EXPOSURES IN THE GLASS MANUFACTURING INDUSTRY

1. Exposure Data

1.1 Historical overview

Morey (1938) defined glass as 'an inorganic substance in a condition which is continuous with, and analogous to, the liquid state of that substance but which, as the result of having been cooled from a fused condition, has attained so high a degree of viscosity as to be, for all practical purposes, rigid.' Similarly, the American Society for Testing Materials defines glass as 'an inorganic product of fusion that has cooled to a rigid condition without crystallizing' (de Jong, 1989).

While the precise origin of glass manufacture is unknown, glasses occur abundantly in nature and may have been a source of inspiration for development of the technology. Obsidian, pumice (a natural foam glass) and tektites (glassy bodies probably of meteoric origin) are examples of naturally occurring glass. The earliest tektites worked by humans date from the Magdalenian period about 25 000 years ago (de Jong, 1989). Knowledge of smelting glass was developed in the period 3500–2000 BC. Techniques for melting the raw materials in glass manufacture played an important role in the development of glass.

Glass melting technology passed through four stages: (i) glass manufacture in open pits ca. 3000 BC, until the invention of the blowpipe in about 250 BC; (ii) use of mobile wood-fired melting-pot furnaces, until about the seventeenth century, by travelling glass manufacturers; (iii) use of local pot furnaces, fired by wood and coal (1600–1850); and (iv) use of gas-heated melting-pot and tank furnaces from 1860, followed by the electric furnace of 1910 (de Jong, 1989).

A major breakthrough in glass production was the invention of the blowpipe by the Romans, which was used to its finest expression by the Venetian glass-blowers of Murano. With regard to art glass, the method of blowing glass seems to be much the same today as it probably was more than a millenium ago. The flexibility of this technique still makes it popular in fabricating complicated special items. The blowpipe is a hollow, stainless-steel pipe; a gob of glass is collected in the pipe by dipping it into the melt, and blowing air through the pipe swells the gob, provided the viscosity of the glass is still sufficiently low. The gob may then be placed in an iron or wooden mould and blown to the shape of the mould, or it may be worked into the desired shape without the aid of a mould.

1.2 Description of the industry (from de Jong, 1989, except where indicated)

1.2.1 *Introduction*

There are five main sectors in the glass manufacturing industry: flat glass, containers and pressed ware, art glass, special glass (e.g. optical, ophthalmic, electronic) and fibre glass.

Fibre glass was considered in a previous monograph (IARC, 1988) and is not included here (see General Remarks, p. 36, for evaluations). Figure 1 illustrates the basic principles of glass manufacture. The modern production of flat glass is the most highly automated and usually involves tank melting with continuous feeding of batch ingredients and the float (Pilkington) process (Grundy, 1990) for forming. The production of containers and similar products has also become increasingly mechanized. Modern production techniques involve tank melting with continuous feeding of batch ingredients and mechanical blowing or pressing of molten glass. The production of art and special glass can involve a variety of modern and traditional techniques, including manual loading of melting pots and mouth blowing. The production processes currently used to produce glass, other than fibre glass, are discussed below.

1.2.2 *Raw materials*

Glass has some of the physical properties of both liquids and solids: when cooled from the hot molten state, it gradually increases in viscosity without crystallization over a wide temperature range until it assumes its characteristic hard, brittle form; cooling is controlled to prevent high strain (Boyd & Thompson, 1980).

Any mixture with those physical properties is theoretically a glass. Glass has a very large number of chemical compositions, which fall into four main types:

(i) **Soda-lime–silica glasses**: These are the most important glasses in terms of quantity produced and variety of use, including almost all flat glass, containers, low-cost mass-produced domestic glassware and electric light bulbs.

(ii) **Lead–potash–silica glasses**: These contain a varying but often high proportion of lead oxide (see IARC, 1987a). For example, in the production of heavy crystal glass, the glass batch contains about 30% lead (Andersson *et al.*, 1990), while in semi-crystal glass production the amount of lead is less than 10%. Fabrication of optical glass and hand-blown domestic and decorative glassware depends on the high refractive index and ease of cutting and polishing leaded glass. The high electrical resistivity and radiation protection of leaded glass are important in electrical and electronic applications.

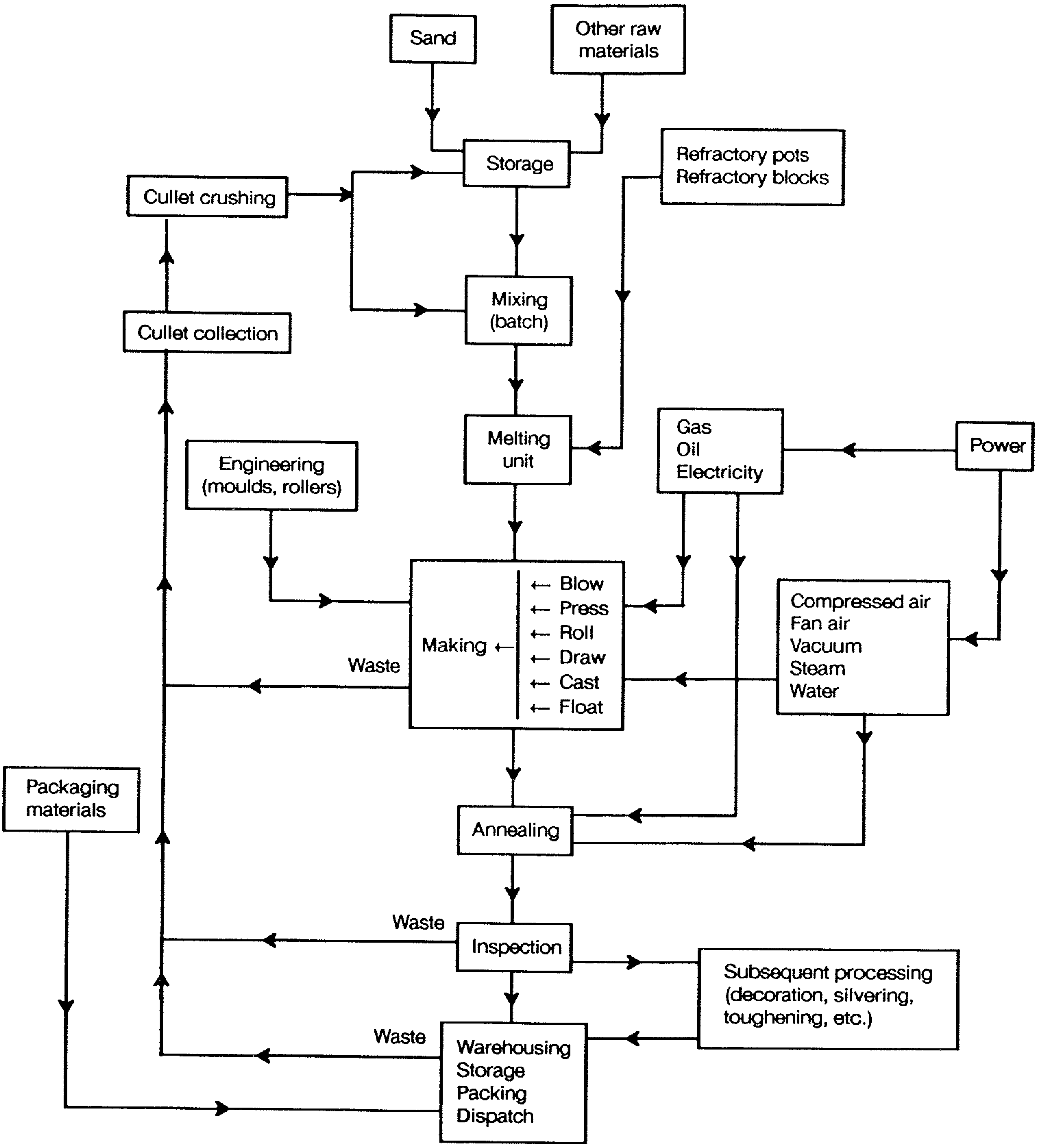
(iii) **Borosilicate glasses**: Borosilicate glasses, with low thermal expansion, are resistant to thermal shock, making them useful for domestic oven and laboratory glassware (Cameron & Hill, 1983).

(iv) **Other glasses**: There are many other glass-forming systems, with a variety of compositions.

The raw materials for glass are mainly: silica (see IARC, 1987b), in the form of sand or crushed rock quartz; soda ash, or in some cases salt cake (sodium sulfate); potassium carbonate or nitrate; crushed limestone or dolomite; red lead or litharge; boric acid or borax; and cullet, which consists of broken or crushed glass (Cameron & Hill, 1983).

The major proportion of almost all glass batches is silica sand. Waste glass, or cullet, is an almost universal addition to the batch melted in glass furnaces. The advantages of this raw material are that it facilitates the melting of other components, requires up to 25% less heat to melt than an isochemical batch of raw materials and normally reduces dust during the batching. Batches with optimal melting efficiency may contain about 30–40 wt% cullet. Recycled bottles constitute about 15% of the cullet used in the container glass industry. This

Fig. 1. Processes and materials involved in the manufacture of glass



From Cameron & Hill (1983)

amount is expected to increase with the increasing introduction of recycling laws. Raw materials are selected according to purity, consistency, grain size, water content, supply, pollution potential, ease of mixing and melting and cost. The commonest ingredients in glass production are listed in Table 1; not all of the constituents are contained in every type of glass.

Table 1. Raw materials used in glass production

Raw material	Chemical composition	Glass-making oxide
Sand	SiO_2[a]	SiO_2
Soda ash	Na_2CO_3	Na_2O
Trona	$Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$	Na_2O
Limestone	$CaCO_3$	CaO
Dolomite	$CaCO_3 \cdot MgCO_3$	CaO MgO
Feldspar	$(K,Na)_2O \cdot Al_2O_3 \cdot 6SiO_2$[a]	SiO_2 Al_2O_3 $(K,Na)_2O$
Nepheline Syenite	$NaAlSiO_4$[b]	SiO_2 Al_2O_3 $(K,Na)_2O$
Petalite	$LiAlSi_4O_{10}$	Li_2O Al_2O_3 SiO_2
Borax (5 mol)	$Na_2B_4O_7 \cdot 5H_2O$	Na_2O B_2O_3
Boric acid	H_3BO_3	B_2O_3
Colemanite	$Ca_2B_6O_{11} \cdot 5H_2O$	CaO B_2O_3
Ulexite	$NaCaB_5O_9 \cdot 8H_2O$	Na_2O CaO B_2O_3
Red lead[b]	Pb_3O_4	PbO
Litharge	PbO	PbO
Anhydrous potash	K_2CO_3	K_2O
Fluorspar	CaF_2	CaO
Zinc oxide	ZnO	ZnO
Barium carbonate	$BaCO_3$	BaO

From de Jong (1989)
[a]Refractory components
[b]Added by the Working Group

Contaminants and other chemicals are added in small amounts for special purposes. The primary contaminants of sand used in glass-making are ferric oxide (see IARC, 1987c), followed by titanium dioxide (see IARC, 1989a), zirconium dioxide and chromium oxides (see IARC, 1990a). The acceptable limits for ferric oxide in glass are 0.005–0.03 wt%, depending on the product. Oxides of transition metals, such as copper, cobalt (see IARC, 1991), nickel (see IARC, 1990b), vanadium and tungsten, are also often present and normally not desired.

Chemical or physical decoloration of such glasses is therefore important. Chemical decoloration is used to oxidize iron to its weakly coloured trivalent state by increasing the oxygen content of the melt, usually by adding oxygen-producing compounds such as potassium nitrate and sodium sulfate. Physical decoloration is often used when the melt contains a higher concentration of iron. In this case, the addition of other colouring agents compensates for the yellow–green colour of the glass. Common compensating agents are selenium (see IARC, 1975) and oxides of manganese, cobalt and nickel.

Conversely, when coloration of glass is desired, oxides of transition elements are the main colouring agents used. Common transition-metal oxides used in the glass industry include cobalt, nickel, chromium, iron, manganese, copper, vanadium and cadmium. Concentrations are typically 0.5–5 wt%. Oxidation conditions affect the colour achieved.

Other chemicals may be added for different purposes: e.g. fluorides to reduce viscosity and aid melting, zirconium dioxide to raise the softening-point and cerium oxide to stabilize glass against ultraviolet discoloration.

1.2.3 *Mixing and melting*

The three steps involved in the production of glass are melting, fining and homogenization. The cold batch is placed in the tank and melted at 1200–1650 °C. Decarbonation, desulfurization and dehydration are the first chemical processes used, followed by partial melting. Silicate formation occurs at about 500–800 °C.

Fining is the process of removing bubbles from the glass melt. This is accomplished in two ways:

(i) by the addition of chemical fining agents. Sodium sulfate or arsenic (see IARC, 1987d) and antimony trioxides (see IARC, 1989b) are generally used. Typically, about 0.3 wt% arsenic oxides or arsenates are added to the batch, although for some glass types up to 1.5 wt% arsenic trioxide may be used; and

(ii) by varying the melt temperature, either by raising the tank temperature, with an attendant decrease of melt viscosity and increase in bubble expulsion, or by lowering the temperature and increasing gas resorption.

Homogenization of the batch is generally assured by mechanical stirring.

Accuracy and precision in weighing the various batch constituents are important, as are thorough mixing of the ingredients and prevention of subsequent segregation. Batch handling systems vary widely throughout the industry, from manual to fully automatic. Wet mixing and batch agglomeration–pelletizing, briquetting and compaction are becoming popular, especially for the addition of lead and arsenic compounds.

1.2.4 *Pot processing*

The older pot process now serves mainly for the manufacture of high-quality glass, such as optical glass, and for small quantities of special glass, such as hand-blown crystal. The pots vary in size, up to those capable of holding nearly 2 tonnes of ingredients. The pots are made from a number of different types of clay combined with flint or silica flour. Pot melting of glass often involves the hazards inherent in hand shovelling and filling. The pots are tempered slowly at 900 °C by electrical heating, fired at 1200 °C and vitrified at 1400 °C in the pot furnace. Open pots containing 150–1000 kg of melt have been used, especially in Europe, to manufacture coloured and optical glasses as well as crystal glass. Closed pots surrounded by refractory brick walls are the system of choice in the USA. The largest pot furnaces could contain 8–10 pots, each with a diameter of 1 m. Special, valuable products (e.g. specially coloured glass) may be produced in tanks built from refractory brick and heated directly, producing 1–5 tonnes of glass daily. This process is particularly well suited for the manufacture of soft (i.e. low viscosity) glass, such as crystal or soda lime glass, which require special production techniques. Modern techniques for special glasses may involve the use of induction heating with the melt contained in platinum crucibles; this technique also involves manual handling of batch materials.

1.2.5 *Tank processing*

Large volumes of glass are produced exclusively in tanks capable of holding up to 2000 tonnes of melt. Producers of flat glass have always used the largest tanks, formerly for the vertical drawn sheet process and now for the rolled plate and float processes. The tank is divided into two sections, either by a permanent bridge wall or by floating refractory baffles. The larger section into which the fill (i.e. the batch with cullet) is introduced is called the melting end. Most of the tanks provide for enclosed continuous feeding of batch ingredients. The other section, in which the melt starts to cool towards its working viscosity, is called the working or refining end. Partitioning of the tank allows continuous production of glass. The fuel usually used is oil or natural gas.

1.2.6 *Forming/making*

Glass objects are formed from molten glass by blowing, pressing, drawing and casting. 'Hand-blowing' is the classic method of glass fabrication and is used in modern glass plants only for the manufacture of art objects, large objects in low demand that cannot be fabricated by machine, and complicated technical shapes. Partial automation is being introduced into hand-forming operations, where the glassblower blows gobs of the proper viscosity into moulds.

Deep items (e.g. bottles) are formed mechanically by blowing glass into moulds with compressed air. Hinged moulds, which can be opened to remove the ware, are generally used for the blowing operation. These moulds are lined with a water-absorbent coating, which develops a steam cushion between the coating and glass during blowing. A second type of mould is the hinged hot-iron mould, in which the glass comes directly into contact with the mould surface on blowing. Narrow-mouth containers are manufactured in a two-stage process.

Although blowing is used in the manufacture of deep items, pressing is used for relatively flat items, such as dinnerware, optical and sealed-beam lenses, filter glass and television tube panels. Press moulds are commonly made of cast iron, bronze steel or superalloys with galvanized surfaces. Moulds (including hand moulds) are sometimes lubricated with mineral oils (see IARC, 1987f), graphited oils or, occasionally, other organic materials, such as tallow and oleic acid. Hand pressing is now being replaced by machine pressing.

The traditional process for producing sheet glass is to draw it from the furnace by a vertical process which gives it a fire-finished surface. Owing to the combined effects of drawing and gravity, some minor distortion is inevitable. The plate glass passes through water-cooled rollers into an annealing oven. Surface damage must be removed by grinding and polishing. Patterned glasses are still made by this method.

The vertical drawn process has largely been replaced by the float process for flat glass. The Pilkington float process has made possible the manufacture of a glass that combines the advantages of both sheet and plate. Float glass has a fire-finished surface and is free from distortion. Molten glass floats from the huge melting tank (up to 2000 tonnes of glass) along the surface of a bath of molten tin, in which an inert atmosphere of nitrogen prevents oxidation. The glass conforms to the perfect surface of the molten tin. As the glass passes over the tin, the temperature is reduced until the glass is sufficiently hard to be fed on to the rollers of the annealing oven without marking its under-surface. Sulfur dioxide may be applied at this point to reduce further the risk of marking. After annealing, the glass requires no further treatment and is ready for automatic cutting and packing. The advantage of the float process, apart from the mirror quality of the glass surface, is its high production capacity.

1.2.7 *Annealing and other processing*

Annealing of a glass product is nearly always necessary after any forming operation. The glass is heated uniformly to a temperature sufficiently high to relieve any internal stress, without causing deformation of the object under its own weight. The ware is subsequently cooled slowly to prevent formation of new stresses. Glassware is normally annealed in long, continuous ovens called lehrs, which are usually heated electrically.

After production in different processes, glass may undergo secondary processes, including cutting, grinding, polishing, heat processing, chemical treatment and surface coating. Workers may be exposed to chemical agents during grinding, polishing, chemical treatment and surface coating.

The purpose of grinding is to remove the upper layer of the glass surface. An abrasive produces a small check or crack in the glass, the dimensions of which depend on the grain size of the abrasive: increasingly finer abrasives produce a relatively smooth surface. Natural abrasive grits (e.g. quartz, sandstone, corundum, garnet and diamond) are used as well as synthetic grits (e.g. silicon carbide, aluminium oxide and boric oxide). Water or a suitable cutting fluid is used in grinding.

Polishing is done either mechanically or chemically. Mechanical polishing requires finely powdered abrasives such as rouge (ferric oxide) and cerium oxide. These abrasives operate on the same principle as those in grinding. Chemical polishing includes acid polishing and flame polishing. In acid polishing, the glass may be submerged in a mixture of hydrofluoric and concentrated sulfuric acids or in other acids; hydrofluoric acid is also used for etching glass.

Vitreous enamels are applied by spraying, silk screening and the application of decals. They may be fused to the ware at high temperature. Metallic coatings are produced either by applying a liquid suspension of metal to the surface and then firing it or by evaporation of metal on the glass. These coatings are used on flat glass as a means of controlling transmission and reflection of light, as electrical semiconductors in tin oxide films, as resistors in electronic circuits, as defrosting agents and in aircraft glazing. Lacquers are applied to glass for decorative purposes.

1.3 Exposures in the workplace

1.3.1 *Introduction*

A number of potential occupational health hazards are present in the glass industry, including silica dust and certain metallic compounds. Exposure to silica has been evaluated previously (see IARC, 1987b).

The production of glass involves the use of many metals, usually as oxides; nearly every element in the periodic table has been used in modern glass technology (see section 1.2). In particular, exposure to lead has been noted in the past: In the production of heavy crystal glass (about 30% lead) and semi-crystal glass (< 10% lead), lead is an important source of occupational exposure. Other elements to which workers are exposed include antimony, arsenic, cadmium (see monograph, p. 119), manganese, selenium, nickel and chromium (Andersson *et al.*, 1990); they may be exposed to either dusts or fumes. Glass-blowing offers special opportunities for exposure to the metallic compounds in glass and alloy materials, which may migrate up the pipe into the worker's mouth. In Sweden, samples from blowpipes contained lead, manganese, nickel (Andersson *et al.*, 1990; Wingren & Englander, 1990) and arsenic (Andersson *et al.*, 1990).

For chemical polishing and matting of glass surfaces, sulfuric (see IARC, 1992) and hydrofluoric acids are used. Some processes also involve potential exposure to polycyclic aromatic hydrocarbons (see IARC, 1983) and asbestos (see IARC, 1987e). The working environment around a glass furnace is hot, and most of the heat is in the form of radiant energy. Significant heat problems also arise during maintenance and emergency repair work: temperatures in areas where men do routine maintenance is frequently in the range of 120–160 °C; under emergency repair conditions it may reach 200 °C (Cameron & Hill, 1983). In the past, asbestos was used as a thermoinsulator in hot structures, as well as in protective clothing. The workers who were exposed to the largest quantities of asbestos were probably construction and maintenance workers rather than those engaged in the actual production of glass (Lucas, 1981; Sankila *et al.*, 1990; Kronenberg *et al.*, 1991).

Very few surveys involving ambient and biological monitoring of workers exposed to chemicals have been reported from the glass industry, and almost all the quantitative data available to the Working Group were for exposure to lead and other metals. In particular, no quantitative data on past exposures were available for the mortality and cancer morbidity cohort studies carried out in Italy and Finland (Cordioli *et al.*, 1987; Sankila *et al.*, 1990).

1.3.2 *Exposure to lead*

Air measurements in glass manufacturing industries showed concentrations of < 0.001–0.11 mg/m^3 lead, with the highest levels in a heavy crystal glassworks (Andersson *et al.*, 1990; Wingren & Englander, 1990).

Because blood lead levels give better information about total lead exposure than lead concentrations in ambient air, biological monitoring was chosen for the evaluation of individual exposures in the studies described below.

Between 1970 and 1973, 49 workers in three Finnish crystal glass plants were investigated for blood lead: The median concentration was [410 μg/L] (range, 120–820 μg/L). At that time, the recommended limit for blood lead in Finland was 700 μg/L (Tola *et al.*, 1976).

Exposure to lead and other substances was evaluated among workers grinding, polishing and glueing leaded crystal glass art objects. Five of six measurements in the breathing zone in the grinding department exceeded the US National Institute for Occupational Safety and Health (NIOSH) criterion of 50 μg/m^3. The average of all six samples was 60 μg/m^3 (range, 30–80 μg/m^3); however, no blood sample contained more than 400 μg/L. The mean blood lead concentration in the grinding department was 291 μg/L (range, 220–360 μg/L) (Gunter & Thoburn, 1985).

Lüdersdorf *et al.* (1987) examined blood lead concentrations in a group of 109 male workers at two glass-producing factories in Germany. The group was divided into four subgroups, according to their specific activities: melter, batch mixer, craftsman and glass washer. The medians and ranges for blood lead concentrations are given in Table 2, which shows that the highest values occurred in blood specimens from batch mixers.

Table 2. Concentrations of lead in blood in workers in two German glass factories: comparison of subgroups

Specific activity	No.	Blood lead (μg/L)	
		Median	Range
Melter	32	220	130–600
Batch mixer	45	340	200–680
Craftsman	8	275	190–410
Glass washer	24	170	70–430
Total	109	250	70–680

From Lüdersdorf *et al.* (1987)

Schaller *et al.* (1988) studied blood lead levels, determined by flame atomic absorption spectrometry, in the German crystal glass industry for the period 1978–86. A total of 6080 determinations were performed for 1625 men and 269 women. The median concentrations (and 68% ranges) varied from 470 μg/L (275–665 μg/L) for men to 255 μg/L (115–415 μg/L) for women $\leq$ 45 years of age and 270 μg/L (135–455 μg/L) for women $>$ 45 years of age. Table 3 presents the blood lead concentrations in relation to period of examination; it shows a general decrease in internal exposure with time. For men, 764 (14%) of the determinations exceeded the German 'biological tolerance value' of 700 μg/L blood. [The Working Group noted that the large decrease between 1978 and 1979 may have been related, in part, to the phasing out of lead in gasoline in Germany and the resultant decrease in environmental exposures.]

Table 3. Blood lead concentrations (μg/L) in the German glass industry for the period 1978–86

Year	Median	68% range	99% range
1978	545	325/775	165/1300
1979	485	265/725	85/1085
1980	420	235/635	90/1020
1981	440	245/685	75/1065
1982	445	245/635	105/1045
1983	430	215/675	70/1100
1984	435	255/635	50/ 955
1985	440	245/635	65/1010
1986	445	205/605	25/ 880

From Schaller *et al.* (1988)

In a British lead crystal manufacturing plant, 87 people were monitored for concentrations of lead in blood and tibia *in vivo*, the latter reflecting cumulative exposure. The duration of exposure to lead was 10.0 ± 1.1 years. The mean concentration of lead was 481 ± 18 μg/L in blood (non-occupationally exposed, 131 ± 16 μg/L) and 17.5 ± 1.9 μg/g wet weight in tibia (non-occupationally exposed, 9.4 ± 2.1 μg/g wet weight) (Somervaille *et al.*, 1988).

Andersson *et al.* (1990) collected 36 personal air samples in three Swedish glassworks, one producing heavy crystal glass and two producing semi-crystal glass. The results are presented in Table 4. The glassworks producing heavy crystal had a higher air concentration of lead, especially in the foundry area, than those producing semi-crystal. Of the 28 samples from the semi-crystal glassworks, only four contained concentrations above the present Swedish threshold limit value of 50 μg/m^3, whereas in the heavy crystal glassworks 7/12 samples exceeded that limit. Lead was also detected in slag from inside the blowpipes at concentrations (geometric mean) of 6.93 μg/mg slag in the heavy crystal glassworks and 0.72 μg/mg slag in the semi-crystal glass industry (see Table 7, p. 359).

Although stained-glass workers are not involved in the manufacture of glass, they may be exposed to lead during soldering. Landrigan *et al.* (1980) measured blood lead concentrations in 12 professional stained-glass workers, in five hobbyists and in four family members of workers in the USA. The concentrations in professional workers (mean, 207 μg/L) were higher than those of hobbyists (116 μg/L) and family members (113 μg/L). The mean lead concentration in settled dust samples from a stained-glass workshop was 11 000 ppm (mg/kg).

Baxter *et al.* (1985) surveyed 47 workers in the four largest stained-glass workshops in the United Kingdom. The mean blood lead concentration was 300 μg/L (range, 100–700 μg/L); nine workers had concentrations of 400 μg/L or more. The mean concentration of lead in personal air samples of five glaziers inside the workshop was 30 μg/m^3 (range, 10–50 μg/m^3), and samples of general air all contained 10 μg/m^3. All results were well below the current standard for lead in air in the United Kingdom of 150 μg/m^3.

Table 4. Concentrations of lead (μg/m^3) in the air of three Swedish glass factories, presented as geometric means (GM) with 95% confidence intervals (95% CI)

Work area	Semi-crystal glassworks			Heavy crystal glassworks		
	GM	95% CI	No. of samples	GM	95% CI	No. of samples
Foundry	6	3–11	16	61	48–79	7
Oven inlay	72	–	4	71	–	2
Other	8	2–22	8	10	–	3

From Andersson *et al.* (1990)

1.3.3 *Exposure to other metals*

Exposures in the production of hypodermic syringes from glass containing small amounts of antimony and cerium oxide were studied. Environmental concentrations of antimony, stibine (antimony hydride) and cerium were approximately 1% of the NIOSH recommended maximal concentration at the time of the study: 500 μg/m^3, 0.1 ppm and 5000 μg/m^3 (Burroughs & Horan, 1981).

Lüdersdorf *et al.* (1987) studied external and internal exposure to antimony of 109 male workers in two German glass-producing factories. Airborne, blood and urinary concentrations of antimony are presented in Table 5. The airborne concentrations in the batch area exceeded the German 'technical exposure limit' value of 300 μg/m^3 (Deutsche Forschungsgemeinschaft, 1992), and the highest concentrations of antimony in blood and urine were found in workers in the batch area.

Chrostek *et al.* (1980) investigated 35 crystal glassworkers working in the mix and melt area and batch house who were exposed to various compounds, including arsenic trioxide, selenium and silica flour. Personal air monitoring of eight workers revealed arsenic concentrations of 2–11 μg/m^3, all of which were in excess of the NIOSH recommended standard of 2 μg/m^3, although only one exceeded the US Occupational Safety and Health Administration standard of 10 μg/m^3. All eight personal samples indicated exposure to selenium (0.04–7.92 μg/m^3) below the US Occupational Safety and Health Administration standard of 200 μg/m3 [no NIOSH standard given]. The personal samples for respirable dust indicated exposures of 0.14–0.99 mg/m^3. The quartz content of bulk dust samples was 10%. The results of clinical examinations and interviews revealed no arsenic-related health complaint or symptom and no arsenic-related skin disorder. All blood samples contained concentrations of arsenic below the detection limit of 10 μg/kg; however, blood was considered to be a less reliable specimen than urine for assessing exposure to arsenic.

Roels *et al.* (1982) measured total airborne arsenic in a Belgian glassware factory where arsenic trioxide was used to produce uncoloured glass, determined urinary inorganic arsenic and its metabolites and evaluated hand and mouth contamination by arsenic before and after the workshift in 10 workers. The results suggested that the high urinary arsenic

Table 5. Time-weighted average airborne concentrations of antimony in total dust and antimony concentrations in blood and in urine in two German glass factories

Field of activity	Air sampling technique	No. of samples	Antimony trioxide (μg/m³)	Antimony concentration (μg/L)[a]			
				Blood		Urine	
				Median	Range	Median	Range
Melting area							
Melter	Personal	32	< 50	0.8	0.4–1.8	0.9	0.2–2.9
Batch mixer	Stationary	45	< 5–5	1.1	0.5–2.4	5.0	1.5–15.7
Batch bunker							
Craftsman	Personal	8	< 50–840	0.7	0.5–1.0	0.9	0.4–3.7
Glass washer	Stationary	24	40–290	1.1	0.4–3.1	1.2	0.6–6.3
Total		109		1.0	0.4–3.1	1.9	0.2–15.7

From Lüdersdorf *et al.* (1987); detection limits: personal air monitoring, 50 μg/m³; stationary sampling, 5 μg/m³
[a]Antimony levels in non-occupationally exposed population: 0.3–1.7 μg/L blood, 0.2–0.7 μg/L urine

concentrations found (mean, around 300 μg/g creatinine; range, 10–941 μg/g) were probably more closely related to oral intake from contaminated hands than to absorption from the lungs. Urinary arsenic excretion in control workers ranged from 7.6 to 59 μg/L.

In two German cross-sectional studies (in 1976 and 1981) to evaluate internal exposure of employees in the heavy crystal industry, urinary arsenic concentrations of 3–114 μg/g creatinine were found. In 33% (1976) and 16% (1981) of the cases, urinary arsenic elimination exceeded the upper limit of normal (25 μg/g creatinine) (Schaller *et al.*, 1982).

In a study in the United Kingdom, two cases of subacute arsenic poisoning were reported among decorative glass workers. Although air levels in most cases were below the recommended limit of 0.2 mg/m³ (Table 6), excessive uptake seemed to have occurred in some workers (Ide & Bullough, 1988).

Farmer and Johnson (1990) reported exposure to airborne arsenic trioxide, used as a decolourizing agent, in a specialist glass manufacturing industry during the weighing of constituents for glass batches and during mixing of chemicals. Inorganic arsenic (As[V], As[III]) and its metabolites (mono- and dimethylarsonic acid) were determined in 18 first-void urine samples by direct hydride generation–atomic absorption spectrometry. The mean urinary arsenic concentration was 79.4 μg/g creatinine, in comparison with 4.4 μg/g creatinine for controls.

In Swedish heavy crystal and semi-crystal glass industries, Andersson *et al.* (1990) detected only a very small amount (< 6 μg/m³) of arsenic; nickel and manganese were not detected (< 1 μg/m³). Arsenic, nickel and manganese were detected in microgram per milligram concentrations in slag from inside blowpipes (Table 7).

Table 6. Results of personal and background sampling of arsenic in air of decorative glassworks in the United Kingdom (mg/m^3)

Site	Personal		Environment	
	Sample	8-h TWA	Sample	8-h TWA
Factory A				
Mixer 80 min	0.67	0.11	0.69	0.11
Charger 15 min	0.11	0.02	0.71	0.12
20 min	0.03	0.005		
Factory B				
Mixer 76 min	2.40	0.38	0.12	0.02
			0.26	0.04
			4.55	0.72

From Ide & Bullough (1988). TWA, time-weighted average; recommended exposure limit for arsenic: 0.2 mg/m^3

Table 7. Content of some metals (μg/mg slag) in blowpipes, presented as geometric means (GM) with 95% confidence intervals (95% CI)

Metal	Semi-crystal glassworks			Heavy crystal glassworks		
	No. of samples	GM	95% CI	No. of samples	GM	95% CI
Arsenic	79	0.26	0.22–0.31	39	0.27	0.23–0.32
Manganese	79	3.61	3.15–4.13	39	5.44	4.02–7.38
Nickel	75	0.57	0.44–0.73	39	4.99	3.42–7.28

From Andersson *et al.* (1990)

Raithel *et al.* (1991) found very high external and internal exposure to nickel in German shops in which nickel-armoured hollow-glass moulds were produced or repaired. Hollow-glass moulds used in automatic machines are plated with nickel and nickel alloys (70–98%) by flame spraying with nickel-containing powder (75–99%); the moulds also undergo abrasive buffing and polishing with grinding disks, lathes and emery paper. The airborne nickel levels in three factories in 1981 and 1984 are summarized in Table 8. The German technical exposure limit of 500 μg/m^3 for nickel and its compounds was exceeded at three of 24 measuring stations (range, 3.4–623 μg/m^3). Between 1981 and 1984, dust control and working conditions were improved. Urinary nickel excretion of workers in 24 German hollow-glass factories ranged from 0.2 to 60.2 μg/g creatinine (mean, 4.5) in pre-shift samples and were 0.5–211 μg/g creatinine (median, 6.9) in post-shift samples. The highest urinary nickel concentrations were detected in flame sprayers (median, 25.3 μg/L). Lower internal exposure was found for craftsmen, i.e. polishers and chasers (median, 7.4 μg/L).

Table 8. Measurements of nickel fine dust in three German hollow-glass mould repair shops in 1981 and 1984

1981		1984	
Description	Nickel fine dust (μg/m³)	Description	Nickel fine dust (μg/m³)
Mechanical work (chase) with ventilation	190	Mechanical work (grinding) with ventilation	18
	141	Grinding, polishing and thermal spraying with ventilation	410
Electrowelding with ventilation	20	Emery frame with ventilation	180
Flame spraying with ventilation	114	Flame spraying with ventilation	569
Flame spraying with ventilation	444		75
	413	Flame spraying without ventilation	85
	302	Electrowelding with ventilation	50
	243	Mechanical work with ventilation	6.8
Mechanical work with ventilation	145	Flame spraying with ventilation	10.2
	550		3.4
Mechanical work without ventilation	623		
Flame spraying with ventilation	500		
	260		
Mechanical work and flame spraying with ventilation	300		

From Raithel *et al.* (1991)

1.3.4 *Other exposures*

Exposure may occur to polycyclic aromatic hydrocarbons in fumes generated by oil-fired furnaces and in mineral oils used for lubricating moulds. Workers were exposed by inhalation to oil aerosols during casting, where contact of oil with hot moulds at ca. 300–700 °C produces mists and fumes, in two Italian plants. In a plant producing bottles and jars for foods, moulds were lubricated manually with graphited oil; in a crystal glass plant, the moulds were lubricated automatically every few seconds with graphited oil. Typical concentrations of polycyclic aromatic hydrocarbons in the oils were 0.1–5 ppm. A number of airborne compounds (benzo[*a*]anthracene and chrysene) were detected in close proximity to their source during aerosol emission (i.e. during mould lubrication) at concentrations in the order of 1 μg/m³ in both plants. Such levels decreased to about 0.1 μg/m³ in personal air samples. Exposures to oil mist were in the range 0.7–2.4 mg/m³ (time-weighted average), thus complying with the generally accepted limit of 5 mg/m³ (Menichini *et al.*, 1990).

Gunter and Thoburn (1985) measured exposures to airborne petroleum distillate in a US crystal facility, where leaded crystal was cut, grinded, polished and glued together into various art objects. The environmental concentrations were well below the NIOSH evaluation criteria, as were the concentrations of 1,1,1-trichloroethane and toluene in the breathing zone.

Interleaving materials, such as Lucor™ (50:50 mixture of Lucite® beads, a polymer of the acrylic monomer methyl methacrylate, and adipic acid) and wood flour or a combination of the two, are used in the flat glass industry to prevent window panes from adhering to each other during packing and unpacking. In a study of a flat glass industry in the USA, exposures to adipic acid were below the detection limit (2 μg per sample). Results of sampling for particulates (< 2 mg/m^3) showed that all samples were below the threshold limit values of the American Conference of Governmental Industrial Hygienists and the permissible exposure limits of the US Occupational Safety and Health Administration for both total (10–15 mg/m^3) and respirable (5 mg/m^3) nuisance dusts (Almaguer, 1985).

2. Studies of Cancer in Humans

2.1 Descriptive studies

In a Nordic, census-based record-linkage study (Lynge *et al.*, 1986) on the relationship between possible exposure to silica dust and lung cancer in male occupational groups, the authors found an excess among Danish glass-makers (occupational code 356), based on three cases *versus* 1.85 expected (standardized incidence ratio [SIR], 1.62; 95% confidence interval [CI], 0.33–4.74). No such excess was found in the other Nordic countries.

In a Swedish record-linkage study between the National Cancer–Environment Registry and national cancer registries for 1961–79, McLaughlin *et al.* (1987a) studied the risk for intracranial gliomas in various occupations. A significant excess SIR of 1.60 was found [95% CI, 1.03–2.36] among 'potters, kilnmen, and glass workers' (code 81), based on two-digit selection of the work titles and on 25 cases. After selection on the basis of three-digit occupational titles, the number of remaining cases in glass-makers (code 811) was reduced to six with an SIR of 1.7 (not significant). In a second, similar study, McLaughlin *et al.* (1987b) found an SIR of 5.20 [95% CI, 1.90–11.4] for meningiomas among 'glass makers' (code 811), based on six cases. [The Working Group noted that an excess of brain cancer was found in other occupational categories in the area in which glass-works were located (Wingren & Axelson, 1992).]

In a similar record-linkage study on nasopharyngeal cancer in Sweden, Malker *et al.* (1990) found a significant excess risk among glass-makers (code 811) (3 cases; SIR, 6.2 [95% CI, 1.3–18.3]).

In an ecological study (Dolin, 1992) of bladder cancer in England and Wales, the numbers of deaths from that cancer in 1969–73 and 1974–80 were obtained for 400 districts, and the percentages of workers in 220 different occupations were collected from the 1971 census tracts for the same districts. In the 'high-risk' areas identified, there were significantly higher percentages of workers in 23 occupations as compared with the average for England and Wales. Among these occupations were male glass process workers [not further specified] (relative risk [RR], 4.79; 95% CI, 2.79–7.67) and glass formers and finishers (RR, 5.47; 95% CI, 3.79–7.64).

2.2 Cohort studies (see Table 9, p. 364)

Cordioli *et al.* (1987) performed a cohort mortality study in Italy of 468 workers who had been employed for at least one year between 1953 and 1967 at a plant producing 'low-quality' glass containers. Prior to mechanization of the plant in 1967, melting pots were loaded manually, the initial blow was by mouth, and there was no division between work areas. Although the exact nature of the exposures was not known, exposures to mineral-oil fumes, arsenic and dyes containing chromium, nickel, iron, manganese, cobalt, titanium and cadmium were suspected. The cohort was followed through the end of 1985, and 28 deaths due to cancer were observed (RR, 1.27 [95% CI, 0.84–1.84]), including 13 from lung cancer (RR, 2.09 [95% CI, 1.1–3.6]) and four from cancer of the larynx (RR, 4.49 [95% CI, 1.2–11.4]). Although based upon small numbers, the risk for laryngeal cancer appeared to increase with duration of employment, while the risk for lung cancer did not. All laryngeal cancers and 12 of the lung cancers occurred at least 10 years after first employment (RR, 5.72 [95% CI, 1.54–14.6]; and RR, 2.32 [95% CI, 1.20–4.06], respectively). [The Working Group noted that information on smoking was not given.]

Neuberger and Kundi (1990) recruited two cohorts of 1626 men who had been exposed or unexposed to high concentrations of silica dust of any type in 1089 Viennese (Austria) plants and examined during 1950–60; they were followed up through 1985. By the end of follow-up, 87 and 84% had died; 179 lung cancer deaths had occurred in the exposed cohort (RR compared to local rates, 1.69 [95% CI, 1.45–1.96]) and 141 in the unexposed cohort (RR, 1.18 [0.99–1.39]). In the exposed cohort, 28 lung cancer deaths (RR, 2.37 [1.58–3.43]) occurred among subjects with the occupational title 'ceramics and glass' [not further specified]. The authors noted that the cross-sectional recruitment of the study participants is heavily influenced by selection. [The Working Group noted the high risk for lung cancer in the control group and that no data were available on smoking.]

Wingren and Englander (1990) investigated a Swedish cohort of 625 male art glass-workers employed for more than one month between 1964 and 1985. There was a slight excess of all cancers, and mortality from lung cancer was in excess: six deaths *versus* 4.2 (RR, 1.44 [95% CI, 0.52–3.11]) and 2.5 (RR, 2.36 [0.88–5.22]) expected, based on national and county referents, respectively. There was also a small excess mortality from colon cancer: four cases *versus* 1.6 (RR, 2.45 [0.67–6.40]; national rates), and there were two pharyngeal cancers *versus* 0.2 expected (RR, 9.87 [1.2–36.10]; national rates). Similar excesses were seen in comparison with county rates. The excesses of lung cancer occurred mainly in men working in the foundry producing heavy crystal glass (RR, 3.9 [0.8–11.4]) and in refinement workers (grinders, etchers, polishers and controllers) (RR, 2.8 [0.6–8.2]) exposed for more than 15 years. Cancer of the prostate also occurred in slight excess: four cases *versus* 3.0 based on national rates (RR, 1.34 [0.36–3.41]); two were in glass-blowers and workers manufacturing heavy crystal glass and two in refinement workers. The authors had information confirming that smoking was less prevalent in the study group than in the reference population. The smoking-adjusted RR for lung cancer, based on a survey of smoking among 10% of the glass-workers, was 3.5 [1.3–7.7] (based on national rates), assuming a latency of 10 years.

In a Finnish study, the incidence of cancer was studied in a cohort of 1803 men and 1946 women with at least three months of continuous employment in two plain glass manufacturing factories [processes unspecified] and followed from 1953 through 1986 (Sankila *et al.*, 1990). An excess of skin cancer (melanomas and basal-cell carcinomas excluded) was found among male oral glass-blowers (two cases; 0.25 expected; SIR, 8.00; 95% CI, 0.97–28.9), and an excess of lung cancer was found among men in the two plants combined

(62 cases; 47.7 expected; SIR, 1.30; 95% CI, 1.00–1.67). The risk for lung cancer was also increased among glass-blowers using automated methods (SIR, 1.60) but not among oral glass-blowers (SIR, 0.29). The risk for stomach cancer was increased in oral glass-blowers (3 cases; RR, 2.16; 0.44–6.26). [The Working Group noted that no information was given on smoking.]

2.3 Case–control studies (see Table 10, p. 367)

2.3.1 *Cancer of the urinary bladder*

In a Canadian population-based study of 480 male and 152 female incident cases in 1974–76 (Howe *et al.*, 1980), an odds ratio of 6.0 (95% CI, 0.7–276) was found for male 'glass processors'.

A group of 303 incident cases of carcinoma (or papilloma not specified as benign) of the lower urinary tract in white males and 296 white male referent subjects were studied in Detroit (USA) in 1977–78. Patients and controls were interviewed to obtain lifetime work histories: Six case subjects and one referent subject (odds ratio, 5.9; 95% CI, 0.7–49.8) had ever been employed in glass or glass products manufacture (Silverman *et al.*, 1983).

In a hospital-based case–control study on work-related cancer of the urinary bladder in France in 1984–87 (Cordier *et al.*, 1993), 15 of 658 cases among men occurred in 'glass formers and potters' *versus* seven among the referents (odds ratio adjusted for smoking, 1.82; 95% CI, 0.73–4.53). [The Working Group noted that specific information on exposure was not given.]

2.3.2 *Cancers of the respiratory organs*

Milne *et al.* (1983) carried out a case–control study of 925 lung cancer deaths in Alameda County, California, USA, in 1958–62, comparing their occupations with those of 6420 deaths from other cancers in the same County, as identified from death certificates. They found a significant ($p < 0.05$) positive association with employment in glass, clay and stone manufacture (11 cases; odds ratio, 1.9). [The Working Group noted the limitations of using information on occupation derived solely from death certificates.]

Buiatti *et al.* (1985) reported a study comprising 376 incident, histologically confirmed cases of lung cancer in Florence, Italy, admitted to a regional hospital between 1981 and 1983. A total of 892 referent subjects were recruited from among patients who were admitted to the same hospital and who did not have lung cancer. Detailed work histories were compiled directly for each subject. Only one case but five referents had glass-work in their work histories [crude odds ratio, 0.5; 95% CI, 0.1–3.9].

Levin *et al.* (1988) studied the lifetime work histories, smoking histories and other exposure factors among 733 male Chinese with lung cancer in Shanghai in 1984–85 and among 760 male referents selected from the general population. Information was compiled by the use of a structured questionnaire administered in the subjects' homes, in hospital or at work sites. About 35 major occupational categories were examined. A deficit (odds ratio, 0.6; 95% CI, 0.3–1.5; adjusted for each occupation) of lung cancer was found among males working in 'glass, ceramic and enamelled product manufacture'. A parallel study was

Table 9. Cohort studies of exposures in the glass manufacturing industry

Study population	Site	No. of cases	RR	95% or 90% CI	Reference
468 Italian male glass-workers, producing glass containers, 1953–67 (mortality)	Lung	13	2.09	[1.1–3.6]	Cordioli *et al.* (1987)
	Larynx	4	4.49	[1.2–11.4]	
	Stomach	2	0.61	[0.07–2.2]	
191 male ceramics and glass-workers, not otherwise specified, but with occupational histories of exposure to high concentrations of silica dust, Austria, 1950–60 (mortality)	Lung	28	2.37	[1.58–3.43]	Neuberger & Kundi (1990)
	Stomach	6	1.16	[0.42–2.53]	
	Intestine	7	1.50	[0.60–3.09]	
625 Swedish male art glass-workers (mortality)	Lung[a]	6	2.4[b]	[0.9–5.2]	Wingren & Englander (1990)
	Colon[a]	4	2.5	[0.7–6.4]	
	Prostate[a]	4	1.7	[0.5–4.2]	
	Pharynx[a]	2	15.9	[1.8–57.4]	
3749 male and female Finnish glass-workers, unspecified as to process or product, 1953–86 (incidence)	Skin[c]	11	1.53	0.76–2.73	Sankila *et al.* (1990)
	Lung	69	1.28	0.99–1.62	
	Stomach	34	0.93	0.64–1.29	
	Colon	7	0.46	0.19–0.96	
	Bladder	9	0.97	0.44–1.84	
140 male oral glass-blowers	Skin[c]	2	8.00	0.97–28.9	
	Lung	1	0.29	0.01–1.64	
	Stomach	3	2.16	0.44–6.26	

[a]RR based on local county death rates
[b]Smoking-adjusted RR for lung cancer, 3.5 [1.3–7.7], with 10-year latency requirement
[c]Melanoma and basal-cell carcinomas excluded

performed among 672 female cases and 735 referent subjects, but small numbers in each occupational group precluded detailed analyses. The largest excess (odds ratio, 5.1; CI, 1.3–23.5) was found among female glass and glass product manufacturing workers, based on 15 cases and three referents. When 20 years of employment in the industry was applied as an inclusion criterion, the excess was more than seven fold.

2.3.3 *Tumours at multiple sites*

A preliminary study in three parishes with glass industries in southeastern Sweden (Wingren & Axelson, 1985) revealed an excess of deaths from stomach cancer in 1951–79 among glass-blowers (odds ratio, 6.4; 95% CI, 3.0–14.0), based on eight cases. For unspecified glass-workers [known to include glass-blowers], the odds ratio for stomach cancer was 1.5 (0.68–3.2), based on nine cases. Lung cancer was also seen in unspecified glass-workers, with an odds ratio of 2.4 (1.0–5.8), based on seven exposed cases. The same authors (Wingren & Axelson, 1987) expanded the study on mortality among workers in Swedish glass-works by selective causes of deaths, i.e. for total cancer, stomach cancer, colon cancer, lung cancer and cardiovascular deaths. Cases with these causes of death were considered in males aged 45 and over in the registers of deaths and burials in 11 parishes (including the three studied previously) in 1950–82; the eight new parishes were also analysed separately. Control subjects were taken as other causes of death among males aged 45 years and over in the same parishes. Information on exposure to various metal compounds was obtained from seven existing glass-works in the area. Stomach cancer appeared in excess for glass-blowers (odds ratio, 2.6 [95% CI, 1.4–4.9]) based on 11 exposed cases, as did colon cancer (odds ratio, 3.1 [95% CI, 1.2–7.7]), based on five exposed cases, and lung cancer (odds ratio, 2.3 [95% CI, 0.8–6.3]), based on four exposed cases. For unspecified glass-workers, the odds ratio for for stomach cancer was 1.4 [95% CI, 0.8–2.4], based on 18 exposed cases, and that for colon cancer was 1.8 [95% CI, 0.9–3.7], based on nine exposed cases; for lung cancer, the odds ratio was 1.9 [95% CI, 1.0–3.7], based on 11 exposed cases. On the basis of the information on exposure obtained from the glass-works, the authors later made an attempt to identify certain exposures as determinants of the cancer risks found (Wingren & Axelson, 1993) through further case–control evaluations in the art glass industry. The risk for stomach cancer in particular was associated with exposure to arsenic, copper, nickel, manganese and to some extent lead and chromium. For colon cancer, an increasing trend in risk was seen with increasing use of antimony and lead, the two elements being strongly correlated. For lung cancer, no obvious trend with exposure to any metal could be found.

In a case–control study based on death certificates, 9663 white and 3253 black men in Illinois (USA), aged 35–74, who had cancers of the stomach, pancreas, lung, prostate, urinary bladder or brain or non-Hodgkin's lymphomas (Mallin *et al.*, 1989) were compared with control groups chosen by sampling randomly among non-cancer deaths from the same age groups. Occupation was coded on the basis of the 1980 census. A three-fold excess risk for brain cancer was found, based on eight cases among manufacturers of glass and glass products. [The Working Group noted the limitations of using information on occupation derived solely from death certificates.]

A case–control study conducted in the Montréal (Canada) metropolitan area (Siemiatycki, 1991) included all males aged 35–70 with a histologically confirmed diagnosis of cancer at 20 selected sites made between September 1979 and June 1985. A total of 3730 cases were interviewed. Occupational exposure to 293 substances potentially present in the work environment was assessed by a group of experts on the job description in the questionnaires. Cases of cancer at each site were compared with all other cancer cases. Age, cigarette smoking and a number of other potential confounders were controlled for in the analyses. 'Glass dust' was one of the exposure categories with a prevalence of 1% in the total sample and was associated with stomach cancer (5 exposed cases; odds ratio, 1.8 [90% CI, 0.7–4.8]) and lung cancer (18 exposed cases; odds ratio, 2.2 [90% CI, 1.0–5.0]). When only substantial exposure was considered, the figures were: stomach cancer, four exposed cases; odds ratio, 2.7 [90% CI, 0.8–8.6] and lung cancer, six exposed cases; odds ratio, 1.0 [90% CI, 0.3–3.6].

2.4 Childhood cancer

In a proportionate mortality study of the distribution of the occupations of fathers of children who died from neoplasms in the United Kingdom, Sanders *et al.* (1981) found no indication of a relationship with glass and ceramics work (proportionate mortality ratio, 1.02), on the basis of 21 cancer deaths occurring in the period 1959-63. In 1970–72, the proportionate mortality ratio was 0.98, based on nine cancer deaths.

3. Other Relevant Data

3.1 Absorption, distribution, metabolism and excretion

No relevant data were available to the Working Group.

3.2 Toxic effects

Mortality from cardiovascular disease among Swedish glass-workers was studied in a case–control study, described in detail on p. 365 (Wingren & Axelson, 1987). The odds ratio for glass-workers who died of cardiovascular disease was 1.2 [95% CI, 1.0–1.4]. The crude odds ratio was highest (1.3 [95% CI, 0.9–1.8] for glass-blowers.

In a cohort study in the same area of Sweden, where glassworks are prevalent, described on p. 362 (Wingren & Englander, 1990), the SMR for all deaths was 0.98, based on 97 observed deaths, using national rates for comparison and 1.17 when county death rates were used for the comparison. The SMRs for cardiovascular deaths were 1.21 and 1.26 (39 deaths), respectively, and those for cerebrovascular disease, 1.50 and 1.68 (11 deaths). Neither was significantly different from unity. The SMR for cardiovascular disease increased to 1.8 (based on national rates) ($p < 0.01$) when adjustment for smoking was attempted.

[The Working Group noted that it is not clear how many of the cases from the case–control study were included in the cohort study.]

In a cross-sectional study in Germany (Wagner 1975) involving 131 glass-blowers aged 29–76 who had been exposed for 10–46 years, symptoms of chronic bronchitis [not specified]

Table 10. Case–control studies of exposures in the glass manufacturing industry

Study population	Exposure	Sex	No. of exposed cases	Odds ratio	95% CI	Remarks	Reference
Bladder cancer (incidence)							
Population-based, Canada	Glass-workers	M	6	6.0	0.7–276		Howe *et al.* (1980)
Population-based, USA	Glass-workers	M	6	5.9	0.7–50		Silverman *et al.* (1983)
Lung cancer							
Hospital-based, Italy (incidence)	Glass-workers	M	1	[0.5]	[0.1–3.9]	Crude odds ratio	Buiatti *et al.* (1985)
Population-based, China (incidence)	Glass, ceramics and enamelled product workers	M	12	0.6	0.3–1.5	Odds ratio adjusted for other occupation	Levin *et al.* (1988)
	Glass products workers	F	15	5.1	1.3–23.5		
Population-based, Sweden (mortality)	All glass-workers	M	21	1.7	[1.0–2.8]	Mantel–Haenszel odds ratio	Wingren & Axelson (1987)
	Glass-blowers	M	4	2.3	[0.8–6.3]		
	Unspecified	M	11	1.9	[1.0–3.7]		
Population-based, Canada (incidence)	Glass dust (any)	M	18	2.2	[1.0–5.0]	Mantel–Haenszel odds ratio	Siemiatycki (1991)
	Substantial	M	6	1.0	[0.3–3.6]		
Stomach cancer							
Population-based, Sweden	All glass-workers	M	44	1.5	[1.0–2.1]	Mantel–Haenszel odds ratio	Wingren & Axelson (1987)
	Glass-blowers	M	11	2.6	[1.4–4.9]		
	Unspecified	M	18	1.4	[0.8–2.4]		
Population-based, Canada	Glass dust (any)	M	5	1.8	[0.7–4.8]	Mantel–Haenszel odds ratio	Siemiatycki (1991)
	Substantial	M	4	2.7	[0.8–8.6]		
Colon cancer							
Population-based, Sweden	All glass-workers	M	18	1.6	[0.9–2.8]	Mantel–Haenszel odds ratio	Wingren & Axelson (1987)
	Glass-blowers	M	5	3.1	[1.2–7.7]		
	Unspecified	M	9	1.8	[0.9–3.7]		

were reported by 11. Thirty had abnormal lung function tests, and of these, 11 were considered to have emphysema; eight of the 11 smoked 10–30 cigarettes daily. No control group was studied.

Of 47 art glass-blowers (mean age, 34.5 years), 21% reported having usual cough and 31% reported wheezing in a questionnaire study in the USA (Braun & Tsiatis, 1979); 34 of the 47 studied were smokers or ex-smokers. [The Working Group noted that the basis of selection and the number of workers who refused to participate in the study were not indicated.] The frequency of different indicators of abnormal lung function (vital capacity, forced expiratory volume in one second [FEV_1], maximal mid-expiratory flow, maximal flow at 50% vital capacity) ranged from 2 to 19% in 42 art glass-blowers.

Munn *et al.* (1990) studied lung function (forced vital capacity, FEV_1, mid-expiratory flow rate, maximal voluntary ventilation, maximal expiratory and inspiratory muscle pressure) in 87 volunteers (64 were smokers) from three glass factories in the USA. The participants were divided into non-glass-blowers, part-time glass-blowers and full-time glass-blowers. All function measurements were on average no lower than 95% of the predicted value; full-time glass-blowers had significantly higher FEV_1, forced vital capacity and muscle pressure values than their colleagues. [The Working Group noted the possibility of selection bias; reasons for participating and not participating in the study were not elucidated.]

Srivastava *et al.* (1988) studied the etiological factors in chronic bronchitis in a 'representative sample' of 373 glass-bangle workers in a case–control study in India [selection criteria not indicated]. Eighty-nine of the workers were judged to have chronic bronchitis. The risk for chronic bronchitis increased with age, tobacco smoking, low socioeconomic status and duration of employment in the glass-bangle industry. The odds ratio for workers with chronic bronchitis to have worked > 25 years in the glass-bangle industry was 2.30 ($p < 0.1$) (corrected for age but not for socioeconomic status or smoking), compared with those with exposure < 16 years.

In a cross-sectional study of lung function in India, Rastogi *et al.* (1991) observed that 220 asymptomatic glass-bangle workers (123 smokers) [selection criteria not indicated; exposed workers with tuberculosis, bronchial asthma or chronic bronchitis excluded] had lower lung function variables than 88 unexposed controls (37 smokers). A number of heavy metals, such as arsenic, lead, cadmium, zinc, copper, cobalt and selenium are used as colouring agents in the manufacture of glass bangles and are mixed manually with soda ash and silica sand in varying proportions. The difference in forced expiratory flow rate over 75 and 85% of the spirogram reached statistical significance in both smokers and nonsmokers.

In an effort to identify cases of asbestos-related diseases in a glass bottle manufacturing factory in Texas, USA, employees were offered a medical examination. The average duration of employment was 17 years, ranging from 6 months to 36 years. Pleural plaques or pleural fibrosis were observed in 38/334 (224 smokers) workers, fibrosis in 22 and restrictive pulmonary function in 19. Because less than half of the eligible workforce volunteered for the study, thereby resulting in possible selection bias, the authors stated that these figures do not represent the true prevalence of these diseases (Kronenberg *et al.*, 1991). [The Working Group noted that previous employment history of the cases was not described.]

The occurrence of cataract due to heat was first described in the eighteenth century; a nineteenth-century report stated that glass-blowers frequently developed cataracts (Keatinge *et al.*, 1955). In a review of company records and examination of seven workers (10% of the exposed workforce) with long duration of employment, Dunn (1950) found no case of cataract. In a study of 20 Swedish glass-works (Lydahl & Philipson 1984), the risk of people exposed to infrared of having lowered visual acuity was 2.5 times higher than that of controls (95% CI, 1.4–4.4); the probability of having been operated for a cataract was 12 times as high (95% CI, 2.6–54).

3.3 Reproductive and developmental effects

No relevant data were available to the Working Group.

3.4 Genetic and related effects

Šrám *et al.* (1985) performed a cytogenetic analysis on the peripheral blood lymphocytes of 31 workers in a glass factory in the Czech Republic and of 23 unexposed controls. The authors noted exposure to mineral oil mists containing polycyclic aromatic hydrocarbons. Although exposure did not exceed the national maximum allowable concentration for mineral oil aerosols (5 mg/m^3 air), a significant increase in the frequency of aberrant cells and chromosome breaks per cell was detected in exposed workers, with no significant difference between smokers and nonsmokers in either group. In particular, higher rates of dicentrics, reciprocal translocations and cells with pulverization were observed in exposed workers. [The Working Group noted that exposures to other compounds were not taken into account.]

4. Summary of Data Reported and Evaluation

4.1 Exposure data

There are five main sectors in the glass manufacturing industry: flat glass, container and pressed ware, art glass, special glass (e.g. optical, ophthalmic, electronic) and fibre glass (which is not considered here). The basic steps in the manufacture of glass products are melting, fining, homogenization, annealing and forming. Art and special glasses are produced by pot processes, involving manual batch handling. Art glass production has changed little with time and, for the most part, still involves blowing by mouth. During the twentieth century, the production of flat glass and container glass has evolved from traditional batch processes to highly automated processes. The modern production of flat glass is the most highly automated and usually utilizes tank melting with the continuous feeding of batch ingredients and the float (Pilkington) process for forming. The production of containers and pressed ware has also become increasingly mechanized, with mechanical blowing or pressing of the molten glass.

Exposure to lead, arsenic and antimony oxides occurs primarily in sectors of the industry where traditional, non-mechanized techniques are used, such as in the production of crystal and other art glasses. Other potential exposures in glass manufacture include silica, asbestos, other metal oxides and polycyclic aromatic hydrocarbons.

4.2 Human carcinogenicity data

Four cohort studies of workers involved in glass manufacture—at a plant in Italy producing glass containers, among ceramics and glass workers in Austria, at two glass factories in Finland and among art glass-workers in Sweden—found increased risks for lung cancer. Population-based case–control studies in Sweden and Canada also found increased risks for lung cancer in glass-workers; a population-based case–control study in China found a significantly increased risk for lung cancer in female glass-workers and a nonsignificantly decreased risk in male glass, ceramics and enamelled product workers. None of the studies was specifically informative with respect to work in the flat-glass manufacturing industry. It is unlikely that the increased risk for lung cancer can be explained by nonoccupational risk factors such as smoking, in view of the consistency and magnitude of the findings, which were obtained in studies of various designs in different countries. When smoking habits were addressed in one of the studies, the estimated relative risk for lung cancer was increased.

In general, no distinction was made in these studies between different components of the glass manufacturing industry. The only subgroup of glass-workers for whom specific findings were available was glass-blowers. Population-based case–control studies in Sweden on glass-workers and in Canada on people exposed to glass dust found small increased risks for stomach cancer, whereas in three cohort studies of glass-workers in Italy, Austria and Finland the risks for stomach cancer were not increased; in two of the cohort studies, the numbers of cases were small. Only the cohort study in Finland and the case–control study in Sweden specifically reported findings on stomach cancer in glass-blowers; both showed stronger increases in risk in glass-blowers than in glass-workers in general.

The three cohort studies in Austria, Finland and Sweden showed little evidence of an increased risk for intestinal cancer. A Swedish population-based case–control study of colon cancer found a small increase in risk in glass-workers in general but a stronger increase in glass-blowers.

Two population-based case–control studies, in Canada and the USA, showed nonsignificantly increased risks for urinary bladder cancer in glass-workers, but the numbers of cases were small. An Italian cohort study showed an increased risk for laryngeal cancer in glass-workers. In the Finnish cohort study, an increased risk was seen for basal-cell carcinomas of the skin in male workers.

The evidence that favours a causal association between exposures in the glass manufacturing industry and cancer is: a reasonably consistent association with lung cancer in all four cohort studies; a similar though less consistent association with lung cancer in three case–control studies; a larger lung cancer risk than can reasonably be explained by nonoccupational confounding factors; the presence of human lung carcinogens in some components of the glass manufacturing industry; and the finding of an increased risk for stomach cancers in several cohort and case–control studies. Findings that limit the interpretation of causality include: the poorly characterized and heterogeneous exposures of workers in the glass manufacturing industry, which are likely to result in a weak or null association between exposure and cancer risk in some studies; the absence of demonstrated dose–response relationships; the fact that, in some studies, risk estimates were made for the combination of glass-workers and workers in other industries, thereby diminishing the degree to which results can be interpreted for the glass manufacturing industry itself; and the relatively few studies of workers in the glass manufacturing industry.

4.3 Other relevant data

A single study reported an increased frequency of chromosomal aberrations in peripheral blood lymphocytes of subjects working in a glass factory in the Czech Republic.

4.4 Evaluation[1]

There is *limited evidence* that occupational exposures in the manufacture of art glass, glass containers and pressed ware are carcinogenic[2].

There is *inadequate evidence* that occupational exposures in flat-glass and special glass manufacture are carcinogenic.

Overall evaluations

The manufacture of art glass, glass containers and pressed ware entails exposures *that are probably carcinogenic to humans (Group 2A).*

Occupational exposures in flat-glass and special glass manufacture *are not classifiable as to their carcinogenicity to humans (Group 3).*

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[1]For definition of the italicized terms, see Preamble, pp. 26–30.

[2]This evaluation does not apply to glass fibre, which was evaluated previously (see General Remarks, p. 36). The Working Group could not identify the specific exposure, process or activity that is most likely to be responsible for the excess risk.

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