Investigation of the Effects of Trichlorethylene on Workers in Degreasing Plants

By

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DURING THE PAST YEAR, the effect on workers of prolonged exposure to Trichlorethylene was studied and a quick and simple test applied which gives a useful measure of the amount of this substance absorbed by operators.

Historical

Solvents and degreasers are widely used throughout industry, particularly as solvents for paints, lacquer, rubber, cellulose and dyes, in the extraction of oils and fats and degreasing of metals, and in dry cleaning and wool defatting.

Originally, large quantities of tetrachlorethane, carbon tetrachloride and benzene derivatives were used, but Medical Officers in industry have emphasised their serious toxicity, especially to the blood-forming organs and liver, and to-day these solvents have in many cases superseded by Trichlorethylene ("Tri"), petroleum napthas, toluene etc. Substitution of safe for dangerous materials is the best method of eliminating hazards in industry, since it does not depend on the co-operation of workers and, once achieved, will permanently abolish the hazard. Thus, the use of carborundum in place of sandstone for grindstones, and of steel shot instead of sand for shotblasting, has effectively removed the risk of silicosis. In this case, however, "Tri" is only one of the least of many evils, for although certainly much safer than other chlorinated hydrocarbons, it is far from non-toxic and our vigilance should not be relaxed simply because its predecessors were much more poisonous.

In 1914, Ullman still considered that Tri was atoxic to man, and even as late as 1937, Trillat maintained this, although in the meantime numerous cases of poisoning, acute and chronic, with a number of deaths, had been described, particularly on the Continent where conditions appear to be less favourable in this respect than in the United Kingdom and U.S.A. In 1916, Plessner had already reported cases of poisoning and since then an extensive literature has accumulated. Acute poisoning causes irritation of mucous membranes, giddiness, excitement, confusion and ataxia, leading to collapse and coma. It occurs most often when tanks are being emptied for cleaning without adequate supervision and precautions. In some cases no immediate narcotic effect occurs, but heart failure may set in several hours after ceasing exposure (often associated with violent exertion) and this may lead to sudden death. Chronic effects are more difficult to demonstrate, since they consist mainly of symptoms unaccompanied by objective physical signs or haematological and biochemical changes.

Recently, even standard textbooks reluctantly admit the condition — vide Hamilton and Hardy (1949) and Browning (1953). These chronic effects, which are generally reversible and disappear as soon as absorption ceases, consist of a variety of disturbances of the autonomic nervous system and cause many "neurasthenic" complaints which may not be attributed to Tri by the physician or even by the patient himself. Addiction to inhaling this substance is not uncommon and causes special problems in diagnosis. Apart from these reversible effects the rare case of irreversible chronic toxicity has been recorded and seems to take the form of a peripheral or cranial neuritis, sometimes with optic atrophy.

In a recent study from Holland, Frant and Westendorp (1950) found proof only of cases of retrobulbar neuritis. Grandjean et al. (1955) in Switzerland showed quite a high incidence of chronic symptoms on direct interrogation. In Vienna Lachnit and Rankl (1950) went so far as to state that chronic effects are more important than the occasional cases of acute poisoning and, having studied the question in the last 18 months, I myself have no doubt that the condition is not rare and is only ignored because of its elusive symptomatology, of the difficulty of convicting Tri...
been scheduled as compensable conditions in France (Fabre 1948). In Britain toxic jaundice only would be notifiable if caused by Tri, but it is very doubtful that the liver is ever affected in man (Cotter 1950 and Brit. J. industr. Med. 1945).

My attention was first drawn to the problem by the case of a workman who blamed his job for various symptoms, like somnolence, fatigue, nausea, lack of appetite and insomnia at weekends. It is well, even when symptoms appear to be "neurotoxic" to inspect the work place. It was then found that the Tri fumes were very heavy. The vapour from the liquid Tri tank is cooled and condensed by a coil of cold water pipes around the top of the tank. The fluid is kept at 30°C, and if work is withdrawn gradually and allowed to drain, further fumes will escape into the surrounding air. In this case, however, the chargehand had set the rheostat at 60°C to allow more work to be put through in unit time but incidentally causing a vapour hazard to operators. As soon as the rheostat control had been made fool-proof, complaints ceased.

I then decided to look for a simple field test or exposure of workers to Tri. Various authorities (Elkins 1950) suggest the safe concentration of 40 ppm (Grandjean 1955) and 400 ppm per eight-hour day (Goldblatt 1952), but determination of the air concentration is an elaborate procedure (Barrett 1936, Dudley 1941, Fahy 1948. Rogers and Key 1947) and not feasible in a very large shop with plentiful ventilation, where atmospheric shop concentration, a careless or addicted operator may lean over his tank unnecessarily, while another takes care to void the vapour. Factors influencing individual absorption include (Withridge 1940) tank design, size, working temperature, quantity of work put through, degreasing technique, size of workshop and method of ventilation, the horizontal lot system apparently being the safest.

Sampling for 5-10 minutes at random may be very misleading, since there are wide fluctuations, especially in open workshops (Grandjean 1955). An apparatus for continuous sampling has not yet been perfected, although efforts to this end were now being made with a new strip sampler (Challen 1953).

Determinations of blood levels are also too complicated to be suitable for field work and require venipuncture, which would make it unacceptable in industry (Habgood 1945).

However, in 1939 (Barrett 1939) it was shown that Tri is oxidised and converted in the body into trichloracetic acid (TCA) and excreted proportionately in dogs.

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\text{Trichlorethylene} \quad \downarrow \\
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\text{CL} \\
\text{OH}
\end{array}
\]

\[
\begin{array}{c}
\text{CL} \\
\text{C-C}
\end{array}
\]

\[
\text{CL} \\
\text{O}
\]

Trichloracetic Acid

In 1945 this was shown to hold equally for man (Powell 1945) and thus furnished a simple urine test for Tri exposure. The main elimination of Tri is via the lungs (Fabre 1948). Some 13 per cent is excreted as TCA in the urine after being transformed into this relatively harmless substance, mainly in the spleen and the lungs. The excretion of TCA in the urine is roughly proportional to the absorption of Tri and therefore gives a useful index which is easily determined.

This has been confirmed by Frant and Westendorp (1950) and it has been stated that there is such a close relation between the air Tri and urine TCA that one can predict one from the other with a simple formula.

More recently, Elkins (1945) however denied that these values move proportionately. He, however, was using a different test altogether and concluded that his findings were so unhelpful that he has now gone over to the Fujiwara test (which was used by Frant and Westendorp and by me in this series). Recently Grandjean et al. (1955) found a poor correlation, varying from 2:1 to 6:1 between air and urine values. But their air sampling was done only for 5 to 10 minutes and showed wide fluctuations even in closed shops. A correction was also required for operators not working continuously with Tri and possibly further corrections for short severe exposures, as in tank cleaning and for other variables as noted above, would improve correlation.

An extensive study by Swedish workers (Ahlmark 1951) also confirmed the usefulness of urinary excretion of TCA as a measure of Tri exposure, but their test is elaborate and not suitable for a small laboratory. A simpler method, based on the Fujiwara test for chlorinated hydrocarbons, was described by Frant and Westendorp (1950), but this is still not simple enough for field work. In 1952, Waldman and Krause (1952) described a simplified test for TCA which is accurate to an error of less than 5 mg per litre. They, however, used a spectrophotometer for the colour comparison, requiring more costly apparatus and special calibration curves compiled daily to compute results. Since we already had a small
“Lovibond” colorimeter, it became a relatively easy matter to get a series of permanent standard coloured discs made and thus to simplify the tests still further. As now performed, the test can be done in 20 minutes and quite a number of tests can be done at one time so that they are generally arranged in batches for convenience.

Lachnit and Rankl (1950) deplored the fact that “there is no sufficiently exact test for investigation of large numbers” of specimens. In this test for the first time this difficulty is overcome, with a method readyly carried out under industrial conditions. The accuracy was checked independently with more elaborate tests. It is not so great because there is only a choice of nine standards, but this is sufficient for all practical purposes. A set of graduated colours is available, calibration is not required before every test and an objective reading is obtained by direct comparison.

Method
The chlorinated hydrocarbon is converted to chloroform by caustic soda and this gives a colour reaction with pyridine.

A total of 240 tests have been carried out in the first year on urines obtained from 101 male workers.

Method—Based on Waldman and Krause (1952)
Place 16 ml. of 25 per cent sodium hydroxide and 4 ml. pyridine in a test tube, then add 1 ml. urine and shake well. Place the test tube in a water bath and keep at 60°C for 15 minutes, shaking it well every 5 minutes. Cool, pour into separator funnel and drain off all the clear layer below.
Add 7 ml. of 95 per cent alcohol to the pink layer in the funnel and shake to clear turbidity. Pour into Lovibond 13.5 mm. glass cell and apply the screen supplied.

Compare against the standard disc supplied by Lovibond’s (Tintometer Ltd., Salisbury).
The result is read in mg. per litre, in 9 stages from 12.5 to 200 mg/l.

In this investigation, the laboratory technician, being a popular man from the factory floor, obtained urine specimens in his own way, without alarming workers, for what was called “a simple urine check”. The result was that the workers were not made conscious of a possible hazard, which might well have produced a spate of complaints, and engineering improvements could be instituted where necessary. Thus, instead of taking the worker off the job, his work conditions were made safer and he continued at his job, unaware of the fact that the specimen of urine he handed in often resulted in quite profound changes in his working conditions. No workman was interviewed or asked about any complaints unless he volunteered them or reported sick spontaneously. This is important because direct questioning will elicit numerous symptoms which are too frequently attributed to work, if this is suggested or implied. The Swedish investigators (Ahlmark 1951) saw only workmen referred to them because of complaints or for specific investigation of Tri hazard, and they asked numerous leading questions. As a result, they found that symptoms were produced by very much lower absorption of Tri than was the case in our series. In this case the investigation was made possible without workers having much idea of the potential toxicity of Tri. Whenever a serious degree of absorption was noted Safety Department was informed, the job checked and altered by the Safety Officers in their routine course of duty, so that no suspicion was aroused and the association of alterations with the Medical Department did not become obvious. The test was employed to pinpoint and correct unsatisfactory conditions and not to remove a worker from the job only to replace him with another victim.

Results
On analysis of 240 tests, substantial confirmation was obtained of the findings of the Swedish workers (Ahlmark 1951) with their more intensive and prolonged investigation. (They analysed 122 cases). This urine test is very satisfactory as a field test for several reasons.

(1) The excretion of TCA by operators is a fairly constant figure while they are at a fixed job and does not vary greatly from day to day, although we find that it is sometimes less after the week-end than on a Friday.

(2) It is immaterial at what time of day the specimen is collected since “as a rule only minor variations occur in the course of the day” (Ahlmark 1951). This makes the test unusual, as it does not matter on what shift the man is and the specimen can be collected at one’s convenience.

(3) TCA begins to be excreted within a day of starting on degreasers and continues to be eliminated at a steady rate while exposure continues, gradually decreasing over some 3 or more weeks after ceasing exposure. Even a single acute dose requires 7-10 days to be eliminated completely (Ahlmark 1951). There is, therefore, no urgency for collecting a specimen at once.

(4) TCA remains in the urine without loss for at least 48 hours, so that specimens may be collected and kept for testing next day at a convenient time.

(5) The operator need not attend at a laboratory but, at his convenience and in privacy, can fill a bottle which we supply and he need only be told that this is a routine check.

(6) The test will give a result in 20 minutes, so that action can be taken at once.

(7) It can be done by a technician without special laboratory facilities which previous tests required. Our technician produced correct readings in 20 minutes for the tests, but the results are not complete until the results are entered on the printed form and checked by a supervisor.
results from the first specimen submitted and some sample tests have been checked by a public analyst and found to be accurate.

(8) There is no difference in the sexes or by age in the interpretation of the test (Ahlmark 1948 and 1951). The only specialised equipment required is a colorimeter and this is generally available in an industrial laboratory.

(9) A single test can often be taken as conclusive, and this is a unique feature of this test. Thus one worker reported complaining of fatigue, irritability, somnolence, morning dyspepsia and conjunctivitis and epiphora. A specimen was submitted on the spot and contained 300 mg. per litre TCA. On this finding the Safety Department was informed and measures initiated to remedy the fault which, in this case, consisted in a greatly excessive amount of work passing through the tank and lack of time for extracting it slowly to allow it to drain. Thus, on the strength of the examination of 1 ml. of urine taken at random, one can give the Safety Department a definite recommendation within 20 minutes on how severely a worker has been exposed or how safe a particular environment is.

(10) No other substance gives a positive result unless, as is very unlikely, the worker has recently been given chloroform or chloral. In anyone even slightly exposed to Tri, the urine will give a weak colour reaction within a day or so and one can, therefore, at once discover any specimen submitted which may have been obtained from a friend or even the house cat.

Action

"The Inhalation of Vapours is the main way of entrance for Tri in cases of poisoning" (Frant and Westendorp 1950). Therefore, preventive efforts must be concentrated on dealing with inhaled vapour.

Kleinfeld and Tabershaw (1954) stress that in four of their five fatal cases from Tri poisoning this was caused by inhalation by degreasers and that all continued to work in spite of their complaints and died suddenly, usually away from work, of heart failure which could quite easily have escaped association with their work.

The most useful part of this investigation has been that it was possible to prove that engineering improvements could quickly eliminate this risk to the health of workers. Since it takes about 10 days to eliminate the majority of the poison, a repeat test after this interval will show whether alterations in the process have been effective. The only other way a figure of 300mg./l may be reduced to 30mg./l would be for the operator to be taken right off the job, an expedient to which we only resort in a few special instances, as it is better to make the job safe for the next man. Incidentally, it was the only way of checking the results.

The co-operation of the Safety organisation cannot be over-emphasised, and a campaign was initiated to improve conditions at all tanks pinpointed by our tests. Every worker gave the location of his tank when returning his specimen and a list was prepared of the locations where a high exposure was shown (over 100 mg.) and sent to the Safety Officers for investigation and appropriate action.

The following rules for preventive measures were circulated to all concerned, based on ICI instructions:

(1) Work must be removed slowly from the tanks, so as to avoid excess vapour being dispersed by air currents,

(2) Components must not be degreased packed in cartons or sacks which hold the vapour or liquor,

(3) Work should be raised just above the vapour and allowed to drain before being removed from the tank area,

(4) The steam pressure control must be made foolproof so that pressures above 30-lb. per sq. in. are not produced with consequent overheating of the liquor,

(5) The volume of water in condensing coils must be kept well up. In this connection, the co-operation of the Work Standards (Time and Motion Study) Department was enlisted and their understanding of these principles helped in making working methods safe. It was specially emphasised that extra time must be allowed in their time studies of a degreaser's job, to allow work to drain just above the tank before being removed. This is time well spent, even though apparently unproductive.

Mechanical Alterations were made by the Safety Department in conjunction with the Engineering Department and among these were the following changes:

(1) Changes of Process from cold liquor tanks to liquid vapour plant,

(2) Repositioning of Tanks to obviate unnecessary carrying of treated work from tank to bench etc,

(3) Mechanisation of handling work or baskets containing components. (Electric lifting tackle was fitted which prevented the operator from coming into close proximity with the tank and having to lean over it.),

(4) Exchange of unserviceable tanks for new ones,

(5) Provision of vents at floor level in the enclosure to allow the heavy vapour to escape,

(6) Fitting of electric controllers for heating where necessary,
(7) Provision to unhook work from hoists after immersion, to allow tank covers to be used,

(8) Provision of a vertical air curtain between operator and his work, produced by a fan which blows air upwards near the front edge of the tank.

(9) Provision of a device coupling the thermostatic control of the steam supply providing heating of the liquid Tri and the cooling water of the condensing coils, so that a rise in one temperature will cause a fall of the other and vice versa.

Further methods are under consideration. Thus, it has been suggested that an unpleasant substance should be added to the Tri to discourage workers from voluntarily inhaling it or forgetting to move away from the tank. The difficulty, however, in this instance is that degreasers are not situated in separate rooms and complaints may be widespread in the vicinity, if not from the operators themselves, and such a method would be unpopular.

**Symptoms**

The most difficult facet of the problem is to obtain an objective idea of symptomatology attributable to the toxin. Questioning without controls may be quite misleading.

It is well known that workers quickly realise that an investigation is being carried out and promptly attribute all sorts of ailments to the work about which previously they had never thought. Thus, in Ahlmark and Forssman’s investigation, all workers interviewed had been sent up for investigation at an independent institute and were asked numerous leading questions. This may probably account for the fact that toxic effects were noted in about half the persons excreting 40 to 75 mg. per litre and in almost all those (80 per cent) excreting 100 mg. per litre or more. In my experience toxic effects were rarely complained of spontaneously with figures below 100 mg. per litre. In this respect I have no accurate data, since care had to be exercised so much higher than those reported in this paper. Therefore, it is always difficult to assess neurasthenic symptoms.

Most symptoms caused by Tri are vague, non-specific and often “neurotic” complaints. Direct questioning will often elicit these, but workers do not usually blame their work for them or, if they do, they put up with them. Nevertheless, they are very real and Ahlmark and Forssman state that (1948) most of those excreting over 70 mg. per litre have some symptoms or signs. “Since symptoms are non-specific, this quantitative analysis will be of great value for diagnosis and, in many cases, necessary.”

All their cases excreting over 300 mg. per litre had definite effects and in certain cases they required sick leave. In our series, most of those who reported with definite symptoms had 150-300 or more mg. per litre, yet there were cases of very high figures without spontaneous complaints.

Consideration must therefore be given to the question of what factors cause the difference between the Swedish results and our own.

(1) That the British worker is more long suffering than his Swedish colleague is very doubtful.

(2) There was no difference in method of TCA estimation. The test is a simplification of the Swedish test and has been checked independently by an analyst who confirmed our results.

(3) Our workers were not specifically asked about their symptoms, but they may have had symptoms and definite signs without attributing them to Tri. This is unlikely, where over 100 men are concerned.

(4) The main difference between the two series was that the Swedish investigators examined and interrogated workers thoroughly and with specific questions, assessed whether they suffered from any effects and only then asked about Tri exposure. Thus, they would get many positives, of which even the workers would be unaware, and this is probably the main reason why their figures are so much higher than those reported in this investigation.
A control questionnaire among workers not in contact with Tri might bring out quite a high percentage of similar complaints. It is, therefore, surprising that Grandjean et al. (1955) in their thorough study did not include a control group.

Frant and Westendorp (1950) emphasize that "correlation between complaints and the level of TCX in the urine was small". Therefore, the tests are a better guide than complaints to sanitary conditions" in the plant.

Conclusions

The following tentative conclusions can be drawn from the first 240 tests done on 101 workers.

A simple Fujiwara test on urine has been described and this is a very useful and fool-proof simple screening test for rapid estimation of Tri exposure.

Tests for 'Tri' in air may have no advantage in the field, since concentrations change greatly and Tri absorption depends on many factors apart from the air concentration at a particular moment of the working day and an arbitrary point in the workshop (Witheridge 1940).

Individual susceptibility to 'Tri' appears to vary greatly and considerable absorption can occur without ill effect.

The suggested safety limits of 6 to 30 mg. per litre TCA probably err on the safe side, at least under conditions of exposure in this factory and the suggested limit of 100 mg./l coincides with that of 96 mg./l recently proposed by Grandjean et al. (1955).

The differences in individual susceptibility to symptoms from "Tri" exposure may, theoretically, be caused by three factors:

i The amount of Tri absorbed into the blood after inhalation and therefore converted proportionately and excreted in the urine as TCA may not entirely depend only on the concentration to which the worker is exposed. There is a possibility that some difference exists in individual absorption in the same atmospheric concentration. This problem is to be further studied by using a simple new test, which measures the atmospheric concentration of Tri.

ii It seems unlikely (Ahlmark 1951) that the amount metabolised varies very much from one person to another and the urinary TCA is considered to be directly proportional to the amount of Tri inhaled. Lack of correlation may be due as much to the inadequacy of air analyses as of the urine estimations.

iii There is no reason, however, for assuming that persons with similar amounts of the substance circulating in their blood and acting on their nerve cells or livers will react quantitatively alike. Some people can tolerate larger quantities of alcohol or chloroform than others and this must obviously be true of other toxins. However, an arbitrary criterion of intoxication must be chosen for the "average" person if any progress is ever to be achieved in toxicology.

The next stage in our investigation will, therefore, have to be concerned with the amount of Tri absorbed from the air and the correlation with urine TCA values. In their thorough study, Frant and Westendorp (1950) conclude that "the urinary concentration of TCA is nearly directly proportional to the atmospheric concentration of Tri." To confirm this, it will be necessary to compare air concentrations with indices of absorption and this is the next stage in this investigation.

A simple colour test is being tried at present which may be sufficiently accurate for industrial purposes.

Another useful enquiry will be a comparison of symptoms between Tri workers and a comparable control group, to assess what percentage of "neurasthenic" symptoms is shared by the average workers in the engineering industry.

The present test should be useful for a rapid estimate of Tri hazard in industry. With proper supervision, method control and periodic urine checks it should be possible to eliminate cases of poisoning. Tri is not poisonous in small doses but workers should not be allowed to suffer lowered health or fall asleep on their way home or soon after returning home, night after night, as many of them do.

As long ago as 1931, Stuber in her very thorough study concluded that "on the basis of the present experiences the use of open apparatus for washing with Tri is condemned." This is already being enforced in some countries like Switzerland and will go a long way to eliminate this hazard if combined with strict supervision of the periodic cleaning of tanks.

Everyone should respect the warning of the industrial hygienists (Nash 1953): "We believe that much occupational disease is never diagnosed or notified and that discomfort due to working conditions, as distinct from actual illness, is common." For Tri is a very typical case in point of this.

I hope that I have shown on a small scale that "it is possible to do a lot of investigation in factories without a special team" (Nash 1953) and in the midst of the daily routine work in a medical department not specially equipped for toxicological studies.

Summary

(1) A simple urine test for Trichlorethylene absorption in industry is described.

(2) Its application in pinpointing and controlling unsatisfactory working conditions and degreasing methods was investigated.

(3) It is concluded that with adequate control of methods, particularly of the periodic tank cleaning process, and substitution of safer tanks, preferably of the closed variety, a good deal of vague ill-health among workers could be prevented.

(4) A controlled series is required to investigate...
further the true incidence of symptoms caused by trichloroethylene.

Acknowledgement

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REVIEW

Health in Industry


LIKE ALL OTHER large undertakings, London Transport has had its share of major problems in industrial medicine; and it has been similarly unfortified by accurate data on the frequency and causes of sickness absence against claims of excessive morbidity, e.g., from gastric disorders among the drivers. That fault has now been rectified by the development of the most complete system of sickness absence recording and analysis now in routine use in this country. The methods and mechanics of collection and machine tabulation have already been described in detail (1951). The present volume presents, in concise tables and clear graphs, the morbidity experience of men and women in all the major occupational groups such as drivers, mechanics and clerical and technical staff. For each group the age-specific attack or inception rates and average duration rates are given for the major specific causes of sickness absence. Enough about the standards of pre-employment examination, medical supervision, hours, duties and sickness benefit is given to allow anyone to interpret the data with reasonable insight. Although as doctor and actuary in the service of the London Transport Executive they are in the best position to make worthwhile comment, the authors do not discuss the results. Any disappointment this may cause is dissipated by a realisation of the unique value of the material as a work of reference on disabling disease in industry and perhaps even more as a source of clues of wider epidemiological interest. It will also serve as a standard of absenteeism against which any industrial medical officer, who knows the age-structure of his form's population, can measure his own experience.

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Reference