V. ASSESSMENT OF CARCINOGENIC POTENTIAL OF TRICHLOROETHYLENE TO HUMANS

The predominant data on which to base suspicion of carcinogenic potential of TCE is that of the animal bioassay test conducted by the NCI, although the MCA inhalation test may well provide comparable results. Standard methodology was used by the NCI with highly significant positive results only in the mouse and only with regard to liver cancer. While there may have been contributing factors, the evidence clearly points to exposure to TCE as the primary causative factor. The nature of the results in mice, indicate the induction of liver tumors; however, they are also consistent with a promotional mechanism. In view of the scientific uncertainties surrounding those results, other evidence that might support or refute a carcinogenic association has been reviewed.

Mutagenicity has been demonstrated in three different test systems: microbial (Salmonella typhimurium and E. Coli), yeast (Saccharomyces cerevisiae), and Tradescantia. Malignant transformation of mammalian cells has also been observed. Enzyme activation systems were required for both mutation and transformation.

Based on the similarity of TCE to vinyl chloride in structure and on TCE's electrophilic activity, a certain suspicion that it might possess a potential for carcinogenicity had been expressed even prior to the generation of the animal and in vitro results. Metabolism to an epoxide (or oxirane), likely to impart alkylating potential, has now been reasonably well shown to be possible, adding additional support to the test data.

It would appear from the research conducted recently on species differences in metabolism of TCE to an epoxide, and the inactivation of the epoxide by hepatic epoxide hydrase, that the potential degree of epoxide activity might be in the order mice > rats > humans. On this basis, it is not to be expected that TCE is as potent a carcinogen in humans as has been found in mice.

As of this time, no evidence has been found to associate TCE with carcinogenicity in humans. However, a causal relationship in U.S. workers would be difficult to detect because of the generally transient employment of degreaser operators (the major occupationally exposed group), the likelihood of their exposure to several different chemicals during employment, and the inadequate records available on employment, exposure and health effects. Such is not the case in Sweden. Axelson et al. (1977), are monitoring the health experiences of a group of 518 men exposed to TCE prior to 1970 (and having 10 years latent period) and an additional 1,100 with exposure in 1970 and later. An epidemiologic study for carcinogenic risk because of TCE exposure is feasible in Sweden as workers exposed to TCE have received periodic exposure measurements (trichloroacetic acid in urine) since the 1950's, with records available for review on the groups identified above. The cohort of 518 men is further subdivided into groups with high and low exposures, the high-exposure group excreting a mean of slightly more than 100 mg/l TCA in the urine. That level roughly corresponds to the Swedish standard of 30 ppm. The majority are in the low-exposure group, with 3,095 person-years of observation compared with 548 for the high-dose group at the time of the initial evaluation now being reported (Axelson et al., 1977). Current mortality statistics show a close agreement between the observed number of cancer cases in the TCE-exposed men and that expected from the incidences of cancer in the general population. However, only 49 deaths have occurred in the group of 518. Eleven of the decedents had tumors. The authors admit the low sensitivity of the study and conclude that the risk to man from induction of cancer by TCE can by no means be ruled out. In their opinion, however, the lack of an observed effect at this time makes it improbable that TCE is a very serious cancer hazard at low exposures.

Epidemiologic studies are also underway in Finland with vital statistics determined on 1868 workers exposed to TCE from 1965-1976. Preliminary analysis indicates 10 cases of cancer (no predominant type or site) in the 47 deaths that have occurred so far in the cohort. While there is no suggestion of an increased risk for cancer, exposure levels are not known with accuracy and the exposed population is quite young, 50% less than 40 years of age (Tola, 1977). It is important that both studies continue for several more years in view of the generally long latency period for cancer development in humans and the probability that TCE may not be a strong carcinogen. NIOSH so far has not been able to identify in this country a similarly appropriate worker population exposed to TCE for an epidemiologic investigation to test for such an association with cancer. Only the strongest of carcinogens could be detected without a well-designed and conducted epidemiologic study on an appropriate group of workers.

Based upon these considerations, the assessment for carcinogenicity must be based largely upon the animal and in vitro test results and on considerations of biochemical activity. A summary of evidence for the carcinogenic potential of TCE is presented in Table 9. Although NIOSH generally agrees that the weight of available evidence justifies considering trichloroethylene as a potential carcinogen, it notes that the bioassay does not provide information on the response at low levels of exposure; mutagenicity or transformation tests did not reveal strong responses, and the Swedish epidemiologic study would argue against a potent carcinogenic effect. The data so far available do not suggest that TCE should be viewed as a particularly strong carcinogen. The mechanism, i.e., induction or promotion, is not resolved.

Table 9. Evidence for carcinogenicity of trichloroethylene

Epidemiologic:	None at this time[1]
Animal bioassay:	Positive in mouse (liver cancer) Not positive in rat

Mutagenicity:

- Salmonella typhimurium (TA100)
  - two weakly positive tests (Simmons; Greim)
  - negative test (Bartsch et al.)
- Escherichia coli, K12 - weakly positive test
- Saccharomyces cerevisiae - 2 positive tests
- Tradescantia (clone 4430) - positive test
- Host mediated assay (S. cerevisiae) - positive in rat
- Dominant lethal test - negative in rat

Cell transformation: Positive with Fisher rat embryo cells

Chemical activity:

- Reactive metabolite (epoxide)
- TCE covalent bonding to cellular macromolecules
- Electrophilic activity

[1] Studies underway in Finland and Sweden (Tola, 1977; Axelson, 1977).

VI. CHARACTERIZATION OF OCCUPATIONAL EXPOSURE

While estimates of the numbers of workers exposed and an evaluation of the biological effects of TCE have been stated earlier in this report, it is also necessary to address the nature of the occupational exposures to this chemical in assessing the overall hazard. Useful information from which such an analysis can be made comes primarily from occupational hazard surveys which attempt to assess the hazards under actual working conditions. From use and exposure information (Sections III C. and D.) it can be seen that most high-level occupational exposures to TCE arise from its use in metal cleaning operations and specifically from vapor degreasing. The following survey information helps to characterize the nature of the TCE exposures from this widely used industrial process.

A. EXPOSURE FROM THE VAPOR DEGREASING PROCESS

The commonly used open top vapor degreasers, as shown in Figures 4-6, consist basically of two sections: a lower section consisting of a reservoir containing liquid solvent and a heat source to boil the solvent creating a vapor and an upper section containing only the vapor and emission control items. Optional emission control items on some degreasers can include a cover to hold in vapor and reduce drafts, freeboard ventilator system to reduce vapor escaping from top of tank, and cooling coils around the freeboard to condense the vapor. Metal parts soiled with grease, oil, metal fines, etc., are lowered, usually by basket, into the solvent vapor-zone of the tank with the aid of a hand-operated or automatic crane. The hot vapor condenses onto the cooler metal parts and the condensate dissolves the soil, carrying it along as it drains back into the boiling liquid reservoir below. When the metal parts reach vapor temperature, the condensation stops. Parts should then be withdrawn from the vapor zone slowly, so as not to create updrafts of the vapor, and allowed to dry before raising above the top edge of the tank. The vapor-degreasing process takes advantage of the fact that the solvent boils at a much lower temperature than the oil and grease and if the temperature of the liquid reservoir is maintained at the boiling point of the solvent, only pure solvent vapor is found in the vapor zone of the degreaser. As water can interfere with the degreasing activity, degreasers are also equipped with a water drainoff valve. Other types of degreasers, such as in Figures 7-11, may be more enclosed or conveyorized as an integral step in a production line.

Several surveys, both by NIOSH and by industry, have been conducted to assess the nature and extent of TCE exposure problems associated with the vapor degreasing process. Fifteen

NIOSH Health Hazard Evaluations have been conducted to evaluate health problems suspected to be associated with TCE exposure at specific workplaces, the findings of which are presented in Section B.

A recent field survey was also conducted by NIOSH personnel specifically to examine different models of degreasers as they were in use in a variety of working operations. Because of EPA's concurrent interest in controlling fugitive emissions of chlorinated solvents, a representative from that agency accompanied the NIOSH survey team. An attempt was made to evaluate the potential for exposure based upon the performance of the equipment and the procedures followed by degreasing operators. A variety of different industrial operations was visited, in which the major types of degreaser units, as depicted in Figures 4-11, were observed. Some of the facilities utilized degreasing solvents other than TCE. However, because of basic design and process similarities among degreasers, the observations made at all facilities are considered relevant. Although the survey involved only a limited sampling, it is likely that the findings throughout the industry would be similar to those observed in the survey.

A number of design features are used to contain the vapor, including partial process enclosure, vapor condensing coils, and local exhaust ventilation. The efficiency of such features varies with the degreaser model, some being less likely to cause exposure problems than others. However, improper operating procedures and negligence in regard to equipment maintenance or repair often negate the benefits of many features that are available. Such was found to be the case during the field survey. While many degreasers were properly installed and maintained and were being operated according to good procedures, many others were not. The highest concentrations of vaporized TCE, correlated with unsatisfactory operating conditions, as was expected.

Among the observations of unsatisfactory conditions made during the field survey, the following were considered most serious:

1. The vapor layer of several open-top degreasers lacked continuity because of excessive amounts of moisture in the solvent, poorly engineered or maintained ventilation systems, and drafts over the degreaser top. This situation lends itself to vapor loss and increased exposure risk to the operator.

2. In some cases, parts were not given adequate time to drain prior to their removal from the degreasing unit, allowing for increased concentrations of solvent vapor in the operators' breathing zones.

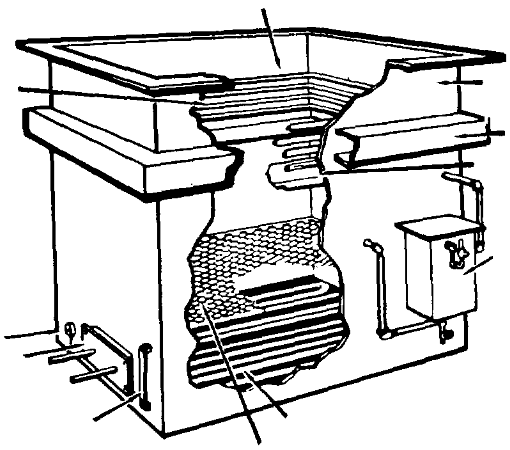

Figure 4. A typical open top degreaser

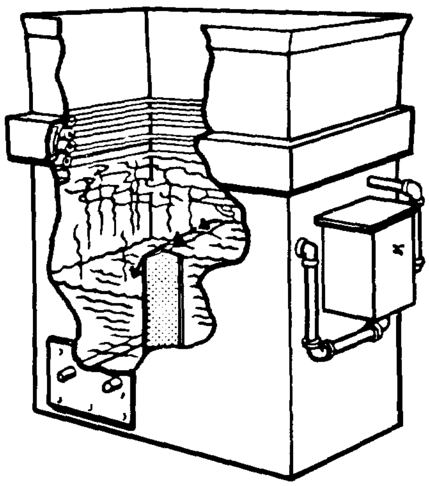

Figure 5. A two-compartment open top degreaser

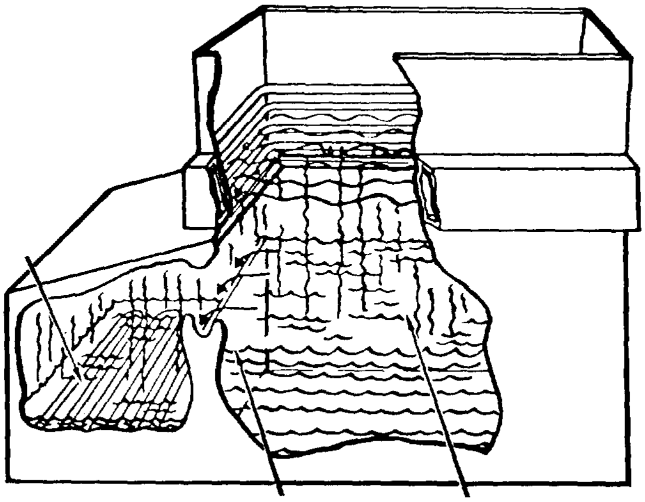

Figure 6. A two compartment open top degreaser with offset boiling chamber

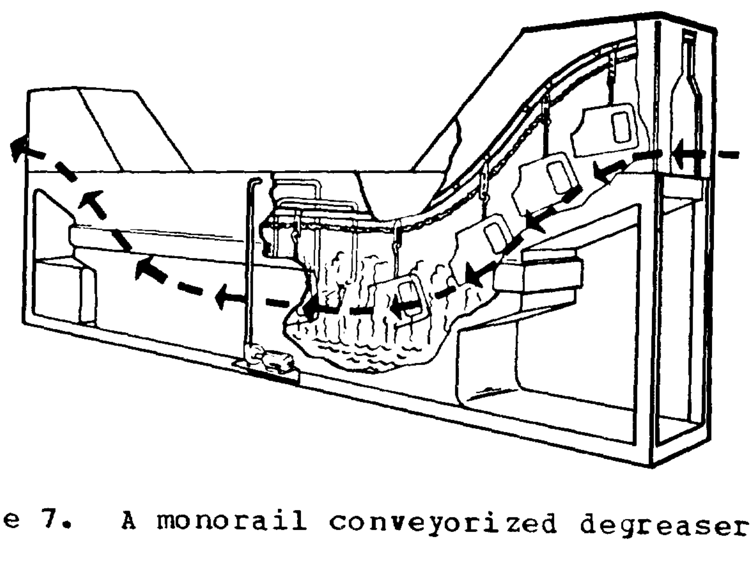

Figure 7. A monorail conveyorized degreaser

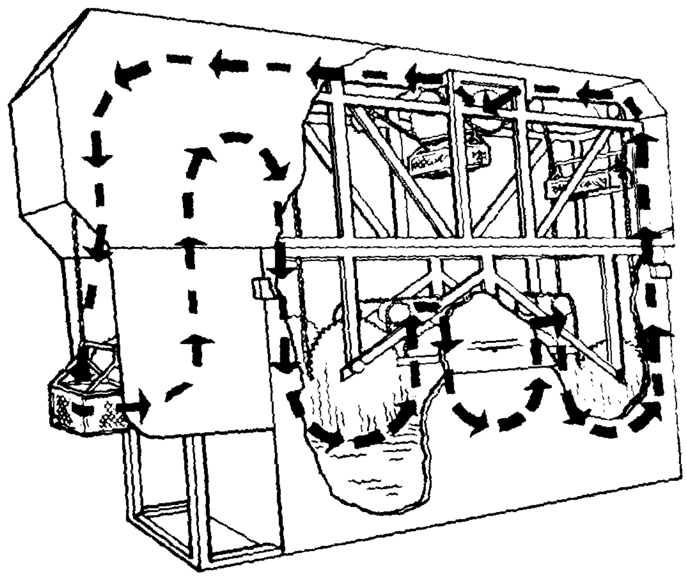

Figure 8. A cross-rod conveyorized degreaser

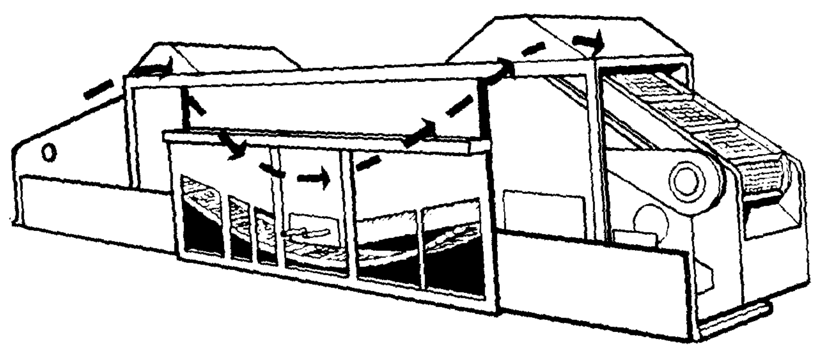

Figure 9. A mesh belt conveyorized degreaser

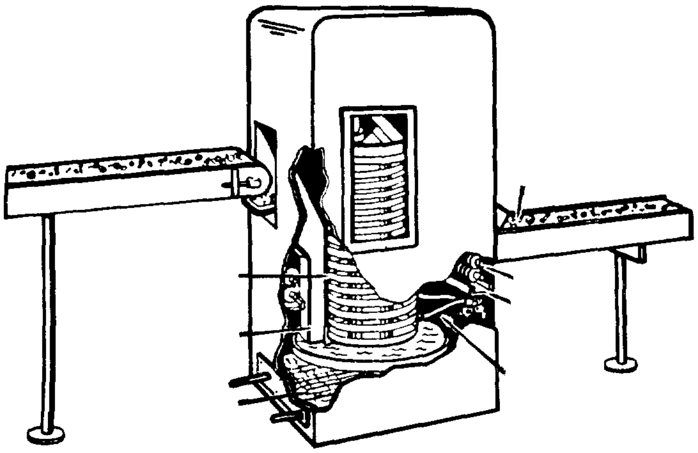

Figure 10. A vibra degreaser

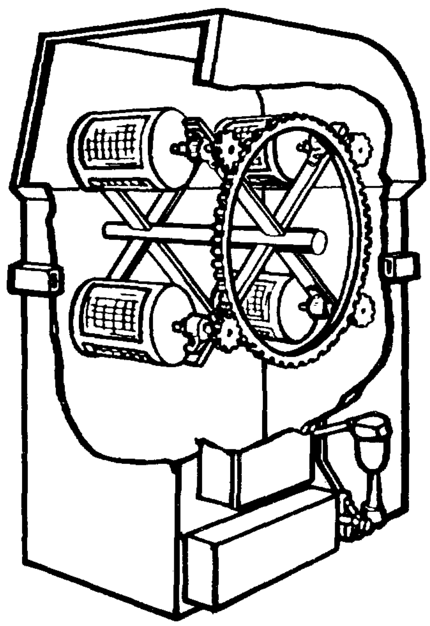

Figure 11. A ferris wheel degreaser

3. Disturbances of the vapor layer and solvent "dragout" also occurred from removing or introducing parts too quickly.

4. Freeboard exhaust ducts sometimes were badly in need of cleaning and were partially clogged, thereby interfering with proper exhaust.

5. In some cases, heat exchange coils on the compressor of freeboard chillers needed cleaning for the unit to operate effectively in condensing the vapor and containing it within the degeasing unit.

6. In most cases, degreaser covers were not in use. In some cases they had never been installed, while for others they had been removed or intentionally not used even while the unit was idling.

7. Employees were not always familiar with the solvent they were using, its potential hazards, and the appropriate precautionary measures.

In addition to the above observations, Draeger tube air samples were taken in the proximity of the operators' breathing zones. TCE concentrations of 20, 70, and 100 ppm were found at points of emissions from a monorail and two open-top degreasers, respectively. While such Draeger tube samples offer only very rough estimates of exposure levels, the above findings are in agreement with those of extensive surveys conducted by other groups.

Dow Chemical U.S.A. surveyed over 200 vapor degreasing facilities, using a Halide meter, and calculated the TWA exposure levels. They found that with existing control technology 37% of open-top degreasers using TCE maintained a 25 ppm exposure level, 58% were below a 50 ppm level, and 81% were in compliance with the current Federal standard of 100 ppm (Skory et al., 1974). These concentrations represent averages from what would be considered both good and poor operating conditions. A continuation of this survey to include over 1,000 vapor degreasing facilities has not resulted in changes of these estimates (Fulkerson, 1977).

Likewise, in a survey conducted by the Du Pont Company (Hargarten et al., 1961), very similar results were obtained. Data from air samples taken at 280 degreasers of various types and covering a 5-year period, 1952-57, showed that 48% of the units were below a 50 ppm exposure level and 86% were below a 100 ppm level. These figures represent exposure levels from degreasers which were operating under "problem" conditions. Data from a group of degreasers which were operating under "typical" conditions showed that 60% were under a 50 ppm level and 93% were under 100 ppm. As with the NIOSH and the Dow surveyors, the Du

Pont survey team concluded that most exposure problems could be substantially reduced by simple equipment maintenance and by proper use of the equipment and solvent by the operator. Based on their observations, the du Pont team developed the following list of common exposure-causes along with their relative frequency of occurrence:

Excessive drafts	55%
Dragout of solvent	48%
Overloading degreasers	43%
Spraying above vapor zone	21%
Excessive work speeds	13%
Poor machine maintenance	9%

Grandjean et al. (1955), evaluated the problem of dragout and determined that extending the time in which parts are allowed to drain and dry inside the tank, from 1/2-minute to 2-minutes, reduced the TCE emissions by 75%. Extending the period to 5-minutes resulted in a reduction of more than 85% from that of 1/2-minute.

Staheli (1972) conducted an experiment to test the effectiveness of certain engineering controls and work practices in eliminating some of the above problems. Specifically he tested the effectiveness of (1) using adequately trained personnel, (2) properly designed fans, blowers, and ventilation ducts, (3) baffles and shield to protect the degreasers from air currents, (4) use of a vapor zone freeboard height of 60% of the machine width, (5) use of a freeboard refrigerator device, commonly called a "freeboard chiller", (6) limiting entrance/removal speed for parts to 10 to 20 feet per minute, (7) eliminating overloading, (8) keeping cross sectional area of workload to less than 50% of the available machine area, and (9) removing work only when degreasing action is over. Vapor levels in the operator breathing zone were measured to compare the effectiveness of the various control measures with either TCE or methyl chloroform as the solvent. The results showed that with the freeboard chiller operating, even with no degreaser exhaust, ambient readings at the operators' breathing level were below 4 ppm for methyl chloroform and that zero stack emissions could be obtained. The test also showed a reduction in solvent consumption of 80% during a 6 month period because of the above controls (except the freeboard chiller). With the freeboard chiller, an additional reduction of 50% was obtained. For a continuously working degreaser, the freeboard chiller reduced TCE levels to as low as 12 ppm.

In a similar experiment, Esmen and Clearwater (1974) investigated the physical parameters influencing the physical formation of solvent vapors and subsequent emissions under laboratory conditions. Utilizing the experimental data obtained, they developed a mathematical model designed to predict emissions following modifications of the physical characteristics of an actual industrial vapor degreaser under field conditions. The operating degreaser chosen to verify the model was of the open-top variety with a surface area of 28 x 58 inches; equipped with cooling coils, slot-type local ventilation powered by a 16-inch fan exhausting to the outside atmosphere; and a cover; and utilizing TCE as the solvent. TCE concentrations were measured under the following conditions: exhaust fan on, degreaser covered; exhaust fan off, degreaser covered; exhaust fan on, degreaser uncovered; and exhaust fan off, degreaser uncovered. Samples were taken both 6 inches above the freeboard and in the operators' breathing zone via personal sampling equipment. The most dramatic results were obtained when the fan was on and the degreaser covered. Under these conditions averages of 6 ppm and 13 ppm of TCE were found in the freeboard-area and operators' breathing zone. As is evident from the data presented in Table 10, a dramatic increase in exposure levels results when either the fan is shut off or when the degreaser is uncovered. When both were off, levels were further magnified and greatly exceeded the current OSHA standard. These findings, in actual operations, correlated well with the predictions of the mathematical model, prompting the investigators to emphasize the imperative nature of a degreaser cover in reducing solvent emissions. Esmen and Clearwater also demonstrated that the use of a cover reduced the solvent usage rate to only 7% of that previously required without a cover, a considerable economic savings to the industry. To overcome the operators' reluctance to use a cover and to reduce the potential fanning action sometimes associated with the conventional lid covers, they suggested the use of a roll-type design.

Table 10. Effect of local exhaust venting and cover in reducing trichloroethylene emissions from an operating degreaser

Operating conditions		Measurements (ppm)	
Fan	Cover	6 " Above Freeboard	Operator's Breathing zone
On	On	6	13
Off	On	22	32
On	Off	89	55
Off	Off	633	163

Reference: Esmen and Clearwater (1974).

In support of all the above findings, is a survey by Ahlmark et al. (1963) of vapor degreasers in Sweden. Using a "Davies Halogen Detector" the investigators measured TCE concentrations in 570 degreasing plants over approximately a 10-year period. The samples were taken in the operators' breathing zones of predominantly open-top degreasers which utlized condensing coils and local exhaust ventilation to control vapor emissions. In taking 50 samples, every 30 seconds at each degreaser, over 35,000 individual checks were recorded. From analysis of these data the investigators found the average TCE concentration to be 16 ppm. Ahlmark et al. credit this performance to Swedish workers' conscientious adherence to safe work practices and proper engineering controls. The Swedish vapor degreasing industry emphasizes the importance of proper heating and condensing elements, adequate general and local ventilation, monitoring of workplace air, and employee training.

Other NIOSH surveys have gone one step further in characterizing occupational exposure to TCE by correlating biological effects with measured industrial-exposure levels.

B. RESULTS OF NIOSH HEALTH HAZARD EVALUATIONS

Fifteen surveys or Health Hazard Evaluations involving TCE use have been conducted by the NIOSH staff as the result of employee or employer requests. Most operations involved very low exposures (< 10 ppm) and no obvious toxic effects were noted. In three surveys where the concentrations of TCE in the workplace approached the current OSHA standard of 100 ppm (535 mg/m^3), however, consistent symptomatology was reported.

At one plant surveyed by Vandervort and Polakoff (1973), complaints of continued sickness involved employees in a pump room and metal fabrication area. During interviews, only one of 19 employees did not complain of a variety of illnesses, over one-half of them listed symptoms of eye irritation, tiredness, heart palpitation, coughing, weakness, dizziness, and changes in skin color. Some also indicated that they became severely intoxicated from small amounts of alcohol consumed when not on duty. The NIOSH surveyors also experienced nausea and weakness when making the survey. The obvious hazard was from TCE vapors arising from degreasing vats. Of 43 samples taken either in the personal breathing zone or as area samples, most were in the range of 37-75 ppm (200-400 mg/m^3) while directly over the degreasers the range was somewhat higher, 56-112 ppm (300-600 mg/m^3), for an 8-hour TWA.

The Vandervort and Polakoff survey noted several design or operational features which contributed to the release of TCE vapor from the degreasers. Among these were: (1) many parts had cavities that carried the solvent out of the degreaser when the parts were removed without tumbling to allow the solvent to drain out of these hollows, (2) there was no exhaust-controlled area in which to place parts for evaporation of residual solvent, (3) parts were abruptly immersed into or raised from the solvent, causing splashing and vapor turbulence, (4) solvent was sprayed onto parts while they were held above the condensing coils of the degreaser, (5) the exhaust ventilator over the degreasers was operating at an airflow only one-half that recommended by the ACGIH (1971), and (6) the degreaser was near a brazing operation, which could result in the inadvertent formation of phosgene and HCl from degradation of TCE vapor. Also, one degreaser was near a space heater which could cause a similar situation. Many of the problems cited could be easily corrected by good administrative controls and improved ventilation.

In another survey by Bloom et al. (1974), medical interviews were conducted of 11 women employees who had previously reported illness, allegedly associated with TCE exposure. While a wide diversity in symptomatology was reported, over one-half complained of nausea and vomiting. Other symptoms registered were nervousness, irritability, headache, shortness of breath, sleepiness, cramps, depression, numbness of lips and head, crying, and a general feeling of heaviness of the body or extremities. Many illnesses coincided with the detection of an odor in the workplace. Generally, exposure concentrations were less than one-half the OSHA limit (ranges of 10-20 ppm at one degreaser and 20-100 ppm at the other). At one area where TCE-soaked rags had been piled, an airborne concentration of TCE of over 100 ppm was measured. One contributing factor causing escape of TCE vapor from the degreasers was the practice of placing a parts-basket at the "vapor line," thus interrupting the vapor lock created by the cooling coil. Employees were also potentially exposed to low levels of an epoxy anhydride curing agent. The surveyors and employees felt that TCE was the likely agent of concern. Relocation of the TCE tank and improved local ventilation resulted in a great decrease in employee complaints. This result supplies further support for the idea that TCE was the cause of the symptoms experienced.

In a third survey of a degreasing department, Hervin et al. (1974) found consistent symptoms of lightheadedness, headache, nausea, and tightness of the chest. Low levels of trichloroacetic acid and trichloroethanol were found in the urines of workers although the exposures were on the average much less than one-half the standard, ranging from 10-95 ppm (53 to 508 mg/m^3). The TWA concentration of airborne TCE for the degreaser operators was 47 ppm (253 mg/m^3). Employees who worked at some distance from the degreasers experienced effects also although they were exposed to lower TWA concentrations. TCE was detected throughout the plant, the result of obviously poor general and local ventilation.

In a fourth study (Okawa and Bodner, 1973), symptoms similar to those previously described were found among workers in an electrical company, where they were exposed to levels ranging from 13-40 ppm (average 25.3 ppm). Urine levels of trichloroethanol correlated well with exposures below 50% of the Federal limit. The exposures were intermittent and only for a portion of the working period. Even so, toxic effects were reported.

From these Health Hazard Evaluations there seems ample reason to challenge the current Federal standard based upon acute effects alone. Effects have been documented at levels of one-fourth to one-half the OSHA limit.

VII. SUMMARIZATION OF BIOLOGICAL AND EXPOSURE DATA

1. The toxicity of trichloroethylene has been adequately documented and in itself elicits concern regarding the adequacy of the present OSHA standard of 100 ppm TWA. Messite (1974) concluded, from a review of toxic effects other than cancer, that both the current Federal standard and that recommended in the NIOSH criteria document were inadequate. Most other countries, having assessed the toxicity and exposure to TCE, have established much lower permissible levels than the current U.S. standard.

2. Trichloroethylene has been demonstrated to be carcinogenic by gavage in the mouse but not in the rat. The studies are considered appropriate for assessing the potential of TCE for inducing occupational cancer although the doses were considerably higher and via a different route than encountered in the workplace.

3. Studies have indicated mutagenicity in four different systems in vitro, producing gene, frameshift, and base substitution mutations. In all, however, the effect was judged to be a relatively weak response in comparison with those produced by strong carcinogens. A positive response was obtained in a host-mediated assay with mice having an artificial saccharomycetemia. A negative response was obtained from a dominant lethal test with rats.

4. Transformation of cultured mammalian cells into malignant tumor cells has been produced, again with the response not as strong as that produced by more potent carcinogens or other chlorinated hydrocarbons.

5. Strong evidence exists that TCE may be metabolized to an epoxide having electrophilic activity, and the capability to react and bind to cellular macromolecules with potential for induction of carcinogenic lesions.

6. The evidence, as presented in this report, requires that TCE be considered as a potential carcinogen for humans; however, the animal and in vitro results do not warrant considering TCE as a potent carcinogen. The current occupational limit and control measures in use were established with no concern for carcinogenic potential and thus may be inadequate to assure worker protection from such a carcinogenic potential.

7. From inspection of a series of NIOSH Health Hazard Evaluations which were conducted in TCE degreasing facilities,

and from other surveys by NIOSH, Dow Chemical U.S.A., and the Du Pont Company, it appears that major exposure problems can be avoided through strict adherence to degreaser manufacturer's operating instructions. Further, it appears that with simple maintenance, repair and/or upgrading of existing engineering controls, substantial reductions in worker exposure could be effected even in facilities which are already operating below the current Federal standard. NIOSH believes that the existing engineering control technology is readily available to attain a TWA exposure level of 25 ppm, with the potential good for even further reductions.

VIII. EXPOSURE MEASUREMENT METHODS

A NIOSH-recommended sampling and analytical method for organic solvents (including TCE) can be found in the NIOSH Manual of Analytical Methods (1977d). This method involves sample collection by adsorption on charcoal, desorption with carbon disulfide and subsequent analysis by gas chromatography and an electron-capture detector. About 180 ug of TCE per sample should be collected for accurate measurement at 100 ppm TWA. A detailed discussion of this method can also be found in the NIOSH Criteria Document on TCE (NIOSH, 1973). Minor modifications to this method are required in order to measure at lower levels. For example, to sample for a 25 ppm TWA requires collection of 10 liters at a rate of 1 liter/minute. For a 10 ppm TWA, 10-100 liters are needed with a rate of 50-200 cc/minute. Further, NIOSH has published an efficiency evaluation of activated-charcoal tubes for TCE vapor collection (Reckner and Sachdev, 1975). This report addresses some of the pertinent aspects of TCE sampling such as pump calibration, flow rates and desorption factors, including their individual contributions to the overall analytical error associated with this sampling method. Other methods for analyzing TCE include spectrophotometry, neutron activation, spark source mass spectroscopy, and infrared spectroscopy. Gas chromatography offers the greatest specificity and sensitivity of the various methods of analysis and is therefore the recommended method (NIOSH, 1973).

It should be noted that direct reading instruments, i.e., detector tubes, for monitoring TCE workplace concentrations are available: Draeger tubes which detect down to 10 ppm; MSA tubes which are "certified" to 50 ppm; HNU Photoionization detector with a limit of measurability of 0.2 ppm; and the Wilks Miran Analyzers A1 and 101 with a limit of detection of 0.1 ppm.

Two methods for analyzing TCE exposure which utilize biological indicators also have been developed. Measurements of the amounts of trichloroethanol and/or trichloroacetic acid metabolites excreted in the urine over defined periods of time can be used to determine TCE exposures many hours, or even days, after the exposure to TCE has occurred; however, these measurements generally have led to wide ranges in the individual values reported (Grandjean et al., 1955; Stewart et al., 1974).

NIOSH has validated a method which uses the measurement of TCE present in the breath after exposure as an index of the magnitude of exposure (Stewart et al., 1974). Breath samples can easily be obtained from the workers and analyses of these samples are considered to yield reliable estimates of worker exposure to TCE. Measurements of TCE in the breath should be taken shortly after a known or suspected overexposure has occurred, however, as the TCE concentration in the breath decreases to low levels rather rapidly. Experimentation has shown that 5 hours following exposure to 265 ppm of TCE for 83 minutes the concentration in the breath had declined to near the limit of detection, i.e., 0.8 ppm for the analytical method employed, i.e., infrared spectroscopy (Stewart et al., 1962). Further, a rather large percentage of a dose of TCE is metabolized by humans, with the result that the amount metabolized will be unavailable for excretion as the unchanged material in the expired air (Stewart et al., 1962).

It thus appears that biological sampling itself is not a reliable guide to the degree of exposure of workers but must be accompanied by air analysis.