

SOLVENT EXPOSURE ON THE RAILROAD

R. Dean Hartley
Hartley & O'Brien
827 Main Street
Wheeling, West Virginia 26003
(304) 233-0777

I. INTRODUCTION.

The railroad industry has historically been a heavy consumer of cancer-causing solvents. Over the past 40 or 50 years railroad workers, including machinists, electricians, painters, carmen, and laborers have been unnecessarily exposed to excessive levels of benzene, ethyl benzene, paint thinners, lacquer thinners, mineral spirits, naphtha, carbon tetrachloride, trichloroethylene, trichloroethane, and perchloroethylene.

The medical and scientific literature is rich with studies and reports relating solvent exposure to blood and organ diseases. Industrial hygiene literature, as well as trade association proceedings, delineate the appropriate safety precautions necessary to protect workers from the hazards associated with solvent exposure. Yet for decades, railroad workers were required to labor in perilous conditions without the benefit of respirators, rubber gloves, aprons, or boots. After decades of unchecked solvent exposures, workers are now contracting leukemia, lymphoma, multiple myeloma, liver disease and cancer, kidney disease and cancer, organic brain damage and neurotoxic injuries.

II. RAILROAD WORKERS WITH POTENTIAL SOLVENT EXPOSURES.

A. Background.

By definition, solvents are substances capable of dissolving other substances. Solvents are quite heterogenous and include aliphatic, aromatic, and alicyclic compounds. The National Institute for Occupational Safety and Health has estimated that as many as 9.8 million workers were occupationally exposed to organic solvents during the 1970's.¹ The degree of solvent exposure can vary considerably among individual workers as well as from one time to another. Workers may be heavily exposed to degreasers one day, and have no exposure the next day. Open handling of solvents and primitive degreasing operations were/are common in railroad shops. More problematical is the fact that instead of using one particular solvent for a certain job, solvent mixtures have been used or various solvents were used interchangeably. These mixtures and interchangeable solvents make a determination of a worker's particular exposure to a specific substance much more difficult.

¹National Institute for Occupational Safety and Health. "Organic solvent neurotoxicity." NIOSH Pub. No. 87-104 (U.S. Govt. Printing Office 1987).

B. Specific Job Classifications.

1. Laborers.

Generally speaking, these individuals performed the dirtiest and most hazardous jobs on the railroad. They cleaned out the inside of tanks, vats, and vessels that had contained solvents or cleaned other containers with solvents.² They used pressurized spray guns and trichloroethylene to clean engines while they were running. The heat generated by the engine caused the solvents to vaporize creating unhealthy exposure situations.³ They cleaned the floors of the shops by spilling 55 gallon drums of solvents onto the floor, and mopping up the grease, oil and residue. Laborers helped carmen clean pinions with rags and buckets of solvents to remove old lubrication protectorants -- dipping their hands and rag into the bucket on a regular basis. These workers helped electricians clean generator compartments with mineral spirits to remove old residue that remained from the last service. They helped electricians by spraying solvents on the face of the electrical compartment, and wiping them off by hand. They cleaned batteries with carbon tetrachloride.

2. Painters.

Similar to the laborers, painters probably had some of the highest levels of solvent exposure on the railroad. Painters, both car and bridge, mixed their own paint. While solvent exposure is well recognized among painters, paint is actually a complex mixture of pigments, solvents, binders and additives.⁴ Railroad painters used 50% paint (pigment, binders, and additives), and added an equal part of thinners, lacquer, and/or other solvents. The thinners and lacquer contained benzene. This mixture was then applied by brush or spray gun. Clean-up was done with the same thinners or lacquer that was mixed with the paint. Clean-up of car stencils was done with pure benzene on some railroads.⁵ Painters were therefore exposed in mixing the paint, applying the paint, and cleaning-up afterward.

3. Machinists.

Railroad machinists cleaned engine parts with rags and buckets of solvent. They dipped their hands in solvent almost all day long. They cleaned out lines on the engine by forcing solvent through the lines. They sprayed solvent on the engines, waited for

²One CSX Railroad laborer explained to his physician that he was held by his ankles over a vat and used mineral spirits and other solvents to clean the inside of vessels on numerous occasions.

³Laborers employed by the N&W Railway described clouds of vapor forming in the shop when solvents were sprayed on the hot running engines.

⁴IARC. International Agency for Research on Cancer. IARC Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Humans. Some Organic Solvents, Resin Monomers and Related Compounds, Pigments and Occupational Exposures in Paint Manufacture and Painting. Vol. 47. 535 pp. Lyon, France: IARC, 1989.

⁵Railroad painters for the N&W (at least in the Roanoke Shops) have in the past cleaned their stencils with pure benzene.

the dirt, grime and oil to dissolve, and then sprayed hot water on the engine to remove the solvent. They used Safety-Kleen parts washers, soaking parts for hours in an attempt to clean them. Vapors emanated from the parts washer and, as designed, required machinists to emerge their hands in the solvent. They were exposed as by-standers when laborers performed almost any job function in the shop.

4. Carmen.

Carmen used naphtha to clean brakes. They cleaned bearings by soaking rags in five gallon buckets of solvents, removing the rags from the bucket with their bare hands, and placing the rags on the bearings. They would clean the bearings with the solvent soaked rags, and then dry the parts with a clean rag. They were exposed to solvents when the floors were cleaned. Axles were cleaned with solvents.

5. Electricians.

Electricians sprayed carbon tetrachloride from 55 gallon drums for 30 minutes at a time on electrical parts. They were required to climb into generator compartments immediately or shortly after the equipment had been sprayed with carbon tetrachloride to clean the mechanisms. They were exposed as by-standers when other crafts were using solvents.

III. SPECIFIC SOLVENT CHARACTERISTICS.

Over the past several decades, the pattern of industrial solvent use has been influenced heavily by discoveries of hazards and undue risks associated with certain compounds. Initially, the untoward health and safety effects of solvents were easily observed because they were so prevalent and severe: Fires, explosions, and unconsciousness from central nervous system effects occurred with alarming regularity.⁶

1. Benzene.

Benzene is a myelotoxic agent which causes leukemia, lymphoma, aplastic anemia, and multiple myeloma.⁷

a. Chemistry.

Benzene (C₆H₆) is an aromatic hydrocarbon. It is a volatile liquid, with a pleasant, distinctive odor. Benzene is significantly heavier than air, having a vapor density of 2.7 (air=1.0). It is hardly used today in the developed world as a solvent per se, but it may be present as a impurity in other organic solvents.

⁶Frangos, Stephen A. and Peters, John M. (1993). "Chlorinated hydrocarbon solvents: substituting our way toward human carcinogenicity." Am. J. Ind. Med. 24:355-364.

⁷Carcinogenicity will be discuss *Infra*.

b. State of the Art Knowledge.

[V]oluminous scientific publications dating as far back as 1928 ... associated benzene exposure to various cancers of the blood. A 1948 study commissioned by the American Petroleum Institute ("API") ... examined the state of art knowledge at that time and concluded that there were well-documented cases of leukemia resulting from benzene exposure. By the 1960's, many widely-disseminated scientific publications, including standard American medical journals and textbooks, were reporting the carcinogenic danger of benzene exposure as established through hundreds of individual cases. The literature also indicated that this danger existed even at relatively low concentrations of benzene vapor.⁸

c. Exposure Routes.

1. Oral Effects -- Oral ingestion of 9 to 12 g benzene has caused signs of staggering, gait, vomiting, somnolence, tachycardia, loss of consciousness, and delirium, with subsequent chemical pneumonitis, collapse involving initial stimulation, then abrupt CNS depression.⁹

2. Dermal Effects -- Benzene is irritating to the skin¹⁰ and, by defatting the keratin layer, causes erythema, vesiculation, and dry and scaly dermatitis.¹¹ Skin uptake of benzene in other solvents has become an important issue in exposure quantification.¹²

3. Inhalation Effects -- The geometric mean odor threshold for benzene is 60 parts per million (ppm), and 90 ppm for recognition.¹³ Workers exposed to 25 ppm benzene for two hours demonstrate benzene in the blood. When exposure rises to 50-150

⁸*Mason v. Texaco, Inc.*, 741 F.Supp. 1472, 1482 (D.Kan. 1990), *affirmed with remittitur*, 948 F.2d 1546 (10th Cir. 1991), *cert. denied*, ___ U.S. ___, 112 S.Ct. 1941, 118 L.Ed.2d 547 (1992).

⁹Von Oettingen, W.F. (1940). "Public Health Bulletin No. 255." U.S. Public Health Service, Washington, D.C.

¹⁰*Id.*

¹¹"Occupational Diseases, a Guide to their Recognition." (1977). M.M. Key, A.F. Henschel, J. Butler, R.N. Ligo, and I.R. Tabershaw, eds. NIOSH:Washington, D.C.

¹²Benzene skin exposure quantification is beyond the scope of this paper. However, consideration should be given to the following articles: Fiserova-Bergerova, V. *et al.* (1990) "Absorption potential of industrial chemicals: Criteria for skin notation." *Am. J. Ind. Med.* 17:617-635; Fiserova-Bergerova, V. (1993). "Relevance of occupational skin exposure." *Br. Occup. Hyg.* 37(6):673-685; Maibach, H. I. (1981). "Percutaneous penetration of benzene and benzene contained in solvents used in the rubber industry." *Arch. Environ. Health* 36(5):256-260; Wester, R. C. and Maibach, H. I. (1987). "Percutaneous absorption of organic solvents." In Maibach, H. I. (ed.) *Occupational and Industrial Dermatology*, 2nd Ed., Year Book Medical Publishers, Inc., Chicago, pp. 213-226; Blank, Irvin and McAuliff, Daniel (1985). "Penetration of benzene through human skin." *J. Invest. Derm.* 85:522-526; Ursin, Christian, *et al.* (1995). "Permeability of commercial solvents through living human skin." *Am. Ind. Hyg. Assoc. J.* 56:651-660.

¹³AIHA. (1989). "Odor Thresholds for Chemicals with Established Occupational Health Standards." American Industrial Hygiene Association. pp. 1-25.

ppm for five hours, headaches, lassitude, and weariness occur. High concentrations may result in paresthesia, disturbance of vision, dizziness, nausea, CNS depression and collapse.¹⁴

d. References.

1. U.S. Dept. of Labor, OSHA. 29 CFR Part 1910, Occupational Exposure to Benzene: Final Rule. Part II, Dept. of Labor. Fed. Reg. 52(176):34460-34578 (September 11, 1987).
2. "Benzene." In: Documentation of the Threshold Limit Values and Biological Exposure Indices. Vol. I, American Conference of Governmental Industrial Hygienists, Inc., Cincinnati, OH. 6th ed., (1991) pp. 188-120.
3. ATSDR. 1993. "Toxicological Profile for Benzene." U.S. Dept. of Health & Human Services. Agency for Toxic Substance and Disease Registry. Atlanta, GA. TP-92/03.
4. ATSDR. 1995. "Toxicological Profile for Benzene (Update)." U.S. Dept. of Health & Human Services. Agency for Toxic Substance and Disease Registry. Atlanta, GA. (Draft for Public Comment).

2. Carbon Tetrachloride.

Carbon Tetrachloride is no longer used as a solvent due to its ability to cause liver and kidney disease.

a. Chemistry.

Carbon tetrachloride (CCl₄) is a clear, colorless, heavy, mobile liquid with a sweet, ether-like characteristic odor. Carbon tetrachloride is significantly heavier than air, having a vapor density of 5.32 (air=1.0).

b. Exposure Routes.

1. Oral Effects -- Occasional fatalities from carbon tetrachloride-induced acute liver and/or kidney necrosis continue to occur as a result of ingestion.
2. Dermal Effects -- Volunteers who immersed one thumb in carbon tetrachloride for 30 minutes had measurable amounts of carbon tetrachloride in exhaled air five hours later. The investigators concluded that the amount of carbon tetrachloride that could penetrate the skin depended on the type of skin, the area exposed, and the duration of exposure. Using the data from the experimental exposure of one thumb, it was estimated that the amount of carbon tetrachloride absorbed during topical exposure of both

¹⁴Cavender, Finis. (1994). "Aromatic Hydrocarbons." In: *Patty's Industrial Hygiene & Toxicology*. 4th Ed. (George D. Clayton & Florence E. Clayton, eds.) Vol. 2, Part B. John Wiley & Sons, New York, NY. pp.1301-1442.

hands for 30 minutes would be equivalent to a vapor exposure of about 10 ppm for three hours.¹⁵

3. Inhalation Effects -- Acute and chronic carbon tetrachloride poisoning produces clinical symptoms ranging from abnormal serum-enzyme levels, nausea, anorexia, flatulence, vomiting, abdominal pain, diarrhea, jaundice, and enlarged/tender/fatty liver to renal failure, blurred vision, bleeding, dizziness, convulsions, unconsciousness, coma, and death. Kidney injury has been reported from what were thought to be single exposures in humans. The milder the exposure, the greater the tendency for the injury to be predominantly in the liver.¹⁶

d. Resources.

1. U.S. Dept. of Labor, OSHA. 29 CFR Part 1910.1000, Air Contaminants: Amended. Fed Reg. 58:35308-35340 (June 30, 1993); Corrected. Fed Reg. 58:40191 (July 27, 1993).

2. "Carbon Tetrachloride." In: Documentation of the Threshold Limit Values and Biological Exposure Indices. Vol. I, American Conference of Govt Industrial Hygienists, Inc., Cincinnati, OH. 6th ed., (1996 Supplement) pp. "Supplement: Carbon Tetrachloride 1-12."

3. ATSDR. 1992. "Toxicological Profile for Carbon Tetrachloride (Update)." U.S. Dept. of Health & Human Services. Agency for Toxic Substance and Disease Registry. Atlanta, GA. (Draft for Public Comment).

3. Trichloroethylene.

Trichloroethylene is used for vapor degreasing and as a solvent. There is extensive, sometimes conflicting, literature on the toxicology of trichloroethylene.

a. Chemistry.

Trichloroethylene (C₂HCl₃) is a colorless, nonflammable liquid with a sweetish odor resembling chloroform. It is heavier than air, having a vapor density of 4.53 (air=1.0). Under certain circumstances and in the presence of oxygen and heat, trichloroethylene is decomposed to hydrochloric acid and phosgene.

b. Exposure Routes.

¹⁵Steward, R.D. and Dodd, H.C. (1964). "Absorption of carbon tetrachloride, trichloroethylene, tetrachloroethylene, methylene chloride, and 1,1,1-trichloroethane through the human skin." Am. Ind. Hyg. Assoc. J. 25:439-446.

¹⁶Torkelson, T.R. (1994). "Halogenated Aliphatic hydrocarbons." In: *Patty's Industrial Hygiene & Toxicology*. 4th Ed. (George D. Clayton & Florence E. Clayton, eds.) Vol. 2, Part E. John Wiley & Sons, New York, NY. pg. 4072.

1. Oral Effects -- One report indicates an individual accidentally drank trichloroethylene. Severe injury occurred in both the liver and kidneys.¹⁷ The effects from ingestion are similar to inhalation.¹⁸ Long-term ingestion of trichloroethylene by mice caused increased liver and kidney weights in both sexes.¹⁹

2. Dermal Effects -- Like other solvents, trichloroethylene acts as a defatting agent and is absorbed through the skin. "Severe" contact with the skin has been reported to produce no metabolite of trichloroethylene in the urine.²⁰

3. Inhalation Effects -- Several laboratory studies have investigated trichloroethylene effects at concentrations near the TLV. Generally, these studies show no CNS effect at 100 ppm, marginal CNS effects at 200 ppm, and slight CNS effects above 300-400 ppm.²¹ However, case reports have found a variety of CNS disturbances at 40 ppm.²²

c. References.

1. U.S. Dept. of Labor, OSHA. 29 CFR Part 1910.1000, Air Contaminants, Table Z-2; Amended. Fed Reg. 58:35308-35340 (June 30, 1993); Corrected. Fed Reg. 58:40191 (July 27, 1993).

2. "Trichloroethylene." In: Documentation of the Threshold Limit Values and Biological Exposure Indices. Vol. I, American Conference of Govt Industrial Hygienists, Inc., Cincinnati, OH. 6th ed., (1996 Supplement) pp. "Supplement: Trichloroethylene 1-6."

3. ATSDR. 1993. "Toxicological Profile for Trichloroethylene." U.S. Dept. of Health & Human Services. Agency for Toxic Substance and Disease Registry. Atlanta, GA. TP-92/19.

¹⁷Kleinfield, M. and Tabershaw, I.R. (1954). "Trichloroethylene toxicity." Arch. Ind. Hyg. Occup. Med. 10:134-141.

¹⁸Torkelson, T.R. (1994). "Halogenated Aliphatic Hydrocarbons." In: *Patty's Industrial Hygiene & Toxicology*. 4th Ed. (George D. Clayton & Florence E. Clayton, eds.) Vol. 2, Part E. John Wiley & Sons, New York, NY. '3.5.3.2.1, pg. 4196. (hereinafter "Torkelson (1994)").

¹⁹Torkelson (1994), *Id.* at '3.5.3.3.1, p. 4197, citing Tucker, A.N., *et al.* (1982). "Toxicology of trichloroethylene in the mouse." Toxicol. Appl. Pharmacol. 62:351-357.

²⁰Frant, R. and Westendorp, J. (1950). "Medical control on exposure of industrial workers to trichloroethylene." Am. Med. Assoc. Arch. Ind. Hyg. Occup. Med. 1:308-318. But see, skin uptake discussion, fn. 12.

²¹Torkelson (1994), *Id.* at '3.5.3.6.1, pp. 4200-4201.

²²Haas, P.A. (1960). "Industrial hygiene investigation of trichloroethylene. Thesis No. 2979." Technische Hochschule, Zurich; Grandjean, E. *et al.* (1955). "Investigations into the effects of exposure to trichloroethylene in mechanical engineering." Br. J. Ind. Med. 12:131-142; Bardodej, Z. and Vyskocil, J. (1956). "The problem of trichloroethylene in occupation medicine. Trichloroethylene metabolism and its effects on the nervous system evaluated as a means of hygienic control." Arch. Ind. Health 13:581-592; and Lillis, R. *et al.* (1969). "Chronic effects of trichloroethylene exposure." Med. Lavoro 50:595-601.

4. Mineral Spirits.

Mineral spirits have been used as a diluent in paints and coatings, and as a degreaser and cleaner in mechanical shops. The significant problems associated with mineral spirits result from benzene contamination of mineral spirits. Many times the terms "mineral spirits," "Stoddard solvent," and "white spirits" are used interchangeably in the literature. The difference in the three solvents derives from the boiling range of each.

a. Chemistry.

Mineral spirits are a clear, colorless, mixture of hydrocarbons, with a boiling range of 302E to 392E F. They have a pleasant sweetish odor, and contain about 30% to 65% paraffins, 15 to 55% naphthenes and 10% to 30% aromatic hydrocarbons.

b. Exposure Routes.

Millions of industrial workers have been exposed to mineral spirits (Stoddard solvents, white spirits) through dermal contact and inhalation. The majority of the time no serious health effects have occurred.

However, follicular dermatitis can develop rapidly on repeated immersion of the hand and forearms in Stoddard solvents.²³ Combined percutaneous and inhalation exposure of Stoddard solvent (at concentrations associated with nausea) has been held responsible for production of frank hepatic toxicity and jaundice.²⁴ A number of fatalities due to aplastic anemia have been ascribed to occupational and consumer use of mineral spirits.²⁵

c. References.

1. U.S. Dept. of Labor, OSHA. 29 CFR Part 1910, Air Contaminants; Final Rule. Fed. Reg. 54(12);2429 (January 19, 1989).
2. "Stoddard solvent." In: Documentation of the Threshold Limit Values and Biological Exposure Indices. Vol. III, American Conference of Govt Industrial Hygienists, Inc., Cincinnati, OH. (1992) pp. 1428-1430.
3. NIOSH 1977. Criteria for a Recommended Standard -- Occupational Exposure to Refined Petroleum Solvents. DHEW (NIOSH) Pub. No. 77-192;

²³Braunstein, L.E. (1940). "Subacute yellow atrophy of the liver due to solvent." J. Am. Med. Assoc. 114:136-138.

²⁴Braunstein, *Id.*

²⁵Scott, J.L. *et al.* (1959). "Acquired aplastic anemia. An analysis of thirty-nine cases and review of the pertinent literature." *Medicine* 38:119-172; Prager, D. and Peters, C. (1970). "Development of aplastic anemia and the exposure to stoddard solvent." *Blood* 35:286-287.

5. Methylene chloride.

Methylene chloride is used in many industries as a degreaser, as a paint solvent, and as a paint stripper.

a. Chemistry.

Methylene chloride is a colorless, volatile liquid. The sweetish, not unpleasant odor, although distinctive, is not a good indication of exposure since the odor threshold is above the TLV.

b. Exposure Routes.

1. Dermal effects -- Methylene chloride causes pain when in contact with the skin. Burns are possible when the substance is confined by gloves, shoes, or tight clothing.

2. Inhalation effects --Numerous studies have demonstrated symptoms due to inhalation, including headache, giddiness, stupor, irritability, numbness, fatigue, and tingling in the limbs.²⁶

c. References.

1. U.S. Dept. of Labor, OSHA. 29 CFR Part 1910, Air Contaminants; Final Rule. Fed. Reg. 54(12);2429 (January 19, 1989).

2. NIOSH 1986. "Methylene Chloride, pp 1-16. Current Intelligence Bulletin 46. DHHS (NIOSH) Pub No. 86-114; NTIS Pub. No PB-86-208-303. National Technical Information Service, Springfield, VA.

3. "Methylene Chloride." In: Documentation of the Threshold Limit Values and Biological Exposure Indices. Vol. II, American Conference of Govt Industrial Hygienists, Inc., Cincinnati, OH. (1992) pp. 981-987.

IV. DISEASES ASSOCIATED WITH SOLVENT EXPOSURES.

A. Non-malignant Diseases.

1. Liver Diseases.

²⁶Collier, H. (1936). "Methylene dichloride intoxication in industry -- a report of two cases." *Lancet* 1:594-595; and Kuzelova, M. *et al.* (1966). "The effect of methylene chloride on the health of film production workers and studies of fomic acid as the methylene chloride metabolite." *Pracovni Lekarstvi* 18:167-170 (abstract. In: *Scientific Reports on Industrial Hygiene and Occupational Diseases in Czechoslovakia*, p. 69. Prague.)

a. Hepatocyte death (liver cell death) is the end-result of excessive or prolonged exposure to hepatotoxic agents. Carbon tetrachloride and trichloroethylene have been implicated in hepatocyte death.

b. Fatty liver is an excess accumulation of lipid in the parenchymal tissue of the liver. Carbon tetrachloride has been implicated as a cause of fatty liver, as has ethanol. It has been suggested that trichloroethane should be re-examined as a potential cause of fatty liver.²⁷

2. Kidney Disease.

Acute renal failure, acute tubular necrosis, chronic tubulointerstitial damage and different types of glomerulonephritis have been associated with various hydrocarbons, including carbon tetrachloride, methylene chloride, trichloroethylene, and 1,1,1-trichloroethane.²⁸

B. Malignant Diseases.

1. Leukemia.

a. All of the acute non-lymphatic leukemias (ANLL) as well as acute lymphocytic leukemia (ALL) and chronic myeloid leukemia (CML) are thought to originate as a result of genetic lesions to primitive stem cells in the bone marrow.²⁹ Experimentally, benzene has been shown to affect all cellular elements at all levels of stem cell hierarchy.³⁰ Thus, the type of cell to which these stem cells commit may result in the form of leukemia related to that cell line. Thus, it seems biologically plausible that benzene should cause most forms of leukemia.

b. Recent analyses of the Rinsky cohort by Crump³¹ shows a significant association between myeloid and monocytic leukemia and benzene exposure. Data in the Yin³² study also indicate a significant association between benzene exposure and AMoL

²⁷Hodgson, M. J., *et al.* (1989). "Liver disease associated with exposure to 1,1,1-Trichloroethane." *Arch. Intern Med.* 149:1793-1798.

²⁸See two excellent review articles: Yaqoob, M. and Gordon, M. B. (1994). "Occupational factors and renal disease." *Renal Failure* 16(4):425-434; and Nelson, Nancy A., *et al.* (1990). "Solvent nephrotoxicity in humans and experimental animals." *Am. J. Nephrol.* 10:10-20.

²⁹Bloomfield, *et al.* (1978). "The Philadelphia chromosome in acute leukemia." *Virchows Arch. B Cell Path.* 29:81-91; Yunis, J. J. (1983). "The chromosomal basis of human neoplasia." *Science* 221:227-235; Gill, D.P., *et al.* (1988). "The importance of pluripotential stem cells in benzene." *Toxicol.* 16:163-171.

³⁰Jacobs, Allan. (1989). "Annotation, benzene and leukaemia." *Br. J. Haematol.* 72:119-121.

³¹Crump, Kenny A. (1994). "Risk of benzene-induced leukemia: A sensitivity analysis of the Pliofilm cohort with additional follow-up and new exposure estimates." *J. Toxicol. Environ. Health* 42:219-242.

³²Yin, S.N., *et al.* (1989). "A retrospective cohort study of leukemia and other cancers in benzene workers." *Environ. Health Persp.* 82:207-213.

(3 observed vs. 0.66 expected, $p < 0.05$). The recent update of the study of Chinese workers exposed to benzene by the National Cancer Institute³³ (NCI) shows a significant dose response between cumulative benzene exposure and risk of AML (NCI includes AMoL in its category of AML).

2. Lymphoma.

- a. Benzene has been associated with lymphoma.³⁴
- b. Solvent exposure has been associated with lymphoma.³⁵

3. Multiple myeloma.

- a. Benzene can produce multiple myeloma.³⁶
- b. Painters are in a job classification that is exposed to various solvents and in which a relationship between multiple myeloma has been observed.³⁷
- c. An analysis of the American Cancer Society Prospective Study demonstrated a statistically significant risk of the development of multiple myeloma when

³³Yin, S.N. (1995). "A cohort study of cancer among benzene-exposed workers in China." Presented: Benzene '95: Program (June 17 - 20, 1995), New Brunswick, NJ.

³⁴Vianna, N.J. and Polan, A. (1979). "Lymphomas and occupational benzene exposure." *Lancet* 1:1394-1395.

³⁵Zoloth, S.R., *et al.* (1986). "Patterns of mortality among commercial pressmen." *J. Nat. Cancer Int.* 76:1047-1051; Hardell, L. *et al.* (1981). "Malignant lymphoma and exposure to chemicals, especially organic solvents, chlorophenols and phenoxyacids." *Br. J. Cancer* 43:169-176; Woods, J.S., *et al.* (1987). "Soft tissue sarcoma and non-hodgkin's lymphoma in relation to phenoxyherbicide and chlorinated phenol exposure in western Washington." *J. Nat. Cancer Int.* 78:899-910; Olsson, H. *et al.* (1988). "Risk of non-Hodgkin's lymphoma among men occupationally exposed to organic solvents." *Scand. J. Work Environ. Health* 14:246-251; Persson, B., *et al.* (1989). "Malignant lymphomas and occupational exposures." *Br. J. Ind. Med.* 46:516-520; Anttila, A., *et al.* (1995). "Cancer incidence among Finnish workers exposed to halogenated hydrocarbons." *J. Occup. Environ. Med.* 37(7):797-806; and Spirtas, R. *et al.* (1991). "Retrospective cohort mortality study of workers at an aircraft maintenance facility. I. Epidemiologic results." *Br. J. Ind. Med.* 48:515-530.

³⁶Rinsky, R.A., *et al.* (1987). "Benzene and leukemia, an epidemiologic risk assessment." *N. Eng. J. Med.* 316:1044-1050; Goldstein, B. (1990) "Is exposure to benzene a cause of human multiple myeloma?" *Ann. N.Y. Acad. Scien.* 609:225-230.

³⁷See Demers, Paul A., *et al.* (1993). "A case-control study of multiple myeloma and occupation." *Am. J. Ind. Med.* 23:629-639. (Lifetime job histories from a population-based, case-control study were analyzed to investigate the relationship between multiple myeloma and employment in various occupations and industries. An elevated risk for multiple myeloma was observed among persons ever employed as painters, odds ratio (OR)=2.1 [95% confidence interval (CI)=1.2-3.6]. The OR increased to 4.1 [95% CI=1.8-10.4] for those employed for 10 or more years.); Adelstein, A.M. (1972). "Occupational mortality: cancer." *Ann. Occup. Hygiene* 15:53-57; Berthwaite, P.B., *et al.* (1990). "Cancer risks in painters: Study based on the New Zealand Cancer Registry." *Br. J. Ind. Med.* 47:742-746; Cuzick J. and De Stavola, B. (1988). "Multiple myeloma--A case-control study." *Br. J. Cancer* 57:616-520; Freidman, G.D. (1986). "Multiple myeloma: Relation to propoxyphene and others drugs, radiation and occupation." *Int. J. Epidemiol.* 15:424-426; and Lundberg, I. (1986). "Mortality and cancer incidence among Swedish paint industry workers with long term exposure to organic solvents." *Scand. J. Work Environ. Health* 12:108-113.

"railroad" was identified as occupation [OR=6.0, p#0.05].³⁸ However, the odds ratio is based on a small number of exposed subjects.

d. A sheet metal worker with more than 10 years in the trade, appears to be an occupation related to multiple myeloma in a study of 4,576 cancer patients in Montreal, Canada.³⁹

4. Liver Cancer.

a. Degreasing solvents trichloroethylene, perchloroethylene, as well as carbon tetrachloride have produced liver tumors in animals.⁴⁰

b. Carbon tetrachloride may play a role in liver carcinogenesis.⁴¹

c. There is some epidemiological evidence suggesting a link between mixed solvent exposures and liver cancer.⁴²

d. A Chinese study of 3,400 patients found a small statistically significant excessive number of primary liver cancer cases among blacksmiths/machine-tool operators, offering some support for a potential link between employment in metal-related industries and liver cancer risks.⁴³

5. Brain Cancer.

a. Brain cancer has been linked to a variety of occupations, many of which involve exposure to organic solvents.⁴⁴

³⁸Boffetta, P. (1989). "A case-control study of multiple myeloma nested in the American Cancer Society Prospective Study." *Int. J. Cancer* 43:554-559.

³⁹Fritschi, Lin and Siemattyci, Jack. (1996). "Lymphoma, myeloma and occupation: results of a case-control study." *Int. J. Cancer* 67:498-503 [OR=6.5, Statistically Significant].

⁴⁰See Santodonato, J., *et al.* (1985a). "Monograph on Human Exposure to Chemicals in the Workplace: Trichloroethylene." Springfield, VA: National Technical Information Service; Santodonato, J., *et al.* (1985b). "Monograph on Human Exposure to Chemicals in the Workplace: Tetrachloroethylene." Springfield, VA: National Technical Information Service; and Louria, D.B. and Bogend, J.D. (1980). "The dangers from limited exposure to carbon tetrachloride." *CRC Crit. Rev. Toxicol.* 7:177-188.

⁴¹Pond, S.M. (1982). "Effects on the liver of chemicals encountered in the workplace." *West. J. Med.* 137(6):506-514; Neugut, Al. *et al.* (1987). "Occupational cancers of the gastrointestinal tract. II. Pancreas, liver, and biliary tract." *Occup. Med.* 2(1):137-153.

⁴²See Blair, A. (1980). "Mortality among workers in the metal polishing and plating industry, 1951-1969." *J. Occup. Med.* 22:158-162; Hernberg, S., *et al.* (1980). "Primary liver cancer and exposure to solvents." *Int. Arch. Occup. Environ. Health* 54:147-153; and Stenham, A., *et al.* (1983). "Occupational risk factors and liver cancer--a retrospective case-control study of primary liver cancer in New Jersey." *Am. J. Epidemiol* 117:443-454.

⁴³Wong-Ho Chow, *et al.* (1993). "Occupational risks for primary liver cancer in Shanghai, China." *Am. J. Ind. Med.* 24:93-100. (Standardized Incident Ratio (SIR)=1.20 (p#0.01)

⁴⁴See, Thomas, T.L. and Waxweiler, R.J. (1986). "Brain tumors and occupational risk factors: A review." *Scand. J.*

b. There have been a few epidemiologic studies which attempted to evaluate the potential for chlorinated aliphatic hydrocarbons⁴⁵ (CAHs) to cause cancer.⁴⁶ Most of these studies have been small in size and therefore have little power to detect increased risks.⁴⁷ Taken as a whole, the studies are inconsistent, but a trend is suggested that some of the CAHs may cause cancer.

c. CAHs ability to produce brain cancers is biologically plausible, and is supported by: (1) glial cells' (of which astrocytes are a subset) capability to transport environmental toxins and their ability to replicate;⁴⁸ (2) CAHs can pass the blood-brain barrier because of their high solubility in fats⁴⁹; and (3) CAHs demonstrate central nervous system effects.⁵⁰

d. In 1994, the National Cancer Institute conducted a case-controlled study of brain cancer among white males in Louisiana, New Jersey, and Philadelphia, Pennsylvania who had had previous exposure to CAHs.⁵¹ Carbon tetrachloride,

Work Environ. Health 12:1-15; Cordier, S., *et al.* (1988). "Gliomas and exposure to wood preservatives." *Br. J. Ind. Med.* 45:705-709; Preston-Martin, S., *et al.* (1989). "Risk factors for gliomas and meningiomas in males in Los Angeles County." *Cancer Res.* 49:6137-6143; Park, R. M. *et al.* (1990). "Brain cancer mortality at a manufacturer of aerospace electromechanical systems." *Am. J. Ind. Med.* 17:537-552.

⁴⁵Chlorinated hydrocarbons are typically colorless, volatile liquids with excellent solvent properties. Chlorinated hydrocarbon solvents are moderately well absorbed by inhalation. Skin absorption following prolonged contact of the skin with liquid can be significant. They have found wide use as solvents in degreasing. Six chlorinated aliphatic hydrocarbons are used as general industrial solvents: methylene chloride, chloroform, carbon tetrachloride, methyl chloroform, trichloroethylene, and perchloroethylene. Hall, Stephen K. (1997). "Solvent exposure and toxic responses." In: *Chemical Exposure and Toxic Responses* (S.K. Hall, Joana Chakraborty, R.J. Ruch, eds.) CRC Press, Inc., Boca Raton, FL, pg. 44.

⁴⁶See Preston-Martin, S. *et al. Id.*; Park, R. M., *et al., Id.*; Axelson, O. (1980). "Chlorinated hydrocarbons and cancer: Epidemiologic aspects." *J. Toxicol. Environ Health* 6:1245-1251; Blair, A. (1980). "Mortality among workers in the metal polishing and plating industry, 1951-1969." *J. Occup. Med.* 22:158-162; Blair, A., *et al.* (1990). "Cancer and other causes of death among a cohort of dry cleaners." *Br. J. Ind. Med.* 47:162-168; Hearne, T. F., *et al.* (1987). "Methylene chloride mortality study: Dose-response characterization and animal model comparison." *J. Occup. Med.* 29:217-228; Hearne, T. F., *et al.* (1990). "Absence of adverse mortality effects in workers exposed to methylene chloride: an update." *J. Occup. Med.* 32:234-240; Lanes, S. F. (1990). "Mortality of cellulose fiber production workers." *Scand. J. Work Environ. Health* 16:247-251; Norman, J.E. and Fraumeni, J. F., Jr. (1981). "The mortality experience of army World War II chemical processing companies." *J. Occup. Med.* 23:818-822.

⁴⁷Axelson, O., (1980) *Id.*; Blair, *et al., Id.*; Hearne, *et al., (1987) Id.*; Hearne, *et al., (1990) Id.*; Lanes, S.F. *et al., (1990) Id.*

⁴⁸Glees, P. (1988). "The Human Brain." Cambridge, NY: Cambridge University Press.

⁴⁹Sato, A. and Nakajima, T. (1979a). "A structure-activity relationship of some chlorinated hydrocarbons." *Arch. Environ. Health* 34:69-75; Sato, A. and Nakajima, T. (1979b). "Partition coefficients of some aromatic hydrocarbons and ketones in water, blood and oil." *Br. J. Ind. Med.* 36:231-234.

⁵⁰Putz, V. R., *et al.* (1976). "A comparative study of the effects of carbon monoxide and methylene chloride on human performance." *J. Environ. Pathol. Toxicol.* 2:97-112.; Waters, E. M., *et al.* (1977). "Trichloroethylene. I. An overview." *J. Toxicol. Environ. Health* 2:671-707.; Haley, T. J. and Berndt, W. O. (1987). *Handbook of Toxicology*. Hemisphere Publishing Corp. Washington, D.C.

⁵¹Heineman, Ellen F., *et al.* (1994). "Occupational Exposure to Chlorinated Aliphatic Hydrocarbons and Risk of Astrocytic Brain Cancer." *Am. J. Ind. Med.* 26:155-169.

chloroform, methylene chloride, methyl chloroform, tetrachloroethylene, and trichloroethylene, were studied individually and as a group under the matrix "organic solvents" to permit an evaluation of more generalized exposures.⁵² Work histories were determined, and exposure information formulated and assigned to each job classification. The NCI study concluded that:

- (1) Risk of astrocytic brain cancer increased significantly with the probability of exposure to organic solvents in general, and to methylene chloride in particular.
- (2) A two-fold risk of brain tumor was found to be statistically significant for men judged to have medium probability of exposure to carbon tetrachloride. (There was a two-fold risk of brain tumor in the same exposure category for chloroform and methyl chloroform but the finding was not statistically significant.)
- (3) Risk of brain cancer increased with duration in jobs considered exposed to all six CAHs and the "organic solvents" category. The increasing trends were statistically significant for "organic solvents" and methyl chloroform.
- (4) A 20-year latency consideration resulted in higher risks.
- (5) Brain tumor risk increased significantly with cumulative exposure scores for organic solvents and for carbon tetrachloride.
- (6) The strongest association was with methylene chloride, for which relative risks rose with probability, duration and average intensity.

6. Kidney cancer.

Tetrachloroethylene, trichloroethylene, petroleum solvents, and carbon tetrachloride have been demonstrated to be associated with kidney cancer in men and women.⁵³

IV. Conclusion.

Given the fact that fires, explosions, and unconsciousness were common occurrences with solvent use, it is difficult to fathom why railroads failed to protect their workers with personal protective equipment or even warn their employees of the hazards associated with

⁵²*Id.* at 158.

⁵³See Mandel, Jack S. (1995). "International renal-cell cancer study. IV. Occupation." *Int. J. Cancer* 60:601-605; See also Hardell L., *et al.* (1984). "Aetiological aspects on primary liver cancer with special regard to alcohol, organic solvents and acute intermittent porphyria - an epidemiological investigation." *Br. J. Cancer* 50:389-397; Hernberg, S. *et al.* (1988). "Increased risk for primary liver cancer among women exposed to solvents." *Scand. J. Work Environ. Health*, 14:356-365; Kadamani, S. *et al.* (1981). "Occupational hydrocarbon exposure and risk of renal-cell carcinoma." *Amer. J. Ind. Med.* 15:131-141; Spirtas R., *et al.*, (1991). *Supra.*; Axelson, O., *et al.* (1994). "Updated and expanded Swedish cohort study on trichloroethylene and cancer risk." *J. Occup. Med.* 36:556-562; Anttila, A., *et al.*, (1995). *Supra.*

solvent exposure that was being reported in the medical and scientific literature. Instead, workers were required to labor in unsafe conditions at least until the late 1980s, and in some instances until the 1990s. The development of blood and organ diseases was essentially preventable by simply following good industrial hygiene practices. To adequately vindicate these reprehensible acts, detailed work histories, including job classifications and solvent identification, along with a good working knowledge of solvent toxicology are essential in establishing a causal relationship between a railroad worker's disease process and his/her work environment.