IV. ENVIRONMENTAL DATA AND BIOLOGIC EVALUATION

Air Sampling and Analytical Methods

Methods of collection of trichloroethylene in air have included use of evacuated gas sampling flasks, [94] plastic bags, absorptive liquids such as pyridine or toluene [95-97] and silica gel or activated carbon adsorbents. [98-103] Field methods for the estimation of trichloroethylene vapor concentrations have included the use of the Davis Halide Meter and direct reading colorimetric indicator tubes. [104,105]

The analytical methods for determining trichloroethylene fall into three classes: physical methods such as interferometry or gas chromatography; chemical methods which depend on the reaction of trichloroethylene with a chemical reagent; and destructive methods such as the combustion techniques which decompose trichloroethylene and liberate hydrochloric acid. [95]

Adsorption on activated charcoal offers the greatest efficiency and ease of collection. [98,101-103] of absorbing liquids is inconvenient for obtaining breathing-zone samples, especially when two or more scrubbers must be connected in series to assure high collection efficiency. [95,96] The use of plastic bags or evacuated containers for collecting air samples may result in a loss of sample due to adsorption on the walls or to permeation through the plastic or around the joints in addition to being inconvenient for transport to the laboratory for analysis. Excessive water vapor tends to displace the chlorinated hydrocarbons from silica gel when it is used as an adsorbent in a humid atmosphere. [106]

Gas chromatography offers the greatest specificity and sensitivity of the various methods of analysis, and is the method of choice. [101,102,106,107] The other methods including the field methods are subject to interferences from a wide variety of compounds, particularly other chlorinated solvents or other chloride-containing compounds and are useful only if trichloroethylene is the sole contaminant. [97,104] There are direct reading instruments which are not recommended for compliance purposes, but may be useful for emergencies, engineering control studies, and for estimation purposes. The Scott-Davis Halide Meter, and equivalents, have been used to determine trichloroethylene vapors in air. It is a nonspecific method and must be calibrated prior to each use. Detector tubes manufactured by several companies have been used to estimate trichloroethylene atmospheric concentrations. Care should be taken in using these tubes and each batch must be calibrated just prior to use. These are nonspecific as there are numerous interfering chemical contaminants and they are also affected by variations in temperature and humidity. Portable gas chromatographs are highly specific for trichloroethylene; however, they are very costly and can be used only by a well-trained investigator.

Environmental Data

Since 90% of the trichloroethylene produced in the United States is used in vapor degreasing operations, the majority of the limited available environmental data were obtained from such operations. There are no published reports of environmental levels experienced in manufacture of trichloroethylene. The purpose of this section is to investigate the feasibility of controlling exposures to trichloroethylene to within the recommended standard. The sparse number of surveys and differing methods of analysis limit the discussion to chronological presentation of control methods and their effectiveness. Later in this section are suggestions for improving controls. Specific suggestions are avoided because of the variability of processes, equipment, climate.

In 1943 Morse and Goldberg [108] reported results of a study of chlorinated solvent exposures in different degreasing plants. Three types of controls were encountered: Type I, degreaser tanks equipped with both local exhaust ventilation and condenser coils to condense the vapor; Type II, tanks with condensers but no local exhaust ventilation; and Type III, tanks with no local exhaust ventilation and no condenser. The effectiveness of engineering controls is demonstrated in the following results. The general average for total atmospheric chlorinated solvents was 96 ppm (range 5-393) for Type I, 135 ppm (range 3-900) for Type II, and 221 ppm (range 24-880) for Type III. It was emphasized that perchloroethylene was used with trichloroethylene and sampling was done for total chlorinated solvents, not trichloroethylene exclusively.

Grandjean et al [27] measured trichloroethylene concentrations in workshops using degreasing tanks. All of the tanks studied were equipped with refrigerated coils and exhaust systems. Atmospheric concentrations near the tanks varied from 20 to 40 ppm. Grandjean reported the operation of cold trichloroethylene vats wholly lacking in safety devices or any ventilation system on two occasions. Concentration of trichloroethylene in the air varied from 67 to 157, averaging 105 ppm.

As part of this study the effectiveness of different types of engineering control was evaluated. Air analyses were made using various methods of ventilation while normal work was performed. The workshop tank under consideration was fitted with a mixed system of mechanical ventilation including both air suction and air blowing. On the upper edge of the trichloroethylene tank there was a fixed lateral exhaust system which was intended to remove the rising trichloroethylene vapor. With no ventilation the average concentration of trichloroethylene in the air was 167 ppm. With the lateral exhaust system at the end of the tank operating, the average concentration was reduced to 112 ppm. The average concentration was lowered further to 53 ppm when general ventilation was used in conjunction with local exhaust. Atmospheric values of trichloroethylene showed a great variation with the degree of ventilation and utilization of the ventilation equipment. Atmospheric trichloroethylene samples were taken with impingers, and measured colorimetrically using the Fujiwara reaction. [27]

Grandjean also studied atmospheric concentrations during the cleaning of tanks and reported the following: "Trichloroethylene equipment is cleaned once or twice a week. We examined the concentration of trichloroethylene near the tank during one cleaning operation. In the case in question, the workman emptied the tank, rinsed it with water from a powerful hose pipe, then got inside the tank and spent half an hour cleaning with a scrubbing brush. Analyses of the air showed a concentration of 1,120 ppm outside the tank while the hose pipe was in action, with 815 and 395 ppm inside the apparatus during and after the scrubbing respectively."

Skinner [109] reported the use of baffles on windows near degreasers in the plant to control high velocity drafts. Trichloroethylene concentrations of 170 to 230 ppm were reduced to 30 to 40 ppm with this approach to control.

Hargarten et al [110] reported results of tests carried out from 1952 to 1957 around 43 degreaser operations. Ninety-three percent of the operators' breathing zone samples taken during the cleaning cycle of the degreasers were 100 ppm or less. Methods of sampling and analysis were not stated.

In a 1963 report Ahlmark et al [111] found that during the preceding decade, when 570 degreasing plants were inspected in Sweden, the average trichloroethylene concentration exceeded 30 ppm in only 3% of the cases. A more intensive study was then performed on 18 degreasing tanks at 14 works. The breathing zone samples taken with a Davis Halide Meter and with LKB Halogen Detector Tubes are presented in Table X-3 along with relative exposure times for different operations. The mean exposure to trichloroethylene was 50 ppm (range

0-400) for degreasing operations while the highest mean value was 225 ppm (range 10-375) in the cleansing operation.

There are no published environmental data on trichloroethylene concentrations in other industries beyond the descriptions of health hazards associated with the use of this solvent in those industries. Thus, the effectiveness of engineering controls can be demonstrated only for degreasing operations.

Engineering Controls

Industrial or commercial operations that use trichloroethylene have one or more methods available to control the emission of solvent vapors into the general work environment. The strategy of controlling hazardous industrial levels of trichloroethylene includes the following:

1. Substitution of less harmful solvents
2. Proper equipment design
3. Process location
4. Process ventilation
5. Proper operating, maintenance, and waste disposal procedures

1. Substitution

In solvent using industries it is common practice to substitute a solvent with a less toxic one. Full consideration must be given to other solvent properties such as effectiveness, relative volatility, volume of air required to dilute the vapor in the work environment to a safe level, relative amounts of each solvent required for the task, likelihood of control of the vapor concentrations, and flammability.

2. Equipment design

Hazardous environmental conditions result from solvent escape, resulting from solvent evaporation, carry-out and spills, both those accidental and those incidental to operations, especially in degreasers. It is imperative that the evaporation and condensation of solvents be carefully controlled by balanced heat inputs. Careful and proper design of process operations is still the simplest and most economical method for controlling dangerous vapor emissions.

3. Process location

Process location is one of the most often overlooked and yet most effective methods of minimizing dangerous trichloroethylene vapor levels in the work environment. For example, degreasing operations should be installed in large rooms with good general ventilation wherein the entire work area is constantly flushed with sufficient uncontaminated air to dilute the toxic vapor and thus, in conjunction with local exhaust ventilation render the workroom atmosphere harmless. Areas in the vicinity of doors, windows, or other possible sources of draft conditions should be avoided since excessive air movements in the vicinity of trichloroethylene operations could decrease the effectiveness of local exhaust systems and thus enhance the possibility of vapor escape. Location of trichloroethylene operations in the vicinity of high temperature from high energy sources should be avoided to reduce the possibility of decomposition of trichloroethylene into chlorine, hydrogen chloride, or the very toxic gas, phosgene.

4. Process ventilation

Ventilation is by far the most common engineering method for controlling solvent vapors. Vapor recovery sytems are sometimes used when a high airflow exhaust system is required for good ventilation.

5. Proper operating, maintenance, and waste disposal procedures

Trichloroethylene losses from industrial operations can be minimized by proper operating procedures and careful supervision. Factors such as the rate of work entering and leaving the vapor zone and the shape of the parts can be critical to the degree of vapor emissions from degreaser operations as indicated in a report by Grandjean et al. [27]

Biologic Evaluation

Biologic monitoring is not part of the recommended standard although such monitoring is used in much of the research dealing with trichloroethylene exposure. Methods used in establishing a diagnosis of exposure to trichloroethylene are based upon the direct analysis of this chlorinated hydrocarbon in the blood or in the breath [17,29,30] or the determination of its metabolites, monochloroacetic acid, trichloroacetic acid or trichloroethanol, in the blood or urine. [18,23,30,112,113] The determination of trichloroethylene in blood samples is generally not considered to provide a reliable index of exposure because of its rapid conversion to several metabolites. [17,29] The concentrations of individual metabolites found in blood or urine provide very little correlation with levels of exposure among individual human subjects. [18,30,112]

The measurement of trichloroethylene in the expired air of subjects exposed to different, nonfluctuating vapor concentrations of this solvent in the postexposure period offers promise as a good index of exposure levels. The concentration of trichloroethylene in the breath in the immediate postexposure period represents washout from the lungs and indicates the concentration of the vapor to which the subject was exposed most recently. A breath sample collected approximately three hours after the exposure is considered to provide a concentration of the solvent which is directly related to the time-weighted average vapor exposure. [30] Thus, breath analysis is particularly valuable in the prompt examination of a case of suspected overexposure but it may also prove useful in estimating a time-weighted average exposure when serial analyses of the breath are made on an individual. Since the concentration of trichloroethylene in the breath is influenced further by the duration of the exposure period, concentration-time relationships must be worked out.

V. DEVELOPMENT OF STANDARD

Basis for Previous Standards

In 1943 the United States Public Health Service [114] published its Manual of Industrial Hygiene and Medical Service in War Industries which listed "maximum allowable concentrations" for several contaminants of the workroom atmosphere. These values were based on cumulative knowledge and collective experience developed in the field of industrial hygiene. Trichloroethylene was given a limit of 200 ppm with the indication that this value was the maximum allowable concentration most widely accepted at that time based on an 8-hour daily exposure.

The list of acceptable concentrations from the same manual was critically reviewed, unified, and extended by Cook [115] in 1945. This list was supplemented by lists of acceptable concentrations supplied by other sources including the California Industrial Accident Commission, the American Standards Association, and the states of Connecticut, Massachusetts, New York, Oregon, and Utah. Each of these sources listed a value of 200 ppm as the maximum acceptable concentration for trichloroethylene. Cook, who also recommended the 200 ppm maximum allowable concentration, cited the works of Seifter [68] and Morse and Goldberg [108] as the bases for his standard.

The Z-37 Committee of the American Standards Association, now the American National Standards Institute, published its standard for trichloroethylene in 1946. The Committee recommended a maximum allowable concentration of trichloroethylene of 200 ppm for an 8-hour workday. In 1967 this standard was revised by the Z-37 Committee. [116] The revision established 100 ppm as an acceptable time-weighted average concentration for an 8-hour workday. In addition, an acceptable ceiling concentration of 200 ppm, provided that the time-weighted average is kept at or below 100 ppm, was recommended. Furthermore, a concentration of 300 ppm for a duration of not more than 5 minutes was judged acceptable if encountered not more than once in 2 hours during an 8-hour workday. These standards are based on the reports of von Oettingen, [9] Adams et al, [72] Stewart et al, [29] and Kleinfeld and Tabershaw. [36]

The American Conference of Governmental Industrial Hygienists (ACGIH) [117] Threshold Limit Value (TLV) for trichloroethylene was 200 ppm from 1947 to 1961. In 1961 it was lowered to 100 ppm based on the report of Adams et al [72] that there is an extremely small probability of adverse effects on human subjects if the vapor concentrations of trichloroethylene are kept below 100 ppm.

The Hygienic Guides Committee of the American Industrial Hygiene Association [6] has recommended a concentration of 100 ppm of trichloroethylene for a time-weighted average concentration for a normal workday, based on human experience and animal studies, which further indicates that fluctuations of the concentrations should be kept below 200 ppm.

The Occupational Safety and Health Administration, Department of Labor, has adopted a standard for trichloroethylene of 100 ppm for an 8-hour time-weighted average, 200 ppm for an acceptable ceiling concentration, and 300 ppm for an acceptable maximum peak above the acceptable ceiling provided that it occurs no more often than 5 minutes in any 2 hours. These were developed from and based on the current American National Standards Institute Z-37 limits. [116]

Some European investigators have recommended occupational health standards for trichloroethylene of less than 75 ppm. However, in most cases these recommendations were based on gross estimations of environmental conditions based on extrapolations from the results of biological sampling (analysis of blood or urine for metabolites of trichloroethylene). Where air sampling was conducted the investigators stated that concentrations varied greatly during a normal workday. A summary of the environmental standards, ranging from 2 to 200 ppm, promulgated by foreign countries is presented in Table X-4. [118]

Basis for Recommended Environmental Standard

The number of studies in which comprehensive environmental surveys have been supplemented with a well planned surveillance program for adequate numbers of workers exposed to trichloroethylene are so few that it is difficult to establish an environmental standard based upon unequivocal scientific data. Much of the information correlating exposure and effects have been obtained through experimental studies with human volunteers. [22,29,30,91-93] Such studies are necessarily limited in the total duration of exposure and thus valuable primarily for evaluation of short-term effects, that is exposure to tolerable concentrations of a substance for relatively short periods of time, up to 5 days.

It is apparent from the literature that exposures to concentrations between 200 and 500 ppm for periods of time less than the normal workday will result in symptoms of "prenarcosis" as well as mild irritation of the upper respiratory tract. This is corroborated by the previously mentioned reports of Stewart et al [29,30] and Stopps and McLaughlin. [92]

The studies with trichloroethylene most relevant directly to the development of an occupational standard are those in which human volunteers were exposed to carefully controlled atmospheric concentrations of the contaminant. The most important observations are the following:

(a) Adverse subjective responses have been reported [29,30] by test subjects exposed to concentrations exceeding 150 ppm. These include mild eye irritation by three of seven subjects exposed to 160 ppm for up to 83 minutes [29] and by one of five subjects exposed to 200 ppm for 7 hours, [30] and feeling of fatigue and sleepiness by all five or by three of five exposed to 200 ppm for 7 hours on the fourth and fifth consecutive days of exposure. [30]

(b) Exposure to 100 ppm for periods of 2-to 3-hours duration did not result in any decrease in psychophysiological performance. [91,92]

(c) Concentrations of approximately 100 ppm trichloroethylene interfered with psychophysiological performance after exposures of 8-hours duration; this was demonstrated by Salvini et al. [93]

(d) Quantitative evaluations of objective and subjective responses of human subjects exposed under controlled conditions to concentrations of less than 100 ppm trichloroethylene have not been reported.

In summary, deaths of several workers from exposure to trichloroethylene have been reported [36,90]; in the best documented case, exposure was at levels estimated to be between 1700 and 3300 ppm for ten minutes. Exposures at 1000 ppm for even short periods of time have resulted in effects on the central nervous system. Subjective complaints by one of 8 male volunteers was reported [91] at exposure levels of 300 ppm for two hours. No adverse effects were noted by psychophysiological testing of the same subjects at 100 ppm. In another paper, [92] results of psychophysiological testing of one subject for 2-1/2 hours indicated no significant effect on psychomotor performance from exposure at 100 ppm, but a slight effect was noted at 200 ppm. Adverse effects were reported by 3 of 7 subjects exposed at 160 ppm for less than 83 minutes. These effects, subjective in nature, included headache, drowsiness and mild eye irritation. [29]

Salvini et al [93] reported a statistically significant decrement in performance without clinical signs or symptoms at 90 to 130 ppm (average exposure level of 110 ppm). He concluded that 100 ppm was very close to the average concentration that would interfere with psychophysiological efficiency. This study included two groups of 6 males each, one of university students and the second of trichloroethylene workers. The same conclusions were drawn from the results of each study group from which it is inferred that the threshold for psychophysiological effects is not affected by prolonged exposure. There is also evidence that prolonged exposure to trichloroethylene may result in dependency. It is significant that reports of liver damage from trichloroethylene are uncommon. Perhaps the suggestion [21] that liver damage is not caused by trichloroethylene except when it is contaminated by other compounds, especially tetrachloroethane, is the correct explanation.

As discussed above, the study by Salvini et al [93] indicates that exposures of approximately 100 ppm may interfere with the psychophysiological efficiency of the worker. Therefore, a TWA limit of 100 ppm will protect most of the workers but with probably very little margin of safety at this level of exposure.

VI. REFERENCES

1. Kirk RE, Othmer DF (eds.): Encyclopedia of Chemical Technology, ed 2. New York, Interscience Publishers, 1969, vol 5, pp 183-94

2. Plessner W: [On trigeminal disease due to trichloroethylene intoxication.] Neurol Zentr 34:916-18, 1915 (Ger)

3. Stecher PG (ed.): The Merck Index, ed 8. Rahway, N J, Merck & Co, 1968, p 1069

4. Trichloroethylene, data sheet 389 (revised). Chicago, National Safety Council, 1964

5. Blackford JL: Trichloroethylene, in Chemical Economics Handbook, Inorganic Chemicals P-Z 697. Menlo Park, Cal, Stanford Research Institute, 1972

6. Trichloroethylene (revised 1963) CCl2:CHCl, Hygienic Guide Series. Am Ind Hyg Assoc J 25:94-97. 1964

7. Weast RC (ed.): Handbook of Chemistry and Physics--A Ready Reference Book of Chemical and Physical Data, ed 49. Cleveland, Chemical Rubber Co, 1968, p C-314

8. Stern AC (ed.): Analysis, Monitoring, and Surveying in Air Pollution, ed 2. New York, Academic Press, 1968, vol II, p 325

9. Trichloroethylene, in von Oettingen WF: The Halogenated Hydrocarbons of Industrial and Toxicological Importance. Amsterdam, Elsevier Publishing Co, 1964, pp 240-71

10. Rinzema LC, Silverstein LG: Hazards from chlorinated hydrocarbon decomposition during welding. Am Ind Hyg Assoc J 33:35-40, 1972

11. Irish DD: Aliphatic halogenated hydrocarbons, in Patty FA (ed.): Industrial Hygiene and Toxicology, ed 2 revised. New York, Interscience Publishers, 1962, vol II, p 1309-13

12. Striker C, Goldblatt S, Warm IS, Jackson DE: Clinical experiences with the use of trichlorethylene in the production of over 300 analgesias and anesthesias. Anesth Analg 14:68-71, 1935

13. Glaser MA: Treatment of trigeminal neuralgia with trichlorethylene. JAMA 96:916, 1931

14. Butler TC: Metabolic transformations of trichloroethylene. J Pharmacol Exp Ther 97:84-92, 1949

15. Barrett HM, Johnston JH: The fate of trichloroethylene in the organism. J Biol Chem 127:765-70, 1939

16. Barrett HM, Cunningham JG, Johnston JH: A study of the fate in the organism of some chlorinated hydrocarbons. J Ind Hyg Toxicol 21:479-90, 1939

17. Powell JF: Trichlorethylene: Absorption, elimination and metabolism. Brit J Ind Med 2:142-45, 1945

18. Soucek B, Vlachova D: Excretion of trichloroethylene metabolites in human urine. Br J Ind Med 17:60-64, 1960

19. Ahlmark A, Forssman S: Evaluating trichloroethylene exposures by urinalyses for trichloroacetic acid. Arch Ind Hyg Occup Med 3:386-98, 1951

20. Bartonicek V: Metabolism and excretion of trichloroethylene after inhalation by human subjects. Br J Ind Med 19:134-41, 1962

21. Bardodej Z, Vyskocil J: The problem of trichloroethylene in occupational medicine. Arch Ind Health 13:581-92, 1956

22. Kylin B, Axell K, Samuel HE, Lindborg A: Effect of inhaled trichloroethylene on the CNS as measured by optokinetic nystagmus. Arch Environ Health 15:48-52, 1967

23. Frant R, Westendorp J: Medical control on exposure of industrial workers to trichloroethylene. Arch Ind Hyg Occup Med 1:308-18, 1950

24. Friberg L, Kylin B, Nystrom A: Toxicities of trichlorethylene and tetrachlorethylene and Fujiwara's pyridine-alkali reaction. Acta Pharmacol Toxicol 9:303-12, 1952

25. Ogata M, Takatsuka Y, Tomokuni K: Excretion of organic chlorine compounds in the urine of persons exposed to vapours of trichloroethylene and tetrachloroethylene. Br J Ind Med 28:386-91, 1971

26. Andersson A: [Health dangers in industry from exposure to trichloroethylene.] Acta Med Scand (Suppl 323) 157:7-220, 1957 (Ger)

27. Grandjean E, Munchinger R, Turrian V, Haas PA, Knoepfel HK, Rosenmund H: Investigations into the effects of exposure to

trichlorethylene in mechanical engineering. Br J Ind Med 12:131-42, 1955

28. Ikeda M, Ohtsuji H, Imamura T, Komoike Y: Urinary excretion of total trichloro-compounds, trichloroethanol, and trichloroacetic acid as a measure of exposure to trichloroethylene and tetrachloroethylene. Br J Ind Med 29:328-33, 1972

29. Stewart RD, Gay HH, Erley DS, Hake CL, Peterson JE: Observations on the concentration of the trichloroethylene in blood and expired air following exposure of humans. Am Ind Hyg Assoc J 23:167-70, 1962

30. Stewart RD, Dodd HC, Gay HH, Erley DS: Experimental human exposure to trichloroethylene. Arch Environ Health 20:64-71, 1970

31. Kimmerle G, Eben A: Metabolism, excretion and toxicology of trichloroethylene after inhalation--2. Experimental human exposure. Arch Toxikol 30:127-38, 1973

32. Stuber K: [Injuries to health in the industrial use of trichloroethylene and the possibility of their prevention.] Arch Gewerbepathol Gewerbehyg 2:398-456, 1932 (Ger)

33. Persson H: [On trichloroethylene intoxication.] Acta Med Scand 59:410-22, 1934 (Ger)

34. Krantz JC Jr, Carr CJ, Musser R, Harne WG: A contribution to the pharmacology of trichlorethylene. J Pharmacol 54:327-33, 1935

35. Boulton TB, Sweet RB: The place of trichlorethylene in modern anesthesia. J Michigan State Med Soc 59:270-73, 1960

36. Kleinfeld M, Tabershaw IR: Trichloroethylene toxicity--Report of five fatal cases. Arch Ind Hyg Occup Med 10:134-41, 1954

37. James WRL: Fatal addiction to trichloroethylene. Br J Ind Med 20:47-49, 1963

38. Tomasini M, Sartorelli E: [Chronic intoxication from commercial trielin inhalation with compromise of the eighth cranial nerves.] Med Lav 62:277-80, 1971 (It)

39. St Hill CA: Occupation as a cause of sudden death. Trans Soc Occup Med 16:6-9, 1966

40. Maloof CC: Burns of the skin produced by trichloroethylene vapors at room temperature. J Ind Hyg Toxicol 31:295-96, 1949

41. Mitchell ABS, Parsons-Smith BG: Trichloroethylene neuropathy. Br Med J 1:422-23, 1969

42. McNally WD: A case of phosgene poisoning due to the inhalation of decomposition products of trichlorethylene. Ind Med 6:541, 1937

43. Quadland HP: Petroleum solvents and trichlorethylene--Part 3 of the literature study of reports of occupational diseases attributed to volatile solvents. Ind Med 13:45-50, 1944

44. Kunz E, Isenschmid R: [The toxic effect of trichloroethylene on the eye.] Klin Monatsbl Augenheilkd 94:577-85, 1935 (Ger)

45. McBirney RS: Trichloroethylene and dichloroethylene poisoning. Arch Ind Hyg Occup Med 10:130-33, 1954

46. Fra L, Gandiglio G, Riccio A, Sandigliano G: [Clinical observation and neurophysiological study of a case of chronic trichloroethylene intoxication.] Med Lav 57:606-13, 1966 (It)

47. Todd J: Trichlorethylene poisoning with paranoid psychosis and lilliputian hallucination. Br Med J 7:439-40, 1954

48. Bell A: Death from trichlorethylene in a dry-cleaning establishment. N Z Med J 50:119-26, 1951

49. Bernstine ML: Cardiac arrest occurring under trichloroethylene analgesia--Report of a case with recovery. Arch Surg 68:262-66, 1954

50. Lilis R, Stanescu D, Muica N, Roventa A: Chronic effects of trichloroethylene exposure. Med Lav 60:595-601, 1969

51. Secchi GC, Chiappino G, Lotto A, Zurlo N: [Actual chemical composition of the "commercial trichloroethylenes" and their liver toxicity. Clinical and enzymological studies.] Med Lav 59:486-97, 1968 (Ital)

52. Cotter LH: Trichloroethylene poisoning. Arch Ind Hyg Occup Med 1:319-22, 1950

53. Lachnit V, Brichta G: [Trichloroethylene and liver damage.] Zentralbl Arbeitsmed 8:56-62, 1958 (Ger)

54. Albahary C, Guyotjeannin C, Flaisler A, Thiaucourt P: [Transaminases and occupational exposure to trichloroethylene.] Arch Mal Prof 20:421-46, 1959 (Fr)

55. Guyotjeannin C, Van Steenkiste J: [Action of trichloroethylene on proteins and serum lipids--Study of 18 employees working in a contaminated atmosphere.] Arch Mal Prof 19:489-94, 1958 (Fr)

56. Tolot F, Viallier J, Roullett A, Rivoire J, Figueres JC: [Hepatic toxicity of trichloroethylene.] Arch Mal Prof 25:9-15, 1964 (Fr)

57. Milby TH: Chronic trichloroethylene intoxication. J Occup Med 10:252-54, 1968

58. Armstrong DM: The assessment of liver damage following trichlorethylene and di-ethyl ether anaesthesia. Anaesthesia 2:45-50, 1947

59. Joron GE, Cameron DG, Halpenny GW: Massive necrosis of the liver due to trichlorethylene. Can Med Assoc J 73:890-91, 1955

60. Gutch CF, Tomhave WG, Stevens SC: Acute renal failure due to inhalation of trichlorethylene. Ann Int Med 63:128-34, 1965

61. Friborska A: The phosphatases of peripheral white blood cells in workers exposed to trichloroethylene and perchloroethylene. Br J Ind Med 26:159-61, 1969

62. Bartonicek V, Teisinger J: Effect of tetraethyl thiuram disulphide (disulfiram) on metabolism of trichloroethylene in man. Br J Ind Med 19:216-21, 1962

63. Seage AJ, Burns MW: Pulmonary oedema following exposure to trichlorethylene. Med J Aust 2:484-86, 1971

64. Reinl W: [Scleroderma under the influence of trichloroethylene?] Zentralbl Arbeitsmed 7:58-60, 1957 (Ger)

65. Stewart RD, Dodd HC: Absorption of carbon tetrachloride, trichloroethylene, tetrachloroethylene, methylene chloride, and 1,1,1-trichloroethane through the human skin. Am Ind Hyg Assoc J 25:439-46, 1964

66. Taylor H: Experiments on the physiological properties of trichlorethylene. J Ind Hyg Toxicol 18:175-93, 1936

67. Barrett HM, MacLean DL, Cunningham JG: A comparison of the toxicity of carbon tetrachloride and trichlorethylene. J Ind Hyg Toxicol 20:360-79, 1938

68. Seifter J: Liver injury in dogs exposed to trichloroethylene. J Ind Hyg Toxicol 26:250-52, 1944

69. Hunter AR: The toxicity of trichlorethylene. Br J Pharmacol 4:177-80, 1949

70. Kylin B, Sumegi I, Yllner S: Hepatotoxicity of inhaled trichloroethylene and tetrachloroethylene--Long-term exposure. Acta Pharmacol Toxicol 22:379-85, 1965

71. Nowill WK, Stephen CR, Margolis G: The chronic toxicity of trichloroethylene--A study. Anaesthesiology 15:462-65, 1954

72. Adams EM, Spencer HC, Rowe VK, McCollister DD, Irish DD: Vapor toxicity of trichloroethylene determined by experiments on laboratory animals. Arch Ind Hyg Occup Med 4: 469-81, 1951

73. Prendergast JA, Jones RA, Jenkins LJ Jr, Siegel J: Effects on experimental animals of long-term inhalation of trichloroethylene, carbon tetrachloride, 1,1,1-trichloroethane, dichlorodifluoromethane, and 1,1-dichloroethylene. Toxicol Appl Pharmacol 10:270-89, 1967

74. Desoille H, Pinchon RA, Lille F, Bourguignon A: [Sequelae of acute intoxication by solvents--Importance of electroencephalography.] Arch Mal Prof 23:5-17, 1962 (Fr)

75. Desoille H, Pinchon RA, Jans M, Bourguignon A: [Acute experimental trichloroethylene intoxication--Aggravating effects of associated chronic alcoholism.] Arch Mal Prof 23:653-64, 1962 (Fr)

76. Mazza V, Brancaccio A: [Characteristics of the formed elements of the blood and bone marrow in experimental trichloroethylene intoxication.] Folia Med 50:318-24, 1967 (It)

77. Baetjer AM, Annau Z, Abbey H: Water deprivation and trichloroethylene--Effects on hypothalamic self-stimulation Arch Environ Health 20:712-19, 1970

78. Grandjean E: Trichloroethylene effects on animal behavior--The effects of trichloroethylene vapors on a food motivated conditioned climbing reaction of rats. Arch Environ Health 1:106-08, 1960

79. Battig K, Grandjean E: Chronic effects of trichloroethylene on rat behavior--Effects on swimming performance, exploratory behavior, and maze and avoidance learning. Arch Environ Health 7:694-99, 1963

80. Grandjean E: The effects of short exposures to trichloroethylene on swimming performances and motor activity of rats. Am Ind Hyg Assoc J 24:376-79, 1963

81. Goldberg ME, Johnson HE, Pozzani UC, Smyth HF Jr: Effect of repeated inhalation of vapors of industrial solvents on animal behavior--I. Evaluation of nine solvent vapors on pole-climb performance in rats. Am Ind Hyg Assoc J 25: 369-75, 1964

82. Wirtschafter ZT, Cronyn MW: Relative hepatotoxicity-- Pentane, trichloroethylene, benzene, carbon tetrachloride. Arch Environ Health 9:180-85, 1964

83. Mikiskova H, Mikiska A: Trichloroethanol in trichloroethylene poisoning. Br J Ind Med 23:116-25, 1966

84. Bartonicek VJ, Brun A: Subacute and chronic trichloroethylene poisoning: A neuropathological study in rabbits. Acta Pharmacol Toxicol 23:359-69, 1970

85. Forssmann S, Holmquist CE: The relation between inhaled and exhaled trichlorethylene and trichloracetic acid excreted in the urine of rats exposed to trichlorethylene. Acta Pharmacol Toxicol 9:235-44, 1953

86. Forssmann S, Owe-Larsson A, Skog E: [Metabolism of trichloroethylene in the organism--Animal experiments.] Arch Gewerbepathol Gewerbehyg 13:619-23, 1955 (Ger)

87. Bartonicek V, Soucek B: [The metabolism of trichloroethylene in rabbits.] Arch Gewerbepathol Gewerbehyg 17: 283-93, 1959 (Ger)

88. Fabre R, Truhaut R: [Contribution to the study of trichloroethylene toxicology--II. Results of experimental studies in animals.] Br J Ind Med 9:39-43, 1952 (Fr)

89. Leibman KC, McAllister WJ Jr: Metabolism of trichloroethylene in liver microsomes--III. Induction of the enzymic activity and its effect on excretion of metabolites. J Pharmacol Exp Ther 157:574-80, 1967

90. Longley EO, Jones R: Acute trichloroethylene narcosis--Accident involving the use of trichloroethylene in a confined space. Arch Environ Health 7:249-52, 1963

91. Vernon RJ, Ferguson RK: Effects of trichloroethylene on visual-motor performance. Arch Environ Health 18:894-900, 1969

92. Stopps GJ, McLaughlin M: Psychophysiological testing of human subjects exposed to solvent vapors. Am Ind Hyg Assoc J 28:43-50, 1967

93. Salvini M, Binaschi S, Riva M: Evaluation of the psychophysiological functions in humans exposed to trichloroethylene. Br J Ind Med 28:293-95, 1971

94. Stack VT Jr, Forrest DE, Wahl KK: Determination of trichloroethylene in air. Am Ind Hyg Assoc J 22:184-86, 1961

95. Elkins HB, Hobby AK, Fuller JE: The determination of atmospheric contaminants--I. Organic halogen compounds. J Ind Hyg Toxicol 19:474-85, 1937

96. Lugg GA: Fujiwara reaction and determination of carbon tetrachloride, chloroform, tetrachloroethane, and trichloroethylene in air. Med J Aust 38:1532-36, 1966

97. Campbell EE, Milligan MF, Miller HM: Evaluation of methods for the determination of halogenated hydrocarbons in air. Am Ind Hyg Assoc J 20:138-41, 1959

98. Cook WA, Coleman AL: Determination of injurious constituents in industrial atmospheres--II. Determination of solvent vapors in air by means of activated charcoal. J Ind Hyg Toxicol 18:194-210, 1936

99. Fahy JP: Determination of chlorinated hydrocarbons in air. J Ind Hyg Toxicol 30:205-07, 1948

100. Peterson JE, Hoyle HR, Schneider EJ: The analysis of air for halogenated hydrocarbon contaminants by means of absorption on silica gel. Am Ind Hyg Assoc Q 17:429-33, 1956

101. Reid FH, Halpin WR: Determination of halogenated and aromatic hydrocarbons in air by charcoal tube and gas chromatography. Am Ind Hyg Assoc J 29:390-96, 1968

102. White LD, Taylor DG, Mauer PA, Kupel RE: A convenient optimized method for the analysis of selected solvent vapors in the industrial atmosphere. Am Ind Hyg Assoc J 31:225-32, 1970

103. Kupel RE, White LD: Report on a modified charcoal tube. Am Ind Hyg Assoc J 32:456, 1971

104. Schaffer AW, Hoyle HR: Nine years experience with the Davis Halide meter. Am Ind Hyg Assoc J 22:93-96, 1961

105. Saltzman B: Direct reading colorimetric indicators, in American Conference of Governmental Industrial Hygienists: Air Sampling Instruments for Evaluation of Atmospheric Contaminants, ed 4. Cincinnati, Ohio, 1972, pp S1-S10 & S28

106. Whitman NE, Johnston AE: Sampling and analysis of aromatic hydrocarbon vapors in air: A gas-liquid chromatographic method. Am Ind Hyg Assoc J 25:464-69, 1964

107. Urone P, Smith JE: Analysis of chlorinated hydrocarbons with the gas chromatograph. Am Ind Hyg Assoc J 22:36-41, 1961

108. Morse KM, Goldberg L: Chlorinated solvent exposures at degreasing operations. Ind Med 12:106-13, 1943

109. Skinner JB: Control of health hazards in the operation of metal degreasers. Am Ind Hyg Assoc Quart 13:11-16, 1952

110. Hargarten JJ, Hetrick GH, Fleming AJ: Industrial safety experience with trichlorethylene--Its use as a vapor degreasing solvent 1948-1957. Arch Environ Health 3:461-67, 1961

111. Ahlmark A, Gerhardsson G, Holm A: Trichloroethylene exposure in Swedish engineering workshops, in Proceedings of the XIVth International Congress on Occupational Health, Madrid, September 1963, pp 448-50

112. Abrahamsen AM: Quantitative estimation of trichloracetic acid in the urine and serum in trichlorethylene poisoning. Acta Pharmacol Toxicol 17:288-94, 1960

113. Tanaka S, Ikeda M: A method for determination of trichloroethanol and trichloroacetic acid in urine. Br J Ind Med 25:214-19, 1968

114. Gafafer WM (ed.): Manual of Industrial Hygiene and Medical Service in War Industries. Philadelphia, WB Saunders Co, 1943, p 264

115. Cook WA: Maximum allowable concentrations of industrial atmospheric contaminants. Ind Med 14:936-46, 1945

116. USA Standard Acceptable Concentrations of Trichloroethylene Z37.10-1967, Revision of Z37.19-1946. New York, American National Standard, ANSI, 1967, 8 pp

117. Trichloroethylene, in American Conference of Governmental Industrial Hygienists: Documentation of the Threshold Limit Values for Substances in Workroom Air, ed 3. Cincinnati, Ohio, ACGIH, 1971, pp 263-65

118. International Labour Office: Permissible Levels of Toxic Substances in the Working Environment. Sixth Session, Joint ILO/WHO Committee on Occupational Health, Geneva, 4-10 June 1968, pp 80-81,192,198,204,209,215,219,227,240,243,337,353