Human Exposure to 1,1,1-Trichloroethane Vapor: Relationship of Expired Air and Blood Concentrations to Exposure and Toxicity

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A study of controlled human exposures to 1,1,1-trichloroethane vapor has revealed a prolonged exponential "decay curve" when the concentration in the postexposure expired air is plotted against hours after exposure. This measurement was predictable enough to allow a reasonable estimation of the magnitude of exposure. Chemical, physiological, and clinical laboratory studies were carried out and correlated with the vapor exposures. The determination of urinary urobilinogen proved to be the most sensitive test of liver stress produced by markedly excessive exposures to 1,1,1-trichloroethane. Data from this study support 500 ppm as a satisfactory threshold limit for this compound.

Introduction

THE probability of human exposure to the vapors of 1,1,1-trichloroethane is increasing rapidly as this compound gains popularity as a solvent in cold degreasing applications.[1] Because of its low toxicity, its use as a solvent in several other applications, *e.g.*, agricultural chemicals, hair sprays, and dry cleaning, is also being investigated. Thus, the physician, the industrial hygienist, and the toxicologist will be called upon to evaluate acute and chronic exposures to 1,1,1-trichloroethane vapor in an increasingly large segment of the population.

A major obstacle which has prevented accurate evaluation of the significance of exposures to 1,1,1-trichloroethane vapor has been the lack of a practical method to identify and measure the concentration of the compound in the blood or expired air of the exposed individual. This has prevented a correlation of the blood or expired air concentration with the magnitude of exposure. A second obstacle has been the lack of a reliable means of determining the magnitude of an accidental exposure after it has occurred.

It is the purpose of this paper to report a series of acute human exposures to 1,1,1-trichloroethane vapor in which these obstacles were studied. Volunteers were exposed in a chamber in which the concentration of 1,1,1-trichloroethane vapor was controlled by simultaneous atmospheric analyses. Concentration of the chemical in the blood was determined by infrared spectrometric methods described previously,[2,3] while postexposure expired air concentration was determined directly through the use of an infrared spectrometer employing a long path-length gas cell. Blood and expired air concentrations were then correlated with the magnitude of the exposure and with the physiological effects of the 1,1,1-trichloroethane.

Experimental Procedure

A series of timed human exposures to known concentrations of 1,1,1-trichloroethane vapor was conducted. The first two exposures to be described, Experiments 1 and 2, were to atmospheric concentrations of 500 ppm. During the next exposure, which was to an atmospheric concentration approaching 1000 ppm, subjects were removed from the exposure chamber at three time-intervals. These groups will be discussed as Experiments 3, 4, and 5. The above concentrations were chosen because of the studies

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of Torkelson, *et al.*,[3] which indicated that the atmospheric concentration of 1,1,1-trichloroethane for daily exposures of 7 to 8 hours duration should not exceed 500 ppm, and that concentrations approaching 1000 ppm would have anesthetic effects. In a final exposure, Experiment 6, the atmospheric concentration was increased rapidly until anesthetic levels were reached. Table I outlines the time and degree of exposure for the experiments in this series.

Material Used

The 1,1,1-trichloroethane (CH_3CCl_3) used in this series of experiments was the inhibited product, commercially available Chlorothene[4] solvent. Chlorothene solvent has the following composition: 94 to 97% 1,1,1-trichloroethane, 2.4 to 3.0% dioxane, 0.12 to 0.3% butanol, and small amounts of ethylene dichloride, water and other materials. The acute toxicity and the vapor pressure of Chlorothene have been shown to be essentially identical with those of 1,1,1-trichloroethane.[3] The latter designation will generally be used throughout this paper since infrared analysis specifically identifies this chemical in the composition.

Exposure Chamber

An interior room, measuring 11′ × 12′ × 7′2″ high, served as the exposure chamber. The room had a continuous positive air supply. After the subjects were seated in the closed room, Chlorothene was poured into a flat, partially covered dish. A pedestal fan was used to blow air across the dish and circulate the vapors throughout the room. As seen in Table I, it was possible to keep the atmospheric concentration of the 1,1,1-trichloroethane within the room relatively constant by regulating the exposed surface area of the material in the dish.

Analysis of Exposure Atmosphere

The atmospheric concentration of 1,1,1-trichloroethane in Experiment 6 was determined by absorption of known volumes of air on silica gel.[5] In the exposure to atmospheric concentrations just over 900 ppm, three monitoring methods were simultaneously employed; two Dow-modified Davis Halide Meters,[6] a Perkin-Elmer Model 12C[7] infrared spectrometer equipped with a 10-meter path-length gas cell, and a Draeger Gas Detector Kit.[8] At the lowest level of exposure, 500 ppm, one Dow-modified Davis Halide meter was used to monitor the atmosphere in Experiment 2, while in Experiment 1 both the Halide Meter and the infrared spectrometer were used.

TABLE I

Human Exposure to 1,1,1-Trichloroethane Vapor

Experiment	No. of Subjects	Desired Concentration (ppm)	Time to Reach Desired Conc. (min)	Length of Total Exposure (min)	Concentration[a] During Total Exposure (ppm)	Range After Reaching Desired Concentration (ppm)[b]
1	6	500	13	78	500 (average of methods)	
					470 (Davis Halide)	305-575
					531 (Infrared)	301-655
2	6	500	8	186	496 (Davis Halide)	420-610
3	3	1000	5	73	955 (average of methods)	
					978 (Davis Halide #1)	855-1075
					961 (Davis Halide #2)	710-1090
					931 (Infrared)	750-1075
					950 (Draeger)	
4	2	1000	5	35	910 (average of methods)	Same as Exp. 3
5	3	1000	5	20	900 (average of methods)	Same as Exp. 3
6	7	anesthetic	15	15	1380 (silica gel)	0-2650[b]

[a] Time-weighted average concentrations

[b] Range from start to finish

With the exception of the Draegar Detector Kit which was used in the chamber, air from the chamber was sampled by the use of probes of saran tubing suspended to head height at the center of the room. These probes were passed under the door to the continuous monitoring devices outside. The Halide Meter and the infrared spectrometer were coupled to recorders which provided a continuous record of the concentration. These machines were calibrated against known concentrations of 1,1,1-trichloroethane. At the higher concentration of 1,1,1-trichloroethane, the blue glass filter of the Halide Meter required frequent cleaning, therefore two meters were used. As seen in Table I, Experiment 3, the data obtained from each of the three monitoring techniques showed remarkably close agreement. The time-weighted average from each method was therefore used, when more than one monitoring device was

used, to calculate an overall average for the respective experiment.

Subjects

Healthy male volunteers from The Dow Chemical Company, ranging in age from 30 to 60 years were selected for the exposure studies. Each subject had received a complete preemployment history and physical examination, chest x-ray and, in some cases, lumbar spine x-ray, complete blood count (C.B.C.), urinalysis, and orthorator eye examination. Each subject had then been followed by the Medical Department with periodic history and physical examinations, which included chest x-ray, C.B.C., urinalysis, orthorater check, and, in recent years, timed vital capacity and audiometric examination. Only one subject had an abnormal physical finding. The 60-year old male had a liver palpable 4 cm below the right costal margin, but there was no history of liver disease, and liver function tests were within the normal range.

Several of the same subjects participated in all of these exposures. No subject participated in any exposure who had had a known exposure to any chlorinated hydrocarbon within the previous six days.

Preexposure and Postexposure Data

Immediately before each exposure the following clinical data and laboratory samples were obtained from each subject: blood pressure, expirogram (timed vital capacity), serum for glutamic oxaloacetic transaminase (SGO-T) and urine for urinary urobilinogen. Preexposure blood, urine and expired air samples were analyzed for 1,1,1-trichloroethane for control purposes. A complete urinalysis was obtained both before and after several of the exposures. A 15-minute phenolsulfonphthalein (P.S.P.) determination was done before and after Experiment 2. Table II lists the pre- and postexposure data obtained.

During the exposures serial urine and blood samples were obtained for analysis of 1,1,1-trichloroethane. Subjective responses were noted. Romberg and heel-to-toe tests were performed at 15-minute intervals by those in Experiments 1, 3, 4 and 5.

Following the exposures, serial samples of blood, urine, and expired air were analyzed for 1,1,1-trichloroethane. Preexposure laboratory tests were repeated at appropriate intervals (see Table II). Expirograms and blood pressures were obtained within 5 to 10 minutes following the exposures in which these were studied.

Analysis of Blood, Urine, and Expired Air for 1,1,1-Trichloroethane

Venous blood was obtained through an indwelling siliconized 20-gauge needle equipped with a siliconized stylet. Two ml of blood were added to a 4-ml aluminum-capped, glass vial containing 2 ml of carbon bisulfide and one drop of 0.83% heparin solution. The sample was gently agitated by end-over-end inversion for 5 minutes. The solvent was withdrawn and analyzed for 1,1,1-trichloroethane in a double beam infrared spectrometer.[7, 8] This method for determining organic compounds in biological fluids has been described previously in detail.[7, 8] Voided urine samples were analyzed in a similar manner. The minimal amount of the compound detectable in blood and urine by this solvent extraction technique was 1 ppm with an accuracy of ±1 ppm.

Expired air samples were collected in six-liter volume saran bags. The bagged air was allowed to flow into the evacuated ten-meter path-length gas cell, and was scanned on the appropriate spectrometer. The absorbance at 9.2μ was measured to determine the concentration of 1,1,1-trichloroethane. The minimal amount of the compound detectable in expired air was 0.5 ppm with an accuracy of ±0.1 ppm.

Results

Experiment 1, 500 ppm, 78 minutes

Six subjects were exposed to 1,1,1-trichloroethane at 500 ppm (the Threshold Limit recommended by the American Conference of Governmental Industrial Hygienists) for 78 minutes. From a subjective standpoint, no significant untoward effects were noted. Three of six subjects noted a slight eye irritation which rapidly disappeared. There was no dizziness noted; balance and coordination were unaffected. Pre- and postexposure clinical laboratory data, listed previously, were normal with the exception of subject 5 who exhibited a trace of albumin and 3-6 red blood cells per high power field (RBC/HPF) in the 20-hour postexposure urine. The relationship of this observation to the exposure was questionable.

Analysis of serial blood samples obtained during the exposure revealed that the average concentrations of 1,1,1-trichloroethane in the blood at 30, 60 and 75 minutes after the start of the exposure were all between 3 and 4 ppm, with a range of 1.5 to 6.5 ppm. Twenty-five minutes after cessation of exposure, the compound was just detectable in the blood of 4 of the 6

TABLE II

1,1,1-Trichloroethane Pre- and Postexposure Data

	Subject	SGO-T			Urinary Urobilinogen				Urinalysis				15 min P.S.P.	
		Preexposure	20 hr. Post	7 da Post	Preexposure	6 hr. Post	20 hr Post	7 da Post	Preexposure Alb.	Preexposure Micro	20 hr Postexposure Alb	20 hr Postexposure Micro	Preexposure	20 hr Postexposure
Normal Value		6-40			1:40 or less				0-5 RBC/HPF				Greater than 25%	
Experiment 1	1	22	10	12	1:10		1:10	1:10	neg	neg	neg	neg		
500 ppm, 78 min.	4	11	14	10	1:10		1:10	1:10	neg	neg	neg	rare RBC		
	5	15	9	16	1:10		1:10	1:10	neg	rare RBC	trace	3-6 RBC		
	6	16	10	12	1:10		1:10	1:10	neg	1-2 RBC	neg	rare RBC		
	8	16	16	14	1:10		1:10	1:10	neg	rare RBC	neg	rare RBC		
	11	12	16	14	1:10		1:10	1:10	neg	neg	neg	neg		
Experiment 2	1	20	20	14	1:10		1:10	1:10					30%	44%
496 ppm, 186 min	2	20	18	16	1:10		1:10	1:10					38%	31.5%
	5	16	16	10	1:10		1:10	1:10					40%	39%
	6	23	20	18	1:10		1:10	1:10					43%	44%
	8	20	18	19	1:10		1:10						29%	24%
	10	24	19		1:10		1:10							
Experiment 3	5	16	18	16	1:10		1:10	1:10	neg	0-2 RBC	neg	rare RBC		
955 ppm, 73 min	6	19	16	12	1:10		1:10	1:10	neg	neg	neg	neg		
	8	18	16	15	1:10		1:10	1:10	neg	neg	neg	neg		
Experiment 4	3	14	16	6	1:10		1:10	1:10	neg	rare RBC	neg	rare RBC		
910 ppm, 35 min	4	18	18	16	1:10		1:10	1:10	neg	neg	neg	neg		
Experiment 5	2	17	15	14	1:10		1:10	1:10	neg	rare RBC	neg	neg		
900 ppm, 20 min.	7	18	20	17	1:10		1:10	1:10	neg	neg	neg	neg		
	9	16	18	20	1:10		1:10	1:10	neg	neg	neg	neg		
Experiment 6	1	14	16	15	1:10	1:640	1:10	1:10	neg	neg	neg	neg		
0-2650 ppm, 15	2	16	15	15	1:10		1:10	1:10	neg	neg	neg	neg		
min.	3	10	11	16	1:10	1:640	1:10	1:10	neg	neg	neg	rare RBC		
	4	14	14	18	1:10	1:10	1:10	1:10	neg	neg	neg	rare RBC		
	5	14		14	1:10		1:10	1:10	neg	neg				
	6	15	15	19	1:10		1:10	1:10	neg	neg	neg	0-2 RBC		
	7	14	16	20	1:10	1:40	1:10	1:20	neg	neg	neg	1-5 RBC		

subjects. Urine samples taken during exposure indicated that some samples possibly contained up to 2 ppm 1,1,1-trichloroethane, while none was detected in one sample. The samples obtained 15 minutes after exposure revealed the presence of a trace amount of 1,1,1-trichloroethane in 2 of the 6 samples, while none was detected in the other four.

The expired air concentrations of 1,1,1-trichloroethane, plotted versus time obtained following the exposure, are graphed on log-log paper in Figure 1. A free-hand curve was drawn through points representing the average expired air concentrations. Each point, with its maximum and minimum, represents the average of all of the available samples at that given time postexposure. The number of samples was never less than 4, and was usually 6. Points plotted without maximum and minimum designations represent individual samples. Concentrations at 24 hours postexposure were near the lower limit of sensitivity, 0.5 ppm.

Experiment 2, 496 ppm, 186 minutes

Six subjects were exposed to the Threshold Limit recommended for 1,1,1-trichloroethane for approximately 3 hours (186 minutes). From a subjective standpoint, no untoward effects were noted. No eye irritation or dizziness occurred. Balance and coordination were unaffected. Pre- and postexposure clinical data, listed in Table II, were normal.

Analyses for 1,1,1-trichloroethane in the blood and urine during and following exposure were inaccurate because the samples were processed in the exposure chamber, allowing contamination of the carbon disulfide used for extraction. In all other experiments, transfer of the

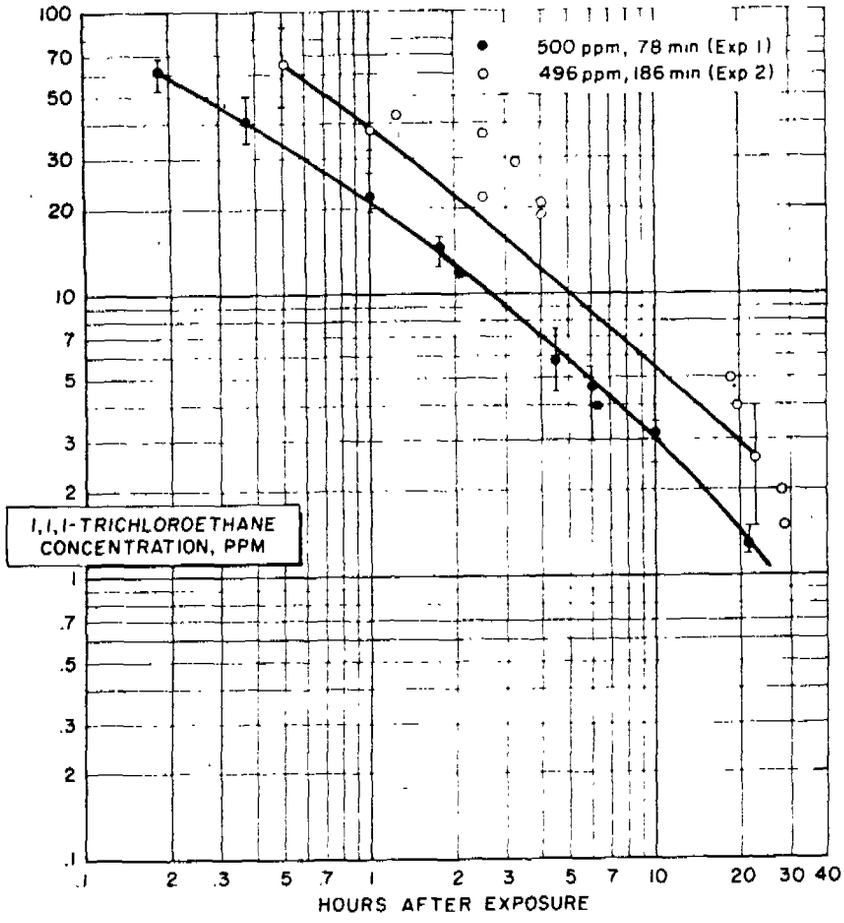

FIGURE 1. 1,1,1-Trichloroethane Expired Air Concentration. Humans were exposed to atmospheric concentrations of 500 ppm for 78 minutes (Exp. 1) and 496 ppm for 186 minutes (Exp. 2).

extractant was done outside the exposure chamber.

The average concentrations of 1,1,1-trichloroethane in the expired air following exposure are also plotted in graph form in Figure 1. Due to leakage from unsealed bags, many samples did not contain sufficient air for analysis after holding overnight. Therefore there were only three times at which five or more samples obtained simultaneously could be analyzed. The averages of these are designated with a maximum and minimum. Individual values are denoted without a maximum and minimum. A free-hand curve was drawn between the points representing average values.

Experiments 3, 4 and 5: 900 to 955 ppm for 73, 35 and 20 minutes

Three subjects were exposed to 955 ppm of 1,1,1-trichloroethane vapor for 73 minutes, two subjects to 910 ppm for 35 minutes and three subjects to 900 ppm for 20 minutes. The subjective and physiological responses are recorded in Table III. Within three minutes following the conclusion of the exposures no subject experienced any difficulty in performing a normal Romberg test. No difficulty in performing simple mental calculations was experienced, neither were there any untoward effects such as malaise, headache, or nausea noted following these exposures.

The concentrations of 1,1,1-trichloroethane in the blood during the exposure to 955 ppm for 73 minutes were as follows: 1 ppm at 15 minutes, 2–4 ppm at 30 minutes, and 7–10 ppm at 65 minutes after the start of the exposure. None of the chemical could be detected in the blood samples taken 30 minutes after the end of the exposure. In the groups exposed to 910 ppm and

900 ppm, in which exposures were of shorter duration, a similar rise in blood concentration was noted while the subjects were in the exposure chamber. The concentration of 1,1,1-trichloroethane in the urine at 45 minutes after the start of the exposure was 1–2 ppm in Experiment 3. Samples obtained seven minutes following exposure did not contain the compound in detectable amounts. In the shorter experiments the compound was not detected in the urine either during the exposure to postexposure.

Pre- and postexposure clinical laboratory data obtained from the three groups are listed in Table II. One subject who had a 20-minute exposure to an average concentration of 900 ppm had an elevated urinary urobilinogen 7 days after exposure. The remainder of the clinical laboratory data was normal. There also was no change in the timed vital capacity or blood pressure values.

Average concentrations of 1,1,1-trichloroethane in the expired air following these exposures are plotted versus hours after exposure in Figure 2. Each point with its maximum and minimum, plotted for Experiments 3 and 5 represents the average of 3 values. The upper two points of those plotted for Experiment 4 each represent the average of 2 values and the others a single value.

Experiment 6, 0 to 2650 ppm, 15 minutes

Seven subjects were exposed to a constantly increasing atmospheric concentration of 1,1,1-trichloroethane. When two of the subjects no longer were able to stand, the experiment was halted. This occurred at a peak vapor concentration of 2650 ppm. The total time of exposure was 15 minutes.

The subjective and physiological responses observed during this exposure are recorded in Table IV. Within the first five minute interval following the exposure all subjects had fully regained their sense of equilibrium. No nausea or vomiting occurred. It required marked concentration during the first fifteen minutes following exposure to perform simple mental calculations accurately. The five subjects who had become lightheaded stated that they didn't "feel normal" until approximately three hours following the exposure. They defined this abnormal feeling as "malaise."

The concentration of 1,1,1-trichloroethane in the blood 9 minutes following exposure was 5 ± 1 ppm, while 20 minutes following exposure the compound was questionably detectable in blood (0.5–1 ppm). Urine, collected 15 minutes following exposure, did not contain measurable amounts of 1,1,1-trichloroethane.

TABLE III

Subjective and Physiological Responses to 1,1,1-Trichloroethane Vapor Concentrations of 900 to 1000 ppm

Average Concentration	Responses to Exposure[a]
900 ppm for 20 minutes (3 subjects) (Exp. 5)	Positive Romberg in 1 subject. Greater effort required to perform a normal Romberg in 2 subjects after 10 minutes of exposure. Heel-to-toe walking normal. Two subjects experienced lightheadedness above 900 ppm
910 ppm for 35 minutes (2 subjects) (Exp. 4)	Greater mental effort required to perform a normal Romberg test after 10 minutes of exposure. All heel-to-toe walking performed well. One subject experienced persistent lightheadedness above 900 ppm.
951 ppm for 73 minutes (3 subjects) (Exp. 3)	Greater mental effort required to perform a normal Romberg test after 10 minutes of exposure. After 15 minutes of exposure one subject had consistently positive Romberg. Heel-to-toe walking performed well by all during exposure. No lightheadedness

[a] Mild eye irritation was noted by all subjects when vapor concentrations rose above 1000 ppm.

Pre- and postexposure clinical laboratory data are listed in Table II. Two laboratory findings of questionable significance were noted following the exposure. Two subjects had positive urinary urobilinogen 1:640, noted to be present seven hours postexposure. A repeat urobilinogen test twenty hours postexposure was negative for all subjects. Five subjects were noted to have from 1 to 2 RBC' HPF on a centrifuged urine sample, obtained sixty minutes postexposure, whereas no red blood cells had been detected prior to exposure. It is to be remembered that dioxane (the inhibitor) in sufficient concentration is a renal toxin. No change occurred in the timed vital capacities or blood pressure measurements.

The mean and the range of the expired air concentrations of 1,1,1-trichloroethane following exposure are graphed on log-log paper in Figure 3.

Discussion

It was noted after the first exposure to 1,1,1-trichloroethane at its Threshold Limit that this compound was detectable in the expired air for many hours after exposure. From the work of Hake, *et al.*,[7] it was known that the rat expires unchanged almost all of an intraperitoneal dose of 1,1,1-trichloroethane-C^{14}. Therefore it was not surprising that the compound could be detected in human expired air after an exposure. However, it was not predictable that it would be

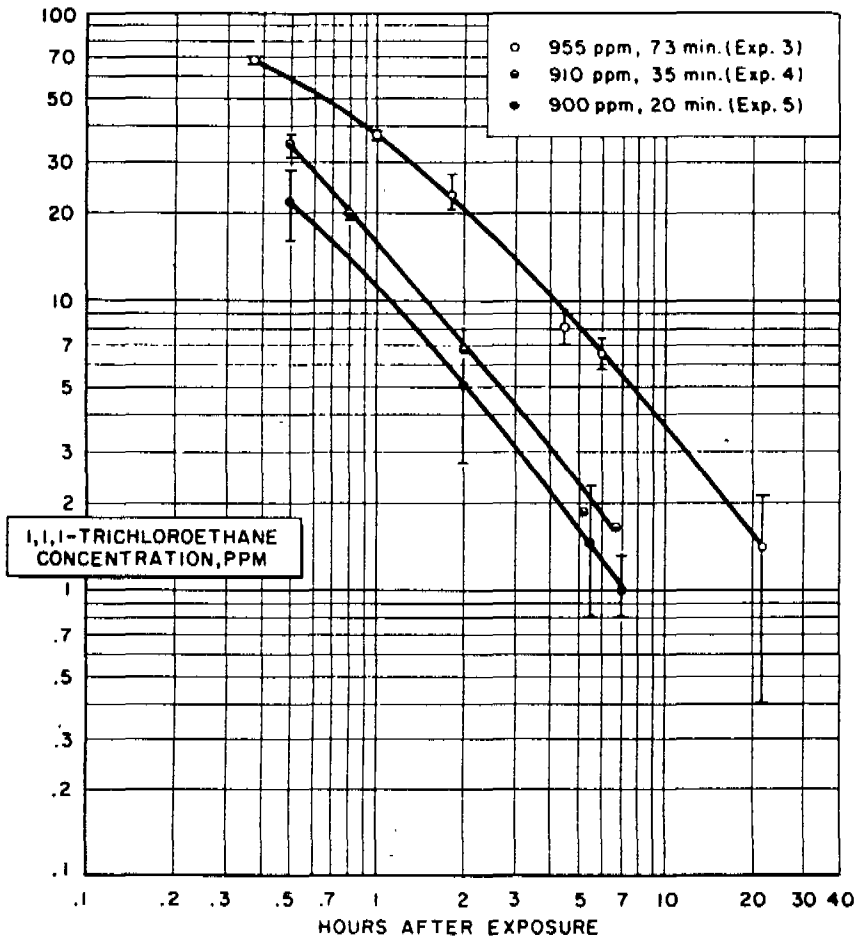

FIGURE 2. 1,1,1-Trichloroethane Expired Air Concentration. Humans were exposed to atmospheric concentrations of 955 ppm for 73 minutes (Exp. 3), 910 ppm for 35 minutes (Exp. 4), and 900 ppm for 20 minutes (Exp. 5).

detected more than 20 hours after an exposure to approximately 500 ppm, the recommended Threshold Limit. When this long expiration time was found, it suggested that the measurement of the compound in the postexposure expired air might be helpful in estimating the magnitude of the exposure.

It was found that the most significant manner in which the concentration of 1,1,1-trichloroethane in the expired air could be compared to the time after exposure (decay curve) was by plotting these points on log-log graph paper. From the plot of these points in Figure 1, it can be seen that the decay curve is almost a straight line and it can therefore be concluded that the expiration of 1,1,1-trichloroethane has an inverse exponential relationship to time after exposure. Figure 1 also demonstrates another important point. From a comparison of the two decay curves after 78- and 186-minute exposures to 500 ppm, it can be seen that the duration of exposure has a direct bearing on the concentration of 1,1,1-trichloroethane in the expired air, especially during the early hours after exposure.

It was of interest to further determine the effect of the length of exposure on the expired air decay curve. Figure 2, in which the decay curves for 20-, 35-, and 73-minute exposures to 1,1,1-trichloroethane concentrations of just over 900 ppm are plotted, shows that though the two curves from the 20- and 35-minute exposures contain considerable overlap, the 73-minute exposure gives a much higher curve. This would also indicate that the decay curves are sensitive to length of exposure differentials at higher exposure concentrations.

Figure 4 demonstrates the effect of exposure

TABLE IV

Subjective and Physiological Responses to a Constantly Increasing 1,1,1-Trichloroethane Vapor Concentration Over a Period of Fifteen Minutes

Concentration (ppm)	Responses to Exposure
0-1000	Increasing awareness of a slightly sweet, not unpleasant odor.
1000-1100	Mild eye irritation noted in 6 of 7 subjects.
1900-2000	6 of 7 subjects aware of throat irritation.
2600	1 subject very lightheaded.
2650	2 subjects unable to stand, 3 subjects very lightheaded, but able to stand, 2 subjects were not lightheaded, and one of these was able to demonstrate a normal Romberg test.

concentration upon the decay curve when the time of exposure is held constant. Points from Experiments 1 and 3 are plotted for comparison. It can be seen that for the first 2 to 3 hours after exposure there was no overlapping of points from the exposures to 500 and 955 ppm of equal duration. More than 4 hours after exposure, there was some overlapping of points, with the probability becoming greater as time after exposure increased. From this limited data, it appears that a valid conclusion as to the atmospheric exposure concentration of 1,1,1-trichloroethane can be drawn from the decay curve after an exposure if the duration of exposure is known. Many more experiments of differing duration and concentrations would have to be carried out in order to determine a family of curves. However, from the data in this paper, one could conclude with reasonable accuracy whether a person had been exposed to 500 or 900 ppm, if the dura-

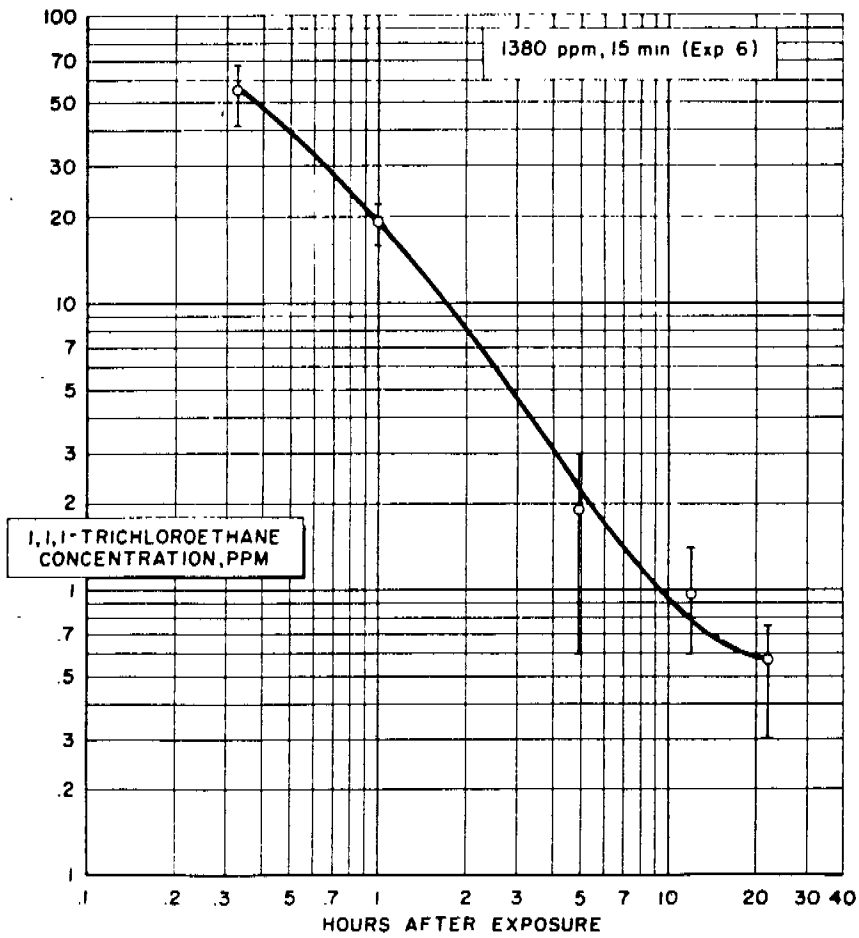

FIGURE 3. 1,1,1-Trichloroethane Expired Air Concentration. Humans were exposed to a rising concentration, 0 to 2650 ppm, of 1,1,1-trichloroethane for 15 minutes (Exp. 6).

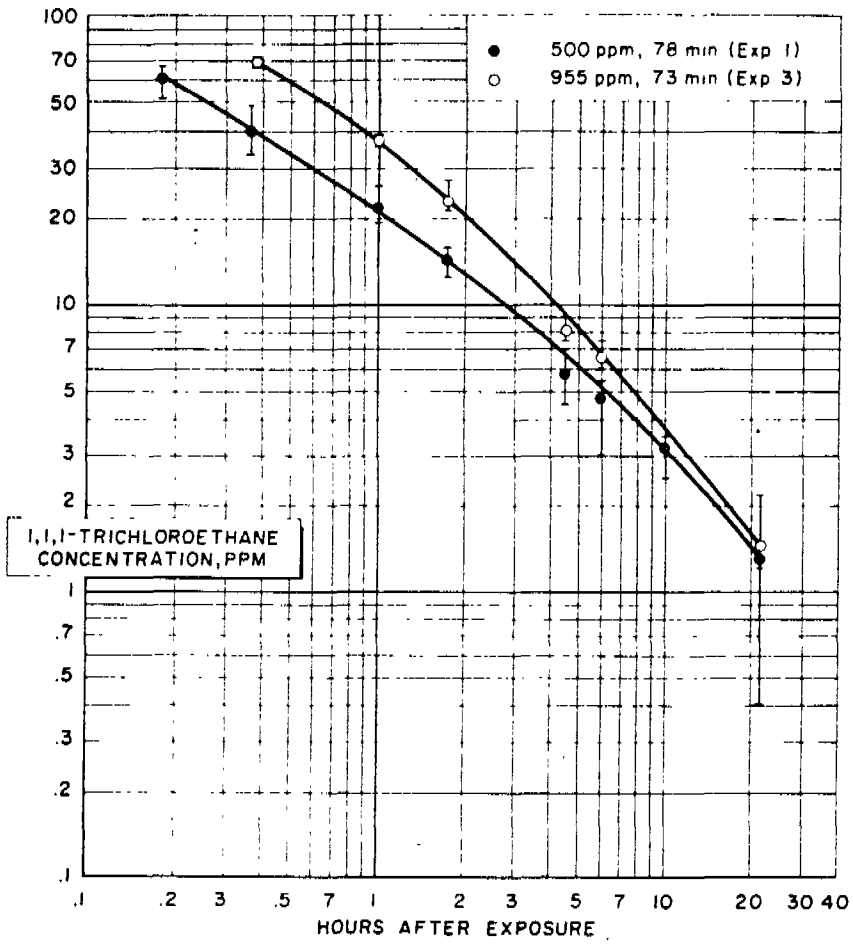

FIGURE 4. 1,1,1-Trichloroethane Expired Air Concentration. Comparison of exposures of nearly equal length; 500 ppm for 78 minutes (Exp. 1) and 955 ppm for 73 minutes (Exp. 3).

tion of exposure was about 70 minutes. It may be possible to obtain a family of curves which would be applicable to human exposures by exposing animals for various periods of time to several concentrations of 1,1,1-trichloroethane.

Infrared analysis of the postexposure expired air for measuring 1,1,1-trichloroethane proved to be an efficient method for three reasons. First, it provided an absolute, quantitative identification of 1,1,1-trichloroethane vapor. Second, it was rapid. One minute was required to obtain the air sample while five minutes were required for the analysis. Third, it was sensitive to 0.5 ± 0.1 ppm of 1,1,1-trichloroethane in air, allowing the detection of the compound many hours after the exposure occurred.

This infrared method has proven useful for the analysis of other chlorinated hydrocarbons in the expired air,[11, 12] as well as for other volatile compounds possessing strong absorption in the infrared.[13]

The concentration of 1,1,1-trichloroethane in the blood was determined by measuring the change in the infrared spectrum at the wave length where this chemical is known to have strong absorption. Though the results obtained indicated a positive relationship between the concentration of 1,1,1-trichloroethane in the blood and the concentration in the atmosphere, the concentrations in the blood were at such a low level that the results were not of significance for predicting exposure concentrations, neither were they high enough to give an infrared spectrum which could positively be identified as that of 1,1,1-trichloroethane. From the results

of the exposure to near anesthetic concentrations, it would appear that the blood of a person overcome by 1,1,1-trichloroethane vapor would probably attain the 10–15 ppm concentration necessary for a positive identification of 1,1,1-trichloroethane by its infrared spectrum. The results of the urine analyses verify the experiments of Hake, *et al* [10] in which it was found that only trace amounts of 1,1,1-trichloroethane are excreted in the urine. Urinary analysis for 1,1,1-trichloroethane by infrared was of no practical value.

The subjective and physiological responses to 1,1,1-trichloroethane vapor noted during these exposures agree closely with those reported by Torkelson, *et al.*[3] There was a rapid onset of lightheadedness at atmospheric concentrations exceeding 900 ppm. Hence, in order to have a desirable margin of safety for prevention of accidental injury due to lightheadedness, the atmospheric concentration in the working environment should not exceed 500 ppm. The eye irritation experienced by 1,1,1-trichloroethane users is too mild to be relied upon as a good warning property of excessive exposure.

The laboratory data obtained indicate that these acute exposures produced no significant liver damage. The data adds support to previous studies which have indicated that 1,1,1-trichloroethane in high concentration acts as an anesthetic agent and has only slight capacity to cause reversible injury to liver or kidneys.[3, 14] Transient elevation of the urinary urobilinogen in two subjects following the anesthetic exposure suggests that 1,1,1-trichloroethane does exert an adverse effect upon liver function. However, none of the other liver function tests employed showed any change following the exposures. If a subject is chronically exposed to this compound it would seem advantageous to periodically check his urinary urobilinogen concentration for this laboratory test has proven to be the most sensitive index to liver stress produced by this type of compound.[11]

Summary

A series of six controlled human exposures to 1,1,1-trichloroethane vapor was conducted. Using infrared spectrometric methods, the presence of the compound in blood during the exposures and the concentration of the compound in the expired air after the exposures were determined. 1,1,1-Trichloroethane was observed to give a prolonged exponential "decay curve" when its concentration in the postexposure expired air was plotted versus hours postexposure. This "decay curve" was predictable enough to allow a reasonable estimation of the magnitude of exposure, 0.5 to 3 hours after the exposure had occurred. Therefore, the analysis of postexposure expired air allowed a positive identification of the compound, and provided data with which the magnitude of the exposure might be estimated.

Chemical, physiological, and clinical laboratory studies were carried out and correlated with the vapor exposures. The determination of the concentration of urinary urobilinogen proved to be the most sensitive test of liver stress produced by markedly excessive exposures to 1,1,1-trichloroethane. The laboratory studies and subjective responses which were noted lend further assurance that 500 ppm is a satisfactory threshold limit for this compound.

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Radiation Standard

A NEW AMERICAN STANDARD specifying minimum requirements for the protection of workers from overexposure to radiation and radioactive dusts and gases in the uranium mining and milling industry has been approved by the American Standards Association. This publication *American Standard Radiation Protection in Uranium Mines and Mills (Concentrators) N7.1-1960* covers the mining, transporting and refining of ores to produce uranium concentrates suitable for the feed materials of production plants. Suggesting procedures for the proper control of the environment and examination of workers with a view toward protection from radiation, the standard is intended to serve as a guide for management and regulatory agencies having responsibility in this field of activity. In addition to offering definitions of all terms used, the standard specifies maximum permissible doses from external radiation, permissible concentrations of radioisotopes in air, hazards, management responsibility, medical supervision, protective measures and equipment, and transportation of ores. A five-part appendix, though not a part of the standard, deals with suggested procedures for measuring external radiation and atmospheric concentrations of radon daughters, for obtaining breath radon samples, for surveys of uranium concentrating mills, and the ventilation of uranium mines.

Twenty-one organizations including the Atomic Industrial Forum, Inc., and the National Safety Council, administrative sponsors, are represented on the ASA sectional committee which developed the standard. Participating for the government are the U. S. Atomic Energy Commission, U. S. Department of Labor, Bureau of Labor Standards, U. S. Public Health Service, and National Bureau of Standards.

Copies of the standard, N7.1-1960, which sell for $2.00 each, are available from the ASA, Department PR 211, 10 East 40th Street, New York 16, New York.