

VINYL CHLORIDE\*

1. Chemical and Physical Data

1.1 Synonyms and trade names

Chem. Abstr. No.: 75-01-4

Chlorethene; chlorethylene; chloroethene; chloroethylene;  
ethylene monochloride; monochloroethene; monochloroethylene

VC; VCM; Vinyl chloride monomer; Vinyl C monomer

1.2 Chemical formula and molecular weight

$H_2C=CHCl$

$C_2H_3Cl$

Mol. wt: 62.5

1.3 Chemical and physical properties of the pure substance

- (a) Description: A colourless, flammable gas under normal conditions of temperature and pressure but usually handled as a liquid under pressure
- (b) Melting-point:  $-153.7^{\circ}C$
- (c) Boiling-point:  $-13.9^{\circ}C$
- (d) Density:  $d_4^{20}$  0.9121
- (e) Refractive index:  $n_D^{10}$  1.4066
- (f) Solubility: Slightly soluble in water ( $<0.11\%$  w/w at  $25^{\circ}C$  (Hardie, 1964)); soluble in ethanol; very soluble in ether, carbon tetrachloride and benzene
- (g) Volatility: Vapour pressure is 2660 mm Hg at  $25^{\circ}C$ .
- (h) Chemical reactivity: Vinyl chloride monomer polymerizes in light or in the presence of a catalyst. On combustion, it is degraded mainly to hydrogen chloride, carbon monoxide, carbon

\* Considered by the Working Group in Lyon, 18-24 June, 1974. The Working Group was aware of many ongoing studies; however, this document is based upon published data or data already accepted for publication which were available at that time.

dioxide and to traces of phosgene (O'Mara et al., 1971). It loses HCl on treatment with strong alkalis at high temperatures (Miller, 1969).

(i) Flash-point: -78°C

#### 1.4 Technical products and impurities

Vinyl chloride monomer is available commercially in cylinders or in bulk and is generally supplied as a liquid under pressure. The technical grade is 99.9% pure (Condensed Chemical Dictionary, 1971). Specifications for a typical commercial product call for maximums in mg/kg by weight of the following impurities: unsaturated hydrocarbons - 10; acetaldehyde - 2; dichloro compounds - 16; water - 15; hydrogen chloride - 2; nonvolatiles - 200; iron - 0.4. Phenol at levels of 25-50 mg/kg by weight is used as a stabilizer to prevent polymerization.

## 2. Production, Use, Occurrence and Analysis

Two review articles on vinyl chloride monomer have been published (Hardie, 1964; Keane et al., 1973).

### 2.1 Production and use<sup>1</sup>

The first synthesis of vinyl chloride monomer appears to have been made in 1835 by Regnault (Regnault, 1835). It has been produced commercially in the United States for at least 46 years (US Tariff Commission, 1928). Addition of hydrogen chloride to acetylene, formerly the most important route of synthesis, has been displaced by a method using the halogenation of ethylene; almost 90% of the vinyl chloride monomer produced in the US in 1971 was made from ethylene. In this process, ethylene is reacted with hydrogen chloride and oxygen to give ethylene dichloride, which is subsequently cracked to produce vinyl chloride monomer and hydrogen chloride.

In 1971, 10 US producers reported a total vinyl chloride monomer production of 1,969 million kg (US Tariff Commission, 1973). Preliminary

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<sup>1</sup> Data from Chemical Information Services, Stanford Research Institute, USA

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data indicate that in 1972 US production amounted to 2,310 million kg (US Tariff Commission, 1974c) and in 1973 to 2,428 million kg (US Tariff Commission, 1974b). US imports of vinyl chloride monomer have been negligible; but in 1972, US exports were reported to have been 282 million kg, over half of which was exported to Norway, Belgium and Spain (US Department of Commerce, 1972).

World production of vinyl chloride monomer in 1971 in various areas is estimated as follows (in millions of kg): Western Europe - 2,497; United States - 1,969; Japan - 1,275; Eastern Europe - 817; other areas - 499; total - 7,057. Countries producing vinyl chloride monomer (listed in decreasing order of estimated annual production in recent years) and the numbers of producers in each country are as follows: Japan (15), the Federal Republic of Germany (5), Italy (3), France (4), Belgium (3), the United Kingdom (4), The Netherlands (2), Brazil (3), Spain (3), Turkey (3), Taiwan (2), Argentina (2), Sweden (1), Mexico (1), USSR (2), South Korea (1), Finland (1), Czechoslovakia (1), Venezuela (1), Egypt (1), Thailand (1), Rumania (1), Chile (2), Greece (1) and Australia (1) (Keane et al., 1973).

In 1971, 77 million kg of vinyl chloride monomer were imported into the Common Market countries, as compared to an export volume of 52 million kg. Belgium/Luxembourg, Italy and The Netherlands were not exporters, whereas the Federal Republic of Germany and France were not importers; however, the situation is subject to rapid change due to the establishment of new plants and with changing short-term regional needs (European Communities, 1971). Japan exported 323 million kg of vinyl chloride monomer in 1972, principally to Taiwan (52%) and to the Republic of South Korea (30%).

At least 97% of the nearly 1,600 million kg of vinyl chloride monomer consumed in the US in 1971 was for the production of vinyl chloride homo-polymer and co-polymer resins. The remainder was used in a variety of applications, the most significant of which are in the production of methyl chloroform; as an additive to specialty coatings; and, in several products, as a component of certain propellant mixtures. Hardie (1964) has reported that vinyl chloride monomer has been used as a refrigerant, as an

extraction solvent for heat-sensitive materials and in the production of chloroacetaldehyde, an intermediate in the synthesis of sulpha drugs; however, no evidence was found that vinyl chloride monomer is presently being used for these purposes.

The polyvinyl chloride resins made from vinyl chloride monomer find their largest markets in the building and construction industries. Other important outlets are their use in household products, in consumer goods, in electrical applications, in packaging and in transportation (see Appendices A and B for additional information on the uses of polyvinyl chloride and vinyl chloride-vinyl acetate co-polymers).

The consumption patterns for vinyl chloride monomer in Western Europe and Japan are believed to be similar to that in the US. An estimated 5% of the polymers made in Japan in 1972 were co-polymers of vinyl chloride monomer with other monomers.

In early April 1974, the US Environmental Protection Agency (EPA) announced that no new pesticide products containing vinyl chloride monomer as a propellant would be registered for use, and this body subsequently suspended from sale all pesticide aerosols containing vinyl chloride monomer for use in the home, in food-handling establishments, in hospitals or in other enclosed areas. Twenty-eight products were reported to be affected by the decision (US Environmental Protection Agency, 1974). In the USSR, vinyl chloride monomer has been banned for use in aerosol propellants, because of its hazardous effects (Grikitis, 1967).

In April 1974, three US manufacturers recalled from the market aerosol hairspray products containing vinyl chloride monomer, and the US Food and Drug Administration (FDA) was reported to have written to other manufacturers requesting that they identify products containing vinyl chloride monomer (Anon., 1974b).

In May 1974, the US Consumer Product Safety Commission issued an order proposing to ban the sale of all self-pressurized products containing vinyl chloride monomer which were intended for household use.

## 2.2 Occurrence

Vinyl chloride monomer is not known to occur in nature.

### (a) Occupational exposure

Cook et al. (1971) reported that the air concentration of vinyl chloride monomer in a polymerization reactor prior to ventilation is of the order of  $7800 \text{ mg/m}^3$  (3000 ppm); that during the scraping procedure,  $130\text{--}260 \text{ mg/m}^3$  (50-100 ppm); and that close to the hands during scraping,  $1560\text{--}2600 \text{ mg/m}^3$  (600-1000 ppm). Lange et al. (1974a) found a concentration of  $1560\text{--}2600 \text{ mg/m}^3$  (600-1000 ppm) vinyl chloride monomer in a polymerization reactor after washing. Concentrations of  $50\text{--}800 \text{ mg/m}^3$  (20-312 ppm) vinyl chloride monomer have been found in the working atmosphere in a plant producing polyvinyl chloride (Filatova & Gronsberg, 1957); air concentrations of vinyl chloride monomer in working places in polyvinyl chloride-producing factories were reported by these authors to range from  $100\text{--}800 \text{ mg/m}^3$  (40-312 ppm) with peaks up to  $87,300 \text{ mg/m}^3$  (34,000 ppm). Anghelescu et al. (1969) have reported values from  $112\text{--}554 \text{ mg/m}^3$  (44-216 ppm). It has been estimated that 20,000 US workers, past and present, have been exposed to the chemical in manufacturing plants (Heath et al., 1974).

It has been reported that, on a time-weighted average, the concentration of vinyl chloride monomer to which coagulator operators are exposed ranges from  $130\text{--}650 \text{ mg/m}^3$  (50-250 ppm). The close relationship between the concentrations of vinyl chloride monomer in air to which subjects have been exposed and that in their expired air after exposure has ceased suggests that monitoring of vinyl chloride monomer in air and breath analysis are both valid means of estimating the exposure of individuals to vinyl chloride monomer (Baretta et al., 1969).

Vinyl chloride monomer has been recognized as a potentially dangerous contaminant in manufacturing plants. In the USSR a maximum allowable concentration (MAC) of  $30 \text{ mg/m}^3$  (12 ppm) has been recommended generally (Schottek, 1969), and in the Federal Republic of Germany a MAC of  $260 \text{ mg/m}^3$  (100 ppm) has been introduced (Deutsche Forschungsgemeinschaft, 1973). In the US a maximum of  $1300 \text{ mg/m}^3$  (500 ppm) in working atmospheres was allowed

until April 1974 when the Occupational Safety and Health Administration (OSHA) of the US Department of Labor instituted a temporary emergency standard of 130 mg/m<sup>3</sup> (50 ppm) vinyl chloride monomer in the working atmosphere (US Code of Federal Regulations, 1974a). On May 6 1974, the OSHA proposed a permanent standard which would set employee exposure at no detectable level, as determined by a sampling and analytical method capable of detecting concentrations of 1 ppm vinyl chloride monomer with an accuracy of 1 ppm  $\pm$  50%. This proposal also calls for monitoring, control methods, medical surveillance and records and reports (US Code of Federal Regulations, 1974b).\*

Recently, it has been reported that polyvinyl chloride leaving certain manufacturing plants may contain 200-400 mg/kg (ppm) vinyl chloride monomer; on delivery to the customer this level is about 250 mg/kg (ppm); and after processing, levels of 0.5-20 mg/kg (ppm) are reached, depending on the method of fabrication (Anon., 1974e). Another source found 100 mg/kg (ppm) residual vinyl chloride monomer in polyvinyl chloride dispersions (Wilkinson et al., 1964).

(b) Air and rain

In early May 1974, an official of the EPA estimated that US plants were discharging 90 million kg vinyl chloride monomer into the atmosphere annually (Anon., 1974c). The EPA is also reported to have found 6% losses of vinyl chloride monomer from polyvinyl chloride-producing plants and concentrations of 2.6-5.2 mg/m<sup>3</sup> (1-2 ppm) in the air near these plants (Anon., 1974d). On May 30 1974, that body requested US companies making vinyl chloride monomer and polyvinyl chloride to provide process, emission and air quality data on their plants for possible use in establishing air pollution control standards (Anon., 1974f).

It has been reported (US Federal Register, 1974) that the use of aerosol products in enclosed spaces, even in short bursts (e.g., 30 seconds), could result in air concentrations of vinyl chloride monomer as high as 1000 mg/m<sup>3</sup> (400 ppm) and that these levels could persist for several hours after spraying.

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\*See also p. 310

(c) Food

In May 1973, a branch of the US Treasury Department banned the use of polyvinyl chloride for the packaging of alcoholic beverages (Anon., 1973b). This action was a result of studies reported by the FDA indicating that levels of up to 20 mg/kg (ppm) vinyl chloride monomer were present in alcoholic beverages packaged in this material (Anon., 1973a).

2.3 Analysis\*

Unsaturated polymerizable compounds such as vinyl chloride monomer can be separated and identified as mercuric acetate adducts by thin-layer chromatography on silica gel (Braun & Vorendohre, 1964). Methods have also been described for the separation and determination of mixtures of halogenated compounds containing vinyl chloride monomer (Hollis, 1966; Hollis & Hayes, 1962), and one is available for the determination of residual vinyl chloride monomer in polyvinyl chloride dispersions (Wilkinson et al., 1964).

Infra-red spectroscopy using a long-path cell has been used for time-weighted monitoring in factory atmospheres (Baretta et al., 1969). Although the limit of detection was given in this report as 5 ppm, another source (Stewart et al., 1965) gave limits of detection of 0.26-26 mg/m<sup>3</sup> (0.1 and 10 ppm) vinyl chloride monomer in breath but stated that a sample 5-10 times 10 ppm is necessary for positive confirmation of vinyl chloride monomer. The analysis made by Stewart et al. (1965) involved chromatography and infra-red spectroscopy.

Vinyl chloride monomer can be detected at levels as low as 130 mg/m<sup>3</sup> (50 ppm) by a Tilley Refrigerant Leak Detector Lamp (Christie et al., 1965); it can also be determined by gas chromatography (Galipern et al., 1968; Hinshaw, 1966; Popova et al., 1967) and by gas-liquid chromatography (Hollis & Hayes, 1962). Porous polyaromatic polymer bead columns have been employed to concentrate gas samples at room temperature prior to their gas-chromatographic determination (Hollis, 1966; Williams & Umstead, 1968). The presence of vinyl chloride monomer in air samples has also been determined by colorimetry (Gronsberg, 1966).

\*See also p. 310

### 3. Biological Data Relevant to the Evaluation of Carcinogenic Risk to Man

#### 3.1 Carcinogenicity and related studies in animals

##### (a) Inhalation and/or intratracheal administration

Mouse: A total of 360 Swiss mice (180 males and 180 females) was exposed to concentrations of 10000, 6000, 2500, 500, 250 or 50 ppm vinyl chloride monomer (VCM) 4 hours daily on 5 days per week for 30 weeks. A total of 139 mice (95 males and 44 females) died within 34 weeks; 42 had adenomas and/or adenocarcinomas of the lung, 15 had mammary adenocarcinomas and 3 had angiosarcomas of the liver. In 28 (19 males and 9 females) of the 80 male and 70 female untreated controls which died within this time, no tumours were observed. The lifetime studies were still in progress at the time of reporting (Maltoni & Lefemine, 1974a). [See also Table I.] Further details of the experiments still in progress are available (Maltoni & Lefemine, 1974b).

Angiosarcomas of the liver have also been reported in 2 mice exposed by inhalation to 50 ppm VCM in a further experiment carried out in the US (US Federal Register, 1974).

Rat: A group of 26 male Ar/IRE Wistar rats was exposed to an atmospheric concentration of 3% v/v (equivalent to 30,000 ppm) commercial-grade VCM (99% pure) 4 hours per day on 5 days per week for 12 months. Altogether 17 rats survived or were killed from 40-54 weeks after the initial exposure, at which latter time the experiment was terminated. Skin tumours developed in all 17 rats (14 epidermoid carcinomas, 2 mucoepidermoid carcinomas, 1 papilloma); in addition, lung tumours developed in 7 rats (5 adenocarcinomas, 1 adenoacanthoma, 1 squamous-cell carcinoma) and osteochondromas in 5 rats. The skin tumour development was confined to the region of the submaxillary and parotid glands, and the bone tumours developed in the metacarpal and metatarsal regions of the four limbs. No tumours were observed in 25 untreated controls killed at an unstated time (Viola et al., 1971). [Maltoni & Lefemine (1974a) examined slides from the experiment and concluded that the skin tumours were Zymbal gland tumours and that the lung tumours were metastases of these.]

TABLE 1\*

Incidences of tumours in mice exposed to VCM  
for 30 weeks and dying within 34 weeks

| Concentrations<br>of VCM (ppm)<br>given 4 hrs/day<br>on 5 days/week | Total<br>no. of<br>animals<br>at start | Survivors<br>at<br>34 weeks | Adenomas &<br>adenocarci-<br>nomas of<br>the lungs | Mammary<br>adeno-<br>carcinoma | Angio<br>sarcoma<br>of the<br>liver | Others |
|---------------------------------------------------------------------|----------------------------------------|-----------------------------|----------------------------------------------------|--------------------------------|-------------------------------------|--------|
| 10,000                                                              | 60                                     | 26                          | 12                                                 | 5                              | 0                                   | 3      |
| 6,000                                                               | 60                                     | 32                          | 12                                                 | 4                              | 1                                   | 2      |
| 2,500                                                               | 60                                     | 37                          | 6                                                  | 2                              | 0                                   | 0      |
| 500                                                                 | 60                                     | 40                          | 8                                                  | 1                              | 2                                   | 0      |
| 250                                                                 | 60                                     | 44                          | 4                                                  | 2                              | 0                                   | 0      |
| 50                                                                  | 60                                     | 42                          | 0                                                  | 1                              | 0                                   | 0      |
| Controls                                                            | 150                                    | 122                         | 0                                                  | 0                              | 0                                   | 0      |

\* From Maltoni & Lefemine (1974a)

Groups of 30 male and 30 female Sprague-Dawley rats, 13-21 weeks old, were exposed by inhalation to 10000, 6000, 2500, 500, 250 or 50 ppm VCM 4 hours daily on 5 days per week for a period of 17 weeks. Carcinomas of the Zymbal gland developed in 3/24 rats of the highest dose group and in 1/12 rats of the 6,000 ppm group that died before the 59th week. No tumours of this organ were observed in the 183 untreated rats which survived up to this time. Rats of the same strain (69-96 per group) were also treated for 52 weeks at the same dose levels, and the following tumours developed within 130 weeks in various organs: carcinomas of the Zymbal gland in 28/282 rats treated with the 4 highest doses and nephroblastomas (24/349 rats) and angiosarcomas of the liver (45/349 rats) among the groups treated with the 5 highest dose levels. A total of 9 angiosarcomas was observed in organs other than the liver. The liver and kidney tumours metastasized to other organs. No tumours were observed within 130 weeks in 96 rats treated with 2,500 ppm vinyl acetate 4 hours daily on 5 days a week, nor in 68 untreated controls. [See also Table 2.] In a group of 60 Sprague-Dawley rats treated with 30,000 ppm VCM 4 hours daily on 5 days a week for 43 weeks, 2 Zymbal gland carcinomas developed within 34 weeks (Maltoni & Lefemine, 1974a). Further details of this experiment still in progress are available (Maltoni & Lefemine, 1974b).

(b) Other experimental systems

Prenatal exposure: Two groups of 30 female Sprague-Dawley rats were treated by inhalation between the 12th and 18th day of pregnancy with 10,000 or 6,000 ppm VCM for 4 hours daily. Of the resulting offspring, 4/54 and 2/32, respectively, had died by the 68th week after birth, and 1 subcutaneous angiosarcoma was observed in each group. The experiment was still in progress at the time of reporting (Maltoni & Lefemine, 1974a).

3.2 Other relevant biological data

(a) Animals

In 10 male and 10 female rats exposed by inhalation to 500 ppm VCM 7 hours per day on 5 days per week for 4.5 months, an increase in liver weight, "some central lobular granular degeneration in the liver and interstitial and tubular changes in the kidneys" were reported to have occurred

TABLE 2\*

Incidence of tumours in rats exposed to VCM  
for 52 weeks and surviving up to 130 weeks

| Concentration<br>of VCM (ppm)<br>given 4 hrs/day<br>on 5 days/week | Total<br>no. of<br>animals<br>at start | Survivors<br>at<br>130 weeks | Zymbal<br>gland<br>tumour | Nephro-<br>blastoma | Angio-<br>sarcoma<br>of the<br>liver | Angio-<br>sarcoma<br>at other<br>sites | Others |
|--------------------------------------------------------------------|----------------------------------------|------------------------------|---------------------------|---------------------|--------------------------------------|----------------------------------------|--------|
| 10,000                                                             | 69                                     | -                            | 16                        | 4                   | 7                                    | 0                                      | 6      |
| 6,000                                                              | 72                                     | -                            | 7                         | 4                   | 13                                   | 2                                      | 1      |
| 2,500                                                              | 74                                     | -                            | 2                         | 6                   | 14                                   | 3                                      | 1      |
| 500                                                                | 67                                     | -                            | 3                         | 4                   | 7                                    | 2                                      | 1      |
| 250                                                                | 67                                     | 1                            | 0                         | 6                   | 4                                    | 2                                      | 2      |
| 50                                                                 | 64                                     | 3                            | 0                         | 0                   | 0                                    | 0                                      | 0      |
| Controls                                                           | 68                                     | 1                            | 0                         | 0                   | 0                                    | 0                                      | 0      |

\* From Maltoni & Lefemine (1974a)

in animals killed at that time. An increase in liver weight was also noticed in rats exposed to 200 or 100 ppm VCM 7 hours daily on 5 days per week for a period of 26-29 weeks. In rabbits inhaling concentrations of 200 ppm VCM 7 hours per day on 5 days per week, for 138-144 exposures within 204 days, "central lobular granular degeneration of the liver" was observed histologically in both male and female animals. No histological changes were observed in rats, guinea-pigs, rabbits or dogs inhaling 50 ppm VCM 7 hours per day on 5 days per week for 6 months (Torkelson et al., 1961).

Viola (1970) reported degeneration of the bone and connective tissue in male Wistar rats exposed to a concentration of 30,000 ppm VCM 4 hours per day on 5 days per week for up to 12 months. These lesions are similar to the acro-osteolysis of the hand in workers exposed to VCM. Degenerative changes were observed in the liver (interstitial hepatitis, necrosis, proliferation of Kupfer cells and fibrosis), brain (neuronal and glial cell degeneration) and kidney (tubular nephrosis and chronic interstitial nephritis). Basalaeu et al. (1972) also reported degenerative changes of the bone in rats and rabbits exposed to 30-40 mg/m<sup>3</sup> (12-15 ppm) VCM 4 hours daily for a period of up to 6 months.

(b) Man

Workers exposed to VCM have been found to develop various lesions (Anon., 1974a), including sclerotic changes of the skin, circulatory disturbances, osteolysis, thrombocytopenia, marked fibrosis of the portal tract and impaired liver function.

The occurrence of acro-osteolysis in workers engaged in the polymerization of VCM is frequently associated with Raynaud's syndrome. The acro-osteolysis is generally located in the distal phalanges of the hands, but other sites are also affected. The ages of the affected people ranged from 20-47 years and the exposure time from 5-42 months. The incidences of cases so far reported by various authors does not appear to exceed 5% of personnel involved in the polymerization of VC, and the disease seems mainly to affect autoclave cleaners (Angheliescu et al., 1969; Chatelain & Motillon, 1967; Cordier et al., 1966; Dirman et al., 1971; Harris & Adams, 1967; Lange et al., 1974a; Marin et al., 1967; Viola, 1971; Wilson et al., 1967).

Among 338 workers not involved in the cleaning of autoclaves but only in the handling of the newly-produced polyvinyl chloride (PVC), no signs of acro-osteolysis were observed (Chatelain & Motillon, 1967). No cases of acro-osteolysis were observed in a total of 1178 workers handling PVC powder (Cordier et al., 1966; Wilson et al., 1967).

In 48 workers exposed to 140-1200 mg/m<sup>3</sup> VCM during the production of PVC in a Russian factory, some workers were reported to have had signs of irritation of the respiratory tract and hepatitis. Twenty-three workers were found to have an increased haemoglobin level in their blood (Tribuch et al., 1949).

Suciu et al. (1967) studied 168 workers involved in the polymerization of VCM, in whom they reported narcotic symptoms, asthenic nervous symptoms, Raynaud's syndrome and liver enlargement. The incidence of Raynaud's syndrome was 6% and that of liver enlargement 30%. Lange et al. (1974a) also reported liver disturbances in 11 patients employed in the manufacture of PVC; and in 5 liver biopsies marked periportal fibrosis and slight parenchymal damage were apparent.

In an investigation of 98 men employed for up to 25 years in 2 factories in which the polymerization of VCM was carried out, it was found that the time-weighted average concentrations of VCM in the atmosphere ranged from 400 mg/m<sup>3</sup> (155 ppm) in 1950 to 26 mg/m<sup>3</sup> (10 ppm) at the end of the study, although average concentrations of 800 mg/m<sup>3</sup> (300 ppm) VCM had been encountered prior to the introduction of continuous monitoring in 1950. It was found that "several" individuals, after approximately 20 years of exposure to time-weighted average concentrations of 800 mg/m<sup>3</sup> (300 ppm) VCM in the early part of their careers, showed changes in liver function as measured by retention of bromsulphalein and by the icterus index (Kramer & Mutchler, 1972).

Twenty male autoclave cleaners working in one PVC-producing factory in the Federal Republic of Germany were subjected to a series of liver function tests, their livers were examined by laparoscopy and histological examination of liver biopsies was carried out. Of these men, 19 had elevated bromsulphalein retention times, 16 had thrombocytopenia, 7 had splenomegaly

and 6 had hepatomegaly. In almost all cases there was histological evidence of portal fibrosis, and in 14 cases fibrosis of the liver capsule was observed during laparoscopy. In addition, 4 of the workers had signs of acro-osteolysis (Marsteller et al., 1973).

### 3.3 Observations in man

The first association of exposure to VCM with the development of cancer was made by Creech & Johnson (1974) who reported 3 cases of angiosarcoma of the liver in men working with this substance.

By following up medical records, reviewing pathological material and by systematic medical screening, Heath et al. (1974) have discovered to date 13 such cases, including the 3 cases reported by Creech & Johnson, among men employed at 4 VCM-polymerization plants. The first case involved a worker dying in 1961. In 2 of the cases, angiosarcomas were also present in tissues other than the liver. All 13 cases have occurred in white males aged 36-60 years, with a mean age at the time of diagnosis of 48.2 years. The length of time between first exposure to VCM and diagnosis of the tumour ranged from 12-29 years (mean, 20.3 years), and the mean total duration of work involving exposure to VCM was 18 years.

Heath et al. (1974) reported that data from the National Cancer Institute's Third National Cancer Survey (1969-71) indicate that only 25-30 cases of angiosarcoma of the liver should be expected each year among the entire US population. These authors also estimated the total VCM work population in the US, past and present, to be about 20,000. On this basis, the number of cases which would be predicted to occur over a period of 10 years would be 0.03. The ratio of the observed to expected number of cases (relative risk) is thus in the order of 400. However, at the plant most fully investigated, which at present has a work force of 270 men directly engaged in VCM polymerization activities, 7 of the 13 cases have been found. For these 7 cases the authors found no evidence to show that exposure to other potentially hepatotoxic material outside the plant played a role in the development of this tumour, and there was no history of acro-osteolysis.

At the same plant, medical records were reviewed for cases of non-malignant liver diseases, and a total of 4 such cases has been identified

to date, all in workers exposed to VCM. All were white males, and the average age was 46.5 years at the time of first diagnosis; work involving exposure to VCM began on average 20.8 years prior to diagnosis. Liver biopsies were performed in all 4 cases, and portal fibrosis was seen in each, accompanied by the observation in 3 cases of discrete nodules of subcapsular fibrosis. The latter feature was pathologically indistinguishable from the subcapsular lesions observed in 1 of the 7 tumour cases.

Suciu et al. (1967), Lange et al. (1974a) and Marsteller et al. (1973) have reported similar disorders, including periportal fibrosis, splenomegaly, hepatomegaly, slight parenchymal damage and fibrosis of the liver capsule in workers exposed to VCM (see also pp. 302-304).

In Western Europe 3 cases of fatal angiosarcoma of the liver have so far been reported, 2 in the Federal Republic of Germany (Lange et al., 1974b) and 1 in the UK (Lee & Harry, 1974). All 3 workers had been involved in VCM polymerization processes, and exposure to VCM ranged from 11-20 years.

#### 4. Comments on Data Reported and Evaluation\*

##### 4.1 Animal data

Vinyl chloride monomer (VCM) is carcinogenic in mice and rats following exposure by inhalation. The tumours in mice were mainly lung tumours, mammary carcinomas and angiosarcomas (malignant haemangioendotheliomas) of the liver. Angiosarcomas of the liver and other organs, Zymbal gland carcinomas and nephroblastomas occurred in exposed rats. Preliminary studies have suggested that VCM also produces subcutaneous angiosarcomas in the offspring of rats that have been exposed during pregnancy.

##### 4.2 Human data

In view of the extreme rarity of angiosarcoma of the liver in the general population, the observation of 16 cases in workers exposed to vinyl chloride monomer during the polymerization process is evidence of a causal relationship.

\* This evaluation is based upon published data or data accepted for publication up to 26 June 1974.

## APPENDIX A

### VINYL CHLORIDE POLYMERS

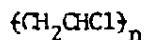
#### 1. Chemical and Physical Data

##### 1.1 Synonyms and trade names

Chem. Abstr. No.: PM 9002-86-2

Chloroethylene polymer; polyvinyl chloride; polyvinylchloride; PVC  
Bakelite\*; Blacar; Boltaron; Breon; Carina; Corvic; Dacovin;  
Ekavyl; Etinox; Flamenol; Flovic; Geon\*; Halvic; Hostalit;  
Kaylite; Kayrex; Koroseal; Lacqvyl; Lucoflex; Lucovyl; Marvinol;  
Niacet; Norvinyl; Opalon; Pevikon; Plioflex; Pliovic; Quirvil;  
Ravinyll; Rhodopas; Rhovyl; Rucoblend; Ryertex - Omicron; Scon;  
Seilon PVC; Sicron; TPC; ttp; Ultron; Upalon; Vestolit; Vinnol;  
Vinoflex; Vipla; Viplavil; Vybak; Vycell; Vygen; Vyram; Vyron;  
Welvic; Yardley

##### 1.2 Chemical formula and molecular weight



Mol. wt: 60,000-150,000

##### 1.3 Chemical and physical properties of the pure substance

- (a) Description: White powder
- (b) Stability: Polyvinyl chloride is relatively unstable to heat and light in the absence of added stabilizers. HCl gas is a decomposition product of degradation.
- (c) Solubility: Solvents for unmodified polyvinyl chloride of high molecular weight are: cyclohexanone, methyl cyclohexanone, dimethyl formamide, nitrobenzene, tetrahydrofuran, isophorone and mesityl oxide. Solvents for lower polymers are: dipropyl ketone, methyl amyl ketone, methyl isobutyl ketone, acetonylacetone, methyl ethyl ketone, dioxane and methylene chloride (Merck & Co., 1968).

\* These trade names are also used for other types of polymers.

#### 1.4 Technical products and impurities

A wide variety of vinyl chloride homo- and co-polymers is available, with varying properties designed for specific applications. Consequently, the specifications vary widely.

Polyvinyl chloride resins for the production of rigid plastics contain essentially no plasticizer: the polymer may be a homo-polymer or a co-polymer made with low levels of co-monomers such as acrylates, vinyl acetate or ethylene. The co-monomers are used to aid in the processing of the resulting polymer.

Most of the flexible and semi-rigid polyvinyl chloride currently used contains plasticizer, generally at a level of 10-100% of the resin weight. The plasticizers most commonly used are dialkyl esters of dibasic aliphatic acids, such as dioctyl phthalate. Polyester plasticizers (e.g., adipic acid-glycol polyesters) and epoxy plasticizers (e.g., epoxidized soybean oil) are also widely used.

Other compounding materials, such as pigments, fillers and light- and heat-stabilizers, are also used in the production of commercial polyvinyl chloride.

Polyvinyl chloride resins are also used in the form of plastisols (polyvinyl chloride resin dispersed in plasticizer), organosols (polyvinyl chloride resin dispersed in plasticizers and a balanced mixture of solvents and diluents) and lattices (polyvinyl chloride resin dispersed in water with small amounts of surfactants).

## 2. Production, Use, Occurrence and Analysis

### 2.1 Production and use<sup>1</sup>

A method for the synthesis of polyvinyl chloride was reported in 1872 (Baumann, 1872). Commercial homo-polymers of vinyl chloride were introduced in 1933 (Darby & Sears, 1968).

<sup>1</sup> Data from Chemical Information Services, Stanford Research Institute, USA

Vinyl chloride polymers are presently produced by one of four processes: suspension, emulsion, bulk or solution polymerization. All are free-radical, exothermic processes. In the US in 1972 approximately 78% of homo-polymer and co-polymer output was produced by the suspension polymerization process.

In 1972, 22 US manufacturers produced 1,962 million kg of polyvinyl chloride resins of all types (US Tariff Commission, 1974a); it is estimated that approximately 685 million kg of the total were co-polymers. Preliminary data indicate that 1973 production amounted to 2,008 million kg (US Tariff Commission, 1974b).

US exports of all polyvinyl chloride resins (homo-polymer and co-polymer combined) are estimated to have been 69 million kg in 1972; imports were negligible.

More than 30 companies in Western Europe manufacture vinyl chloride polymers in plants located in Austria, Belgium, the Federal Republic of Germany, Finland, France, Greece, Italy, The Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom. Total Western European production was reported to have been 2,290 million kg in 1970 and 1971 (Organisation for Economic Cooperation & Development, 1972), and it is estimated to have been approximately 2,950 million kg in 1972.

Polyvinyl chloride resins are produced by 20 companies in Japan. Production in 1972 was approximately 1,078 million kg; in the same year, imports were 22 million kg, while exports totalled 49 million kg (Anon., 1973c).

Apart from these three major producing areas there are also about 20 producing facilities in Eastern Europe, namely in Bulgaria, Czechoslovakia, the German Democratic Republic, Hungary, Poland, Rumania, the USSR and Yugoslavia. About 15 companies produce polyvinyl chloride in Argentina, Brazil, Chile, Colombia, Mexico and Venezuela; there are about 20 companies in Formosa, India, Iran, Israel, Pakistan, the Philippines, Thailand and Turkey; and in Africa there are 4 companies, located in Algeria, Egypt and South Africa. Polyvinyl chloride is also produced in Canada and Australia (Anon., 1971).

In 1972, US consumption of polyvinyl chloride resins was as follows: building and construction industries (42%), household uses (15%), consumer goods (12%), electrical applications (11%), packaging (9%) and transportation (6%), with miscellaneous uses accounting for the remainder. Since 1968, the major uses have been in the building and construction industries and in household goods and packaging.

The major uses for polyvinyl chloride resins in building and construction industries are in piping and conduits, including water pipes, in flooring, in windows and other rigid structures, in pipe fittings, in sidings and as swimming-pool liners. The primary applications in household products are for upholstery, wall coverings, garden hoses and appliances. Consumer goods utilizing polyvinyl chloride resins include gramophone records, footwear, toys, outerwear, sporting goods and baby pants. Electrical applications consist primarily of wire and cable coatings. The major uses of polyvinyl chloride in packaging are in film, sheets, bottles, coatings and bottle-cap liners and gaskets; however, in the US, its use for the packaging of alcoholic beverages has been banned because of migration of vinyl chloride monomer into the alcohol. In the transportation industry major uses include upholstery and seat covers, automotive tops and automotive floor mats. Miscellaneous applications include its use in laminates, in medical tubing and in stationery supplies.

Of the total UK production in 1973 (400 million kg) the use of polyvinyl chloride in millions of kg for various applications was reported as follows: pipes and fittings for water pipes and electrical conduits - 100 million kg; electrical cables - 46 million kg; hard flooring - 30 million kg; packaging (foil and film) - 24 million kg; bottles - 13 million kg; bottle closures - 5 million kg; gramophone records - 21 million kg; car upholstery, roof interiors and wirings - 20 million kg; footwear - 20 million kg; conveyor belting - 6 million kg; total - 285 million kg (Anon., 1974e).

In Japan in 1972, polyvinyl chloride consumption is estimated to have been as follows: piping (28%), film (15%), fittings (11%), plate (9%), sheet (9%), wire and cable coatings (8%), leather (7%) and extruded products (6%).

## 2.2 Occurrence

Vinyl chlorine polymers are not known to occur in nature.

## 2.3 Analysis

No information was available to the Working Group.

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\* Footnote to pp. 296, 297

At the time of submitting this volume to press, the Occupational Safety and Health Administration of the US Department of Labor had proposed a new permissible exposure limit for vinyl chloride monomer which will require that no employee may be exposed to concentrations greater than 2.6 mg/m<sup>3</sup> (1 ppm) averaged over any 8-hour period, and that no employee may be exposed to concentrations greater than 5 ppm averaged over any period not exceeding 15 minutes. The method of monitoring and measurement should have an accuracy of not less than  $\pm 50\%$  from 0.25-0.5 ppm,  $\pm 35\%$  from 0.5-1.0 ppm and  $\pm 25\%$  over 1 ppm; such methods are available in the "NIOSH Manual of Analytical Methods". The effective date of the amendment to section 1910.93q of the US Code of Federal Regulations will be 1 January 1975 and the permissible exposure limit will apply to fabrication, monomer and polymer industries (US Federal Register 1974, 39 (no. 194), 35890-35898).

## APPENDIX B

### VINYL CHLORIDE-VINYL ACETATE CO-POLYMERS

#### 1. Chemical and Physical Data

##### 1.1 Synonyms and trade names

Chem. Abstr. No.: PM 9003-22-9

VA/VC1; VAc/VC1; PVAc/VC1

Airflex\*; Bakelite\*; Gelva\*; Resyn\*; Vinyon; Vipla

##### 1.2 Chemical formula and molecular weight

$\{\text{CH}_2\text{CHCl}\}_n$  in combination with  $\{\text{CH}_2\text{CH}\}_n$   
 $\text{OOCCH}_3$

Mol. wt: approx. 100,000

##### 1.3 Chemical and physical properties of the pure substance

(a) Description: White powder

(b) Stability: Vinyl chloride-vinyl acetate co-polymers are relatively unstable to heat and light in the absence of added stabilizers. HCl gas is a decomposition product of degradation.

##### 1.4 Technical products and impurities

Low levels of vinyl acetate are co-polymerized with vinyl chloride monomer to obtain specific properties for different applications in the resulting polymer. Depending upon the potential use destined for the polymer, the vinyl acetate level may vary from 2-20%, with an average of 11-12%.

Vinyl chloride-vinyl acetate resins are available both as solid resins and as emulsions. Solid resins, for the formulation of rigid plastics, contain little or no plasticizer; however, when they are formulated into products they generally contain pigment, filler and light- and heat-

\* These trade names are also used for other types of polymers.

stabilizers. Flexible and semi-rigid vinyl chloride-vinyl acetate resins contain plasticizers, e.g., dibasic aliphatic acid esters, polyesters and epoxy plasticizers.

Vinyl chloride-vinyl acetate polymer emulsions usually consist of neutral polymer dispersions in water, containing 50-60% solids and including small amounts of surfactants. Vinyl chloride-vinyl acetate co-polymers are also used in the manufacture of organosols (co-polymers dispersed in plasticizer and a balanced mixture of solvents and diluents) and of plastisols (co-polymers dispersed in plasticizer).

## 2. Production, Use, Occurrence and Analysis

### 2.1 Production and use<sup>1</sup>

Vinyl chloride-vinyl acetate co-polymers were introduced commercially in 1934 (Darby & Sears, 1968). Vinyl chloride-vinyl acetate dispersion co-polymers are manufactured by free-radical-initiated suspension and emulsion polymerization techniques. Solution polymerization is used for the manufacture of some special coating resins. It is believed that in the US approximately 78% of vinyl chloride-vinyl acetate co-polymer resins are made by suspension processes.

It was estimated that in 1971 the 15 US manufacturers produced 281 million kg of vinyl chloride-vinyl acetate co-polymer resin.

More than 10 companies in Western Europe manufacture vinyl chloride-vinyl acetate co-polymers in plants located in the Federal Republic of Germany, France, Italy, Switzerland and the United Kingdom. Total Western European production in 1972 is estimated to have been approximately 400 million kg.

In Japan there are 9 producers of vinyl chloride-vinyl acetate co-polymers. Approximately 11.8 million kg of co-polymer were manufactured in 1972, and 1.1-2.3 million kg of vinyl chloride-vinyl acetate solution co-polymers were imported from the US.

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<sup>1</sup> Data from Chemical Information Services, Stanford Research Institute, USA

In the US the major use for vinyl chloride-vinyl acetate co-polymers is in the production of calendered flooring and of gramophone records. Other applications include injection molding, rigid sheet production and special coatings.

Co-polymers containing 2-8% acetate are used for calendering, since they have better processing characteristics than did the vinyl chloride homo-polymers available in the past. Calendered products include film and sheeting, floor tiles and coated fabrics. The better homo-polymers developed in recent years are competing with the co-polymers in the rigid sheet and floor-tile markets.

Co-polymers containing 10-16% acetate are used for compression molding of gramophone records because of their good flow properties. Some of these co-polymers are also used in injection molding for pipe fittings and industrial parts, and they are also used in blends with vinyl chloride homo-polymers for rigid extrusions (e.g., piping and siding).

Minor quantities of co-polymer dispersion resins are believed to be used in the form of latex for special applications (e.g., vinyl wall coverings). Solutions of co-polymers containing 8-12% acetate in solvents such as cyclohexanone and tetrahydrofuran are used in surface coatings of tins and metals, and for maintenance coatings.

Small amounts of the co-polymers are also used to produce specialty fibres: in 1971, the 2 US producers of such fibres are estimated to have manufactured approximately 1.36 million kg. This consisted mostly of staple (used in making heat-sealable papers, e.g., for tea bags), but some mono-filaments (used in automobile interiors) were also produced.

In Japan, vinyl chloride-vinyl acetate co-polymers are used for the manufacture of flooring, coatings, adhesives and gramophone records.

## 2.2 Occurrence

Vinyl chloride-vinyl acetate co-polymers are not known to occur in nature.

## 2.3 Analysis

No information was available to the Working Group.

## 5. References

- Anghelescu, F., Otoi, M., Dobrinescu, E., Hagi-Paraschiv-Dossios, L., Dobrinescu, G. & Ganca, V. (1969) Consideratii clinico-patogenice asupra fenomenului Raynaud la muncitorii din industria policlorurii de vinil. Med. interna (Buc.), 21, 473-482
- Anon. (1971) Chlorure de polyvinyle. Informations Chimie, 99, 131-147
- Anon. (1973a) FDA to propose ban on use of PVC for liquor use. Food Chemical News, May 14, pp. 3, 4
- Anon. (1973b) "Prior sanction" regulation proposed for PVC. Food Chemical News, May 21, p. 42
- Anon. (1973c) 1972 Year Book of Chemical Industries Statistics - Japan, Tokyo Research and Statistics Department, Minister's Secretariat, Ministry of International Trade and Industry
- Anon. (1974a) Vinyl chloride and cancer. Brit. med. J., i, 590-591
- Anon. (1974b) The vinyl chloride recall. Drug and Cosmetics Industry, May, pp. 76, 78
- Anon. (1974c) Scientists hear reports vinyl chloride may be more dangerous than realized. Wall Street Journal, May 13
- Anon. (1974d) The vinyl chloride fight is on. Chemical Week, May 22, p. 19
- Anon. (1974e) CIA argues case against zero VCM exposure limits. European Chemical News, May 24, p. 24
- Anon. (1974f) EPA asks emission data on vinyl chloride. Chemical and Engineering News, June 10, pp. 4-5
- Baretta, E.D., Stewart, R.D. & Mutchler, J.E. (1969) Monitoring exposures to vinyl chloride vapor: Breath analysis and continuous air sampling. Amer. industr. Hyg. Ass. J., 30, 537-544
- Basalaev, A.V., Vazin, A.N. & Kochetkov, A.G. (1972) On the pathogenesis of changes developing due to a long-term exposure to the effect of vinyl chloride. Gig. Tr. Prof. Zabol., 16, 24-27
- Baumann, E. (1872) Über einige Vinylverbindungen. Justus Liebig's Ann. Chem., 163, 308-322
- Braun, D. & Vorendohre, G. (1964) Dünnschichtchromatographie einiger ungesättigter polymerisierbarer Verbindungen. Z. analyt. Chem., 199, 37-41

Chatelain, A. & Motillon, P. (1967) Un syndrome d'acro-ostéolyse d'origine professionnelle et de constatation nouvelle en France. J. Radiol. Electrol., 48, 277-280

Christie, A.A., Hands, G.C. & Lidzey, R.G. (1965) The detection of certain organic halogen compounds using refrigerant leak detector lamps. Chem. Industr., 47, 1935-1936

Condensed Chemical Dictionary (1971) 8th ed., New York, Van Nostrand Reinhold, p. 927

Cook, W.A., Giever, P.M., Dinman, B.D. & Magnuson, H.J. (1971) Occupational acroosteolysis. II. An industrial hygiene study. Arch. environm. Hlth, 22, 74-82

Cordier, J.M., Fievez, C., Lefevre, M.J. & Sevrin, A. (1966) Acroostéolyse et lésions cutanées associées chez deux ouvriers affectés au nettoyage d'autoclaves. Cah. Méd. Trav., 4, 3-39

Creech, J.L. & Johnson, M.N. (1974) Angiosarcoma of liver in the manufacture of polyvinyl chloride. J. occup. Med., 16, 150-151

Darby, J.R. & Sears, J.K. (1968) Plasticizers. In: Kirk, R.E. & Othmer, D.F., eds, Encyclopedia of Chemical Technology, 2nd ed., Vol. 15, New York, John Wiley & Sons, p. 798

Deutsche Forschungsgemeinschaft (1973) Maximale Arbeitskonzentrationen 1973, Mitteilung IX der Kommission zur Prüfung gesundheitschädlicher Arbeitstoffe, Weinheim, Verlag Chemie GmbH

Dinman, B.D., Cook, W.A., Whitehouse, W.M., Magnuson, H.J. & Ditchek, T. (1971) Occupational acroosteolysis. I. An epidemiological study. Arch. environm. Hlth, 22, 61-73

European Communities (1971) Foreign Trade Statistics, Analytical Tables (Nimexe), Vol. 3, Chapters 28-38, Brussels, Luxembourg, Statistical Office of the European Communities

Filatova, V.S. & Gronsberg, E.S. (1957) Sanitary-hygienic conditions of work in the production of polychlorvinyllic tar and measures of improvement. Gig. i Sanit., 22, 38-42

Galipern, G.M., Gudkova, G.A., Novoruskaya, N.V., Kireev, L.G. & Klark, L.N. (1968) Determination of hydrogen chloride by reaction gas chromatography (exchange of experience). Zavod. Lab., 34, 282-283

Grikitis, E.J. (1967) Consumer Aerosols, Moscow

Gronsberg, E.S. (1966) Colorimetric determination of vinyl chloride in air. Khim. Prom., 42, 510-511

- Hardie, D.W.F. (1964) Chlorocarbons and Chlorohydrocarbons. Vinyl chloride. In: Kirk, R.E. & Othmer, D.F., eds, Encyclopedia of Chemical Technology, 2nd ed., Vol. 5, New York, John Wiley & Sons, pp. 171-178
- Harris, D.K. & Adams, W.G.F. (1967) Acro-osteolysis occurring in man engaged in the polymerization of vinyl chloride. Brit. med. J., iii, 712-714
- Heath, C.W., Jr, Falk, H. & Creech, J.L., Jr (1974) Characteristics of cases of angiosarcoma of the liver among vinyl chloride workers in the United States. Ann. N.Y. Acad. Sci. (in press)
- Hinshaw, L.D. (1966) Gas chromatographic determination of chlorinated hydrocarbons in 1,2-dichloroethane. J. Gas Chromat., 4, 300-302
- Hollis, O.L. (1966) Separation of gaseous mixtures using porous polyaromatic polymer beads. Analyt. Chem., 38, 309-316
- Hollis, O.L. & Hayes, W.V. (1962) Gas-liquid chromatographic analysis of chlorinated hydrocarbons with capillary columns and ionization detectors. Analyt. Chem., 34, 1223-1226
- Keane, D.P., Stehaugh, R.B. & Townsend, P.L. (1973) Vinyl chloride: How, Where, Who - Future. Hydrocarbon Processing, February, pp. 99-110
- Kramer, C.G. & Mutchler, J.E. (1972) The correlation of clinical and environmental measurements for workers exposed to vinyl chloride. Amer. industr. Hyg. Ass. J., 33, 19-30
- Lange, C.E., Jühe, S., Stein, G. & Veltman, G. (1974a) Die sogenannte Vinylchlorid-Krankheit - eine berufsbedingte Systemsklerose? Int. Arch. Arbeitsmed., 32, 1-3?
- Lange, C.E., Jühe, S., Stein, G. & Veltman, G. (1974b) Further results in polyvinyl chloride production workers. Ann. N.Y. Acad. Sci. (in press)
- Lee, F.I. & Harry, D.S. (1974) Angiosarcoma of the liver in a vinyl-chloride worker. Lancet, i, 1316-1318
- Maltoni, C. & Lefemine, G. (1974a) Le potenzialità dei saggi sperimentali nella predizione dei rischi oncogeni ambientali. Un esempio: il cloruro di vinile. Rend. Sci. fis. mat. nat. (Lincei), 66, 1-11
- Maltoni, C. & Lefemine, G. (1974b) Carcinogenicity bioassays on vinyl chloride. I. Research plan and early results. Environm. Res., 7, 387-405
- Marin, A., Strauss, J., Michiels, R., Benoit, J.P., Baltié, R. & Pierre, C. (1967) Acro-ostéolyse d'origine professionnelle. Rev. Rhum., 6, 340-351

Marsteller, H.J., Leibach, W.K., Miller, R., Jühe, S., Lange, C.E.,  
Rohner, H.G. & Veltman, G. (1973) Chronisch-toxische Leberschäden  
bei Arbeitern in der PVC-Produktion. Dtsch. med. Wschr., 98, 2311-2314

Merck & Co. (1968) The Merck Index, 8th ed., Rahway, N.J., p. 849

Miller, S.A. (1969) Ethylene and its industrial derivatives, London, Benn

O'Mara, M.M., Crider, L.B. & Daniel, R.L. (1971) Combustion products from  
vinyl chloride monomer. Amer. industr. Hyg. Ass. J., 32, 153-156

Organisation for Economic Cooperation and Development (1972) The Chemical  
Industry 1971/72, Paris, p. 157

Popova, T.P., Revyagina, K.I. & Mamedov, M.A. (1967) Gas-chromatographic  
analysis of a vinyl chloride mixture. Azerb. Khim. Zh., 5, 116-120

Regnault, V. (1835) Über die Zusammensetzung des Chlorkohlenwasserstoffs  
(Oel des ölbildenden Gases). Justus Liebig's Ann. Chem., 14, 22-38

Schottek, W. (1969) Zur Toxikologie des Vinylchlorids. Chemische Technik,  
21, 708-711

Stewart, R.D., Dodd, H.C., Erley, D.S. & Holder, B.B. (1965) Diagnosis of  
solvent poisoning. J. Amer. med. Ass., 193, 1097-1100

Suzin, I., Drejman, I. & Valaskai, M. (1967) Etude des maladies dues au  
chlorure de vinyle. Med. Lav., 58, 261-271

Torkelson, T.R., Oyen, F. & Rowe, V.K. (1961) The toxicity of vinyl  
chloride as determined by repeated exposure of laboratory animals.  
Amer. industr. Hyg. Ass. J., 22, 354-361

Tribuch, S.L., Tichomirova, N.P., Levina, S.V. & Kozlov, L.A. (1949) The  
conditions of work and measures of improvement in the production and  
use of vinyl chloride plastics. Gig. i Sanit., 10, 38-44

US Code of Federal Regulations (1974a) Occupational safety and health  
administration emergency temporary standard for exposure to vinyl  
chloride, April 5, 1910.93g, Washington DC, US Government Printing  
Office, pp. 1437-1438

US Code of Federal Regulations (1974b) Proposed occupational standard for  
vinyl chloride to be published in Federal Register by the Labor  
Department, May 6, 1910.93q, Washington DC, US Government Printing  
Office, pp. 1567-1573

US Department of Commerce (1972) US Exports, Bureau of the Census,  
Washington DC, US Government Printing Office, FT-410-72-12

- US Environmental Protection Agency (1974) EPA bans use of certain vinyl chloride pesticides. Environmental News, April 24, Washington DC, US Government Printing Office, pp. 1-2
- US Federal Register (1974) Vinyl chloride. Emergency suspension order concerning registrations for certain products and intent to cancel registrations. US Federal Register, 39, no. 82, Washington DC, US Government Printing Office, pp. 14573-14574
- US Tariff Commission (1928) Census of Dyes and of Other Synthetic Organic Chemicals, 1927, Tariff Information Series No. 37, Washington DC, US Government Printing Office, p. 139
- US Tariff Commission (1973) Synthetic Organic Chemicals, US Production and Sales, 1971, TC Publication 614, Washington DC, US Government Printing Office, p. 207
- US Tariff Commission (1974a) Synthetic Organic Chemicals, US Production and Sales of Plastics and Resin Materials, 1972 Preliminary, February, Washington DC, US Government Printing Office, p. 4
- US Tariff Commission (1974b) Preliminary Report on US Production of Selected Synthetic Organic Chemicals, Preliminary Totals 1973 and January 1974, SOC Series C/P-74-1, March 6, Washington DC, US Government Printing Office
- US Tariff Commission (1974c) Synthetic Organic Chemicals, US Production of Miscellaneous Chemicals, 1972 Preliminary, April, Washington DC, US Government Printing Office, p. 8
- Viola, P.L. (1970) Pathology of vinyl chloride. Med. Lav., 61, 174-180
- Viola, P.L. (1971) Pathology of vinyl chloride. In: Proceedings of the 16th International Congress on Occupational Health, Tokyo, 1969, Tokyo, Japan Organizing Committee, pp. 296-297
- Viola, P.L., Bigotti, A. & Caputo, A. (1971) Oncogenic response of rat skin, lungs and bones to vinyl chloride. Cancer Res., 31, 516-522
- Wilkinson, L.B., Norman, C.W. & Buettner, J.P. (1964) Determination of residual monomers in latex by gas chromatography. Analyt. Chem., 36, 1759-1762
- Williams, F.W. & Umstead, M.E. (1968) Determination of trace contaminants in air by concentrating on porous polymer beads. Analyt. Chem., 40, 2232-2234
- Wilson, R.H., McCormick, W.E., Tatum, C.F. & Creech, J.L. (1967) Occupational acroosteolysis. J. Amer. med. Ass., 201, 577-581