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Metal fumes in foundries

by ANTTI TOSSAVAINEN, Lic.Sc. (Eng.)

TOSSAVAINEN, A. Metal fumes in foundries. Scand. j. work environ. & health 2 (1976): suppl. 1, 42—49. The metal content of melting and casting fumes was analyzed with X-ray fluorescence, atomic absorption, and mass spectrometric methods. The composition of fumes varied with the kind of alloy, the quality of scrap, and the type of melting process. In addition foundry workers' exposure to metal fumes was evaluated. The measurements of airborne metal concentrations in 10 steel foundries, 15 iron foundries, and 11 copper alloy foundries showed that exposure to lead, copper, and zinc may present a health hazard.

Key words: metal analysis, metal fumes, foundry.

Metal fumes are formed by the evaporation, condensation, and oxidation of metals in air. In foundries furnace tenders, melters, casters, ladlemen, pourers, and crane operators are exposed to the smoke and fumes from molten metal.

The total emission of smoke and fumes depends upon the quality of the scrap charged. If the scrap contains large quantities of impurities, high concentrations of organic and inorganic compounds are emitted to the workroom air, unless the exhaust system is extremely efficient.

Inorganic material emitted from furnaces, ladles, and castings in iron foundries is primarily composed of oxides of iron, manganese, calcium, magnesium, aluminium, and silicon. The fumes of steel melting contain the same oxides plus those of chromium and nickel. Table 1 shows the composition of dust samples from an electric furnace shop in a steel foundry (7).

In iron and steel foundries, the oxides of lead and zinc are the predominant minor constituents in the fumes (3, 6, 8). Lead and zinc come from galvanized or painted scrap and from nonferrous alloys or automation steels that are occasionally present in the charge. Table 2 presents estimates of minor constituents in fumes from electric arc furnaces (15). Neutron activation analyses have indicated the presence of 34 elements in cast iron fumes (21).

The pyrolysis of oil, grease, and rubber in the furnace during the melting and the decomposition of the organic ingredients of molding sand in the casting process may produce a complex mixture of organic compounds, including polyaromatic hydrocarbons (13, 17).

In the melting of metals various types of furnaces are used, e.g., cupolas, electric arc and electric induction furnaces, and each has its own emission problems. Most of the cast iron produced in Finland is melted in cupolas, which emit mainly such gases as carbon dioxide, carbon
monoxide, sulfur dioxide, nitrogen, and oxygen (16). The flue gas volume from an electric furnace is low, except when oxygen is lanced into the furnace, but the furnace workers may be exposed to extremely fine metal oxide with 90 to 95% of the particles below 0.5 μm in size (6). Exposure to zinc and other metals around the electric furnaces is likely to be so high that the installation and maintenance of efficient fume collection equipment is necessary (2, 4, 5, 12).

In the production of nodular iron abundant metal fumes are released by the triggering process. The composition of this smoke and its effect on man were investigated by Vanhoorne et al. (21). The subjects showed a decrease in vital capacity shortly after exposure to the smoke.

In a British study of industrial lung diseases of iron and steel foundry workers it was concluded that after some years furnace workers develop abnormal X-ray appearances, probably due to siderosis, and that the abnormal changes are more pronounced in steel furnacemen than in furnacemen in iron foundries (14).

The melting of copper alloys in induction furnaces or crucibles heated by oil burners may present health hazards due to the high concentration of zinc, copper, and lead oxides in the fumes. One such health hazard, zinc fume fever or “Brass founder’s ague,” which occurs from inhaling metal fumes, especially zinc oxide, has been described by Drinker (9). Several observers have found that, although concentrations of zinc fume rarely exceed

| Component | Range (%) |
|-----------|-----------|
| Fe₂O₃ | 19–44 |
| FeO | 4–10 |
| Total Fe | 16–36 |
| SiO₂ | 2–9 |
| Al₂O₃ | 1–13 |
| CuO | 5–22 |
| MgO | 2–15 |
| MnO | 3–12 |
| Cr₂O₃ | 0–12 |
| CuO | < 1 |
| NiO | 0–3 |
| PbO | 0–4 |
| ZnO | 0–44 |
| Alkaline | 1–11 |
| P | < 1 |
| S | < 1 |
| C | 2–4 |

Table 2. Qualitative spectrochemical analysis of fumes from electric arc furnaces (15).

| Element | Plant A | Plant B | Plant C |
|---------|---------|---------|---------|
| Iron | 5—50 | Major constituent | 0.05 — 0.05 | Major constituent |
| Calcium | 3—30 | 2.0 — 20 | 2.0 — 20 |
| Silicon | 0.10 — 1.00 | 0.30 — 3.0 | 0.05 — 0.50 |
| Zinc | 0.01 — 0.10 | 0.20 — 2.0 | 0.20 — 2.0 |
| Manganese | 0.50 — 5 | 0.010 — 0.10 | 0.005 — 0.05 |
| Magnesium | 0.50 — 5 | 0.05 — 0.50 | 0.01 — 0.10 |
| Sodium | 0.50 — 5 | 0.02 — 0.20 | 0.05 — 0.50 |
| Chromium | 0.50 — 5 | 0.05 — 0.50 | 0.005 — 0.05 |
| Nickel | 0.05 — 0.50 | 0.05 — 0.50 | 0.01 — 0.10 |
| Aluminum | 0.05 — 0.50 | 0.20 — 2.0 | 0.01 — 0.10 |
| Lead | 0.05 — 0.50 | 0.20 — 2.0 | 0.01 — 0.10 |
| Molybdenum | 0.05 — 0.50 | 0.05 — 0.05 | 0.005 — 0.05 |
| Copper | 0.02 — 0.20 | 0.03 — 0.30 | 0.03 — 0.30 |
| Tin | 0.01 — 0.10 | 0.01 — 0.10 | 0.01 — 0.10 |
| Titanium | 0.0005 — 0.005 | 0.0001 — 0.01 | 0.01 — 0.10 |
| Vanadium | 0.005 — 0.05 | 0.005 — 0.05 | 0.005 — 0.005 |
| Bismuth | 0.005 — 0.05 | 0.005 — 0.05 | 0.005 — 0.005 |
| Strontium | 0.005 — 0.05 | 0.005 — 0.05 | 0.005 — 0.005 |
| Cobalt | 0.0005 — 0.005 | 0.003 — 0.03 | 0.001 — 0.01 |
| Silver | 0.001 — 0.01 | 0.0005 — 0.005 | 0.0005 — 0.005 |
| Cadmium | 0.001 — 0.01 | 0.003 — 0.03 | 0.0005 — 0.005 |
| Potassium | 0.30 — 3.0 | 0.003 — 0.03 | 0.0005 — 0.005 |
Table 3. Number and production of Finnish foundries and the number of foundry workers in 1972.

| Type of production       | Number of foundries | Annual production (tons) | Number of workers | Number of workers exposed to metal fumes |
|--------------------------|---------------------|--------------------------|-------------------|-----------------------------------------|
| Steel castings           | 10                  | 18,000                   | 1,200             | 150                                     |
| Iron castings            | 53                  | 120,000                  | 3,100             | 300                                     |
| Copper alloy castings    | 64                  | 6,600                    | 950               | 500                                     |
| Aluminium alloy castings |                     | 3,300                    |                   |                                         |
| Total                    | 127                 | 5,250                    | 950               |                                         |

15 mg/m³ in nonferrous foundries, metal fume fever frequently occurs in such establishments and has even been reported from foundries with concentrations below 5 mg/m³ (1). Gleason found a condition similar to metal fume fever in workers exposed to metallic copper dust in concentrations of the order of 0.1 mg/m³ (10). It has also been suggested that the increased zinc concentration in the gastric secretion of furnace operators in brass foundries might account, in part, for the gastric complaints among them (11). High blood lead concentrations have also been reported among brass founders (18).

The main objective of the present study was to characterize the metal content of melting and casting fumes from various types of foundries. In addition the exposure of furnace workers to metals was evaluated.

MATERIAL AND METHODS

The metal fume surveys were made in 10 steel foundries, 15 iron foundries, and 11 copper alloy foundries in 1973 and 1974. The number of Finnish foundries and foundry workers and the production of the foundry industry are presented in Table 3. The number of workers exposed to metal fumes was estimated after the foundry workers were divided into an exposed and nonexposed group on the basis of job classification. Fettlers and welders were not included in the exposed group because they are mainly exposed to metal fumes from other sources, i.e., from welding and flame cutting activities.

Sampling

Three types of particulate monitoring samplers were used in the study. High-volume samplers (sampling rate 500 l/min) with Delbag Microsorban polystyrene filters and low-volume samplers (sampling rate 20 l/min) with Millipore membrane filters were operated at fixed positions in the melting and casting areas. The worker's exposure to dust was measured by means of personal samplers (sampling rate 2 l/min) equipped with Millipore filters. In each foundry a number of air samplers were in operation during two work shifts. The accuracy and precision of the sampling instruments and dust exposure estimates have been discussed elsewhere (20).

Analysis of dust samples

The present investigation was directed partly toward ascertaining which of the elements present in metal fumes can be

Table 4. Relative standard deviation of the X-ray fluorescence analyses in comparison to corresponding atomic absorption analyses. (Number of samples analyzed = 120)

| Metal analyzed | Relative standard deviation (%) |
|----------------|--------------------------------|
| Lead           | 13.7                           |
| Zinc           | 14.3                           |
| Copper         | 13.2                           |
| Nickel         | 15.8                           |
| Iron           | 15.4                           |
| Manganese      | 18.4                           |
determined to the desired precision and
accuracy at the expected level of con-
tamination. Atomic absorption, X-ray
fluorescence, and mass spectrometric meth-
ods were found suitable for determining
several major and trace components of
the particulate matter collected on a
filter.

Atomic absorption analysis requires
destruction of the filter and dissolution
of the dust sample. For the wet ashing
and dissolving, nitric acid and hydro-
chloric acid were used. The solubilities of
the 10 metals analyzed (calcium, chromium,
manganese, iron, cobalt, nickel, copper,
zinc, cadmium, and lead) were over
95%, except when calcium, chromium, or
iron were present as compounds coming
from foundry sand. The interferences in
the analysis were established as less than
15% for most of the metal fume samples
(19).

X-ray fluorescence spectrometry can
nondestructively analyze dust samples
without the need for chemical processing.
The method was applied in determining 23
elements heavier than silicon in the high-
volume samples. The X-ray methodology
was based on the mathematical correc-
tion of the sample matrix effect.

The agreement between the atomic
absorption and the X-ray fluorescence
analyses was very satisfactory. A com-
parison of the methods is presented in
table 4. The mean standard deviation in
per cent was calculated by:

| Element       | Lead | Barium | Antimony | Tin | Cadmium | Silver | Molybdenum | Zirconium | Zinc | Copper | Nickel | Cobalt | Iron | Manganese | Chromium | Chromium | Titanium | Calcium | Potassium | Sulfur | Phosphorus | Silicon |
|---------------|------|--------|----------|-----|---------|--------|------------|-----------|------|--------|--------|--------|------|-----------|----------|----------|----------|---------|-----------|--------|------------|---------|
| Average conc. | 1.2  | 1.7    | 0.78     | 0.70| 2.5     | <0.5   | <0.5       | 0.15      | 2.1  | 0.01   | 0.01   | <0.02  | 10.2| 1.7        | 1.4      | 0.13     | 0.098    | 3.5     | 1.0       | 0.11   | 0.29       |
| Analytical    | AA   | RF     | AA       | RF  | AA      | AA     | AA         | AA        | AA   | AA     | AA     | AA     | AA   | AA         | AA       | AA       | AA       | AA      | AA        | AA     | AA         |

**Table 5.** Composition of metal fumes in high-volume samples. Average percentage concentrations of the elements in samples collected in the work areas of furnacemen. (SI = steel foundry, electric induction furnace; SA = steel foundry, electric arc furnace; II = iron foundry, electric induction furnace; IC = iron foundry, cupola; CC = copper alloy foundry, crucible; AA = atomic absorption analysis; RF = X-ray fluorescence analysis)

| Element       | Lead | Barium | Antimony | Tin | Cadmium | Silver | Molybdenum | Zirconium | Zinc | Copper | Nickel | Cobalt | Iron | Manganese | Chromium | Chromium | Titanium | Calcium | Potassium | Sulfur | Phosphorus | Silicon |
|---------------|------|--------|----------|-----|---------|--------|------------|-----------|------|--------|--------|--------|------|-----------|----------|----------|----------|---------|-----------|--------|------------|---------|
| Average conc. | 1.2  | 1.7    | 0.78     | 0.70| 2.5     | <0.5   | <0.5       | 0.15      | 2.1  | 0.01   | 0.01   | <0.02  | 10.2| 1.7        | 1.4      | 0.13     | 0.098    | 3.5     | 1.0       | 0.11   | 0.29       |
| Analytical    | AA   | RF     | AA       | RF  | AA      | AA     | AA         | AA        | AA   | AA     | AA     | AA     | AA   | AA         | AA       | AA       | AA       | AA      | AA        | AA     | AA         |

**Table 5.** Composition of metal fumes in high-volume samples. Average percentage concentrations of the elements in samples collected in the work areas of furnacemen. (SI = steel foundry, electric induction furnace; SA = steel foundry, electric arc furnace; II = iron foundry, electric induction furnace; IC = iron foundry, cupola; CC = copper alloy foundry, crucible; AA = atomic absorption analysis; RF = X-ray fluorescence analysis)

| Element       | Average conc. (%) | Analytical method |
|---------------|-------------------|-------------------|
| Lead          | 1.2               | AA                |
| Barium        | <0.5              | RF                |
| Antimony      | <0.1              | RF                |
| Tin           | <0.05             | RF                |
| Cadmium       | 0.006             | AA                |
| Silver        | <0.01             | AA                |
| Molybdenium   | <0.03             | AA                |
| Zirconium     | 0.01              | RF                |
| Zinc          | 2.0               | AA                |
| Copper        | 0.097             | AA                |
| Nickel        | 0.15              | AA                |
| Cobalt        | <0.02             | AA                |
| Iron          | 10.2              | AA                |
| Manganese     | 1.7               | AA                |
| Chromium      | 1.4               | AA                |
| Chromium a    | 0.13              | AA                |
| Titanium      | 0.098             | AA                |
| Calcium       | 3.5               | AA                |
| Potassium     | 1.0               | AA                |
| Sulfur        | 0.11              | AA                |
| Phosphorus    | 0.29              | AA                |
| Silicon       | 20                | AA                |

**Table 5.** Composition of metal fumes in high-volume samples. Average percentage concentrations of the elements in samples collected in the work areas of furnacemen. (SI = steel foundry, electric induction furnace; SA = steel foundry, electric arc furnace; II = iron foundry, electric induction furnace; IC = iron foundry, cupola; CC = copper alloy foundry, crucible; AA = atomic absorption analysis; RF = X-ray fluorescence analysis)

| Number of foundries | 7   | 3   | 6   | 12  | 12  |
|---------------------|-----|-----|-----|-----|-----|
| Number of samples   | 35  | 32  | 42  | 19  | 36  |
|                     | 31  | 21  | 40  | 12  | 24  |
SD = 100 \sqrt{\frac{1}{2n} \sum_{i=1}^{n} \left( \frac{C_{RF} - C_{AA}}{C_{AA}} \right)^2 },

where \( C_{RF} \) = concentration obtained from the X-ray analysis, \( C_{AA} \) = concentration obtained from the atomic absorption analysis, and \( n \) = number of samples. The standard deviation is primarily affected by the precisions of the two methods. There was no systematic difference, except in cases of the previously mentioned limited solubility.

The accuracy of the trace element determinations was checked also by spark-source mass spectrometry. X-ray diffraction was used for the identification of crystalline compounds in the fume samples. These analytical methods have been described in detail elsewhere (19).

Table 6. Composition of metal fumes (ppm) determined in spark source mass spectrometric analyses of typical fume samples. (SA = steel foundry, electric arc furnace; SI = steel foundry, electric induction furnace; CC = copper alloy foundry, crucible)

| Element      | SA sample 1 | SA sample 2 | SI       | CC       |
|--------------|-------------|-------------|----------|----------|
| Bismuth      | 20          | 80          | 100      | 10       |
| Lead         | 20,000      | 30,000      | 8,300    | 1,000    |
| Wolfram      | 10          | 30          | 50       | 100      |
| Hafnium      | 5           | 10          | 800      | 5        |
| Dysprosium   | 5           | 5           | 10       | 30       |
| Neodymium    | 10          | 20          | 30       | 20       |
| Praseodymium | 5           | 5           | 50       | 20       |
| Lanthanum    | 5           | 10          | 30       | 60       |
| Barium       | 150         | 700         | 1,600    | 700      |
| Cesium       | 30          | 80          | 20       | 150      |
| Iodine       | 20          | 10          | 20       | 70       |
| Tellurium    | 5           | 5           | 5        | 5        |
| Antimony     | 100         | 200         | 1,500    | 300      |
| Tin          | 700         | 1,000       | 800      | 500      |
| Indium       | 5           | 10          | 20       | 15       |
| Silver       | 60          | 150         | 350      | 30       |
| Molybdenum   | 150         | 100         | 500      | 200      |
| Niobium      | 10          | 30          | 70       | 20       |
| Zirconium    | 80          | 200         | 35,000   | 100      |
| Strontium    | 100         | 400         | 800      | 1,000    |
| Rubidium     | 300         | 1,000       | 800      | 1,200    |
| Bromine      | 200         | 500         | 500      | 400      |
| Selenium     | 50          | 90          | 70       | 50       |
| Arsenic      | 500         | 1,000       | 1,300    | 700      |
| Germanium    | 50          | 30          | 150      | 100      |
| Gallium      | 50          | 100         | 200      | 100      |
| Zinc         | 40,000      | 9,000       | 1,800    | 1,200    |
| Copper       | 730         | 1,600       | 1,000    | 150      |
| Nickel       | 300         | 400         | 500      | 50       |
| Cobalt       | 200         | 300         | 500      | 400      |
| Iron         | 90,000      | 150,000     | 100,000  | 100,000  |
| Manganese    | 12,000      | 15,000      | 10,000   | 8,000    |
| Chromium     | 400         | 700         | 1,600    | 400      |
| Vanadium     | 150         | 250         | 300      | 400      |
| Titanium     | 300         | 700         | 1,500    | 1,000    |
| Scandium     | 20          | 30          | 10       | 20       |
| Calcium      | > 10,000    | > 10,000    | > 10,000 | > 10,000 |
| Potassium    | > 10,000    | > 10,000    | > 10,000 | > 10,000 |
| Chlorine     | 1,000       | 1,000       | 1,000    | 5,000    |
| Sulfur       | 5,000       | 5,000       | 3,000    | 10,000   |
| Phosphorus   | 5,000       | 5,000       | 5,000    | 5,000    |
| Silicon      | > 100,000   | > 100,000   | > 100,000| > 50,000 |
| Aluminum     | > 100,000   | > 100,000   | > 100,000| > 100,000|
| Magnesium    | > 10,000    | > 10,000    | > 10,000 | > 50,000 |
| Sodium       | > 10,000    | > 10,000    | > 10,000 | > 10,000 |
| Fluorine     | 1,000       | 1,000       | 500      | 500      |
Table 7. Average metal concentrations in the air (μg/m³) and the percentage of samples exceeding (exc.) the threshold limit value (TLV) during melting and casting — Personal sampling.

(SI = steel foundry, electric induction furnace; SA = steel foundry, electric arc furnace; II = iron foundry, electric induction furnace; IC = iron foundry, cupola; CC = copper alloy foundry, crucible)

| Metal      | TLV  | SI mean ± Se | % exc. TLV | SA mean ± Se | % exc. TLV | II mean ± Se | % exc. TLV | IC mean ± Se | % exc. TLV | CC mean ± Se | % exc. TLV |
|------------|------|--------------|-------------|--------------|-------------|--------------|-------------|--------------|-------------|--------------|-------------|
| Lead       | 150  | 50 ± 20      | 8 ± 3       | 49 ± 20      | 10 ± 3      | 41 ± 20      | 5 ± 3       | 15 ± 20      | 0 ± 20      | 100 ± 20     | 25 ± 3      |
| Cadmium    | 10   | <2 ± 0.1     | <2 ± 0.1    | <2 ± 0.1     | 0 ± 0.1     | <2 ± 0.1     | 0 ± 0.1     | 1.0 ± 0.1    | 0 ± 0.1     | 880 ± 100    | 5 ± 0.1     |
| Zinc       | 4,000| 110 ± 100    | 0 ± 10      | 220 ± 100    | 0 ± 10      | 220 ± 100    | 0 ± 10      | 47 ± 10      | 0 ± 10      | 880 ± 100    | 5 ± 0.1     |
| Copper     | 100  | 8.3 ± 0.5    | 0 ± 0.1     | 5.8 ± 0.5    | 0 ± 0.1     | 7.9 ± 0.5    | 0 ± 0.1     | 9.2 ± 0.5    | 0 ± 0.1     | 210 ± 10      | 53 ± 3      |
| Nickel     | 1,000| 10.9 ± 0.10  | 2.0 ± 0.1   | 0 ± 0.1      | 5 ± 0.1     | 5 ± 0.1      | 0 ± 0.1     | 5 ± 0.1      | 0 ± 0.1     | 32 ± 0.1     | 1.3 ± 0.1   |
| Cobalt     | 100  | <5 ± 0.5     | 0 ± 0.1     | <5 ± 0.5     | 0 ± 0.1     | <5 ± 0.5     | 0 ± 0.1     | <5 ± 0.5     | 0 ± 0.1     | <5 ± 0.5     | 0 ± 0.1     |
| Iron       | 7,000| 1,050 ± 100  | 0 ± 10      | 620 ± 100    | 0 ± 10      | 1,590 ± 100  | 3 ± 10      | 860 ± 10      | 0 ± 10      | 120 ± 10     | 0 ± 0.1     |
| Manganese  | 5,000| 80 ± 20      | 0 ± 10      | 190 ± 20     | 0 ± 10      | 130 ± 20     | 0 ± 10      | 32 ± 10      | 0 ± 10      | 130 ± 20     | 1.3 ± 0.1   |
| Chromium a | 1,000| 5 ± 0.1      | 6 ± 0.1     | 3 ± 0.1      | 4 ± 0.1     | 4 ± 0.1      | 1 ± 0.1     | 1 ± 0.1      | 0 ± 0.1     | 100 ± 20     | 20 ± 0.1    |
| Calcium    |      | 150 ± 20     | 710 ± 20    | 230 ± 20     | 140 ± 20    | 84 ± 20      |             |             |             |             |             |
| Total dust | 10,000| 5,100 ± 100  | 4 ± 10      | 6,100 ± 100  | 14 ± 10     | 8,600 ± 100  | 36 ± 10     | 10,000 ± 200 | 39 ± 10     | 6,700 ± 200  | 20 ± 10     |

Number of foundries: 7, 3, 7, 10, 11
Number of samples: 23, 22, 41, 26, 59

a Acid soluble.

RESULTS

Composition of metal fumes

The composition of fumes varied not only with the kind of metal melted, such as carbon steel, high alloy steel, cast iron, bronze, or brass, but also with the quality of scrap used and the type of melting process (table 5). Table 6 shows the concentrations of the 46 elements found in four typical fume samples examined by semiquantitative mass spectroscopy. The results are comparable with earlier analyses (21) (tables 1 and 2). The compounds identified by X-ray diffraction were iron oxides (Fe₂O₃, Fe₃O₄), manganese oxide (Mn₃O₄), zinc oxide (ZnO), and calcium oxide (CaO). In addition molding and parting materials (quartz, feldspar, chromite, olivine, zircon, talc or graphite) were found in the dust samples taken from the different work areas.

The count median particle diameter of the fumes and dust was determined to be below 1 μm by light microscopy. The number of dust count samples was 60; they were taken from 15 foundries. The type of melting process did not seem to have an appreciable effect upon the distribution of the particle size.

Metal concentrations in the ambient air during melting and casting operations

The average metal concentrations in the ambient air, as measured by personal samplers during various melting processes, are presented in table 7. The percentage of samples with concentrations exceeding the Finnish threshold limit value (TLV) for workroom air is also shown in the table. The sampling period was 6 h during a work shift. The prevalence of overexposure to lead, i.e., exposure to levels over the TLV of 150 μg/m³, among the exposed was from 5 to 10 % in steel and iron melting with electric furnaces and 25 % in copper alloy melting and casting. In the copper alloy foundries, the prevalence of workers exposed excessively (levels above the TLV of 100 μg/m³) to copper was 53 %, and
Table 8. Temporal variation of airborne metal concentrations during melting and casting. (Logarithmic standard deviation of concentrations)

| Metal       | Personal sampling (6-h period) | Low-volume sampling (6-h period) | High-volume sampling (1.4-h period) |
|-------------|-------------------------------|---------------------------------|-----------------------------------|
| Lead        | 0.23                          | 0.31                            | 0.28                              |
| Zinc        | 0.26                          | 0.28                            | 0.34                              |
| Copper      | 0.21                          | 0.24                            | 0.25                              |
| Iron        | 0.20                          | 0.21                            | 0.24                              |
| Manganese   | 0.25                          | 0.27                            | 0.33                              |
| Chromium a  | 0.21                          | 0.25                            | 0.25                              |
| Calcium a   | 0.21                          | 0.25                            | 0.29                              |
| Average of metals | 0.23                   | 0.26                            | 0.29                              |
| Total dust  | 0.18                          | 0.16                            | 0.20                              |
| Degrees of freedom | 51                        | 45                              | 101                               |

a Acid soluble.

that of workers with overexposure (above the TLV of 4,000 μg/m³) to zinc, 5%.
These prevalence figures are based on the assumption that the use of a uniform sampling scheme in each foundry produced a representative and unbiased sample.

The temporal variation of a contaminant concentration in an environment, as measured by repeated sampling, is described by the logarithmic standard deviation of the samples, i.e., the standard deviation of the logarithms of the concentrations. The log-normal distribution of concentrations in time may be applied to the statistical treatment of air sampling data when an estimation is made of the confidence intervals of the sampling results or when the prevalence of different exposure levels is estimated for a group of workers (20). The logarithmic standard deviations of metal concentrations during melting and casting are presented in table 8. The remarkable stability of the parameter can be noted. The calculations showed that the standard deviations were mainly affected by the characteristics of the melting process and the contaminant, as well as the length of the sampling period, and to a lesser degree by the precision of the dust sampling devices and metal analyses.

CONCLUSIONS
Analysis of the measurements of airborne metal concentrations from 36 foundries revealed that exposure to lead, copper, and zinc may present an appreciable health hazard to workers during melting and casting operations. This finding and the high blood lead concentrations found in furnace workers have resulted in the recommendation of periodical health examinations for melters and casters in cases when iron or steel scrap is melted in electric induction or electric arc furnaces and when copper alloy castings are melted, poured, or ground.

It is important that workers' exposure to metal fumes be prevented. Enclosing the furnace, removing the fumes during pouring and casting with efficient local exhaust systems, and attending to the general ventilation of melting and casting areas are all procedures which should help prevent such exposure.

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