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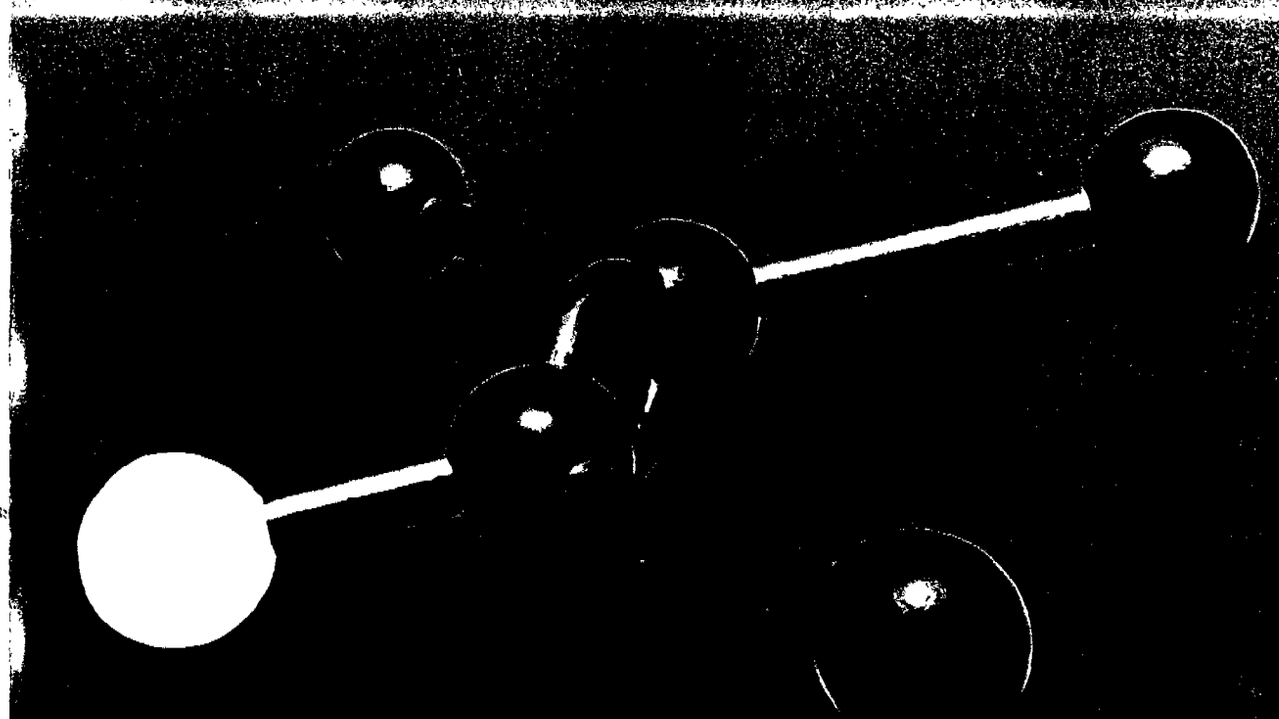
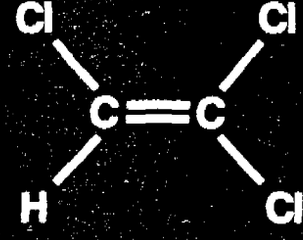
B.I.T. Solvants Chlorés





Trichloroethylene in metal cleaning and other industrial applications

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TRICHLOROETHYLENE IN METAL CLEANING

AND OTHER INDUSTRIAL APPLICATIONS

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TRICHLOROETHYLENE IN METAL CLEANING AND OTHER INDUSTRIAL APPLICATIONS

This paper has been prepared by several European manufacturers of trichloroethylene.

SUMMARY

Ten companies produce trichloroethylene in Europe with a total capacity of 400 KT. In 1983, sales amounted to 161 KT of which 94% was used for metal cleaning.

Trichloroethylene is of major economic importance for the engineering industry where practically all companies rely on degreasing with chlorinated solvents in their production lines. Trichloroethylene has gained this position because of obvious technological advantages, due to favourable properties in economical and occupational respects. These include low energy requirements and the ability to be recovered, both factors being of increasing importance.

The available capacity is the result of significant financial investment and trichloroethylene must be counted amongst the main outlets of the petrochemical industry. Trichloroethylene, and more generally chlorinated solvents are a significant end user for chlorine. Its production forms part of a complex chlorine producing and using industry and therefore changes in demand will affect a wide range of chemicals. Consequently the market position for the solvent has a major socio-economic impact as a result of both major use in the engineering and manufacturing industry and in other industries producing many important commodities.

The aim of this paper is to provide an objective view on metal cleaning with chlorinated solvents and more especially with trichloroethylene used in the vapour cleaning process including occupational safety and environmental effects. In order to achieve these needs a summary of the present day toxicology is included.

It is shown that the advantage of non flammability of trichloroethylene is very important and the level of concentration in workrooms usually complies with existing standards. The type of equipment used influences the ambient concentrations but operating practices are the decisive factor. Measurements carried out to estimate worker exposure throughout Western Europe are displayed and discussed.

The major hazard from trichloroethylene is presented by acute central nervous system depression and perhaps cardiac effects associated with short term exposure to high levels. There is no good evidence from any of the animal work or human experimental and field studies which have been carried out to indicate that exposure to atmospheric levels at or below 100 ppm will have any significant effect on human health.

The existing cleaning plants used in Europe are described and it is concluded that based on the measured exposure levels the existing designs are adequate for safe operation. However other ideas are discussed which indicate new technological improvements.

The use of trichloroethylene creates no special burden on the environment since that emitted is readily destroyed and several methods exist for the safe disposal of the wastes produced. It is to be noted that in relation to the quantity of metal cleaned the waste to be disposed of is very small.

1 ECONOMIC POSITION OF TRICHLOROETHYLENE

1.1 Trichloroethylene in the West European Chemical Industry

1.1.1 Producing companies capacity

The total name plate capacity of trichloroethylene (TRI) production in Western Europe was 400,000 metric tons in 1982 (this figure must be considered as an average because of the flexibility of TRI/PER plants). The raw materials used are chlorine/hydrogen chloride and ethylene or acetylene.

The major producing countries are Germany, Italy, UK and France, whose respective capacity is in the order of 100,000 tons. Sweden and Spain are smaller producers.

COMPANY	COUNTRY
Cros	Spain
Donau Chemie	Austria
Chemische Werke Hüls	West Germany
ICI PLC	UK
Montedipe	Italy
Atochem	France
Enichem	Italy
Solvay	France
Billerud	Sweden
Wacker-Chemie	F.R. Germany

The available capacity is the result of significant financial investment and trichloroethylene must be counted amongst the main outlets of the petrochemical industry. Trichloroethylene, and more generally chlorinated solvents are a significant end user for chlorine. Its production forms part of a complex chlorine producing and using industry and therefore change in demand will affect a wide range of other chemicals. Consequently the market position for the solvents has a major socio-economic impact as a result of both major use in the engineering and manufacturing industry and in other industries producing many important commodities.

1.1.2 Consumption in Western Europe - End Uses

In 1983 the sale of trichloroethylene in Western Europe was estimated to be 161,000 metric tons, ie 40% of the total production capacity.

The following table shows the breakdown by end users of consumption in Europe.

APPLICATION	%
Metal cleaning	94
Drycleaning and Textiles	2
Extraction	1
Miscellaneous	3

The use in metal cleaning, generally in the vapour degreasing process is the dominant application for trichloroethylene.

Other uses include Drycleaning and Textile Treatments, and those processes where its strong solvent action is required to dissolve rubbers, resins, etc as in the manufacture of paints, lacquers and adhesives and oils from animal and vegetable matter.

The consumption of trichloroethylene reached a maximum of about 300,000 tons in 1973-74 and has decreased since that period. The most significant reasons for that decrease are :

- a generally lower growth rate of European economies
- better operating conditions leading to lower losses from degreasing equipment due to technological improvements and higher recovery rates
- substitution of trichloroethylene by other chlorinated solvents such as 1,1,1-trichloroethane, tetrachloroethylene and dichloromethane, for a variety of reasons

It is the producers' opinion that the consumption of trichloroethylene is likely to stay near the present level.

1.1.3 Producers' Involvement in Technical Assistance for Customers

Trichloroethylene has been used as a solvent for degreasing for about 50 years. The producing companies have continuously assisted customers in two major ways

- to provide high solvent quality
- to give such advice that operating conditions are improved by the using industries.

Solvent quality

Trichloroethylene is produced with a very high purity level of more than 99.9%. Nevertheless, because of the arduous chemical conditions in metal degreasing (contact with metal particles and metal working additives), small amounts (less than 1%) of stabilisers or inhibitors are added to the pure trichloroethylene in order to prevent the solvent from becoming acidic and corrosive towards equipment and degreased parts. The stabiliser must be present and effective in both the liquid phase and the vapour phase. Major improvements have been made in this direction, and it is considered that stabilised trichloroethylene produced by European companies meets all the requirements of normal and severe operating conditions.

Operating Conditions

Producers have always been aware of the importance of good operating conditions for the safety of workers as well as for maximum economy of the process. Therefore, the producers provide technical advice dealing with :

- Technological improvements to degreasing equipment

- Information to end users, who probably number more than 50,000

Technological improvement to metal degreasing equipment is discussed in detail in a later chapter, but it is important to recognise that good equipment improves the economy of the process as well as the safety of workers.

Producers have developed over many years close relationships and co-operation with equipment manufacturers and indeed some producers have their own integrated department for the design and sale of equipment.

Good information for users is essential both for maximum economy of the process and for safety of workers.

Good operating practices are the key to the safe use of the solvent no matter how well designed the equipment may be. Sophisticated automatic machines can help to minimise operator mistakes but nevertheless this kind of equipment cannot be used in every case for technical or economic reasons. In any case poor operation will lead to unsafe working conditions.

Each European solvent producer makes available specialist advisers, expert in solvent and cleaning technology, to assist customers in the safe and economic use of cleaning processes. This advice is supported by technical service visits, literature, operator training, codes of practice and atmospheric analysis on exposed workers. This service is freely supplied to all customers.

The positive results of this long term task are borne out by the results shown in Section 2 on the exposure of workers and by the generally satisfactory standard achieved in using chlorinated solvent cleaning systems.

1.2 Economic Aspects of Trichloroethylene from Users' Point of View

Only metal degreasing with trichloroethylene is considered here which, as already stated, represents 94% of the consumption of this product in Europe.

1.2.1 Metal Degreasing Processes

Metal degreasing is often not a final operation, being generally followed by:

- machining
- chemical conversion (phosphating)
- electrical deposition (plating)
- coating (painting)

There are two principal methods of degreasing metals and plastic components:

- one, which uses chlorinated solvents like trichloroethylene and
- the other, which uses aqueous solutions of detergents and other additives in so called "alkaline degreasing"

Other methods using mixtures of flammable hydrocarbons such as hexane, toluene, petroleum spirit can be considered as marginal. In addition to their flammability their toxic properties should be taken into account. This is not always obvious to users because of improper labelling.

There is practically no competition between the two principal degreasing methods since they have separate market uses:

- alkaline degreasing is used essentially when the subsequent operations are carried out in an aqueous medium (chemical conversion, electroplating). It is used mostly in continuous processes in mass production of large parts where the cleaned parts do not need to be dry. This degreasing method is relatively slow, requires much space on the ground and is costly in energy (for drying, in particular). The aqueous effluents require special treatment

- degreasing with chlorinated solvents is the process used in most other cases, especially when articles need to be dry after this step.

In the particular case of trichloroethylene, vapour degreasing is the most commonly used process. It consists of bringing trichloroethylene to its boiling point in special equipment and condensing the vapours on the parts concerned, which are thus degreased by hot, clean solvent. The apparatus is, of course, designed to minimise the emission of solvent into the workshop and environment.

Some cold cleaning is practiced with trichloroethylene where items to be cleaned cannot readily be handled in a vapour cleaning machine. This method is relatively unimportant however and is not recommended unless properly designed equipment with appropriate ventilation is employed.

1.2.2 The Benefits of Degreasing with Trichloroethylene from the Users' Point of View

The following three aspects are important

- Technological importance
- Economic value
- Safety of operation

Technological Importance

Degreasing with trichloroethylene is an efficient procedure and this powerful solvent completely dissolves the oils and greases commonly used in industry as processing aids.

The rapidity of the process (about 1 minute) reduces the size of the equipment required and enables it to be integrated in continuous and batch operations.

Vapour phase degreasing with trichloroethylene is simple in principle, and nearly equally so in practice. The operation of a degreasing installation requires operatives to have a minimum but nonetheless essential specialised knowledge.

From the technical point of view, trichloroethylene is thus efficient, simple and versatile.

Economic Value

Efficiency, simplicity and versatility are obviously basic factors from the users' point of view. There are also others.

The speed of the degreasing operation enables the size of the equipment to be kept small, resulting in a saving of space on the ground in workshops. The various equipment used, although increasingly sophisticated, represents a limited investment due to simplicity in design. In addition, its life is very long, generally 10 years or even more.

The energy used in vapour degreasing with trichloroethylene is very small, especially if it is compared with that used in alkaline processes. In theory, the amount of energy required is that to heat the parts to be degreased from ambient temperature to 87°C (the boiling point of trichloroethylene), ie 32,500 kJ per tonne of steel. With good insulation and process control the efficiency of energy used is about 80%.

In this process the parts to be cleaned leave the process both clean and dry. In many alkali cleaning processes the parts leave the unit wet with water and a drying stage may be needed. Since the latent heat of water is high compared to that for solvents a large energy requirement will be needed to dry the parts. It is generally considered that where dry work is required immediately after cleaning that aqueous cleaning will require about 10 times as much energy as solvent cleaning.

Lastly the solvent contaminated by oils and greases from the parts can easily be recovered by simple distillation, generally in the equipment itself, leaving few residues for disposal.

From the economic point of view, vapour phase degreasing with trichloroethylene is of interest to users because it requires:

- LITTLE TIME
- LITTLE SPACE ON THE GROUND
- LITTLE ENERGY
- LITTLE INVESTMENT

and enables

- THE SOLVENT TO BE RECOVERED.

The large number of degreasing plants working with TRI in the engineering industry is proof of the economic importance of such a process. It is rare to find an engineering company using no chlorinated solvent for degreasing for these reasons.

Safety of Operatives

An examination of the exposure of operatives to trichloroethylene under present operating conditions compared with standards in force is covered in the following section.

It should be added, however, the NON FLAMMABILITY of trichloroethylene is an important safety factor for operatives. Any substitution by another, nonhalogenated solvent will increase overall occupational risks.

2 WORKER EXPOSURE TO TRICHLOROETHYLENE

2.1 Existing Standards

Most nations have developed exposure limit values for the concentration of chemical substances in the workroom environment with the aim of protecting workers against adverse health effects. These limits result from carefully considering all information on animal and human toxicity and biological data and from a desired degree of safety.

In some countries the effect of climate and stress from work is also considered as well as the feasibility of appropriate technical measures. Some values are interpreted as ceiling limits and others as a time weighted average (with or without peak limitation). Furthermore the approach adopted may vary between a recommendation and a legal status.

Those countries which have legal or adopted values are shown in the following table. In other countries values are in common use eg Belgium 100, Spain 100.

	Legal or Adopted Values 1983 (ppm vol)
Denmark	30
West Germany	50
France	75
Italy	50
Netherlands	35
United Kingdom	100

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2.2 Survey of Actual Worker Exposure to Trichloroethylene

In order to obtain some assessment of worker exposure to trichloroethylene using the vapour cleaning process the members of BIT have collected results of airborne concentrations around 770 installations all over Western Europe. The results in Fig 1 are an amalgamation of the results using a variety of techniques. A large number were obtained by spot analysis around the cleaning installation during all stages of the cleaning cycle. Also many others were obtained by 8 hr integrated analysis on the machine operator. This method used the adsorption on carbon technique followed by subsequent analysis by GLC. The detailed analytical methods and results for some countries are to be published separately.

The consolidated results in Fig 1 shows the % measurements greater than a given concentration. For example for open topped equipment only 10% of the measurements exceeded 100 ppm and only 25% of the measurements exceeded 50 ppm.

These results are most important and lead to the following conclusions:

- The great majority of degreasing installations are operating below the exposure standard considered safe by most World Authorities.

- The design of existing degreasing machines is adequate for the safe operation of the process.

- Standard open topped degreasing machines can be operated safely.

- Enclosed machines can lead to lower exposure levels than open topped machines.

It is well known that variations in concentration result mainly from the way of operating the equipment. For instance high vapour concentration can occur during unloading of parts if the parts are withdrawn at the wrong speed or too quickly from the equipment.

Other factors which can lead to high concentrations are incorrectly siting the equipment in draughts or inattention to a proper maintenance schedule.

It is because of the importance of operating conditions to exposure levels that machine manufacturers inform users how to install, to use and to maintain properly their equipment. Solvent producers also emphasise how to use properly and safely trichloroethylene thereby providing the willing customer with the necessary help and advice to minimise losses, to measure airborne concentrations, to improve operating conditions, to detect solvent leaks etc.

In fact present equipment technology together with good operating practices are adequate to achieve low exposure levels and improvements in technology are likely to continue.

See Fig 1 : Diagram - Metal Degreasing in Europe with Trichloroethylene

3 FEATURES AND POTENTIAL TECHNOLOGICAL IMPROVEMENTS TO EQUIPMENT FOR METAL DEGREASING

3.1 Introduction

For metal cleaning TRI has been used for about 50 years in specially designed metal cleaning equipment. During recent years this equipment has been steadily improved in order to meet with modern requirements. The equipment presently offered for the various cleaning problems has reached a high technical level and assures safe handling of the solvent with minimum worker exposure if correct operating techniques are practiced. As shown in chapter 2 "Worker Exposure to Trichloroethylene" the TRI concentrations measured for open topped machines are in most cases below the limit values recommended by EEC countries. Incorrect handling of the equipment is in most cases the reason for exceeding the limit values and it is important to stress correct handling to achieve low exposures. Automatic handling can improve productivity in a range of degreasing plants.

The low exposure measurements already reported result from the widespread use of machines whose design features are summarised in the following sections. A number of technical improvements has already been considered in modern machine design. These improvements are reviewed in Section 3.4.

3.2 Process of Metal Cleaning Using Trichloroethylene

According to the nature and contamination of the parts to be cleaned the following processes are known.

1 Vapour degreasing
2 Degreasing by dipping into cold, warm or boiling solvent
3 Spray degreasing by spraying parts with solvents under increased pressure
4 Combined process based on 1, 2 and/or 3. Ultrasonics are also employed in some systems.

A vapour stage is almost always employed in order to gain maximum benefit from the process potential.

Degreasing is carried out in metal degreasing machines according to processes 1 to 4. There are two major machine types.

- Open topped machines. These are dominant in most markets. They can be manually operated or may also involve some form of mechanical handling of the work to be cleaned.

- Enclosed machines. By definition enclosure requires some form of mechanical handling. Plants of this type have a wide spectrum of sophistication of work handling equipment and design features which minimise worker exposure.

3.2.1 Open Topped Machines

These machines are often preferred for metal degreasing because of their uncomplicated, strong design, their simple operation, their versatility and the low investment costs. The size of the machine varies within a large range: small, manually operated machines with bath surfaces of less than $0.5 m^2$ up to large machines with bath surfaces of more than $20 m^2$. From the economical point of view especially large parts can only be degreased in open topped machines. This means that even in future such machines cannot be replaced.

In order to protect workers from solvent vapour the machines are fitted with localised ventilation at the rim of the equipment which exhausts the solvent air mixture away from the working areas. Other safety devices are added to guard against water supply failures, overheating of the solvent or low solvent levels in the machine.

Included in this category are those machines which are partially enclosed and fitted with automatic conveyor systems for the parts to be cleaned. Due to their design they can easily be integrated into continuous processes; the operation itself is reduced to control and maintenance. Exhaust equipment is also fitted to such equipment.

3.2.2 Enclosed Machines

Enclosed machines need a relatively high investment since in addition to enclosure it is necessary to fit automatic handling equipment. They exist in numerous designs and sizes and include monorail systems, lift and transfer devices, carousels etc. They are often designed for not too large parts and special transport mechanisms permit the treatment of hollow bodies with minimum solvent losses. Again operation of the machines is reduced to control and maintenance. Due to their closed design and the existing exhaust equipment, solvent emissions are low as seen from the previous sections dealing with worker exposure.

Machines in this category may well be designed specifically for an individual customer problem and may therefore be very sophisticated in the degree of enclosure, mechanism and exhaust system. It is possible for such machines to be designed so that the solvent consumption per unit treated is very small and such degree of complexity may be justified to solve the cleaning problem.

3.3 Reasons for Solvent Losses and Emissions

There are two main reasons for excessive solvent losses and emissions :

1 Incorrect operation
2 Technical and physical reasons

3.3.1 Incorrect Operation

Inadequate attention to operating methods and maintenance leads to an increased solvent loss and emission in the working area. In the case of open machines careless operation has a greater effect than in the case of enclosed, automatic machines. The most important mistakes are :

- incorrect stacking of hollow bodies
- insufficient drying time of the degreased parts
- operation of work through the machine at too great a speed
- excessive movement of parts in the bath which disturbs the solvent vapour layer
- spraying above the vapour layer during manual spray degreasing
- evaporation from the bath due to lack of bath lids during working breaks
- solvent losses due to leaks
- incorrect filling, emptying and cleanout procedures

3.3.2 Technical and Physical Reasons

Reasons for solvent losses can also be found in the machine design, in the adjustment of the machines and in exterior troubles ie :

- too small freeboard
- incorrect balance between heating and cooling systems
- improper exhaust extraction
- too short drying time in automatic machines
- too finely dispersed sprays
- too high spraying pressures
- draughts in the working area ie incorrect siting of the equipment

3.4 Possible Developments in Machine Designs

As stated earlier, technological developments have occurred in machine designs and this process will continue. Suggestions have been made by solvent and plant manufacturers and by certain authorities (USA EPA) concerning developments and these are summarised below. It should be emphasised that extensive experience will be necessary with some of these experimental ideas before the benefits can be correctly assessed.

The major potential developments are :

1. improved covers
2. higher freeboard
3. refrigerated freeboard
4. solvent exhaust and activated carbon equipment
5. security switches

3.4.1 Improved Covers

All small and medium sized machines are already equipped with covers which are opened and closed manually. This reduces the solvent losses during longer operation breaks. Covers have, however, only an important effect if evaporation losses are high compared to the total emission, which may be so where the machine is idle for most of the day.

A further reduction in solvent losses could occur by using automatically opening and closing covers.

Covers should be designed to avoid disturbing the solvent layer.

It has been estimated that emissions from open machines can be reduced by 20 to 40% by the correct use of covers (EPA). For enclosed machines reductions can be obtained by covering the loading zone such that the machine is open only when work enters or leaves the equipment.

3.4.2 Higher Freeboard

The freeboard height is defined as the distance between the condensation zone and the upper bath edge. The freeboard ratio is calculated as follows :

$$\text{freeboard ratio} = \frac{\text{freeboard height}}{\text{bath width}}$$

By increasing this freeboard ratio of usually 0.5 to 0.75 in open machines the solvent emitted values may be reduced by at most 25 to 30%. Increasing the freeboard beyond these ratios may be in some cases progressively less effective and may also present difficulties due to the excessive overall height of the machine.

3.4.3 Refrigerated Freeboard

Solvent vapours are normally condensed on water cooled condensing coils. Additional cooling above the vapour level in the freeboard area can have the effect of producing a cool air zone which helps to reduce solvent loss by diffusion from the machine. This, so called, refrigerated freeboard operates in a temperature range of + 5°C to -30°C depending on the manufacturers design criteria.

Claims have been made that this device can reduce solvent emissions by about 50%.

A defrosting device is necessary in order to remove ice formed on the cooling coils. During the defreezing process water flows into the solvent which afterwards has to be separated. During this process water soluble stabilisers may be washed out from the solvent and this requires attention to prevent loss of stability.

3.4.4 Solvent Vapour Exhaust and Activated Carbon Equipment

Most metal cleaning machines are already equipped with ventilation systems which remove the solvent vapour to the open air. Further improvements in ventilation systems are unlikely to occur since in open topped machines the ventilation around the rim of the machine already collects the vapour escaping into the workshop. It is possible, however, to extract the solvent from this air mixture by the use of activated carbon recovery systems. The active carbon recovery system is capable of recovering up to 95% of the collected air/vapour stream. However the collection efficiency of the air stream from the operating cleaning machines is often low and generally overall recovery will be about 50%.

It can be shown that activated carbon recovery is usually not economic except for some degreasing plants operating for two shifts per day or for very large installations. This device therefore is less cost effective than other features which can be used to reduce solvent losses from the process.

3.4.5 Other Safety Devices

Safety devices such as

1. vapour level control cut off
2. condenser water flow switch and thermostat
3. sump thermostat
4. solvent level control switch
5. spray safety switch

are already applied or undergoing development in order to increase the safety of the vapour degreasing process. The use of simple mechanical handling devices such as lifts or hoists will also improve safety and economy.

Conclusion

As noted in Section 2.2 plants of current design are and can be operated safely within the standards set in Europe. It is important to emphasise the need however to ensure that the process is well understood by the worker who must be trained to operate in a safe manner. In addition good maintenance standards are important to ensure continued safety.

Design improvements are occurring which will further improve the safety of using these cleaning processes.

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4 ENVIRONMENTAL IMPACT

Trichloroethylene was first synthesized in 1864. In the beginning of this century a process for the production from acetylene was developed (in Austria) and manufacture took place in 1908 in the UK, in 1920 in Germany followed in 1925 by the USA. Since that time, and until recently, the application of TRI has increased steadily especially in metal degreasing.

However in recent years TRI production in the USA has fallen (to approx 50% of the maximum production which was reached in 1970) whereas in Europe the production has remained relatively stable. The reasons for this have been discussed in Chapter 1.

In the course of the last 12 years measurements have been carried out all over the world on the environment, to estimate the presence of TRI and other substances.

Since most of the solvent produced will evaporate during its method of use (eg in cleaning, adhesives or paints etc) it will be found in the general environment. The annual consumption of TRI represents that released into the environment (14).

TRI as well as other similar chlorinated hydrocarbons, is consequently found almost everywhere in the industrialised world, but in very low concentrations i.e. in the troposphere, water, sediment and also in a very varied range of foodstuffs and living creatures (fishes, birds, mammals and man) (1).

This section gives a picture of TRI concentrations found around production centres (2) consumption centres, on remote sites and on places that can be considered as representing the natural background.

It also outlines how TRI is decomposed in the environment and finally describes waste disposal methods.

4.1 Concentrations in Air

Table 1 shows the results of a large number of measurements carried out in the period 1972-1978 in different parts of the world. Table 2 shows the results of air analyses carried out by BIT Members in Western Europe in the period 1972-76.

TABLE 1

AIR ANALYSIS (VARIOUS SITES)

Location	Period	Concentration* ppb	Reference
Los Angeles (air)	Autumn 1972	0.7	6
Liverpool (centre)	1973	0.16	7
Rural areas Britain and North East Atlantic (from N W Africa to Lands End) (air)	1973	0.002-0.00045	7
Western Ireland (air)	June, July 1974	0.015	8
West and Mid Atlantic (air)	Oct 1973-July 1974	<0.005	8
Near Capetown (air)	1974-1975	0.0015	5
Near Cork (Ireland) (air)	1974-1975	0.015	5
Ambient air in Tokyo	May 1974-April 1975	1.2	9
Various populated and industrial areas as well as rural areas in the USA	1975	<0.02-8.8	10
Average Northern Hemisphere	May 1976	0.016	11
California	May 1976	0.016-0.31	12
Four production sites) air one user site) USA back ground site)	1977	<1-270	13
Bochum, West Germany	1978	0.5	15

* In air — ppb (= 10^{-3} µl/l); ppt (= 10^{-6} µl/l)

In water and soil — ppm (= mg/l); ppb (= microgram/l); ppt (= nanogram/l)

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TABLE 2

THE RESULTS OF AIR ANALYSES CARRIED OUT BY BIT MEMBERS IN WESTERN EUROPE

LOCATION	COUNTRY	CONC ppb v/v
Liverpool (Childwall)	UK	0.34-1.19
Widnes (Pex Hill)		1.53
Delamere		0.51-1.36
Frodsham		0.68-3.40
Moel Famau (N Wales)		0.17-1.53
Rannock Moor (Scotland)		0.42-1.36
Forest of Dean		0.85
Hengelo (open country)	NL	<0.02-0.17
Hengelo (centre)		<0.02-0.09
Weiwerd		<0.09
Munich (centre)	D	0.85-3.92
Munich 1 km f.c.		0.17-3.59
Munich 5 km f.c.		0.17-5.45
Munich 20 km f.c.		0.17-3.06
Munich 20 km f.c.		ND
Uberackern		1.36-8.5
Bruxelles Nord	B	0.68-1.02
Uccle		0.68-1.36
Uccle		ND
Namur		0.17-1.36
Saint Auban	F	0.17-8.15
Lyon (centre)	F	<0.83-4.23
Lyon 20 km f.c.)		<0.83-2.54

ND - not detected

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For air analysis it is concluded that:

1 The mode of use is such that the sites of release correspond with heavily populated areas and areas of engineering production, and - to a lesser extent - with sites of their chemical manufacture.

2 The quantities found are almost independent of the site of measurement and that at short distances from production and user sites, the levels are low and typically in the range of 0.1 - 3 ppb.

3 In Western Europe TRI is widely distributed at concentrations of a few parts in 10^9 in industrial and populated areas.

4 In areas remote from industrial and populated regions the background concentrations (65) are lower (0.010-0.015 ppb).

5 A large Northern Hemisphere/Southern Hemisphere gradient has been found (66).

6 There is no evidence of either an upward or downward trend in atmospheric concentration.

4.2 Concentration in Water

Table 3 shows the results of water analysis carried out by BIT Members in Western Europe.

TABLE 3

WATER SAMPLES WESTERN EUROPE

Location		Country	Conc* ppb w/w
Liverpool Bay		UK	0.3-3.6
River Rhine	Hoenningen	D	1-1.5
	Luelsdorf		2-2.5
	Wesseling		1.5-2
River Salzach	Marienberg		0.4-2.1
	Überackern		25-73.9
River Isar	Source of River		0.02-0.03
	Munich		0.2-0.6
	Downstream of Munich		2.5-3.2
	Lake Starnberg		0.13-0.15
	Lake Lerchenau		3.2-8.5
Twente Canal	Hengelo	NL	0.26
Twente Canal	Delden		<0.2
Eemes			11.0
Oostfriese Gaatje (South)			7.5
Oostfriese Gaatje (North)			0.7
Ranselgat			0.2
Huibertgat			<0.2
River Durance	Pont Oraison	F	6-25
	Ste Tulle		<3-9

* ppb w/w = microgram/l

More recent published data suggests that current levels of TRI in water are of very similar order of magnitude.

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From this data it is concluded that:

1 A comparatively small quantity of TRI enters the hydrosphere directly from manufacturing plants and in solution and suspension via the water out-fall from metal cleaning machines.

2 Analysis of river, canal and sea water taking effluent from the production and the user sites nevertheless show the effect of these additions on the background levels to the water source.

3 A dilution effect occurs in the down stream waters and that the chlorinated solvents are rapidly lost into the surrounding air. The average concentration in rivers is also of course dependent on flow rate and other factors.

4 There is no evidence for any increasing trend in the levels of TRI in water.

4.3 Degradation in Environment, Mechanism of Environmental Decay

In pure water the hydrolysis of TRI is slow and a half life of 2.5 years (3) has been suggested. However, it is considered that the real half life may well be less than this due to the catalytic decomposition by metal salts.

Experiments have shown that rapid transfer takes place from the hydrosphere to the atmosphere where faster decomposition occurs. The half life in air is estimated to be only a few days (66).

Free radical photo-oxidation in the troposphere initiated by OH radicals appears to be the main degradation process for unsaturated compounds like TRI. However the detailed mechanism is largely speculative.

Products such as dichloroacetyl chloride, hydrogen chloride and phosgene are likely to be removed from the atmosphere by the scrubbing action of rainfall. Once in the aqueous phase the hydrolysis to dichloroacetic ions is practically immediate; the dichloroacetate ions themselves being degraded in some weeks to CO_2 and chlorine ions by biological processes (1).

In this way the troposphere and hydrosphere can be considered as the sink by which TRI disappears out of the environment within a few weeks. The lifetime with respect to atmospheric oxidation calculated on a global basis would be expected to be less than a week. In certain areas with high pollutant levels the lifetime will be appreciably shorter. Other products such as $CHCl_3$ (4) have been shown to be produced by photochemical reaction in simulated ambient air containing TRI. This phenomenon parallels a previous observation of CCl_4 being formed from perchloroethylene. It should be remembered that $CHCl_3$, itself in its turn is submitted to photo-oxidative decomposition in the troposphere too, initiated by eg hydroxyl radicals.

Therefore, due to the rapid decay of trichloroethylene and its degradation products in the biosphere it is concluded that this solvent does not represent an ecological threat.

4.4 Code of Practice on Disposal of Wastes

In this context wastes mean residues after distillation from users or reclaimers. Harmless disposal to the environment is commonly practiced and some general considerations concerned with disposal are given.

In choosing one method or another there must be compliance with local regulations.

4.4.1 Handling

According to the European Common Market Directive 79/831 of 18 Sep 1979 temporary storage areas should be cool, dry, well ventilated and away from fire hazards. Notwithstanding the fact that TRI is non flammable, corrosive products arise due to thermal decomposition where wastes are exposed to fire. Workers must be protected and safety equipment provided where appropriate. Proper containerisation and labelling should be practiced.

4.4.2 Reclamation

During the planning of waste disposal operations use must be made to the maximum extent possible of methods for the recycling or re-use of the residues concerned, taking into account technical and economic considerations.

In this way the quantities of waste for ultimate disposal will be minimised.

It is important to recognise that the quantities of residues for disposal are relatively small compared with the annual production figures since in the vapour cleaning processes continuous recyling is practiced and only when heavily contaminated with oil and metal swarf etc is final solvent recovery needed. Even then the current operation of the degreasing installation as a still will result in the user recovering most of the solvent from the residues.

The waste arises from the vapour cleaning process as sump residues that may contain up to 50% TRI. It is disposed of by removal during shut-down eg at the weekend, rather than when the build up of contaminants reaches unacceptable levels. Solvent may be recovered on site by simple or steam distillation in separate off-line recovery stills where the scale of operation makes it economically feasible. The residual solvent content after reclamation by steam distillation may be lower than 10% and is often close to zero.

Collection and destruction of oily wastes is very well organised: in most European countries several reclamation companies are in operation.

In addition many countries in Europe have set up materials exchange services giving information on wanted or available residues, thus enabling certain materials which would normally be disposed of to be re-used.

4.4.3 Disposal Methods

Several factors influence the selection of a disposal route including:

- the quantities involved
- the availability of suitable facilities
- overall costs including transport
- local conditions
- national regulations

The two following disposal methods are used:

a Incineration

Incineration can be carried out on land or at sea and is subject to national and international legislation. In Europe several incinerators with facilities for absorbing the acid gases, will accept chlorinated wastes.

b Landfill

Controlled landfill, which is the least expensive disposal method, either alone or in conjunction with domestic or factory waste has been practiced for many years and without ill-effect on the environment.

The sites must be carefully evaluated to ensure that there is no pollution of underground or surface water or nuisance, and they must be well managed.

Small numbers of drums may be deposited on an irregular basis preferably buried in a deep trench. Larger numbers should be emptied and the drums crushed or disposed of separately for scrap. The eventual failure of any quantity of drums containing liquid could lead to environmental problems such as subsidence of the tip. Chlorinated solvents are strongly absorbed by cellulosic waste found on landfill sites.

5 TRICHLOROETHYLENE - TOXICOLOGY

5.1 Animal Studies

The major target organs implicated in the many animal studies that have been carried out are the central nervous system, liver, kidney and heart. The predominant feature is the anaesthetic effect on the central nervous system. Adams et al (16) reported the maximum concentrations survived for different times by rats as 20,000 ppm for 18 min, 6,400 ppm for 90 min and 3,000 ppm for 480 min. Survivors recovered quickly with only a small increase in liver weight accompanied by a slight cloudy swelling of hepatocytes.

Adams et al (16) also exposed rats, guinea pigs, rabbits and monkeys to 400 and 200 ppm for 7 hours/day for extended periods (from one month up to about 6 months). Rats and rabbits were exposed under a similar regime to 3,000 ppm and guinea pigs to 100 ppm.

At 3,000 ppm, rats showed signs of CNS effects, and, although final liver and kidney weights after 27 exposures were increased, histopathology showed no abnormality in the male and possible slight fatty vacuolation in the female. Rabbits showed a similar picture, with no histopathological changes.

At 400 ppm for 173 exposures, rats showed increases in liver and kidney weight with no histopathological changes. Guinea pigs showed slight growth retardation over 167 exposures with increased liver weight. Rabbits showed no abnormality over 161 exposures other than a slight increase in liver weight. One monkey showed no effects.

At 200 ppm, rats showed no effects over 151 exposures, guinea pigs showed some evidence of growth retardation over 163 exposures but were otherwise normal and both rabbits and monkeys showed no effects (178 and 148 exposures respectively).

100 ppm (132 exposures) was shown to be a no effect level in the guinea pig.

This is probably the most comprehensive study of repeated exposure reported.

Approximately 1% v/v has been reported (17) as an EC_{50} in sensitising the hearts of dogs to the effects of adrenalin and similar sympathomimetic drugs.

5.2 Human Studies

Reports in the literature of the effects of trichloroethylene on humans may be subdivided into three categories:

5.2.1 Poisoning cases.
5.2.2 Experimental human exposure
5.2.3 Human field studies

5.2.1 Poisoning Cases

There have been a number of cases of trichloroethylene poisoning reported, including some fatalities (18, 19, 20). The predominant effect is that on the central nervous system, with several fatalities being ascribed to ventricular fibrillation (19).

There have been a number of reports relating liver damage to trichloroethylene over exposure (20). In the majority of these a clear causative link is not established and they must be viewed against the background that, in the past, trichloroethylene undoubtedly contained significant quantities of hepatotoxic impurities such as 1,2-dichloroethane and tetrachloroethane.

5.2.2 Experimental Human Exposure

Stewart (21) exposed volunteers to 100 and 200 ppm for periods between 1 hour and a 5 day work week. He reported mild, inconsistent subjective responses at 200 ppm, with a more consistent mild sleepiness reported on the 4th and 5th days. There were no controls and the subjects were aware of their exposure.

Salvini et al (22) exposed student volunteers to 110 ppm for two four hour exposures. He reported a statistically very significant decrease in performance in various psychophysiological tests. There were no controls and the authors recognised that the effects of the odour of trichloroethylene and the knowledge of exposure could have been confusing factors. They state that the experiments were repeated on six workmen with similar results but surprisingly give no details of these observations.

Nakaaki et al (23) reported that human subjects exposed to 100 ppm showed no significant decline in psychophysiological performance.

Nomiyama and Nomiyama (24) exposed volunteer students to 0, 27, 81 and 201 ppm for 4 hours. They reported a number of subjective responses, most of which (with the exception of headache) did not show a dose/response effect. Headaches were reported at 81 and 201 ppm. The effect of knowledge of exposure (smell was reported by all subjects at all dose levels) serves to confuse these findings. A number of objective physiological tests are reported the results of which are not statistically analysed but, according to the authors, indicate a tendency to bradycardia.

Vernon and Ferguson (25) reported that exposure to 1000 ppm for two hours had a statistically significant effect on performance in six standard psychophysiological tests, but that expsure to 300 ppm and 100 ppm showed no such effect. In a later paper, the same authors (26) observed the effect of alcohol on performance in these tests and noted an augmentation of the effects of a 2 hour exposure to 300 ppm and 1000 ppm, although this was reported to be statistically significant only at 1000 ppm.

Stopps (27) reported, in an experiment in which the smell was masked with lavender oil, that 100 ppm had no effect on psychophysiological performance, but that there was a progressive decline in performance up to 500 ppm.

Ertle et al (28) exposed volunteers to 50 ppm and 100 ppm for 5 successive days in a study which did not have a control group. All subjects reported fatigue and/or lassitude which the authors indicate may have been due to the unfamiliar and constraining conditions of the study. Two cases of headache and one of diarrhoea were also reported, which the authors indicate could not be positively related to exposure.

It is a fundamental principle of psychophysiological experiments that a double blind technique must be used. All these reports (except perhaps Stopps (27)) suffer from a failure to observe this principle and it is in consequence impossible to determine whether effects reported are caused by trichloroethylene or are an artefact related to a knowledge of exposure and the unfamiliar test conditions.

5.2.3 Human field studies

Nomiyama and Nomiyama (24) also studied subjective symptoms in a group of trichloroethylene workers and compared these with a group of controls. They conclude that a number of symptoms (notably irritation, drowsiness, fatigue and headache) are associated with exposure to trichloroethylene. The authors use as an index of exposure total trichloro compounds in urine over a 4 hour period and equate this to atmospheric exposure. They do not fully document this relationship and, although they state that the atmospheric concentration at the workplace was almost constant, they present no evidence for this. Several of the symptoms show an erratic dose response relationship and it is difficult to relate these to actual atmospheric exposure because of the complex relationship between atmospheric exposure and urinary metabolite levels. There is also no indication of whether there was exposure to materials other than trichloroethylene.

Grandjean et al (29) report a field study of trichloroethylene workers in which blood and biochemical tests and clinical observations (including nervous system symptoms) were carried out and related to trichloroethylene exposure. They report a high frequency of subjective complaints, alterations in the vegetative nervous system and of neurological and psychiatric symptoms.

Atmospheric analyses reported range from 1 to 335 ppm. The authors acknowledge that the atmospheric analyses reported are likely to underestimate actual exposure (not taking into account several specific, high exposure situations). There were no controls and the general state of health of the workers was reported as bad (which the authors ascribe to socio-economic factors). It is thus very difficult from this study to relate specific effects in a quantitative manner to exposure to trichloroethylene.

Ahlmark and Forssman (30), in a survey of workers from a number of different industries exposed to trichloroethylene, carried out from 1944 to 1949, determined trichloroacetic acid in urine as an index of exposure and observed a correlation between this parameter and the incidence of a variety of symptoms (fatigue, irritability, headache, diffuse gastric symptoms and others). They conclude that a urinary trichloroacetic acid excretion of 20 mg/l is the maximum tolerable. No mention is made of the atmospheric concentrations of trichloroethylene involved, and Bardodej and Vyskocil (31) state that neither they (Vyskocil and Bardodej (32)) nor Frant and Westendorp (33) were able to confirm the correlation between symptoms and urinary TCA reported in this paper.

Ahlmark and Friberg (34), on the other hand, (referring to Ahlmark and Forssmann (30)), recommend that urinary excretion of TCA should not exceed an average of 50 mg per litre of urine. They suggest that this may correspond to an average exposure to no more than 30 ppm of atmospheric trichloroethylene and tentatively propose this figure as a hygiene standard. They argue that this figure is justifiably lower than those prevailing in other countries since its basis in urinary TCA measurement relates to total exposure, whereas they assert that other limits may be based on atmospheric measurements taken during short periods of severe exposure. They do not present any evidence for this last point.

Bardodej and Vyskocil (31) examined workers in the drycleaning and metal degreasing industries. They report atmosphere concentrations as varying between 5 and 600 ppm, although the basis for sampling and analysis is not described. They observe a variety of symptoms (headache, fatigue, nausea and others) in different groups of workers whose exposure to trichloroethylene varied over the range mentioned above. A correlation between these symptoms and trichloroethylene exposure is claimed only for the prenarcotic symptoms (headache, sleepiness etc). There were no control groups. They recommend a limit of 35 ppm on the basis that only the group of workers with a reported atmosphere concentration of 5-10 ppm were free of the more serious symptoms. The absence of control groups, as well as the impossibility of assessing personal exposure to trichloroethylene from the data presented, make it very difficult to determine the significance of the effects reported for establishing a hygiene standard.

Lilis et al (35) reported prenarcotic symptoms (dizziness, headache, nausea and others) in workers in a semiconductor manufacturing plant; there was no control population.

Trichloroethylene concentration in the atmosphere was reported to vary: 40% of determinations were reported to be above 10 ppm while 12% were above 35 ppm. The methods of sampling and analysis are not given and it is impossible to relate these figures to actual occupational exposure. The absence of control data and adequate data on actual exposure make it difficult to assess the significance of this work.

When assessing the literature reports on the effect of trichloroethylene on humans in the context of an atmospheric hygiene standard, the following points should be borne in mind:

i the difficulty of carrying out experimental human studies to an adequate, double blind protocol. Most of the reported studies fail to meet this criterion, thus adding to the problems of interpretation.

ii in none of the human field studies reported is actual occupational exposure determined by an acceptable occupational hygiene technique (eg personal monitoring). There are indications that the 'spot' sampling technique usually used may underestimate actual exposure by failing to cover certain specific, high exposure operations, particularly in the older studies. This difficulty, combined with the frequent absence of control groups and the generally subjective nature of the symptoms reported, suggest that the correlations and conclusions reported in the literature should be examined critically and a cautious attitude adopted in assessing their value in establishing a hygiene standard.

When the available data are examined in this light, it is concluded that there is no good evidence from any of the human experimental or field studies which have been reported to indicate that exposure to atmospheric levels of trichloroethylene at or below 100 ppm will have any significant effect on human health.

There is a case for a carefully planned and adequately controlled field study, in which actual exposure is determined by personal monitoring, to enable these various reports to be placed in context. Identifying suitable exposed and control populations would be not the least of the problems associated with such a study.

5.3 Carcinogenicity and Mutagenicity

This section may be sub divided into the following categories

5.3.1 Animal Work
5.3.2 Mutagenicity
5.3.3 Biochemical Studies
5.3.4 Epidemiology

5.3.1 Animal Work

In a carcinogenicity bioassay (NCI, (36)), groups of 50 B6C3F1 mice per sex received technical trichloroethylene by gastric intubation at the maximum tolerated dose (MTD) and 1/2 MTD levels. These corresponded to 2339 and 1169 mg/kg body weight for males and 1739 and 869 mg/kg body weight for females 5 times per week for 78 weeks. Surviving mice were sacrificed after 90 weeks. A dose related excess of hepatocellular carcinoma was observed, much higher in males than females. Groups of 50 Osborne-Mendel rats per sex were submitted to the same protocol. MTD and 1/2 MTD corresponded initially to 1330 mg/kg body weight and 650 mg/kg body weight, 5 times per week for 78 weeks. Due to increased mortality, these dose levels were lowered and time weighted average figures corresponded to 1100 mg/kg body weight and 550 mg/kg body weight for both sexes. No excess neoplasms were observed. The trichloroethylene used contained epichlorhydrin and 1,2-epoxybutane as stabilisers.

Early in 1976, the Manufacturing Chemists association (37) and the European chemical industry jointly sponsored a long term inhalation study in rats and mice at concentrations of 100, 300 and 600 ppm. The work was commissioned at Industrial Biotest and it subsequently became clear that, due to unsatisfactory experimental procedures in the conduct of the study, no scientific conclusion was possible.

Maltoni (38, 39) conducted a chronic ingestion study in Sprague Dawley rats which did not indicate any carcinogenic effect. Trichloroethylene (not stabilised with epoxides) was administered in olive oil by gastric intubation 4/5 times per week for 1 year at dose levels of 50 and 250 mg/kg body weight. Maltoni started an experiment in 1979 in which rats, Swiss mice and NCI mice are being exposed by inhalation at 100, 300 and 600 ppm to trichloroethylene stabilised with butylated hydroxytoluene.

Henschler et al (40) exposed NMRI mice, Wistar rats and Syrian hamsters to 100 and 500 ppm amine stabilised trichloroethylene for 6 hour/day, 5 days/week for 18 months. No increased incidence of neoplasms was found in any sex, species or dose group with the exception of a dose dependent increase in malignant lymphoma in the mice. This was attributed to inborn viruses in the mice and not considered to be indicative of a carcinogenic effect caused by trichloroethylene. Henschler (46) has recently completed a lifetime oral gavage study with ICP/HA Swiss mice in which different formulations of both amine and epoxide stabilised trichloroethylene were administered. Mice treated with epoxide stabilised trichloroethylene developed squamous cell carcinoma of the stomach, but no liver tumours, whereas pure trichloroethylene did not show an increased tumour formation. The results implicate epichlorhydrin as a possible causative agent of these stomach tumours but provide no good evidence that epoxybutane is similarly involved. Epoxybutane is the subject of an NTP inhalation bioassay commenced in late 1981.

Van Durren (41) showed no carcinogenic effect with pure trichloroethylene in Swiss mice, using three different routes of administration (skin application - 1 mg trichloroethylene per application 3 times weekly for 581 days; subcutaneous injection - 0.5 mg trichloroethylene weekly; and gastric intubation - 0.5 mg weekly).

NTP are conducting a second bioassay (formerly called NCI bioassays) (47) in B6C3F1 mouse and four different strains of rat using epoxide-free trichloroethylene. Liver tumours have been produced in the mouse, but the rat experiment (Fischer 344) exceeded the maximum tolerated dose and could not be used as a basis for determining whether or not trichloroethylene is carcinogenic in the rat. There are three more strains of rat under test.

Trichloroethylene has been therefore shown to produce liver tumours in B6C3F1 mouse (2 assays) but is not carcinogenic in several other experiments in the mouse and other species. Epoxide stabilisers have been implicated as a possible causative agent for the first NCI bioassay but results of the second NCI (NTP) study showed this not to be the case.

5.3.2 Mutagenicity

There are several reports of studies to investigate the mutagenicity of trichloroethylene using several different in vitro and in vivo test systems. Although positive results have been seen with stabilised trichloroethylene and some specific systems have shown positive responses with pure trichloroethylene, the overall conclusion is that pure trichloroethylene does not show any generalised mutagenic activity.

5.3.3 Biochemical Studies

The species differences between the rat and the mouse has been the subject of investigative work by Elcombe (48,49). He has shown that the mouse metabilises trichloroethylene in a linear manner to trichloracetic acid, whereas in the rat trichloroacetic acid production saturates at a lower level. Marked liver peroxisome proliferation is observed in the mouse but not in the rat. Trichloracetic acid has also been shown to induce peroxisomes in both rat and mouse liver. The species difference in peroxisome proliferation due to trichloroethylene may therefore be explained by saturation of trichloroethylene metabolism in the rat, but not the mouse (62). Hence it appears that the amount of trichloracetic acid produced in the rat is insufficient to proliferate peroxisomes. Longer term (up to 6 months) treatment of mice with trichloroethylene results in a sustained increase of peroxisomes. Such hepatic peroxisome proliferation has been associated with the induction of liver tumours in rodents (63) which could explain the susceptibility of mice to trichloroethylene - elicited hepatocellular carcinoma. There is evidence to show (63,64) that liver peroxisome proliferation is a rodent specific phenomenon and does not occur in humans. It thus appears that trichloroethylene induced mouse liver tumours are unlikely to be relevant to man since:

i human metabolism is closer to that of the rat than the mouse and relatively little trichloroacetic acid is produced.

ii liver peroxisome proliferation appears in any event to be a rodent specific phenomenon.

5.3.4 Epidemiology

In man, after more than half a century of extensive industrial use and despite considerable exposure to this solvent, especially in the past, no causal relationship has been established between exposure to trichloroethylene and cancer. Formal epidemiological studies are, however, few. One such study by Axelson et al (45) on 518 Swedish workers showed no increased cancer mortality, although covering a fairly short elapsed time. Also, a joint study by industry and a cancer registry revealed no association between the incidence of liver cancer and trichloroethylene manufacture (52).

In addition, studies by Malek (50,51) provide limited evidence that occupational exposure to trichloroethylene is not associated with an increased incidence of liver cancer.

The overall conclusion therefore must be that trichloroethylene is unlikely to involve any risk of human liver cancer when handled in accordance with the manufacturers instructions (which will include observation of the relevant occupational exposure limits).

5.4 Reproductive Toxicity

The potential teratogenicity of trichloroethylene has been investigated in the rat and the mouse, exposure being by inhalation.

In one study by Schwetz (53) no evidence of any foetotoxic or teratogenic effects were noted in the rat (Sprague Dawley) following exposure to trichloroethylene at 300 ppm (7 hours/day) on days 6-15 of gestation. Slight foetotoxicity but no teratogenic effect was observed in mice similarly tested. In another investigation Dorfmueller (54) exposed rats (Long-Evans) to 1800 ppm of trichloroethylene (6 hours/day, 7 days/week) on days 0-20 of gestation. No teratogenic effects were noted, but some foetotoxic effects indicative of delayed development were observed.

Trichloroethylene has been assessed for dominant lethal effects in the mouse. Slacik-Erben (55) exposed male mice to 0, 50, 200 and 450 ppm for 24 hours, using 50 animals at each dose level. Each male was then mated with a new untreated female every 4 days, altogether 12 times. There were no biologically significant effects on pregnancy rates, pre or post-implantation losses at any dose level. This is therefore evidence of the absence of any significant effect on the male reproductive parameters.

5.5 Biological Monitoring

Determination of trichloroethanol and/or trichloroacetic acid in body fluids has been proposed for monitoring trichloroethylene exposure. There has been difficulty in establishing reliable quantitative relationships between level of exposure to trichloroethylene and the level of these metabolites, but trichloroacetic acid in urine may be useful as a back up to atmospheric monitoring.

5.6 Conclusion

The major hazard from trichloroethylene is presented by acute central nervous system depression and perhaps cardiac effects associated with short term exposure to high levels. There is no good evidence from any of the animal work or human experimental and field studies which have been carried out to indicate that exposure to atmospheric levels at or below 100 ppm will have any significant effect on human health.

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