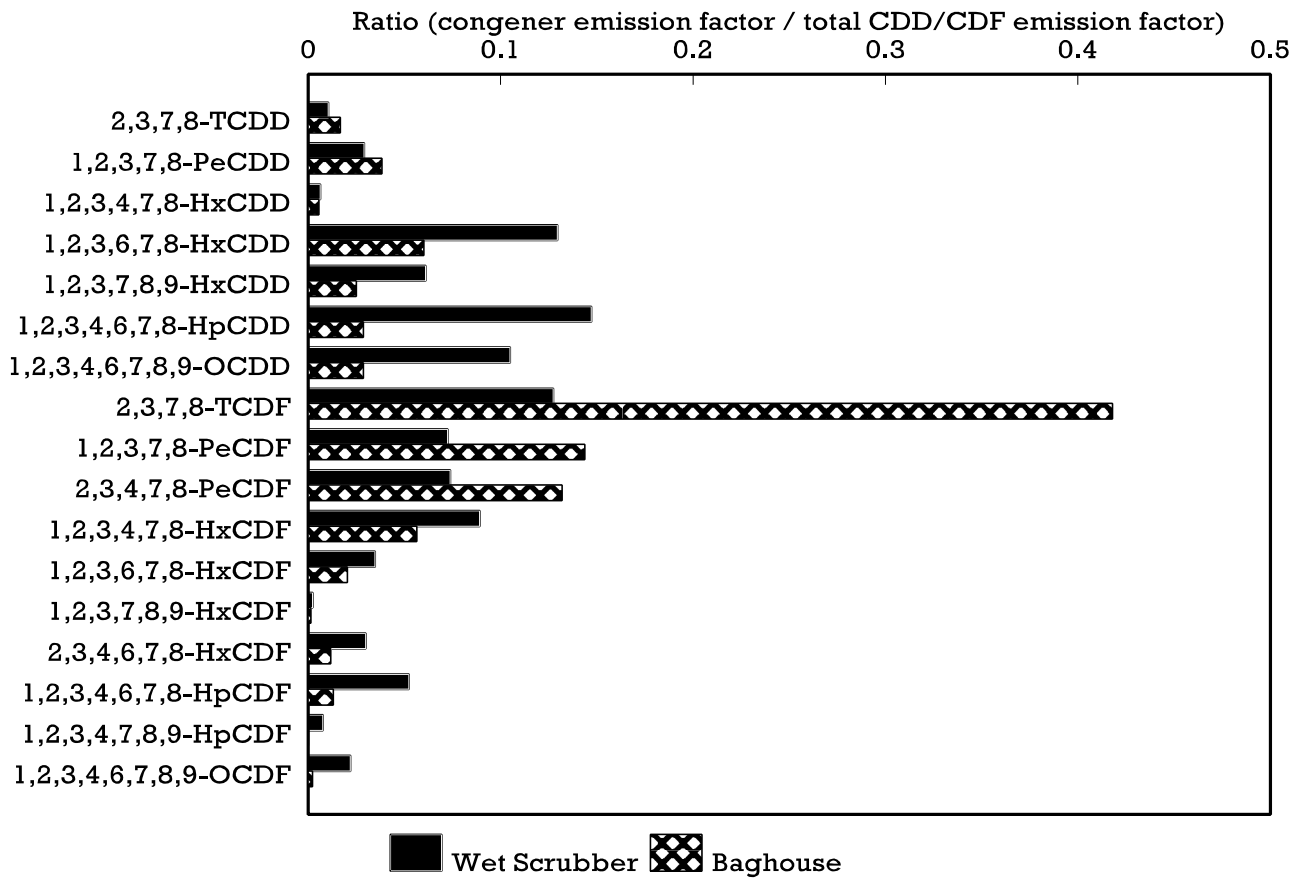
Figure 7-3. Congener and Congener Group Profiles for Air Emissions from Secondary Lead Smelters
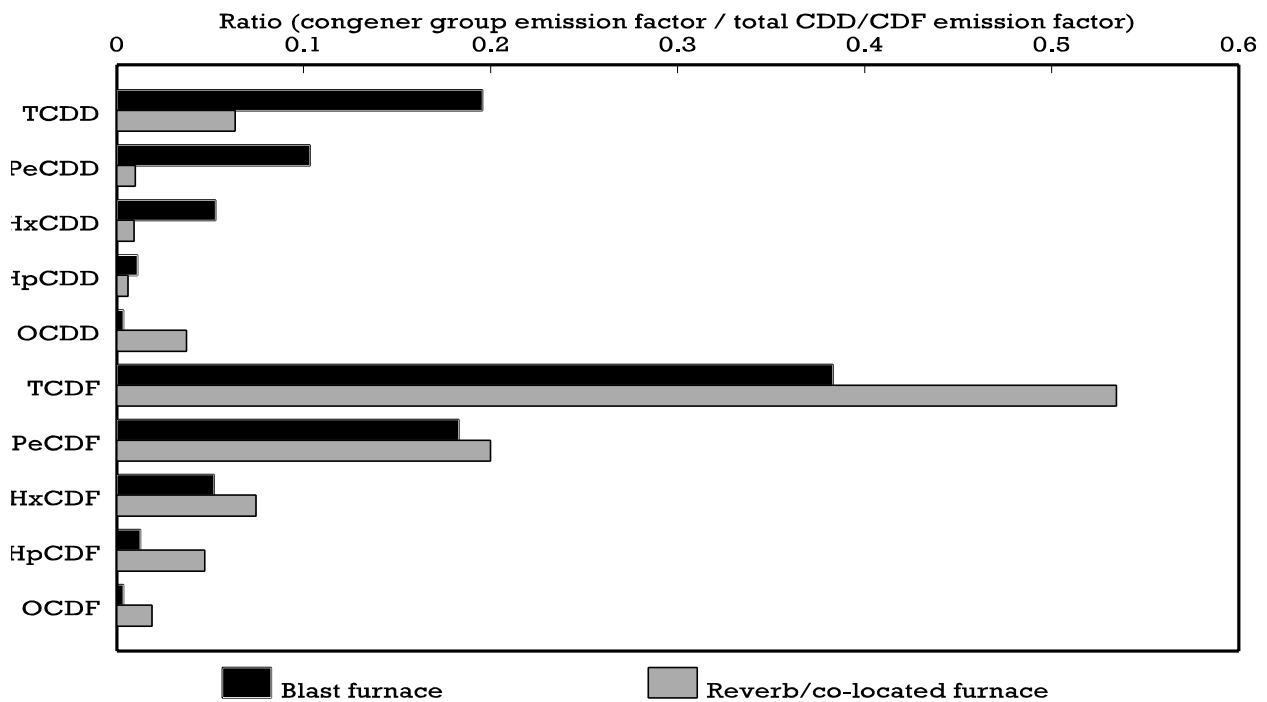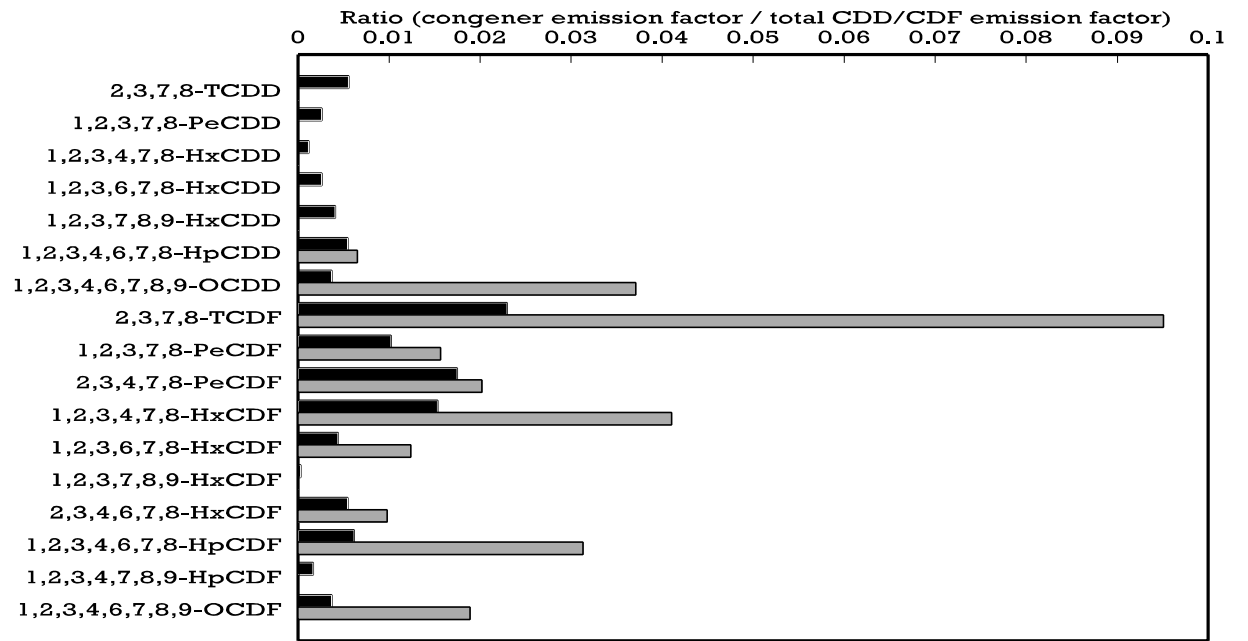
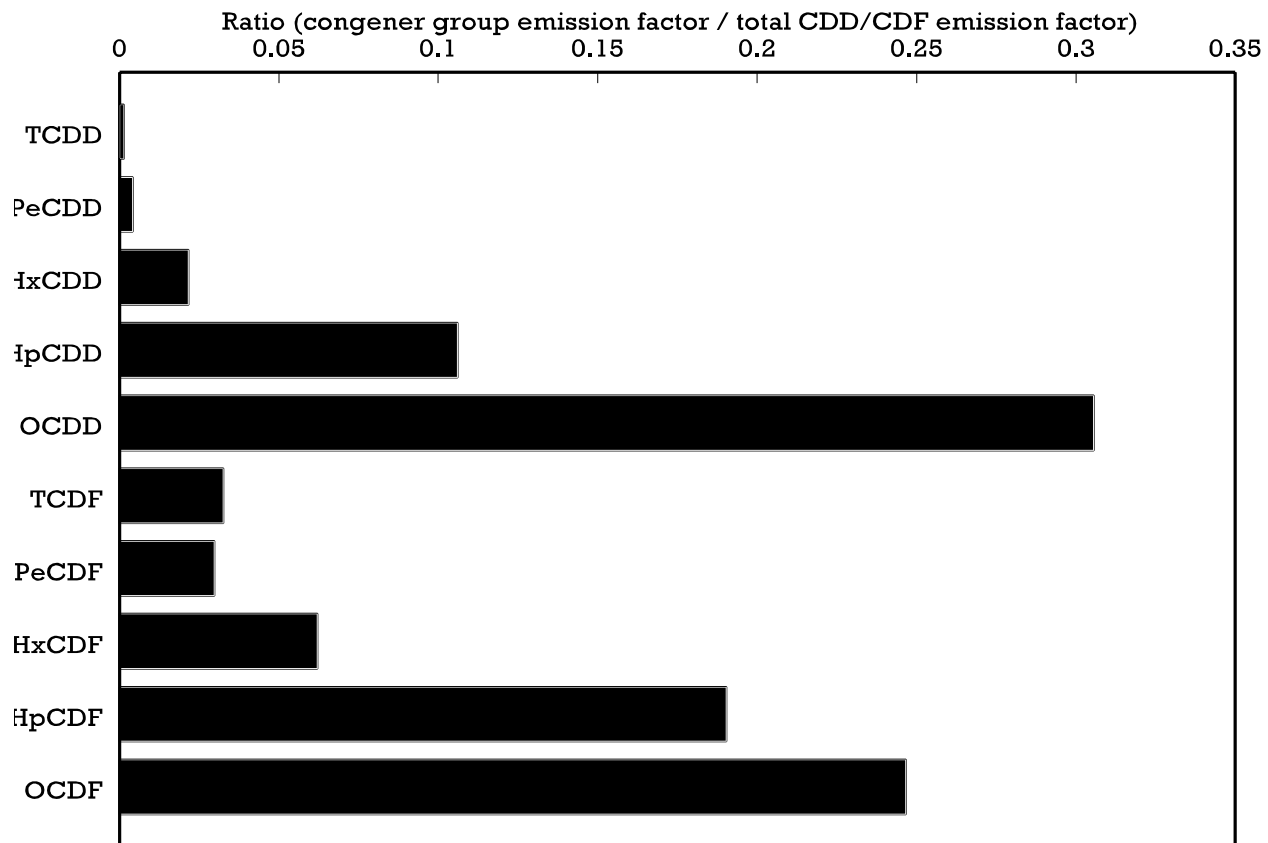Source: U.S. EPA (1992e); U.S. EPA (1995d); U.S. EPA (1995e)

Note: Profiles are for emissions from baghouses; nondetected values set equal to zero.

Ratio (congener emission factor / total CDD/CDF emission factor)

Figure 7-4. Congener Profiles for Air Emissions from U.S. Iron Ore Sinter Plants

Figure 7-5. Congener Group Profile for Air Emissions from a Scrap Wire Incinerator
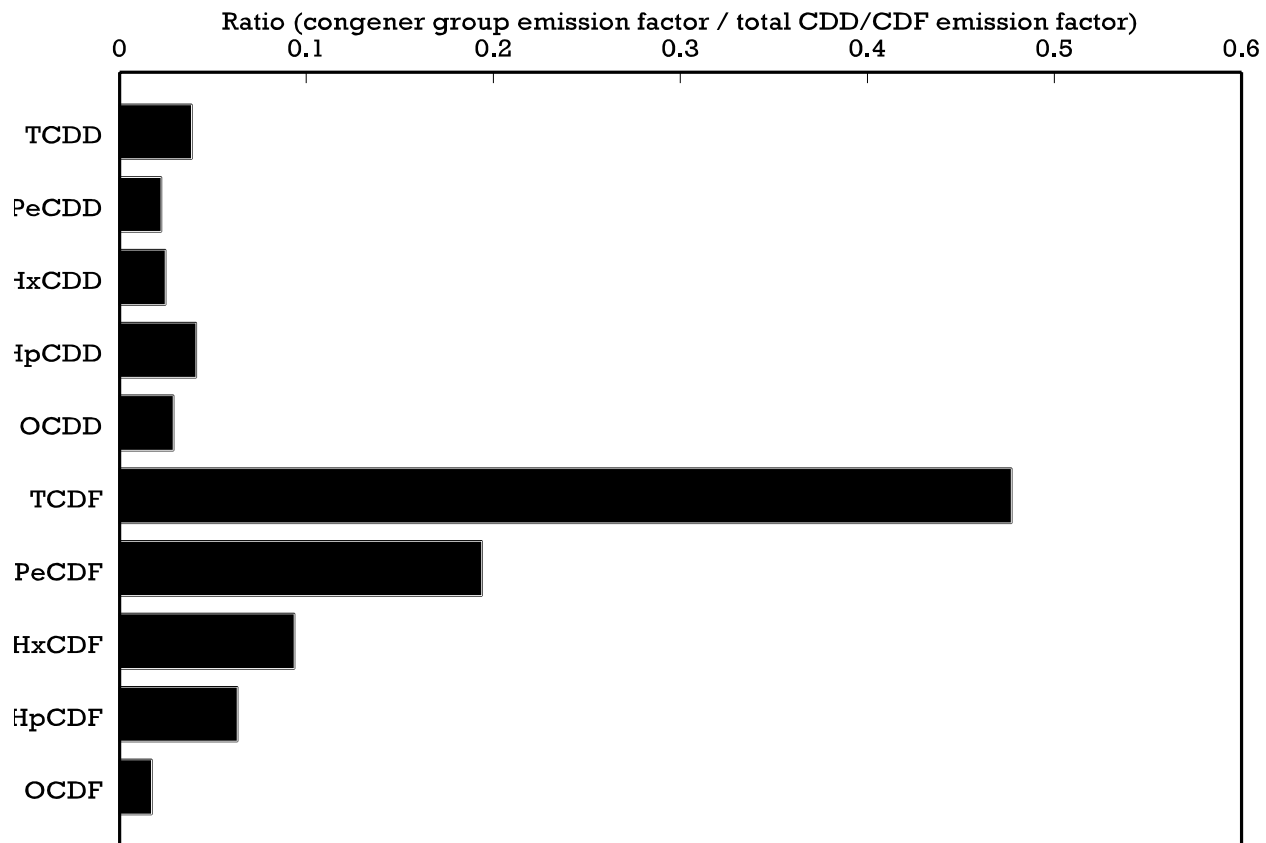
Figure 7-6. Congener Group Profile for Air Emissions from a Drum Incinerator