MERCURY AND MERCURY COMPOUNDS

1. Exposure Data

1.1 Chemical and physical data and analysis

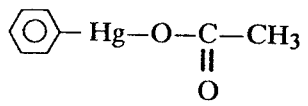
1.1.1 *Synonyms, trade names and molecular formulae*

Synonyms, trade names and molecular formulae for mercury and certain mercury compounds are presented in Table 1. The list of mercury compounds is not exhaustive, nor are those compounds necessarily the most commercially important mercury-containing substances; it includes the mercury compounds for which data on carcinogenicity are considered in this volume.

Table 1. Synonyms (Chemical Abstracts Service [CAS] names are in italics), trade names and atomic or molecular formulae of mercury and mercury compounds

Chemical name	CAS Reg. No.[a]	Synonyms and trade names	Formula
Mercury metal	7439-97-6 (8030-64-6; 51887-47-9; 92355-34-5; 92786-62-4; 123720-03-6)	Colloidal mercury; hydrargyrum; liquid silver; quecksilber; quicksilver	Hg
Mercuric acetate	1600-27-7 (6129-23-3; 7619-62-7; 19701-15-6)	*Acetic acid, mercury (2+) salt*; bis(acetyloxy)mercury; diacetoxymercury; mercuri, diacetic acid; mercury acetate; mercuric diacetate; mercury diacetate	$Hg(O-\overset{O}{\overset{\|}{C}}-CH_3)_2$
Mercuric chloride	7487-94-7	Abavit B; bichloride of mercury; Calochlor; corrosive sublimate; corrosive mercury chloride; CRC; dichloromercury; mercuric bichloride; mercuric chloride; mercuric dichloride; mercury bichloride; *mercury chloride*; mercury(2+) chloride; mercury(II) chloride; mercury dichloride; mercury perchloride; Sublimate; Sulem	$HgCl_2$
Mercuric oxide	21908-53-2 (1344-45-2; 8028-34-0)	Mercuric oxide (HgO); mercury monoxide; mercury oxide; *mercury oxide (HgO)*; mercury(II) oxide; mercury(2+) oxide; red mercuric oxide; santar; yellow mercuric oxide	HgO

Table 1 (contd)

Chemical name	CAS Reg. No.[a]	Synonyms and trade names	Formula
Dimethylmercury	593-74-8	Methyl mercury	$(CH_3)_2Hg$
Methylmercury chloride	115-09-3	Caspan; *chloromethylmercury*; mercury methyl chloride; methylmercuric chloride; methylmercury monochloride; monomethyl mercury chloride	CH_3ClHg
Phenylmercury acetate	62-38-4 (1337-06-0; 8013-47-4; 61840-45-7; 64684-45-3)	*Acetato-O-phenylmercury*; acetatophenylmercury; acetatophenylmercury; acetic acid, phenyl mercury derivative; (acetoxymercurio)benzene; acetoxyphenylmercury; mercuriphenyl acetate; phenylmercuric acetate; phenylmercury(II) acetate	

[a]Replaced CAS Registry numbers are shown in parentheses

1.1.2 *Chemical and physical properties of the pure substances*

Selected chemical and physical properties of mercury and of the mercury compounds covered in this monograph are presented in Table 2.

Mercury (also called quicksilver because of its liquid state at room temperature) was known as early as 1000 BC. The discovery in 1938 of 1 kg of the metal in 2500-year-old sand layers on the eastern coast of Greece indicates that mercury was used in the extraction of gold at an early date. Mercury was mentioned about 200 BC in India as well as in China (Han dynasty). As early as 1556 AD, five different methods for extracting mercury from its ores were reported (Simon *et al.*, 1990).

Inorganic mercury exists in three oxidation states: 0 (metallic), +1 (mercurous) and +2 (mercuric); mercurous ions usually occur as dimers (Hg^{2+}). The mercurous and mercuric states form numerous inorganic and organic chemical compounds. Organomercury compounds are those in which mercury is attached covalently to at least one carbon atom (Aylett, 1973; Simon *et al.*, 1990; WHO, 1990, 1991).

In its elemental form, mercury is a dense, silvery-white, shiny metal, which is liquid at room temperature and boils at 357 °C. At 20 °C, the vapour pressure of the metal is 0.17 Pa (0.0013 mm Hg). A saturated atmosphere at 20 °C contains 14 mg/m^3 (Simon *et al.*, 1990).

Mercury compounds differ greatly in solubility: for example, in water, the solubility of metallic mercury is 60 µg/L at 25 °C, 250 µg/L at 50 °C and 1100 µg/L at 90 °C (Simon *et al.*, 1990); the solubility of mercurous chloride is 2 mg/L at 25 °C and that of mercuric chloride is 69 g/L at 20 °C (Lide, 1991). Methylmercury chloride is more soluble in water than mercurous chloride by about three orders of magnitude, owing to the very high solubility of the methylmercury cation in water. Certain species of mercury, including metallic mercury and the halide compounds of alkylmercury compounds, are soluble in non-polar solvents

Table 2. Chemical and physical properties of mercury and mercury compounds

Chemical name	Relative atomic/ molecular mass	Melting-point (°C)	Typical physical description	Density	Solubility
Mercury metal	200.59	– 38.87	Silvery-white, heavy, mobile, liquid metal	13.546 (20 °C)	Soluble in nitric acid, sulfuric acid upon heavy boiling, lipids, pentane; insoluble in dilute hydrochloric, hydrobromic and hydroiodic acids, water (2 µg/L at 30 °C), ethanol, diethyl ether, cold sulfuric acid
Mercuric acetate	318.7	178–180 (decomposes)	White crystals or crystalline powder	3.27	Soluble in water (250 g/L at 10 °C), ethanol, acetic acid
Mercuric chloride	271.50	276	Colourless, rhombic, odourless, crystal or white powder	5.44 (25 °C)	Soluble in water (69 g/L at 20 °C), methanol, ethanol, amyl alcohol, acetone, formic acid, acetic acid, the lower acetate esters, diethyl ether, benzene, glycerol; slightly soluble in carbon disulfide and pyridine
Mercuric oxide	216.6	500 (decomposes)	Yellow or red, *ortho*-rombic, odourless crystalline powder	11.14	Insoluble in water (53 mg/L at 25 °C), soluble in acids; insoluble in ethanol, diethyl ether, acetone, alkali, ammoniac
Dimethylmercury	230.66	NR	Colourless liquid with a sweet odour	3.19 (20 °C)	Soluble in ethanol and diethyl ether; insoluble in water
Methylmercury chloride	251.10	167–168	White crystalline solid with a disagreeable odour	4.06	Slightly soluble in water
Phenylmercury acetate	336.75	150	White to cream-coloured, small, odourless, lustrous crystalline solid (prism, powder, leaflet)	2.4	Soluble in ethanol, benzene, glacial acetic acid, acetone, ammonium acetate, chloroform, diethyl ether; slightly soluble in water (4.37 g/L) at 25 °C)

From Aylett (1973); Lide (1991); Alfa Products (1990); Budavari (1989); Sax & Lewis (1987); Drake (1981); Singer & Nowak (1981); Worthing (1987); Strem Chemicals (1992). NR, not reported

(WHO, 1991). Mercury vapour is more soluble in plasma, whole blood and haemoglobin than in distilled-water or isotonic saline (Hursh, 1985).

Mercury forms monovalent and divalent compounds with the halogens fluorine, chlorine, bromine and iodine. It also forms monovalent and divalent compounds with sulfur. From the biochemical point of view, the most important chemical property of mercuric mercury and alkylmercury compounds may be their high affinity for sulfhydryl groups (Simon *et al.*, 1990; WHO, 1991).

The main volatile mercury species in air is metallic mercury, but dimethylmercury may also occur. Mercury compounds such as mercuric chloride and methylmercury hydroxide are also relatively stable in fresh water, including snow, rain and standing and flowing water. $HgCl_4^{2-}$ is the dominant form of mercury in seawater (WHO, 1991).

1.1.3 *Technical products and impurities*

Metallic mercury—purities: triple-distilled grade, ≥ 99.99% (4N); ACS reagent grade, 99.995–99.9995%; electronic grade, 99.9998%; ultra-high purity grade, 99.99999–99.999999% (Alfa Products, 1990; CERAC, Inc., 1991; Aldrich Chemical Co., 1992; Strem Chemicals, 1992; Atomergic Chemetals Corp., undated; D.F. Goldsmith Chemical & Metal Corp., undated); impurities (%): Ag, 0.0001; Fe, 0.00005; Pb, 0.00001; Cu, 0.00001; Cd, 0.00001; Zn, 0.00005 (Janssen Chimica, 1990).

Mercuric acetate—purities: 97–99.9%; ACS reagent grade, ≥ 98% (Janssen Chimica, 1990; CERAC, Inc., 1991; Aldrich Chemical Co., 1992; Strem Chemicals, 1992).

Mercuric chloride—purities: ACS reagent grade, 99%; 99.9–99.9995%; impurities (%): Fe, 0.002; Pb, 0.002; Cu, 0.002; Ca, max. 0.002 (Janssen Chimica, 1990; CERAC, Inc., 1991; Aldrich Chemical Co., 1992; Strem Chemicals, 1992).

Mercuric oxide—purities: high-purity, 99.999%; ACS grade (yellow or red), 99% (CERAC, Inc., 1991; Aldrich Chemical Co., 1992).

Dimethylmercury— purities, 95–98% (Aldrich Chemical Co., 1992; Strem Chemicals, 1992)

Methylmercury chloride—purity: ≥ 95% (Alfa Products, 1990)

Phenylmercury acetate—purities: 97–97.5%; practical, US Pharmacopeia and National Formulary grades (Janssen Chimica, 1990; Aldrich Chemical Co., 1992; Strem Chemicals, 1992; D.F. Goldsmith Chemical & Metal Corp., undated). Some of the trade names associated with phenylmercuric acetate include: Agrosan D; Agrosan GN5; Algimycin; Aligimycin 200; Anticon; Antimucin WBR; Antimucin WDR; Bufen; Bufen 30; Caswell No. 656; Cekusil; Celmer; Ceresan; Ceresol; Contra Creme; Dyanacide; Femma; FMA; Fungicide R; Fungitox OR; Gallotox; Hexasan; HL-331; Hostaquick; Intercide 60; Intercide PMA 18; Kwiksan; Lerophyn; Leytosan; Liquiphene; Lorophyn; Meracen; Mercron; Mercuron; Mergal A 25; Mersolite; Mersolite 8; Mersolite D; Metasol 30; Neantina; Norforms; Nuodex PMA 18; Nylmerate; Pamisan; Panomatic; Phenmad; Phix; PMA; PMA 220; PMAC; PMAcetate; PMAL; PMAS; Programin; Purasan-SC-10; Puraturf 10; Quicksan; Quicksan 20; Riogen; Ruberon; Samtol; Sanitized SPG; Sanitol; Sanmicron; Scutl; SC-110; Seed Dressing R; Seedtox; Setrete; Shimmerex; Spor-Kl; Spruce Seal; Tag; Tag 331; Tag Fungicide; Tag HL-331; Trigosan; Troysan 30; Troysan PMA 30; Verdasan; Volpar; Zaprawa Nasienna R; Ziarnik

Impurities of mercury compounds that are the subjects of other monographs are lead (IARC, 1987a) and cadmium (this volume, p. 119).

1.1.4 *Analysis*

Selected methods for the determination of mercury in various media are presented in Table 3. Other methods have been reviewed (WHO, 1990, 1991).

Table 3. Methods for the analysis of mercury in various media

Sample matrix	Sample preparation	Assay procedure	Limit of detection	Reference
Air	Collect on Hydrar sorbent; desorb with nitric then hydrochloric acids	CVAA	0.03 µg/sample	Eller (1989)
Drugs	Digest in water–hydrochloric acid–nitric acid; heat; cool; add potassium dichromate	AAS	NR	Helrich (1990a)
Liquid waste, groundwater	Digest with sulfuric and nitric acids; add potassium permanganate and potassium persulfate solutions; heat; cool; reduce with sodium chloride–hydroxylamine sulfate; add stannous sulfate and aerate	CVAA	0.2 µg/L	US Environmental Protection Agency (1986a) (Method 7470); Helrich (1990b)
		AAS	NR	
Soil, sediment, solid and semisolid waste	Digest with distilled water and aqua-regia; heat; cool; add potassium permanganate and heat; cool; add sodium chloride–hydroxylamine sulfate; or digest as above	CVAA	0.2 µg/L	US Environmental Protection Agency (1986b) (Method 7471)
Blood, urine	Reduce inorganic and organic mercury to Hg^0 with reducing agents (e.g., $SnCl_2$); estimate organic mercury as difference between total and inorganic	CVAA	0.5 µg/L	Magos & Clarkson (1972)
	Reduce total mercury with sodium borohydride; enrich with an amalgamation device (Au/Pt gauze)	CVAA	0.3 µg/L urine or blood	Angerer & Schaller (1988)
Blood, urine, hair, tissues	Automated form of the method of Magos and Clarkson (1972)	CVAA	2.5 µg/kg	Farant *et al.* (1981)

Abbreviations: CVAA, flameless cold vapour atomic absorption spectroscopy; AAS, flame or flameless atomic absorption spectroscopy; NR, not reported

The original 'dithizone' method has been replaced by atomic absorption spectrometry, neutron activation analysis, atomic fluorescence spectrometry, inductively coupled plasma emission spectrometry and spark source spectrometry. Cold vapour atomic absorption is the most popular and reliable technique. Metallic mercury and inorganic mercury compounds and organomercury compounds in biological and environmental specimens are converted by

reducing agents (tin chloride, cadmium chloride–tin chloride, sodium borohydride) to metallic mercury and released as mercury vapour, which is either pumped directly through the quartz cell of the atomic absorption spectrophotometer or analysed after amalgamation on a silver–platinum gauze. The organic mercury content of the sample is given by the difference between total and inorganic compounds. For routine analysis, especially for blood and urine samples, the total mercury content is determined using sodium borohydride as the reducing agent, avoiding time-consuming decomposition of the samples (Angerer & Schaller, 1988).

The neutron activation procedure for analysis in urine is regarded as the most accurate and sensitive procedure and is usually used as the reference method (WHO, 1991).

Helrich (1990a) described several methods (atomic absorption spectrometry, gravimetry, titrimetry) for the determination of mercury and mercury compounds in various forms of drugs (solutions of organomercury compounds, ointments, calomel tablets, tablets containing purgative drugs). Helrich (1990c) described methods (flameless atomic absorption spectrometry, colorimetric dithizone) for the determination of mercury in food and fish and gas chromatographic methods for the determination of methylmercury compounds in fish and shellfish. Helrich (1990d) described methods (volatilization, precipitation, titrimetry, gravimetry) for the determination of mercury in organomercury seed disinfectants.

Pre-analytical and analytical procedures involve the risk of losing mercury from the sample, or contamination. Owing to the small amounts of mercury (in nanogram or even sub-nanogram ranges) in specimens, especially of biological materials, careful quality control must be undertaken. Control materials (blood and urine) are commercially available for intralaboratory quality control, and national and international intercomparison programmes are offered for external quality control. Reference materials covering the range of samples obtained for monitoring are commercially available for both environmental and biological samples (see WHO, 1991); however, the available control materials for daily use and reference materials do not cover the demand for different mercury species.

(a) Metallic mercury

Analytical methods for mercury in air can be divided into instant reading methods and methods with separate sampling and analysis stages. One direct ('instant') reading method is based on the 'cold vapour atomic absorption' technique, which measures the absorption of mercury vapour by ultraviolet light at a wavelength of 253.7 nm. Most of the atomic absorption spectroscopy procedures have a detection limit in the range of 2–5 $\mu g/m^3$ mercury (WHO, 1991).

Another direct reading method employed increasingly is a special gold amalgamation technique, which has been used in a number of studies to evaluate the release of metallic mercury vapour into the oral cavity from amalgam fillings (WHO, 1991). The method is based on an increase in the electrical resistance of a thin gold film after absorption of mercury vapour. The detection limit is 0.05 ng mercury (McNerney *et al.*, 1972).

In an analytical method based on separate sampling and analysis, air is sampled in two bubblers in series containing sulfuric acid and potassium permanganate. The mercury is subsequently determined by cold vapour atomic absorption. With this method, the total mercury in the air, and not just mercury vapour, can be measured. Another sampling

technique involves solid absorbents. Amalgamation techniques using gold have been shown to collect mercury vapour efficiently (WHO, 1991).

Air can be sampled for the analysis of mercury by static samplers or by personal monitoring (WHO, 1991). In a comparison of results obtained using static samplers and personal samplers, the latter yielded higher time-weighted average concentrations than the former in most work places (Roels *et al.*, 1987).

(*b*) *Mercuric chloride and mercuric acetate*

A dual-stage differential atomization atomic absorption technique was developed to allow speciation of 10 mercury-containing compounds, including mercuric chloride and mercuric acetate, in aqueous solution and biological fluids (Robinson & Skelly, 1982).

(*c*) *Methylmercury compounds*

Gas chromatography is usually used for selective measurement of methylmercury compounds and other organomercury compounds, particularly in fish tissues. An alternative approach is to separate methylmercury compounds from inorganic mercury compounds by volatilization, ion exchange or distillation and to estimate them by nonselective methods (e.g. atomic absorption) (WHO, 1990).

(*d*) *Phenylmercury acetate*

Phenylmercury acetate was determined in pharmaceutical products by reverse-phase high-performance liquid chromatography of a morpholinedithiocarbamate derivative. The method is specific and sensitive and has been used to determine a number of phenylmercury salts in pharmaceutical products (Parkin, 1987).

1.2 Production and use

1.2.1 *Production*

Worldwide production data for mercury are presented in Table 4. Over the last 10 years, production figures have changed only slightly. Current production in the USA is approximately 53% of the potential capacity: Because of reduced demand, many mines and smelting plants are no longer operating or have greatly cut back production. A large proportion of Mexican production has been exported to Brazil and Argentina. China claims to have the largest mercury resources in the world; most of the Chinese production is exported to the USA. Italy, once a large producer of mercury, now imports it from Algeria and Yugoslavia. The Almadén mercury mine in Spain accounted for 90% of the total output of the European Economic Community for many years, and most of the production has been exported to Belgium, France, Luxembourg and the USA. Whereas in 1986 the former USSR exported most of its mercury, almost the entire production is now reserved for domestic use (Simon *et al.*, 1990; WHO, 1991).

(*a*) *Metallic mercury*

All mercury ores are relatively low-grade, the average mercury content being about 1%. Mercury ores lie close to the Earth's surface, so that the required mining depth is about 800 m

Table 4. Worldwide production of mercury (tonnes)

Country	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
Algeria	1049	1055	506	841	877	386	828	587	795	690	773	690	586	637	431
China[a]	700	600	700	800	800	800	850	800	800	850	900	940	880	800	700
Czechoslovakia	183	196	171	159	153	151	144	152	158	168	164	168	131	126	120
Dominican Republic	18	17	21	6	3	2	4	2	1	NR	< 0.5	< 0.5	< 0.5	NR	NR
Finland	22	39	46	75	67	71	65	80	130	147	147	130	159	141	125
Germany	99	84	91	56	76	53	NR	NR	NR	NR	NR	NR	NR	NR	NR
Italy	14	3	NR	3	252	159	NR	NR	NR	NR	NR	NR	NR	NR	NR
Mexico	333	76	68	145	240	295	221	384	264	345	124	345	651	735	720
Russia[a]	2200	2000	2000	1800	1700	1700	1700	1600	1600	1500	1650	2300	2300	2100	1900
Spain	926	1020	1116	1721	1560	1540	1416	1520	1539	1471	1553	1716	1380[a]	425[a]	450
Turkey	162	173	163	154	204	246	162	182	226	262	202	97	197	60	60
USA	974	834	1018	1058	962	888	864	657	570	470	34	379	414	NR	NR
Former Yugoslavia	108	NR	NR	NR	NR	NR	52	72	88	75	67	70	51	37	30
Total[b]	6788	6097	5900	6818	6894	6291	6306	6036	6171	5978	5906	6835	6749	5061	4536

From Simon *et al.* (1990); Reese (1992a). NR, not reported

[a]Estimated values

[b]Totals may not add up because some values are estimates.

at most. The most important ore for mercury extraction is α-mercuric sulfide (red) (cinnabar, cinnabarite). The ore is heated with lime in retorts or furnaces to liberate the metal as vapour, which is cooled in a condensing system to form metallic mercury. Other methods include leaching of ores and concentrates with sodium sulfide and sodium hydroxide and subsequent precipitation with aluminium or by electrolysis; alternatively, mercury in ore is dissolved in a sodium hypochlorite solution, the mercury-laden solution is then passed through activated carbon to absorb the mercury, and the activated carbon is heated to produced metallic mercury. The latter methods are, however, no longer used (Drake, 1981; Simon *et al.*, 1990).

Industrial waste containing mercury also contributes to its production. The majority of plants using chloralkali electrolysis employ liquid mercury cathodes, resulting in residues containing 10% mercury or more. In addition to this major secondary source, mercury batteries, mercury fluorescent tubes, electrical switches, thermometer breakage and obsolete rectifiers should be regarded as sources of mercury. Scrap material and industrial and municipal wastes and sludges containing mercury are treated in much the same manner as ores to recover mercury. Scrap products are first broken down to liberate metallic mercury or its compounds. Heating in retorts vaporizes the mercury which, upon cooling, condenses to high-purity metallic mercury. Industrial and municipal sludges and wastes may be treated chemically before roasting (Drake, 1981; Simon *et al.*, 1990). Although the overall production of mercury has decreased over the last 20 years, sufficient potential uses, and therefore secondary sources, remain for the foreseeable future owing to the unique properties of the metal (Simon *et al.*, 1990).

Most of the metallic mercury on the market is 4N material (99.99% mercury). The most common purification methods include: *Dry oxidation*—with this method, readily oxidizable constituents such as magnesium, zinc, copper, aluminium, calcium, silicon and sodium can be removed by passing air or oxygen through the liquid metal; the oxides that form have a lower density than mercury and float on its surface, where they can be removed by filtration, scooping or by removing the mercury from the bottom. *Wet oxidation*—in an aqueous medium, mercury is dissolved by adding nitric, hydrochloric or sulfuric acid (see IARC, 1992) with dichromate, permanganate or peroxide to oxidize impurities; the aqueous solution can be separated from the mercury by decanting, and traces of water can be removed with calcium oxide. *Electrolytic refining*—perchloric acid containing mercuric oxide serves as the electrolyte. *Distillation*—mercury can be evaporated under atmospheric pressure or *in vacuo*; elements with a lower vapour pressure than mercury can be separated in this way. In many cases, mercury must be distilled repeatedly to achieve the desired purity (Simon *et al.*, 1990).

(*b*) *Mercuric acetate*

Mercuric acetate is produced by dissolving mercuric oxide in dilute acetic acid and concentrating the resulting solution (Simon *et al.*, 1990).

(*c*) *Mercuric chloride*

Mercuric chloride is prepared by the direct oxidation of mercury with chlorine gas, the same method (chamber method) that is used to prepare mercurous chloride, except that, for

mercuric chloride, an excess of chlorine gas is used to ensure complete reaction to the higher oxidation state; the reaction is carried out at temperatures > 300 °C. The escaping sublimate vapour is condensed in cooled receivers, where it settles as fine crystals. Excess chlorine is absorbed by sodium hydroxide in a tower; a very pure product results from use of this method (Singer & Nowak, 1981; Simon *et al.*, 1990).

Mercuric chloride can also be prepared from other mercury compounds. For example, if mercuric sulfate is heated in the dry state with sodium chloride, the evolving mercuric chloride vapour can be condensed to a solid in receivers (Simon *et al.*, 1990).

(*d*) *Mercuric oxide*

Mercuric oxide can be prepared *via* the anhydrous route by reaction of mercury and oxygen at 350–420 °C under oxygen pressure or by thermal decomposition of mercury nitrates at about 320 °C. Production *via* the wet route, by precipitation, is more important commercially: The oxide is precipitated from solutions of mercuric salts by addition of caustic alkali (usually mercuric chloride solutions with sodium hydroxide). Whether the yellow or the red form is obtained depends on the reaction conditions: Slow crystal growth during heating of mercury with oxygen or during thermal decomposition of mercurous nitrate leads to relatively large crystals (i.e. the red form); rapid precipitation from solution gives finer particles (i.e. the yellow form) (Simon *et al.*, 1990).

(*e*) *Dimethylmercury*

The reaction of methyl iodide with mercury–sodium amalgam gives dimethylmercury (Drake, 1981).

(*f*) *Methylmercury chloride*

Organomercury compounds can be synthesized by reaction of Grignard reagents with mercury halides. In order to obtain pure products, the mercury salt and the Grignard reagent must contain the same anion (R is an aromatic or aliphatic group and X is a halogen):

$$RMgX + HgX_2 \rightarrow RHgX + MgX_2$$

Organic mercury compounds can also be produced by the reaction of sulfinic acids (RSO_2H) or their sodium salts with mercury halides (Simon *et al.*, 1990).

(*g*) *Phenylmercury acetate*

Phenylmercury acetate is prepared by refluxing a mixture of mercuric acetate and acetic acid in a large excess of benzene (see IARC, 1987b), in what is generally referred to as a 'mercuration reaction'. The large excess of benzene is necessary because more than one hydrogen on the benzene ring can be replaced. The technical grade of phenylmercury acetate contains about 85% pure compound; the remaining 15% is di- and tri-mercurated products, which are less soluble than phenylmercury acetate and are removed by recrystallization. The product is isolated after distillation of excess benzene and acetic acid (Singer & Nowak, 1981).

1.2.2 *Use*

(*a*) *Metallic mercury*

The patterns of use of mercury in Germany and in the USA in different periods are presented in Tables 5 and 6. A major use of mercury is as a cathode in the electrolysis of sodium chloride solution to produce caustic soda and chlorine gas (chloralkali industry). About 50 tonnes of liquid metal are used in each of these plants. In most industrialized countries, stringent procedures have been taken to reduce losses of mercury. Mercury is used widely in the electrical industry (in lamps, arc rectifiers and mercury battery cells), in domestic and industrial control instruments (in switches, thermostats, barometers) and in other laboratory and medical instruments. Another use of liquid metallic mercury is in the extraction of gold from ore concentrates or from recycled gold articles (Kaiser & Tölg, 1984; Sax & Lewis, 1987; Budavari, 1989; Agency for Toxic Substances and Disease Registry, 1989; Simon *et al.*, 1990; WHO, 1991).

Table 5. Use patterns for mercury in Germany (%)

Use category	1973	1976	1979	1982	1985
Chloralkali industry	37	32	28	18	23
Catalysis	13	3	8	7	2
Paints, dyes	6	4	3	1	< 1
Pesticides	9	9	11	2	5
Electrical engineering	8	13	14	21	36
Control instruments and apparatus construction	4	3	4	7	4
Chemicals and reagents	7	14	14	21	None
Medicine	7	8	8	9	13
Miscellaneous	9	14	10	14	17
Total (tonnes)	346	325	313	257	182

From Simon *et al.* (1990)

Table 6. Use patterns for mercury in the USA (%)

Use category	1985	1987	1990	1991	1992
Electrical	64	56	35	33	29
Chloralkali industry	14	12	33	33	34
Paint	9	10	15		
Industrial and control instruments	6	6	7	34	37
Other	7	16	10		

From Carrico (1985, 1987); Reese (1990, 1991, 1992b)

WHO (1991) estimated that, in industrialized countries, about 3% of the total consumption of mercury is in dental amalgams. Dental amalgam is a mixture of mercury with a silver–tin alloy. Most conventional amalgams consist of approximately 45–50% mercury, 25–35% silver, 2–30% copper and 15–30% tin. In industrialized countries, the alloy with mercury is now mixed in sealed capsules and applied in the prepared tooth cavity, where excess amalgam (< 5%) is removed immediately before or during condensation of the plastic mix. The amalgam begins to set within minutes of insertion and must therefore be carved to a satisfactory anatomical form within that period of time. Polishing with rotating instruments can take place after 24 h. Amalgam has been used extensively as a tooth-filling material for more than 150 years and accounts for 75–80% of all single tooth restorations. It has been estimated that each US dentist in private practice uses an average of 0.9–1.4 kg of amalgam per year (Sax & Lewis, 1987).

(*b*) *Mercuric acetate*

Mercuric acetate is used in the synthesis of organomercury compounds, as a catalyst in organic polymerization reactions and as a reagent in analytical chemistry (Singer & Nowak, 1981; Simon *et al.*, 1990).

(*c*) *Mercuric chloride*

Mercuric chloride is an important intermediate in the production of other mercury compounds, e.g. mercurous chloride, mercuric oxide, mercuric iodide, mercuric ammonium chloride and organomercury compounds. It is also used as a catalyst in the synthesis of vinyl chloride, as a depolarizer in dry batteries and as a reagent in analytical chemistry. It has a minor importance as a wood preservative and retains some importance as a fungicide. Other uses (e.g. as a pesticide or in seed treatment) have declined considerably (Simon *et al.*, 1990).

(*d*) *Mercuric oxide*

Red mercuric oxide in particular has become increasingly important commercially in the production of galvanic cells with mercuric oxide anodes in combination with zinc or cadmium cathodes. These cells are distinguished from other systems in that their voltage remains constant during discharge: they are used mainly as small, button-shaped batteries, e.g. for hearing devices, digital watches, exposure meters, pocket calculators and security installations. Additional uses of mercuric oxide are in the production of mercury[II] salts, by treatment with the corresponding acids, and as a reagent in analytical chemistry. Its importance as an additive to antifouling paint for ships and in medicine (e.g. for eye ointment) has decreased (Simon *et al.*, 1990).

(*e*) *Dimethylmercury*

Dimethylmercury is an environmental contaminant that finds limited use as a laboratory reagent (Budavari, 1989; WHO, 1990).

(*f*) *Phenylmercury acetate*

The primary use for phenylmercury acetate has been in latex paint; it is used at low levels as a preservative and at higher levels to protect the dry film from fungal attack or mildew. It

can be used for these purposes in other aqueous systems, such as inks, adhesives and caulking compounds. Phenylmercury acetate is also used as the starting material in the preparation of many other phenylmercury compounds, which are generally prepared by double-decomposition reactions with the sodium salts of the desired acid groups in aqueous solution. It is also used as a slimicide in paper mills, as a catalyst for the manufacture of certain polyurethanes, as a research chemical (Singer & Nowak, 1981; Sax & Lewis, 1987; Budavari, 1989; Campbell *et al.*, 1992), in contraceptive gels and foams, as a preservative (including in shampoos: see IARC, 1993), as a disinfectant and as a denaturant in ethanol.

(*g*) *Other mercury-containing compounds*

A number of mercury-containing compounds have been used as topical antiseptics (mercuric iodide, mercuric cyanide, ammoniated mercuric chloride, merbromin [mercurochrome] and merthiolate) and as fungicides, mildewcides, insecticides and germicides (mercurous chloride, phenylmercury oleate, phenylmercury propionate, phenylmercury naphthenate, phenylmercury lactate, phenylmercury benzoate and phenylmercury borate) (Singer & Nowak, 1981; Sax & Lewis, 1987; Budavari, 1989; Simon *et al.*, 1990). A number of alkylmercury compounds are also used as fungicides in the treatment of seed grains (ethylmercury chloride, ethylmercury *para*-toluenesulfonanilide, ethylmercury acetate, ethylmercury 2,3-dihydroxypropyl mercaptide, bis[methylmercury]sulfate, methylmercury dicyandiamide and methoxyethylmercury acetate or chloride) (Greenwood, 1985; Sax & Lewis, 1987). Mercuric fulminate is used as a detonator in explosives (Singer & Nowak, 1981).

Mercury-containing creams and soaps have long been used by dark-skinned people in some regions to obtain a lighter skin tone. The soaps contain up to 3% mercuric iodide, and the creams contain up to 10% ammoniated mercury. Both the soap and the cream are applied to the skin, allowed to dry and left overnight (WHO, 1991).

1.3 Occurrence

1.3.1 *Natural occurrence*

Metallic mercury occurs as a part of the Earth's natural geochemistry, comprising 50 μg/kg of the Earth's crust. It is 62nd in order of abundance (Aylett, 1973). It is found in the form of the sulfide, as cinnabar ore, which has an average mercury content of 0.1–4%; it is also present in the form of geodes of liquid mercury and as impregnated schist or slate. The major source of atmospheric mercury is suggested to be degassing of the Earth's crust and the oceans (Lauwerys, 1983; Berlin, 1986; WHO, 1990).

Methylmercury compounds are formed in aquatic and terrestrial environments from the methylation of metallic mercury and mercuric mercury. Methylation is likely to occur in bacteria in sediments of sea- or lakebeds. The methylmercury compounds formed are accumulated by aquatic organisms, and dimethylmercury gases are formed by degradation and released into the air. Dimethylmercury can be decomposed in the atmosphere by acidic rainwater to monomethylmercury compounds and thus re-enter the aquatic environment (Berlin, 1986). Little is known about the quantitative aspects of these cycles, and the local load of methylmercury compounds can be increased considerably by anthropogenic sources (Clarkson *et al.*, 1988a; WHO, 1990).

1.3.2 *Occupational exposures*

Approximately 70 000 workers in the USA are regularly exposed to mercury (Campbell *et al.*, 1992). Table 7 lists some potential occupational exposures to the various forms of mercury. Mercury vapour is the commonest form to which workers are exposed in industries such as mining and processing of cinnabar ore and the chloralkali industry, where brine is electrolysed in mercury cells in which the cathode is a flowing sheet of liquid mercury. The manufacture and use of liquid mercury-containing instruments constitute another source of occupational exposure to mercury vapour through breakage, spillage or careless handling. Dental personnel are exposed to mercury vapours through the preparation of dental amalgams (Stokinger, 1981; Clarkson *et al.*, 1988b).

Table 7. Products, industries and jobs in which there is potential occupational exposure to mercury

Metallic mercury	Inorganic mercury compounds	Organomercury compounds
Dental medicine	Disinfectants	Bactericides
Batteries	Paints and dyes	Embalming preparations
Barometers	Explosives	Paper manufacture
Boiler makers	Fireworks manufacture	Farmers
Calibration instruments	Fur processing	Laundry and diaper services
Caustic soda production	Ink manufacture	External antiseptics
Carbon bush production	Chemical laboratory workers	Fungicides
Ceramics	Percussion caps and detonators	Insecticides manufacture
Chloralkali production	Spermicidal jellies	Seed handling
Ultrasonic amplifiers	Tannery workers	Wood preservatives
Direct current meters	Wood preservatives	Germicides
Infrared detectors	Tatooing materials	
Electrical apparatus	Taxidermists	
Electroplating	Vinyl chloride production	
Fingerprint detectors	Embalming preparations	
Silver and gold extraction	Mercury vapour lamps	
Jewellery	Antisyphilitic agents	
Fluorescent, neon, mercury arc lamps	Thermoscopy	
	Silvering of mirrors	
Manometers	Photography	
Paints	Perfumery and cosmetics	
Paper pulp manufacture	Acetaldehyde production	
Photography		
Pressure gauges		
Thermometers		
Semiconductor solar cells		

From Campbell *et al.* (1992)

Mixed exposure to aerosols of organic or inorganic mercury compounds also occurs: Chlorine in combination with mercury vapour, produced in chloralkali industries, forms mercuric chloride aerosols. Another source of occupational exposure is in pathology labo-

ratories, where mercuric chloride is used with formalin as a histological fixative. Exposure to aerosols of methyl- and ethylmercury compounds has been described in connection with the manufacture and use of mercuric salts and during seed treatment (Berlin, 1986). Disinfectant manufacturers, fungicide manufacturers, seed handlers, farmers, lumberjacks, pharmaceutical industry workers and wood preservers may be exposed to organomercury compounds (Campbell *et al.*, 1992).

Data on exposure to mercury in air and the results of biological monitoring in various industries and occupations are described below and summarized in Tables 8 and 9 (pp. 258–260). It should be noted that the concentrations of mercury detectable in the general working environment are generally lower than those to which individual workers are exposed, as detected by personal air sampling. This is due to the fact that mercury can accumulate on the clothes, hair and skin of workers, creating a situation which has been called 'micro-environmental exposure'. In a Belgian manufacturing plant, mercury concentrations in the general work environment were between 8 and 88 μg/m^3, while personal samples from the workers showed concentrations ranging from 16 to 680 μg/m^3 (see Ehrenberg *et al.*, 1991).

Biological monitoring of people occupationally exposed to mercury vapours and inorganic mercury compounds, by measuring mercury in urine and blood mercury, reflects recent exposure. Occupational and environmental exposure to methylmercury compounds can be estimated from blood mercury levels. Mercury in hair can be used as an indicator of environmental exposure to methylmercury compounds but not for monitoring exposure to metallic mercury and inorganic mercury compounds (Elinder *et al.*, 1988).

(*a*) *Chloralkali plants*

Exposures in chloralkali plants have been reviewed (WHO, 1976). In recent studies, covering mainly Swedish plants, average urinary mercury concentrations of 50–100 μg/L were reported (WHO, 1991).

In a study in the USA and Canada of 567 male workers in 21 chloralkali plants, the mean atmospheric concentration of mercury was 65 μg/m^3 (SD, 85); in 12 plants, the time-weighted average concentration was 100 μg/m^3 or less, while in the remainder some employees were exposed to higher concentrations. At an ambient air concentration of 100 μg/m^3, the concentration in blood was about 60 μg/L and that in urine about 200 μg/L. In 117 control subjects, blood mercury concentrations were lower than 50 μg/L; in 138 controls, urinary mercury concentrations were generally less than 10 μg/L (corrected to specific gravity) (Smith *et al.*, 1970).

The airborne concentrations of mercury in a chloralkali plant in Italy were between 60 and 300 μg/m^3; the mean urinary concentration in 55 workers exposed for 11.5 ± 8.8 years in cell preparation rooms was 158 μg/L (range, 0–762 μg/L) and that in 17 workers exposed to mercury irregularly for 15.2 ± 10.7 years was 40.3 μg/L (range, 0–96 μg/L) (Foà *et al.*, 1976).

The atmospheric concentrations of mercury in a chloralkali plant in Sweden in 1975 were 64 μg/m^3 (range, 36–112 μg/m^3); the mean blood mercury concentration in 13 workers employed for 0.5–5.5 years was 238 nmol/L (47.6 μg/L), and the mean urinary concentration in the same subjects was 808 nmol/L (range, 369–1530 nmol/L) [161 μg/L; range, 74–306 μg/L]. Two years later, after improvement of the ventilation systems in the plant, the mean concentrations of mercury were 22.6 (range, 15–43) μg/m^3 in air, 92 nmol/L

(18.4 μg/L) in blood and 196 (range, 117–327) nmol/L [39.2 μg/L; range, 23–65 μg/L] in urine in a group of 16 workers who had been employed for one to seven years (Lindstedt *et al.*, 1979).

Exposure to mercury in a chloralkali plant in Sweden was studied during ordinary maintenance work and in workers hired for a special repair task during a temporary production shutdown. A group of 14 normal maintenance workers were exposed to mean air concentrations of mercury of 65 μg/m^3 (range, 24–123 μg/m^3) and had a mean blood mercury concentration of 73 nmol/L, ranging from 45 to 150 nmol/L [14.6 μg/L; range, 9–30 μg/L], and a mean urinary concentration of 32 nmol/mmol (57.2 μg/g) creatinine (range, 16–43 nmol/mmol; 28.6–76.9 μg/g). The 16 special repair workers were exposed to a mean air concentration of 131 μg/m^3 (range, 38–437 μg/m^3) and had a mean blood mercury concentration of 148 nmol/L, ranging from 85 to 240 nmol/L [29.6 μg/L; range, 17–48 μg/L), and a mean urinary mercury concentration of 6.1 nmol/mmol (10.9 μg/g) creatinine (range, 4.7–8.7 nmol/mmol; 8.4–15.5 μg/g) (Sällsten *et al.*, 1992).

In an epidemiological study of 1190 workers in eight Swedish chloralkali plants (described in detail on p. 271), biological monitoring data indicated a substantial reduction in exposure to mercury with time, from about 200 μg/L in urine during the 1950s to 150 μg/L in the 1960s and less than 50 μg/L in 1990 (Barregård *et al.*, 1990). In another Swedish chloralkali plant, the average levels of mercury in air were 25–50 μg/m^3 throughout the 1980s. The mean concentrations of mercury in 26 male workers were 252 nmol/L (50.4 μg/L) in urine, 48 nmol/L (9.6 μg/L) in plasma and 78 nmol/L (15.6 μg/L) in erythrocytes, and those in 26 unexposed workers were 19 nmol/L (3.8 μg/L) in urine, 7.5 nmol/L (1.5 μg/L) in plasma and 33 nmol/L (6.6 μg/L) in erythrocytes (Barregård *et al.*, 1991). The mean concentrations of mercury in 1985–86 in another group of 89 chloralkali workers in Sweden, who had been exposed for 1–45 years, were 55 nmol/L (11 μg/L) in blood, 45 nmol/L (9 μg/L) in serum and 14.3 nmol/mmol (25.5 μg/g) creatinine in urine. The concentrations in a control group of 75 non-occupationally exposed workers were 15 nmol/L (3 μg/L) in blood, 4 nmol/L (0.8 μg/L) in serum and 1.1 nmol/mmol (1.95 μg/g) creatinine in urine (Langworth *et al.*, 1991).

In chloralkali plants, exposure to asbestos can occur during various maintenance operations (Barregård *et al.*, 1990; Ellingsen *et al.*, 1993).

(*b*) *Thermometer production*

In 1979, exposure to metallic mercury vapour was studied in a small thermometer factory in Israel with generally inadequate engineering and hygiene arrangements. The mean mercury concentrations in five workers exposed to 50–99 μg/m^3 were 299 nmol/L (59.8 μg/L) in urine and 105 nmol/L (21 μg/L) in blood; those in three workers exposed to 100–149 μg/m^3 were 449 nmol/L (89.8 μg/L) in urine and 122 nmol/L (24.4 μg/L) in blood; and those in seven workers exposed to 150–200 μg/m^3 were 628 nmol/L (125.6 μg/L) in urine and 143 nmol/L (28.6 μg/L) in blood (Richter *et al.*, 1982).

Concentrations of mercury were measured in four thermometer plants in Japan: The air concentrations ranged from 25 to 226 μg/m3; those of inorganic mercury compounds in blood ranged from 80 to 1150 nmol/L (16–230 μg/L); those of metallic mercury in blood ranged from not detected to 1.10 nmol/L (not detected–0.22 μg/L); those of inorganic

mercury compounds in urine ranged from 96 to 1560 nmol/L (19.2–312 μg/L); and those of metallic mercury in urine ranged from 0.05 to 1.22 nmol/L (0.01–0.24 μg/L) (Yoshida, 1985).

In a thermometer factory in the USA, 17 personal samples showed mean air concentrations of mercury of 75.6 μg/m^3 (range, 25.6-270.6); 11 area samples showed a mean of 56.7 μg/m^3 (range, 23.7–118.5). The mean urinary mercury concentration in 79 workers employed for 65 ± 48.9 months was 73.2 ± 69.7 μg/g creatinine (range, 1.3–344.5) (Ehrenberg *et al.*, 1991).

In a thermometer factory in Sweden, where filling with mercury was done inside a ventilated hood but with spillage of mercury during temperature conditioning and testing, the mean concentration of mercury in the air was 39 μg/m^3 (range, 15–58). In seven workers, the median blood mercury concentration was 57 nmol/L (11.4 μg/L), and in six workers, the median urinary concentration was 21 nmol/mmol (37.5 μg/g) creatinine (Sällsten *et al.*, 1992).

(*c*) *Hospitals*

In Belgium, a group of 40 chemical and biological laboratory technicians employed for < 1–15 years were exposed to an average airborne mercury concentration of 28 μg/m^3 (range, 2–124). The mean mercury concentration in urine was 10.72 ± 1.49 μg/g creatinine, and that in whole blood was 10.0 ± 0.9 μg/L. The mean mercury concentrations in a group of 23 unexposed technicians were 2.30 ± 1.49 μg/g creatinine in urine and 6.5 ± 1.1 μg/L in blood (Lauwerys & Buchet, 1973).

In a study in Scotland, use of mercuric chloride as a histological fixative was associated with high atmospheric concentrations of mercury vapour (up to 100 μg/m^3) and of all mercury compounds (200 μg/m^3). Twenty-one technicians exposed to this environment had a median urinary mercury output of 265 nmol (53 μg)/24 h. The median urinary output among a control group of 21 subjects was 72 nmol (14.4 μg)/24 h (Stewart *et al.*, 1977).

Hospital employees who repair sphygmomanometers or work in areas in which such machines are repaired are potentially exposed to mercury. In 13 hospitals in the USA, in which most employees had worked for less than 10 years, the airborne concentrations of mercury in repair rooms ranged from 1 to 514 μg/m^3, and 86 employees tested had a mean urinary mercury concentration of 12.4 μg/L (range, 1–200) (Goldberg *et al.*, 1990).

(*d*) *Dental personnel*

Special interest has focused on occupational exposure to mercury in dentistry. Several studies conducted during 1960–80 reported average concentrations of mercury vapour in dental clinics ranging between 20 and 30 μg/m^3 air; in certain clinics concentrations of 150–170 μg/m^3 were measured (WHO, 1991). In some of these studies, urinary mercury concentrations of dental personnel were also reported.

An average urinary mercury concentration of 40 μg/L was found among 50 dentists in the USA, with some values exceeding 100 μg/L (Joselow *et al.*, 1968). In a nationwide US study, the average mercury concentration in the urine of 4272 dentists sampled between 1975 and 1983 was 14.2 μg/L (range, 0–556 μg/L). In 4.9% of the samples, the concentrations were ≥ 50 μg/L, and in 1.3% they were > 100 μg/L. The wide range of values was probably due to variations in occupational exposure to amalgams with time, in addition to variations in

sampling techniques and other methodological problems (Naleway *et al.*, 1985). At the annual sessions of the American Dental Association, on-site screening for exposure to mercury showed mean urinary concentrations of 5.8 μg/L in 1042 dentists in 1985 and 7.6 μg/L in 772 dentists in 1986; 10% contained concentrations above 20 μg/L (Naleway *et al.*, 1991).

Blood samples from a group of 130 dentists in Denmark in 1986 contained a median mercury concentration of 4.0 μg/L (range, 1.2–19.2); 2.0 μg/L (1.1–4.6) were found in controls. Practice characteristics, as stated on questionnaires, were not significantly related to blood mercury concentration, but 49 dentists who ate one or more fish meals per week had a median concentration 47% higher than that of dentists who seldom consumed fish (Möller-Madsen *et al.*, 1988).

In 82 dental clinics in northern Sweden, the median concentration of mercury vapour in air was 1.5 μg/m^3 in public surgeries and 3.6 μg/m^3 in private ones. The urinary mercury concentrations in 505 occupationally exposed subjects ranged from 1.4 to 2.9 nmol/mmol (2.5–5.13 μg/g) creatinine, which are of the same order of magnitude as those of the Swedish population as a whole. The load derived from the amalgam fillings of the exposed subjects was estimated to be of the same order of magnitude as that from the working environment (Nilsson *et al.*, 1990). In the offices of six dentists in Sweden, the mean concentration of mercury in air was 4.5 μg/m^3 (range, 1.7–24); the mean concentrations in 12 subjects were 17 nmol/L (range, 6–29) (3.4 μg/L; range, 1.2–5.8 μg/L) in blood and 2.6 nmol/mmol (4.6 μg/g) creatinine (range, 1.1–5.4 nmol/mmol; 2.00–9.65 μg/g) (Sällsten *et al.*, 1992). In 224 dental personnel in Sweden, the levels of mercury in urine (1.8 nmol/mmol [3.19 μg/g] creatinine) were not significantly higher than those of 81 referents (1.1 nmol/mmol [1.95 μg/g] creatinine), and no difference was seen for the plasma or blood levels. When adjustment was made, however, for amalgam fillings in the mouths of the personnel, significant differences in urinary, plasma and blood mercury concentrations were seen (Akesson *et al.*, 1991).

Urinary excretion of inorganic mercury compounds was determined in 50 individuals attached to Madras Dental College, India. The lowest concentration observed was 3 μg/L and the highest, 136.6 μg/L. Of those subjects who handled mercury, 70% had urinary concentrations > 20 μg/L (Karthikeyan *et al.*, 1986).

(*e*) *Others*

The airborne concentrations of mercury in Idrija, Slovenia, in 1950 were reported to be 0.05–5.9 mg/m^3 in a mine and 0.17–1.1 mg/m^3 in a smelter (Vouk *et al.*, 1950). Similar values were reported during a survey conducted in 1963: 0.1–2.0 mg/m^3 in both the mine and the smelter. The average concentration of mercury in blood from 57 asymptomatic miners in Idrija was 77 μg/L (range, 0–450); the corresponding value in 16 workers with symptoms of intoxication was 110 μg/L (range, 0–510). The concentrations in urine were 276 μg/L (range, 0–1275) in the asymptomatic miners and 255 μg/L (range, 2.0–601) in those with symptoms (Ladd *et al.*, 1966).

Concentrations > 2.0 mg/m^3 were detected in 1964 in a mine and smelter on Palawan Island, the Philippines (Ladd *et al.*, 1966).

The average concentrations of mercury in the air in various departments in the Italian hat manufacturing industry in 1942–52 were 0.09–2.21 mg/m^3. The concentrations were > 0.2 mg/m^3 in 13 of the 17 departments studied, and concentrations as high as 4 mg/m^3 were measured in specific locations (Baldi *et al.*, 1953).

In a mercury distillation plant in Italy, airborne mercury concentrations ranged from 0.005 to 0.278 mg/m^3; the mean urinary concentration in 19 workers was 108.26 ± 55.61 µg/L and the mean blood concentration, 77 ± 28 µg/L. In 13 subjects in a control group, the urinary mercury concentration was < 10 µg/L, while in 11 other subjects, the mean value was 15.27 µg/L (range, 11–21) (Angotzi *et al.*, 1980).

In a recycling distillation plant in Germany, the concentration of mercury in air in February 1984 ranged from 115 to 379 µg/m^3; in 12 workers in the plant, mercury was found at 28–153 µg/L in blood and 128–609 µg/g creatinine in urine. In previous years, the levels of both biological indicators (determined since 1978) were decidedly higher: 44–255 µg/L in blood and 143–1508 µg/g creatinine in urine. The authors cited the 'normal' values for mercury as 0.2–7.2 µg/L (mean, 0.6) in blood and 0.2–5.0 µg/g creatinine (mean, 0.8) in urine (Schaller *et al.*, 1991).

Individual external exposure in a dry alkaline battery plant in Belgium was to 40 µg/m^3 mercury, ranging from 10 to 106 µg/m^3. Urinary mercury concentrations were usually < 50 µg/g creatinine in some parts of the plant and between 50 and 100 µg/g creatinine in others (Roels *et al.*, 1987).

In a plant for the manufacture of fluorescent lamps in Italy, the mercury concentrations in air in maintenance areas in 1984–85 were between 2 and 5 µg/m^3; 27 workers employed for 10.96 ± 1.14 years in those areas had mean urinary concentrations of 5.15 ± 2.2 µg/L (range, 2–11). In the same plant, the concentrations in the air of production areas varied between 6 and 44 µg/m^3, and 22 workers employed for 10.34 ± 1.43 years in those areas showed mean urinary concentrations of 4.94 ± 1.62 µg/L (range, 1.9-8) (Assennato *et al.*, 1989).

In a study of reproductive function among women employed at a mercury vapour lamp factory (described in detail on pp. 296–297), De Rosis *et al.* (1985) reported that time-weighted average concentrations exceeded 50 µg/m^3 in 1972–76; after modification of the ventilation system, the concentrations dropped to < 10 µg/m^3.

1.3.3 *Air*

The most important sources of mercury in the atmosphere are degassing of the Earth's crust, emissions from volcanoes and evaporation of mercury vapours from natural bodies of water. Recent estimates indicate that these natural emissions amount to 2700–6000 tonnes per year; however, it is difficult to determine the relative contributions of natural and anthropogenous sources to the general emission of mercury in the biosphere, since some may have been deposited in water from the atmosphere and produced by human activities (WHO, 1990). Traditional municipal solid-waste incinerators may have a significant impact on the ambient air concentration as well as on the deposition rates of mercury. Rates of emission of mercury from traditional incinerators in Europe, Canada and the USA range from 100 to 2200 µg/m3 and those from advanced incinerators, 30–200 µg/m^3. Such emissions could result in deposition rates of 0.2–4.0 and 0.02–1.0 µg/m^2 per day, respectively (WHO, 1988).

Table 8. Occupational exposure to mercury in various industries and occupations

Industry and activity (country) [year, when available]	No. of workers	Air (μg/m³)		Urine (μg/L, except where noted)		Blood (μg/L)		Reference
		Mean±SD	Range	Mean±SD	Range	Mean±SD	Range	
Chloralkali plants (USA and Canada; 21 plants) Cell room	567	65±85	< 10–270 (TWA) < 1–2640					Smith *et al.* (1970)
Chloralkali plant (Italy) Cell rooms Miscellaneous	72 55 17		60–300	157.79±120.94 40.29±26.16	0–762 0–96			Foà *et al.* (1976)
Chloralkali plant [1975] (Sweden) [1977]	13 16	64±21.8 22.6±7	36–112 15–43	161.6±62.8 39.2±14.4	74–306 23–65	47.6±23.8 18.4±6.8		Lindstedt *et al.* (1979)
Chloralkali plant (Sweden)	26	NR	25–50	50.4	5–186	NR		Barregård *et al.* (1991)
Chloralkali plant (Sweden) [1985–86]	89	NR	NR	25.5[a]	0.5–84[a]	11		Langworth *et al.* (1991)
Chloralkali plant (Sweden) Normal maintenance	NR	65 (14 samples)	24–123	57[a] (8 samples)	29–77[a]	14.6 (8 samples)	9–30	Sällsten *et al.* (1992)
Special maintenance	NR	131 (16 samples)	38–437	10.9[a] (5 samples)	8.4–15[a]	29.6 (7 samples)	17–48	
Thermometer factory (Israel) [1979]	5 3 7	NR	50–99 100–149 150–200	59.8 89.8 125.6		21 24.4 28.6		Richter *et al.* (1982)
Thermometer factories (Japan; 4 factories)	27	NR	25–226	NR	19–312	NR	16–230	Yoshida (1985)
Thermometer factory (USA)	84	75.6 (17 samples)	25.6–271	73.2±69.7[a] (79 samples)	1.3–344.5[a]			Ehrenberg *et al.* (1991)
Thermometer factory (Sweden)	NR	39 (13 samples)	15–58	37.5[a] (6 samples)	1.96–91[a]	11.4 (7 samples)	6–20	Sällsten *et al.* (1992)
Pathology laboratory (Belgium)	40	28	2–124	10.72±1.49[a]	NR	10.0±0.9		Lauwerys & Buchet (1973)

Table 8 (contd)

Industry and activity (country) [year, when available]	No. of workers	Air (μg/m³)		Urine (μg/L, except where noted)		Blood (μg/L)		Reference
		Mean±SD	Range	Mean±SD	Range	Mean±SD	Range	
Pathology laboratory (United Kingdom)	21	200		26.5		NR		Stewart *et al.* (1977)
Sphygmomanometer repair (USA; 13 facilities)	93	86	1–514	12.4±22.2 (86 samples)	1–200	NR		Goldberg *et al.* (1990)
Dental staff (USA) [1975–83]	4272	NR	NR	14.2±25.4	0–556	NR		Naleway *et al.* (1985)
Dental staff (India)	50	NR	NR	NR	3–136.6	NR		Karthikeyan *et al.* (1986)
Dental staff (Sweden; 82 clinics) [1983]	505	NR	1.5–3.6	NG	2.5–5.13	NG		Nilsson *et al.* (1990)
Dental staff (USA) [1985]	1042	NR	NR	5.8±8.5	max, 84	NR		Naleway *et al.* (1991)
[1986]	772			7.6±11.8	max, 115			
Dental staff (Denmark) [1986]	130	NR	NR	NR	NR	4.0	1.2–19.2	Möller-Madsen *et al.* (1988)
Dental staff (Sweden; 6 offices)	NR	4.5 (36 samples)	1.7–24	4.6	1.96–9.65	3.4	1.2–5.8	Sällsten *et al.* (1992)
Mercury distillation (Italy) [1976–78]			5–279					Angotzi *et al.* (1980)
Distillation	19	NR		108.26±55.61	NR	77±28		
Maintenance	19	NR		84.11±45.54	NR	53±16		
Recycling plant (Germany) [1984]	12		115–379		128–609[a]	28–153		Schaller *et al.* (1991)
Dry alkaline battery plant (Belgium) [1984]	10	40 (46 samples)	10–106	< 100[a] (10 samples)				Roels *et al.* (1987)
Fluorescent lamps (Italy) [1984–85]								Assennato *et al.* (1989)
Maintenance	27	NR	2–5	5.15±2.2	2–11	NR		
Production	22	NR	6–44	4.94±1.62	1.9–8	NR		

NR, not reported
[a]μg creatinine

Table 9. Concentration of mercury in the air of work places in Finland during 1977–88 and in blood in 1987

Industrial code or work	Air concentrations (μg/m^3)			Concentration in blood (μg/L)			
	No. of measurements	Mean	Range	No. of workplaces	No. of measurements	Mean	Range
Seed dressing and packing	11	4	1–13	10	27	3.6	1–9
Pesticide manufacture	8	58	29–105	1	24	10.4	3–46
Mercury production	NR	32	13–157	NR	NR	NR	NR
Welding	24	88	2–150	NR	NR	NR	NR
Manufacture of light bulbs, fluorescent tubes and batteries	133	30	1–250	5	17	5.8	2–8
Laboratory work	26	15	1–120	NR	NR	NR	NR
Dentistry	136	10	1–100	21	42	4.4	1–9
Chlorine industry	NR	NR	NR	3	518	13.6	1–69

From Anttila *et al.* (1992). NR, not reported

Mercury concentrations in the atmosphere range from a few nanograms per cubic metre over remote, uncontaminated areas to about 20 ng/m^3 in urbanized areas. Concentrations have been estimated to be 2 ng/m^3 in the northern hemisphere and about 1 ng/m^3 in the southern hemisphere. Concentrations of mercury up to 18 ng/m^3 have been reported in the atmosphere close to active volcanoes (Berlin, 1986; Clarkson *et al.*, 1988a).

Mercury vapour is believed to be the predominant form in the atmosphere. There is evidence that some of the mercury in ambient air is in the form of alkylmercury, and the presence of methylmercury compounds has been reported. The particulate fraction of mercury in air (as a percentage of total mercury) is usually 4% or less (WHO, 1990).

Another source of mercury in the atmosphere is the release of metallic mercury vapour during the cremation of cadavers, when all the mercury from amalgam fillings vaporizes as the temperature reaches above 800 °C. It is difficult to estimate the global release of mercury from cremation because of the uncertainties about dental status at the time of death and about the frequency of cremation (WHO, 1991).

1.3.4 *Water*

Mercury is removed from the atmosphere mainly by precipitation. The chemical species of mercury in water is mainly ionic mercury[II]. Concentrations of mercury in surface water are very low, and accurate analysis is still a problem. Total mercury concentrations range from 0.5 to 3 ng/L in open oceans, from 2 to 15 ng/L in coastal seawater and from 1 to 3 ng/L on average in freshwater rivers and lakes (WHO, 1990). The bottom sediment of lakes and oceans may contain 20–250 µg/kg mercury (Berlin, 1986). Concentrations in drinking-water are generally less than 25 ng/L (WHO, 1990).

Concentrations of mercury in inland waters of gold-mining areas in Rondônia, Brazil, were between < 0.1 and 8.6 µg/L (Pfeiffer *et al.*, 1989). A study of water from the Madeira River and its tributaries, in the centre of the gold rush area in Brazil, showed an average mercury level of 24.6 ng/L (Nriagu *et al.*, 1992).

1.3.5 *Soil and plants*

The commonest form of mercury in soil is the bivalent ion. Concentrations measured in soils are generally less than 1 ppm (mg/kg). Methylation of mercury has been demonstrated in soil and is influenced by humidity, temperature and the mercury concentration of the soil (Sequi, 1980; Simon *et al.*, 1990).

The accumulation of mercury in plants increases with increasing soil concentration. Soil type has a considerable influence on this process: a high content of organic matter decreases the uptake. Generally, the highest concentrations of mercury are found at the roots, but translocation to other organs (e.g. leaves) occurs. In contrast to higher plants, mosses take up mercury from the atmosphere (WHO, 1989a).

Mercury concentrations in bottom sediments of Brazilian polluted rivers ranged between 50 and 19 800 µg/kg (Pfeiffer *et al.*, 1989).

1.3.6 *Food*

Environmental contamination with mercury leads to a critical concentration effect in animals that occupy higher positions in the food chain (large fish and fish-eating sea fowl)

(Simon *et al.*, 1990). The factors that determine the methylmercury concentration in fish are the mercury content of the water and bottom sediments, the pH and redox potential of the water and the species, age and size of fish (Berlin, 1986).

The concentrations of mercury in most foods are generally below the reported limit of detection, which is usually 20 μg/kg fresh weight. A large proportion of the mercury in food—at least in animal products—is likely to be in the form of methylmercury compounds. Most of the mercury in fish is as methylmercury compounds, which are formed in the bottom sediment of the ocean and in freshwater systems and are enriched to a high degree in the aquatic food chain, with the highest levels occurring in the predatory fish: The concentrations of total mercury in edible tissues of shark and swordfish are > 1200 μg/kg, whereas anchovies and smelt have average values of < 85 μg/kg (Berlin, 1986; WHO, 1990).

In a survey sponsored by the Ministry of Food, Agriculture and Forestry of Germany, the average mercury contamination of 759 specimens of fish from German fishing grounds was < 100 μg/kg (Jacobs, 1977). The mercury concentrations in edible parts of fish from polluted rivers in Brazil were between 70 and 2700 μg/kg wet wt (Pfeiffer *et al.*, 1989).

The average daily intake of mercury can be estimated by assuming that intake from non-fish food sources is negligible in comparison with that from fish. FAO estimated an average worldwide fish intake of 16 g per person per day but an average daily intake of 300 g in populations that are largely dependent on fish; therefore, the average daily intake of total mercury will result in 3 μg, of which 80% is methylmercury compounds and 20% inorganic mercury. The average intake of methylmercury compounds can thus be calculated as 2.4 μg per day, with 2.16 μg retained (90% absorption), and the average daily intake of inorganic mercury is 0.6 μg per day, with 60 ng retained (10% absorption) (Clarkson *et al.*, 1988a; Table 10). Daily intake from the consumption of fish from polluted water, however, can rise to toxic levels, as occurred in Minamata and Niigata in Japan around 1953–66: Concentrations of 1–20 mg/kg in fish resulted in daily intake, in people with frequent fish consumption (200–500 g per day), of 5 mg per day (Berlin, 1986).

Table 10. Estimated average daily intake and retention of various forms of mercury in populations not occupationally exposed to mercury

Source	Estimated daily intake and retention (ng mercury/day)					
	Mercury vapour		Inorganic mercury compounds		Methylmercury compounds	
	Intake	Absorbed	Intake	Absorbed	Intake	Absorbed
Atmosphere	40	32				
Water			50	5		
Food			600	60	2400	2160
Total intake	40		650		2400	2160
Absorbed		32		65		

From Clarkson *et al.* (1988a)

Toxic levels have also been reached following consumption of bread prepared from wheat treated with methylmercury dicyandiamide fungicide, as occurred in Iraq in the winter of 1971–72 (Bakir *et al.*, 1973; Greenwood, 1985).

1.3.7 *Dental amalgam*

Dental amalgams are a potential source of exposure to mercury vapour not only for dental staff but also for the general population. Hardening of the amalgam continues over many months, so that stress on the amalgam surface, produced by chewing or grinding of the teeth, causes breakdown of a surface barrier and release of mercury vapour into the mouth. This results in the deposition of mercury in body tissues like kidney and brain and increased urinary excretion. The release of mercury from amalgams makes a significant contribution to human exposure to inorganic mercury, including mercury vapour (Clarkson *et al.*, 1988b; WHO, 1991; US Department of Health and Human Services, 1993).

Different concentrations of mercury are released from unstimulated amalgams (3.3–7.4 ng/min) and stimulated amalgams (16.3–163.2 ng/min) (Clarkson *et al.*, 1988b). Average daily intake of metallic mercury vapour can thus range from 3.8 to 21 μg/day, with corresponding retentions of 3–17 μg/day (WHO, 1990, 1991).

In 147 individuals in an urban Norwegian population, correlations were found between the concentrations of mercury in urine (mean, 17.5 nmol/L [3.5 μg/L]) and in exhaled air (mean, 0.8 $\mu g/m^3$) and between both urinary and air concentrations and the number of amalgam restorations, the number of amalgam-restored surfaces and the number of amalgam-restored occlusal surfaces. The results suggested that individuals with more than 36 restored surfaces absorb 10–12 μg of mercury per day (Jokstad *et al.*, 1992).

1.3.8 *Mercury-containing creams and soaps*

The mean concentration of mercury in the urine of 60 African women who used skin-lightening creams, containing 5–10% ammoniated mercury, was 109 μg/L (range, 0–220). Those in the urine of six women who had used skin-lightening creams containing 1–3% ammoniated mercury for two years ranged from 28 to 600 μg/L (WHO, 1991).

Mercury was found in the blood (91.1 μg/L) and urine (784 μg/g creatinine) of a woman who had been using soap containing 1% mercuric iodide for about 15 years. Mercury was also present in the blood (19 μg/L) and urine (274 μg/g creatinine) of her three-month-old child, who was not directly exposed to mercury (Lauwerys *et al.*, 1987).

1.3.9 *Mercury-containing paint*

Air samples from 19 homes recently painted with an interior latex paint with a median mercury concentration of 754 mg/L contained a median of 2 $\mu g/m^3$ mercury, while concentrations in 10 uncoated houses were below the detection limit of 0.1 $\mu g/m^3$. The median concentration in urine was higher for 65 exposed inhabitants (8.4 μg/g creatinine) than for 28 unexposed people (1.9 μg/g creatinine) (Agocs *et al.*, 1990; WHO, 1991).

1.3.10 *Human tissues and secretions*

In order to establish reference values for mercury concentrations in whole blood, blood cells and plasma, 98 publications in the international scientific literature presenting

biological data on individuals not occupationally exposed to mercury were reviewed critically and graded for quality (Brune *et al.*, 1991). The mean levels of mercury in non-fish eaters were 2.0 μg/L (10th-90th percentiles, 0–4.3) in whole blood, 3.8 (2.8–4.8) in blood cells and 1.3 (0.3–2.3) μg/L in plasma. Although the authors recognized the importance of retrieving information on the number of amalgam restorations, few data were available.

In 380 Italian subjects non-occupationally exposed to mercury, the mean urinary concentration of mercury was 3.5 μg/L (range, 0.1–6.9) (Minoia *et al.*, 1990). Average urinary mercury concentrations in 50 male and 54 female residents of the Monte Amiata mercury mine area in Italy were greater than those in 104 controls from other regions of the country: men, 2.3 μg/g creatinine (95% CI, 1.7–3.0); women, 3.9 μg/g creatinine (95% CI, 2.2–5.6); men and women combined, 3.1 μg/g creatinine (95% CI, 2.2–4.1) (Cicchella *et al.*, 1968).

Mercury levels in the hair of unexposed populations are generally between 0.5 and 4 mg/kg. Hair mercury is indicative of blood mercury concentration at the point of growth, so that sequential analysis of hair segments provides information on past exposure to mercury and particularly to organomercury compounds (Bakir *et al.*, 1973; Kazantzis *et al.*, 1976).

In Sweden, increased concentrations of mercury were found in samples from former dental staff (seven dentists and one dental assistant) of the pituitary gland (average, 9.8 μmol [1.96 mg]/kg wet weight; range, 0.7–28 [0.14–5.6]), occipital cortices (average, 0.33 μmol [0.07 mg]/kg wet weight; range, 0.07–1.43 [0.014–0.3]), renal cortices (average, 8.6 μmol [1.7 mg]/kg wet weight; range, 4.7–11.3 [0.9–2.3]), and thyroid gland (range, 0.32–140 μmol [0.06–28 mg]/kg wet weight). Mercury was found together with selenium at a rough stoichiometric ratio of 1:1. In the general population, the average concentrations were 0.12 (0.03–5.83) μmol/kg wet weight in pituitary gland, 0.053 (0.012–0.114) in occipital cortices, 1.4 (0.11–4.04) in renal cortices and 0.019 (0.004–0.047) in abdominal muscles (Nylander & Weiner, 1991).

1.4 Regulations and guidelines

Occupational exposure limits and guidelines established in different parts of the world are given in Table 11. The recommended health-based occupational exposure limit is 0.05 mg/m^3 (WHO, 1980; Simon *et al.*, 1990). The recommended health-based limit for long-term occupational exposure to mercury vapours is 50 μg/g creatinine in urine (WHO, 1980).

The American Conference of Governmental Industrial Hygienists (1992) gave notice of their intent to establish biological exposure indices for mercury in blood and urine. The values proposed are 35 μg/g creatinine for total inorganic mercury in urine in preshift samples and 15 μg/L for total inorganic mercury in blood at the end of a working week. The German biological tolerance values for metallic mercury and inorganic mercury compounds are 50 μg/L in blood and 200 μg/L in urine; that for organomercury compounds is 100 μg/L in blood (Deutsche Forschungsgemeinschaft, 1992). The Finnish guideline values for biological measurements are 10 μg/L in blood and 25 μg/L in urine (Anttila *et al.*, 1992).

The WHO recommended guideline for all forms of mercury in drinking-water is 1 μg/L (WHO, 1992). The maximum contaminant level of mercury in drinking-water and the

permissible level in bottled water in the USA is 2 μg/L (US Environmental Protection Agency, 1991; US Food and Drug Administration, 1992).

Table 11. Occupational exposure limits and guidelines for mercury and mercury compounds

Country or region	Year	Concentration (mg/m^3)	Substances affected	Interpretation[a]
Australia	1990	0.01	Alkyl mercury compounds (as Hg)	TWA, S
		0.03	Alkyl mercury compounds (as Hg)	STEL, S
		0.05	Mercury and mercury vapour	TWA, S
		0.1	Aryl mercury compounds, inorganic mercury compounds (as Hg)	TWA, S
Austria	1982	0.1	Mercury and mercury vapour	TWA
		0.01	Organic mercury compounds (as Hg)	TWA, S
Belgium	1990	0.01	Alkyl mercury compounds (as Hg)	TWA, S
		0.03	Alkyl mercury compounds (as Hg)	STEL, S
		0.05	Mercury and mercury vapour, mercury compounds except alkyls (as Hg)	TWA, S
		0.1	Aryl mercury compounds, inorganic mercury compounds (as Hg)	TWA, S
Brazil	1978	0.04	Inorganic mercury compounds (as Hg)	TWA
Bulgaria	1984	0.01	Mercury and mercury vapour, inorganic mercury compounds (as Hg)	TWA
Chile	1983	0.008	Alkyl mercury compounds (as Hg)	TWA, S
		0.04	Mercury and mercury vapour	TWA
China	1979	0.01	Mercury and mercury vapour	TWA
		0.005	Organic mercury compounds (as Hg)	TWA, S
Former Czechoslovakia	1991	0.05	Mercury and mercury vapour, mercury compounds except mono- and dialkyls (as Hg)	TWA
		0.15	Mercury and mercury vapour, mercury compounds except mono- and dialkyls (as Hg)	Ceiling
Denmark	1990	0.01	Alkyl mercury compounds (as Hg)	TWA, S
		0.05	Mercury and mercury vapour, mercury compounds except alkyls (as hg)	TWA
Egypt	1967	0.1	Mercury and mercury vapour	TWA
Finland	1992	0.01	Alkyl mercury compounds (as Hg)	TWA, S
		0.05	Mercury and mercury vapour, inorganic mercury compounds (as Hg)	TWA
France	1990	0.01	Alkyl mercury compounds (as Hg)	TWA, S
		0.05	Mercury and mercury vapour	TWA, S
		0.1	Aryl mercury compounds, inorganic mercury compounds (as Hg)	TWA, S
Germany	1992	0.1	Mercury and mercury vapour	TWA, S
		0.01	Organic mercury compounds except methylmercury (as Hg) (total dust)	TWA, S, sensitizer
		0.01	Methylmercury (total dust)	TWA, PR1, S, sensitizer

Table 11 (contd)

Country or region	Year	Concentration (mg/m^3)	Substances affected	Interpretation[a]
Hungary	1990	0.02	Mercury and mercury vapour, inorganic mercury compounds (as Hg)	TWA, sensitizer
		0.04	Mercury and mercury vapour, inorganic mercury compounds (as Hg)	STEL
		0.01	Inorganic mercury compounds (as Hg)	STEL
		0.01	Organic mercury compounds except mono- and dialkyl compounds (as Hg)	TWA, STEL
India	1983	0.01	Alkyl mercury compounds (as Hg)	TWA, S
		0.03	Alkyl mercury compounds (as Hg)	STEL, S
		0.05	Mercury and mercury vapour	TWA
		0.15	Mercury and mercury vapour	STEL
Indonesia	1978	0.01	Organic mercury compounds (as Hg)	TWA, S
		0.1	Alkyl mercury compounds (as Hg)	TWA, S
Italy	1978	0.01	Organic mercury compounds (as Hg)	TWA, S
		0.05	Inorganic mercury compounds (as Hg)	TWA, S
Japan	1991	0.05	Mercury and mercury vapour, mercury compounds except alkyl compounds (as Hg)	TWA
Mexico	1991	0.05	Mercury compounds except alkyl compounds (Hg)	TWA
		0.01	Alkyl mercury compounds (as Hg)	TWA
		0.03	Alkyl mercury compounds (as Hg)	15-min, 4 ×/day, 1-h interval
Netherlands	1986	0.05	Inorganic mercury compounds (as Hg)	TWA
		0.01	Alkyl mercury compounds (as Hg)	TWA, S
Poland	1990	0.01	Mercury and mercury vapour, organic mercury compounds (as Hg)	TWA
		0.05	Inorganic mercury compounds (as Hg)	TWA
Republic of Korea	1983	0.05	Mercury and mercury vapours	TWA
		0.03	Alkyl mercury compounds (as Hg)	TWA
Romania	1975	0.05	Mercury and mercury vapour	TWA, S
		0.15	Mercury and mercury vapour	STEL, S
		0.01	Organic mercury compounds (as Hg)	STEL, S
Sweden	1992	0.01	Alkyl mercury compounds (as Hg)	TWA, S
		0.05	Mercury and mercury vapour, mercury compounds except alkyl compounds (as Hg)	TWA, S
Switzerland	1990	0.05	Mercury and mercury vapour	TWA, S
		0.01	Organic mercury compounds (as Hg)	TWA, S, sensitizer
		0.1	Inorganic mercury compounds (as Hg)	TWA, PR1, S, sensitizer
Taiwan	1981	0.01	Organic mercury compounds (as Hg)	TWA, S
		0.05	Inorganic mercury compounds (as Hg)	TWA, S

Table 11 (contd)

Country or region	Year	Concentration (mg/m^3)	Substances affected	Interpretation[a]
United Kingdom	1992	0.01	Alkyl mercury compounds (as Hg)	TWA, S
		0.03	Alkyl mercury compounds (as Hg)	STEL, S
		0.05	Mercury and mercury vapour, mercury compounds except alkyls (as Hg)	TWA
		0.15	Mercury and mercury vapour, mercury compounds except alkyls (as Hg)	STEL (10 min)
USA				
OSHA	1992	0.01	Alkyl mercury compounds (as Hg), organic mercury compounds (as Hg)	TWA, PEL, S
		0.03	Alkyl mercury compounds (as Hg), organic mercury compounds (as Hg)	STEL, PEL, S
		0.05	Mercury and mercury vapour	TWA, PEL, S
		0.1	Aryl mercury compounds, inorganic mercury compounds (as Hg)	Ceiling, PEL, S
NIOSH	1990	0.01	Alkyl mercury compounds (as Hg), organic mercury compounds (as Hg)	TWA, REL, S
		0.03	Alkyl mercury compounds (as Hg), organic mercury compounds (as Hg)	STEL, REL, S
		0.05	Mercury and mercury vapour	TWA, REL, S
ACGIH	1992	0.01	Alkyl mercury compounds (as Hg)	TWA, TLV, S
		0.03	Alkyl mercury compounds (as Hg)	STEL, TLV, S
		0.05	Methylmercury, all forms except alkyl vapours	TWA, TLV, S
		0.1	Aryl mercury compounds, inorganic mercury compounds (as Hg)	TWA, TLV, S
Former USSR	1990	0.005	Mercury and mercury vapour	TWA
		0.05	Inorganic mercury compounds (as Hg)	TWA
		0.2	Inorganic mercury compounds (as Hg)	STEL
Venezuela	1978	0.01	Alkyl mercury compounds (as Hg)	TWA, S
		0.03	Alkyl mercury compounds (as Hg)	Ceiling, S
		0.05	Inorganic mercury compounds (as Hg)	TWA
		0.15	Inorganic mercury compounds (as Hg)	Ceiling
Former Yugoslavia	1971	0.1	Mercury and mercury vapour	TWA
		0.01	Alkyl mercury compounds (as Hg)	TWA, S

From Arbeidsinspectie (1986); Cook (1987); US Occupational Safety and Health Administration (OSHA) (1992); US National Institute for Occupational Safety and Health (1990); International Labour Office (1991); American Conference of Governmental Industrial Hygienists (ACGIH) (1992); Arbejdstilsynet (1992); Deutsche Forschungsgemeinschaft (1992); Health & Safety Executive (1992); UNEP (1993)

[a]The concentrations given may or may not have regulatory or legal status in the various countries; for interpretation of the values, the original references or other authoritative sources should be consulted. PR1, a risk of damage to the developing embryo or fetus has been demonstrated unequivocally, even when exposure limits have been adhered to; S, absorption through the skin may be a significant source of exposure; TWA, time-weighted average; STEL, short-term exposure limit; PEL, permissible exposure limit; REL, recommended exposure limit; TLV, threshold limit value.

The Joint FAO/WHO Expert Committee on Food Additives set a provisional tolerable weekly intake of 300 μg total mercury per person, of which no more than 200 μg (3.33 μg/kg bw for a 60-kg individual) should be present as methylmercury compounds (WHO, 1989b). In Japan, a provisional tolerable weekly intake of 250 μg mercury per week, with no more than 170 μg as methylmercury, was calculated from the WHO values on the basis of 50 kg body weight. This weekly intake is considered to be one-tenth of the minimum toxic dose of adults and is therefore expected to give protection against fetal damage (WHO, 1990).

Stationary sources in the USA where mercury ore is processed to recover mercury, where mercury chloralkali cells are used to produce chlorine gas and alkali metal hydroxide and where wastewater treatment plant sludge is incinerated or dried are subject to the US national emission standard for mercury. Thus, atmospheric emissions from mercury ore processing facilities and mercury-cell chloralkali plants cannot exceed 2300 g of mercury per 24-h period. Atmospheric emissions from sludge incineration plants, sludge drying plants, or a combination of these, where wastewater treatment plant sludges are processed cannot exceed 3200 g of mercury per 24-h period (US Environmental Protection Agency, 1992).

In the countries of the European Communities, no detectable quantity of mercury is allowed in colouring matter authorized for use in food intended for human consumption (Commission of the European Communities, 1981). The threshold value for mercury in tuna fish in Denmark is 0.5 mg/kg (Rasmussen, 1984). In Sweden, it was recommended that the consumption of fish caught in areas of high contamination (but below 1.0 mg/kg) be restricted to one meal per week (Swedish Expert Group, 1970).

Use of mercury compounds as cosmetic ingredients in the USA is limited to eye-area cosmetics, at concentrations not exceeding 65 ppm (0.0065%) of mercury calculated as the metal (about 100 ppm or 0.01% phenylmercury acetate or nitrate) (US Department of Health and Human Services, 1992). In the European Communities, mercury and its compounds must not be used in cosmetic products, except that thiomerosal (mercurothiolate) and phenylmercury salts (including borate) can be used for eye make-up or eye make-up remover, with a maximum concentration of 0.007% mercury (Commission of the European Communities, 1990, 1991).