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Historical Exposures to Chemicals at the Rocky Flats Nuclear Weapons Plant: A Pilot Retrospective Exposure Assessment

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Historical Exposures to Chemicals at the Rocky Flats Nuclear Weapons Plant: A Pilot Retrospective Exposure Assessment

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LIST OF ACRONYMS AND ABBREVIATIONS

ACGIH	American Conference of Governmental Industrial Hygienists
CAS	Chemical Abstract Service
CI	confidence interval
CL	confidence limit
GM	geometric mean
GSD	geometric standard deviation
HEPA	high efficiency particulate air
IARC	International Agency for Research on Cancer
MDL	minimum detection limit
MLE	maximum likelihood estimate
MSHA	Mine Safety and Health Administration
NIOSH	National Institute for Occupational Safety and Health
NOHS	National Occupational Hazard Survey
OR	odds ratio
OSHA	Occupational Safety and Health Administration
PEL	permissible exposure limit
PIR	proportional incidence ratio
PMR	proportional mortality ratio
RR	rate ratio
RTECS	Registry of Toxic Effects of Chemical Substances
SIR	standardized incidence ratio
SMR	standardized mortality ratio
TLV	Threshold Limit Values

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by

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ABSTRACT

In a mortality study of white males who had worked at the Rocky Flats Nuclear Weapons Plant between 1952 and 1979, an increased number of deaths from benign and unspecified intracranial neoplasms was found. A case-control study nested within this cohort investigated the hypothesis that an association existed between brain tumor death and exposure to either internally deposited plutonium or external ionizing radiation. There was no statistically significant association found between estimated radiation exposure from internally deposited plutonium and the development of brain tumors. Exposure by job or work area showed no significant difference between the cohort and the control groups.

An update of the study found elevated risk estimates for (1) all lymphopoietic neoplasms, and (2) all causes of death in employees with body burdens greater than or equal to two nanocuries of plutonium. There was an excess of brain tumors for the entire cohort. Similar cohort studies conducted on worker populations from other plutonium handling facilities have not yet shown any elevated risks for brain tumors.

Historically, the Rocky Flats Nuclear Weapons Plant used large quantities of chemicals in their production operations. The use of solvents, particularly carbon tetrachloride, was unique to Rocky Flats. No investigation of the possible confounding effects of chemical exposures was done in the initial studies.

The objectives of the present study are to (1) investigate the history of chemical use at the Rocky Flats facility; (2) locate and analyze chemical monitoring information in order to assess employee exposure to the chemicals that were used in the highest volume; and (3) determine the feasibility of establishing a chemical exposure assessment model that could be used in future epidemiology studies.

CHAPTER 1. INTRODUCTION

The purpose of this study is to evaluate the information available on chemical exposures at the Rocky Flats Nuclear Weapons Plant. The Rocky Flats Nuclear Weapons Plant was constructed in Golden, Colorado, in 1951. Its primary mission was the production of components used in nuclear weapons. Plant activities included manufacture and assembly of parts containing plutonium, beryllium, uranium, and other metals; recovery of plutonium; separation of americium from plutonium; and weapons research and development.

In a mortality study of white males who worked at the Rocky Flats Nuclear Weapons Plant between 1952 and 1979, an elevated number of deaths from benign and unspecified intracranial neoplasms was found (Voelz *et al.*, 1983). In a case-control study nested within this cohort, the hypothesis that an association existed between brain tumor death and exposure to either internally deposited plutonium or external ionizing radiation was investigated. No statistically significant association was found between estimated radiation exposure from internally deposited plutonium and the development of brain tumors (Reyes *et al.*, 1984). Likewise, no association was found between job or work area and brain tumors.

An update of the cohort mortality study (Wilkinson *et al.*, 1987) found elevated risk estimates for all lymphopoietic neoplasms and for all causes of death in employees with body burdens greater than or equal to two nanocuries of plutonium. There was an excess of brain tumors for the entire cohort. Similar cohort studies conducted on worker populations from other plutonium handling facilities have not yet shown any elevated risks for brain tumors (Voelz, 1991).

In Chapter 2, the Rocky Flats cohort studies and studies done at other nuclear facilities are reviewed in detail. A short discussion of the history and hazards of plutonium is included in this chapter.

Chapter 3 focuses on suspected causes of brain cancer and provides background for identifying other compounds which could be investigated as potential risk-increasing agents.

The use and handling of plutonium and the acids and bases used in its purification were similar in other the Department of Energy plutonium facilities, but the elevated brain tumor risk found at the Rocky Flats Nuclear Weapons Plant has not been observed at other plutonium facilities. The extensive use of solvents, particularly carbon tetrachloride, was unique to Rocky Flats.

Chapter 4 gives a short review of carbon tetrachloride toxicology. Carbon tetrachloride was used at the Rocky Flats facility as the primary degreasing agent for plutonium. The facility used hundreds of gallons of carbon tetrachloride per year. The degreasing of the parts was performed in glove boxes. The glove boxes are used at nuclear facilities to protect the employees from radiation. The amount of ventilation required to cause the boxes to be at negative pressure, relative to the atmosphere, is low since the boxes are not open to the atmosphere. This can lead to an accumulation of vapor within the box. The gloves installed in the boxes are designed to protect against radiation; they are not designed to protect against chemical contamination.

Since increased brain cancer rates have not been associated with either external radiation exposure or internal plutonium deposition, the possible relationship with chemical usage comes into question. The existing records from Rocky Flats are not sufficient to perform a direct epidemiological study of this question since the amount of industrial hygiene monitoring for chemical exposures was limited to only a few chemicals and operations. Therefore, the feasibility of performing a retrospective occupational exposure assessment was evaluated. Chapter 5 includes a literature survey of the basic methodologies used to assess retrospective exposure.

Chapter 6 gives a history of the Rocky Flats Nuclear Weapons Plant. The primary processes are described, and the chemicals used in each process are identified.

The methods used to identify, locate, and use the available information on chemical exposures at Rocky Flats are described in Chapter 7. The available historical exposure information located had to be compiled into a computer database so that the exposure information could be analyzed. The development of this database is explained in this chapter.

In Chapter 8, the information included in the database is detailed. The statistical analysis of the carbon tetrachloride data is explained. A high percentage of censoring was found in the data; the problems that this created are outlined. A computer program was written to assist in the statistical analysis. This computer program is described and the results of the statistical analysis presented.

The conclusions drawn from the results of the data analysis are discussed in Chapter 9.

CHAPTER 2. BACKGROUND

Plutonium has been called the most toxic substance on earth. Few compounds cause as much fear among the public as the radioactive metal used in the manufacture of nuclear weapons. The concern for the radioactive hazard has overshadowed the potential hazards caused by chemicals that are used in the manufacture and purification of plutonium.

Plutonium is a man-made transuranic metal. It was discovered in trace quantities in 1941 by G. T. Seaborg. Plutonium is structurally similar to radium, and like radium, is also an alpha emitter. The known relationship between radium exposure and bone cancer in radium dial painters caused concern about the hazards of plutonium. Consequently, studies on the effects of plutonium began immediately after the first man-made plutonium was produced in 1944 (Voelz, 1991).

Animal studies using both rodents and dogs were begun in 1944–45. The uptake, distribution, and excretion mechanisms were studied, as well as the acute and subacute effects of the metal. The acute toxicity was found to be less than that of curare, strychnine, or botulin. Internal deposition occurs after inhalation or absorption from contaminated wounds. Gastrointestinal absorption is low. Absorption through intact skin is negligible (Voelz, 1991).

Plutonium uptake is measured by analyzing urine samples. This method is a sensitive biological monitor and has been available since 1944. The primary ways employees have been exposed to plutonium are accidental inhalation and skin wounds. The plutonium that remains in the body serves as a reservoir. Alpha particles continue to be released, potentially causing damage to nearby cells. Plutonium decays according to the law of exponential radioactivity decay. Relative activity is a function of time. After exposure, plutonium is excreted throughout the lifetime of the employee. The biological half-life in the liver is approximately 40 years and in the bone, is approximately 100 years (Turner, 1986).

Plutonium deposits on bone surfaces and concentrates in the liver. Between 50 and 90 percent of inhaled, insoluble plutonium particles are retained in the lung and lymph nodes. The remainder becomes soluble in the body fluids and distributes to the bone (50 percent) and liver (30 percent) or is excreted (20 percent). The distribution pattern correlates with the results of long-term animal experiments that have shown elevated levels of bone, lung, and liver cancers (Voelz, 1991).

Since plutonium was first used in 1944, over 15,000 people have worked with the metal at Department of Energy (and predecessor) facilities. As of the late 1970s, approximately 5,000 of these employees have had positive body burdens (Voelz *et al.*, 1983).

The health of 26 workers who were heavily exposed to plutonium in 1944–45, during the initial development of the atomic bomb, has been studied. Their systemic burden has been estimated to be 7 to 230 nanocuries. The current allowable "lifetime" permissible body burden is 40 nanocuries. One subject died due to osteogenic sarcoma; however, no definitive adverse health effects were found in 40 years of follow-up (Voelz, 1991; Wilkinson *et al.*, 1987).

The study of the effects of plutonium was expanded in 1973 to include all workers from Los Alamos National Laboratory with greater than 10 nanocuries of estimated plutonium deposition. The cohort included 241 subjects who were exposed between 1943 and 1979. No excess mortality from any cause was seen (Voelz, 1991).

In 1976, the investigation was expanded to include all workers in the United States potentially exposed to plutonium and other transuranic elements. The majority of these workers had worked at the Rocky Flats Nuclear Weapons Plant in Colorado, Los Alamos National Laboratory in New Mexico, Savannah River Plant in South Carolina, or the Mound Facility in Ohio. A small number of workers from the Hanford Reservation in Washington and Oak Ridge National Laboratory in Tennessee were also included (Voelz *et al.*, 1983). Employment data was collected on 54,000 plutonium and nonplutonium workers. Approximately 80 percent of all the workers who had worked with plutonium in the United States were included. The vital status of 95 percent of the cohort members is known through 1983 (Voelz, 1991).

Within each cohort, workers were divided into groups. Exposed workers were defined as those with greater than one rem of external radiation and/or greater than 74 becquerels (2 nanocuries) of plutonium deposition. Twenty percent of the total cohort had been exposed to external radiation and 5.6 percent to internal deposition (Voelz, 1991).

Entry into plutonium use areas and the work done there has been severely regulated because of security requirements, making it easier to identify potentially exposed personnel. Approximately 25 percent of the employees of the facilities had been monitored at least once for plutonium deposition. Only 50 people had been identified as having above 1,480 becquerels (40 nanocuries) plutonium deposition (Voelz, 1991).

A preliminary mortality study of white males who worked at the Rocky Flats facility between 1952 and 1979 was done to evaluate the hypothesis that workers experienced elevated mortality rates (Voelz *et al.*, 1983). Because plutonium caused bone, liver, and lung cancer, as well as leukemia in animals, these diseases were of specific interest. Mortality ratios were not elevated for either all causes of death or for all malignant neoplasms.

Subdividing the cohort based on exposure to external radiation, above or below a total penetrating dose of 100 millirem, did not alter the results. There was no increased mortality among workers with cumulative plutonium exposure of more than one microcurie-day. The number of deaths from benign and unspecified intracranial neoplasms was higher than expected for the total white male population [8 observed versus 2.4 expected, standardized mortality ratio (SMR) = 332, 95% confidence interval (CI) = 143–653]. The excess among the plutonium-exposed (greater than 1 microcurie-day) cohort from these causes was not significantly high (2 observed versus 0.8 expected; SMR = 251, 95% CI = 28–907, p = 0.24). The excess was significant for the plutonium-unexposed (cumulative exposure less than or equal to 1 microcurie-day) cohort (6 observed versus 1.62 expected; SMR = 371, 95% CI = 136–808, p = 0.008). The group exposed to greater than 100 millirem of external radiation had a similar elevation (7 observed versus 1.89 expected; SMR = 371, 95% CI = 149–764) (Voelz *et al.*, 1983).

A nested case-control study was performed on a subset of those followed in the mortality study to investigate the hypothesis that an association existed between brain tumor death and exposure to either internally deposited plutonium or external radiation. No significant association was found with internally deposited plutonium. None of the cases identified had body burdens greater than background (1 nanocurie). The cases had higher external radiation exposure compared to the control group, but the difference was not statistically significant. Brain cancer levels were not significantly elevated (Voelz *et al.*, 1983). See Table 1 for a summary of the results of the study.

Estimates of exposure for different job or work areas were made. There was no significant difference found between the cases and the controls. No specific jobs or work areas had an elevated number of cases (Reyes *et al.*, 1984; Voelz, 1991).

TABLE 1

Summary of Rocky Flats Nested Case Control Study: Mortality from Cancer of the Brain and Other Cancers of the Central Nervous System for White Male Cohort (*N* = 7112) from Voelz *et al.*, 1983

Group	Standardized Mortality Ratio (SMR)	95% Confidence Interval of SMR
Total Cohort	123	53–243
Workers Exposed to > 1 microcurie-day	no cases observed	
Workers Exposed to ≤ 1 microcurie-day	188	81–370
Workers Exposed to > 100 mrem	117	43–254
Workers Exposed to ≤ 100 mrem	147	16–530

The initial cohort study (Voelz *et al.*, 1983) was updated in 1987 (Wilkinson *et al.*, 1987). The excess of intracranial brain tumors (categorized as benign and unspecified neoplasms) for the entire cohort was confirmed [SMR = 376; 90% Fisher's exact confidence limit (CL) = 177–707]. The rate ratios (RR) were elevated for all causes of death (RR = 1.14, 90% CL = 0.91–1.43) and for all lymphopoietic neoplasms (RR = 7.69, 90% CL = 0.99–72.93) in the group with a plutonium body burden of greater than two nanocuries, for a two-year induction period. There was an increase in unspecified brain and other central nervous system tumors for the group with a cumulative exposure of 1 rem for a 10-year induction period. The rate ratio was 3.96 (90% CL = 0.6–27.16) (Wilkinson *et al.*, 1987). Within the plutonium-exposed group, possible excesses for esophageal, stomach, colon, and prostate cancers were also present at certain induction times. Lung cancer rates were not elevated (Voelz *et al.*, 1992).

Nuclear Industry

Many studies have been performed to investigate the mortality patterns at nuclear facilities (Wilkinson, 1991). The results have not shown a consistent pattern. In studies of United Kingdom Atomic Energy Commission sites, Carpenter *et al.* (1990) found that all standardized mortality ratios (SMRs) were low after 25 years of follow-up, for both cancers and all other causes of death. Increased radiation exposure had no effect on overall death rates (Carpenter *et al.*, 1990). Beral *et al.* (1985) found increased mortality from prostate cancer with increased radiation exposure levels ($p = 0.01$). Inskip *et al.* (1987) found that employees with surface exposure from beta particle radiation had increased mortality from prostate cancer ($p = 0.001$).

Gilbert and Marks (1979) found no increased mortality levels in a study of Hanford. Excess mortality rates were found in nuclear fuels fabrication workers. In the cohort of male workers exposed to low-level gamma radiation and various industrial chemicals, the SMR for brain tumors was 2.67 ($p < 0.01$). There was no link to job group and no common chemical or radiation exposure (Hadjimichael *et al.*, 1983).

Checkoway *et al.* (1985) studied mortality among employees at Oak Ridge National Laboratory Y-12 Plant, where uranium was processed. Overall mortality, from all causes, was lower than expected. In the initial study, cancer of the brain and central nervous system, when compared to the United States average, was 9 observed versus 9.4 expected (SMR = 0.96), mortality from leukemia was 16 observed versus 10.72 expected (SMR = 1.49). The increase was not statistically significant (Checkoway *et al.*, 1985).

Carpenter *et al.* (1987) studied both internal and external radiation source exposures in a nested case-control study of the Y-12 and Oak Ridge National Laboratory populations. No support for an association between brain tumors and low-level radiation exposure or radiation exposure from deposited uranium was found.

A later study of the same population found that the mortality for lung cancer had an SMR of 1.36 (95% CL = 1.09–1.67), cancers of the brain and central nervous system had an SMR of 1.8 (95% CL = 0.98–3.02), and other lymphatic cancers had an SMR of 1.8 (95% CL = 0.85–3.53). There was no dose-response trend for either cumulative alpha or gamma radiation dose (Checkoway *et al.*, 1988). An SMR of 1.28 (95% CL = 0.76–2.02) for brain cancer and an SMR or 1.46 (95% CL = 0.92–2.22) for lymphatic cancer were found in a mortality study with an updated cohort (Loomis and Wolf, 1996).

A companion study investigated the effect of exposure to chemicals. Carpenter *et al.* (1988) used job classification codes and pay codes as surrogates for socioeconomic status. An industrial hygienist subjectively ranked each job for potential exposure to 26 chemicals. Several chemicals had elevated odds ratios: beryllium (OR = 1.5, 95% CI = 0.6–3.9); 4,4'-methylenebis(2-chloroaniline) (OR = 2.21, 95% CI = 0.8–6.0); and mercury (OR = 1.8, 95% CI = 0.5–5.8). None of the chemicals or chemical groups had significant effects on the risk of central nervous system cancers (Carpenter *et al.*, 1988).

Alexander (1991) reviewed the epidemiological studies that have been done at 10 United States nuclear facilities; he analyzed the brain tumor risks. Between 1970 and 1979, brain cancer rates for United States males were 4.9 deaths per 100,000. This type of cancer is unusual; therefore, a small number of cases can reveal an excess in a workforce of several thousand employees. There are no recognized confounding environmental risk factors (Alexander, 1991).

The combined standardized mortality ratio for 10 studies was 115 (142 observed versus 123 expected). For the period from 1970 to 1979, none of the counties in which the studies were conducted had significantly increased countywide brain cancer risk compared to the United States as a whole. Brain cancer was elevated in more of the studies (8) than any other tumor type. Alexander concluded that the increase in brain cancer risk is probably a "substantial" finding (Alexander, 1991).

Animal Studies

Ionizing radiation has been linked to the occurrence of brain tumors. Knowles produced nervous system tumors in groups of rats given 1 to 2 Grays of radiation. All but one of the tumors were gliomas. The tumors occurred at a frequency of 12 percent (Knowles, 1982).

This type of association was not found with inhalation exposure. Sanders *et al.* (1992) exposed 70-day-old Wistar rats to an aerosol of weapons grade ^{239}plutonium oxide for 30 minutes. The initial lung burden of one group was determined by a whole body count. The radiation dose to the lung was calculated. This group of rats were sacrificed 14 days post-exposure. Two other groups were similarly exposed and followed for their entire lifespan. The astrocytoma incidences for plutonium-exposed groups were approximately double that of the control groups for both sexes. The increase was not significant to the $p = 0.05$ level. No significant relationship between brain tumors and plutonium exposure was found (Sanders *et al.*, 1992).

Chemical Exposure

The next chapter contains a literature survey of the suspected links between chemicals and brain tumors, both benign and malignant. Some of the occupations and chemicals identified as related to brain tumors in the reviewed studies were potentially present at Rocky Flats. No investigation of the possible confounding effects of chemical exposures was done in the studies reported earlier (Voelz *et al.*, 1983; Reyes *et al.*, 1984; Wilkinson *et al.*, 1987). Consequently, there is a need to further investigate the possibility that a chemical or combinations of chemicals contributed to the elevated risk.

CHAPTER 3. SUSPECTED CAUSES OF BENIGN AND MALIGNANT BRAIN TUMORS

Brain tumors (benign and malignant combined) are the second leading cause of death from neurological disease, behind strokes (Preston-Martin, 1989). Approximately two percent of all cancers are brain cancers. Incidence rates of brain tumors in the United States increased between 1937 and 1971. Brain tumors are more frequent in males than in females (1.4 : 1.0) and are more frequent in whites than in other races (1.5 : 1.0) (Gold, 1980).

Central nervous system tumors in people over 55 have been increasing in incidence and mortality since the 1940s. The highest mortality occurs in white males (Kessler and Brandt-Rauf, 1987). Davis *et al.* (1991) analyzed age-specific trends in brain cancer from 1968 to 1987 in six industrialized countries. In all of the countries studied, older people had increased brain cancer mortality rates in 1986 over 1968, and males had higher rates than females. France and Italy had increasing rates of brain and nervous system cancer mortality in all age groups: in the 45 to 84 age group, the 1986 brain and central nervous system cancer mortality rate was 40 percent above the 1968 rate and in the 65 to 84 age group, the brain and nervous system mortality rate ranged from two to three times the 1968 rate (Davis, *et al.*, 1991).

The United States, West Germany, and the United Kingdom had similar age-specific trends, with the greatest mortality rate increases in the oldest age groups (Davis *et al.*, 1991). This apparent increase has lead to research for carcinogens which can be linked to brain cancer. The cause could be environmental or occupational in origin, given the age of occurrence and the time trend (Kessler and Brandt-Rauf, 1987).

General Studies

Several studies have been published that implicate chemical exposure in the etiology of brain tumors. Brain tumor clusters have been identified in polyvinyl chloride production workers, oil refinery workers, pharmaceutical manufacturing workers, formaldehyde production workers (Thomas and Waxweiler, 1986), firefighters (Aronson *et al.*, 1994), plumbers and pipefitters (Cantor *et al.*, 1986), petrochemical production workers, chemists, rubber workers (Monson and Fine, 1978; Mancuso, 1982; Englund *et al.*, 1982), and workers in occupations linked to organic solvent use (Heineman *et al.*, 1994; Gomez *et al.*, 1994; Anttila *et al.*, 1995). Thomas and Waxweiler reviewed the published literature in 1986. White collar workers, who presumably had minimal occupational exposure to chemicals, had elevated brain cancer risk compared to the general population [standardized mortality ratio (SMR) = 1.34, $p < 0.05$]. Four surveys showed elevated brain cancer mortality ratios for electricians and power servicemen (Thomas and Waxweiler, 1986). Demers *et al.* (1991) found that the risk of all brain tumors, gliomas, and astrocytomas increased with increased socioeconomic status [highest quartile odds ratio

(OR) for all brain tumors = 1.9, 95% confidence interval (CI) = 1.4–2.5, $p <$ 0.001]. In a survey of primary brain tumors in Los Angeles County, California, the occupations with an age-adjusted proportional incidence ratio (PIR) excess of gliomas included aeronautical and astronautical engineers (PIR = 161.4, $p \leq$ 0.05), airline pilots (PIR = 276.5, $p \leq 0.05$), electricians (PIR = 175.6, $p \leq 0.05$), and construction laborers (except carpenters) (PIR = 186.6, $p \leq 0.05$). Meningioma excess occurred in woodworkers (PIR = 227.3, $p \leq 0.05$), computer specialists (PIR = 884.8, $p \leq 0.01$), chemists (PIR = 720.6, $p \leq 0.01$), and machine operators (PIR = 531.3, $p \leq 0.01$) (Preston-Martin, 1989).

Correlations with ethnicity, religion, birthplace, and social class were also found. People of Jewish origin had an excess of all tumor types, except meningioma (PIR of 117 to 189 with $p \leq 0.05$). Among males, there was an increase in incidence with increase in social class for gliomas (PIR = 136, $p \leq$ 0.01), nerve sheath tumors (PIR = 165, $p \leq 0.01$), and all histologic types combined (PIR = 130.5, $p \leq 0.01$) (Preston-Martin, 1989). (PIRs given are for the highest social class.)

Table 2 lists some of the occupations which have been investigated for increased brain tumor risk.

Heineman *et al.* (1996) evaluated 276 women diagnosed with brain tumors in Shanghai, China. They identified the patient's occupation and industry of employment at the time of the diagnosis. There was an excess

TABLE 2

Summary of Epidemiology Study Results Reporting Elevated Odds Ratios for Brain Tumors by Occupation and Tumor Type

Occupation	Cancer Type	Odds Ratio	95% Confidence Interval of Odds Ratio	Reference
Electricians, electronics workers, and utility workers	brain cancer	3.94	1.52–10.2	Speers, et al., 1988
Livestock farmers	brain cancer	2.69	1.46–4.95	Reif, et al., 1989
Occupations with potential for high exposure to electric and magnetic fields	astrocytomas	4.3	1.2–15.6	Preston-Martin et al., 1989
Occupations with exposure to electromagnetic fields	astrocytomas	10.3	1.3–80.8	Mack et al., 1991)
Plant and systems operators	brain tumors and gliomas	4.5	1.1–9.0	Demers et al., 1991
Plant and systems operators	astrocytic tumors	4.7	1.1–20.4	Demers et al., 1991
Social science professionals	"other" cell types	19.0	2.1–145.6	Brownson et al., 1990
Teachers	brain tumors	4.1	1.4–12.3	Cordier et al., 1988
Utility workers	brain cancer	13.10	1.33–128.97	Speers, et al., 1988

among grain farmers [standardized incidence ratio (SIR) = 6.5, CI = 1.3–19.1], and rubber workers (SIR = 5.0, CI = 1.6–11.6). Potential exposure to solvents also increased the risk (SIR = 1.3, CI = 1.1–1.6) (Heineman *et al.*, 1996).

Musicco *et al.* (1988) investigated 240 brain glioma cases and 742 controls in the area of Milan, Italy. They found that farmers had a statistically significant risk increase (relative risk (RR) = 1.6, $p = .0025$). Farmers who did not use chemicals did not have an elevated relative risk. Insecticide and fungicide users had a relative risk of 2.0, $p = 0.006$ (Musicco *et al.*, 1988).

Vinyl Chloride Studies

Vinyl chloride was identified as a carcinogen because of a small cluster (three cases) of a very rare angiosarcoma of the liver. During the study of this disease, it was found that an increased risk for brain tumors existed among workers exposed to vinyl chloride for more than 15 years. Inhalation studies in rats also found elevated brain tumors (Moss, 1985). Recent epidemiology studies have failed to confirm the association of vinyl chloride monomer and brain cancers (Hagmar *et al.*, 1990; Wu *et al.*, 1989).

Petroleum Industry Studies

Many studies have been performed to investigate suspected elevated cancer levels at oil refineries (Waxweiler *et al.,* 1983; Wen *et al.,* 1982; Divine and Barron, 1986; Theriault and Provencher, 1987; Thomas *et al.,* 1982a, b, 1987a; Bertazzi *et al.*, 1989; Nicholson *et al.*, 1982). The results are not conclusive.

Thomas *et al.* (1982a) studied mortality patterns at three oil refineries. The proportional mortality ratios (PMR) for all cancers were1.17 for white males and 1.23 for nonwhite males. Malignant brain tumor deaths among oil refinery workers were twice that expected among the white male cohort. Among active union members, brain tumor deaths had a PMR of 2.29. No specific compounds were identified (Thomas *et al.*, 1982a). Among people who had ever (versus never) been employed in either the petroleum refining industry or in the chemical manufacturing industry, the odds ratios for astrocytic brain tumors were not significantly elevated (Thomas *et al.*, 1987a). Wen *et al.* (1982) found no significant excess among benzene workers (1952 to 1976) and solvent dewaxing workers (1935 to 1976).

In a National Institute for Occupational Safety and Health (NIOSH) mortality study of petrochemical workers, the SMR for brain tumor deaths increased with duration of employment. Fifteen years after initial hiring, there were 19 deaths versus 7.2 expected among males (SMR = 263) (Waxweiler *et al.*, 1983).

Theriault and Provencher (1987) studied the mortality of workers at a Canadian oil refinery. In the group employed between 6 and 19 years, four brain cancers were found. This resulted in an SMR of 519.5. When production worker mortality rates were analyzed separately, the SMR was 310.08. The only common exposure identified was to petroleum residues (Theriault and Provencher, 1987).

Bertazzi *et al.* (1989) performed a similar study at an Italian refinery. Most cancers were elevated (brain SMR = 170, 95% CI = 54–411; lymphatic and hematopoietic cancer SMR = 186, 95% CI = 87–354; and kidney SMR = 325, 95% CI = 83–887). Brain tumor and kidney cancer elevations were related to the early years of employment. The brain tumor excess could not be linked to any specific job or exposure (Bertazzi *et al.*, 1989).

Nicholson *et al.* (1982) compared the deaths of 590 members of the International Union of Operating Engineers employed in chemical and petrochemical industries to 742 members employed in construction or maintenance. Cancer-related mortality among members employed in the chemical and petrochemical industries was elevated by 22 percent over that expected. The incidence of brain tumors was elevated 73 percent. When employment categories were considered, nonmalignant brain tumors were elevated among operators with less 20 years of employment (PMR = 476, $p < 0.05$). Among operators with less than 20 years employment in chemical plants, the ratio for all brain tumors was elevated (PMR = 385, $p = 0.05$) (Nicholson *et al.*, 1982).

Wong and Raabe (1989) performed a meta-analysis of site-specific cancer mortality, using data from almost 100 published and unpublished studies about petroleum industry employees. The meta-standardized mortality ratio was 1.0, $p = .99$, identical to mortality in the general population (Wong and Raabe, 1989).

Chemical Industry Studies

Several studies have attempted to link chemical exposure to brain tumors (Bond *et al.* 1983; Reeve *et al.*, 1983; Rinsky *et al., 1988;* Austin and Schnatter, 1983b; Teta *et al.*, 1991; Delzell *et al.*, 1989). Olin and Ahlbom (1980) reported increased malignant gliomas among Swedish chemical engineers. However, a later case-control study failed to identify any specific chemical which was related to increased relative risk (Olin *et al.*, 1987).

Bond *et al.* (1983) performed a plant-wide case-control study to investigate an apparent excess brain tumor risk among Dow Chemical workers who were first employed before 1945. Subjects were classified by presumptive exposures. With one control group, the matched odds ratio for employees with potential exposure to carbon tetrachloride was 1.5 (90% CI = 0.6–3.74). Only two cases were involved (Bond *et al.*, 1983, 1982). Reeve *et al.* (1983) reported that in a sample-based cohort study of the same plant, the SMR of brain tumor deaths for those employed over four years was 170.

Austin and Schnatter (1983b) investigated chemical exposures and malignant brain tumors by following a cluster of cases among former employees of the Union Carbide Corporation chemical plant in Texas City, Texas. They studied 6,588 white male workers who had been employed for at least one day between 1941 and 1977. There were 12 cases of malignant neoplasm of the brain and central nervous system observed versus 7.42 expected (SMR = 162; 95% CI = 83–283, not significantly elevated). Among hourly employees, there were 10 cases of malignant neoplasm of the brain and central nervous system observed versus 5 expected (SMR = 200, $p < 0.05$). No specific compounds were suspected of causing the excess (Austin and Schnatter, 1983b). When known or suspected carcinogens were studied (benzene, ethylene dichloride, ethylene oxide, diethyl sulfate, and vinyl chloride), as well as 37 other chemicals to which brain tumor patients had been exposed; no specific associations were found (Austin and Schnatter, 1983a).

Teta *et al.* (1991) updated this study, adding six years to the follow-up. Benign and unspecified brain tumors cases were elevated (7 observed versus 2.5 expected, SMR = 280, 95% CI = 114–577, $p < 0.05$). Brain cancer was elevated (17 observed versus 9.4 expected, SMR = 181; 95% CI = 106–289, $p < 0.05$). The highest number of cases assigned to any one production area was three. The polyethylene finishing area accounted for 20 percent of production workers with brain tumors. These employees had worked in the area for an average of 16 years, compared to the overall plant average of 4 years. Thirty percent of the men who developed brain neoplasms had worked in vinyl chloride related work areas, compared to 24 percent of all production workers. Among the maintenance workers, there was an SMR of 190 for total brain neoplasms. The excess was greater in nonwhites. These results were not sufficient to identify a specific chemical cause (Teta *et al.*, 1991).

Rubber Industry

Monson and Fine (1978) found increased brain cancer (8 observed versus 1.3 expected, SMR = 4.1) among men under 65 who worked in tire assembly and began work before 1925. No specific chemical was linked to the elevation. Some possibilities included coal tar volatiles and various solvents. Carbon tetrachloride was used as an additive to reduce the flammability of other solvents (Monson and Fine, 1978). Symons *et al.* (1982) reviewed several studies from the United States rubber industry. This study found no increase in cancer among workers in these areas versus controls (Symons *et al.*, 1982).

Electrical Workers

Lin *et al.* (1985) studied white male Maryland residents who died from brain tumors between 1969 and 1982. Men employed in electricity-related occupations had a higher proportion of primary brain tumors, especially gliomas/astrocytomas. The odds ratio was positively related to the level of possible exposure to electromagnetic fields. The groups with "definite electromagnetic exposure" and "possible electromagnetic exposure" had 95% confidence intervals above 1.0 (OR = 2.15 and 1.44 respectively). Glioma/astrocytoma patients with definite electromagnetic field exposure died at younger ages than those without exposure ($t = 2.23$, $p < 0.05$) (Lin *et al.*, 1985). Ryan *et al.* (1992) found an increased risk of glioma in women who reportedly worked with cathode-ray tubes [rate ratio (RR) = 4.1, 95% CI = 1.3–13.2]. Other studies (Tynes *et al.*, 1992; Sahl *et al.*, 1993) have not found increased risk.

Sinks *et al.* (1993) investigated whether the cumulative exposure to polychlorinated biphenyls (once used in electrical transformers and capacitors) was related to brain cancer. An increase above the expected number of deaths from brain and nervous system cancer (5 observed versus 1.8 expected) was seen. The individuals with brain cancer had had a longer duration of employment and had received more than two times the estimated cumulative dose of the comparison group (Sinks *et al.*, 1993).

Thomas *et al.* (1987b) performed a case-control study of brain tumor deaths chosen from among death certificates in New Jersey, Philadelphia, Pennsylvania, and the gulf coast of Louisiana. Men who had worked in jobs with potential exposure to microwave and radiofrequency radiation were identified. An excess risk was found for men who had a job involving the design, manufacture, installation, or maintenance of electronic or electrical equipment (RR = 2.3; 95% CI = 1.3–4.2). Astrocytic tumors were then investigated separately. The relative risk increased to 4.6 (95% CI = 1.9–12.2). For men who had ever worked in manufacturing or repair of electronics, the risk of astrocytic tumors rose with duration of employment to a peak of 10-fold after 20 years of employment (Chi-square test, $p < 0.05$) (Thomas *et al.*, 1987b).

Heineman *et al.* (1994) expanded upon the study by Thomas. Job-exposure matrices were developed for six chlorinated aliphatic hydrocarbons with demonstrated mutagenic or carcinogenic effects. Each industry and job was assigned a semi-quantitative estimate of probability and intensity of exposure. The matrices were linked to the work histories. Three surrogates of dose were assigned to each study subject: duration of employment in exposed jobs, cumulative exposure, and "average" exposure (Heineman *et al.*, 1994).

Risk increased as the probability of exposure to organic solvents, specifically to methylene chloride, increased. It also increased with duration of employment in jobs with exposure to organic solvents and the individual solvents. Risks were highest among subjects with a high intensity of exposure, and risk increased with more than 20 years employment at high intensity. The strongest association was for carbon tetrachloride (all probabilities: OR = 1.8, 95% CI = 0.7–4.6), methylene chloride (all probabilities: OR = 6.7, 95% CI = 1.3–4.74), and trichloroethylene (all probabilities: OR = 5.1, 95% CI = 0.9–36.7). When a logistic regression was run to separate the effects of different chlorinated aliphatic hydrocarbons, the risk of astrocytic brain tumor increased two-fold among men exposed to methylene chloride (controlling for exposure to other solvents). They found the strongest association with methylene chloride, and relative risks rose with probability, duration, and average intensity of exposure (the Chi test for trends had $p < 0.05$) (Heineman *et al.*, 1994; Gomez *et al.*, 1994).

Park *et al.* (1990) performed a proportional mortality ratio analysis of a plant which manufactured guidance systems. Sixteen brain cancer deaths met the study criteria of 10 or more years of service. The PMR for deaths between 1981 and 1986 was 7.8 (p = .00001). Among hourly workers, PMR was 4.4 (p = .00005). Among men with job histories, the PMRs were highest in groups with high cumulative exposures to chlorofluorocarbons, chlorinated hydrocarbon solvents, and cutting fluids. For females, the PMR was highest for those who had clean-room jobs for a long duration (PMR = 12, p = .004) (Park *et al.*, 1990).

Chemicals Linked to Brain Tumors in Animals

The results of animal studies have identified several chemicals as potential carcinogens. Gliomas can be induced by experimental exposure of rats to aromatic hydrocarbons, N-nitroso compounds, triazenes, and hydrazines (Moss, 1985). Methylnitrosourea intravenously administered produces tumors at the site of application. When given at a rate of 5 mg/kg of body weight each week for 32 to 36 weeks, mehylnitrosourea produced a 90 to 100 percent brain tumor incidence in male Sprague-Dawley rats. Acrylonitrile produced brain tumors in a dose-related manner following inhalation or ingestion by drinking water (Swenberg, 1982). Acrylonitrile was also reported to produce increased incidence of gliomas at 20 and 40 parts per million (Maltoni *et al.*, 1982). The same study found that vinyl chloride produced neuroblastomas in rats at concentrations above 2,500 parts per million (Maltoni *et al.*, 1982).

In the National Cancer Institute bioassay program, propylene imine and propane sultone induced brain or central nervous system tumors. When administered intracranially, polynuclear aromatic hydrocarbons induced brain tumors in rodents (Ward and Rice, 1982). Examples of these polynuclear aromatic hydrocarbons include 3-methylcholanthrene, polycyclic hydrocarbons, dibenzanathracene, trimethylbenzanthracene (Crafts and Wilson, 1977), N-nitroso compounds, hydrazines, aryl diakytriazenes, and alkylating agents (Ward and Rice, 1982).

CHAPTER 4. CARBON TETRACHLORIDE

Summary of Toxicity

Carbon tetrachloride is a volatile, colorless, nonflammable liquid. It is miscible with organic solvents. While generally stable, it will decompose to carbon dioxide, hydrogen chloride, phosgene, and chlorine on contact with fire. It was used as an anesthetic beginning in 1847, but was later replaced by chloroform when its liver toxicity was discovered (Recknagel, 1967). In 1970, over one billion pounds of carbon tetrachloride was produced in the United States (IARC, 1972). Solvent usage included degreasing and dry cleaning (IARC, 1972). The toxicity of carbon tetrachloride has been extensively studied.

The oral LD_{50} in rats is 2.92 grams per kilogram of body weight (IARC, 1972). High doses cause death by central nervous system depression within hours of the exposure. Even subnarcotic doses can cause death by liver damage. Rabbits and guinea pigs exposed to 50 parts per million over 200 days (40 to 150 exposures) developed increased liver weight, moderate fatty degeneration, and cirrhosis. Rats and monkeys exposed to 100 parts per million had similar adverse effects (IARC, 1972).

In 1970, the Occupational Safety and Health Administration (OSHA) adopted a permissible exposure limit (PEL) of 10 parts per million for an eight-hour time-weighted average, over a 40-hour week (Paustenbach, 1985). The

American Conference of Governmental Industrial Hygienists (ACGIH) establishes voluntary Threshold Limit Values (TLV) based upon available information from industry, and from human and animal studies. They are intended for use as guidelines to control potential health hazards (Department of Energy facilities use the ACGIH guidelines whenever they are lower than the OSHA regulations). The 1996 TLV for carbon tetrachloride is 5 parts per million. It carries a "skin" notation, indicating that a potentially significant portion of the overall exposure may be by the cutaneous route via contact with vapors or direct contact. Carbon tetrachloride is also listed as a "suspected human carcinogen" (American Conference of Governmental Industrial Hygienists, 1996).

Routes of Exposure

Carbon tetrachloride is absorbed rapidly after inhalation or application to injured skin. Human deaths have occurred from central nervous system depression, pulmonary edema, alveolitis, and cardiac arrhythmias after inhalation. Renal failure severity is increased when alcohol is also consumed. Inhalation is the principal documented occupational exposure route.

An estimated 60 percent of inhaled carbon tetrachloride is absorbed across the lungs of humans (Lehmann and Schmidt-Kehl, 1936). Stewart *et al.* (1961) investigated inhalation exposure of carbon tetrachloride by human volunteers. The men were exposed to a time-weighted average of 10 to 11 parts per million for 3 hours, or to 49 parts per million for 70 minutes. None reported adverse physiologic effects. Expired air was collected over a 6 hour period. The 10 to 11 parts per million exposure resulted in an expired air value of 2.5 parts per million immediately post exposure, 1 parts per million after 15 minutes, and 0.27 parts per million after 5 hours. The higher exposure test resulted in 15 parts per million immediately post exposure, 3 parts per million at 30 minutes, and 0.29 parts per million at 5.5 hours. The amount of carbon tetrachloride in expired air decreased exponentially with time (Stewart *et al.*, 1961).

Skin absorption is a potentially significant source of exposure. Solvents are often splashed onto the skin during handling of degreased parts. Jakobson *et al.* (1982) measured the uptake of carbon tetrachloride via the blood after epicutaneous exposure of guinea pigs. The concentration in the blood increased rapidly within one hour of exposure. It then decreased, even with continued exposure, possibly due to (1) vasoconstriction in exposed skin, (2) rapid transport from the blood to adipose tissue, or (3) biotransformation (Jakobson *et al.*, 1982). Tsuruta (1975) found that the uptake rate in mice (540 nanomole per minute per centimeter^2) is high enough to be comparable to inhalation.

Stewart and Dodd (1964) investigated the skin absorption of carbon tetrachloride. Three volunteers immersed their thumb in the solvent for 30 minutes. Immediately after the 30-minute immersion, the mean peak breath concentration was 0.64 parts per million. The mean breath concentration after 2 hours was 0.36 parts per million. The authors estimated that the immersion of both hands (with a 40-fold increase of surface area) for 30 minutes would increase the absorption 40 times. This would approximate a 30-minute inhalation exposure of 100 to 500 parts per million. They believed that "topical application to both hands for 30 minutes would be equivalent to a vapor exposure of about 10 parts per million for three hours" (Stewart and Dodd, 1964). Sufficient material can be absorbed through the skin to result in systemic injury. Kronevi *et al.* (1979) applied one milliliter of carbon tetrachloride to guinea pig skin. Sixteen hours after the start of the exposure, hepatocytes in the central two-thirds of each liver lobule showed cytoplasmic changes (Kronevi *et al.*, 1979).

Metabolism, Distribution, and Toxicokinetics

Once a material enters the body, it is absorbed, redistributed to the major organ systems, and metabolized; the remainder is eliminated. Distribution is proportional to regional blood flow. Excretion is via the renal or pulmonary routes (Baker and Fine, 1986). The blood to air partition coefficient of carbon tetrachloride in rats is 4.52, the fat to blood partition coefficient is 79.4, and the liver to blood partition coefficient is 3.14 (Gargas *et al.*, 1986).

Gargas *et al.* (1986) investigated the inhalation absorption of carbon tetrachloride in rats. The shape of the uptake curves were a function of the tissue partition coefficient and the metabolic constants. The carbon tetrachloride curves fit the model representing a single saturable metabolic pathway (Gargas *et al.,* 1986).

Twenty-five percent of cardiac output goes to the liver. The biotransformation of solvents often occurs there. This decreases the concentration of the solvent in the hepatic and mixed venous blood, permitting continuous uptake from the lungs (Astrand, 1985). In humans, carbon tetrachloride has been found in the blood six weeks after carbon tetrachloride poisoning, possibly indicating storage in the adipose tissue (Teschke *et al.*, 1983).

Kim *et al.* (1990) studied the pharmacokinetics of orally administered carbon tetrachloride in rats. The total body clearance was 0.13 ± 0.02 milliliter per minute per gram of body weight. A comparison of the volume in the central compartment (1.63 ± 0.39 milliliter/ gram) versus volume of distribution (19.2 ± 5.4 milliliter/ gram) indicates that a large part of the solvent distributes into peripheral tissues. The biological half-life was similar to the injected value (105 minutes) (Kim *et al.*, 1990).

Paustenbach *et al.* (1986a, b; 1988) have proposed a physiologically based pharmacokinetic model for inhaled carbon tetrachloride. Rats were exposed to 100 parts per million of carbon tetrachloride for either 8 or 11.5 hours per day over 1 or 2 weeks. The principal elimination was via exhaled air (biological half-life of 1 to 3 hours) with small amounts eliminated in the urine and feces (Paustenbach *et al.*, 1986a, b).

After four days, the tissue burdens were higher (20–45 percent) in the liver, kidney, adrenals, lung, spleen, and brain tissue of the group exposed eight hours per day for one week. After 1 to 2 weeks of exposure, the amount of carbon tetrachloride eliminated in the urine was greater in the 8 hours/day group than in the 11.5 hours/day group. The half-life was 30 percent longer for this group. Elimination in the feces was less in the 8 hours/ per day group (Paustenbach *et al.*, 1986a, b).

Forty percent was excreted in the feces (Paustenbach *et al.*, 1986a). Three percent of the exhausted material was chloroform ($CHCl_3$). Six percent was metabolized to carbon dioxide and exhaled. Forty to fifty percent was eliminated unchanged in exhalation. Clearance of tissue radioactivity had a biological half-life of 24 hours, indicating that the metabolite was bound to long-residence time adducts (Paustenbach *et al.*, 1988). Other studies have found similar exhalation products (Slater, 1966; Mehendale and Klingensmith ,1988; Cai and Mehendale, 1990). The model was scaled up to humans. Good agreement was found with the Stewart data (Stewart *et al.*, 1961).

Bogers *et al.* (1987) investigated the effects of different exposure schemes on hepatotoxicity. Interrupted exposures (2 periods of 3 hours with 1.5 hours in between) resulted in significantly higher activity levels ($p < 0.05$) of serum glutamic oxalacetic transaminase (SGOT) and serum glutamic pyruvic transaminase (SGPT). The hydropic degeneration of hepatocytes was more severe in animals intermittently exposed. The microsomal enzyme system may recover during the interval without exposure (Bogers *et al.*, 1987). This would allow for additional metabolism of the carbon tetrachloride to a toxic compound.

Neurologic Effects

The early symptoms of acute poisoning include headache, vertigo, ataxia, visual blurring, dizziness, headache, nausea, irrational behavior, and lethargy progressing to coma (Cohen, 1958; Barnes and Jones, 1967). Hepatic and renal involvement follow the early neurologic symptoms (altered blood chemistry, decreased blood urea, serum potassium, plasma prothrombin index, and serum glutamic oxalacetic transaminase) (Barnes and Jones, 1967). There is some direct action on the nervous tissue. Purkinje cells decrease in number. The brain tissue shows venous thrombosis with hemorrhage and hemorrhagic infraction, and areas of necrosis and desalination (Cohen, 1958).

Altered functional properties of astrocytes (Desaiah *et al.*, 1991) and decreased brain mitochondrial oxygen consumption, oscillation amplitude, and proportion of unsaturated fatty acids (Diaz-Munoz and Tapia, 1989) have been reported.

Calcium adenine triphosphatase (Ca^{+2} ATPase) and calmodulin activities were determined in gerbil brain fractions and cytosol by Desaiah *et al.*

(1991). *In vitro,* 5 micromoles of carbon tetrachloride inhibited Ca^{+2} ATPase up to 50 percent and calmodulin by 40 percent. The inhibition was concentration dependent. The authors proposed that carbon tetrachloride may interact with calmodulin hydrophobic regions, decreasing its activity (Desaiah *et al.*, 1991).

Benedetto *et al.* (1981) investigated the activation of carbon tetrachloride and the tissue distribution of NADPH-cytochrome *c* reductase and cytochrome *P*450. Similarly, NADPH-ADP/Fe^{+2}-linked lipid peroxidation was 61 nanomoles O_2 per minute per milligram of protein in the liver versus 13 in brain tissue indicating that carbon tetrachloride is not metabolized to any major extent except in the liver (Benedetto *et al.*, 1981).

Molecular Metabolism

Liver damage from carbon tetrachloride occurs rapidly. Hepatic triglyceride secretion is blocked within 10 to 15 minutes of administration. Liver lesions appear after 12 hours and liver necrosis after 24 hours. During the initial 48 hours, liver enzymes (glutamic oxalacetic transaminase and gultamic pyruvic transaminase) appear and recede from the plasma. Lipid accumulation starts within one hour. Single cell necrosis begins within six hours. Damage to the mitochondria and Golgi apparatus is followed by disassociation of ribosomes from rough endoplasmic reticulum to the cytoplasm and the disarray of the smooth endoplasmic reticulum. This damage leads to the further accumulation of lipids. Protein synthesis, cytochrome *P*450, and glucose-6-phosphatase are depressed (Rechnagel and Glende, 1973). Mitochondrial elements of the cell become dysfunctional and hepatocellular necrosis, resulting in "fatty" liver develops (Rechnagel and Glende, 1973).

Uemitsu (1986) exposed male rats to carbon tetrachloride concentrations of 35 to 450 parts per million for 5 hours. Cytochrome *P*450 concentration began to fall after 1 hour of exposure to 340 parts per million of carbon tetrachloride. It was 78 percent of the control value after 5 hours. Significant ($p < 0.05$) reductions occurred at 240, 340, and 440 parts per million. In rats pretreated with 100 and 200 microliters of carbon tetrachloride per 100 grams body weight, values were 40 percent of the control values. The pretreatment with carbon tetrachloride caused a loss of liver microsomal cytochrome *P*450. The rate of metabolism decreased with increasing carbon tetrachloride concentration consistent with the loss of cytochrome *P*450 (Uemitsu, 1986).

Carbon tetrachloride toxicity depends upon the cleavage of the carbon-chlorine bond. Homeolytlic cleavage of the bond yields free radicals which interact with lipid-rich material, altering structure and function. Recknagel and Ghoshal (1966) proposed that methylene bridges and unsaturated fatty acid side chains of microsomal lipids are attacked by free radicals, causing diene conjugation.

The liver endoplasmic reticulum shows the first toxic effects. In male rats, the diene conjugate content of microsomal lipids doubled one hour after carbon tetrachloride exposure, glycine incorporation into protein dropped to one-third, and oxidative demethylation decreased by one-half. Protein content, glucose-6-phosphatase, and NADPH-NT (nicotinamide adenine dinucleotide phosphate) reductase were unchanged (Reynolds, 1972).

Carbon tetrachloride seems to have two possible reaction mechanisms. Metabolites covalently bind to membrane proteins and lipids, primarily those in the endoplasmic reticulum, causing an alkylation reaction. They may also interact with unsaturated fatty acids in the membrane, causing lipid peroxidation (Comporti, 1985).

Lipid peroxidation occurs *in vivo* within minutes of exposure. There is an associated loss of enzyme activity in the microsomes. Antioxidants or free-radical trapping agents protect against hepatoxic effects (Plaa and Witschi, 1976). The free radicals add to double bonds of the unsaturated fatty acids which initiate lipid peroxidation. The chloromethyldiene products formed by condensation with the carbon tetrachloride radicals are responsible for the diene conjugation seen in liver microsomal lipids (Comporti, 1985). It has been shown that carbon tetrachloride is metabolized to phosgene by rat liver microsomes through the following chemical process (Anders and Pohl, 1985).

$$CCl_4 \xrightarrow[+e^-]{P\text{-}450} CCl_3\bullet + Cl^- \xrightarrow{O_2} CCl_3\text{-}O\text{-}O\bullet \xrightarrow{\text{phosgene}} COCl_2 + \text{electrophilic } Cl \longrightarrow CO_2$$

trichloromethyl free radical — trichloromethyl peroxyl radical

The reactive metabolite has an absolute requirement for dioxygen. Neither phosgene nor electrophilic chlorine are formed when dioxygen is absent. This is consistent with the initial formation of a trichloromethyl radical which is trapped by the dioxygen in the rate-determining step (Anders and Pohl, 1985).

The trichloromethyl free radical binds either to the heme group of cytochrome *P*450 or at the active site of the enzyme (Kalf *et al.*, 1987).

$$Fe^{3+}\text{—}[CCl_3 \leftrightarrow Fe^{2+}\text{—}\bullet CCl_3]$$

The trichloromethyl radical ferric cytochrome *P*450 [$Fe^{3+}\bullet CCl_3$] accepts a second electron, forming the ferrous cytochrome *P*450-trichloromethyl radical complex [$Fe^{2+}\bullet CCl_3$]. Its mesomeric structure is equivalent to trichloromethyl carbanion-ferric cytochrome *P*450 complex. It may accept an electron and undergo alpha-elimination to form dichlorocarbene, which reacts with ferrous cytochrome *P*450 to yield cytochrome *P*450-dichlorocarbene adduct [$Fe^{2+}:CCl_2$] (Anders and Pohl, 1985). The residual *P*450(Fe^{2+}) can react with carbon tetrachloride again (Kalf *et al.*, 1987).

The trichloromethyl radical may react with oxygen to form a trichloromethylperoxy radical ($CCl_3OO\bullet$). This radical has been proposed as the agent which induces lipid peroxidation by removing hydrogen atoms from unsaturated lipids. The radical abstracts a hydrogen to form chloroform. The chloroform is either reduced by cytochrome *P*450 to form dichlorocarbene or it reacts with microsomal lipids (Anders and Pohl, 1985). Figure 1 shows several proposed pathways for the metabolism of chloroform. Products of lipid peroxidation diffuse to other parts of the cell, bind to cellular macromolecules, and cause functional damage (Monks and Lau, 1988).

$$\bullet CCl_3 \xrightarrow{+e^-} {}^-CCl_3 \xrightarrow{-Cl_2^-} :CCl_2 \longrightarrow CO_2$$

$$\bullet CCl_3 \xrightarrow{+H\bullet} \underset{\text{chloroform}}{CHCl_3}$$ Reacts with thiols and polyunsaturated fatty acids

$$\bullet CCl_3 \xrightarrow{\text{addition}}$$ Covalent binding (Slater, 1984)

$$\bullet CCl_3 \xrightarrow{\text{scavengers}}$$ Removal of toxic species (Slater, 1984)

FIGURE 1. Proposed pathways for chloroform metabolism.

Carbon tetrachloride can inhibit microsomal calcium sequestration. This may elevate cytosolic free calcium, damaging plasma membranes, which is followed by an influx of extracellular calcium across the damaged membrane, causing cell death (Monks and Lau, 1988; Kalf *et al.*, 1987).

Carbon tetrachloride metabolism may activate Kupffer cells due to the increase in intracellular calcium. When Kupffer cells were destroyed *in vivo*, carbon tetrachloride toxicity was reduced (Edwards *et al.*, 1993). Edwards *et al.* proposed that the cytochrome *P*450IIE1 metabolic pathway may be depressed by the treatment, reducing the amount of trichloromethyl radical.

In their study, carbon tetrachloride exposure elevated neutrophils in the liver. Carbon tetrachloride can activate Kupffer cells. They concluded that Kupffer cells attracted activated neutrophils secondary to $\bullet CCl_3$ radical generation by parenchymal calls. The neutrophils secrete superoxide anions which cause cell injury and ultimately cell death (Edwards *et al.*, 1993).

Immunosuppression

Experiments performed to determine whether carbon tetrachloride affects the immune system have produced contradictory results. Kaminski *et al.* (1990) treated mice with high levels of carbon tetrachloride (250 to 1,500 milligrams per kilogram of body weight) for 7 days. There was dose-dependent suppression of T-cell-dependent antibody response to sheep red blood cells (36 percent with 500 milligrams per kilogram, 48 percent with 1,000 milligrams per kilogram, and 53 percent with 1,500 milligrams per kilogram). In a 30-day exposure test, 25 milligram per kilogram caused a 20 percent suppression of antibody response. The effect reached a plateau at 50 percent with 50 and 100 milligram per kilograms doses (Kaminski *et al.*, 1990).

In contrast, studies in rats failed to show similar effects. Smialowicz *et al.* (1991) gave carbon tetrachloride to 9-week-old rats by oral gavage, in the dose of 0 to 40 milligrams per kilogram body weight per day for 10 days. There was no effect on (1) spleen or thymus weight, (2) natural killer cell activity, (3) *in vitro*–generated allergenic cytotoxic T lymphocyte response, (4) one-way T-cell-dependent PWN (Pokeweed mitogen) or MLR (mixed lymphocyte reaction) responses, (5) PFC (plaque-forming cells) response to sheep red blood cells, or (6) primary antibody responses (PFC/total spleen) or serum hemagglutination titer (Smialowicz *et al.*, 1991).

Cancer

Mice have been shown to develop hepatomas after repeated oral administration of carbon tetrachloride. Thirty doses of 0.1 milligram per kilogram body weight over 90 days caused a significant number of tumors. The amount of necrosis correlated with the incidence of hepatomas (IARC, 1972, 1987). For 78 weeks, 50 female and 50 male mice were given 2 to 5 percent carbon tetrachloride solution by oral gavage, 5 times per week at a dose of 1,250 to 2,500 milligrams per kilogram body weight. After 90 to 92 weeks, all animals exposed to the low dose developed hepatocellular carcinomas; the high dose produced carcinomas in 47 of 48 males and 43 of 45 females (IARC, 1987). The International Agency for Research on Cancer concluded that there is sufficient evidence that carbon tetrachloride is carcinogenic in animals (IARC, 1987).

A National Cancer Institute study of dry cleaners found an elevated number of cancer deaths (87 versus 67.9 expected). Lung, cervix, uterus, and skin cancer accounted for the excess. There was a slight excess of leukemia and liver cancer. A later study found significant elevations in esophageal cancer [standardized mortality ratio (SMR) = 2.1, 95% confidence interval (CI) = 1.1–3.6)] and cervical cancer (SMR = 1.7, 95% CI = 1.0–2.0) (Blair *et al.*, 1990). The chemicals used by dry cleaners are carbon tetrachloride, trichloroethylene, and tetrachloroethylene (Blair *et al.*, 1979).

Monson and Fine (1978) found elevated brain cancer risks among rubber workers. Potential exposures included carbon tetrachloride, which was used as a solvent. There was no direct link to carbon tetrachloride, and other suspected carcinogens were present (e.g., coal tar) (Monson and Fine, 1978). Wilcosky *et al.* (1984) identified the solvents used at a rubber and tire manufacturing plant. Lymphatic leukemia was related to carbon tetrachloride exposure [the odds ratio (OR) = 15.3, $p < .001$] and carbon disulfide (OR = 8.9, $p < .003$) (Wilcosky *et al.*, 1984). Spirtas *et al.* (1991) studied an aircraft maintenance facility. Women exposed to carbon tetrachloride had elevated levels of non-Hodgkin's lymphoma (SMR = 325, 95% CI = 119–560) (Spirtas *et al.*, 1991). In a study of people involved in the production and repair of electronic equipment, Heineman *et al.* (1994) found elevated levels of astrocytic brain tumors associated with the use of several solvents. For carbon tetrachloride, the odds ratio was 1.8 (Heineman *et al.*, 1994).

Carbon tetrachloride was used at the Rocky Flats Nuclear Weapons Plant as the primary degreasing agent for plutonium (see Chapter 6). Although the target organ for carbon tetrachloride is the liver, several studies have linked it with increased risk of cancer (IARC, 1987; Blair *et al.*, 1979, 1990; Heineman *et al.*, 1994). Therefore, carbon tetrachloride was chosen as the focus of the study.

CHAPTER 5. RETROSPECTIVE EXPOSURE ASSESSMENT

Since Percival Pott linked scrotal cancer in chimney sweeps to their occupational exposure to soot, epidemiologists, toxicologists, and industrial hygienists have searched for links between diseases and chemicals. Research on causes of occupational disease requires identification of exposures to agents, determination of exposure levels, and division of personnel into exposure-level groups. In determining the "risk" of a particular operation, the initial step is to identify the hazards. This is followed by exposure assessment, estimation of dose-response relationships, and finally, a characterization of risk (Stayner, 1992).

Dose versus Exposure

One criterion for establishing causality between an agent and disease is the existence of a dose-response relationship. This means that the risk of disease increases as the dose of an agent increases. Dose refers to the amount of material reaching the critical organ. There must be a receptor which comes into contact with the compound. "Exposure" refers to the interaction of humans with the compound in the environment. Exposure can be considered to be the environmental precursor of dose and therefore can sometimes be used as a surrogate (Herrick, 1992). The amount of material that enters the body must be estimated (Stewart *et al.*, 1991a). The intensity and variability of the exposure is determined by the strength, variability, composition, and configuration of the source, as well as air movements, exposure controls, and the employees' proximity to the source (Smith *et al.*, 1991).

Some measures of exposure are the exposure intensity, the duration of the exposure, and the cumulative exposure. Cumulative exposure is the best measure for health effects that require prolonged exposure. Peak exposure information is best for acute health effects (Checkoway and Rice, 1992).

Exposure Assessments

Exposure assessment is used to classify workers into groups with different exposure levels to determine if there is a positive dose-response relationship (Smith, 1987). The amount of information available on chemicals handled, operational processes, employees' work histories, engineering controls, and personal protective equipment used, as well as the availability of personal and environmental sampling records, will determine the degree of quantification that is possible. Exposure-level estimates can be used as part of an epidemiology study to identify differences that could account for elevated risk. Retrospective exposure assessment methodology combines available data into a model which estimates worker exposure to chemical compounds (Waxweiler, 1981; Chen *et al.*, 1988). The basic premise of a retrospective exposure assessment is to use existing direct measurements or develop surrogate measures to document exposure over time (Rice, 1991; Rice *et al.*, 1984) and thereby characterize worker population exposures.

Approaches to Estimating Exposure

The amount of quantitative sampling information can range from none, to limited, to substantial. When no quantitative sampling information is available, the simple dichotomy of ever versus never exposed may be used. In an occupational study, this can translate into documenting those employed in a job area or with a job title where exposure was possible.

Ever versus Never. In many epidemiology studies, the only division which can be made with relative certainty is "exposed" versus "not exposed" (Stille and Tabershaw, 1982; Tsai *et al.*, 1991). This may simply involve identifying people who worked in a given industry (Hayes *et al.*, 1990), in specific plants (Rinsky *et al.*, 1988) or in specific jobs (Forman *et al.*, 1987); identifying groups of occupations and departments within an industry (Theriault and Provencher, 1987, Garshick *et al.*, 1988); or identifying specific chemicals or chemical classes (Harrington *et al.*, 1989). If a disease is unusual, e.g., mesothelioma, or the population under study is large, e.g., smokers, this type of division may be sufficient to locate suspected correlations. This gross division is often insufficient to identify smaller risks.

Duration of Employment or Exposure. Duration of employment in an occupation can be used to develop an ordinal classification system based on time (Delzell *et al.*, 1989; Stayner *et al.*, 1985; Silverstein *et al.*,1988). This approach assumes that the exposure level is uniform for all study subjects; therefore, time can be used to separate exposure groups (Marsh *et al.*, 1991).

A problem with this approach is that long-employed workers with heavy exposure will be classified with long-employed workers with light exposure. Consequently, if the chemical has a low risk, it may be classified as having no risk (Stewart *et al.*, 1991a). Duration of employment should only be used as a surrogate for exposure level if certain conditions are met: (1) exposure is constant for all workers in the job or industry under study, (2) exposure does not change over time, and (3) exposure is related to tenure of employment (Stewart and Herrick, 1991).

Exposure Zones. Additional subdivisions can be made using the "exposure zone" concept (Corn and Esmen, 1979). Within an exposure zone, the information obtained when a sufficient number of employees have had personal breathing-zone samples taken describes the exposure levels of all employees. This eliminates the need for all employees with similar jobs or exposures to be monitored. One method of forming exposure groups is to use specific job or occupational titles, or to use work areas linked with other criteria such as duration (McMichael *et al.*, 1975; Goldsmith *et al.*, 1980; Gamble and Spirtas, 1976; Blair *et al.*, 1990). Each job category can then be ranked for potential exposure (Cook *et al.*, 1980; Acquavella and Owen, 1990; Rice *et al.*, 1984).

Ott *et al.* (1974, 1975, 1977, 1989a, b) developed an agent-based exposure classification system. In a study of lymphatic and hematopoietic cancer, six major work activities were investigated. Using department and job assignments and historical information, the authors identified 111 work areas and 52 chemical groups. Workers were considered to have been exposed when any one chemical of a chemical group was in the employee's assigned work area. The index of exposure was the duration of contact with at least one member of the chemical group. The odds ratios were calculated for each exposure measure (ever/never exposed and four disease categories) as part of a hypothesis-generating study (Ott *et al.*, 1989b).

Classifications Relying on Plant/Industry-Specific Data. Marsh (1987) proposed a double-denominator concept for pooling work history data in industry-wide studies: "job-exposure/job title-based uniform coding scheme." Jobs were grouped into exposure categories. Experts familiar with company-specific exposure-related parameters (e.g., ventilation, manufacturing processes, and work practices) made the exposure-category assignments.

A generalized exposure matrix with time-period-of-exposure versus job-code was used. Known hazardous chemicals were linked with specified exposure classes. Job assignments were usually time dependent; therefore, a time by job-code exposure matrix could be formed. Exposure might be measured (a) as present = 1, absent = 0; (b) as high = 3, medium = 2, low = 1, none = 0; or (c) with actual measurements. A cohort should be defined by start and finish date, job code, and a vector of qualitative or quantitative values for each chemical or exposure class (Marsh, 1987). Several studies have expanded this system by utilizing industrial hygienists to provide exposure rankings (Goldberg *et al.*, 1986; Wu *et al.*, 1989).

Job-Exposure Matrix. One means of correlating exposure and disease is to develop a job-exposure matrix. A job-exposure matrix is basically a databank which contains the job classification by occupational title or by job activity or both, an agent list, and indications of exposure by job and by agent (Gerin *et al.*, 1985; Gerin, 1990). A matrix can be created by first classifying occupations by industry and classifying tasks within the industry. Compounds are then linked to the industries and tasks, allowing all subjects with employment histories that suggest contact with an agent to be placed in the same category (Hoar, 1983–84). Job-exposure matrices are designed to link specific jobs with potential exposures in a systematic, unbiased manner (Kauppinen and Partanen, 1988). Kauppinen and Partanen (1988) found that plant and period matrices based on homogeneous exposure zones are useful in nested case-referent and cohort studies.

In a multiplant study of rubber workers, Gamble and Spirtas (1976) generated occupational-title groups which were used as the exposure categories. Jobs with functionally similar operations or materials (stock or products) were grouped together under one occupational title with a code, in order to generate an objective classification of jobs and reduce the number of agents. Each occupational title was specific enough to be identifiable within the industry, and each had relatively few members. Four hundred departments were grouped into seventy occupational titles. The categories were used to form a hierarchical system where each major process contained functionally similar subprocesses. This minimized the dilution effect which occurs when low-risk and high-risk workers are combined in a category (Gamble and Spirtas, 1976).

The major exposure for each occupational title was characterized and exposure categories established. A cumulative measure of time spent by each worker in prespecified groups of occupational titles was calculated. Occupational titles were then used instead of exposure measurements to provide a link between "dose" and response (Gamble and Spirtas, 1976). McMichael *et al.* (1975) used this system to investigate lymphopoietic leukemia.

An alternative to simply using job titles, which are often specific to a company, is to broaden the definition of occupation. Hoar *et al.* (1980) developed a linkage system in which occupations were classed by industry and by task within the industry. All study subjects with employment histories suggesting contact with a specific agent were placed into the same exposure category. Occupational data could then be analyzed based on exposure rather than industry or task. There are three components to this system: an occupational code (which designates task or process), a list of compounds, and

1983–84). The main disadvantage of this system is that it cannot account for individual variability caused by differences in processes, tasks, work conditions, use of personnel protective equipment, or changes in exposure over time (Milligi and Masala, 1991).

Hinds *et al.* (1985) utilized the coding list and linkage system in a case-control study of lung cancer. They found that it inconsistently identified known and suspected carcinogens. Only two agents had statistically significant elevations in risk and dose-response effects. They concluded that this system had a low sensitivity and was not very useful for their purposes (Hinds *et al.*, 1985).

National Institute for Occupational Safety and Health (NIOSH) scientists developed a computer system that uses toxicological and occupational survey data to provide an estimate of potential occupational health risk due to chemical exposure (Pedersen and Hornung, 1986). The NIOSH job-exposure matrix has three levels of classification: industry, occupation, and hazard. Each level is nested within the previous one (Sieber *et al.*, 1991; Pedersen *et al.*, 1983).

The NIOSH performed a case-control study of leukemia and potential exposure to ionizing radiation using this database. The association between exposure and leukemia increased when both industry and occupation were considered (Sieber *et al.*, 1991).

Pannett *et al.* (1985) developed a matrix based upon the United Kingdom Registrar General's 1966 classification of occupations and 1968 classification of industries. They performed a case-control study using data from a survey of cancer and occupation in young and middle-aged men. Each job was coded to describe occupation and industry. Those with similar exposure profiles were combined into "job-groups" (Pannett *et al.*, 1985).

The exposure axis contained 49 agents, chosen because of their suspected link to occupational disease and presence in multiple occupations and industries. There were four levels of exposure: high, moderate, low, and none (Pannett *et al.*, 1985).

Two of the authors reviewed the occupational histories (blind to the case-control status) and made revised estimates of exposure. Subjects were classified according to the highest grade of exposure assigned to any of their jobs. The risk estimated for the known lung carcinogens were greater in the higher exposure categories, when the exposures were inferred directly. The direct method gave steeper dose-response curves for the known carcinogens (Pannett *et al.*, 1985).

Interview-Based Method. Gerin *et al.* (1985) developed a population-based hypothesis-generating matrix. They used a team of trained coders to deduce the exposures of subjects through detailed interviews. They interviewed all males between 35 and 70 years old who were diagnosed as having cancer at any of several sites in the body. The control subjects were selected from the general population. The interviews were intended to identify any confounding factors and to obtain a detailed description of each job. Each subject was given a form on which to list jobs held and a checklist of 20 common materials that the subject may have had contact with (Gerin *et al.*, 1985; Gerin, 1990; Gerin and Siemiatycki, 1991; Siemiatycki *et al.*, 1981a, 1989).

Reported job histories were compared with the records of the Quebec Pension Plan. The inference of exposures was done by "chemist-engineers" using professional expertise, library research, technical documents, and local industry consultants. A qualitative index of exposure was generated. Subsets of job-title categories could be distinguished on the basis of common exposure categories. Workers in different job categories were placed in common exposure categories (Siemiatycki *et al.*, 1989; Gerin, 1990).

Exposures were chosen based on frequency, adequacy of documentation, and uniqueness. The coder entered a four-digit code representing semiquantitative estimates of reliability, mode of contact, relative level of exposure, and frequency of exposure. This code provided the epidemiologist with a stratification variable (Gerin *et al.*, 1985).

In a case-control study of cancer risks associated with 10 inorganic dusts, the system allowed for sufficient identification of exposures to correlate nonadenocarcinoma of the lung with exposure to several dusts (Siemiatycki *et al.*, 1989). Keefe *et al.* (1991) modified the method used by Gerin and developed a hierarchical system for coding chemicals which was designed to assist in the identification of carcinogens. This system allows for analysis on more than one level, i.e., exposure to one agent, classes of agents, or to broad groups of agents, and the differentiation of similar structures with different carcinogenic potential (Keefe *et al.*, 1991).

Quantitative Data. There are several types of air-monitoring data which may be available and are usable in exposure assessment. Historical exposure data for the specific chemical under investigation is helpful in identifying previous employee exposures. Historical exposure data for a parallel agent may be used to estimate possible exposure to the agent of interest if there is a known correlation between the two (i.e., if both are used in the same operation or in a similar manner). To rank relative dustiness, Cooper *et al.* (1988) used the results of quartz sampling as a surrogate for asbestos. Current exposure data may be useful for extrapolation to previous operations (Esmen, 1979).

If some sampling data is available, the degree of exposure for each participant can be estimated using the available exposure data, the job characteristics, and the proximity of the participant to the exposure source (Hornung, 1991). Cumulative exposure, cumulative exposure indices, or time-weighted average concentration information may be used (Lee-Feldstein, 1989; Bolla *et al.*, 1990; Dement *et al.*, 1983; Collins *et al.*, 1989; Smith *et al.*, 1984; Chen and Fayerweather, 1988; Ott *et al.*, 1974).

Statistical Models. Esmen (1979) proposed a model and survey procedure to reconstruct the dose of one or more agents received by an employee over a long period of time. He defined occupational titles to be a vector function with time-dependent components. For each industry cross section, occupational titles are uniform and independent of a given plant. The exposure of members within an occupational-title category can be calculated using the historical data (Esmen, 1979).

The arithmetic mean of the exposure for a given occupational title is calculated. The "Upper Exposure Profile" is the summation of the arithmetic means over the working life of a worker. The mode values are summed to generate the "Lower Exposure Profile." A worker's actual exposure is assumed to be between the two values (Esmen, 1979).

This type of methodology was used by Dement *et al.* (1983) in a reconstruction of asbestos exposures in the textile industry. Industrial hygiene samples taken between 1930 and 1975 were used to determine exposures for specific jobs. Jobs were grouped into four uniform job categories based on tasks. Employees were linked to jobs by their occupational history. For each sample, an exposure zone and a uniform job category was determined The exposures within a zone were adjusted for different uniform job categories by keeping track of the fraction of the day spent in the zone or at a specific task. The model was used to predict the mean of the log of the concentration (Dement *et al.*, 1983).

Greife *et al.* (1988) developed a weighted linear-regression model to estimate exposure to ethylene oxide by plant year for different exposure categories. Twelve plants supplied a total of 2,350 eight-hour time-weighted average samples which were used for the model. For each job location, the data were grouped by plant, year, and sampling media. An exposure category consisted of a group of jobs and/or locations with similar potential exposures. Seven variables (of 23) explained 85 percent of the ethylene oxide variation.

The model was validated by testing its ability to accurately estimate the exposure levels of a subset of the data which was not used in developing the model. The estimates were used to fill in cells of a job-exposure matrix and to predict annual exposures for workers. The average exposure was underestimated by 0.5 parts per million compared to the actual arithmetic mean exposure levels (Greife *et al.*, 1988; Hornung *et al.*, 1994).

Quantitative Estimates. In a study of the effects of solvent exposure, Ford *et al.* (1991) integrated industrial hygiene data documenting cumulative exposure with lifetime weighted-average exposure. Ford *et al.* visited two plants and generated exposure zones using a three-level ordinal scale. Job histories were used to categorize employees by exposure zone. Breathing-zone samples were available for the previous 7 to 15 years. These results were grouped by exposure zone. Cumulative exposure [in parts per million-year (ppm-year)] was calculated for each study participant. This was then divided by the total duration of employment in "exposed" jobs. When neurobehavioral tests were performed, this variable was more useful in explaining the variance seen than exposure duration was (Ford *et al.*, 1991).

Kriebel *et al.* (1988) had geometric mean levels of beryllium exposures from a beryllium extraction and manufacturing facility. Two thousand samples had been taken beginning in 1947. They standardized a set of job titles. Generally, only three data points were available per job (pre-1960, 1960 to 1970, and late 1970s). A daily weighted-average exposure was calculated (2- to 5-minute samples weighted using a time study of each job). Work histories were used to identify the years each worker was employed in each job. Each worker was then asked to fill in a job matrix which was then checked by an interviewer. Several exposure parameters were developed. Each worker's estimated annual exposure, as an eight-hour concentration, was calculated for every year of work. The cumulative exposure was partitioned into components to separate out the time and intensity features (Kriebel *et al.*, 1988).

Dodgson *et al.* (1987) also utilized this procedure to estimate past exposure levels in wool insulation plants. The geometric mean concentration values for respirable fibers were used to estimate past airborne concentration. Multipliers, which were a function of time and the factors affecting fiber concentration, were applied to the overall plant mean concentration for 1977 through 1980. Plant history was used to calculate upper and lower estimates of concentration values using a multiplier applied to the geometric mean (Dodgson *et al.*, 1987).

Average exposure is an alternative which is sometimes used. In a study of coke oven workers, Dong *et al.* (1988) developed an average intensity index using sampling results. Three indices of average exposure were listed. The exposure duration score for each job was calculated by multiplying the mean exposure by the time spent in each job. The sum for all jobs was the exposure-intensity index (Dong *et al.*, 1988).

Use Existing Data to Estimate Earlier Data. Seixas *et al.* (1990, 1991,1993) and Attfield and Morring (1992) estimated personal exposures to coal mine dust. Seixas *et al.* used the results of samples taken from 36 mines between 1970 and 1987. The Mine Safety and Health Administration inspectors collected samples for the occupations with the highest expected exposure. Using the exposure data, the arithmetic mean of yearly exposure within the occupation/mine/year categories was calculated and matched to the work history data. For each mine, the yearly means and standard error were calculated within the four occupation groups. Each mine job was matched to the estimated means of occupation, mine, and year. The adjusted three-way mean was used as the mean exposure for the job. Cumulative years in mining and years worked underground were also calculated. The stratification of mine, occupation, and year was chosen to maximize accuracy (Seixas *et al.*, 1991).

Use of a Job-Exposure Matrix with Exposure Information. Job-exposure matrices are limited for a number of reasons: most are based on inferred exposures, not on actual exposure histories for individuals; job titles vary over time, leading to inaccurate exposure assignment; chemical information may include only the class of chemical, not specifically hazardous ones; associations observed may be confounded by nonoccupational factors; and exposures vary widely between workers in the same occupation due to differences in processes and specific tasks (Hoar, 1983–84).

Blair *et al.* (1990), Stewart *et al.* (1986, 1991b), and Spirtas *et al.* (1991) performed a series of retrospective exposure assessments. They developed a model to estimate historical exposures to formaldehyde in a study of ten companies. Most of the companies had performed air monitoring of formaldehyde beginning in the 1970s. One company had data from the 1960s. Information about each plant's history and operations was obtained from its industrial hygiene and production staff and a walk-through inspection of the plant. An exposure matrix was developed by job and time exposed. The effects of engineering controls and production or process changes were considered. When exposure data existed, an eight-hour time-weighted average exposure was calculated. When no air samples were available, the current exposure levels were estimated from similar jobs in the same area (Stewart *et al.*, 1986).

An exposure form was generated for each position in the job dictionary. On this form, an industrial hygienist entered the exposure period (if the exposure level changed, a new form was generated), a rank (six levels) reflecting the industrial hygienist's estimate of the concentration, the confidence that the industrial hygienist had in the estimate, whether peaks occurred, whether a respirator was worn, frequency of the peaks, other exposures, job duties, estimated concentration, and comments. Company personnel reviewed the results and made recommendations.

The final exposure estimate was made by integrating the historical estimates, the company evaluations, and the sampling results. Those jobs for which there was little confidence in the reliability of the exposure estimate were eliminated from some analyses. Current sampling data was used to confirm or change the historical estimates. Historical estimates were then put into a computer file and merged with the job history file (Stewart *et al.*, 1986).

Stewart *et al.* (1992b, 1995, 1996) expanded the above system into a computerized data management system for job-exposure profiles as part of a study of workers exposed to acrylonitrile. Information was collected as described above. A menu-driven computer program was designed to organize the information (Stewart *et al.*, 1992b, 1995, 1996).

A second computer program, the exposure assessment program, was developed for use in deriving historical exposure estimates. The program allowed the user to select from several methods of estimation, depending on the amount of air-monitoring data available (Stewart *et al.*, 1995, 1996).

Other investigators have used similar methodologies in their investigations (Owen *et al.*, 1992; Ott *et al.*, 1974; Walrath *et al.*, 1989; Nelson *et al.*, 1985, 1993). Walrath *et al.* (1989) performed a case-control study of cancer among workers exposed to dimethylformamide. The exposure estimate utilized information on the potential for dermal exposure to dimethylformamide and potential exposure to other chemicals, including N-methlyformamide. Each job-title category was assigned a time-weighted average exposure to dimethylformamide based on an average eight-hour day (geometric mean value) and a value based on peak eight-hour day exposures (95th percentile value). Each unique combination of job title, area, and time period was given an exposure profile. Each subject was given an exposure classification independent of their case-control status. The final ranking was based on exposure to both dimethylformamide and N-methylformamide. This exposure data was used to extrapolate the exposure which had occurred in earlier years (Walrath *et al.*, 1989).

Supplementation of Data by Use of "Experts." One of the inherent problems in the development of a job-exposure matrix is estimating the exposure. Estimates made by "qualified" experts are often used when minimal data is available (Deadman *et al.*, 1995; Teschke *et al.*, 1989)

Macaluso *et al.* (1993) investigated both the feasibility and the reproducibility of results using "experts." They performed a retrospective exposure assessment on solvents used in automobile assembly plant painting operations. Five industrial hygienists were provided with the information from the retrospective exposure assessment. Each industrial hygienist assigned an intensity estimate and a confidence range to each exposure category in each department-job combination for a specific time period. The inter-rater agreement was evaluated in an attempt to assess the reproducibility of subjective exposure estimates. The greatest variability was found in the assessment of very low exposure levels (1 to 5 parts per million). Agreement was higher for chemical use categories (overall concordance = 81%) (Macaluso *et al.*, 1993).

Nelson *et al.* (1985) used exposure categories in a retrospective cohort mortality study of employees from 10 petroleum refineries. All departments were placed into one of six organizational job groups. Each employee was categorized by the department of longest employment (Nelson *et al.*, 1985).

In the second system, an industrial hygienist familiar with all ten plants assigned job-type and exposure categories to each location/title combination. Exposures were estimated and placed into three categories (none, occasional, and unknown) (Nelson *et al.*, 1985).

The two systems were compared by stratifying the population by organization code and industrial hygiene categorization in a two-way frequency distribution. Nelson *et al.* (1985) concluded that the industrial hygiene categories appeared to classify subjects more accurately, and that the additional work involved was justified.

Recreate Historical Conditions. In plants or industrial operations where the earlier conditions can be recreated, it is sometimes possible to use current sampling methods to evaluate historical operations. In a study by Ayer *et al.* (1973), five granite cutters, wearing respirators, worked in a granite shed without the ventilation operating in order to recreate the conditions which existed in the 1920s. Stewart *et al.* (1992a) simulated the historical exposure conditions of funeral homes to evaluate the relative importance of workplace conditions.

Comparison of Assessment Models

The proliferation of models leads to confusion concerning which is "best." Consequently, several authors have compared different models to ascertain the strengths and weaknesses of each.

Cicioni *et al.* (1991) evaluated the NIOSH job-exposure matrix (Pedersen *et al.*, 1983; Pedersen and Hornung, 1986; Sieber *et al.*, 1991). They applied the matrix to Los Angeles County, California, mesothelioma cases identified by the county cancer surveillance system. The goal was to determine the number of cases which could be assigned as having had asbestos exposure and to determine how the exposure affected mesothelioma risk. An expert panel classified asbestos exposure by occupation and industry. The NIOSH matrix exposure assignments were compared to those assigned by an "expert" panel. Fifty-five percent of the industry/occupation combinations created by the expert panel were not found in the NIOSH job-exposure matrix. Forty-five percent of the combinations listed as having the probability of asbestos exposure by the NIOSH matrix were in the author's "none" category . The expert panel system was able to assign cancer cases to industry/occupation combinations more often. The problems identified with the NIOSH matrix were (1) many occupation/industry combinations were not classified by the NIOSH matrix; (2) some combinations with past asbestos exposure (e.g., shipbuilding) dating from before the National Occupational Hazard Survey were not classified as having asbestos exposure; and (3) there was no exposure intensity assessment. The degree to which the exposure classification assigned by the two methods agreed was tested. The Spearman correlation coefficient was 0.28, indicating that correlation was weak (Cicioni *et al.*, 1991).

Dosemeci *et al.* (1990) developed and compared three semiquantitative exposure-assessment models; these were intended to be alternatives to the job-exposure matrix and interview-based methods. The exposure-source evaluation and the job-function evaluation methods use information from current and historical working conditions. The parallel-agent evaluation method uses exposure data from the compound or agent which is used in parallel with the one under study.

To determine the level of agreement, Dosemeci *et al.* (1990) compared the estimated historical phenol exposure in phenol-formaldehyde plants produced by these three semiquantitative methods and by the direct semiquantitative estimate method. In the direct semiquantitative estimate method, the exposure levels (none, low, medium, and high) were assigned for the job-title/area/plant/calendar-year combination by an industrial hygienist after a walk-through survey (Dosemeci *et al.*, 1990).

The Spearman correlation coefficient was used as the measurement of agreement between methods. The Spearman correlation coefficient between exposure-source evaluation and job-function evaluation was 0.93. The correlation between these two methods and the parallel-agent evaluation was 0.85 and 0.86, respectively. The direct semiquantitative estimate method, when compared to the exposure-source evaluation and job-function evaluation methods, had correlation coefficients of 0.86 and 0.87, respectively.

The quantitative estimates for formaldehyde exposure were compared to the estimates produced by the three semiquantitative methods. The Spearman correlation coefficients were 0.76 for the exposure-source evaluation, 0.74 for the direct semiquantitative estimate, and 0.78 for the job-function evaluation.

Dosemeci *et al.* (1990) created a hypothetical worker population and compared the exposure-source evaluation, the job-function evaluation, the direct semiquantitative estimate, and the parallel-agent evaluation to the job-exposure matrix and interview-based evaluation. They determined the number of estimates required, the complexity of the judgments, time spent, and cost.

Dosemeci *et al.* (1990) concluded that no single method was best for use under all circumstances. The interview-based method was the most accurate, but was also very time consuming. The job-exposure matrix method had good consistency and was faster, and therefore less costly. Their results indicated that the exposure-source evaluation and job-function evaluation methods could be used effectively to optimize accuracy, consistency, and practicability (Dosemeci *et al.*, 1990).

Siemiatycki (1990) compared several data collection strategies: (1) employee interview and expert (chemist or industrial hygienist) evaluation of job history, (2) interview only, (3) interview supplemented by a job-exposure matrix, (4) records survey for job titles, and (5) records survey supplemented by a job-exposure matrix. The first method was assumed to be the most accurate (the "gold standard") and therefore by definition, had the greatest statistical power (based upon the criteria of being able to find a two-fold risk). The other strategies resulted in misclassification. The statistical power of the interview-only and record-only strategies was low. The use of a job-exposure matrix improved the power. The use of a job-exposure matrix with an employee interview had reasonably high power (> 0.60) for 61 of the 160 substances investigated (Siemiatycki, 1990).

Dewar *et al.* (1991) expanded upon this study. A job-exposure matrix was generated for a case-control study of cancer. The degree of misclassification was measured by testing sensitivity and specificity. Dewar *et al.* (1991) concluded that combining interviews with job history evaluations by a team of experts provided more valid exposure data than a job-exposure matrix.

Kromhout *et al.* (1987) evaluated exposure estimates based on employee interviews combined with expert evaluation. The qualitative estimates produced by these methods were compared to actual exposure estimates. In the study, tasks in each department of five small plants were identified and groups of estimators (workers, supervisors, and industrial hygienists) completed self-administered questionnaires. A four-point scale of exposure was used. Workers were asked about exposure in the tasks they were performing. Plant supervisors and industrial hygienists estimated the chemicals present for the tasks performed in each plant. Descriptive statistics were calculated for the estimated categories. Kromhout *et al.* (1987) found that the industrial hygienists made the best estimates, and that the workers' estimates were better than those of the supervisors.

Kromhout *et al.* (1992) compared the job-exposure matrix developed by Hoar *et al.* (1980) to that developed by Pannett *et al.* (1985). "Self-reported" exposure data was used to evaluate the validity of both. Job history information was collected using a self-administered questionnaire. The cohort members were also interviewed. The agreement between the two matrices was calculated for the subset of agents common to both job-exposure matrices. For most agents, the Hoar matrix generated more exposed subjects than the Pannett matrix. Agreement between the two on the classification of high exposures was generally poor for most agents. When risk estimates for seven-year lung cancer incidence were compared, the differences between the estimates generated by the job-exposure matrix and the self-reported exposure estimates were substantial. Most of the differences were due to the assignment of specific exposures to certain occupations and to differences in the level of detail in the job axis between the two job-exposure matrices. This emphasizes the need for the exposure criteria used in any job-exposure matrix to be as explicit as possible (Kromhout *et al.*, 1992).

Roeleveld *et al.* (1993) investigated the applicability of job-exposure matrices in the study of mental retardation and parental occupation. The Pannett and Hoar matrices were applied and exposures generated for each parent. These exposures were compared with the exposures reported in the interviews. The sensitivity and percentage of false-positive exposures were calculated for each matrix. The agreement was low. The matrices generated a large number of false positives (Roeleveld *et al.*, 1993).

Sources of Error in Exposure Estimates

There are several basic problems which researchers often encounter when performing a retrospective estimation of occupational exposures. The purpose of sampling is often to determine whether the employer is in compliance with regulations, or to verify that exposures have been controlled. High-exposure jobs are more commonly sampled; therefore, data is not representative of all available jobs. Consequently, representative data of routine operations which were not suspected to be hazardous are difficult to obtain (Rappaport, 1991a). Operations are seldom constant over time, making it difficult to acquire representative samples (Smith *et al.*, 1991). Periodic measurements fail to compensate for the daily variation in concentrations, spatial variations when the sampling point is not identical to the inhalation point, or the nonhomogeneity of most occupational groups. When there are too few sampling points, any long-term variations will be missed (Heederik and Miller, 1988).

Exposures are often misclassified due to incomplete specificity or lack of sensitivity in the exposure assessment. Low specificity occurs when job-title classes are very broad and many workers are classified as exposed when in reality, they were not exposed. Low sensitivity occurs when exposures are not identified. This occurs when the complete occupational history is not taken into account, and some jobs and exposures are missed (Kauppinen and Partanen, 1988).

Subjects can be easily misclassified if the specification of the exposure or the dose are incorrect, or too general for effective use. For some chemicals, the time-weighted average concentration of the exposure may be only roughly related to the final effect. Acute effects due to the level and duration of peak exposures may be more important. Consequently, exposure group assignments could be inaccurate, depending on which type of exposure is chosen as the dose index (Smith, 1987).

The following are some of the problems involved in the use of models which attempt to enhance historical data by the use of expert opinions: (1) subjective judgments being too responsive to perceived management interests, (2) biased recall by people with limited range of experience, and (3) recall bias towards exposures with acute health effects. Park *et al.* (1991) proposed a method to minimize these problems. A group of production, maintenance, management, and operational personnel and retirees (with long duration of employment at the facility) reviewed department and job dictionaries and plant process histories. They then developed a consensus concerning the exposure levels (Park *et al.*, 1991). Committees of current and former employees have also been used to assess exposures to fiberglass (Chaizze *et al.*, 1993) and epichlorohydrine (Enterline *et al.*, 1990). Employee interviews (Park *et al.*, 1990) and questionnaires (Fidler *et al.*, 1987) have been used to help gather and validate exposure information.

Summary

There are three basic steps in the development of a retrospective exposure assessment: (1) create a job dictionary, (2) evaluate historical exposures, and (3) develop and apply a method of assessing the exposure (Stewart *et al.*, 1991b). This is the basis for classification of the department, area, or job with potential exposure.

A job-exposure profile can be created by compiling estimated exposures for each chemical and physical agent encountered by employees within a single job classification and homogeneous exposure group, at a specific work site during a defined period of time. The job-exposure profile should include (1) a list of hazardous agents; (2) the frequency, duration, and degree of employee exposure; (3) the building/area locations; (4) processes associated with exposure; (5) a summary of employee-exposure monitoring data; (6) personal protective equipment used; and (7) the health effects associated with overexposure (Holzner *et al.*, 1993).

The ability to quantify the results depends on what records are available. The type of information needed is summarized below.

Work history. When performing different job tasks entails different exposures to a compound, knowledge of work histories can be used to differentiate and possibly estimate exposures. Ideally, a work history should identify work locations over the course of employment. The jobs held and descriptions of the tasks involved in each job should be identified (Checkoway *et al.*, 1987). Job and department codes must be specific enough to identify employment areas. Changes in department and location of employment should be included (Steenland *et al.*, 1987).

Work histories are often incomplete due to faulty recall and/or inadequate records. Some of the potential problems identified are that self-reported jobs may be erroneous or classified by the wrong work task, exposures may be misclassified due to lack of exposure data, and nonoccupational exposures can be confounding factors (Steineck *et al.*, 1989).

Job titles are often inadequate for use as descriptors of occupational exposures for several reasons: it is difficult to accurately determine which chemical exposures are associated with elevated risks found in broad occupational categories, there is considerable variation in the occupational exposures of people with the same job title, and there is lower statistical power in a study if people with similar exposures but different job titles are not pooled. Exposure information, when available, can be used to reduce these problems (Siemiatycki *et al.*, 1981b).

Plant Records. These records provide indirect information which can be used to help validate measurements or to estimate exposure levels. These include: standard operating procedures; process flow charts; purchasing records; engineering reports; plant blueprints; accident reports; quality control reports; records of shutdowns, strikes and layoffs; records of engineering controls; and records of the use of personal protective equipment. Medical and workers' compensation records are also useful but may be more difficult to obtain because of legal and privacy issues (Stewart *et al.*, 1991a; Checkoway *et al.*, 1987).

Exposure Information. Exposure information would ideally consist of accurate quantitative and qualitative information recorded at the time of exposure (Hoar, 1983–84).

Biological Monitoring. Biological monitoring data such as blood, urine, or alveolar air levels of a compound can be used to rank the subjects directly. Under ideal circumstances, exposure groups would be classified by the concentration of a bioactive chemical at a biological receptor.

Biological monitoring results can be used to validate exposure measurements and help correlate estimates of dose (Hertzman *et al.*, 1988; Ellingsen *et al.,* 1993a, b; Droz *et al.*, 1991). This type of data has been used to estimate cumulative dose and to investigate the dose-response relationship. The relationship between the amount of a compound found in the air and the biological monitoring data has wide variability because (1) biological indicators represent multiple days, weeks, or even months of exposure while air-monitoring samples usually represent only one day; (2) routes of exposure other than inhalation may be present (e. g., oral and dermal); and (3) the distribution and metabolism of chemicals within the body varies between individuals (Droz *et al.*, 1991).

Air Monitoring. The following information should be included with the air-monitoring data: location, job title of the workers being monitored, date, duration, type of monitoring, whether the sample is representative of routine daily exposure, and chemical interferences present in the work area. Missing information can often be discovered by the review of other records and employee interviews.

CHAPTER 6. PROCESS HISTORY OF THE ROCKY FLATS NUCLEAR WEAPONS PLANT

The Rocky Flats Nuclear Weapons Plant was constructed in Golden, Colorado, in 1951. From the 1952 opening until the discontinuation of plutonium operations in 1990, the primary work at the facility was the manufacture of triggers for nuclear weapons and the recovery of plutonium from obsolete weapons. Since the 1950s, there have been three basic trigger designs. The production processes were similar throughout the plant history. The plant also dismantled the triggers of obsolete weapons being removed from the stockpile (ChemRisk, 1992b).

Rocky Flats became the primary facility for trigger production in the early 1960s when a "single mission" concept was adopted by the Department of Defense. Initial construction of the facility began in 1951. The four main buildings (44, 71, 81, and 91) were operational by April 1952. The plant was completed in 1954 (ChemRisk, 1992b). The area was divided into four self-contained areas, Plants A through D. Each area was specialized for specific operations.

A Plant

Building 44 (later renamed 444) opened in 1953. Depleted uranium was initially used in this area. Beryllium was handled beginning in 1954. Full-scale operations did not begin until 1958.

Beryllium. The initial use of beryllium involved pressed powder. In Building 444, beryllium was heat treated and then machined. In 1958, the process changed to involve the shaping of parts from blanks supplied by a vendor. Initially, the blanks were pressed and then machined. Later the plant converted to using foundry-cast parts which were encased in steel. The blanks were heated and rolled flat into a sheet. The covering was cut away and the beryllium was then milled, turned, drilled, and polished as required. In the mid-1970s, the process was changed to the molding of parts from pressed-powder blanks. The foundry ceased operation in 1975. Subsequently, the blanks were received from outside suppliers (ChemRisk, 1992b).

The machine shop was designed with local exhaust ventilation consisting of cyclones at each machine. In 1964, a downdraft central exhaust plenum with a cyclone separator and high efficiency particulate air (HEPA) filtration was installed. The most recent upgrade was in 1986, when a two-stage HEPA filtration system was installed: a "low-vacuum" system for fine particulates and a "high-vacuum" system for heavier particles (ChemRisk 1992a, b). Air monitoring samples were taken at each machine during operations, and medical surveillance of the employees was instituted (Putzier, 1982).

Depleted Uranium. Depleted uranium contains less than 0.7 percent (by weight) fissile ^{235}U isotopes. All depleted uranium operations were originally in Building 444, which included a foundry, a machine shop, and a carbon shop for making molds (Putzier, 1982). Building 83 (later 883) was built when additional rolling and forming operations were required. Shapes were cut and formed in Building 883 and then shipped to Building 444 for turning, trimming, and polishing (ChemRisk, 1992b). The local exhaust system around the machine operations was composed of moveable exhaust inlets (Putzier, 1982). Research and development of uranium casting using electron beam energy, robotics, and remote manipulator arms was performed in the northeast part of Building 331. Some rolling of enriched uranium occurred in 1964 (ChemRisk, 1992b).

B Plant

Enriched Uranium. Building 81 (later 881) was built in 1952. The work performed there included an enriched uranium (greater than 0.7 percent fissile ^{235}U) component: casting, forming, machining, and assembly. Components were cast, machined to shape, and then sent to Plant D for assembly (ChemRisk, 1992b). The enriched uranium operations were enclosed with a ventilation system that would exhaust most metal particulates (Putzier, 1982).

A chemical recovery line began operating in 1954. Dibutylethylcarbutol was used as a solvent. The uranium was recovered using nitric acid. "Oralloy leaching" involved the spraying of returned uranium parts with hot nitric acid to remove residual plutonium contamination. Solutions were evaporated and a solid precipitated using ammonia gas. This solid was calcinated to an oxide form.

The enriched uranium operations began to be shut down in 1962 and work with enriched uranium was completely discontinued by 1964. After the enriched uranium operations were discontinued, this area was converted to beryllium rolling and forming operations. Oralloy leaching to remove external plutonium contamination continued in Building 771 until 1989 (ChemRisk, 1992b).

Special Tracers. In Building 881, neptunium tracer was used for some uranium components. Other tracers which might have been used include curium and cerium.

Stainless Steel. Stainless steel operations ("J line") were performed in Building 881 from 1966 until 1984. The operation was moved to Building 460 in 1984. Stainless steel was fabricated into tritium reservoirs, tubes, and fasteners. The building was then used for multipurpose research and development, analytical chemistry, plant support, record storage, and administration (ChemRisk, 1992b)

Metallurgy Research. Operations in Building 865 began in 1970. Research in metallurgy of uranium and beryllium was performed. Beryllium powder was used in glove boxes. Metals were melted, cast, forged, press formed, extruded, rolled, diffusion bonded, drawn, hydrospun, cut, sheared, and heat treated (ChemRisk, 1992a).

C Plant

Plutonium operations included plutonium recovery and purification, plutonium button fabrication from plutonium nitrate, component manufacturing, and storage. Initially, all plutonium work was done in Building 71 (later 771) which opened with only one processing line. A second line was added in 1955. The production area was expanded by five dissolution lines in 1965. Building 371 was designed to replace Building 771. It opened in 1981, but was never fully operational before being shut down in 1985 (ChemRisk, 1992b).

Starting in 1953, plutonium was shipped to Rocky Flats from Hanford as plutonium nitrate. It was vacuum transferred into a vessel which was placed in the processing line, and the nitrate was drawn into a precipitation vessel. Hydrogen peroxide was added to precipitate plutonium dioxide. The filtrate was washed with alcohol and dried. The oxide was converted to fluoride and the metal purified through calcium-iodine reduction in a reduction furnace (Putzier, 1982).

Plutonium nitrate was introduced into the "West Chem" line in approximately May 1953. The south part of Building 771 was the fabrication area where the buttons were cast and then pressed. The machining was minimal. In 1955, the "East Chem" line started operation (Putzier, 1982).

Building 777 housed all plutonium operations except assembly. Some of the plutonium fabrication operations were moved to Building 776 when it was completed in 1958 (ChemRisk, 1992a), but the recovery operations remained in Building 771.

In 1969, after a fire in Building 776 and 777, machining and foundry operations were moved from Building 776 to Building 707. Solid waste treatment and size reduction operations moved into Building 776 after it was reopened.

Originally, manufacturing wastes containing plutonium, uranium, and americium were sent through recovery (ChemRisk, 1992b). Beginning in 1959, the majority of the plutonium used at the plant came from recycling and recovery operations. Later, material was brought from Savannah River (ChemRisk, 1992b).

Fabrication of Plutonium Components. A memorandum written in 1974 listed the following uses of carbon tetrachloride in fabrication operations: (1) plutonium chip degreasing, (2) plutonium machining operations, (3) plutonium part-cleaning operations, (4) cleaning interior of dry-box system, (5) leak checking of crucibles and funnels, and (6) sample drilling of plutonium buttons (Love, 1971). The amount of carbon tetrachloride used in these processes made Rocky Flats the largest single user of carbon tetrachloride in the United States (12,500 kilograms in 1974 and 7,060 kilograms in 1988-89) (ChemRisk, 1992a, b).

During the initial operations, plutonium machining was reportedly done without oils. Carbon tetrachloride was used as a coolant. Components were cast, pressed, machined, and cadmium plated. The plating was done to reduce alpha and neutron exposure of personnel. It also reduced the risk of spontaneous combustion. Later (from the mid-1950s until the late 1960s) nickel carbonyl was used to nickel coat the parts (ChemRisk, 1992a).

The parts were initially shape cast. By 1958, closer tolerances were required. Operations included rolling, forming, cutting, and heat treating. The foundry cast ingots, which were then rolled flat. Pieces were stamped from the sheet of metal, formed into the needed shape, then turned and polished (ChemRisk, 1992b).

Building 707 was built in 1972. It contained the foundry, casting operations, and product assembly (ChemRisk, 1992a). Carbon tetrachloride was mixed with oil and used as a coolant in the machining operation (Fenner, 1987). Carbon tetrachloride was also used to clean glove-box walls, furnaces, machinery, and instruments (ChemRisk, 1992a). In 1974, Building 707 used 1,000 gallons per month (Fruehauf and Richter, 1974). The air emission of carbon tetrachloride from Building 707 was estimated to be over 32 tons per year, 80 percent of the site emission total. Module C accounted for over 22 tons of the emissions (ChemRisk, 1992a).

Module A and J of Building 707 contained the casting operations. Module K contained casting operations and storage and retrieval of plutonium metal. Plutonium was weighed, melted in a furnace, and formed into ingots.

Module B had operations which rolled and formed plutonium ingots. Carbon tetrachloride was used to clean the rollers (ChemRisk, 1992a).

Module C contained the machining and briquetting operations. After the parts were machined, they were weighed and cleaned with carbon tetrachloride (emission: 22.62 tons/year) (ChemRisk, 1992a). The use of carbon tetrachloride as a degreaser continued until the plutonium operations were discontinued (ChemRisk, 1992b). An estimated 20 percent of the carbon tetrachloride was lost from chip degreasing and 75 percent from machining and cleaning (Unknown, 1986).

In 1971, the industrial hygiene staff sampled the air inside the Module B to Module C inert conveyor line glove-box train (Hornbacher, 1971). Grab samples were taken and analyzed by mass spectroscopy. Five carbon tetrachloride degreasing tanks were next to the conveyor line interlock. The glove box also contained a balance, a canner, and a press (Hornbacher, 1971). The carbon tetrachloride sample results ranged from 1,000 parts per million in the canning area up to 22,000 parts per million in the degreasing tank area.

Glove Boxes in Module C. Plutonium was handled within stainless steel glove boxes with lead-glass windows and lead shielding to contain radioactivity. Lead-impregnated gloves were attached to the glove ports. Plutonium, when finely divided, can react with oxygen in the air, creating a fire hazard. The glove boxes containing this type of plutonium were filled with nitrogen to keep the oxygen content in their atmosphere below five percent

(U.S. Department of Energy, 1980). The glove boxes were set up in lines based upon the work to be performed. Where possible, the glove boxes were connected by closed conveyor lines. Each line was separately ventilated, to keep the air pressure in the line negative relative to the module (U.S. Department of Energy, 1980).

Module C had glove boxes on either side of the room. Parts were brought into the area by an enclosed conveyor which ran down the center aisle and passed into each glove box through an airlock. A one-half-inch line carrying carbon tetrachloride was connected to most of the glove boxes.

Glove Boxes 25, 30, 45, 60, and 65 had turning machines. These glove boxes as well as glove boxes 40, 70, 80, 85, and 95 were identified as machining boxes by the plant industrial hygiene personnel. Glove Box 75 was a process tool storage box. Glove Boxes 110 and 115 were connected across the aisle. The unit contained a solvent still, a degreasing operation, and a briquetting machine (used to make briquettes out of metal turnings). Glove Box 110 was also connected to a briquette conveyor and transfer box.

The metal chips and turnings generated during the machining operations were degreased in Glove Box 110. They were submerged consecutively in a series of five carbon tetrachloride baths, transferred to a holding pot to drain and drip dry, and then placed in another pot where a fan blew the glove-box atmosphere over them to further dry them (Santiago, 1985). Industrial hygiene sampling in 1974 revealed carbon tetrachloride escaping into the room air from some of the bottom glove-box ports of the briquetting operation. Increased ventilation was installed. Less than 1 part per million was found after installation. Annual air monitoring was recommended (Fruehauf and Richter, 1974).

Glove Boxes 50, 85 and 95 contained some inspection operations. Inspection involved the use of radiography, visual methods, gauging ultrasonics, tensile tests, dye penetrants, and the measurement of electric eddy currents (U.S. Department of Energy, 1980).

Since the glove boxes were not open to the atmosphere, the airflow required to keep the glove boxes negative relative to the atmosphere was low. This led to an accumulation of vapor within the glove boxes and possible leakage through the glove material into the room.

The gloves installed in the glove boxes were designed to protect against radiation, not chemical contamination. The initial testing at Rocky Flats focused on visible physical degradation (Giebel and Riegel, 1963). Neoprene and later Hypalon gloves were used in the glove boxes.

Vahdat *et al.* (1995) tested gloves 15 mil (1mil = 0.001 inch) thick using a standard two-inch permeation cell. The breakthrough time for neoprene gloves was 42 minutes ± 5 minutes. The breakthrough time for Hypalon was 57 minutes ± 11 minutes. The permeation overloaded the gas chromatograph (Vahdat *et al.*, 1995).

In 1977, samples were taken inside the finger of glove-box gloves using a direct reading infrared spectrometer while the operator simulated machining a part (Hyman and Cichorz, 1977). The peak values for the machining box ranged from none detected up to 138 parts per million with levels up to 30 parts per million. The test was repeated for the briquetting glove box. Sample values ranged from 15 to 460 parts per million. A steady state level of 10–55 parts per million was attained while the employee worked. The machining box had more ventilation than the briquetting box. Hyman and Cichorz (1977) concluded that the carbon tetrachloride permeation rate and buildup was affected by the age of the glove, duration of exposure, location of the glove relative to large sources of liquid or vapor, glove storage, and the amount of ventilation within the box.

A study was conducted in July 1986 to look at carbon tetrachloride absorption through gloves. Carbon tetrachloride can be absorbed through the skin (Stewart and Dodd, 1964). If carbon tetrachloride permeated through the gloves, skin absorption is a potential route of exposure. Glove-box gloves were soaked in carbon tetrachloride for 24 hours, and a volunteer donned the gloves while they were still immersed. Carbon tetrachloride uptake was measured via the amount found in exhaled breath. The breath concentration was 1.7 parts per million (Potter, 1987).

One example of integrated sampling was located (Carpenter, 1988). Personal samples were taken using organic vapor badges. Detector tube samples were taken within glove-box gloves, and employee exhaled breath samples were taken on the same day. Breathing-zone samples were less than 0.1 parts per million, glove permeation samples varied from less than 1 part per million up to greater than 50 parts per million, and the breath analyses were all less than 50 parts per billion (Carpenter, 1988).

Plutonium Recovery. The recovery process changed little from the time of its inception in the 1950s. Recovery operations were designed to recover and purify both fissionable material from retired weapons systems and waste produced during the manufacturing processes. The process had two functional divisions. "Fast" recovery processed plutonium nitrate solution into metal. "Slow" recovery was used on materials with more impurities, when preprocessing was required (ChemRisk, 1992a). Materials were first converted to the plutonium nitrate form in the slow recovery operation, then sent to the fast recovery operation. The slow recovery process used anion exchange, dissolution, and cation exchange to recover plutonium. The exact steps required depended upon the incoming material.

The combustible materials were incinerated to convert the plutonium to an oxide form. Anion exchange received effluents from fast recovery, dissolution, and cation exchange. The dissolution process received incinerator ash and plutonium dioxide from other buildings. Laboratory waste and chloride salt process effluents went to cation exchange. Until 1960, dissolution was followed by solvent extraction using tributylphosphate and dodecane. When recovery process materials became more varied, solvent extraction was replaced by anion exchange (ChemRisk, 1992b).

Fast cycle recovery operations began with the dissolution of the plutonium compound. Nitric acid was the primary chemical used, along with aluminum nitrate, calcium fluoride, and water. The mixture was converted to a peroxide (Crisler, 1991), precipitated as plutonium peroxide, and heated to convert it to plutonium dioxide. Anhydrous hydrogen fluoride was reacted with the oxide to form plutonium tetrafluoride. This compound was reduced to plutonium using calcium. Wastes were sent to the slow cycle for recovery of the metal or to Building 774 for treatment (ChemRisk, 1992b).

Molten salt extraction was introduced in 1968; it was used to remove americium. The plutonium metal could then be sent directly to the foundry (ChemRisk, 1992b).

The "special recovery" lines were used to process the "special order" tracer radionuclides. Operations included the leaching lines which removed surface impurities from enriched uranium and plutonium components (ChemRisk, 1992b).

Plutonium Research and Development. Building 779 was built in 1965. The primary areas of research were plutonium chemistry and metallurgy, improvement of manufacturing processes, and recovery of plutonium and other actinides (ChemRisk, 1992b). Research work was done on the physical chemistry of plutonium, physical metallurgy, welding and brazing, molten salt extraction and electrorefining processes, plutonium hydration, aqueous recovery techniques, machining and gauging, and substrate coating (ChemRisk, 1992a).

The plutonium analytical laboratory was located in Building 559. This laboratory analyzed incoming plutonium, site returns, feed material, recovered/purified and cast plutonium for impurities, and the concentration of plutonium alloys.

Until 1965, criticality tests were performed in the buildings where plutonium and uranium were handled. When Building 886 was opened in 1965, critical mass experiments using uranium and plutonium were then conducted in this building (ChemRisk, 1992).

Americium Processing. ^{241}Americium is a decay product of ^{241}plutonium. It absorbs neutrons, decreasing the fission yield of plutonium and its effectiveness. Unlike ^{241}plutonium, ^{241}americium is a gamma emitter and more of a personnel exposure concern.

Americium work was initiated in 1957. A limited number of other radionuclides were produced on "special order" components. These included ^{237}neptunium, ^{238}plutonium, and a curium isotope. An americium recovery line was built in Building 771. Americium was recovered for resale until the late 1970s. Between 1957 and 1967, the plutonium peroxide precipitation effluent was evaporated and the americium separated from the remaining solution by anion exchange using ammonium thiocyanate. Americium chloride was the final product. In 1962, oxalate precipitation and calcination steps were added to give americium oxide as the final, more stable, product. The plutonium was brought into contact with molten NaCl-KCl-$MgCl_2$ and the americium was removed by oxidation-reduction reactions. The salts were treated by dissolution, hydroxide precipitation, and anion exchange. Due to elevated personnel exposure, the hydroxide precipitation step was replaced by a cation-exchange procedure in 1973. In 1975, the ammonium thiocyanate steps were eliminated, and the anion effluent was treated with oxalate precipitation followed by calcination to form americium oxide (ChemRisk, 1992b).

Purification of americium stopped in 1976. A salt-scrub process was used to make a “scrub alloy” containing americium, plutonium, and gallium, which was shipped to Oak Ridge National Laboratory for processing. The recovery and purification operation at Rocky Flats was discontinued in 1980, and americium work continued only to extract americium from the plutonium on-site returns (ChemRisk, 1992b).

Waste Processing. The wastes produced by the manufacturing processes included fissionable and nonfissionable materials, lubricating oils, cleaning solvents, and paints. Solid wastes included contaminated clothing, rags, and tools. There was an economic incentive to recover many of the expensive metals.

Building 774 was the main radioactive aqueous waste treatment facility for Building 771. It was built in 1952. Liquids were pH adjusted and then sent through a precipitation step. Until 1973, the remaining aqueous wastes were sent to evaporation or holding ponds. Around 1965, an evaporator was installed to treat wastes from solar evaporation ponds. The concentrate was further dried in a dryer. The dry salt was removed by a scraping blade. In 1980, liquids began being transferred to Building 374 (ChemRisk, 1992b).

Building 776 was the central collection point for waste oil. Liquids and solids were separated and sent to Building 771. In Building 771, carbon tetrachloride was distilled out of the oil. Some of the oil-carbon tetrachloride mixture was filtered and recirculated. When the mixture was no longer usable, it was filtered and solidified. (ChemRisk, 1992a).

D Plant

Assembly Area. Assembly of plutonium-containing parts into completed components was done in Building 991. Small amounts of solvents were reportedly used for a final wipe down. The early weapons required relatively little assembly (Putzier, 1982). The hollow-core design required additional operations: drilling, welding, brazing, turning, and polishing. This work was done in Building 777 when it opened in 1957. In 1969, final assembly operations were moved to Building 707 where they remained until the production facility was closed in 1990.

CHAPTER 7. METHODS AND SOURCES OF INFORMATION

The specific objectives of this research were to (1) identify current and historical data from industrial hygiene air monitoring for chemicals at Rocky Flats, (2) identify individuals knowledgeable about the processing and industrial hygiene activities, and (3) identify and evaluate information that could be used to estimate employee exposures to chemicals at the Rocky Flats plant.

The initial investigation identified which chemicals had been used in large quantities at the Rocky Flats plant. This involved reviewing the available written information about the history of the plant, especially the plutonium facility, reviewing specifications for processes, and extracting information about chemical use. The major chemicals used in each location were identified (see Chapter 6). The plutonium facility has been nonoperational since 1990.

Written Histories

Much of the documentation about the history of Rocky Flats is available only in unpublished materials. These materials include memos and unpublished internal Rocky Flats reports. These materials cannot be cited explicitly because of the lack of peer review and because of classification, privacy, and corporate legal issues. This type of information is referenced as "internal documents."

The other principal sources of information for basic historical information about the general plant procedures are (1) public reports on historical operations, chemical and radiation releases, and plutonium operations (ChemRisk, 1992a, b; Cristler, 1991); (2) health physics operations (Putzier, 1982); and (3) the plant environmental impact statements.

Employee Interviews

Employee interviews were conducted to gather information on specific job duties, process changes, chemicals handled, personal protective equipment used, and engineering and administrative control measures. People in the following areas at Rocky Flats were interviewed: legal department, occupational medicine department, analytical chemistry laboratory, purchasing department, health physics, industrial hygiene, industrial safety, and environmental protection. The information determined by interview is summarized below. Names are not listed to ensure privacy.

Analytical Chemistry Laboratory Employee. The employee was often assigned to analyze the unusual or special samples. Based on his knowledge of the work performed at Rocky Flats, he believed that the production facilities usually had exhaust hoods. He stated that perchloroethylene was used in uranium machining, trichloroethylene was used in the maintenance shops, and carbon tetrachloride was used as a degreaser in plutonium work areas. Neoprene gloves were used in those operations.

Chemist. The chemist analyzed many of the solvent samples between 1974 and 1977. At that time, the laboratory probably did not run blank samples. Standards were generated in dilution flasks; the pure compound was injected into the flask and diluted to make a known concentration. The standard was run through a gas chromatograph at a known flow rate. After samples were analyzed, the laboratory analyst calculated back to the total volume of the sample. The chemist had no information on the location of any laboratory notebooks. The chemist confirmed that information which was not related to weapons was usually destroyed after two years. The industrial hygiene and environmental samples would have been in that category.

Plant Purchasing Employee. This employee worked at Rocky Flats from 1973 until 1990. Purchase order files were destroyed within three years. The industrial safety department reviewed the purchase requests. The employee remembers purchasing large amounts of the following chemicals: nitric acid, sodium hydroxide, potassium hydroxide (in tanker loads for Building 771), perchloroethylene (used as a coolant for machining), and carbon tetrachloride (used in the plutonium area).

Retiree. This retiree started work at the plant in 1959. He said that initially, from 1952 to 1956, there were no glove boxes used for the assembly of parts. The dry boxes were used beginning in 1956. The heavy production years lasted until 1978. Before 1962, there was little movement of employees across plants and between buildings. Employees were generally assigned to one work location and could not enter other areas without special permission.

He reported that stainless steel, depleted uranium, and beryllium were used in Buildings 444 and 447. The coolant used was water based and caused some dermatitis. Beryllium was cleaned using trichloroethylene and later 1,1,1-trichloroethane. Carbon tetrachloride was used occasionally. Acids were not used.

He stated that Buildings 771, 776, 777, and 707 contained plutonium operations. The solvents used were isopropyl alcohol and carbon tetrachloride. Trichloroethylene and 1,1,1-trichloroethane were also present to a lesser extent. Acids (hydrochloric, hydrofluoric, nitric, and sulfuric) were used in Building 771.

Health Physicist. He recalled that plutonium was first used in 1953. Air monitoring began at the same time. Processing included the use of hydrogen peroxide, hydrofluoric acid, and calcium iodide. Radiation samples were recorded on cards which were sent to the Federal Records Center.

Few solvents were used in Building 71 (later renamed 771). Carbon tetrachloride and trichloroethylene were used in Buildings 76 and 77. Some of the glove boxes had nitrogen atmospheres, to reduce oxygen content to less than that of ambient air. The buildings had high ventilation rates. The health physicist thought that glove boxes were used from the beginning. Neoprene and butyl gloves, sometimes laminated with lead, were used in the glove boxes.

Health physics technicians checked the gloves daily for contamination. Personnel wore white coveralls and booties. Half-facepiece respirators were carried.

Environmental Management Employee. This employee worked from January 1968 until January 1988. The employee was involved in environmental work beginning in 1972. He noted that both a historical release report and a waste stream characterization report were prepared. Both provide historical information on plant processes.

Perchloroethylene was used with uranium processes, followed by trichloroethylene, and then 1,1,1-trichloroethane. Acetone was used as a final wipe. Diethyl ether was used in many of the laboratories for extracting chemicals. Some alcohols, especially isopropyl alcohol, were used. The employee believes that the earliest chemical inventory was probably done in 1974.

Industrial Hygienist. This employee started work in March 1953. He began working in the industrial hygiene area in 1961. The industrial hygienist kept a logbook and recorded the results of any air sampling done using direct reading instruments. These logbooks were kept from December 1961 until April 1983. The Building 81 laboratory did most of the analyses.

The chemicals used in the highest volume were carbon tetrachloride, perchloroethylene, trichloroethylene, and 1,1,1-trichloroethane. Carbon tetrachloride was used as a degreasing agent for plutonium in Buildings 771, 774, and 707. The others were used as degreasing agents for other metals. Freons were used occasionally, but not extensively, due to the cost. The ventilation hoods were checked annually. Each laboratory had its own analytic procedures. Sampling was done according to Dow Chemical Company procedures prior to 1970. Any accidents or illnesses were reported to the industrial safety organization.

The industrial hygienist was brought to Los Alamos National Laboratory for consultation about the sample results and his notebooks. The industrial hygienist proved invaluable in helping this author to understand the Rocky Flats records. The industrial hygienist reviewed the early (1957–1974) Dow Company correspondence and memos, identified and described the various operations, and explained much of the idiosyncratic terminology used at the plant. The industrial hygienist also explained his personal notebooks, as well as memory allowed. The sampling data sheets which had been collected were reviewed. The industrial hygienist provided information on terminology used, sampling rationale, operations present, and personnel protective equipment used, which helped explain much of the information on the data sheets. The data which had been entered into a computer database was also reviewed.

Workers' Compensation Lawyer. This lawyer has been the workers' compensation lawyer for the plant since 1980. The files included notebooks written by the plant industrial hygienists from 1962 through 1985, air-monitoring records (with all personal identifiers removed) used in workers' compensation cases, carbon tetrachloride glove permeation data, and some job descriptions. The records were photocopied and used in the development of the sampling database.

Director of the Building 881 Chemistry Laboratory. Most of the sample results found had been analyzed by the 881 laboratory, but the original results or sample forms were not located, and the chemist's notebooks were not located in the archives. The laboratory director stated that all records which were not directly related to weapons concerns were routinely destroyed after two years.

Retiree Questionnaire

In August 1992, approximately 500 salaried employees retired. Most were given a short questionnaire requesting information about chemical usage. Over 400 forms were distributed; 60 were returned. The information gathered was not specific enough to add to the sampling database, but it was reviewed and used to supplement and confirm data from the historical records and interviews. A file containing information on job title, department, location, process, and materials handled was begun (Jobsexit.doc).

Written Records

There are several repositories of records for the Rocky Flats plant. The document storage and retrieval system from each was used to identify and obtain copies of memos, records, and reports dealing with the use of chemicals at the plant.

Union Contracts. Copies of the union contracts were provided by the Rocky Flats Legal Department. All contracts contained some information on salary and labor-grade level of assignment by job classification. The contracts negotiated before 1972 contained varying amounts of section and department information. Some of the contracts included information linking department and job title or building. Contracts from later years listed the classification and pay rate, but not the job location. The available information on job titles, organizations, and locations were extracted from the union agreements (Rfjobsaf.doc). The first page of this file is in Appendix A.1.

Organizational Charts. The organizational charts from 1953 through 1957 were located at the Department of Energy Las Vegas Office. The following information was abstracted into a computer file (Orgchart.doc): month, year, organization, sections, job titles, number of employees in each job, and location. The first page of this file is in Appendix A.2.

Technical Library. The Technical Library contains copies of internal reports and publications produced by employees of Rocky Flats. The contents were indexed using a key word in context (KWIC) listing. The listing for unclassified holdings was reviewed. Documents and reports related to chemical monitoring and handling, e.g., chemical operating procedures, were read and information abstracted.

Chemical operating procedures (available for the 1980s) were identified by title from the procedures master list. They contained the following type of information: personal protective equipment required, general hazards of the chemicals present, and details on the machinery controls. They were designed to specify the mechanical operating procedures and controls, not safe operating procedures.

Classified Archives in Building 881. The material is stored in boxes which are identified by a code number. The contents of each box are listed in the archive index; the entire archive index was reviewed. The file titles were not very descriptive and gave little information as to the actual contents of the boxes. Boxes which appeared to contain information on chemicals were reviewed. The "M" and "SEPA" documents contained specific information on the configuration of parts, and they specified the materials used in the parts and in the cleaning of the parts. The amount of chemical information available was minimal (e.g., use one milliliter of carbon tetrachloride on cheesecloth to clean this part).

Monthly strength reports consist of reports filed by supervisors listing employee work location for each pay period. These reports are available on microfiche dating back to approximately 1958. The monthly strength reports have not been computerized and were not used in this study.

Environmental Master File. The Environmental Master File is an archive of unclassified optically scanned copies of internal memoranda and reports. Its creation was motivated by a need for information to be used in legal proceedings. Computer searches were done to locate data on the following subjects: carbon tetrachloride, Area C, buildings in the 700 area, industrial hygiene, specific industrial hygienists, industrial safety, industrial hygiene sampling, bioassays, chemical analysis, trichloroethylene, and 1,1,1-trichloroethane. Few memoranda or other reports relating to industrial hygiene sampling were located.

Federal Records Center. A list of all records sent to the Federal Records Center, Denver, Colorado, by the industrial hygiene and health physics groups at Rocky Flats was acquired. This was used to identify applicable records. The applicable records were then retrieved and reviewed (approximately 100 boxes). Information about chemical exposure was abstracted by project staff. (Frcboxhp.Doc and RFfrcbo1.Doc contain lists of the reviewed material.)

Medical Records. Medical records are personal and confidential information. The medical director described the type of information available in the medical files. No routine biomonitoring was performed for people potentially exposed to solvents. The records are not computerized in a manner which would allow them to be searched without an employee name. Liver function tests were part of the routine physical. No linkage could be made to the chemicals used. The medical department could not list all personnel located in an area or job and correlate this with test results.

Health Physics Files. The health physics department files were reviewed. No additional industrial hygiene information was located.

Industrial Hygiene Files. The current industrial hygiene files were reviewed. Information on personal monitoring for chemical exposures done by the plant industrial hygiene program was abstracted. Current and historical data on industrial hygiene air monitoring for chemicals was computerized (described in the following section: "Development of a Computerized Industrial Hygiene Sample Database") in order to determine potential chemical exposures.

The following types of information were located: job descriptions; weekly highlights of the industrial hygiene program for 1975–76; books of sampling data sheets on dioctyl phthalate, carbon tetrachloride, and trichloroetylene; the logbooks kept by the industrial hygienists employed at the plant; and miscellaneous Dow Chemical Company records and correspondence. The weekly highlights contained information extracted from sampling records or the industrial hygienists' notebooks. The sampling data from the above sources was abstracted separately and added to the computer data file. All records were reviewed for classified material before being copied.

Engineering Files. The engineering department keeps building blueprints on microfiche. The blueprints were used to determine general information on how carbon tetrachloride lines were connected to glove boxes and the types of machines used within a glove box. The Module C general glove-box line diagrams are unclassified controlled nuclear information and will not be included in this report.

Classified Information. Some classified weapons information was transferred to Los Alamos National Laboratory as a part of a stockpile maintenance project. A small portion of the microfilm was reviewed to determine whether any of the information could be of use for this project.

Every employee who handled a weapon part signed off after completion of work. If the information was readily accessible, it might be possible to search for employee numbers and dates and to use the information to link an employee to a work location. These files are still classified; they were not used during this project.

Development of Job Information and a Job Dictionary

There was no single source of information on all of the job titles used at the Rocky Flats plant over its history. Consequently, the project undertook several activities aimed at establishing a master job dictionary.

The original study (Voelz *et al.,*1983) extracted the job histories of 25 percent of the cohort. Although no computer file containing that information was located, a printed version was. It was optically scanned into an ASCII file, converted into a Word 5 file, and manually edited (Jobtxt.doc).

Job descriptions were obtained from two of the primary operating contractors at Rocky Flats, Dow Chemical Company and Rockwell

International. The information added to the original job dictionary included job title, company job number, department, date the job description was written, and whether the description noted possible use of chemicals. Job numbers from both companies were listed. Additional entries were made for new jobs, organizations, and job numbers. A copy of the first page of the file (RFjobdic.doc) is in Appendix A.3.

The next activity was the extraction of job titles from the full occupational histories of 900 people. The organization titles and codes were included with all job titles. The file was sorted by job title, organization, and organization code. The file was edited in order to remove duplicate lines (8,975 lines reduced to 5,586). The unedited original file was then sorted by job title, date, and organization code. The two files were compared to ensure that the earliest date of each job title was preserved. The edited file was resorted into three versions, one by job title, one by organization, and one by organization code (Eddat6.doc).

The abbreviations used in job titles and organizations were standardized (Eddat6ab.doc). Employee numbers were removed. The earliest date was saved for each set. One page of this document is in Appendix A.4. The full document is available from the project.

The job titles used at the Rocky Flats plant did not identify the location of the work being done. The work histories identified the job titles, organization code, and organization. There was no consistency in the use of organization codes; they changed frequently. Their use was principally in connection with budget and accounting processes. The organization names also changed frequently. In some cases, the building number was included in the name. The location could sometimes be inferred from the operation described in the name, but this was not always the case. The carbon tetrachloride sample results listed the location of the sampling, but reference was not made to job titles or organizations. Very little process information was included and few individuals were identified.

For the 1976 to 1977 time period, job descriptions for the hourly workers of Dow Chemical Company (the primary contractor) sometimes contained information on the materials handled. The job title, job description, and materials handled are listed in Appendix A.5 (Jobmathd.doc). Most of these job descriptions also included a small amount of "exposure" information. In the job descriptions, the frequency of the following activities were ranked from rare to continuous: dry box work, respirator use, supplied air use, handling of radioactive material, handling of chemicals, and work in proximity to radioactive material. These rankings are in Appendix A.6 (Jobtable.doc) There were 63 jobs for which this information was available.

The health physics records from the cohort used in the original epidemiological study were available on microfiche at Los Alamos National Laboratory. Fifty-six files were reviewed. The types of information available were employee record card (which sometimes listed buildings the employee was assigned to and job title), whole body counts, urinalysis results, annual radiation dosimetry reports, health physics exposure data, health physics reports of accidents or possible exposures, and occasionally, memoranda (Microfh.doc).

Job titles which appeared to be related to plutonium usage in Building 707 were abstracted from the revised job history list, the original epidemiological study job list, the union agreement list, and the job histories of personnel listed in the carbon tetrachloride sampling database (Job707#2.doc). One page is included in Appendix A.8. Table 3 is a summary of the information identified in this chapter, with where it can be located in the appendices.

TABLE 3

Information Described in the Methods Chapter and Its Location in Appendices

LOCATION	DESCRIPTION
Appendix A.1	Information extracted from union contracts.
Appendix A.2	Information extracted from 1953–1957 organizational charts for Dow Chemical Co.
Appendix A.3	Information extracted from contractor (Dow Chemical Co. and Rockwell International) job descriptions.
Appendix A.4	Job title, job description and materials handled information from Dow Chemical Co. hourly worker job descriptions.
Appendix A.5	"Exposure" information from Dow Chemical Co. hourly-worker job descriptions.
Appendix A.6	Information extracted from 900 job histories.
Appendix A.7	Information from job histories of employees listed in carbon tetrachloride database.
Appendix A.8	Combined file of all Building 707 job information.
Appendix B	Description of CompChem database

Computer files containing additional information not included in the appendices are recorded on a computer disk which is included at the end of the dissertation. Throughout this chapter, the names of the computer files are listed in parentheses when the files are first mentioned.

The records gathered for this research will be available from the document archives at Los Alamos National Laboratory, Los Alamos, New Mexico. The CompChem database is available from the Department of Energy Comprehensive Epidemiologic Data Resource Center at Lawrence Berkeley National Laboratory, Berkeley, California, and the Environment, Safety, and Health Division at Los Alamos National Laboratory.

The State of Colorado Department of Health, the University of Colorado, and the National Institute for Occupational Safety and Health have been developing a job-exposure matrix as part of a five-year study of morbidity at the Rocky Flats plant. The resources available to these agencies exceeded those available to this project. Consequently, the evaluation of the computerized sampling data became the principal focus of this study.

Development of a Computerized Industrial Hygiene Sample Database

The available historical exposure information had to be compiled into a computer database which could be analyzed. The CompChem database, an ORACLE®-based information system, was created for this project.

Several thousand sampling sheets and their analytical results were located in the industrial hygiene group office at Rocky Flats. Additional copies were in the archived industrial hygiene files. The files received from the workers' compensation lawyer were determined to be copies of information available in the industrial hygiene files, with all personal identifiers removed.

A sample sheet described a single sample. A sample could be analyzed for several chemicals. The information fields included operation sampled; material being sampled; building; room; location in room; sample point in relation to operation; date and time sample started; date and time sample stopped; daily time (if more than one day); total time; flow rate at start; flow rate at end; total volume sampled; equipment used; dial settings on instruments used; calibration information; reagents used; sampling done by (for identification of the person who performed the sampling); personnel involved in operation; analysis; and results. The analysis field was used to identify where the sample was sent (e.g., 881 lab). A sample identification number was written on the bottom of the sheet (this is named "sampidnum" in the database). The person who performed the sampling was responsible for completing the results field after the laboratory analysis was performed. The field was not always completed. Each sample was assigned a number ("epidsamnum") when it was entered into the database. This number is the only unique identifier. It is a required field and is used as the primary link between all tables.

The samples were sent to the analytical laboratory; copies of the sampling sheets were supposed to be sent with the samples. The analytical laboratory performed the analysis and issued an analysis report. The laboratory analysis report was assigned a laboratory number. The number was composed of an abbreviation which designated the laboratory (e.g., M for the Building 881 laboratory), the last two digits of the year, and the number of the analysis (starting with #1 at the beginning of the year). The analysis report listed a sample description, the sample identification number, sample volume, and the analytical results.

The sampling records were often found separated from the appropriate laboratory results report. They were matched to make a complete record for each individual sample. The copies were filed numerically by the laboratory report number. The computer file was cross-checked with the original data and any errors found were corrected. These samples were initially computerized using EPI INFO, Version 5.

Duplicates were found and eliminated. The final set of laboratory reports was compared with the computer file to ensure that all sample results had been entered into the database. The logbooks of former industrial hygienists were reviewed to identify industrial hygiene sampling data to be entered into the database. Most information on chemicals in the industrial hygiene notebooks were from direct reading instruments. No long-duration samples were recorded there. Copies of memoranda from the industrial hygiene and safety department and status reports from the industrial hygiene operations contained some sample results. Sample data were found in monthly progress reports from the 1950s. Information gleaned from written industrial hygiene "Weekly Hi-Lites" were also entered into a separate database created in EPI INFO 5.0.

When available, industrial hygiene sampling data was correlated with employee names and work locations. Area samples were correlated with location. The majority of the samples were area samples rather than personal samples. Chemical names, locations, sampling information, employee names, and other common data were standardized throughout the file.

The original data set was too large to be run and manipulated on a personal computer. It was necessary to convert the file to a VAX-based system. A computer programmer attached to the Los Alamos National Laboratory Epidemiology Section outlined a database, CompChem, containing the following linked tables: (1) agent dictionary ("Agent_dictionary"); (2) personnel ("Personnel"); (3) sample details ("Det_Samp"); (4) sample results ("Sample_Results"); (5) general sample location and operation information ("Gen_Samp"); and (6) people exposed ("Person_exp"). The database and tables are described in Appendix B. Figure 6 illustrates the table linkages.

The "Agent_dictionary" table contains all of the agents which were sampled, the full chemical name of each agent, the Chemical Abstract Service (CAS) number, and the abbreviations used in much of the database development.

The "Personnel" table contains a list of all personnel identified on the data sheets, the people working in the area as well as the people who performed the sampling. The field contains the Rocky Flats employee numbers. A dummy "employenum" was assigned (starting with 99___) when no record of the actual Rocky Flats employee number was found.

The "Det_samp" table contains detailed sample collection information: date, sample type, sample area, sampling method, sampling flow rate, duration, volume, the laboratory report number, an assigned validity rating, work shift, and an assigned sample number.

The date is listed in a day/month/year format. If no date was available, it was assigned 9/9/99. The instrument flow rate, sample duration, sample volume, and the on/off times were listed on the sampling data sheet. The volume and duration were also listed on the laboratory analysis sheet.

The shift field is filled by the work shift during which the sample was taken. The on/off times sometimes indicated that a sampling pump would be left in a location in the morning and picked up the next day. These were listed as "day+" (single day shift with less than one hour of the next day). The "day" and "day+" samples were analyzed together. The duration was accepted as 480 minutes. For shorter samples, they would pick up the sample at the end of the day. By 1976, most of the samples taken were picked up the same day. Two-day shifts were 960 minutes and three-day shifts were 1,440 minutes. Occasionally the multiple-day samples were split over a weekend.

Beginning with laboratory report number 75–2596, there were multiple-shift samples, i.e., day and swing. These were denoted as "dayswing" or "multidayswing." There were relatively few multiple-shift samples.

The samples identified on the sample data sheet as "breathing zone" samples are actually area samples taken at breathing-zone level. The location is described in relationship to the glove box. Most samples have no employee names listed. The sample sheets which do list names state only that the people were working in the area. No statement is made that the employees were actually wearing the sampling equipment. The industrial hygienist who supervised the sampling program stated that the samples were not personal samples. In the computer database, these types of samples are listed with a sampling location ("samparea") of "breathing zone" and sample type ("samptype") of "area." Personal and lapel samples are given a sampling location of "breathing zone" and sample type of "personal." Other examples of sample locations include "environmental" and "box atmosphere." Other examples of sample type includes "grab" (e.g., a bag or bottle was filled with an air sample).

The "Sample_Results" table contains the results of the sampling as reported by the laboratory or as listed in the source material (in the case of direct reading instruments). Most of the solvent and gas samples were reported in parts per million. The parts per million calculation is based upon the volume of air pulled through the sample, and the volume is related to the duration. Therefore, the parts per million values of slightly different duration samples can be compared to each other. Results that were reported as a percentage were converted to parts per million when comparisons were required. The "Sample_Results" table includes the agent abbreviation, the quantity of the agent, the units, and a qualifier where applicable. The qualifier could be either greater than (>) or less than (<) in cases where the analysis limits were either exceeded or where the amount of agent present was below the minimum detection limit. The latter was very common. This led to statistical analysis problems which will be discussed later.

The "Gen_Samp" table contains the location and operation data for the samples. Each sample which was analyzed by the Rocky Flats analytical laboratory was assigned a number by the laboratory. In the database, this number is called "sampidnum." Most were unique, but several sets of duplicate laboratory numbers were found. When the sample results were not duplicates, they were given numbers and included in the database. Samples which were not analyzed by the laboratory had no laboratory assigned numbers. Consequently, not all assigned sample numbers ("epidsamnum") have corresponding sample identification numbers. The "Gen_Samp" table includes the information about the building, room, glove box, and operation. Database fields were available for description of the operation, details about the location, and personal protective equipment used. Most of these fields are blank because the information was not available. The final table, "Person_Exp," contains the employee identification number for exposed employees.

"Epidsamnum," the number that identifies each sample, is common to all tables and can be used to link data from the tables (see Figure 6, "Structure of CompChem database," in Appendix B). The sampling database can link the sample to the date it was taken, the building, and often the room within the building. This allows the determination of chemical use by location and date.

The glove box numbers from Building 707 were 7 (the last digit of the building number), a letter identifying the module (A through K), and the glove box number. Sometimes only the glove box number was listed (e.g., 45 or Box 45, instead of 7-C-45).

The sampling sheet did not always have the glove box number listed. When this occurred, it was sometimes possible to use information from the other samples to draw inferences about the missing information. The briquetting operation is listed as occurring only in 7-C-110. The term "press box" was sometimes linked with briquetting when the glove box number was listed. When the operation was listed as "press box" without the glove box number, the glove box number was assumed to be 7-C-110 and was listed as such in the database. This reduced the number of samples without glove box numbers.

A company which specializes in location, retrieval, and review of archival information was contracted by the Department of Energy to perform an inventory of records relating to industrial hygiene. A review of the inventory indicates that this project located and computerized most of the available industrial hygiene sampling data.

Quality Control Concerns

The majority of the carbon tetrachloride samples were taken between 1974 and 1977. The samples were taken with charcoal tubes and were analyzed by gas chromatography. No additional information was located on the analytical method used at Rocky Flats. The laboratory analysis books were reportedly destroyed two years after analysis was completed. It was not possible to determine systemic errors in either the sampling or the analysis.

Until August 1974, all carbon tetrachloride samples were taken during single day shifts. Beginning at laboratory report 74–1260 (up to 75–1299), most samples listed are single-day samples collected with the assistance of a time clock. Presumably the clock acted as a timer and turned the pump off automatically. In some cases, the duration and time clock report agreed (480 minutes and 8:00–16:00, respectively), but the actual time recorded lists two days. For example one day will begin at 7:45 a.m. and the end time will be 7:30 a.m. of the following day. One possible explanation is that the technician left the pump at the beginning of one shift (with the timer set for 480 minutes) and returned for it the next day. These were listed as day+ for tracking purposes. No written sampling procedure was located. Consequently, it is not possible to fully understand the discrepancies.

The laboratory analytical result values were accepted as valid values, unless there was a clear reason to do otherwise. In cases where the wrong sample duration or sampling pump flow rate values were used by the laboratory, the sample validity was reported as "void" and the results were not included in the data analysis. In cases where the laboratory and the technician listed slightly different times, the values were accepted as valid if they were within 10 percent of each other.

The sample data sheets stated that the pumps had been calibrated, but no specific information was located. The sampling data sheets also did not document any periodic spot-checks of the sampling system during the sample period.

Methods for Dealing with Censored Data

Data is considered censored when (1) the attribute of interest cannot be detected or quantified or (2) it is known that the attribute falls below a known value (Perkins *et al.*, 1990). The actual value could be zero or somewhere between zero and the minimum detection limit, but the exact value is unknown or "censored."

Nelson *et al.* (1993) described the estimation of historical exposures to organic solvents and lead at several automobile assembly plants.

Documentation of 6,000 air samples from 25 assembly plants was available. The authors evaluated the jobs for potential exposures to halogenated and nonhalogenated solvents, potential dermal exposure, and the approximate level of exposure. When the results listed "nondetectable" or "less than" values, a value one one-hundredth of the 1990 Threshold Limit Value was used (Nelson *et al.*, 1993). This is the only study located which discussed in detail the disposition of below minimum detection limit data. When categories are semiquantitatively decided, the presence of these values may not affect the categorization. In other cases, the presence of these values may lower the average value and possibly cause placement in a lower category.

An initial review of the carbon tetrachloride samples from the CompChem database revealed that many were below the minimum detection limit of the analysis. Several methods for dealing with the problem of nondetectable values have been commonly used: (1) set values below the minimum detection limit to zero; (2) set values below the minimum detection limit to the minimum detection limit; (3) assign one-half the minimum detection limit to all censored points; (4) assign 0.707 (1/square root of 2) of the minimum detection limit to all censored points; or (5) delete the samples which are below the minimum detection limit from the data set.

Choosing a very low value will reduce the mean while choosing a high value (close to the minimum detection limit) will elevate the mean. Using a single value as a substitute for all censored points will usually reduce the standard deviation. Deleting the below minimum detection limit samples will reduce the number of data points and will bias the mean high and the standard deviation low. The first two methods of substitution (using a very low value and using the minimum detection limit) do not seem satisfactory for use with data containing high levels of censoring. The last method (deleting censored data) was rejected as a viable possibility because of the high percentage of censoring found in the Rocky Flats data.

Substituting a value of one-half of the minimum detection limit assumes that the censored data are uniformly distributed between zero and the minimum detection limit. The assumed distribution is shaped like a rectangle (Hornung and Reed, 1990). Hornung and Reed believed that the shape of the distribution should be closer to the shape of a lognormal distribution. A right triangle would be a better approximation of this shape than a rectangle. Consequently, they proposed the method of multiplying the minimum detection limit by 0.707 (1 divided by the square root of 2) (Hornung and Reed, 1990).

Hornung and Reed compared the effect of substituting the two values (0.5 and 0.707 times the minimum detection limit) on the mean and standard deviation. They used simulated data from four distributions (geometric standard deviations of 1.5, 2.0, 2.5, and 3.0 with geometric mean of 1.0). They also used four levels of censoring (15, 30, 45, and 60 percent) to determine the difference between the geometric mean and geometric standard deviation when calculated using substituted values and when calculated using the actual values of the data (Hornung and Reed, 1990).

The two methods produced differing degrees of accuracy depending upon the geometric standard deviation and the percent of censoring. Their simulation data showed that multiplying the minimum detection limit by 0.5 produced less biased geometric mean estimates than multiplying by 0.707 when the geometric standard deviation was 3.0, at all levels of censoring. The estimate of the geometric standard deviation had less bias when the percentage of censoring was above 30 percent and when the distribution was highly skewed (Hornung and Reed, 1990).

When the censoring was below 45 percent and the geometric standard deviation was below 2.5, multiplying the minimum detection limit by 0.707 produced less biased geometric mean estimates than multiplying by 0.5. The geometric standard deviation estimate was better for all levels of censoring when the test geometric standard deviation was 1.5. The method worked best on data which were not highly skewed (Hornung and Reed, 1990).

Maximum likelihood is the most common statistical method for obtaining estimates of unknown parameters of data. The likelihood function of *n* random variables is the joint density of the *n* random variables evaluated at the observed outcomes (Mood *et al.*, 1963). It represents the probability of obtaining the observed sample and is a function of the mean and standard deviation. The maximum likelihood estimate is the value of the function that maximizes the probability of obtaining the observed sample (Bowker and Lieberman, 1972). The estimation process consists of choosing values for the mean and standard deviation which maximize the likelihood function. For example, if the density function for the mean and standard deviation of a normal distribution is used, the maximum likelihood of the mean occurs when the slope of the function equals zero. The maximum is obtained either by setting the derivative of the function to zero and solving for the value, or by an iterative approach of searching until the maximum value is found.

Hald (1952) developed a method of maximum likelihood to derive estimators of the mean and standard deviation of censored data. The method requires two tables of auxiliary estimation functions and is labor intensive. It cannot be used when more than 50 percent of the data is below the minimum detection limit (Hornung and Reed, 1990). The method involves a tabular determination of a dependent variable given two independent variables, followed by a second tabular determination given a single independent variable (Kushner, 1976).

Kushner (1976) simulated air pollution data. A lognormal distribution with a known geometric mean and geometric standard deviation and an infinite number of measurements was assumed. The distribution was truncated at levels of 0 to 50 percent. The estimated geometric mean and geometric standard deviation were obtained as a function of the amount of truncation. Estimates of the geometric mean using Hald's method were equal (up to 4 significant digits) to the actual geometric mean. The geometric standard deviation estimated by Hald's method agreed with the actual value (up to 3 significant digits) (Kushner, 1976).

Hornung and Reed (1990) compared the two methods (substituting 0.5 times the minimum detection limit or substituting 0.707 times the minimum detection limit for the censored values) discussed above with Hald's method. Hald's method produced the least biased results, for both the estimate of the geometric mean and the geometric standard deviation, for all data sets with less than 60 percent censoring.

The method Cohen (1961) developed is similar but requires only one table. It can be used when there is more than 50 percent censoring (Perkins *et al.*, 1990). With Cohen's method for dealing with censored data, the left-hand tail is extrapolated based upon information in the uncensored data. It allows for censored values greater than the median. One table is used to estimate a parameter. This parameter is then used to estimate the mean and standard deviation of a normal distribution.

Perkins *et al.* (1990) used the results of 268 asbestos air samples to compare Cohen's method with the method of substituting the value of 0.5 times the minimum detection limit value for the minimum detection limit value. For sets of normally distributed data, the exposure values were used; for sets of lognormally distributed data, the natural logarithms of the exposure values were used. Use of 0.5 times the minimum detection limit reduced the estimated variance and underestimated the mean. Perkins *et al.* (1990) concluded that Cohen's method should provide an unbiased estimate of the mean for a normal distribution.

The above discussion shows that the common methods used to deal with censored data all have disadvantages: the results depend on the amount of censoring and the parameters of the distribution. Hald (1952) and Cohen (1961) each developed methods which have little bias. However, both are time consuming and labor intensive. Both were designed for use with data containing a single truncation point; or a single minimum detection limit value. The Rocky Flats Plant data had several minimum detection limit values due.

Maximum Likelihood Estimate Program

The amount of censoring in the Rocky Flats carbon tetrachloride data was 49.3 percent, with individual glove boxes having from 15.4 to 85 percent censoring. A method for dealing with this data had to be chosen. The literature discussed above indicates that a maximum likelihood estimation process such as Hald's or Cohen's would be advantageous. Because Hald's method and Cohen's method are both time consuming to perform, a statistician was consulted for assistance. No computer program designed to perform either of these tests with data containing several minimum detection limit values was located. The statistician wrote a computer program that could be used instead of either Hald's or Cohen's method. This program will be referred to as the

Maximum Likelihood Estimate (MLE) program. A copy of the program can be found in Appendix C.

In the MLE program, the first line of each file is a comment line which describes the data being analyzed. Up to four minimum detection limit values can be input. The number of censored data points for each minimum detection limit value were added as the second line of the data file. When less than four minimum detection limit values were present in a given file, those unused were assigned a value of 1.0 and a sample size of zero. The files were proofread against the master data file to verify that no points were missing. The distribution of the air concentration data was assumed to be lognormal. The values were transformed to their natural logarithms. The number of uncensored points was counted. The mean and standard deviation of the logarithms of the uncensored values were calculated.

The MLE program is a FORTRAN® computer program which uses an interactive direct search method; i.e., a direct search is made for the mean and standard deviation of all of the log-transformed data. The density function for the log of the i-th carbon tetrachloride measurement (assumed to be normally distributed) is

$$f(x_i) = \left(\frac{1}{\sqrt{2\pi}\sigma}\right)e^{(x_i-\mu)^2/2\sigma^2}$$

The FORTRAN computer program assigns a probability to the nondetectable values. The probability that the log of a censored observation is less than a certain cutoff value, x_0 = (the log of the minimum detection limit), is the integral

$$\int_0^{x_0} f(x_i;\, \mu,\, \sigma)dx$$

and this was substituted for the missing observation in the likelihood function.

The maximum likelihood estimation was performed using a search subprogram called "Simpnox." Simpnox performs a Nelder-Mead simplex search to minimize the function. Because the Nelder-Mead method searches for the minimum function, the MLE program converts the input function to a negative quantity, producing the maximum of the function. The Nelder-Mead method locates the minimum for a function of *n* variables by a comparison of function values at the (n + 1) vertices of a general simplex. The vertex is replaced with the highest value from another point. The simplex contracts to a final minimum value (Nelder and Mead, 1965). When two variables are involved, the simplex is a triangle (Kotz, 1985). The triangle is moved along the response surface searching for the minimum (Olsson and Nelson, 1975).

In the MLE program, the starting values and initial step sizes must be chosen. The mean and standard deviation of the natural logarithms of the uncensored data were used as the starting values and the step size was set to 0.001. Contraction and extension occurs to create a new simplex. The program initially moves away from the point with the largest value of the objective function towards a lower objective function value. The iteration of the steps stops when there are no detectable differences in successive values of the objective function or in any of the parameter values. (Kotz, 1985) The maximum number of iterations used is 1,000. The output values include the estimated mean and standard deviation of the values; the estimated mean and standard deviation of the log-transformed values; and the estimated geometric mean and geometric standard deviation of the log-transformed values.

Comparison of Maximum Likelihood Estimation Methods

One sample set of 100 random values from a lognormal distribution with a known mean and standard deviation was generated. The geometric mean was 0.56 and the geometric standard deviation was 2.93. These values were chosen to be representative of the carbon tetrachloride data in the CompChem database.

The results produced by the MLE program were compared with those produced by Hald's method and Cohen's method to determine whether they were similar enough to justify further use of the program. The three methods provided very similar results, showing that the computer program could be very useful in generating estimators as good as those generated by Hald's method and by Cohen's method. Table 4 compares the estimates of the geometric mean and geometric standard deviation from the three methods.

TABLE 4

Comparison of Three Maximum Likelihood Estimation Methods: Estimated Geometric Means (GM) and Geometric Standard Deviations (GSD) by Percentage of Censored Data for a Data Set of 100 Random Values, GM = 0.56 and GSD = 2.93 (values in parts per million)

Percent Censored	Maximum Likelihood Estimate Program		Hald		Cohen	
	GM	GSD	GM	GSD	GM	GSD
5	0.56	2.97	0.56	2.97	0.56	3.00
10	0.55	3.00	0.55	3.03	0.55	3.03
15	0.55	3.10	0.55	3.10	0.55	3.10
20	0.54	3.16	0.54	3.16	0.54	3.16
25	0.53	3.19	0.53	3.19	0.53	3.19
30	0.53	3.25	0.53	3.25	0.53	3.25
35	0.53	3.25	0.52	3.25	0.52	3.25
40	0.51	3.39	0.51	3.39	0.51	3.39
45	0.50	3.46	0.50	3.46	0.50	3.46
50	0.52	3.29	0.52	3.29	0.52	3.29

A test was also performed using values from the Rocky Flats data. Twenty-two values were chosen; six of these values (27.3 percent) were censored. The maximum likelihood estimators of the geometric mean and geometric standard deviation of the log-transformed values were calculated using the three methods discussed above. The results are listed in Table 5.

TABLE 5

Comparison of Three Maximum Likelihood Estimation Methods: Estimated Geometric Means and Geometric Standard Deviations of Twenty-Two Carbon Tetrachloride Sample Results with 27.3 Percent Censored Values Taken from CompChem Database, Rocky Flats Plant, Golden, Colorado, Building 707, Module C (values in parts per million)

	Maximum Likelihood Estimate Program	Hald	Cohen
Estimated Geometric Mean	0.26	0.27	0.27
Estimated Geometric Standard Deviation	1.98	1.95	1.98

The robustness of the program was tested by removing 5, 10, and 15 percent of the data from a data set to determine the consistency of the results. The data was removed randomly using a random number table (Hamburg, 1974). Three glove boxes were chosen: Glove Box 45 (N = 151, 66 percent censored), Glove Box 70 (N = 45, 46.7 percent censored), and Glove Box 110 (N = 136, 15.4 percent censored). Tables 6–8 show the results of removing a percentage of the data; three trials were run for each percentage. The results were within 10 percent of the original estimate.

TABLE 6

CompChem Database, Rocky Flats Plant, Golden, Colorado, Building 707, Module C, Glove Box 45 Maximum Likelihood Estimate Program Estimators with 5, 10, or 15 Percent of Data Removed, Three Trials of Each

Percent Data Removed		5%			10%			15%		
Trial	Original	#1	#2	#3	#1	#2	#3	#1	#2	#3
Number of Samples	151	143	143	143	136	136	136	128	128	128
Percent Censored	62.2	61.5	62.2	62.2	61.8	63.2	62.5	62.5	63.3	64.1
Estimated Mean of Air Concentration (parts per million)	0.32	0.32	0.31	0.32	0.33	0.32	0.31	0.33	0.33	0.27
Estimated Standard Deviation of Air Concentration (parts per million)	0.83	0.86	0.81	0.84	0.93	0.89	0.82	0.96	0.94	0.68
Estimated Mean, Natural Log of Air Concentrations	-2.18	-2.18	-2.17	-2.20	-2.19	-2.22	-2.22	-2.24	-2.24	-2.27
Estimated Standard Deviation, Natural Log of Air Concentrations	1.44	1.44	1.43	1.45	1.48	1.47	1.44	1.5	1.5	1.4
Estimated Geometric Mean Natural Log of Air Concentrations (parts per million)	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.10
Estimated Geometric Standard Deviation Natural Log of Air Concentrations (parts per million)	4.21	4.24	4.16	4.25	4.38	4.35	4.24	4.49	4.46	4.05

TABLE 7

CompChem Database, Rocky Flats Plant, Golden, Colorado, Building 707, Module C, Glove Box 70 Maximum Likelihood Estimate Program Estimators with 5, 10, or 15 Percent of Data Removed, Three Trials of Each

Percent Data Removed		5%			10%			15%		
Trial	Original	#1	#2	#3	#1	#2	#3	#1	#2	#3
Number of Samples	45	43	43	43	40	40	40	38	38	38
Percent Censored	46.7	46.5	46.5	46.5	47.5	45.0	47.5	44.7	44.7	47.4
Estimated Mean of Air Concentration (parts per million)	0.26	0.26	0.26	0.26	0.26	0.26	0.25	0.27	0.26	0.24
Estimated Standard Deviation of Air Concentration (parts per million)	0.2	0.21	0.21	0.21	0.20	0.20	0.19	0.2	0.2	0.16
Estimated Mean, Natural Log of Air Concentrations	-1.57	-1.57	-1.57	-1.57	-1.58	-1.56	-1.60	-1.54	-1.56	-1.60
Estimated Standard Deviation, Natural Log of Air Concentrations	0.69	0.70	0.70	0.70	0.68	0.67	0.67	0.66	0.67	0.61
Estimated Geometric Mean Natural Log of Air Concentrations (parts per million)	0.21	0.21	0.21	0.21	0.21	0.21	0.2	0.21	0.21	0.2
Estimated Geometric Standard Deviation Natural Log of Air Concentrations (parts per million)	1.98	2.0	2.0	2.0	1.97	1.95	1.95	1.94	1.95	1.85

TABLE 8

CompChem Database, Rocky Flats Plant, Golden, Colorado, Building 707, Module C, Glove Box 110 Maximum Likelihood Estimate Program Estimators with 5, 10, or 15 Percent of Data Removed Three Trials of Each

Percent Data Removed		5%			10%			15%		
Trial	**Original**	**#1**	**#2**	**#3**	**#1**	**#2**	**#3**	**#1**	**#2**	**#3**
Number of Samples	136	129	129	129	122	122	122	116	116	116
Percent Censored	15.4	16.3	15.5	14.7	16.4	13.9	14.8	17.2	13.8	14.7
Estimated Mean of Air Concentration (parts per million)	0.97	0.94	0.92	1.0	0.92	0.95	1.03	0.93	0.99	0.98
Estimated Standard Deviation of Air Concentration (parts per million)	1.45	1.4	1.31	1.49	1.37	1.31	1.56	1.42	1.39	1.42
Estimated Mean, Natural Log of Air Concentrations	-0.61	-0.65	-0.64	-0.58	-0.66	-0.59	-0.57	-0.67	-0.56	-0.58
Estimated Standard Deviation, Natural Log of Air Concentrations	1.08	1.08	1.05	1.08	1.08	1.04	1.09	1.09	1.04	1.06
Estimated Geometric Mean Natural Log of Air Concentrations (parts per million)	0.54	0.52	0.53	0.56	0.52	0.55	0.57	0.51	0.57	0.56
Estimated Geometric Standard Deviation Natural Log of Air Concentrations (parts per million)	2.95	2.95	2.87	2.95	2.94	2.82	2.98	2.99	2.84	2.89

Evaluation of Bias from Three Estimation Methods

All estimation or substitution methods contain some bias. Bias is the difference between the estimate and the "true" value. The bias generated by the MLE program and two substitution methods (0.5 times the minimum detection limit and 0.707 times the minimum detection limit) was determined.

The statistician used a program to generate sets of 100 random numbers. The random number generator created a normal distribution using the following parameters: mean = –1.62 and standard deviation = 0.92. These values were the average of the estimated means and standard deviations of the natural logs calculated by the MLE program for 12 of the glove boxes (Glove Box 40 data was located later). The values were exponentiated to create a lognormal distribution of random numbers with values in the range of those found in the data. The statistician used standard statistical tables to determine the cutoff values; i.e. values at which a designated percent of the values would be censored. The program censored all values at or below that cutoff point. One hundred random number sets of 100 numbers each were generated for each test run. The amount of censoring was from 10 to 80 percent, at 10 percent intervals. The actual means and standard deviations of each data set (before censoring) were calculated. For the substitution methods, the censored values were assigned values of one-half the minimum detection limit, or 0.707 times the minimum detection limit. For the MLE program, the probability that the measured value was less than the cutoff value was substituted for each censored value. The bias as a percentage of the estimated mean or estimated standard deviation value was calculated (e.g., the estimated value minus the actual value was divided by the actual value; this number was then multiplied by 100 and reported in percent of the estimated mean or estimated standard deviation). Tables 9–11 list the bias correction (in percent) of the mean and the standard deviation of the values for the three methods.

TABLE 9

Maximum Likelihood Estimate Program:
Degree of Bias in Estimated Standard Deviation of Log-Transformed Data by Percent Censoring, 100 Data Sets per Percent Censored, 100 Random Numbers per Set, Mean = –1.62, Standard Deviation = 0.92

Percent Censored	Percent Bias in Estimated Mean	Percent Bias in Estimated Standard Deviation
10	0.129	–0.141
20	–0.064	–0.769
30	0.709	1.466
40	–0.319	–1.454
50	0.130	–0.361
60	0.960	0.909
70	0.547	–0.009
80	0.117	–1.389

TABLE 10

**Minimum Detection Limit Multiplied by 0.5:
Degree of Bias in Estimated Mean and Standard Deviation of Log-Transformed Data by Percent Censoring, 100 Data Sets per Percent Censored, 100 Random Numbers per Set, Mean = –1.62, Standard Deviation = 0.92**

Percent Censored	Percent Bias in Estimated Mean	Percent Bias in Estimated Standard Deviation
10	1.660	4.534
20	2.175	3.662
30	2.254	1.048
40	0.669	–5.222
50	–0.997	–10.785
60	–4.563	–19.341
70	–10.412	–30.872
80	–20.359	–44.640

TABLE 11

**Minimum Detection Limit Multiplied by 0.707:
Degree of Bias in Estimated Mean and Standard Deviation of Log-Transformed Data by Percent Censoring, 100 Data Sets per Percent Censored, 100 Random Numbers per Set, Mean = –1.62, Standard Deviation = 0.92**

Percent Censored	Percent Bias in Estimated Mean	Percent Bias in Estimated Standard Deviation
10	–0.510	–2.347
20	–2.017	–7.169
30	–4.447	–12.670
40	–7.778	–20.340
50	–11.646	–26.965
60	–17.399	–35.466
70	–25.455	–46.467
80	–37.531	–58.317

Figure 2 is a graph of the percent bias in the mean for all three methods. The MLE program had a bias of less than one percent of the value of the mean of the log-transformed data for the entire range of censoring. The 0.5 minimum detection limit method was better than the 0.707 minimum detection limit method, but both had significant levels of bias when censoring is greater than 60 percent.

Figure 3 is a graph of the percent bias in the standard deviation for all three methods. The MLE had the lowest percentage of bias in the value of the standard deviation of the log-transformed data. The 0.5 minimum detection limit method again performed better than the 0.707 minimum detection limit method.

The MLE program had very little bias when tested using this large a test population (each run had 10,000 numbers). The program was designed to give a better estimate of the mean and standard deviation than the other methods. The above results indicate that it did so. The bias levels compare favorably with those reported by Hornung and Reed (1990) for the Hald method in which the bias in estimating the geometric mean was less than ± 0.3 percent. Because of these results, the MLE program results were used for comparing the glove boxes in Chapter 8.

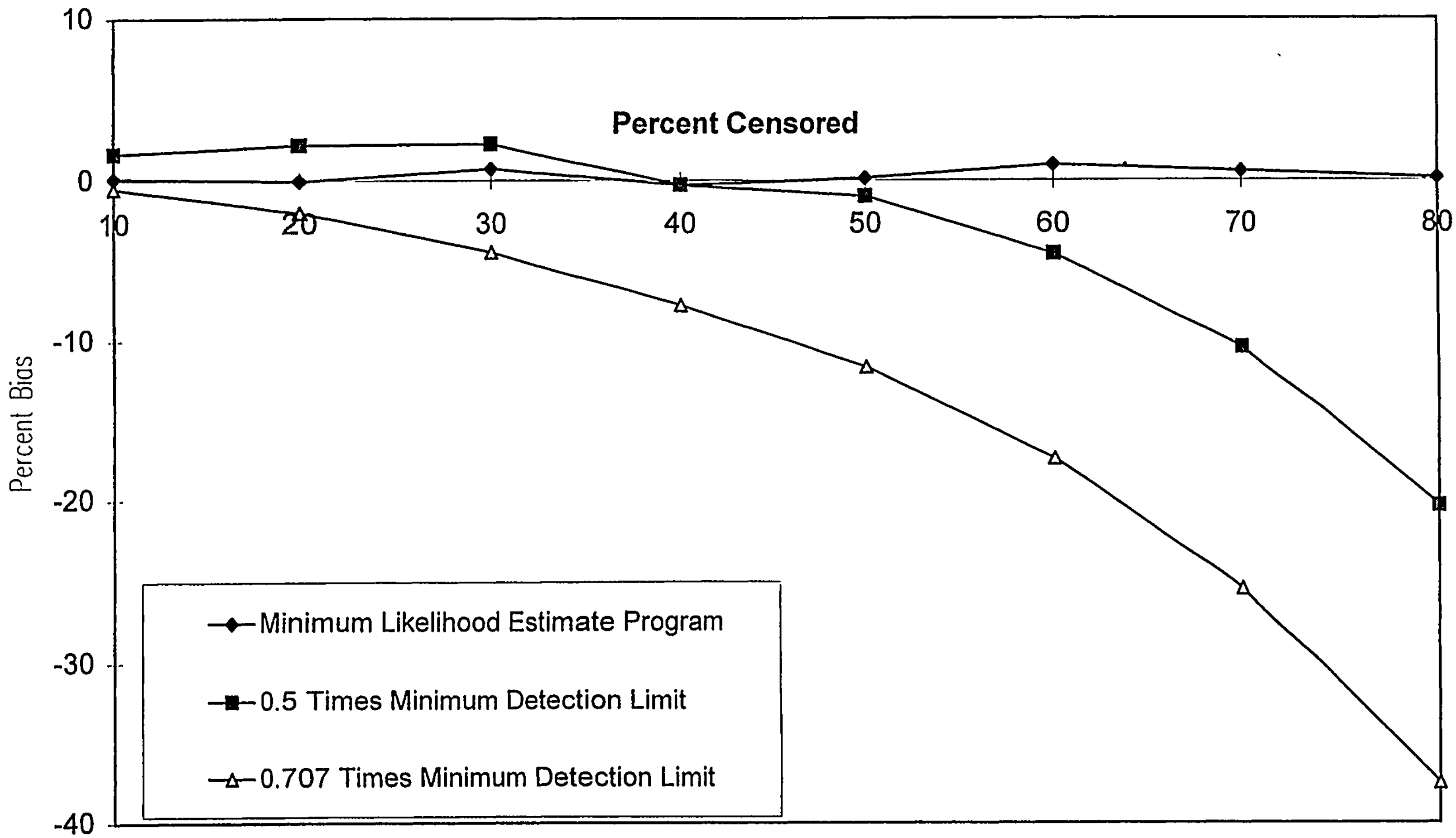


Figure 2. Percent bias in estimating mean of log-transformed data.

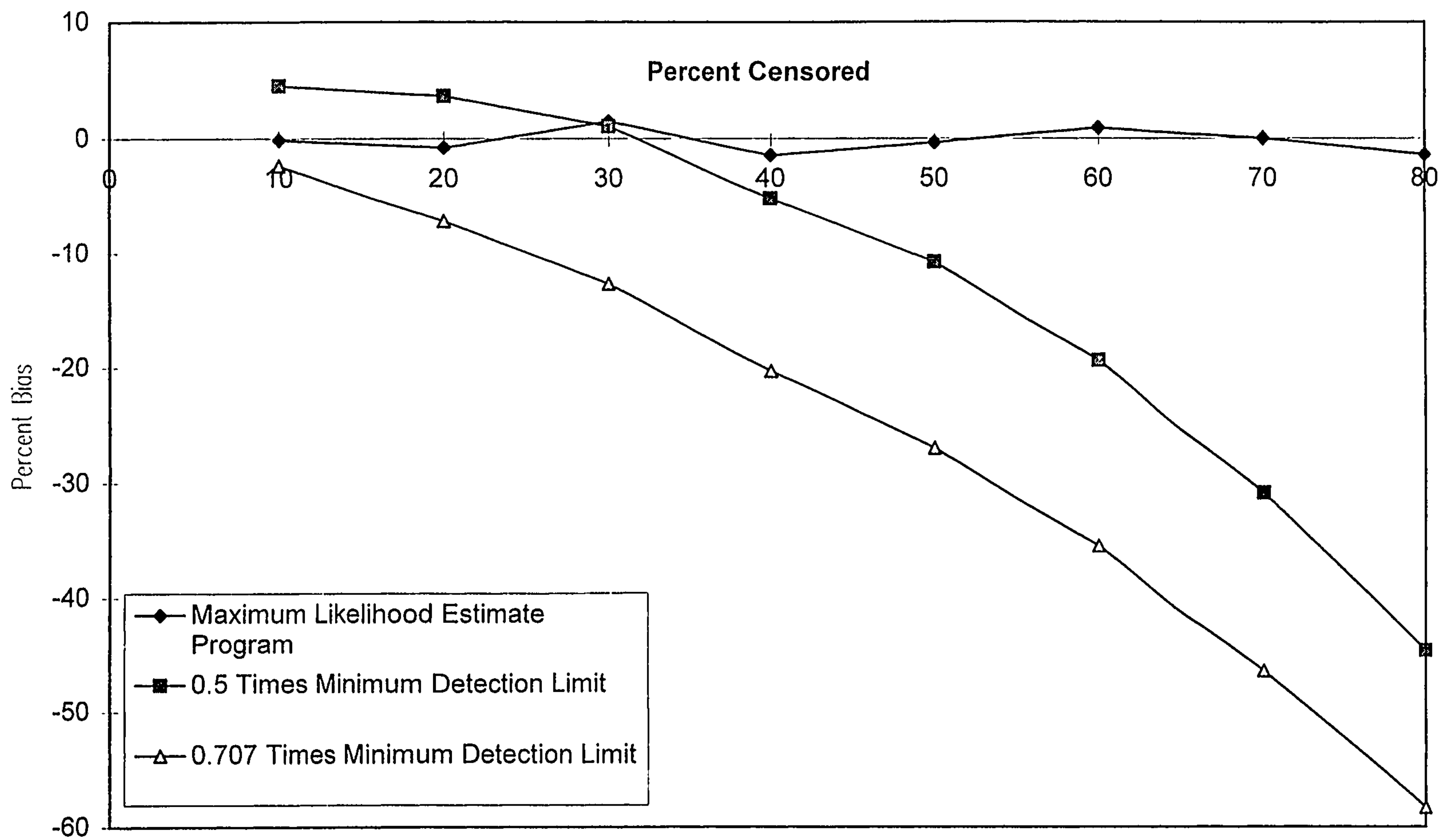


Figure 3. Percent bias in estimating standard deviation of log-transformed data.

Limitations of Maximum Likelihood Estimate Program

The MLE program has several limitations. Two parameters (mean and standard deviation) are being estimated. There must be a minimum of three distinct values in each set of data in order for two parameters to be calculated. Glove Box 40 had a range of values from less than < 0.2 up to 0.2 parts per million and the MLE program failed to converge to produce an estimate. The program requires a starting point from which to begin the Nelder-Mead directed search for the maximum likelihood estimators. The mean and standard deviation of the natural logarithms of the uncensored values are used as this starting point. If the natural logarithms of uncensored values do not fit a normal distribution, the program will not converge; e.g., if there are a greater number of high values than of low values or if the tail of the distribution is very long, the distribution will not fit a normal distribution curve and the starting points will create a line which will not lead to convergence. Glove Box 50 is an example of this. There were six values of 0.3 parts per million and only three values of 0.2 parts per million.

CHAPTER 8. ANALYSIS OF DATA

Description of Data

Chemical sampling results put into the CompChem database include results from direct reading instruments reported in the industrial hygienists' logbooks; memoranda to supervisors reporting on sampling which occurred in their work area; a computer printout of sampling done during the 1980s (no analytical reports or sampling sheets which could have been the original source of these results were located); and 881 laboratory analysis reports. (The results of routine air sampling for beryllium in Building 444 were not included in the database. Rocky Flats medical department personnel are conducting a separate study that involves computerization of these data.)

Once it was decided that carbon tetrachloride would be the focus of the investigation, an attempt was made to put all carbon tetrachloride samples into the database. Extraction of information from memoranda and the personal notes of Rocky Flats plant industrial hygienists was complicated because results reported in memoranda were also often reported in the notebooks and monthly summaries. Information was extracted from each of these sources and added to the database when sufficient details were provided. The complete entries for all of the carbon tetrachloride samples were printed and proofread, and any errors corrected. Duplicates were removed from the database when they could be identified. The completed database contains 6,860 sample reports. Reports in the original records may contain information on more than one compound, e.g., the carbon tetrachloride tanks were sampled for carbon tetrachloride and for chloroform, a suspected contaminant. Therefore, the number of analytical results for all compounds is higher than the number of samples.

The database is searchable by compound. Upon completion of the database, it became possible to statistically analyze the sampling results. Search statements were written to subdivide the original data set and define the output file. Table 12, "Number of Chemical Sample Results from Rocky Flats Plant, Golden, Colorado, in CompChem Database Sorted by Building," shows the four buildings with the largest number of samples. The building with the greatest number of samples (2,110) is Building 707.

TABLE 12

Number of Chemical Sample Results from Rocky Flats Plant, Golden, Colorado, in CompChem Database Sorted by Building

	Number of Sample Results
Samples in Database	6860
Samples with Bldg. Information	6653
Bldg. 707	2110
Bldg. 444	1201
Bldg. 771	1086
Bldg. 776	351

Twenty-eight percent of all sample results in the database were of carbon tetrachloride. The four compounds with the largest number of samples are listed in Table 13, "Percentage of Chemical Sample Results from Rocky Flats Plant, Golden, Colorado, in CompChem Database Sorted by Agent." Due to the amount of carbon tetrachloride sampling which had been done, carbon tetrachloride became the focus of this study. A detailed analysis of the carbon tetrachloride data was performed to determine whether there was sufficient information available to characterize potential worker exposure.

The distribution of carbon tetrachloride samples by sampling location shows that most of the samples were taken in Area C, particularly in Building 707. Of the 1,945 carbon tetrachloride sample results located, 1,514 were taken in Building 707. Building 707 was also the only facility where one

TABLE 13

Percentage of Chemical Sample Results from Rocky Flats Plant, Golden, Colorado, in CompChem Database Sorted by Agent

Agent	Number of Sample Results	Percent
CCl_4	1945	28.35
Beryllium	1114	16.24
1,1,1-Trichloroethane	486	7.08
DOP	421	6.14
Other (115 compounds)	3737	54.47

operation was extensively sampled over several years (1,177 samples for carbon tetrachloride were taken of glove box operations), as illustrated in Table 14, "Number of Carbon Tetrachloride Sample Results from Rocky Flats Plant, Golden, Colorado, in CompChem Database Sorted by Building Number."

TABLE 14

Number of Carbon Tetrachloride Sample Results from Rocky Flats Plant, Golden, Colorado, in CompChem Database Sorted by Building Number

Location	Number of Sample Results
Total	1945
Bldg. 707, Total	1514
Bldg. 707 Glove Boxes	1177
Bldg. 559	134
Bldg. 701 Storage Tank/Vault	119
Bldg. 776	54
Bldg. 774	48
Bldg. 771	18
Bldg. 427	13
Bldg. 3	10
Bldg. 777	4
Bldg. 767	1
Location Unknown	30

Note: In the listing for Building 707, Total, the void samples and samples which are not associated with specific glove boxes (e.g., samples taken elsewhere in the building) were counted. The void samples are not included in the analysis.

Review of the chemical sampling and analysis data showed that carbon tetrachloride was sampled extensively between 1974 and 1977 (see Table 15, "Number of Carbon Tetrachloride Sample Results in CompChem Database for Rocky Flats Plant, Golden, Colorado, by Year of Sampling.").

TABLE 15

Number of Carbon Tetrachloride Sample Results in CompChem Database for Rocky Flats Plant, Golden, Colorado, Building 707 Glove Boxes by Year of Sampling

Year	Number of Sample Results
1974	141
1975	457
1976	503
1977	69
Unknown	7

The amount of sampling was reduced after plant personnel decided that the air levels of carbon tetrachloride were significantly below 10 parts per million (the occupational exposure limit which applied in the 1970s). No sampling sheets or laboratory analysis reports of continued routine air monitoring were located for later years. The more recent samples (early 1980s) did not identify the glove-box location.

The largest number (90.7 percent) of samples were day shift samples (see Table 16, "Number of Carbon Tetrachloride Sample Results in CompChem Database for Rocky Flats Plant, Golden, Colorado, Building 707

Glove Boxes by Work Shift"). The operations performed in each glove box are listed in Table 17, "Glove Box Numbers and Associated Process Operations in Building 707, Module C, at Rocky Flats Plant, Golden, Colorado." The extent of the glove box data further refined the focus of the statistical analysis of the CompChem database.

TABLE 16

Number of Carbon Tetrachloride Sample Results in CompChem Database for Rocky Flats Plant, Golden, Colorado, Building 707 Glove Boxes by Work Shift

Work Shift	Number of Sample Results
All	1177
Day*	1067
Multiday**	77
Other	33

*day = daytime shift, 8 hours
**multiday = several 8-hour daytime shifts

Data sets were sorted by glove box number from Building 707, Module C. There are sixteen glove boxes with data available. Fourteen glove boxes had a sufficient number of samples for an analysis. (Glove Box 60 had four samples and Glove Box 75 only one; therefore, they were not analyzed).

In the methods section (Chapter 7), the rationale used to assign a "validity" code to the samples was described. Samples which were identified as

TABLE 17

Glove Box Numbers and Associated Process Operations in Building 707, Module C, at Rocky Flats Plant, Golden, Colorado

Glove Box Number	Operation
Glove Box 25	Machining
Glove Box 30	Drilling
Glove Box 40	Machining
Glove Box 45	Machining
Glove Box 50	Inspection
Glove Box 60	Machining
Glove Box 65	Machining
Glove Box 70	Machining and inspection
Glove Box 75	Fabrication
Glove Box 80	Machining, washing, or inspection
Glove Box 85	Inspection
Glove Box 95	Machining and inspection
Glove Box 110	Briquetting and degreasing
Glove Box 115	Machining
Glove Box 120	Filter box
Glove Box 125	Waste box

having a validity code of "void" (4.4 percent) were not included in the analysis of the carbon tetrachloride data. Results where the analysis report could not be matched with sample sheets, or where the sample sheet contained insufficient information, were not included in the analysis. Table 18, "Number of Void and Suspect Carbon Tetrachloride Sample Results in CompChem Database from Building 707, Rocky Flats Plant, Golden, Colorado," shows that among the carbon tetrachloride samples from Building 707, 8.7 percent were "suspect." The number of suspect samples varied by glove box. Suspect samples had sample volume discrepancies within ± 10 percent of the total and were included in the database. (Please see the discussion in Chapter 7, in the section titled "Development of a Computerized Industrial Hygiene Sample Database.")

TABLE 18

Number of Void and Suspect Carbon Tetrachloride Sample Results in CompChem Database from Building 707, Rocky Flats Plant, Golden, Colorado

Type	Number of Sample Results
All CCl4 Samples, Bldg. 707	1514
Void Samples, Bldg. 707	67
Suspect Samples, Bldg. 707	131

The data file for each glove box was run through a short FORTRAN® program which counted the number of censored values in the file. Censored values are those that fall below the minimum detection limit. The most common minimum detection limits were either 0.1 parts per million or 0.2 parts per million. The latter was more common (558 samples compared to 17). A very small number of samples had a minimum detection limit of 1.5 parts per million (6 samples). The "<" symbol is listed in the qualifier column in the CompChem database; this identifies samples which have results below the minimum detection limit. Accuracy of the program was tested by manually verifying the counts for several glove boxes.

The percentage of censored data ranged from 15.4 percent for Glove Box 110 up to 85 percent for Glove Box 40. Table 19, "Number, Range, and Percentage of Censored Carbon Tetrachloride Sample Results in CompChem Database by Glove Box Number—Building 707, Module C, Rocky Flats Plant, Golden, Colorado" lists the number of sample results per glove box, the range of the monitoring results, and the percent of the data which was censored for each glove box.

Overall, in the entire set (carbon tetrachloride samples with glove box information available), 49.3 percent of the data are below the minimum detection limit. Six of the glove boxes have more than 50 percent of the data censored and five more glove boxes have 40 to 49 percent censored data, leaving only two glove boxes with less than 40 percent censored data.

The glove boxes have several sets of glove ports (located at different directional points around the glove box, e.g., east and west) which may be blocked off or may have gloves attached. The amount of censoring in the data was not uniform across sections of the same glove box. The different amount of censoring may be related to either the amount or the type of work performed in each area. There was insufficient information available for an accurate

TABLE 19

Number, Range, and Percentage of Censored Carbon Tetrachloride Sample Results in CompChem Database by Glove Box Number—Building 707, Module C, Rocky Flats Plant, Golden, Colorado

Glove Box	Number of Sample Results	Range (parts per million)	Percent Censored
Glove Box 25	140	< 0.1–7.0	37.9
Glove Box 30	109	< 0.2–1.3	65.1
Glove Box 40	20	< 0.2–0.2	85.0
Glove Box 45	151	< 0.1–3.3	62.3
Glove Box 50	43	< 0.2–0.3	79.1
Glove Box 60	4	< 0.2–3.4	50.0
Glove Box 65	116	< 0.2–9.7	45.7
Glove Box 70	45	< 0.2–1.6	46.7
Glove Box 75	1	< 1.5	100
Glove Box 80	47	< 0.2–2.8	46.8
Glove Box 85	111	< 0.1–2.3	50.5
Glove Box 95	92	< 0.2–2.6	46.7
Glove Box 110	136	< 0.2–9.5	15.4
Glove Box 115	58	< 0.2–2.8	50
Glove Box 120	45	< 0.2–1.2	42.2
Glove Box 125	59	< 0.1–0.7	74.6
Total	1177	< 0.1–9.7	49.3

assessment of this possibility. The Maximum Likelihood Estimate (MLE) program was run for subsets of glove box data, when such subsets were available. The results are included with the glove box summary in Appendix E. The glove box subsections were not analyzed further.

Statistical Analysis of the Rocky Flats Carbon Tetrachloride Data

The Rocky Flats data was analyzed using the MLE program. Four substitution methods were also performed using the statistical program BMDP® (BMDP® Statistical Software, Inc., 1990a, b): (1) the minimum detection limit (MDL) value was used for all censored data; (2) a value of 0.0001 was used as the value for all censored data (a value of zero could not be used due to the log transformations); (3) the minimum detection limit value was multiplied by 0.5 and that value was used for the censored data; and (4) the minimum detection limit value was multiplied by 0.707 and that value was used for all censored data. The resulting values were transformed to their natural log and both sets of values analyzed. Two standard programs, 2D ("Detailed Data Description Including Frequencies") and 5D ("Histograms and Univariate Plots"), were used to perform standard descriptive statistics. The results are in Appendix D.

The general description of environmental and occupational exposure data matches a lognormal distribution. The values cannot go below zero and there are usually a few large values (causing the distribution to be skewed to the right), even when most values are small. For airborne contaminants, the values generally follow a lognormal distribution (Jones and Brief, 1971; Esmen and Hammad, 1977; Rappaport, 1991a; Kumagai *et al.*, 1997; Buringh and Lanting, 1991; Dement *et al.*, 1983; Ford *et al.*, 1991; Dodgson *et al.*, 1987; Kromhout *et al.*, 1987; Rice *et al.*, 1984; Rappaport and Selvin, 1987). Natural logarithms of air concentrations follow a normal distribution, allowing the use of standard normal distribution statistics (Buringh and Lanting, 1991). Rice *et al.* (1997) studied silica exposure in North Carolina industries. Comparison of the frequency distribution of log-transformed sampling data showed that the distribution was normal. In a later study of refractory ceramic fiber exposure, the Shapiro-Wilks (also known as the Wilks-Shapiro) statistic was calculated for each exposure zone which had sufficient data. The data was found to follow a lognormal distribution (Rice *et al.*, 1997). Eisen *et al.* (1984) collected 1,153 personal samples in Vermont granite sheds. Use of the natural logarithms of the dust measurements corrected the skewness and made the distribution symmetric and bell shaped (Eisen *et al.*, 1984).

The MLE program produces estimates of the mean and standard deviation of a normal distribution. The natural logarithms of the air concentration values are used to form the normal distribution. The Wilk-Shapiro test was performed on the data sets to determine which distribution, normal or lognormal, better fit the values.

The Wilk-Shapiro (W-statistic) test for normality is part of the BMDP® descriptive statistics. A W-statistic of 1.0 denotes a perfect normal distribution; therefore, the closer to 1.0 the W-statistic, the better the fit of the normal distribution (BMDP® Statistical Software, Inc., 1990b). The air concentration data (in parts per million) and the natural logarithims of the air concentration were analyzed. Table 20 lists the highest W-statistic from among all data treatments. When the best W-statistic was found in the log-transformed data, the distribution is listed as lognormal; when the best W-statistic was found in the air concentration data, the distribution was listed as normal; and when W-statistics from all of the trials were below 0.8, the distribution was listed as uncertain.

TABLE 20

Distribution (Normal, Lognormal, or Uncertain) with Highest W-Statistic—Building 707 Carbon Tetrachloride Sample Results in CompChem Database by Glove Box Number, Rocky Flats Plant, Golden, Colorado

Glove Box	Best W-Statistic	Minimum Detection Limit Substitution Method[a]	Percent Censored	Distribution
25	0.87	1, 4	37.9	Lognormal
30	0.69	--	65.1	Uncertain
40	0.43	--	85	Uncertain
45	0.77	--	62.3	Uncertain
50	0.52	--	79.1	Uncertain
65	0.82	3	45.7	Lognormal
70	0.82	3	46.7	Lognormal
80	0.83	3	46.8	Lognormal
85	0.86	3	50.5	Lognormal
95	0.81	3	46.7	Lognormal
110	0.95	3	15.4	Lognormal
115	0.78	--	50	Uncertain
120	0.84	4	42.2	Lognormal
125	0.59	--	74.6	Uncertain

[a] Minimum Detection Limit Method
Method 1 : Minimum detection limit (MDL) values used
Method 2: 0.0001 substituted for actual MDL
Method 3: MDL multiplied by 0.5, substituted for actual MDL
Method 4: MDL multiplied by 0.707, substituted for actual MDL

The W-statistics were similar and uniformly low for glove boxes with a very high percentage of censored data (Glove Boxes 30, 40, 45, 50, 115, and 125). This would be expected; when over 50 percent of the data is below the minimum detection limit, the mean is in the section of the distribution which contains the censored data.

The log-transformed data from the Rocky Flats glove boxes had higher W-statistics in the eight cases (57 percent) where there was less than 50 percent censoring. All eight glove boxes with less than 50 percent of the data censored have lognormal distributions. None have normal distributions. For six of the glove boxes, all with 50 percent or greater censoring, the distribution cannot be determined. The highest W-statistic for all of the glove box log-transformed data combined (1,177 samples with 49.3 percent censored) was 0.82. The MLE program used the log-transformation of the air concentrations to normalize the distribution.

The range listed in BMDP® was used to identify possible outliers. For each glove box, the MLE program was rerun with the highest value of each data set removed. The results are shown in Table 21. When the range was narrow, as in Glove Box 50 (< 0.2 to 0.3), no outliers were removed. The mean values changed by a maximum of $\pm$ 7.7 percent after removing the highest values (Glove Box 125, range < 0.2–2.8, 50 percent censoring). The standard deviations were changed by up to a maximum of 15 percent (Glove Box 115, range < 0.1–0.7, 74.6 percent censoring). The outliers were not removed when the differences between the glove boxes was tested.

TABLE 21

Geometric Mean and Geometric Standard Deviation from the Maximum Likelihood Estimate Program, Before and After the Highest Value of the Carbon Tetrachloride Sample Results Removed, Rocky Flats Plant, Golden Colorado, Building 707, Module C, by Glove Box Number (values in parts per million)

Glove Box Number	Geometric Mean	Geometric Mean, Highest Value Removed	Geometric Standard Deviation	Geometric Standard Deviation, Highest Value Removed
25	0.33	0.33	5.85	5.76
30	0.15	0.15	1.96	1.80
45	0.11	0.11	4.21	4.02
65	0.21	0.21	3.61	3.32
80	0.20	0.20	2.23	2.28
85	0.16	0.16	3.40	3.28
95	0.18	0.18	2.02	1.82
110	0.54	0.53	2.95	2.86
115	0.16	0.17	2.33	1.99
120	0.21	0.21	1.63	1.64
125	0.13	0.14	1.78	1.56

The BMDP® program and the MLE program were used to statistically analyze the carbon tetrachloride sampling results (except the void samples) for each glove box. The sample results included data from day shift samples, multiple day samples, multiple shift samples, and samples without shift information. The largest alternate shift data set contained 12 samples. These samples were combined into an "all samples" data set for the comparison of the glove box data. The results of the analyses are included in Appendices D and E.

Not all glove boxes had sampling data from the same years. The number of samples and the amount of censoring was also variable. It was not possible to compare all glove boxes against each other across each year. The results of the analysis are summarized below in Table 22.

Table 22 shows that the largest subset of the samples were those taken during the day shift. The estimated geometric mean and geometric standard deviation calculated by the MLE program for each subset are listed. The estimated geometric mean and geometric standard deviation of the day shift subset are within ± 11 percent and ± 5.3 percent, respectively, of the estimates for the full data set of all samples. The day shift samples for each glove box were not compared separately. The annual sampling was also not compared separately. Glove Box 60 had only 4 samples; this glove box was not included in the test between glove boxes. The use of the largest data set available for each glove box minimizes the effect of any random sampling errors and maximizes the power of the analysis. The results of both the BMDP® and MLE program analyses are displayed in Appendices D and E, respectively.

TABLE 22

Results from Maximum Likelihood Estimate Program Analysis of Carbon Tetrachloride Sample Results in CompChem Database for Building 707, Module C Glove Boxes, Rocky Flats Plant, Golden, Colorado, by Year or Work Shift of Sampling

Glove Box Number	Year or Shift	Number of Samples	Percent Censored	Range (parts per million)	Estimated Geometric Mean (parts per million)	Estimated Geometric Standard Deviation (parts per million)
25	All	140	37.9	<0.1–7.0	0.33	5.85
	Day	131	36.6	<0.1–7.0	0.36	5.64
	1974	52	9.6	<0.1–7.0	0.96	4.97
	1975	33	3.3	<0.2–2.2	0.62	2.01
	1976	54	85.1	<0.2–0.6	Did not converge[a]	
30	All	109	65.1	<0.2–1.3	0.15	1.96
	Day	103	65	<0.2–1.3	0.15	1.97
	1975	49	36.7	<0.2–0.7	0.23	1.64
	1976	36	94.4	<0.2–0.3	Did not converge[a]	
	1977	22	86.4	<0.2–0.6	Did not converge[a]	
40	All	20	85	<0.2–0.2	Did not converge[b]	
45	All	151	62.3	<0.1–3.3	0.11	4.21
	Day	144	63.2	<0.1–3.3	0.11	4.33
	1974	19	31.6	<0.1–3.3	0.12	3.40
	1975	56	42.9	<0.2–3.1	0.24	3.39
	1976	62	90.3	<0.2–0.5	Did not converge[a]	
	1977	12	50	<0.2–0.4	0.19	1.28
50	All	43	79.1	<0.2–0.3	Did not converge[a]	
	Day	40	82.1	<0.2–0.3	Did not converge[a]	
60	All	4	50	<0.2–3.4	0.18	7.77
65	All	116	45.7	<0.2–9.7	0.21	3.61
	Day	103	44.7	<0.2–9.7	0.21	3.41
	1975	46	10.9	<0.2–9.7	0.53	2.71
	1976	55	80	<0.2–0.7	Did not converge[a]	
	1977	11	72.7	<0.2–0.8	Did not converge[a]	
70	All	45	46.7	<0.2–1.6	0.21	1.98
	Day	41	46.3	<0.2–0.8	0.21	1.95
	1975	27	18.5	<0.2–0.8	0.28	1.70
	1976	18	84.2	<0.2–1.6	Did not converge[a]	

TABLE 22 (continued)

Glove Box Number	Year or Shift	Number of Samples	Percent Censored	Range (parts per million)	Estimated Geometric Mean (parts per million)	Estimated Geometric Standard Deviation (parts per million)
80	All	47	46.8	<0.2–2.8	0.20	2.23
	Day	45	47	<0.2–2.8	0.20	2.16
	1975	29	21	<0.2–1.2	0.29	1.90
	1976	18	88.9	<0.2–2.8	Did not converge[a]	
85	All	111	50.5	<0.1–2.3	0.16	3.40
	Day	105	48.6	<0.1–2.3	0.17	3.46
	1974	20	30	<0.1–2.3	Did not converge[a]	
	1975	40	22.5	<0.2- 1.8	0.29	1.90
	1976	51	80.4	<0.2–1.3	Did not converge[a]	
95	All	92	46.7	<0.2–2.6	0.18	2.02
	Day	81	40.7	<0.2–2.6	0.20	2.05
	1975	23	60.9	<0.2–2.2	0.14	3.14
	1976	68	42.6	<0.2–2.6	0.19	2.01
110	All	136	15.4	<0.2–9.5	0.54	2.95
	Day	119	15.9	<0.2–9.5	0.54	2.94
	1974	38	0	0.2–7.4	0.81	2.24
	1975	76	11.8	<0.2–9.5	0.57	2.86
	1976	20	55	<0.2–0.5	0.18	1.42
115	All	58	50	<0.2–2.8	0.16	2.33
	Day	56	50	<0.2–2.8	0.16	2.36
	1975	16	43.7	<0.2–0.8	0.20	1.76
	1976	39	57.9	<0.2–0.6	Did not converge[a]	
120	All	45	42.2	<0.2–1.2	0.21	1.63
	Day	42	37.8	<0.2–1.2	0.21	1.63
	1975	42	38.1	<0.2–1.2	0.22	1.60
125	All	59	74.6	0.1–0.7	0.13	1.78
	Day	55	74.5	0.1–0.7	0.13	1.73
	1975	20	45	<0.2–0.5	0.19	1.48
	1976	37	94.6	<0.2–0.3	Did not converge[a]	

[a] Did not converge because the uncensored data did not fit a normal distribution. This could occur if the tail of the distribution was too long or if the number of high values exceeded the number of small values (e.g., Glove Box 25, 1976, had data where there were two values of 0.2, four values of 0.3, and one value each of 0.5 and 0.6, with the remainder below the minimum detection limit).

[b] Did not converge because there were only two uncensored values (e.g., Glove Box 40).

The MLE program results have less bias than either the 0.5 times the MDL value substitution or the 0.707 times the MDL value substitution (see Chapter 7). The results of the 0.5 times the MDL method, the 0.707 times the MDL method, and the MLE program are listed in Tables 23–25.

TABLE 23

Estimate of Log-Transformed Carbon Tetrachloride Sample Results from CompChem Database for Rocky Flats Plant, Golden, Colorado, Building 707, Module C, by Glove Box Using 0.5 Times the Minimum Detection Limit Value Substitution Method

Glove Box Number	Percent Censored	Estimated Mean	Estimated Geometric Mean (parts per million)	Estimated Standard Deviation	Estimated Geometric Standard Deviation (parts per million)
25	37.9	-0.84	0.43	1.439	4.22
30	65.1	-1.9	0.15	0.608	1.84
40	85	-2.2	0.11	0.245	1.28
45	62.3	-1.67	0.19	0.985	2.68
50	79.1	-2.1	0.12	0.412	1.51
65	45.7	-1.34	0.26	1.072	2.92
70	46.7	-1.58	0.21	0.781	2.18
80	46.8	-1.52	0.22	0.877	2.40
85	50.5	-1.51	0.22	1.005	2.73
95	46.7	-1.61	0.20	0.787	2.20
110	15.4	-0.58	0.56	1.072	2.92
115	50	-1.65	0.19	0.825	2.28
120	42.2	-1.53	0.22	0.721	2.06
125	74.6	-2.04	0.13	0.51	1.67

TABLE 24

Estimate of Log-Transformed Carbon Tetrachloride Sample Results from CompChem Database for Rocky Flats Plant, Golden, Colorado, Building 707, Module C, by Glove Box

Using 0.707 Times the Minimum Detection Limit Substitution Method

Glove Box Number	Percent Censored	Estimated Mean	Estimated Geometric Mean (parts per million)	Estimated Standard Deviation	Estimated Geometric Standard Deviation (parts per million)
25	37.9	-0.71	0.49	1.304	3.68
30	65.1	-1.67	0.19	0.458	1.58
40	85	-1.9	0.15	0.126	1.13
45	62.3	-1.46	0.23	0.849	2.34
50	79.1	-1.83	0.16	0.265	1.30
65	45.7	-1.18	0.31	0.943	2.57
70	46.7	-1.42	0.24	0.632	1.88
80	46.8	-1.36	0.26	0.742	2.10
85	50.5	-1.34	0.26	0.86	2.36
95	46.7	-1.45	0.23	0.656	1.93
110	15.4	-0.53	0.59	0.99	2.69
115	50	-1.48	0.23	0.693	2.00
120	42.2	-1.39	0.25	0.566	1.76
125	74.6	-1.78	0.17	0.387	1.47

TABLE 25

Estimate of Log-Transformed Carbon Tetrachloride Sample Results from CompChem Database for Rocky Flats Plant, Golden, Colorado, Building 707, Module C, by Glove Box Using the Maximum Likelihood Estimate Program

Glove Box Number	Percent Censored	Estimated Mean	Estimated Geometric Mean (parts per million)	Estimated Standard Deviation	Estimated Geometric Standard Deviation (parts per million)
25	37.9	-1.1	0.33	1.766	5.85
30	65.1	-1.9	0.15	0.674	1.96
40	85	Did not converge		Did not converge	
45	62.3	-2.18	0.11	1.439	4.21
50	79.1	Did not converge		Did not converge	
65	45.7	-1.55	0.21	1.283	3.61
70	46.7	-1.57	0.21	0.686	1.98
80	46.8	-1.6	0.20	0.803	2.23
85	50.5	-1.81	0.16	1.223	3.40
95	46.7	-1.71	0.18	0.703	2.02
110	15.4	-0.61	0.54	1.081	2.95
115	50	-1.81	0.16	0.847	2.33
120	42.2	-1.56	0.21	0.487	1.63
125	74.6	-2.06	0.13	0.579	1.78

The geometric mean values of the glove box data from the three estimation methods are compared below in Table 26. The geometric mean estimated by the MLE program is lower than the estimates generated by the other two methods. This is because the program uses values in the full range between zero and the minimum detection limit. It is therefore not a worst case estimate of the exposure. Table 27 compares the geometric standard deviations calculated by the three methods.

TABLE 26

Comparison of Estimated Geometric Means of Log-Transformed Carbon Tetrachloride Sample Results from CompChem Database for Rocky Flats Plant, Golden, Colorado, Building 707, Module C, by Glove Box (values in parts per million)

Glove Box Number	Number of Samples	Percent Censored	0.5 times Minimum Detection Limit	0.707 times Minimum Detection Limit	Maximum Likelihood Estimate
25	140	37.9	0.43	0.49	0.33
30	109	65.1	0.15	0.19	0.15
40	20	85	0.11	0.15	Did not converge
45	151	62.3	0.19	0.23	0.11
50	43	79.1	0.12	0.16	Did not converge
65	116	45.7	0.26	0.31	0.21
70	45	46.7	0.21	0.24	0.21
80	47	46.8	0.22	0.26	0.20
85	111	50.5	0.22	0.26	0.16
95	92	46.7	0.20	0.23	0.18
110	136	15.4	0.56	0.59	0.54
115	58	50	0.19	0.23	0.16
120	45	42.2	0.22	0.25	0.21
125	59	74.6	0.13	0.17	0.13

TABLE 27

Comparison of Estimated Geometric Standard Deviations of Log-Transformed Carbon Tetrachloride Sample Results from CompChem Database for Rocky Flats Plant, Golden, Colorado, Building 707, Module, C by Glove Box (values in parts per million)

Glove Box Number	Number of Samples	Percent Censored	0.5 times Minimum Detection Limit	0.707 times Minimum Detection Limit	Maximum Likelihood Estimate
25	140	37.9	4.22	3.68	5.85
30	109	65.1	1.84	1.58	1.96
40	20	85	1.28	1.13	Did not converge
45	151	62.3	2.68	2.34	4.21
50	43	79.1	1.51	1.30	Did not converge
65	116	45.7	2.92	2.57	3.61
70	45	46.7	2.18	1.88	1.98
80	47	46.8	2.40	2.10	2.23
85	111	50.5	2.73	2.36	3.40
95	92	46.7	2.20	1.93	2.02
110	136	15.4	2.92	2.69	2.95
115	58	50	2.28	2.00	2.33
120	45	42.2	2.06	1.76	1.63
125	59	74.6	1.67	1.47	1.78

In Figure 4, the mean of the log-transformed data for each glove box is shown. The standard deviations are shown as the error bars. Figure 5 shows the geometric mean and geometric standard deviation of the glove box carbon tetrachloride data.

Glove Boxes 25 and 110 have large geometric standard deviations and may be different from the other glove boxes. A test of the hypothesis that the means of two normal distributions are equal was performed for these glove boxes (Bowker and Lieberman, 1972). This test is for normal distribution where

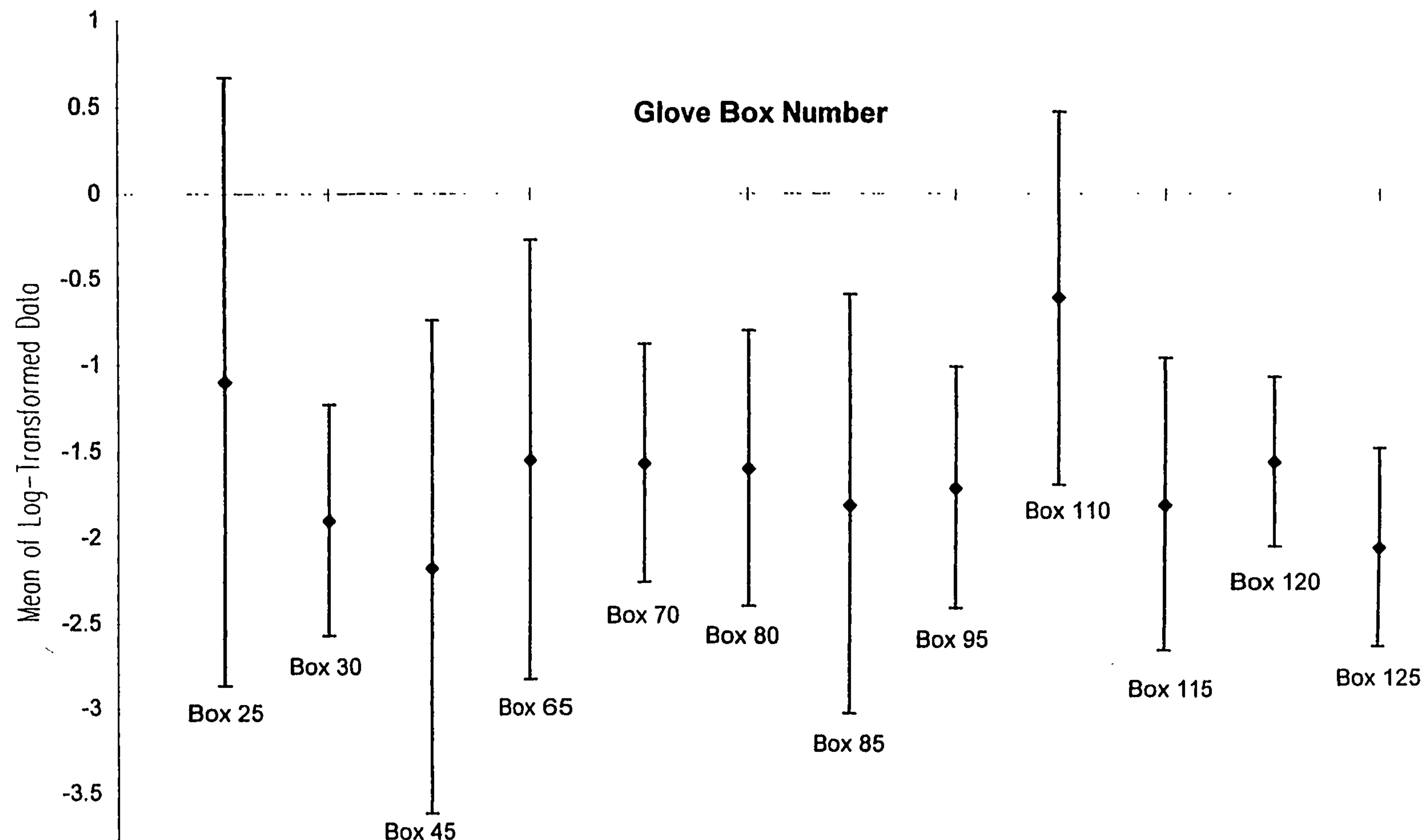


FIGURE 4. Means of log-transformed carbon tetrachloride data by glove box in Building 707, Rocky Flats Plant, Golden, Colorado, estimated by Maximum Likelihood Estimate Program.

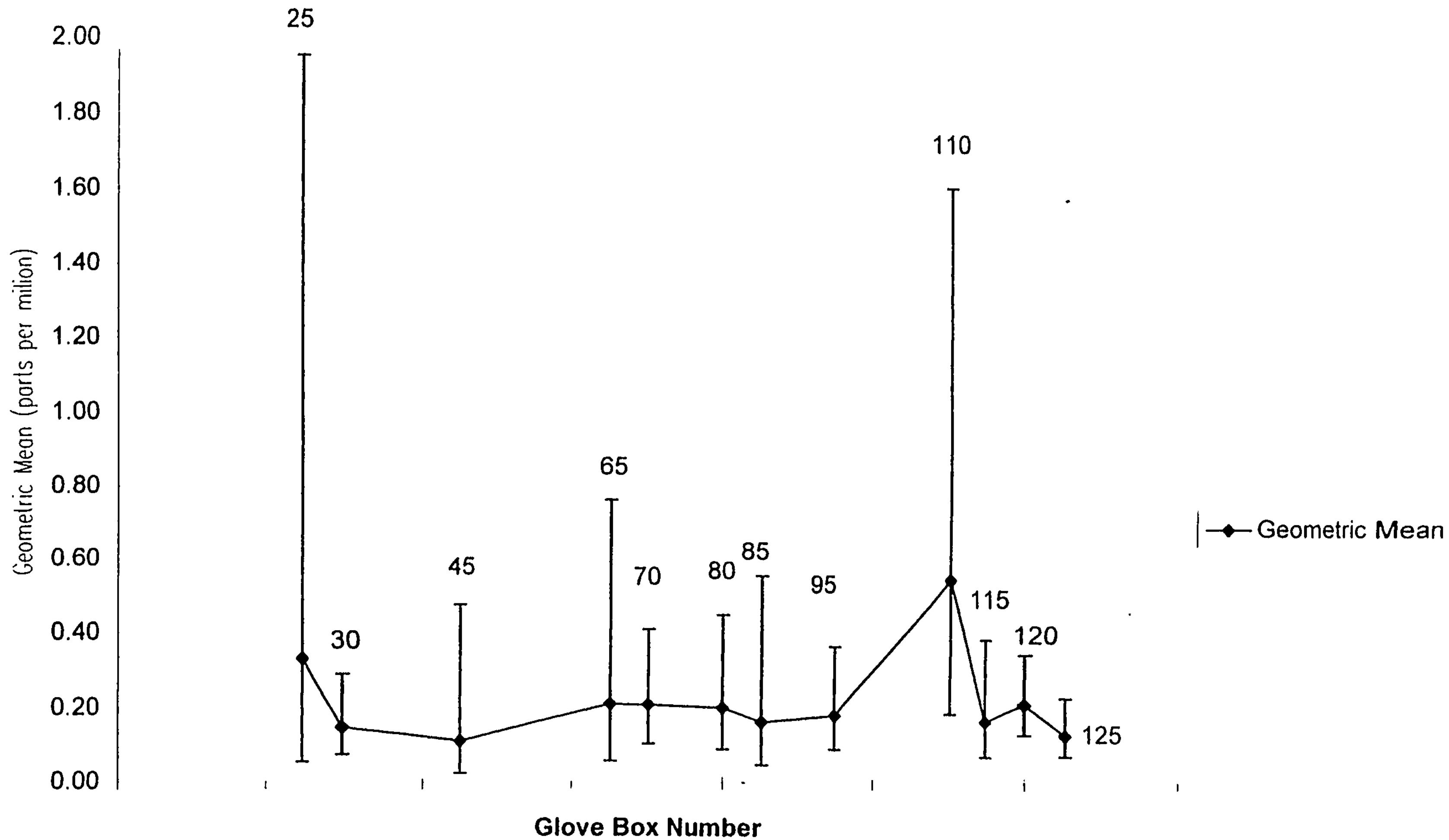


FIGURE 5. Geometric means and standard deviations of carbon tetrachloride concentrations by glove box in Building 707, Rocky Flats Plant, Golden, Colorado.

the standard deviations are known; they do not have to be equal. This is considered to be an approximate test because the mean and standard deviation of the log-transformed data were estimated using the MLE program and include estimates of the censored observations. The test statistic then has a normal distribution rather than a t-distribution. In order to minimize the problem of multiple comparisons, as few tests as possible were performed. The test statistic is a "z-score" and the probability of exceeding the test statistic can be read from a standard normal distribution function table. That probability is the significance level of the test.

The mean of the log-transformed data for each glove box was ranked from highest to lowest. As described above, the first test was between Glove Box 110 and Glove Box 25. Then Glove Box 25 and Glove Box 65 were compared. In both cases, the test statistic was above a z-score of 2.326 (the value for the 99th percentile), indicating that each of these glove boxes is in a group by itself (with $p < 0.01$). Glove Box 65, which had the next highest mean, was then compared to the remaining glove boxes (Glove Boxes 25 and 110 were removed). The results of these tests are shown in Table 28.

TABLE 28

Test of the Hypothesis that the Estimated Means of Two Glove Boxes are Equal Using Means of Log-Transformed Data Estimated by the Maximum Likelihood Estimate Program

Test Statistic = (Mean1 – Mean 2)/ (Sqrt (Std Dev1 x Std Dev1/Number1) + (Std Dev2 x Std Dev 2/Number2))

Glove Box 110 vs. Glove Box 25		
Test Statistic =	((-0.61 – (-1.1))/Sqrt(((1.08 x 1.08)/136) + ((1.77 x 1.77)/140)))	
Test Statistic =	2.79	*p* = 0.0027
Glove Box 25 vs. Glove Box 65		
Test Statistic =	((-1.1 – (-1.55))/(Sqrt((1.77 x 1.77/140) + (1.28 x 1.28)/116)))	
Test Statistic =	2.36	*p* = 0.0091
Glove Box 65 vs. Mean of Remaining Other Glove Boxes		
Test Statistic =	((-1.55 – (-1.8))/(Sqrt((1.28 x 1.28/116) + (0.989 x 0.9893)/717)))	
Test Statistic =	2.02	*p* = 0.022

The estimated geometric means of Glove Boxes 25 and 110 are higher than the other glove boxes ($p < 0.01$). Glove Box 65 is not different from the rest of the glove boxes. The geometric means of both Glove Box 25 and Glove Box 110 are below the concentration values which have been shown to be of toxicological concern (see Chapter 4).

Linking Personnel To Glove Boxes

The CompChem database contains a total of 595 samples that identify employees. The samples taken in the 1980s were probably personal samples; however, the documentation is insufficient to confirm this assumption. As previously discussed in Chapter 7, none of the carbon tetrachloride samples taken between 1974 and 1977 are true personal breathing-zone samples. The samples were area samples taken at breathing-zone level. Some of the samples taken in Building 707 listed employees who worked in the area near the sampling location. There were a total of 177 carbon tetrachloride samples from Building 707, Module C; all but 25 had glove box identifiers. There were 47 samples taken in or outside of Building 707; 18 listed locations other than Module C and 29 contained only the building location. The summary of this data in Table 29 includes both the area samples from the 1970s which had employee names associated and those from the 1980s which are probably personal samples.

The names of 26 Rocky Flats employees were provided by the Los Alamos National Laboratory epidemiology group, the 13 brain tumors cases and 13 others (the names of the cases were not identified). Their health physics files were reviewed. Information about work location and chemical usage was abstracted. Work location was given by building and sometimes room. Information was available for 12 out of the 26 people. One person worked in Building 81 and was exposed to a material fire. Nine people worked in the 700 Area. One worked in Building 91 and one in Building 44. None of these individuals were on the list of personnel for whom some sampling information was located.

Forty-four people in the CompChem database were listed as having worked in areas where carbon tetrachloride was present. Thirty of these employees had either job histories or health physics records among the microfiche from the original cohort. The files were reviewed and the job title, organization name and number, and dates of job and organization changes were abstracted. The health physics files were reviewed and any information indicating chemical usage abstracted. Of the 44 people who were listed as having worked in areas where carbon tetrachloride was present, 10 were machinists, 7 of whom worked in the 700 area.

TABLE 29

Number of Carbon Tetrachloride Samples with Associated Employee Names in CompChem Database, Building 707, Rocky Flats Plant, Golden, Colorado

Location	Number of Samples
Glove Box 25A	8
Glove Box 25B	16
Glove Box 30	1
Glove Box 45A	18
Glove Box 45B	41
Glove Box 65A	42
Glove Box 65B	23
Glove Box 75	1
Glove Box 85	1
Glove Box 95	1
Building 707, Module C	25
No Location	29
Other Location	18
Total	224

Table 30, "Employee Information Summary from Employment History (1953–1979) and CompChem Database, Rocky Flats Plant, Golden, Colorado," lists the location (Building 707 plus other available information), job title, and organization of each employee, when that information was available. The microfiche detailing employee job histories were available through 1979. When the samples were taken before that time, the job title closest to the year of the sample was used. Others are listed as unknown.

Five of the machinists had health physics incident reports. The location of the incident was sometimes listed. That information was useful in determining some of the rooms, glove boxes, and equipment used.

TABLE 30

Employee Information Summary from Employment History (1953–1979) and CompChem Database, Rocky Flats Plant, Golden, Colorado

Employee	Job Title	Department	Location	Number of Samples	Year
1	Machinist	Plutonium Fabrication, 707-776	Glove Box 30E	1	1976
			Glove Box 65B	15	1976
			Glove Box 85B	1	1976
			Module C	1	1979
			Bldg. 707	3	1979–80
2	Machinist	Plutonium Fabrication, 707-776	Glove Box 45A	3	1976–77
			Glove Box 45B	31	1976–77
			Glove Box 65A	2	1976
			Module C	2	1979
			Bldg. 707	4	1980
3	Machinist	Plutonium Fabrication, 707-776	Glove Box 45A	10	1976
4	Machinist	Production, 707-776	Glove Box 45A	4	1976–77
			Glove Box 65A	40	1976–77
			Glove Box 65B	8	1976–77
			Glove Box 95E	1	1976
			Module C	1	1979
			Bldg. 707	1	1980
5	Machinist	Plutonium Production, 707-776	Glove Box 45B	9	1976
			Bldg. 707	5	1980
6	Machinist	Plutonium Fabrication, 707-776	Glove Box 25B	15	1976
			Glove Box 65B	1	1979
			Bldg. 707	2	1980
7	Machinist	Unknown	Glove Box 25A	8	1976
8	Machinist	Unknown	Module C	3	1989
9	Machinist	Unknown	Module C	5	1989
10	Sr. Dev. Specialist	Mach. R & D	Module C	1	1979
11	Inspector	QA 707 Inspection	Glove Box 75	1	1979
12	Inspector	707 Inspection	Module C	1	1979
			Bldg. 707	1	1979
13	Sr. Eng. R & D	Environmental Research	Stack	1	1971

TABLE 30 (continued)

Employee	Job Title	Department	Location	Number of Samples	Year
14	Machinist	Plutonium Production	Glove Box 45B	1	1979
			Bldg. 707	1	1979
15	Adm. Clerk	Unknown	Glove Box 25 B	1	1979
			Bldg. 707	4	1979
16	Machinist Appr.	Unknown	Bldg. 707	3	1980
17	Machinist	Production, 881-83	Module C	1	1989
18	Unknown	Unknown	Module C	1	1989
			Module N	1	1989
19	Unknown	Unknown	Module C	2	1989
			Module N	2	1989
20	Unknown	Unknown	Module C	1	1989
			Module N	2	1989
21	Unknown	Unknown	Outside	3	1989
22	Unknown	Unknown	Module B	2	1989
23	Unknown	Unknown	Module C	2	1989
24	Unknown	Unknown	Module C	2	1989
			Module B	1	1989
25	Industrial Hygienist	Industrial Hygiene	Tank D2	1	1986

The health physics files of the employees listed in Table 30 were reviewed to determine whether any information related to Building 707 was available. The information found in the health physics files is summarized in Table 31.

TABLE 31

Building 707 Location Information from Health Physics Records (1953–1979), Rocky Flats Plant, Golden, Colorado

Employee	Job Title	Organization	Date	Location
1	Jour. Mach.	Pu Fab 776-707	7/16/71	707-110, Glove Box 95
	Jour. Mach.	Pu Fab 776-707	4/19/72	707-110
	Jour. Mach.	Pu Fab 776-707	4/1/75	707, Module C
	Machinist	Pu Fab 776-707	5/21/76	707-110, Glove Box 65
	Machinist	Pu Fab 776-707	7/30/76	707, Glove Box 60A
	Machinist	Pu Fab 776-707	11/9/76	707-110, Glove Box 25B
2	Jour. Mach.	Mfg. Fab Pu 776-777	9/30/70	707, Module C, Glove Box 60
3	Jour. Mach.	Pu Fab 776	3/1/71	707, Module C, Heald #4
	Jour. Mach.	Pu Fab 707	3/15/71	707, Module G, Beryllium Lathe
	Jour. Mach.	Pu Fab 707	5/8/73	707, Module C, Lathe 2, cutting part
	Jour. Mach.	Pu Fab 707	5/2/75	707 Module A
	Machinist	Pu Prod	4/7/76	707-110, Module C, Glove Box 95
4	Jour. Mach.	Pu Fab 776-707	2/16/71	707, Module C, #5 Heald
	Jour. Mach.	Pu Fab 776-707	5/4/71	707, Glove Box 125, Bldg. 707, Module C, #1 Heald
	Jour. Mach.	Pu Fab 776-707	1/7/72	Module C, #6 Lathe
	Jour. Mach.	Pu Fab 776-707	4/27/73	707, Module C, #5 Heald Lathe
	Jour. Mach.	Pu Fab 776-707	5/16/73	707, Glove Box 65A, 707-110, Glove Box 125
	Jour. Mach.	Prod 707-776	9/30/76	707, Glove Box 60, 707, Module C, #1 Heald
6	Jour. Mach.	Pu Fab 776-707	11/8/73	707, Module C, #1 Heald
	Jour. Mach.	Pu Fab 776-707	3/12/75	707-110, Glove Box 125
	Jour. Mach.	Pu Fab 776-707	4/2/75	707, Module C, #1 Heald
11	Inspector		9/30/76	707, 60A

Eight of the ten people associated with glove boxes were machinists. In four of those machinists' health physics files, there were references to one or more glove boxes. The other employees in Table 30 either had no health physics file or had no information in their file which linked them to Building 707. Comparison of the glove boxes listed in Tables 30 and 31 showed that these machinists were not associated with a single glove box, but were associated with several glove boxes: principally, the machining glove boxes, and occasionally, an inspection glove box or combination machining and inspection glove box.

The carbon tetrachloride sampling data for Building 707 indicated that the following glove boxes were used for machining: 25, 60, 65, and 95. Glove Box 125 was used for waste storage. These are the only Building 707 glove boxes mentioned specifically by number in association with the above employees. This indicates that machinists did work in the glove boxes designed for machining. This does not eliminate the possibility that they also did work in other types of glove boxes.

There were six people with enough samples for the MLE program to be run. Table 32 summarizes these results.

TABLE 32

Estimates by Maximum Likelihood Estimate Program of Individual Employee Log-Transformed Carbon Tetrachloride Sample Results from Building 707, Module C, Rocky Flats Plant, Golden, Colorado

Employee	Number of Samples	Percent Censored	Estimated Mean of Natural Log Data	Geometric Mean (parts per million)	Estimated Standard Deviation of Natural Log Data	Geometric Standard Deviation (parts per million)
1	21	66.7	Did not converge [a]	–	Did not converge	–
2	42	83.3	–2.89	0.06	1.1	3.01
3	10	100	Did not converge [b]	–	Did not converge	–
4	58	62.1	Did not converge [a]	–	Did not converge	–
5	14	64.3	–3.32	0.04	1.5	4.66
6	19	47.1	–1.53	0.22	0.51	1.67

[a] Did not converge because the uncensored data did not fit a normal distribution. This could occur if the tail of the distribution was too long or if the number of high values exceeded the number of small values.
[b] Did not converge because there were only two uncensored values.

In these groups of samples, the percentage of censoring was high and the program converged to produce estimates for only three of the people. These samples associated with individual workers have more censoring than the general glove box samples and the number of samples is less. The samples which can be linked to employee names were taken over a longer period of time than the glove box samples, and they are more heterogeneous. They include the samples taken in association with the glove boxes in the 1970s (these samples are included in the glove box analysis), as well as samples taken at later dates which do not always list an associated glove box (listed in Table 29 under Building 707, Module C, Other Location, or No Location). The type of sampling method also varied. Some of the samples were taken using charcoal badge diffusion monitors, which had different minimum detection limits than the charcoal tubes. (The charcoal badge diffusion monitors usually had a minimum detection limit of 1.5 parts per million; occasionally, the minimum detection limit was reported to be as low as 0.01 parts per million. In comparison, the charcoal tubes had a minimum detection limit of 0.1 or 0.2 parts per million.) The estimated exposure levels for the samples which could be linked to individual employees are compared to the values found for the corresponding glove boxes in Table 33.

TABLE 33

Estimates by Maximum Likelihood Estimate Program of Individual Employee Log-Transformed Carbon Tetrachloride Sample Results Compared with the Estimates of Corresponding Glove Boxes, Building 707, Module C, Rocky Flats Plant, Golden, Colorado

Employee	Glove Box	Glove Box Estimated Geometric Mean (parts per million)	Glove Box Estimated Standard Deviation	Employee Estimated Geometric Mean (parts per million)	Employee Estimated Geometric Standard Deviation
2	45	0.11	4.22	0.06	3.01 [a]
5	45	0.11	4.22	0.04	4.66 [a]
6	25	0.33	5.86	0.22	3.6

[a] $p < 0.01$

Two of the employee estimated geometric mean concentrations are lower than the corresponding boxes. There are several possible reasons. One of the employee in the group (Employee 2) had sample results with a minimum detection limit of 0.01 parts per million and had reported values as low as 0.01 parts per million. These low values enabled the MLE program to provide a lower estimate. These samples were not identified with a glove box number and are not included in the Glove Box 45. Some of the samples were taken in other locations, not near the glove boxes. The samples which were actually personal samples would reflect the lack of exposure to carbon tetrachloride during times when the employees were working elsewhere, e.g., in other parts of the module or building. All of the estimated geometric mean concentrations are below the levels which are of toxicological concern (see Chapter 4).

CHAPTER 9. CONCLUSIONS

Summary

In a mortality study of white males who worked at the Rocky Flats Nuclear Weapons Plant between 1952 and 1979, an elevated number of deaths from benign and unspecified intracranial neoplasms was found (Voelz *et al.*, 1983). No statistically significant association was found between estimated radiation exposure from internally deposited plutonium and the development of brain tumors (Reyes *et al.*, 1984). Likewise, no association was found between job or work area and brain tumors.

An update of the cohort mortality study (Wilkinson *et al.*, 1987) found an excess of brain tumors for the entire cohort. Similar cohort studies conducted on worker populations from other plutonium handling facilities have not yet shown any elevated risks for brain tumors (Voelz, 1991).

Historically, the Rocky Flats Nuclear Weapons Plant used large quantities of chemicals in their production operations. Since increased brain cancer rates have not been associated with either external radiation exposure or internal plutonium deposition at Rocky Flats, the possible relationship with chemical usage comes into question. The existing records from Rocky Flats were not sufficient to perform a direct epidemiological study. Therefore, a pilot retrospective exposure assessment was initiated.

This assessment determined that there was no single source of information on all of the job titles used at the Rocky Flats plant over its history. This is a key piece of information needed for conducting a full retrospective exposure assessment. Consequently, the project undertook several activities aimed at establishing a master job dictionary, but it was found that the job titles used at the Rocky Flats plant could not be linked to the location of the work being done.

At the same time, information available about chemical use and exposure was surveyed. The initial investigation identified which chemicals had been used in large quantities at the Rocky Flats plant. The use of solvents, particularly carbon tetrachloride, was unique to Rocky Flats. The largest amount of carbon tetrachloride was used in the fabrication area of Building 707. Carbon tetrachloride sampling began in 1974 and continued until 1978. Few other compounds were sampled as extensively. Although the target organ for carbon tetrachloride is the liver, several studies have linked it with increased risk of cancer (IARC, 1987, Blair *et al.*, 1979, 1990, Heineman *et al.*, 1994). Therefore, carbon tetrachloride became the focus of the study.

The industrial hygiene files were reviewed and information on personal monitoring for chemical exposures done by the plant industrial hygiene program extracted. Prior to this study, no evaluation of specific chemical exposures was possible. None of the chemical sampling data was readily accessible in a form in which it could be statistically analyzed. The general information concerning chemical usage by building was available, but the sampling results could not be analyzed until they were consolidated.

The available historical exposure information located during the records search was compiled into a computer database which could be analyzed statistically. The CompChem database, an ORACLE®-based information system, was created for this project.

The carbon tetrachloride sampling data located for the Rocky Flats plant presented interpretation problems. When statistical analysis was begun, it was discovered that within most of the carbon tetrachloride data sets, a significant portion of the sample results were below the minimum detection limit of the analytical method. The amount of censoring in the Rocky Flats carbon tetrachloride data was 49.3 percent, with individual glove boxes having between 15.4 and 85 percent censoring. It was necessary to develop a method to deal with the high levels of censored data in order to analyze and summarize the available carbon tetrachloride data. A statistician was consulted; he wrote a computer program (the Maximum Likelihood Estimate program) based on maximum likelihood estimation procedures. The program was used to estimate the mean and standard deviation of the log-transformed data. It was compared with commonly used substitution methods.

Conclusions and Discussion

This study shows that the Maximum Likelihood Estimate (MLE) program, developed for this project, can be used effectively with censored data. The amount of bias produced by the MLE program was compared to that produced by the substitution of either 0.5 times the minimum detection limit or 0.707 times the minimum detection limit for the censored values. The MLE program produced the least biased estimates for both the mean and standard deviation of the log-transformed data. Table 9, Figure 2, and Figure 3 show that the MLE program had a bias of less than two percent for the mean and the standard deviation of the log-transformed data for the entire range of censoring.

Table 21 illustrates that the MLE program estimation of the geometric mean is not highly sensitive to outliers (the estimates changed by $\pm$ 7.7 percent). The geometric standard deviation changed by $\pm$ 15 percent. Tables 6–8 verify that the program is capable of producing results within 10 percent of the original estimate even when an additional 15 percent of the data is removed.

The MLE program produced estimates comparable to those produced by either Hald's method or Cohen's method (see Tables 4 and 5). An advantage of this method is that it is computerized. The tabular methods of both Hald and Cohen are time consuming. Few of the studies reviewed in the course of the project used a maximum likelihood estimate method to address censored data. In fact, few occupational exposure studies addressed censored data. The subject was not mentioned. This may be because most studies have focused on industries where exposure levels were great enough so that few samples were below the minimum detection limit of the analysis. The studies which addressed censored data (Nelson *et al.*, 1993; Barnard *et al.*, 1996) used a substitution method to deal with that data. As the study of occupational exposure expands beyond industries with historically high levels of exposure, the need to deal with censored data will probably increase, as has been the case with environmental pollution data.

The MLE program could be helpful to others with censored data concerns. The program is designed for use with a normal distribution (or one which can be normalized by log-transformation of the data). Additional studies should be made to expand and verify the usefulness of the program. Data sets with different means and standard deviations could be tested to determine whether the bias is as low as that found in this study.

The geometric mean of the carbon tetrachloride samples for each glove box estimated by the MLE program (see Table 25) was the least biased and was determined to be the best estimate given the sampling results available. In Module C, the estimated geometric means of air concentrations of carbon tetrachloride was very low. All estimated geometric mean values were lower than 1 part per million (the highest was Glove Box 110 which had a geometric mean of 0.54 part per million). Employees were not exposed to levels of carbon tetrachloride vapor above legal limits. The range of the sampling results (see Table 19) show that all of the individual values were below 10 parts per million, the American Conference of Governmental Industrial Hygienists (ACGIH) 1976 Threshold Limit Value for carbon tetrachloride. The majority of the individual values were less than the 1996 Threshold Limit Value of 5 parts per million. The most common minimum detection limit at Rocky Flats (<0.2 part per million for carbon tetrachloride) was less than 5 percent of the 1996 limit.

These results meet the goal designed by the Rocky Flats industrial personnel of verifying "compliance" with the standard. One must assume that the industrial hygienist and industrial hygiene technicians took samples in the areas where they expected to find the highest exposures. The workers at Rocky Flats were not exposed to large amounts of carbon tetrachloride via inhalation. The inhalation exposure levels of carbon tetrachloride were below the level currently of toxicological concern. The information available is insufficient to link carbon tetrachloride inhalation exposure alone to brain tumor excess.

Organic solvents have been linked to excess brain tumors (Heineman *et al.*, 1994; Gomez *et al.*, 1994; Anittila *et al.*, 1995). Carbon tetrachloride was not the only organic solvent used at the Rocky Flats plant. One can speculate that other solvents not part of this study may be a possible link to the increased brain tumor mortality at Rocky Flats. In a study of chlorinated solvents, trichloroethylene had a strong association with elevated risk of astrocytic brain tumor [odds ratio (OR) = 5.1, 95% confidence interval (CI) = 0.9–36.7] (Heineman *et al.*, 1994; Gomez *et al.*, 1994). Trichloroethylene was used at Rocky Flats as the solvent in ultrasonic cleaning units in Building 707, Module G, before being replaced by 1,1,1-trichloroethane. Additional research could be done, possibly utilizing employee interviews, to identify workers potentially exposed to these two chemicals and investigate a possible increased risk among them.

The data analysis verified that low levels o f carbon tetrachloride were found in Building 707. Prior to the study, this was suspected but not proven. Several possible exposure assessment options are available for future research. One could compare the morbidity or mortality of people who worked in Building 707 to those who did not using a simple binary model. Additional research into job histories may allow a ranking by duration of employment in the area. In future epidemiology studies of nuclear workers at the Rocky Flats plant, the possible confounding effect of carbon tetrachloride exposure must be considered (e.g., one could compare carbon tetrachloride use across groups of plutonium workers, in addition to comparing the plutonium exposure). At other facilities, the presence or absence of solvents must be determined. The exposures of plutonium workers should not be limited to radioactive materials. This study verifies that chemical exposure, while it may not prove to be at high levels, should at least be documented and a decision made concerning the need for inclusion as a possible risk factor.

The people who could be linked to carbon tetrachloride sampling in Module C were machinists. The glove boxes which had the most samples associated with the machinists were machining boxes (Glove Box 25, 45, and 65). There are no good descriptions of work activities which could be used to place an employee at a given glove box for a certain percent of their time. The amount of time actually spent at a given glove box is not known. There are no notes taken by the person doing the sampling which would tell what the people were actually doing. The personal information is too minimal to be conclusive; however, it is clear that people did not work at only one glove box.

Because Module C glove boxes can be linked to machinists, machinists in Building 707 can be shown to have different exposures than machinists in other buildings. Machinists working in Building 444 worked with beryllium, but not with plutonium. The medical department at Rocky Flats is performing an epidemiology study of beryllium workers. Health information gathered about machinists in that study could be compared with that of machinists who worked in Building 707 and with machinists who did not work in either location.

The machinists to focus on in a later study would be those who worked in Glove Boxes 110 and 25, compared with those who did not. Within Module C, Glove Boxes 110 and 25 had higher estimated mean values of carbon tetrachloride than the other glove boxes. Glove Box 110 had the highest value (0.54 part per million) among the glove boxes. The work performed there, briquetting, used large amounts of carbon tetrachloride in five degreasing baths for cleaning machine turnings. Glove Box 25 had a geometric mean of 0.33 part per million. Because Glove Box 25 was the first machining box, more machining may have been performed in this box. The coolant used on the lathes was machine oil mixed with carbon tetrachloride.

Carbon tetrachloride has also been shown to be absorbed through the skin (Stewart and Dodd, 1964). This is another source of exposure which was not routinely evaluated. Once a material enters the body, it is absorbed, redistributed to the major organ systems, and metabolized; the remainder is eliminated. The carbon tetrachloride levels found in the Module C briquetting press glove box were shown to reach as high as 22,000 parts per million. Ventilation was installed in 1974 after low levels of carbon tetrachloride were found in the module near the briquetting box. Carbon tetrachloride vapor was shown to permeate the gloves used in the glove boxes (Hyman and Chicorz, 1977). If one assumes that the airborne levels are at least partially caused by leaks through the gloves, then workers using Glove Boxes 25 and 110 may have had higher skin exposure. The sampling performed at Rocky Flats was intended to evaluate potential inhalation exposure. Skin absorption may be another source of exposure which in this instance may be of greater concern than the inhalation exposure. In a future epidemiology study, it may be possible to identify the people who worked principally in or near these boxes. Those people might have had a higher potential exposure than other people working in the building.

The Rocky Flats cohort mortality study (Wilkinson *et al.*, 1987) found elevated risk estimates for all lymphopoietic neoplasms [rate ratio (RR) = 7.69, 90% confidence limit (CL) = 0.99–72.93] and for all causes of death in employees with body burdens greater than or equal to two nanocuries of plutonium for a two-year induction period.

Mice have been shown to develop hepatomas after repeated oral administration of carbon tetrachloride. The International Agency for Research on Cancer (IARC) concluded that there is sufficient evidence to show that carbon tetrachloride is carcinogenic in animals (IARC, 1987). Lymphatic leukemia was related to carbon tetrachloride exposure (OR = 15.3, $p < .001$) and carbon disulfide exposure (OR = 8.9, $p < .003$) (Wilcosky *et al.*, 1984). Spirtas *et al.* (1991) studied an aircraft maintenance facility. Women exposed to carbon tetrachloride had elevated levels of non-Hodgkin's lymphoma [standardized mortality ratio (SMR) = 325, 95% CI = 119–560] (Spirtas *et al.*, 1991). Brain tumors may not be the disease of concern when carbon tetrachloride exposure is investigated. The medical follow-up should evaluate damage to the liver and other forms of cancer.

The CompChem database could be used to assist in further research of contributing to retrospective exposure assessments for a limited number of chemicals. The database contains 6,653 samples which have building information. Within Building 444, 1,201 samples were taken, and within Building 776, 351 samples were taken (see Table 12). A total of 119 compounds are in the database (see Table 13). It is possible to link the chemicals to specific buildings where sampling was performed.

This type of information could be used to help create an "ever versus never" categorization of chemical use by location as part of a retrospective exposure assessment. The presence of sampling data indicates that the chemical was used in the area where the sample was taken. Unfortunately, the absence of sampling data does not confirm that a chemical was not present at a given location, but merely that it was not sampled.

The dates for which sampling data is available can be used to infer duration of use. Carbon tetrachloride sampling data is available for Building 707 from 1971 up until 1988. This information verifies that carbon tetrachloride was used in that building during its entire lifetime. Consequently, people working in the building were potentially exposed throughout that period.

The CompChem database can be used to link location (building and sometimes room) to the agent sampled and the date of the sampling. This information would enable a researcher to estimate when the plant changed chemicals for a process; e.g., in Building 707, Module G, first trichloroethylene and then 1,1,1-trichloroethane was used for ultrasonic cleaning. There are also 595 "personal" samples (samples associated with individual employee names). The names can then be linked to location, agent used, and date. In a future study, the people listed in the database could be interviewed and additional information gathered to supplement the exposure data.

The results found in this study could be helpful in expanding the research being done by the National Institute for Occupational Safety and Health, the Colorado Department of Health, the University of Colorado, and the Tri-County Health Department. Over the last five years, these organizations have begun several epidemiology studies. The cohort of Rocky Flats workers studied has been expanded to include those who worked during the years up until 1989. There are two principal studies: a mortality study and a cancer incidence study. The primary focus is on radiation, but some chemicals will be investigated. The choice of which chemicals to investigate was based upon job descriptions and interviews.

The researchers had access to the job histories of the cohort. They did extensive employee interviews. Fifteen chemicals were identified for further investigation and a job-exposure matrix generated. The researchers found that they could not determine which solvents were used except for carbon tetrachloride. The plant emphasized the hazard associated with carbon tetrachloride; therefore, people were able to remember its use (Martyny, 1997). During employee interviews, the employees self-identified chemicals used and estimated the percent of the time they were used. The researchers created parts-per-million/year rankings. These rankings could be compared to the CompChem data to help validate their estimates.

Although the MLE program generates estimates with less bias than the other methods, the level of censoring in the Rocky Flats data still made it

Although the MLE program generates estimates with less bias than the other methods, the level of censoring in the Rocky Flats data still made it impossible to define the actual distribution with any confidence. The values below the minimum detection limit are unknown. The low end of the distribution remains opaque.

The reliance upon an exposure limit as the driver of a sampling strategy may create problems for future researchers interested in estimating employee exposure to low levels of a compound. A minimum detection limit of one-fiftieth of an allowable exposure limit may be acceptable when documenting that employees are not overexposed to that limit. The same minimum detection limit may not be acceptable for an exposure assessment. The ability to estimate the exposure down to very low levels may be important if the chemical under study has possible health risks at low levels.

Sampling strategies should take analytical detection limits into consideration. The benzene Threshold Limit Value was 10 parts per million in 1974; now it is 0.1 part per million. If the carbon tetrachloride Threshold Limit Value had been lowered as much, the data from the Rocky Flats sampling would be useless in verifying that the people were not exposed to hazardous levels.

When designing a sampling strategy, the industrial hygienist should look carefully at the detection limits of the analysis. If the percentage of censoring is 50 percent, the entire low end of the distribution is unknown. The common unusual, for example bimodal, the common estimation methods will not detect this and will therefore produce poor estimates of the actual exposures. When a significant percentage of the sample results are below the minimum detection limit, the results may not be good enough to warrant the expense of extensive air monitoring.

When air sampling is performed with the intent of assessing exposure, it is advisable to use the method with the lowest analytical minimum detection limit. The most sensitive analytical methods are often more expensive. If this is the case, it may be possible to use the more sensitive analytical method to help characterize the distribution and define the best estimation method. One could reanalyze samples which are below the minimum detection using the most sensitive analytical method (Sanderson *et al.*, 1997). This is possible if a nondestructive test method is available, or if the samples can be divided. The results could be used to replace some of the values which are below the minimum detection limit, thereby reducing the percentage censoring. The new analytical values could then be added to the distribution, the distribution tested for normality (and lognormality), and the mean and standard deviation recalculated. The recalculated mean and standard deviation could then be compared to estimates produced by methods such as the MLE program, 0.5 times the minimum detection limit, and 0.707 times the minimum detection limit to determine which one produced the best estimate for the existing operation. That method could then be used with increased confidence.

As soon as a sufficient number of samples have been taken, the level of censoring should be determined. If the amount of censoring is sufficiently high that the low end of the distribution cannot be estimated, the sampling strategy may need to be adjusted. If the air monitoring cannot provide enough information to estimate the mean and standard deviation of the exposure data, then air monitoring may not be the best way to access exposure. If no alternative analytical methods are available, alternative ways of determining exposure should be investigated. Time and effort might be put to better use documenting the employee work habits, including time and motion studies, to determine the actual exposure time. Biological monitoring may be helpful when methods are available. The presence and use of engineering controls and personal protection equipment should be documented. Sources of exposure other than inhalation may be significant and should be investigated. The information gathered by detailed observation of personnel and operations may ultimately be more useful than reliance on air samples.

The lack of information concerning the actions of employees being sampled is a problem even today. Personnel often spend a significant amount of time sampling a small number of people, yet fail to link people to specific machines and fail to adequately describe the operations in the document which reports the sampling results. A proactive approach to evaluating potential employee exposures to hazardous compounds is needed. Job descriptions should be specific enough to identify the compounds being used. Employers should know where their employees' work assignments place them within the facility and should inform their employees of the hazards posed by the compounds that they use.

APPENDICES

Appendix A.1

Information Extracted from Union Contracts

The following is a list of job titles, their respective organizations, and the years the titles were in effect, based on the union agreement handbooks at the Rocky Flats Plant from 1954 to 1961. No job titles were available for 1953.

Job Title	Organization	Years
ADT Technician	Electric Shop	1954/57
ADT Technician-Electrician	Electric Shop	1956/57
Assembler	Building 77	1955,58/61
Assembler-Helper	Building 77	1955,58/61
Asst. Chem Operator-Chem Dept	Production C	1955
Asst. Chem Operator-Fabrication	Production C	1955
Asst. Chem Process Operator	Production C	1954/55
Asst. Cook	Cafeteria	1954/57
Asst. Furnace Operator	Production A	1954/55
Asst. Inspector	Production A	1954
Asst. Operator	Production A	1954/61
Asst.. Operator	Production B	1954/61
Asst. Operator	Production C	1956/61
Asst.. Recovery Operator	Production C	1955
Auto Mechanic	Garage	1954/61
Bldg 41 Instrument Man	Instrument Dept.	1955
Bldg 44 Laundry Clerk	Production A	1955/61
Boiler Operator	Heating Plant-Bldg 43	1954/61
Boiler Operator	Quality Control/Plant D	1954/61
Boiler Operator Helper	Production C	1955/61
Boiler Ventilator Helper	Production B	1960/61
Boiler Ventilator Operator	Production B	1954/61
Boiler Ventilator Operator	Production C	1954/61
Cable Fabricator	Health Physics	1954/61
Cafeteria Worker	Cafeteria	1954/61
Carbon Shop Tool Grinder	Production A	1954
Carbon Shop Tool Man	Production A	1955
Carpenter Helper	Miscellaneous Maint.	1954/61
Charge Preparation Operator	Production A	1955
Chemical Process Operator	Production C	1954/55

Appendix A.2

Information Extracted from 1953–1957 Organizational Charts for Dow Chemical Company, Rocky Flats Plant

Year	Organization	Section	Job Title	Number Employees	Location
1953	Prod. Div. C	Bldg. 71 General	Boiler Operators	4	71
1953	Prod. Div. C	Chem. Op. And Recov. And Waste Treat.	Prof. Design Eng. Chem.	3	71
1953	Prod. Div. C	Chem. Op. And Recov. And Waste Treat.	Prof. Chem.	1	71
1953	Prod. Div. C	Chem. Op. And Recov. And Waste Treat.	Chemical Opr. VII	7	71
1953	Prod. Div. C	Chem. Op. And Recov. And Waste Treat.	Chemical Opr. VI	6	71
1953	Prod. Div. C	Chem. Op. And Recov. And Waste Treat.	Chemical Opr. V	1	71
1953	Prod. Div. C	Fabrication	Assist. Dept. Supt.	1	71
1953	Prod. Div. C	Fabrication	Prof. Design Engr. Met.	1	71
1953	Prod. Div. C	Fabrication	Prof. Design Engr. Mech.	2	71
1953	Prod. Div. C	Fabrication	Final Inspector	2	71
1953	Prod. Div. C	Development Lab	Group Leader	1	
1953	Prod. Div. C	Development Lab	Prof. Chemist	1	
1953	Prod. Div. C	Development Lab	Prof. Design Engr. Met.	1	
1953	Prod. Div. C		Div. Superintendent	1	
1953	Prod. Div. C		Stenographer	1	
1953	Prod. Div. C		Prod. Record Clerk	1	
1953	Prod. Div. C	Purchasing And Traffic	Purchasing Agent	1	
1953	Prod. Div. C	Purchasing And Traffic	Adm. Secretary	1	
1953	Prod. Div. C	Purchasing And Traffic	Buyers	2	
1953	Prod. Div. C	Purchasing And Traffic	Stenographers	4	
1953	Prod. Div. C	Technical Staff	Technical Director	1	
1953	Prod. Div. C	Technical Staff	Prof. Design Engr. Chem.	1	
1953	Prod. Div. C	Technical Staff	Prof. Scientist-Physicist	1	
1953	Prod. Div. C	Technical Staff	General Clerk	1	
1953	Prod. Div. C	Bldg. 71 Bldg. Services	Boiler Vent. Opr	5	71
1953	Prod. Div. C	Bldg. 71 Bldg. Services	Prof. Design Engr. Mech.	1	71

Appendix A.3
Information Extracted from Contractor (Dow Chemical Co. and Rockwell Internation) Job Descriptions

Job titles were listed with the job descriptions. The Epi code is a number assigned by the Los Alamos National Laboratory Epidemiology Group for their study (Voelz, *et al.*, 1983; Reyes *et al.*, 1984). Additions were made to the computer file when contractor job descriptions were available. These have no Epi code numbers. The RF code is the Rocky Flats job code. The Rocky Flats organization and the date of the job description are listed next. When the job description contained industrial hygiene information the last column has a denotation.

Job Title	Epi code	RF code	Organization	Date	IH
A C & S Info Mgr	792				
A V Illus Splst	231				
A V Illus Trainee	231				
A V Photo Splst	231				
A V Photo Trainee	231				
A V Tech Splst	231				
Access Cont Splst	611				
Access Cont Splst C		N46078	Access Cnt	2/25/80	N
Access Cont Rec Splst C		N46079	Access Cnt	1/22/83	N
Access Sys Mgr		X46401	Pers Sec	1/26/90	N
Accountant	161				
Accountant Credit Union	161				
Accountant Union Credit	161				
Accounting Clk	731				
Accounting Clk 3		N20022	Gen Acct	2/14/86	N
Accounting Clk 4		N30024	Gen Acct	2/14/86	N
Acct-Nmc Dept	161				
Accts Payable Clk	731				
Adj Clerk	731				
Adj Sales Clerk	721				
Admin Aide	791				
Admin Analyst	791				
Admin Assistant	791				
Admin Clk	731				
Admin Info Sys Mgr	792				
Admin Secretary	711				
Admin Sfc-Cashier	711				

Appendix A.4 Job Title, Job Description, and Materials Handled Information from Dow Chemical Co. Hourly Worker Job Descriptions for Rocky Flats Plant.

JOB TITLE	JOB DESCRIPTION	MATERIALS HANDLED
Air filter tech. (Filter Test Tech.)	Maintaining the air filter system: inspection, replacement, testing, cleaning and packaging air filters for disposal. Set-up and operate various types of equipment to test and certify respirator canisters, full-face and half-masks and all sizes of HEPA filters.	Cleaning solvents, neutralizing agents, oil, lacquer thinner, beryllium, adhesives, neoprene gaskets, and di-octyl phthalate. Proximity to radioactive material.
Alarm/ Teleco. Tech.	Assemble, test, diagnose, repair and install electrical, electronic and digital systems, radio, video, paging, fire and security systems.	
Analytical Laboratory Technician	Perform physical and chemical tests to determine the composition, qualitatively and quantitatively, of incoming materials, in process materials, products, and research and development materials for certification. Analytical procedures could include: extraction, distillation, filtration, rinsing, heating and burning of material.	Radioactive and non-radioactive metals, acids, bases, solvents, cryogenic materials, high pressure gas cylinders, welding and photo graphic developers.
Assembler	Preparing parts for assembly by operating ultrasonic equipment, vapor degreaser, grit blaster, abrasive cleaner, caustic tanks and passivation equipment. Assembling and disassembling units by using glue, air pressure, refrigeration, heat, and autoclave equipment. Prepare large volumes of acid solutions. Passivated parts by acid leaching process.	Radioactive, non-radioactive and toxic metals, vapor degreaser and ultrasonic cleaning equipment, caustic tank, and acid detergent.
Auto Mechanic	Inspection, preventive maintenance, and repair of mobile and stationary engine driven equipment.	Solvents, grease, oil, coolants, and chemicals.

JOB TITLE	JOB DESCRIPTION	MATERIALS HANDLED
Bio-Assay Technician (Health Environ. Technician)	Operate various laboratory equipment and instruments in the chemical and radioactive analysis of trace elements in environmental, biological, and autopsy samples. Separation and determination of various radioisotopes in materials. Analyze samples to quantitate toxic substances present.	Solvents, acids, bases, resin reagents and chemicals used to dissolve and analyze biological material.
Cable Fabricator	Fabrication, assembling and repairing alpha radiation detector probes and cables.	Solder, freon, solvents, and KW solution.
Carpenter	Using tools of the trade to do rough and finish carpentry work, masonry work, roofing and repair, millwright and cement work.	Occasional use of solvents.
Chemical Control Operator	Operation of control boards, sequence panels and process data systems. Set-up and operate process support systems, i.e. vacuum receivers, vent receivers, resin transfer system, deforming and shearing presses, criticality tanks, evaporators, stills, ion exchange columns, leachers. dissolvers, grit blasters, refrigeration systems, incinerators, ovens, storage tanks, furnaces and associated pumps and valving.	Process chemicals (acids, bases, calcium metal, hydrogen peroxide, hydrogen fluoride, fluorine, diesel fuel, methane gas, cleaning solvents and cryogenic materials). Fissile and radioactive materials (plutonium, americium, uranium) and other metals (tantalum, calcium and beryllium).
Chemical Operator (titled Metallurgical. Opr., in 1981)	Operating equipment in the chemical processing areas to recover and produce a product of specified quality and process the waste materials for disposal. Operate furnaces, incinerator, oven storage tanks and ponds, crushing and grinding equipment, ion exchange columns, hydrofluorinators, calcinor, scrubbers, dissolvers and leachers, evaporators, and argon drying equipment. Processes include: batching, precipitating, leaching, pulverizing, evaporating, calcining, burning, electrorefining, ion-exchange and metal oxidation.	Process chemicals and catalysts (acids, bases, calcium metal, hydrogen peroxide, hydrogen fluoride, cryogenic materials, resin, cleaning solvents, plutonium, americium, Portland cement and process waste materials).

JOB TITLE	JOB DESCRIPTION	MATERIALS HANDLED
Chemical Operator, Solid Waste Operator	Incinerating solid and liquid wastes. Involves: waste preparation and feeding, primary incineration, afterburning, off-gas clean-up and ash disposal. Maintaining records, inventory control, preparing reports and supplying information to other departments. Receiving, packaging, shipping, serializing and handling classified or unclassified stainless steel or non-stainless steel material, parts, and assemblies. Engrave or otherwise serialize parts by grit blasting, electronic etching vibra-tool and laser beammarker. Operate ultrasonic cleaning equipment.	Radioactive material
Counting Technician	Operating the various electronic counters to measure the radioactive content of samples.	Radioactive material.
Decontamin. Worker	Cleaning of overheads, decontamination tools and equipment using steam, pressurized water, caustics and acids, reduce the size of waste by disassembling, cutting up and re-boxing, handle, package, inspect, and prepare drums of waste for shipment. Operate crane to load rail cars.	Caustics, acids, radioactive material, solvents, and absorbents.
Dispatcher	Receiving calls for trucking service, heavy equipment operations and labor needs by the plant personnel. Schedules and dispatches vehicles to maintain an efficient operation. Maintains records and logs of the departmental functions and personnel.	
Dosimetry Tech.	Collecting, distributing, preparing and assembling dosimetry badges. Reading and annealing LiF crystals. Preparing standards by exposing LiF crystals to calibrate counters. Developing film, reading, and recording of data.	Alcohol, sulfur, cadmium

JOB TITLE	JOB DESCRIPTION	MATERIALS HANDLED
Electrician	Installing, diagnosing, and troubleshooting, repairing, maintaining and testing the various electrical, pneumatic and mechanical controlling systems through the plant (motors and generators, transformers, lighting, power distribution, alarm systems, HVAC equipment, etc.)	Proximity of radioactive material, grease, oil and solvents.
Electrician Technician	Assemble, test, diagnose, repair, perform preventative maintenance and install electrical, electronic and mechanical systems. Modify and update existing equipment. (Examples include fire and security systems, X-ray equipment, and service panels.)	Proximity of radioactive material, grease, oil, and solvents.
Electronic Technician	Design, fabricate, modify, maintain, repair, calibrate and certify radiation instrumentation. Assists in the research and development of new instrumentation and equipment. Calibrates and certifies instruments from outside vendors.	Proximity of radioactive material.
Experimental Machinist	Assist engineers, scientists and supervision in the design and fabrication of development fixtures, tooling jogs, gages, and parts. Machine experimental parts, develop machining processes for new materials, prepare non-routine samples for analysis, and fabricate developmental tooling..	Steels (tool, stainless, mild), tungsten, vanadium, molybdenum, uranium and uranium alloys, plutonium and plutonium alloys, beryllium, aluminum and aluminum alloys, copper, plastic, and resins.

JOB TITLE	JOB DESCRIPTION	MATERIALS HANDLED
Experimental operator	Assisting engineers and scientists in the research and development departments by performing tests and studies on the various equipment and materials used in the chemical, metallurgical, physical and mechanical processing areas to help establish the operating procedures and parameters used throughout the plant. Perform solvent extraction separation, ion exchange purification, filtration, calcination, hydriding, hydrofluorination and reduction, oxide and metal dissolution and precipitation. Perform heat treatments of metals and alloys. Perform selective leaching for metals.	Process chemicals, reagent chemicals, solvents, resin, glass, metals and alloys such as plutonium, americium, beryllium, aluminum, steel, tungsten, copper, silver, gold, chromium, titanium, uranium, neptunium and platinum.
Experimental Operator for Special Recovery	Perform aqueous unit operations. Operations consist of oxide/metal dissolution, selective metal leach, solvent extraction, separation of actinides, ion exchange, precipitation, calcination, hydrofluorination, preparation of custom materials and verification of off-site scrap and residues.	Plutonium, uranium and other actinide materials, chromium, silver and gold.
Heavy Equipment Operator	Operating the various portable heavy equipment (bulldozers, mobile cranes, backhoes, road graders, and front end loaders) to load and unload heavy machinery and material, dig ditches, maintain roads, and maintain a sanitary landfill operation.	Grease, oil and coolants.
Inspector	Setting up and using the various tools, gages and equipment provided to dimensionally and visually inspect parts and assemblies of various materials and configurations to determine whether they are within specifications.	Proximity of radioactive material and solvents. (Continuous in some areas)

JOB TITLE	JOB DESCRIPTION	MATERIALS HANDLED
Janitor	Maintaining clean and orderly work areas, cafeterias, and restrooms. Assists with decontamination as needed.	Abrasive cleaners, soap, steel wool, germicidal detergent, and other cleaning agents.
Laborer	Assisting all other departments requiring manual labor. Unloads freight cars, installs culverts, fences and signs. Assists in maintaining roads, walks, roofs and fences. Assists with furniture moving, snow removal, loading waste trailers, and landscaping.	Proximity of radioactive material.
Laundry Worker	Operate laundry equipment. Inspect and repair cleaned respirator and full face masks. Sort, mark, distribute, monitor, repair and alter laundry.	Radioactive material, beryllium, detergent, fabric softener, and bleach.
Lubrication worker	Regular lubrication and routine servicing of mechanical tools, equipment, and machinery.	Grease, oil, hydraulic fluid, solvents, and special lubricants. Some waste may contain radioactive material.
Machinist (Production Machinist)	The set-up and operation of the machine tools and equipment to produce various parts for scheduled or special production.	Metals and alloys, such as plutonium, uranium, beryllium, stainless steel, tungsten, copper, aluminum, and tantalum.
Maintenance Machinist (J. Maintenance Machinist)	Troubleshooting and repairing of machine tools and equipment. Set-up and operate all machine tools to fabricate various components, repair the machine tools and equipment or build new equipment.	Lubricants, metals, plastics, ceramics, Teflon, rubber, rare earths.
Master Glassworker	Designing, laying out, fabrication, repairing, and testing the glassware apparatus and assemblies used on the plant site.	Proximity of radioactive material, solvents and chemicals.

JOB TITLE	JOB DESCRIPTION	MATERIALS HANDLED
Material Analyst	Setting up and operating the various equipment to pressure test, make leak rate determinations, vacuum bake and heat treat., perform flow volume determination and solve complex equations to determine if the product is within specification.	Proximity of radioactive material, solvents and grease. Flammable and inert gases.
Metallurgic. Operator	Operating various types of metallurgical equipment (casting furnaces, rolling mills, presses, heat treat. Furnaces, grinders, sandblaster, ultrasonic cleaner and other metal fabricating and process techniques) to produce a product of specified quantity and quality. Transfer liquid from all buildings to processing area. Make-up and maintain solutions for process operations. Decontaminate, degrease, sand blast or otherwise clean or polish equipment with solvents, acid or water. Perform electrolysis nickel plating; salt bath and vacuum annealing; coat billets and graphite molds with solution by spraying, briquette, cast and seal scrap metal; and chemical milling to produce finished parts.	Plutonium, uranium, americium, gallium, neptunium, niobium, aluminum, copper, titanium, beryllium, chromium, molybdenum, solvents, acids, X-ray, microwave and chemical process equipment.
Metrology Technician	Provide plant with known standards of accurate for physical measurements. Work on evaluating and certifying new measurements in instrumentation and the survey of production, R & D and environmental measurement systems that require certified results. Use test and measuring equipment to repair, calibrate, and certify vacuum, temperature, pressure, electrical, humidity, flow, force, mass and density measuring equipment.	Proximity of radioactive material and solvents.

JOB TITLE	JOB DESCRIPTION	MATERIALS HANDLED
N/C Lathe Machinist	Set-up and operation of N/C lathes to produce various machined parts for scheduled or special production.	Metals, micarta, plastics and metal alloys (plutonium, uranium, beryllium, stainless steel, tungsten, copper, aluminum, tantalum and brass).
Non-destructive test (NDT) Machinist	Training and operation of equipment in the nondestructive testing laboratory to make tests to determine the condition of incoming materials, process materials, research and development materials and products. Perform tests using eddy current, ultrasound, leak detection, fluorescent penetrant, radiation gauge, radiographic and tensile testing equipment.	*Handling of radioactive material,* solvents, grease, oil, coolants and chemicals.
NDT Tech	Nondestructive testing utilizing various methods for the detection and/or measurement of significant properties or performance capabilities of materials, parts, assemblies, equipment or structures, by tests which do not impair their serviceability.	Solvents, handle radioactive sources
Painter	Repairing and maintaining the painted surfaces of the equipment and buildings on the plant site. Operates a sandblaster to clean and finish material surfaces. Paints signs in equipment and material. Performs silk-screen processing. Fiberglass tanks, pipes and waste disposal boxes. Installs floor covering, wall covering, and window glass.	Epoxy, lacquer, latex, plastic, acrylic, chromate, fiberglass, solvents (thinners), primers, urethanes, alkyds, vinyl, asphalt, rubber tile, wood veneers, and wallpaper
Parts and tool Attendant	Maintaining and controlling a parts or tool crib to provide tooling and gaugng, parts and supplies. Maintaining inventory record, costs, tool drawings and inspection report files.	Solvents, grease and oil. Proximity to radioactive material.

JOB TITLE	JOB DESCRIPTION	MATERIALS HANDLED
Personnel Meters Tech.	Collecting, distributing, preparing and assembling dosimetry badges. Reading and annealing LiF crystals. Preparing standards by exposing LiF crystals to calibrate counters. Developing film, reading, and recording of data.	Cadmium, indium, foil, alcohol, sulfur and copper
Pipefitters	Installing and maintaining the piping system for production processes, plumbing, heating, vacuum, steam, refrigeration and welded construction.	Solvents, grease, oil, coolants and chemicals. Proximity of radioactive material.
Production Records Clerk	Preparing reports, maintaining files and records. Processing inspection forms and picking up mail for the department.	Proximity of radioactive material.
Production Welder	Setting-up and operating the various joining equipment, Heli-arc, MIG, shielded metal-arc, resistance, cold wire and electron beam welding or vacuum industrial and electron bombardment brazing and silver soldering to join the various metals used in production. Perform vapor deposition of silver, chromium and aluminum.	Plutonium, uranium, titanium, stainless steel, black iron, mild steel, aluminum, monel, inconel, molybdenum, magnesium, copper, brass, beryllium, tungsten, silver, chromium, gold and other exotic metals.
Radiation Monitor, Radiation Protection Technologist	Use detection instruments to measure radiation, contamination, impurities in air, gases, air flows, vacuum, noise, light, etc. then record readings. The measurements are used to control exposure to radiation, spread of contamination and various aspects of industrial hygiene.	Proximity of radioactive material.
Security Dispatcher	Maintain the security of the plant by operating various types of communication equipment and alarms to receive and dispatch information and direction to Plant Protection and other personnel.	

JOB TITLE	JOB DESCRIPTION	MATERIALS HANDLED
Security Guard (Security Inspector)	Maintain required security on plant site by patrolling designated areas and guarding entrances and exits, protecting classified items and areas, escorting personnel, shipping and receiving classified items, looking for unusual conditions, receive training on handling emergencies.	Proximity of radioactive material.
Service Attendant	Dispensing oil and gas, change oil and filters, repair tires, wash, steam clean and lubricate vehicles.	Grease, oil, coolants, and detergents.
Service Laboratory Technician	Training and operation of the equipment in the chemical, spectrographic or radiochemical laboratories to make physical and chemical tests to determine the composition of incoming materials, in process materials, products, research and development materials and various other materials. Perform tests using mass spectrophotometers, coulometrics, atomic absorption, has chromatographs, X-ray equipment, and various other laboratory equipment.	Radioactive material, coolants, solvents, grease, oil and chemicals.
Sheetmetal worker	Fabricating, installing, and maintaining sheetmetal equipment, duct work for heating, ventilation and drybox systems and welded constructions required for plant operations.	Stainless steel, galvanized steel, platinum, gold, tantalum, iconel, aluminum, copper, tin, lead, plexiglass, plastics, and polypropylene. Occasional use of solvents, grease and oils.
Stationary Operating Engineer	Continuous operation of the various equipment to supply heat, power, water, ventilation, refrigeration, dehumidification and sewage treatment for the plant needs.	Lime, alum, chlorine, oils, freon, gasoline, fuel oil, acids, caustics, natural gas, propane, and various water treatment chemicals.

JOB TITLE	JOB DESCRIPTION	MATERIALS HANDLED
Stock Clerk	Receiving, storing, issuing and shipping all materials on the plant site other than by courier. Assuring the proper utilization and disposal of property.	Proximity of radioactive materials, solvents, oil and coolants.
Tool and Gage Inspector and Standardizer	Inspect, certify and adjust new and reworked tools, dies, gages, jigs, fixtures and measuring equipment to specified dimensions, performance tolerance and hardness.	Proximity of radioactive material, solvents, grease and oil.
Tool Crib Attendant	Maintaining and controlling a tool crib to provide various tooling, gauging and supplies to all crafts.	Proximity of radioactive materials, solvents, oil and coolants.
Tool Grinder	Silver soldering and single point, ID and OD radial, ID and OD cylindrical, form and surface grinding to fabricate and sharpen the tools as needed and other types of grinding that may be required. Perform titanium carbide sputtering process.	Solvents, oils, coolants, and chemicals.
Toolmaker	Setting up and operating the various machine tools and equipment to fabricate the components of various metals and materials to make tools, dies, jigs, gages, and fixtures.	Stainless steel, mild steel, aluminum, magnesium, silver solder, oil, coolants, and lapping and polishing compounds.
Trailer Assembly Helper	Assembling and installing components in trailers such as: flooring, tie downs, conduit, electrical boxes, and armor sections. Assist with installation of motor generators, heaters, air-conditioners, instruments, piping and controls. Operate hand drills, power hacksaws, tube benders, thread cutters, and bandsaws. Spot welds armor sections and brackets.	

JOB TITLE	JOB DESCRIPTION	MATERIALS HANDLED
Vehicle Driver (Light)	Operating vehicles in a safe manner to pick-up and deliver material and equipment (including sensitive) products, furniture, hazardous and radioactive waste, certified and registered waste, certifies and registered mail. Respond to all onsite emergency conditions, 24 hour call, including snow removal. Operate snow removal equipment and sanders. Keep logs on material moved. Operate bus or taxi to transport personnel.	Frequent proximity of radioactive and hazardous waste, grease, oil and coolants.
Vehicle Driver Heavy	Operating vehicles to pick-up and deliver materials or equipment on and off the plant site. Operate snow removal equipment and spread gravel. Greater percentage of time will be spent operating trucks with capacity of 5 ton and over and forklifts greater than 3 ton capacity. Operate bus or taxi to transport personnel. Must respond to onsite emergency condition, 24 hour call and snow removal. Transportation of Hazardous and Radioactive waste in accordance with DOE regulations and RCRA requirements.	Proximity of radioactive materials, grease, oil, and coolants.
Vehicle Modification Mechanic	Fabrication, assembling and installing components such as: flooring, tie downs, conduit, electrical boxes, armor sections, and fiberglass in order to modify transportation equipment such as trailers and truck tractors. Operates hand drills, power hacksaws, tube benders, thread cutters, bandsaws, and welders. Install motor generators, heaters, air conditioners, instruments, piping and controls.	

JOB TITLE	JOB DESCRIPTION	MATERIALS HANDLED
Waste Certification Inspector	Visually examine waste containers, waste container contents and final waste packages for compliance to procedures. Verify procedural compliance of waste generators as waste is being generated, sorted, processed, packaged and loaded for shipment.	Radioactive, toxic, and corrosive materials. Solvents.
Waste Tech., Solid Waste Operator (Chemical Operator)	Job consists of size reducing various types of equipment and packaging; the repackaging, treatment, compacting, baling and packaging of various waste form and the shipment thereof; neutralize hazardous waste as necessary; maintain records; ensure regulatory compliance; the stripping of paint in plutonium buildings as required after decontamination and clean-up of surfaces; the removal and packaging of radioactive contaminated concrete or soil; and removal and packaging of sewer sludge.	Acids, radioactive material, neutralizing agents, methylene chloride solution, cleaning solvents, salt, oil dry, and Portland cement.
Wastewater Plant Operator	Operate the Wastewater Treatment Plant with all the associated equipment, the pond and land irrigation system. Operate chlorination dechlorination, anaerobic digestors, chemical treatment systems and perform water analyses and tests of the activated sludge.	Alum, polymers, chlorine, sulfur dioxide, oils, gasoline, fuel oil, acids, caustics, natural gas, propane, and various water treatment chemicals.

Appendix A.5. "Exposure" information from Dow Chemical Co. Hourly Worker Job Histories: Job title, amount of drybox (glove box), respirator, and supplied-air suit usage, the frequency that radioactive material and chemicals are handled, and whether work was performed in proximity to radioactive material.

Job Title	Drybox Use	Respirator Use	Supplied-Air Suit	Handle Radioactive Material	Handle Chemicals	Proximity Radioactive Mat.
Air Filter Tech	Occasional	Frequent	Frequent	Occasional	Occasional	Occasional
Alarm/telecomm. Tech	Occasional	Occasional	Occasional		Occasional	Frequent
Anal Lab Tech	Frequent	Frequent		Frequent	Frequent	
Assembler	Frequent	Frequent		Frequent	Frequent	
Auto. Mech.		Occasional			Frequent	
Bio Assay Tech				Occasional	Frequent	
Cable Fabricator		Occasional			Occasional	Occasional
Carpenter		Occasional	Occasional		Occasional	Yes
Chemical Control Operator	Frequent	Frequent	Occasional			
Chemical Operator	Frequent	Frequent	Occasional	Frequent	Occasional	
Chemical Operator, Solid Waste Operator	Frequent	Occasional	Occasional	Frequent	Occasional	
Clerk Packer	Occasional	Occasional		Occasional	Occasional	
Counting Tech		Occasional				Occasional
Decontamination Worker		Frequent	Occasional (for long periods)	Frequent	Frequent	
Dispatcher						
Dosimetry Tech				Occasional (neutron)	Very Frequent	
Electrician	Occasional	Occasional	Occasional (for long periods)	Frequent	Frequent	

Job Title	Drybox Use	Respirator Use	Supplied-Air Suit	Handle Radioactive Material	Handle Chemicals	Proximity Radioactive Mat.
Electical Tech	Occasional	Occasional	Occasional	Frequent	Occasional	
Experimental Operator	Occasional	Occasional	Occasional	Frequent	Frequent	
Filter Test Tech		Yes				
Garage Parts & Tool Attendant (Bldg 331)					Occasional	
Inspector	Continuous (in some areas)	Occasional		Occasional	Frequent	
Janitor		Occasional		Occasional	Frequent	
Heavy Equip. Operator					Yes	
Journeyman Maint. Machinist	Occasional	Occasional	Occasional		Frequent	Continuous
Laborer		Occasional		Occasional		
Laundry Worker		Occasional			Yes (detergents)	
Lubrication Man	Frequent	Frequent		Frequent	Frequent	
Machinist (Production)	Continuous	Occasional		Frequent		
Master Glassworker	Occasional	Occasional			Occasional	Occasional
Material Analyst	Occasional	Occasional			Occasional	Continuous (in some areas)
Metallurgical Operator	Occasional	Occasional		Occasional	Frequent	
Metallurgical Operator (2/81 version)	Frequent	Occasional		Frequent	Frequent	

Job Title	Drybox Use	Respirator Use	Supplied-Air Suit	Handle Radioactive Material	Handle Chemicals	Proximity Radioactive Mat.
Metrology Tech	Occasional	Occasional	Occasional		Occasional	Frequent
N/C Lathe machinist	Continuous (in some areas)	Occasional				Frequent
NDT Tech	Occasional	Occasional		Frequent	Occasional	
Painter	Occasional	Frequent	Occasional		Frequent	Occasional
Parts & Tools Attendant		Occasional			Frequent	Occasional
Personnel Meters Tech					Occasional	
Pipefitter	Occasional	Occasional	Occasional		Occasional	Occasional
Production Records Clerk		Occasional				Occasional
Probe & Cable Fabricator		Occasional			Frequent	Yes
Production Welder	Occasional	Occasional			Frequent	Occasional (continuous in some areas)
Radiation Monitor	Occasional	Frequent	Occasional			Frequent
Security Dispatcher						
Security Guard		Occasional				Occasional
Security Inspector		Occasional				Occasional
Service Attendant					Frequent	
Service Lab Tech	Frequent	Occasional	Frequent	Frequent	Frequent	
Sheetmetal Worker	Occasional	Occasional	Occasional		Occasional	Occasional
Stationary Operating Engineer		Occasional			Occasional	Occasional

Job Title	Drybox Use	Respirator Use	Supplied-Air Suit	Handle Radioactive Material	Handle Chemicals	Proximity Radioactive Mat.
Stock Clerk		Occasional			Occasional	Occasional
Tool Crib Attendant		Occasional			Occasional	Occasional
Tool Grinder					Occasional	
Tool & Gauge Insp. and Standardizer	Occasional	Occasional			Occasional	Occasional
Toolmaker	Rare	Rare			Frequent	Rare
Trailer Assembly Helper						
Utility Worker (General)		Occasional		Frequent	Occasional	
Vehicle Driver (heavy)					Occasional	Occasional
Vehicle Driver (Light)					Daily	Daily (Hazwaste also)
Vehicle Modification Mechanic						
Wastewater Treatment Plant Operator		Rare			Frequent	Rare

Appendix A.6
Information Extracted from 900 Job Histories of Rocky Flats Personnel, available from the Los Alamos National Laboratory Epidemiology Group.

Date	Job Title	Organization	Org. Code
May-72	Chem Eng	Gpp	21300
Jul-73	Chem Eng	Waste Mgmt	29400
Jan-74	Chem Eng	Area Proj. Engrs	21520
Jan-74	Chem Eng	Waste Mgmt	31400
Jul-75	Chem Eng	Chem Design	11224
Jul-75	Chem Eng	Facil Design	11220
Jul-75	Chem Eng	Waste Mgmt	16140
Jan-76	Chem Eng	Solid Waste Oprns	18520
May-76	Chem Eng	Pu Recov/Waste Treat. Proj.	11240
May-76	Chem Eng	Waste Proc	18500
May-77	Chem Eng	371-374 Proj	20600
May-77	Chem Eng	Facil Design	20220
May-77	Chem Eng	Pu Recov/Waste Treat. Proj	20240
Oct-77	Chem Eng	Exp & Cap Equip Grp	20212
Jun-78	Chem Eng	Pilot Plant Dev	41150
Jun-78	Chem Eng	Pu Recov	32100
Jul-78	Chem Eng	Pu Tech Oprns	32120
Nov-78	Chem Eng	Tech Oprns	23120
Jan-68	Chem Mas Tec	Chem R & D Proc Chem	82300
Oct-72	Chem Mas Tec	Chem Technology	28210
Apr-53	Chem Oper	Prod B	181
Aug-77	Chem Oper Splst	Chem Oprns	32000
Apr-53	Chem Oper	Prod B	181
May-53	Chem Oper	Prod A	144
Apr-54	Chem Oper	Prod C	171
Apr-74	Chem Oper	Pu Recov	29100
Feb-75	Chem Oper	Waste Treat.	31500
Jul-75	Chem Oper	Pu Recov	18100
Jul-75	Chem Oper	Waste Treat.	16150
Jan-76	Chem Oper	Liquid Waste Treat.	18510
Feb-76	Chem Oper	Pu Recov	12900
May-77	Chem Oper	Liquid Waste Proc	32510
May-77	Chem Oper	Pu Recov	32100
Nov-77	Chem Oper	Proc Oprns	32110
Nov-77	Chem Oper	Pu Oprns	32110
Jan-78	Chem Oper	Pu Proc Oprns	32110

Appendix A.7

Information from Job Histories of Employees Listed in CompChem Database

There were 44 employees listed in the database with carbon tetrachloride sampling. Most of the samples were area samples located at breathing zone level. Thirty of the employees were also in the original microfiche containing job histories and health physics records. Ten were machinists, seven worked in the 700 area. Two were experimental operators, and seven were Chemical Operators working in Building 707. Example work histories are included on the following pages.

Examples of Organizational Name Changes listed in the Job Histories

Mfg Fast Recycle
↓
Mfg Pu Chem Support
↓
Mfg Pu Chem & Rec
↘

Mfg Slow Recycle
↓
Mfg Pu Chem & Rec
↙

Pu Chem & Rec
↓
Pu Recovery
↓
Process Operations

Mfg Waste Treatment
↓
Mfg Waste Treatment 74
↓
Waste Treatment
↓
Lq. Waste Treatment
↓
Lq. Waste Proc

JOB: MACHINIST

Date	Job Title	Org. Code	Organization
Mar-61	Machinist	176-Man#	Production C
Jan-62	Machinist	5231	Fab 76 Mach Shop
Aug-63	Machinist	52310	Mfg-Fab 76-Mach
Aug-64	Machinist	52216	Mfg PU Fab 76
Dec-64	Machinist	52217	PU 76 Fab 76 pm
Jun-64	Machinist	52210	Fab-Pu 76
Jun-65	Prod Machinist	52210	Fab-Pu 76
Nov-66	Prod Machinist	52200	Fab-Pu 76
Jul-69	Jrnymn Machinist	52200	Mfg Fab-Pu 776
Sep-70	Jrnymn Machinist	52200	Mfg Fab 776-777
Nov-70	Jrnymn Machinist	52200	Mfg Fab 776-707
Aug-71	Jrnymn Machinist	25200	Pu Fab 776-707 (Fab 776-707)
Apr-74	Jrnymn Machinist	26200	Pu Fab 776-707
Jul-74	Jrnymn Machinist	25500	Pu Fab 776-707
Jun-75	Jrnymn Machinist	25500	Pu Production
Jul-75	Machinist	17400	Pu Fab 707-776
May-77	Machinist	31300	Pu Fab 707-776

The progression for this job is: Apprentice machinist, journeyman machinist, machinist (equivalent to Production machinist), and Crew Leader.

Job titles alone are insufficient to determine the employee's work location. The Organization must be identified either by name or code. The former is preferable because there is no list of all organization code's by organization over time. The same job titles are used in other organizations and locations.

The table was compiled from information contained in the employment record cards of seven machinists. All were in the chemical exposure sampling database listed as having either been in an area where carbon tetrachloride was sampled or as having personal breathing zone samples. All were assigned to the 700 Area.

Six of the machinists had health physics incident reports. Locations at which the employee was working when the incident occurred were sometimes listed. That information can be used to determine some of the rooms, glove boxes and equipment an individual was assigned to. Building 77 is the same as 777. Building 776 is the same as 76. In building 707, Mod C is located in room 110. The first number is the building; the second is the room. Any other location information found is listed third. The carbon tetrachloride sampling data for Building 707 listed the following boxes as being used for machining: 7C-25, 7C-60, 7C-65, and 7C-95. 7C-125 was identified being used for waste storage. These are the only Building 707 boxes mentioned, specifically by number, in association with the above employees. This indicates that machinists worked in the boxes designed for machining, not in the boxes designed for chemical processes.

Emp.	Job & Organization	Date	Location
P.	J. Mach., Mfg/Fab Pu 776	3/7/70	776-131, lathe 743
	J. Mach., Mfg Fab Pu 776	6/8/70	776-134, Box 756
	J. Mach., Fab Pu 776-777	10/21/71	776-134, Box 751
	J. Mach., Pu Fab 776-707	11/8/73	707, Mod C, #1 Heald
	J. Mach., Pu Fab 776-707	3/12/75	707-110, Box 7-C-125
	J. Mach., Pu Fab 776-707	4/2/75	707, Mod C, #1 Heald
	J. Mach., Pu Fab 776-707	5/11/77	776-134, Box 741
Sh.	Prod. Mach., Fab Pu 76	10/15/65	77, Lathe 752, Pu fire
	Prod. Mach., Fab Pu 76	3/27/68	76-134, Box 727
	Prod. Mach., Fab Pu 76	5/6/68	776, Box 749
	Prod. Mach., Fab Pu 76	5/8/68	776-134, Box 744
	Jour. Mach., Mfg Fab Pu 776	8/19/69	776-134, decontamination operation
	Jour. Mach., Mfg Fab Pu 776	8/23/69	776-207 (exhaust duct), decontamination operation
	Jour. Mach., Mfg Fab Pu 776	5/15/70	776-134, Box 716
	Jour. Mach., Mfg Fab Pu 776	6/23/70	776-134, Box 720
	Jour. Mach., Pu Fab 776-707	7/16/71	707-110, Box 7C-95
	Jour. Mach., Pu Fab 776-707	4/19/72	707-110, Mod C
	Jour. Mach., Pu Fab 776-707	4/1/75	707, Mod C, # 6 Heald
	Machinist, Pu Fab 776-707	5/21/76	707-110, Box 7C-65
	Machinist, Pu Fab 776-707	7/30/76	707, Box 7C-60A
	Machinist, Pu Fab 776-707	11/9/76	707-110, Box 7C-25B, Glove 85
D.	Jour. Mach., Fab Pu 76	11/8/68	76-134
	Jour. Mach., Mfg. Fab Pu 76	9/6/69	776-134, removing contaminated waste from fire area
	X-Jour. Mach., Mfg. Fab Pu 776-777	9/30/70	707, Mod C, Box 7C-60
K.	Jour. Mach., Mfg Fab Pu 776	10/10/69	776-134, Lathe 103
	Jour. Mach., Mfg Fab Pu 776	6/19/70	776-134, Box 734
H.	Machinist, Pu-Fab 776-707	2/16/71	707, Mod C, #5 Heald
	Machinist, Pu-Fab 776-707	7/1/72	Mod C, Lathe #6
	Machinist, Pu-Fab 776-707	5/16/71	707, 125B, Dry room, Mod E or F
	Machinist, Pu-Fab 776-707	5/4/71	707 #5 heald
	Machinist, Pu-Fab 776-707	4/27/73	Mod C, #5 Heald lathe
	Machinist, Pu-Fab 776-707	5/16/73	707, 7C-65A, working on lathe

Emp.	Job & Organization	Date	Location
Su.	Jour. Mach., Mfg Fab Cat J 881	5/6/70	776-430, Lathe 741
	Jour. Mach., Pu Fab 776	3/1/71	707, Mod C, Heald #4
	Jour. Mach., Pu Fab 707	3/15/71	707, Mod G, Be Lathe (operating lathe)
	Jour. Mach., Pu Fab 707	5/8/73	707, Mod C, Lathe 2, cutting part
	Jour. Mach., Pu Fab 707	5/2/75	707 Mod A
	Machinist, Pu Prod	4/7/76	707-110, Mod C, Box 7C-95

Examples of the work histories for several job titles are listed in the following tables.

JOB TITLE: CHEMICAL OPERATOR

Date	Job Title	Org. Code	Organization
Jan-68	Process Operator	54210	Mfg. Slow Recycle
	Process Operator	54220	Mfg. Fast Recycle
May-69	Process Operator	56100	Mfg. Slow Recycle
	Process Operator	56200	Mfg. Fast Recycle
Jun-70	Process Operator	56300	Mfg. Waste Treatment
Jan-71	Process Operator	56100	Mfg. Pu Chem. & Recovery
Mar-71	Process Operator	56200	Mfg. Pu Chem. Suppt.
May-71	Process Operator	56100	Pu Chem & Recovery
Aug-71	Process Operator	29100	Pu Chem & Recovery
Aug-71	Process Operator	29300	Waste Treatment
Jan-74	Chemical Process Operator	31410	Waste Treatment
Mar-74	Chemical Operator	29100	Pu Recovery
Feb-75	Chemical Operator	31500	Waste Treatment
Jul-75	Chemical Operator	16150	Waste Treatment
Jul-75	Chemical Operator	18100	Pu Recovery
Jan-76	Chemical Operator	18510	Waste Treatment
May-77	Chemical Operator	32510	Liquid Waste Treatment
May-77	Chemical Operator	32100	Pu Recovery
May-77	Chemical Operator	32510	Liquid Waste Prong.
Nov-77	Chemical Operator	32110	Process Operations

JOB TITLE: EXPERIMENTAL OPERATOR

Occurrence	Date	Job Title	Org. Code	Organization
	Feb-68	Experimental Operator	81300	Product Met R & D
Reorganization	Aug-71	Experimental Operator	28120	MT - Product Met
Reorganization	Aug-73	Experimental Operator	28140	Pu Fabrication
New Org. Name	Aug-73	Experimental Operator	28140	Pu Metallurgy
Reorganization	Jul-71	Experimental Operator	21120	Mt-Pu Met
Reorganization	May-77	Experimental Operator	42120	Mt-Pu Met

JOB TITLE: UTILITIES OPERATOR

Occurrence	Date	Job Title	Org. Code	Organization
	Mar-62	Boiler Vent. Oper. I	3433	Bldg. Serv. 76
	Sep-63	Utility Opr. I	34330	Area Util. 76
Reorganization	Jun-66	Utility Opr. I	34332	Util. 76, 77, 78
Reorganization	Jun-67	Utility Opr. I	75332	PS Util. 76, 77, 78
Org. Code Change	Mar-71	Utility Opr. I	31300	EC Util Area C
	Aug-71	Utility Opr. I	27200	Util Area C
Org. Code Change	Sep-71	Utility Opr. I	27600	Util Area C
Reorganization	Jun-72	Area Util. Super.	27620	Bldgs. 776/777
Reorganization	Jul-73	Area Util. Super.	27432	Bldgs. 776/777
Reorganization	Apr-74	Area Util. Super.	26420	Bldgs. 776/777
Reorganization	Jul-74	Area Util. Super.	33320	Bldgs. 776/777
Reorganization	Jul-75	Area Util. Super.	11400	Util - Area C
Reorganization	Feb-77	Area Util. Super.	14420	Util - Area C & D

JOB TITLE: INSPECTOR

Date	Job Title	Org. Code	Organization
Sep-60	Inspector I	176-Man #	Prod. C
Jan-62	Inspector I	6222	QC Comp Inspection
Aug-63	Inspector	62222	QA 76 Component
Aug-63	Inspector	62200	QA Inspection 76
Jun-64	Inspector	62120	QA Inspection 76
Sep-64	Inspector	32120	QA Inspection 76
Dec-65	Inspector	32200	QA Inspection 76
Mar-66	Inspector	32300	QA Inspection 76
May-66	Inspector	62200	QA Inspection 76
May-66	Inspector	62300	QA Inspection 77
Nov-67	Inspector	62210	QA Inspection 77
Aug-71	Inspector	23235	QA Inspection 777
Dec-71	Inspector	23230	QA Inspection 776
Oct-73	Inspector	23220	QA Inspection 707
Jan-74	Inspector	23220	QA Inspection 707
Jul-75	Inspector	22220	QA Inspection 707
Aug-78	Inspector	33220	Inspection 707

JOB TITLE: METALLURGY OPERATOR

Occurrence	Date	Job Title	Org. Code	Organization
	Aug-60	Asst. Operator	176-Man#	Production C
	Sep-60	Equipment operator	176-Man#	Production C
	Nov-61	Operator	176-Man#	Production C
	Jan-62	Operator	5421	Met Prod Chm
Contract Change	Aug-62	Process Operator	5421	Mfg. Chem 71
	May-63	Process Operator	54210	Mfg. Chem 71
	May-64	Process Operator	54120	Mfg Found 76
Reorganization	Jul-64	Process Operator	54212	Chem 71 Pu Recovery
Transfer	May-65	Process Operator	54130	Foundry - Waste 74
Transfer	Nov-65	Process Operator	54122	76 Foundry
Reorganization	Dec-65	Process Operator	54120	Mfg. Foundry 76
	May-69	Process Operator	54200	Mfg. Foundry 776
Org. Code Change	Oct-69	Process Operator	57200	Mfg. Foundry 776
Reorganization		Process Operator	57200	Mfg. Met Opr 776-707
Reorganization		Process Operator	57200	Met Opr 776-707
	Aug-71	Process Operator	25520	Met Opr 776-707
Classification Change	Aug-72	Met. Proc. Opr.	25520	Met Opr 776-707
Org. Title Change	Dec-73	Met. Operator	25520	Met Opr Pu Area
Reorganization	Apr-74	Met. Operator	26120	Met Opr Pu Area
Reorganization	Jul-74	Met. Operator	25420	Met Opr Pu Area
Org. Code Change	Jun-75	Met. Operator	25510	Met Opr Pu Area
Reorganization	Jul-75	Met. Operator	17410	Met Opr Pu Area

Appendix A.8

Combined File of All Building 707 Job Information

Job Titles in Production Area C and/or Bldg 707, from all sources combined. Removed job titles dated before the opening of 707 and duplicates. Jobs with the same title but different organizations (which were just new names for the same Org.) or org. codes were combined.

Job Title	Organization	Years
Asst. Prodn Insp	531	
Asst. Pu Chem Supt	592	
Asst. Pu Supt	592	Aug-71
Assoc Qc Eng	700 Area Qual Eng 23140	Sep-68
Asst. Qc Eng	700 Area Qual Eng 61400	
Asst. Recovery Operator	511	Oct-69
Asst. Supt-Chem Oprns	Mfg-Fast Recycle 56200	Jan-71
Asst. Supt-Chem Oprns	Mfg Pu Chem & Support 56200	Aug-71
Asst. Supt-Chem Oprns	Pu Chem Support 29200	Dec-71
Asst. Supt-Chem Oprns	Chem Oprns 29000	Apr-72
Asst. Supt-Chem Oprns	Pu Chem & Recov 29100	Jul-73
Asst. Supt-Chem Oprns	Chem Oprns 29000	Oct-69
Asst. Supr-Chem Oper	Mfg Slow Recycle 56100	Jan-71
Asst. Supr-Chem Oper	Mfg Pu Chem & Recov 56100	
	Bldg 707/777 Mgr X69901	
	Production Operations-Rf Plnt	9/15/88
	Bldg Util Eng Util Area C 31300	May-70
	Chem Eng Pu Tech Oprns 32120	Jul-78
	Chem Oper Proc Oprns 32110	Nov-77
	Chem Oper Splst 511	
	Chem Operations Dir 512	
	Chem Operations Eng 131	
	Chem Operator 511 A033 (14)	8/22/88
Plutonium Operations	Chem Operator-Spec 511 X11110	10/7/86
	Chem Physicist Engr X23000	Jun-72
	Plutonium Operations	
	Chem Proc Oper Pu Chem & Recov 29100	
	Chem Process Opr 511	Sep-71
	Chemist Pu Chem 33321	Sep-77
Clerk Packer	Pu Fab 776-707 25200	
Compliance Splst	X11136 Plutonium Operations	1/18/89
Decontam Foreman	832	

Appendix B
Description of CompChem Database

I. DATABASE DESCRIPTION

CompChem is an ORACLE database containing sample exposures, both personal and otherwise, taken in various areas and buildings at Rocky Flats. All agents are included, though the only ones considered complete are the carbon tetrachloride and the trichlorides (chlorothene, trichloroethylene, etc.) from the 700 Area.

Tables have been created within the database as follows:

A. AGENT_DICTIONARY

This table contains all the agents sampled for. Each entry or record consists of an agent abbreviation, the agent name in full, the chemical CAS number, and a comments field. The table was developed as a way to keep the most data on each agent or type of agent without cluttering the main data tables. The fields and definitions follow:

NAME	DESCRIPTION	LENGTH	TYPE
AGENTABBR	Agent abbreviation	7	character
AGENTNAME	Agent name	25	character
CASNUM	Chemical, CAS number	9	integer
OTHERINFO	Comments, etc.	50	character

1. AGENTABBR contains an abbreviation for a chemical agent that is being sampled. The abbreviation is no more than seven characters long. Some of the abbreviations are chemical formula. The intent was to make them easy to remember and identify without necessarily having to have access to the entire table. This field cannot be empty in this table. It links with fields AGENTABBR in table **SAMPLE_RESULTS.**

2. AGENTNAME is the actual agent name spelled out in its entirety. This field cannot be empty.

3. CASNUM is the Chemical Abstract Service number for the agent AGENTNAME. This column is filled in when possible.

4. OTHERINFO is a field to contain any other information that may be relevant about an agent. It does not have to be filled in.

B. PERSONNEL

This table contains a list of the personnel found to either have collected the samples or to have been exposed themselves. This table is separate so that personal identifiers are not automatic. The fields and definitions are.

NAME	DESCRIPTION	LENGTH	TYPE
ORID	Oak Ridge Assoc. University ID #	6	integer
EMPLOYENUM	Rocky Flats employee number	6	integer
LASTNAME	Employee last name	25	character
FIRSTNAME	Employee first name	25	character
MIDDLEINIT	Employee middle initial	1	character
SOCSECNUM	Employee social security number	9	integer

1. ORID is an identification number assigned by the Oak Ridge associated Universities. This field is not required.

2. EMPLOYENUM is the rocky Flats employee number for the person. Dummy employee numbers have been assigned where no record of their real one is found. A list of these will be included in the documentation as an appendix. This field is required as it is the link between **PERSONNEL** and the other tables.

3. LASTNAME - Last name; self-explanatory. Not required.

4. FIRSTNAME - First name; self-explanatory. Not required.

5. MIDDLEINIT - Middle initial; self-explanatory. Not required.

6. SOCSECNUM - The employee's social security number. Not required.

C. DET_SAMP

This table contains many of the details of the sample collected, such as the date, area, and method used to collect the sample.

1. EPIDSAMNUM - This is a unique sample number assigned by the Complex Chemicals project to an individual sample. This is the only one of the several identifiers that is truly unique. This is a required field, as it is the primary link between **DET_SAMP** and the other tables.

2. SAMPDATE - The date listed on the sample form as being the sample date. The format is DD-MM-YY.

3. SAMPTYPE - The type of sample; e.g. area, personal, or grab

4. SAMPAREA - The location or position where the sample was taken; e.g. breathing zone, box atmosphere or environmental.

NAME	DESCRIPTION	LENGTH	TYPE
EPIDSAMNUM	EPI-assigned sample number	5	integer
SAMPDATE	Sample date		date
SAMPTYPE	Type of sample	15	character
SAMPAREA	Area where sample was taken	20	character
SAMPMED	Method used to take sample	40	character
ANALMETH	Method used to analyze sample	50	character
SAMPINST	Instrument used to take sample	50	character
FLOWRATE	Rate of flow	6	decimal, xxx.xx
SAMPDUR	Sample duration	4	integer
SAMPVOL	Sample volume	9	decimal, xxxxx.xxx
LABREPNUM	Laboratory report	15	integer
SAMPCOLLB1	Employee number of the person collecting the sample	6	integer
COMMENT1	Additional descriptive information	80	character
VALIDITY	Notes regarding validity of the sample	35	character
SHIFT	What work-shift(s) the sample covered	15	character

5. SAMPMED - The method of sampling.

6. ANALMETH - The method used to analyze this particular sample.

7. SAMPINST - The type of instrument used to take the sample.

8. FLOWRATE - The rate of air pumped through the sampling media.

9. SAMPDUR - The duration of time over which the sample was taken.

10. SAMPVOL - The total volume of the sample.

11. LABREPNUM - The laboratory report number of the lab analysis for a particular sample (each sample will have only one lab report number, but a lab report number may affect many samples).

12. SAMPCOLLB1 - This field contains the Rocky Flats employee identification number of the person collecting the sample. When a dummy number is replaced, this field as well as the corresponding field in PERSONNEL both have to be checked.

13. COMMENT1 - This field contains any additional descriptive information that might be considered worth keeping in the data, but that does not fit in the other tables.

14. VALIDITY - This field was added to this table because of the number of samples for which the validity is doubtful. The samples will be kept in the data base, but an entry is to be made in this field that starts "VOID" and is followed by a very short reason, if one is considered necessary.

15. SHIFT - this field shows the work shift during which the sample was taken. This information came from the listing of sample times and dates on the sampling data sheet. Most samples were single shift samples (day or swing). In some cases several days were listed along with times which indicated that the sample was turned off at the end of one day and turned back on the following day (multiday). The person performing the sampling sometimes listed the following day as the pick-up time, along with some time period. When the length of the overlap was less than one hour, the samples were considered to be part of the previous day (day+ and dayswing+). The allowable entries in this field are:

ENTRY	**MEANING**
DAY	Single day shift
MULTIDAY	multiple day shifts
SWING	Single swing shift

DAYSWING	Day shift plus swing shift
DAY+	Single day shift with < 1hr of next day
DAYSWING+	Day and swing shift with < 1hr of next day

D. SAMPLE_RESULTS

This table contains the results of the sampling.

NAME	DESCRIPTION	LENGTH	TYPE
EPIDSAMNUM	EPI-assigned sample number	5	integer
AGENTABBR	Abbreviation (from Table Agent_Dictionary) for the agent sampled	7	character
QUALIFIER	Qualifier for the numeric value, if any. Can be < or >	1	character
VALUE	Quantity of the agent	12	xxxxxx.xx
UNITS	The units describing the quantity of the agent, e.g., ppm, m^3	15	character

1. EPIDSAMNUM - This is a unique sample number assigned by the Complex chemicals project to an individual sample. This is the only one of the several identifiers that is truly unique. This is a required field, as it is the primary link between **SAMPLE_RESULTS** and the other tables.

2. AGENTABBR - This field contains an abbreviation for a sample agent and must match with an agent listed in AGENT-DICTIONARY or be black.

3. QUALIFIER - This field contains a "qualifier" for the numeric value or quantity. It can be blank, "<" (less than) , or ">" (greater than).

4. VALUE - This is the numeric portion of the quantity contained in the sample.

5. UNITS - This is the quantity identifier, that is whether the sample was in parts per million (ppm), liters, etc.

E. GEN-SAMP

This table contains the location and operation data for the sample identified by the epidsamnum.

NAME	DESCRIPTION	LENGTH	TYPE
EPIDSAMNUM	EPI-assigned sample number	6	integer
SAMPIDNUM	The sample number that was assigned by Rocky Flats (this was not necessarily unique)	20	character
EMPLOYENUM	The employee number of any exposed employee. There was some confusion about this one, so it is not reliable. Use the data in PERSON_EXP	6	integer
SITE	The site where the sample was taken (not used for the most part)	1	character
BLDG	The building where the sample was taken	5	character
ROOM	The room where the sample was taken	7	character
BOX	The box number where the sample was taken	10	character
OTHERLOC	Any other location information	50	character
OPERATION	The operation being performed in the area where the sample was taken	35	character
OPERATDESC	Description of the operation	80	character
PERSPROTEQ	Whether or not (Y or N) personal protective equipment was in use	1	character
PERSPROTEQ1	Type of personal protective equipment in use	50	character
NUMSAMPDAT	The number of "samples" making up this sample	2	integer

1. EPIDSAMNUM - This is a unique sample number assigned by the Complex Chemicals project to an individual sample. This is the only one of the several identifiers that is truly unique. This is a required field, as it is the primary link between **GEN_SAMP** and the other tables.

2. SAMPIDNUM - For the most part, Rocky Flats had assigned sample numbers to each of the samples. It was discovered, that they are not unique. For that reason, EPIDSAMNUM was assigned. This field contains the Rocky Flats sample ID number that can be found on the laboratory reports and most sample sheets.

3. EMPLOYENUM - This is the Rocky Flats employee identification number (or dummy) for any person who may have been exposed to this sample. Use the data in **PERSON_EXP** instead.

4. SITE - The site where the sample was taken. This field has not been used much.

5. BLDG - The building number where the sample was taken.

6. ROOM - The number of the room from which the sample was taken.

7. BOX - This is the number of the glove box from which the sample was taken. It is frequently preceded by the site identifiers (e.g., 7-C-...)

8. OTHERLOC - Any other location information that may be of value. Indicates if a sample was taken from outside of a building, or from a distinct location within building, room and glove box.

9. OPERATION - The operation being performed in the area where the sample was taken.

10. OPERATDESC - A more detailed description of the operation listed in E.9.

11. PRESPROTEQ - An indicator of whether or not personal protective equipment was in use. May be blank, 'Y' (yes), or 'N' (no).

12. PRESPROTEQ1 - Description of the type of personal protective equipment that was in use. This should only be filled in if E.11 is 'y'.

13. NUMSAMPDAT - In a few cases, several "readings" were taken to provided data for one sample. In this case, NUMSAMPDAT should be filled in with the number of readings.

F. PERSON_EXP

A listing of the exposed people who were sampled.

NAME	DESCRIPTION	LENGTH	TYPE
EPIDSAMNUM	EPI-ASSIGNED sample number	5	integer
EMPLOYENUM	Rocky Flats employee number	6	integer
SAMPNUM	Number of Samples taken of operation	13	characters

1. EPIDSAMNUM - This is unique sample number assigned by the Complex Chemicals project to an individual sample. This is the only one of the several identifiers that is truly unique. This is a required field, as it is the primary link between PERSON_EXP and most of the other tables.

2. EMPLOYENUM - The Rocky Flats employee identification number (or dummy) for the exposed employee. This number matches up with one in **PERSONNEL.**

3. SAMPNUM - Is identical to field **GEN_SAMP**. SAMPIDNUM, but this one is not used very much.

This database is contained in EPI5: [BARNES.COMP_CHEM]. The actual name of the database is COMPCHEM.

II. DATABASE ADDITIONS, DELETIONS, AND MODIFICATIONS

At this time, there are no forms for input or editing in the COMPCHEM database. All insertions, deletions, or changes have to be made either interactively through SQLPLUS, or via a "load" file. The following sections deal with the basic SQLPLUS commands.

A. TO INSERT NEW DATA VIA SQLPLUS:

Remember that for a new sample, an entry will have to be made in each table (with some possible exceptions). Therefore, there will be 6 entries (one for each table) per sample:

INSERT INTO tablename (field1, field2, ...)
values (VAL1, VAL2, ...);
You only have to create entries for those tables and fields for which there are data.

B. TO DELETE DATA VIA SQLPLUS:

Remember that each sample contains in one **or more** tables. A delete command has to be executed for each table containing data on a given sample in order to delete that sample.

DELETE FROM tablename
WHERE EPIDSAMNUM = #####;

Other criteria can be used for selection, but for deletions the EPIDSAMNUM WILL BE THE MOST FREQUENTLY USED.

C. UPDATING/ CHANGING EXISTING SAMPLE DATA VIA SQLPLUS:

First you need to determine which tables need updating. The field descriptions in Section A will be needed for this purpose. The generalized updating command is:

UPDATE tablename
SET field = value, field = value,...
WHERE EPIDSAMNUM = #####;

again, other criteria can be used for selection, but EPIDSAMNUM will be the most frequently used.

D. LOADING NEW DATA VIA "LOAD" FILES:

A "load" file is really only practical for fairly large amounts of data.

The first step is to use KERMIT or some other data-transfer protocol to move the file from the PC to the VAX. You will find all files that I have done this to in the directory EPI5: [BARNES.COMP_CHEM.EPI_FILES].

Next you must determine what columns each field begins in, and what tables each field belongs in. The VAX text-editor FRED is handy for that. There is a command tc# where # is the line number (pick a full line of data that prints the column numbers over each character in that line.

Now you are ready to write a "load" file. Note the many samples of load files in the directory epi5: [BARNES.COMP_CHEM.LOAD FILES] and use them for samples of how to load data from ASCII files.

III. FINDING SPECIFIC DATA VIA SQLPLUS

A. FINDING DATA CONTAINED IN A SINGLE TABLE

There are two ways of finding data contained in a single table: listing the entire entry for each entry meeting the criteria and listing only particular fields for each entry meeting the criteria.

Listing the entire entry is simplest. The command is simply:

```
SELECT *
FROM TABLENAME
[WHERE CRITERION1  (AND  CRITERION2 ...)];
```

Not entering any selection criteria causes the entire table to be printed out on the screen.

Listing particular fields is no more difficult, it just requires more typing. The command is:

```
SELECT field1 (,field2,...)
FROM TABLENAME
[WHERE CRITERION1  (and CRITERION2 .....)];
```

B. FINDING DATA CONTAINED IN MULTIPLE TABLES

Finding data contained in multiple tables is not difficult, you just have to have type of common link between the tables. The command is based on:

C. WRITING DATA TO EXTERNAL ASCII FILES

Creating external ASCII files is accomplished merely by typing

```
SPOOL FILENAME
```

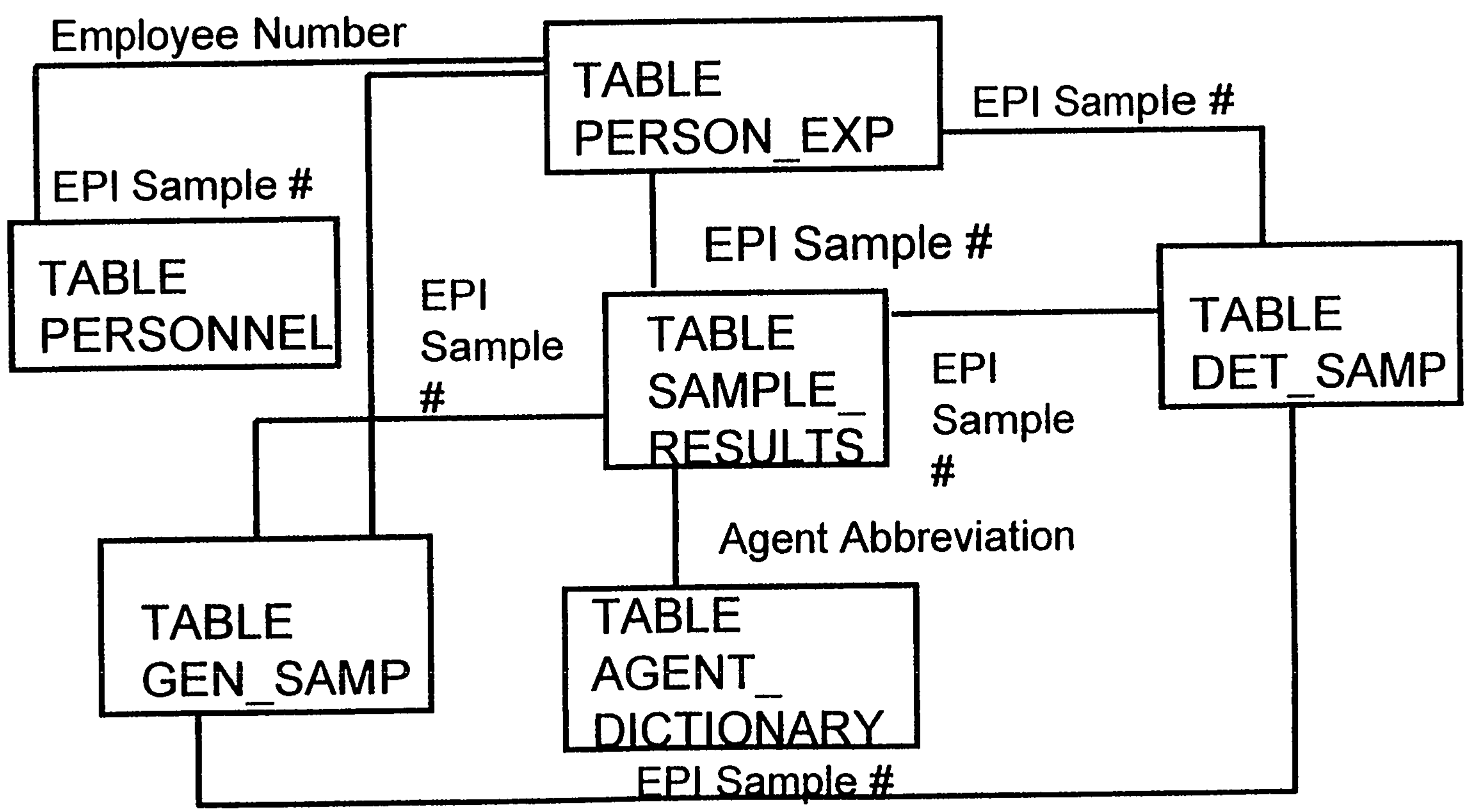
prior to doing a “select” and typing

```
SPOOL OFF
```

after the “select” has executed. This creates a file called FILENAME in whatever the current directory is.

FIGURE 6. Structure of CompChem Database.*

*Table structure for ORACLE database of chemical sample data, Rocky Flats Plant, Golden, Colorado.



Appendix C Program to Generate Maximum Likelihood Estimates

Author: Gary Tietjen, Los Alamos National Laboratory, Statistics Group (TSA-1), Los Alamos, New Mexico

```
c     Newpauls.for, updated version for actual datasets

      dimension x(2),xopt(2)
      character*1 q(3000)
c     character*9 d(3000)
      character*1 label(80)
      character*6 lrn(3000)
      character*6 esn(3000)
      dimension uu(3000)
      common nn,n1,n2,n3,n4,y1,y2,y3,y4,y(3000)
      external tval
      open(1,file='Input filename',status='old')
      open(2,file='output filename',status='new')

C  nn is the number of data points above detection limit (uncensored data)
C Read in up to four censored sample sizes, each with a detection limit;
C  (If these don't exist, use 1. for cut-off, 0 for sample size)
C  The sample sizes are the number of "less-than" values given:
c  Label is the name of dataset upto 80 characters, read in label.
      read(1,119)label
  119 format(80a1)
      write(2,119)label
      read(1,*)n1,x1,n2,x2,n3,x3,n4,x4
      write(2,121)n1,x1,n2,x2,n3,x3,n4,x4
  121 format(4(1x,I2,f4.1))
      write(2,120)
  120 format(' Rept.#  Epi.#  Q   PPM      LogN')
c
C  Take the logs of the censored data cut-off points
      y1=alog(x1)
      y2=alog(x2)
      y3=alog(x3)
      y4=alog(x4)
C Read in the natural logs of the data -- assuming log normal distributions
C Read the data (sum=uncensored logs, xsum=uncensored values, y(j)=natural
c logs, xss=sum of squares of uncensored data, ss=sum of log squares of
c uncensored values, n=total no. of data, nn=no. of uncensored.)
      sum=0.
      xsum=0
```

```
      ss=0.
      xss=0.
      nn=0
      n=0
      do 7 j=1,3000

      read(1,1,end=9)lrn(j),esn(j),q(j),uu(j)
    1 format(a6,15x,a5,1x,a1,5x,f7.2)

C   uu(j) is the measured value of the contaminant

C
C  Calculate the sum of the uncensored values then take the logs of all data
      if(q(j).ne.'<')xsum=xsum+uu(j)
      y(j)=alog(uu(j))
c  Calculate the sum of squares of uncensored data
      if(q(j).ne.'<')xss=xss+uu(j)**2
c  Write data to datafile
      write(2,50)lrn(j),esn(j),q(j),uu(j),y(j)
   50 format(1x,a6,2x,a5,2x,a1,f7.2,2x,f10.4)
C
c  Calculate sum of logs of uncensored data
      if(q(j).ne.'<')sum=sum+y(j)
c  Calculated sum of squares of logs of uncensored data
      if(q(j).ne.'<')ss=ss+y(j)**2
c  Calculate the number of uncensored data points
      if(q(j).ne.'<')nn=nn+1
c     1 format(a6,15x,a5,x,a1,5x,f6.0)
    7 continue
    9 continue


C The initial guesses of the parameters are x(1) and x(2)
c  Calculate the total number of datapoints
      n=nn+n1+n2+n3+n4
c  Calculate the average of the uncensored values
       xbar=xsum/nn
c  Set x(1) parameter equal to the average of the logs of the uncensored data
      x(1)= sum/(nn)
c Calculate variance of logs of uncensored data
      ss=(ss-sum**2/nn)/(nn-1.)
c Calculate variance of uncensored data
      xss=(xss-xsum**2/nn)/(nn-1.)
c Calculate the standard deviation of logs of uncensored data
      st=sqrt(ss)
```

```
c Calculate standard deviation of uncensored data
     xst=sqrt(xss)
c Set x(2) parameter equal to the standard deviation of logs of uncensored data
     x(2)=st
     Write(2,99)xbar,xst
  99 Format(' Mean and std.dev. of uncensored data=',2f10.5)
     write(2,6)x(1),x(2)
   6 format(' Mean and std dev of logs of uncensored data=',2f10.5)

c
     itmax=1000
     call simpnox(x,xopt,f1,tval,2,itmax,alen,.001)
     xmu=xopt(1)
     sig=xopt(2)
     write(2,4)xmu,sig
   4 format(' Est. log mean and std.dev. of original data=',2f10.5)
     w=exp(sig*sig)
     std=exp(xmu)*sqrt(w*(w-1.))
     xmed=exp(xmu)
     sigg=exp(sig)
c  Calculate the mean of all data
     xmean=exp(xmu+.5*sig**2)
     xl=exp(xmu-1.96*sig/sqrt(n*1.))
     xu=exp(xmu+1.96*sig/sqrt(n*1.))
     write(2,11)n,nn
     write(2,14)xmed,sigg
     write(2,13)xl,xu
     write(2,12)xmean,std
  11 format(' No. samples, No. uncensored',2i5)
  14 format(' Est. median and sigma g of original data=',2f10.5)
  12 format(' Est. mean and std. dev of original data=',2f10.5,/)

  13 format(' 95% Conf. inter. on median of original data=',2f10.5)
   3 continue
  59 format(4f10.4)
     end

     function tval(x)
     dimension x(2)
     common nn,n1,n2,n3,n4,y1,y2,y3,y4,y(3000)
C This function is what is minimized;
C x(1)=xmu, x(2)=sigma


C Write the sum for the "greater than" values
```

```
      sumb=0.
    4 format(2f8.3,3e13.5)
      do 7 j=1,nn
      sumb=sumb+(y(j)-x(1))**2/(2.*x(2)**2)
    7 continue
C get the expression for the "less than" values
      xy1=1.
      xy2=1.
      xy3=1.
      xy4=1.
      if(n1.ne.0.)xy1=andist(y1,x(1),x(2))
      if(n2.ne.0.)xy2=andist(y2,x(1),x(2))
      if(n3.ne.0.)xy3=andist(y3,x(1),x(2))
      if(n4.ne.0.)xy4=andist(y4,x(1),x(2))
    5 format(i6,2f8.3)
      xz1=n1*alog(xy1)
      xz2=n2*alog(xy2)
      xz3=n3*alog(xy3)
      xz4=n4*alog(xy4)
      xlike=-nn*alog(2.50663*x(2))-sumb+xz1+xz2+xz3+xz4
c
c  Calculate the constant C
c
      n=nn+n1+n2+n3+n4
      nmk=n-nn
      do 8 i=1,n
      xx=alog(i*1.)
      sum1=sum1+xx
      if(i.le.nmk)sum2=sum2+xx
      if(i.le.nn)sum3=sum3+xx
    8 continue
      summ=sum1-sum2-sum3
      sum1=0.
      sum2=0.
      sum3=0.
      xlike=xlike+summ
C
      tval=-xlike
      return
      end

      subroutine simpnox(x,xopt,f1,tval,n,itmax,alen,acc)
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc*
c
c       subprogram simpnox
```

```
c
c     this subroutine performs nelder-meads simplex
c     search to minimize the function given by tval.
c
c   tval(x,n) function program(external to main program)
c   x(n)      arguments of function(unknown parameters)
c   n         number of arguments
c   f1        optimal value of tval
c   xopt      optimum point
c    acc      convergence criteria (default=1.e-6)
c    itmax    maximum num of iterations. returns the
c             number of iterations.
c    alen     initial length of simplex (default=.1)
c
c
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc*
      dimension x(100),xopt(100),xx(100,101),z(101)
      dimension xcen(100),xre(100),xex(100),xcon(100)
      dimension wt(101)
c
c  determine starting simplex and initialize
c    various constants
c

      if(acc.eq.0.)acc=.000001
      if(alen.eq.0.)alen=.1
      if(itmax.eq.0)itmax=10000
      a=alen
      alpha=1.
      gama=2.
      beta=.5
      it=0
      n1=n+1
      call strtsim(xx,n,x,a)
c
c  calculate function at each point of the simplex
c
      do 7 i=1,n1
7      z(i)=tval(xx(1,i),n)
  110  continue
      it=it+1
  111 continue
      ilo=1
      ihi=1
      zlo=z(1)
```

```
      zhi=z(1)
      if(it.gt.itmax)go to 300
      do 8 i=2,n1
      if(z(i).ge.zlo)go to 9
      ilo=i
      zlo=z(i)
  9   if(z(i).le.zhi)go to 8
      ihi=i
      zhi=z(i)
  8   continue
c
c  determine weights and then compute centroid
c
      if(it.gt.itmax)go to 300
      do 6 i=1,n1
6     wt(i)=1./float(n)
      do 801 i=1,n
      xcen(i)=0.
      do 80 j=1,n1
      if(j.eq.ihi)go to 80
      xcen(i)=xcen(i)+wt(j)*xx(i,j)
80    continue
801   continue
c
c  compute reflected point
c
      do 13 i=1,n
13    xre(i)=xcen(i)+alpha*(xcen(i)-xx(i,ihi))
      zre=tval(xre,n)
      if(zre.lt.zlo)go to 70
c
c  check f(xre) .lt. f(xi), for i .ne. h
c
      do 14 i=1,n1
      if(i.eq.ihi)go to 14
      if(zre.lt.z(i))go to 20
14    continue
      go to 40
20    continue
c
c     replace xhi by xre
c
      do 21 i=1,n
21    xx(i,ihi)=xre(i)
      z(ihi)=zre
```

```
      go to 100
40    continue
      if(zre.lt.z(ihi))go to 50
      go to 55
50    do 51 i=1,n
51    xx(i,ihi)=xre(i)
      z(ihi)=zre
55    continue
c
c  calculate contracted point
c
      do 56 i=1,n
56    xcon(i)=xcen(i)+beta*(xx(i,ihi)-xcen(i))
      zcon=tval(xcon,n)
      if(zcon.gt.z(ihi))go to 60
      do 57 i=1,n
57    xx(i,ihi)=xcon(i)
      z(ihi)=zcon
      icn=icn+1
      go to 100
60    continue
c
c  shrink it down
c
      do 61 j=1,n1
      if(j.eq.ilo)go to 61
      do 67 i=1,n
67    xx(i,j)=0.5*(xx(i,j)+xx(i,ilo))
      z(i)=tval(xx(1,i),n)
61    continue
      do 62 i=1,n1
62    z(i)=tval(xx(1,i),n)
      go to 100
70    continue
c
c  check expansion
c
      do 71 i=1,n
71    xex(i)=xcen(i)+gama*(xre(i)-xcen(i))
      zex=tval(xex,n)
      if(zex.lt.zlo)go to 75
      go to 20
75    continue
c
c  replace worst by expansion
```

```
c
      do 76 i=1,n
76      xx(i,ihi)=xex(i)
      z(ihi)=zex
      go to 100
100   continue
c
c  check convergence
c
      if(it.lt.10000)go to 212
       write(3,*)it
      do 120 j=1,n1
120   write(3,900)(xx(i,j),i=1,n),wt(j),z(j)
      write(3,900)(xcen(i),i=1,n)
900   format(6e12.6)
212   continue
      ihi=1
      do 677 i=2,n1
      if(z(i).le.z(ihi))go to 677
      ihi=i
  677 continue
      ilo=1
      do 678 i=2,n1
      if(z(i).ge.z(ilo))go to 678
      ilo=i
 678  continue
      if(abs(z(ihi)-z(ilo)).gt.acc)go to 131
      do 121 i=1,n
121   if(abs(xx(i,ihi)-xx(i,ilo)).ge.acc)go to 131
c
c  convergence
c
      itmax=it
      f1=z(ilo)
      do 33 i=1,n
33      xopt(i)=xx(i,ilo)
      nstaj=it
      return
300   continue
c     print *,'max iteration exceeded'
      return
131   continue
      go to 110
      end
      subroutine strtsim(xx,n,x,xlen)
```

```
      integer*4 i
      dimension xx(100,101),x(100)
      n1=n+1
      s=sqrt(float(n1))
      do 1 i=1,n
 1    xx(i,1)=x(i)
      t=sqrt(2.)*n
      d1=xlen*(s+n-1.)/t
      d2=xlen*(s-1.)/t
      do 3 j=2,n1
      do 3 i=1,n
      if(i.eq.j-1)go to 4
        xx(i,j)=x(i)+d2
        go to 3
 4    xx(i,j)=x(i)+d1
 3    continue
      return
      end
      function andist(x,xm,s)
      t=(x-xm)/s
      at=abs(t)/1.41421356
      if(at.lt.9.)then
      alt=1.-erfc(at)
      else
      alt=1.
      end if
      andist=.5+(sign(alt,t))/2.0
      return
      end
c     function rnor(xmu,sig)
c     data ic/1/
c     ic=1-ic
c     if(ic.eq.1)go to 20
c     i=0
c 10  u=2.*(ran(i)-.5)
c     v=2.*(ran(i)-.5)
c      po=u*u+v*v
c     if(po.gt.1.)go to 10
c     x=sqrt((-2.*alog(po))/po)
c     rnor=u*x*sig+xmu
c     return
c 20  rnor=v*x*sig+xmu
c     return
c     end
```

Appendix D

Results of BMDP® Statistical Analysis

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 25, ALL DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	1.12	1.04	1.08	1.09	-0.59	-3.45	-0.84	-0.71
STANDARD ERROR	0.11	0.12	0.12	0.12	0.1	0.39	0.12	0.11
MEDIAN	0.4	0.4	0.4	0.4	-0.9	-0.92	-0.92	-0.92
STANDARD ERROR	0.09	0.09	0.09	0.09	0.2	0.2	0.2	0.2
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.75	0.67	0.71	0.73	-0.71	-3.22	-0.95	-0.82
HAMPEL	0.33	0.42	0.37	0.35	-0.7	-1.76	-0.85	-0.75
BWEIGHT	0.32	0.1787	0.22	0.24	-0.63	-3.31	-0.86	-0.74
W STATISTIC	0.74	0.76	0.75	0.75	0.87	0.71	0.86	0.87
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	7	7	7	7	1.9	1.95	1.95	1.95
Z-SCORE	4.36	4.25	4.31	4.33	2.16	1.18	1.94	2.04
MINIMUM VALUE	0.1	0.0001	0.05	0.0707	-2.3	-9.21	-3	-2.65
Z-SCORE	-0.75	-0.737	-0.75	-0.75	-1.48	-1.26	-1.5	-1.49
SKEWNESS	1.74	1.64	1.7	1.72	0.38	-0.4	0.2	0.3
SKEWNESS/S.E.	8.4	7.91	8.19	8.29	1.83	-1.95	0.99	1.46
KURTOSIS	2.93	2.52	2.74	2.83	-1.25	-1.74	-1.45	-1.37
KURTOSIS/S.E.	7.07	6.09	6.63	6.83	-3.02	-4.2	-3.49	-3.32
STD. DEV.	1.35	1.4	1.38	1.37	1.15	4.59	1.44	1.31
VARIANCE	1.82	1.97	1.89	1.86	1.32	21.05	2.07	1.7
LCL	0.89	0.8	0.85	0.86	-0.78	-4.21	-1.08	-0.93
UCL	1.34	1.27	1.31	1.32	-0.4	-2.68	-0.6	-0.49
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
QUARTILE 3	1.8	1.8	1.8	1.8	0.5	0.59	0.59	0.59
DATA POINTS					140			

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 25, ALL DAYSHIFT DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	1.14	1.07	1.1	1.12	-0.56	-3.31	-0.8	-0.67
STANDARD ERROR	0.12	0.12	0.12	0.12	0.1	0.4	0.13	0.11
MEDIAN	0.4	0.4	0.4	0.4	-0.9	-0.92	-0.92	-0.92
STANDARD ERROR	0.12	0.12	0.12	0.12	0.26	0.24	0.24	0.24
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.78	0.72	0.75	0.76	-0.68	-3.04	-0.9	-0.79
HAMPEL	0.34	0.44	0.38	0.36	-0.67	-1.56	-0.8	-0.7
BWEIGHT	0.31	0.18	0.2	0.23	-0.59	-3.14	-0.81	-0.7
W STATISTIC	0.74	0.77	0.76	0.75	0.86	0.71	0.86	0.86
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	7	7	7	7	1.9	1.95	1.95	1.95
Z-SCORE	4.3	4.19	4.25	4.27	2.16	1.15	1.92	2
MINIMUM VALUE	0.1	0.0001	0.05	0.0707	-2.3	-9.21	-3	-2.65
Z-SCORE	-0.76	-0.78	-0.76	-0.76	-1.53	-1.29	-1.54	-1.53
SKEWNESS	1.72	1.61	1.67	1.69	0.38	-0.46	0.18	0.29
SKEWNESS/S.E.	8.05	7.51	7.79	7.9	1.76	-2.14	0.84	1.34
KURTOSIS	2.89	2.46	2.68	2.77	-1.29	-1.69	-1.48	-1.41
KURTOSIS/S.E.	6.76	5.76	6.26	6.47	-3.01	-3.95	-3.46	-3.29
STD. DEV.	1.36	1.41	1.39	1.38	1.14	4.57	1.43	1.3
VARIANCE	1.86	2	1.93	1.9	1.3	20.91	2.05	1.68
LCL	0.9	0.83	0.87	0.88	-0.76	-4.1	-1.04	-0.89
UCL	1.38	1.31	1.34	1.36	-0.36	-2.52	-0.55	-0.45
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
QUARTILE 3	1.8	1.8	1.8	1.8	0.5	0.59	0.59	0.59
DATA POINTS					131			

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 25, 1974 DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	2.23	2.22	2.22	2.22	0.26	-0.37	0.23	0.26
STANDARD ERROR	0.22	0.23	0.22	0.22	0.18	0.43	0.2	0.19
MEDIAN	2.15	2.15	2.15	2.15	0.7	0.77	0.77	0.77
STANDARD ERROR	0.26	0.26	0.26	0.26	0.12	0.12	0.12	0.12
MODE	0.1	0.0001	0.05	0.0707	-2.3	-9.21	-3	-2.65
TRIM (.15)	2.1	2.1	2.1	2.1	0.53	0.58	0.58	0.58
HAMPEL	2.09	2.09	2.21	2.09	0.7	0.81	0.79	0.77
BWEIGHT	2.1	2.09	2.09	2.1	0.81	0.88	0.88	0.88
W STATISTIC	0.94	0.95	0.94	0.94	0.8	0.59	0.78	0.79
SIG. LEVEL	0.018	0.032	0.024	0.021	0	0	0	0
MAXIMUM VALUE	7	7	7	7	1.9	1.95	1.95	1.95
Z-SCORE	2.96	2.94	2.95	2.95	1.3	0.75	1.19	1.23
MINIMUM VALUE	0.1	0.0001	0.05	0.0707	-2.3	-9.21	-3	-2.65
Z-SCORE	-1.32	-1.36	-1.34	-1.33	-2.02	-2.88	-2.24	-2.14
SKEWNESS	0.59	0.56	0.58	0.58	-1.11	-2.23	-1.25	-1.17
SKEWNESS/S.E.	1.74	1.66	1.7	1.72	-3.26	-6.58	-3.68	-3.45
KURTOSIS	0.07	0.04	0.05	0.06	-0.13	3.68	0.23	0
KURTOSIS/S.E.	0.1	0.06	0.08	0.09	-0.19	5.41	0.33	0.002
STD. DEV.	1.61	1.63	1.62	1.62	1.27	3.07	1.44	1.36
VARIANCE	2.61	2.65	2.63	2.62	1.61	9.42	2.07	1.86
LCL	1.78	1.76	1.77	1.77	-0.1	-1.22	-0.17	-0.12
UCL	2.68	2.67	2.67	2.67	0.61	0.49	0.63	0.64
QUARTILE 1	0.93	0.93	0.93	0.93	-0.08	-0.08	-0.08	-0.08
QUARTILE 3	3.08	3.08	3.08	3.08	1.08	1.12	1.12	1.12
DATA POINTS				52				

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 25, 1975 DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.82	0.82	0.82	0.82	-0.42	-0.64	-0.43	-0.42
STANDARD ERROR	0.1	0.1	0.1	0.1	0.11	0.29	0.12	0.12
MEDIAN	0.7	0.7	0.7	0.7	-0.3	-0.36	-0.36	-0.36
STANDARD ERROR	0.14	0.14	0.14	0.14	0.23	0.23	0.23	0.23
MODE					NOT UNIQUE			
TRIM (.15)	0.71	0.71	0.71	0.71	-0.44	-0.45	-0.45	-0.45
HAMPEL	0.7	0.7	0.7	0.7	-0.42	-0.39	-0.42	-0.42
BWEIGHT	0.69	0.69	0.69	0.69	-0.43	-0.39	-0.42	-0.42
W STATISTIC	0.86	0.88	0.87	0.86	0.94	0.53	0.96	0.96
SIG. LEVEL	0.0003	0.0015	0.0007	0.0005	0.1134	0	0.2315	0.24
MAXIMUM VALUE	2.2	2.2	2.2	2.2	0.7	0.79	0.79	0.79
Z-SCORE	2.46	2.43	2.25	2.45	1.76	0.86	1.71	1.76
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
Z-SCORE	-1.12	-1.43	-1.27	-1.2	-1.85	-5.15	-2.62	-2.23
SKEWNESS	1.04	0.97	1.01	1.02	0.06	-4.06	-0.2	0.01
SKEWNESS/S.E.	2.43	2.28	2.37	2.4	0.15	-9.53	0.48	0.012
KURTOSIS	0.09	0.05	0.06	0.07	-1.19	18.44	-0.4	-0.9
KURTOSIS/S.E.	0.1	0.06	0.08	0.09	-1.4	21.62	-0.47	-1.06
STD. DEV.	0.56	0.57	0.56	0.56	0.64	1.66	0.71	0.69
VARIANCE	0.31	0.33	0.32	0.32	0.41	2.76	0.51	0.47
LCL	0.62	0.61	0.62	0.62	-0.65	-1.23	-0.69	-0.67
UCL	1.02	1.02	1.02	1.02	-0.2	-0.05	-0.18	-0.17
QUARTILE 1	0.4	0.4	0.4	0.4	-0.9	-0.92	-0 92	-0.91
QUARTILE 3	1.15	1.15	1.15	1.15	0.05	0.14	0.14	0.13
DATA POINTS					33			

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 25, 1976 DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.22	0.05	0.14	0.17	-1.53	-8.02	-2.13	-1.84
STANDARD ERROR	0.01	0.017	0.014	0.012	0.03	0.39	0.06	0.04
MEDIAN	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
STANDARD ERROR	0	0	0	0	0	0	0	0
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
HAMPEL	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
BWEIGHT	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
W STATISTIC	0.34	0.45	0.42	0.4	0.36	0.43	0.45	0.43
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	0.6	0.6	0.6	0.6	-0.5	-0.51	-0.51	-0.51
Z-SCORE	5.34	4.19	4.68	4.94	4.66	2.6	3.73	4.15
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
Z-SCORE	-0.29	-0.38	-0.35	-0.33	-0.31	-0.413	-0.39	-0.37
SKEWNESS	4.04	2.62	3.12	3.45	3.48	1.94	2.36	2.71
SKEWNESS/S.E.	12.11	7.86	9.37	10.36	10.43	5.81	7.1	8.13
KURTOSIS	16.65	6.29	9.82	12.22	11.92	1.8	4.43	6.66
KURTOSIS/S.E.	24.99	9.43	14.73	18.33	17.89	2.7	6.65	9.99
STD. DEV.	0.07	0.13	0.1	0.09	0.22	2.89	0.43	0.32
VARIANCE	0.005	0.017	0.01	0.01	0.05	8.36	0.19	0.1
LCL	0.2	0.014	0.11	0.15	-1.59	-8.81	-2.25	-1.92
UCL	0.24	0.086	0.16	0.19	-1.47	-7.23	-2.01	-1.75
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
QUARTILE 3	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
DATA POINTS				54				

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 30, ALL DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.25	0.12	0.19	0.22	-1.43	-6.39	-1.9	-1.67
STANDARD ERROR	0.013	0.02	0.016	0.015	0.03	0.37	0.06	0.04
MEDIAN	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
STANDARD ERROR	0	0	0	0	0	0	0	0
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.22	0.07	0.14	0.17	-1.53	-6.99	-2.04	-1.79
HAMPEL	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
BWEIGHT	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
W STATISTIC	0.46	0.65	0.59	0.55	0.57	0.61	0.69	0.67
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	1.3	1.3	1.3	1.3	0.2	0.26	0.26	0.26
Z-SCORE	7.48	5.68	6.53	6.93	4.88	1.72	3.54	4.18
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
Z-SCORE	-0.39	-0.6	-0.52	-0.48	-0.5	-0.73	-0.67	-0.62
SKEWNESS	4.69	2.37	3.33	3.86	2.4	0.64	1.2	1.62
SKEWNESS/S.E.	20	10.09	14.2	16.47	10.24	2.72	5.1	6.92
KURTOSIS	28.23	8.39	15.87	20.45	6.21	-1.59	0.42	2.3
KURTOSIS/S.E.	60.2	17.88	33.83	43.58	13.24	-3.38	0.9	4.97
STD. DEV.	0.14	0.21	0.17	0.16	0.34	3.87	0.61	0.46
VARIANCE	0.02	0.04	0.03	0.02	0.11	15.01	0.37	0.21
LCL	0.23	0.08	0.16	0.19	-1.5	-7.13	-2.02	-1.76
UCL	0.28	0.16	0.22	0.25	-1.37	-5.66	-1.78	-1.58
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
QUARTILE 3	0.3	0.3	0.3	0.3	-1.2	-1.2	-1.22	-1.2
DATA POINTS					109			

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 30 DAYSHIFT DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.26	0.13	0.19	0.22	-1.43	6.39	-1.89	-1.67
STANDARD ERROR	0.014	0.02	0.017	0.015	0.034	0.38	0.061	0.046
MEDIAN	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
STANDARD ERROR	0	0	0	0	0	0	0	0
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.22	0.073	0.14	0.17	-1.54	-6.98	-2.04	-1.79
HAMPEL	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
BWEIGHT	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
W STATISTIC	0.46	0.65	0.59	0.55	0.57	0.61	0.69	0.67
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	1.3	1.3	1.3	1.3	0.2	0.26	0.26	0.26
Z-SCORE	7.29	5.59	6.4	6.77	4.78	1.71	3.51	4.13
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
Z-SCORE	-0.39	-0.6	-0.52	-0.47	-0.5	-0.73	-0.67	-0.62
SKEWNESS	4.59	2.37	3.3	3.81	2.38	0.64	1.21	1.64
SKEWNESS/S.E.	19	9.83	13.69	15.79	9.86	2.63	5	6.78
KURTOSIS	26.78	8.27	15.37	19.64	5.96	-1.59	0.45	2.33
KURTOSIS/S.E.	55.48	17.14	31.84	40.68	12.35	-3.3	0.93	4.82
STD. DEV.	0.14	0.21	0.17	0.16	0.34	3.88	0.61	0.47
VARIANCE	0.02	0.04	0.03	0.025	0.12	15.05	0.38	0.22
LCL	0.23	0.08	0.16	0.19	-1.5	-7.14	-2.01	-1.76
UCL	0.28	0.17	0.22	0.25	-1.36	-5.63	-1.77	-1.58
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
QUARTILE 3	0.2	0.3	0.3	0.3	-1.2	-1.2	-1.2	-1.2
DATA POINTS				103				

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 30, 1975 DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.28	0.21	0.24	0.26	-1.32	-4.13	-1.59	-1.46
STANDARD ERROR	0.017	0.027	0.02	0.02	0.05	0.56	0.09	0.07
MEDIAN	0.2	0.2	0.2	0.2	-1.6	-1.61	-1.61	-1.61
STANDARD ERROR	0.03	0.03	0.03	0.03	0.12	0.12	0.12	0.12
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.25	0.19	0.22	0.23	-1.4	-3.77	-1.63	-1.52
HAMPEL	0.2	0.2	0.23	0.23	-1.6	-1.17	-1.59	-1.49
BWEIGHT	0.2	0.2	0.23	0.24	-1.6	-1.18	-1.59	-1.47
W STATISTIC	0.69	0.85	0.82	0.79	0.75	0.65	0.84	0.85
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	0.7	0.7	0.7	0.7	-0.3	-0.36	-0.36	-0.36
Z-SCORE	3.48	2.59	3.01	3.2	2.83	0.96	2	2.35
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
Z-SCORE	-0.68	-1.09	-0.96	-0.87	-0.78	-1.3	-1.16	-1.05
SKEWNESS	1.9	0.51	1.1	1.42	1.18	-0.52	0.08	0.48
SKEWNESS/S.E.	5.43	1.45	3.14	4.07	3.36	-1.48	0.24	1.38
KURTOSIS	3.64	-0.3	1.08	2.01	0.65	-1.74	-1.3	-0.8
KURTOSIS/S.E.	5.21	-0.43	1.55	2.87	0.93	-2.49	-1.86	-1.15
STD. DEV.	0.12	0.19	0.15	0.14	0.36	3.92	0.61	0.47
VARIANCE	0.014	0.04	0.02	0.02	0.13	15.4	0.38	0.22
LCL	0.25	0.15	0.2	0.22	-1.42	-5.25	-1.77	-1.6
UCL	0.32	0.26	0.29	0.3	-1.22	-3	-1.41	-1.33
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
QUARTILE 3	0.3	0.3	0.3	0.3	-1.2	-1.2	-1.2	-1.2
DATA POINTS					49			

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 30, 1976 DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.2	.014	0.11	0.15	-1.59	-8.78	-2.25	-1.93
STANDARD ERROR	0.002	0.01	0.006	0.005	0.01	0.3	0.04	0.02
MEDIAN	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
STANDARD ERROR	0	0	0	0	0	0	0	0
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
HAMPEL	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
BWEIGHT	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
W STATISTIC	0.17	0.26	0.25	0.24	0.17	0.25	0.26	0.25
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	0.3	0.3	0.3	0.3	-1.2	-1.2	-1.2	-1.2
Z-SCORE	5.83	4.83	5.2	5.47	5.83	4.18	4.91	5.29
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.211	-2.3	-1.95
Z-SCORE	-0.17	-0.23	-0.23	-0.22	-0.17	-0.24	-0.23	-0.22
SKEWNESS	5.51	3.97	4.33	4.71	5.51	3.72	4.03	4.44
SKEWNESS/S.E.	13.5	9.72	10.6	11.5	13.5	9.12	9.87	10.89
KURTOSIS	29.16	14.76	18.42	22.13	29.6	12.23	15.41	19.48
KURTOSIS/S.E.	35.72	18.08	22.56	27.1	35.72	14.97	18.87	23.86
STD. DEV.	0.02	0.059	0.04	0.03	0.07	1.81	0.21	0.14
VARIANCE	0.002	0.003	0.001	0.001	0.004	3.29	0.05	0.02
LCL	0.2	-0.006	0.1	0.14	-1.61	-9.39	-2.33	-1.97
UCL	0.21	0.03	0.12	0.16	-1.57	-8.16	-2.18	-1.88
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
QUARTILE 3	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
DATA POINTS					36			

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 30, 1977 DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.22	0.05	0.14	0.18	-1.51	-8.09	-2.12	-1.82
STANDARD ERROR	0.018	0.03	0.025	0.02	0.05	0.62	0.1	0.078
MEDIAN	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
STANDARD ERROR	0	0	0	0	0	0	0	0
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
HAMPEL	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
BWEIGHT	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
W STATISTIC	0.35	0.42	0.4	0.39	0.39	0.42	0.43	0.42
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	0.6	0.6	0.6	0.6	-0.5	-0.51	-0.51	-0.51
Z-SCORE	4.22	3.63	3.89	4.02	3.97	2.62	3.33	3.58
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
Z-SCORE	-0.31	-0.36	-0.35	-0.34	-0.34	-0.39	-0.38	-0.37
SKEWNESS	3.45	2.53	2.85	3.06	2.99	1.98	2.26	2.47
SKEWNESS/S.E.	6.6	4.84	5.46	5.86	5.72	3.8	4.33	4.73
KURTOSIS	11.5	5.54	7.67	9.01	8.56	2.05	3.81	5.17
KURTOSIS/S.E.	11	5.31	7.34	8.63	8.2	1.96	3.65	4.95
STD. DEV.	0.09	0.15	0.12	0.11	0.26	2.9	0.48	0.37
VARIANCE	0.01	0.02	0.014	0.011	0.07	8.39	0.23	0.13
LCL	0.19	-0.01	0.08	0.13	-1.63	-9.37	-2 34	-1.98
UCL	0.27	0.12	0.19	0.22	-1.4	-6.8	-1.91	-1.66
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
QUARTILE 3	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
DATA POINTS					22			

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 40, ALL DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.2	0.03	0.12	0.15	-1.6	-8.07	-2.2	-1.9
STANDARD ERROR	0	0.016	0.009	0.004	0	0.62	0.06	0.028
MEDIAN	0.2	0.0001	0.1	0.141	-1.6	-9.21	-2.3	-1.95
STANDARD ERROR	0	0	0	0	0	0	0	0
MODE	0.2	0.0001	0.1	0.141	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.2	0.0001	0.1	0.141	-1.6	-9.21	-2.3	-1.96
HAMPEL	0.2	0.0001	0.1	0.141	-1.6	-9.21	-2.3	-1.96
BWEIGHT	0.2	0.0001	0.1	0.141	-1.6	-9.21	-2.3	-1.96
W STATISTIC	0	0.43	0.43	0.43	0	0.43	0.43	0.43
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	0.2	0.2	0.2	0.2	-1.6	-1.61	-1.61	-1.61
Z-SCORE	0	2.32	2.32	2.3	0	2.32	2.32	2.32
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
Z-SCORE	0	-0.41	-0.41	-0.41	0	-0.41	-0.41	-0.41
SKEWNESS	0	1.82	1.82	1.82	0	1.82	1.82	1.82
SKEWNESS/S.E.	0	3.31	3.31	3.31	0	3.31	3.31	3.31
KURTOSIS	0	1.37	1.37	1.37	0	1.37	1.37	1.37
KURTOSIS/S.E.	0	1.25	1.25	1.25	0	1.25	1.25	1.25
STD. DEV.	0	0.07	0.04	0.021	0	2.78	0.25	0.13
VARIANCE	0	0.005	0.001	0.004	0	7.75	0.06	0.016
LCL	0.2	-0.004	0.1	0.14	-1.6	-9.37	-2.32	-1.96
UCL	0.2	0.064	0.13	0.16	-1.6	-6.77	-2 08	-1.84
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
QUARTILE 3	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
DATA POINTS					20			

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 45, ALL DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.42	0.28	0.35	0.38	-1.24	-5.97	-1.67	-1.46
ST. ERROR	0.043	0.046	0.04	0.04	0.059	0.34	0.08	0.069
MEDIAN	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
STANDARD ERROR	0	0	0	0	0	0	0	0
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.26	0.11	0.19	0.22	-1.41	-6.59	-1.89	1.66
HAMPEL	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
BWEIGHT	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
W STATISTIC	0.53	0.56	0.54	0.54	0.75	0.64	0.77	0.77
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	3.3	3.3	3.3	3.3	1.1	1.19	1.19	1.19
Z-SCORE	5.5	5.36	5.51	5.52	3.22	1.71	2.91	3.12
MINIMUM VALUE	0.1	0.0001	0.05	0.0707	-2.3	-9.21	-3	-2.65
Z-SCORE	-0.6	-0.5	-0.56	-0.58	-1.47	-.77	-1.34	-1.4
SKEWNESS	3.33	3.11	3.3	3.32	1.36	0.54	1.07	1.24
SKEWNESS/S.E.	16.69	15.6	16.55	16.67	6.8	2.71	5.39	6.23
KURTOSIS	12.11	10.96	12.21	12.32	1.26	-1.66	0.1	0.71
KURTOSIS/S.E.	30.37	27.48	30.62	30.9	3.17	-4.16	0.24	1.77
STD. DEV.	0.52	0.56	0.54	0.53	0.73	4.2	0.98	0.85
VARIANCE	0.27	0.32	0.29	0.28	0.53	17.62	0.97	0.72
LCL	0.33	0.19	0.26	0.29	-1.35	-6.65	-1.83	-1.6
UCL	0.5	0.37	0.43	0.46	-1.12	-5.3	-1.51	-1.32
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
QUARTILE 3	0.4	0.4	0.4	0.4	-0.9	-0.92	-0.92	-0.92
DATA POINTS					151			

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 45, ALL DAYSHIFT DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.39	0.27	0.33	0.36	-1.28	-6.06	-1.72	-1.51
STANDARD ERROR	0.04	0.047	0.045	0.04	0.06	0.35	0.08	0.07
MEDIAN	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
STANDARD ERROR	0	0	0	0	0	0	0	0
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.24	0.1	0.17	0.2	-1.45	-6.71	-1.96	-1.71
HAMPEL	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
BWEIGHT	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
W STATISTIC	0.49	0.55	0.52	0.51	0.73	0.64	0.75	0.75
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	3.3	3.3	3.3	3.3	1.1	1.19	1.19	1.19
Z-SCORE	5.66	5.34	5.51	5.57	3.41	1.74	3.02	3.25
MINIMUM VALUE	0.1	0.0001	0.05	0.0707	-2.3	-9.21	-3	-2.65
Z-SCORE	-0.57	-0.48	-0.53	-0.55	-1.46	-0.76	-1.31	-1.38
SKEWNESS	3.65	3.18	3.43	3.53	1.51	0.59	1.21	1.4
SKEWNESS/S.E.	17.91	15.6	16.81	17.28	7.39	2.87	5.95	6.85
KURTOSIS	14.42	11.32	12.89	13.54	1.95	-1.61	0.5	1.26
KURTOSIS/S.E.	35.32	27.73	31.59	33.17	4.78	-3.94	1.22	3.09
STD. DEV.	0.51	0.57	0.54	0.53	0.7	4.17	0.97	0.83
VARIANCE	0.26	0.32	0.29	0.28	0.49	17.4	0.94	0.69
LCL	0.31	0.18	0.24	0.27	-1.39	-6.75	-1.88	-1.64
UCL	0.48	0.37	0.42	0.44	-1.16	-5.38	-1.56	-1.37
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
QUARTILE 3	0.38	0.38	0.38	0.38	-0.98	-0.99	-0.99	-0.99
DATA POINTS					144			

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 45, 1974 DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.68	0.65	0.66	0.67	-1.05	-3.25	-1.28	-1.17
STANDARD ERROR	0.2	0.2	0.2	0.2	0.28	0.98	0.34	0.31
MEDIAN	0.5	0.5	0.5	0.5	-0.6	-0.69	-0.69	-0.69
STANDARD ERROR	0.2	0.23	0.22	0.21	0.61	2.59	0.8	0.7
MODE	0.1	0.0001	0.05	0.01	-2.3	-9.21	3	-2.65
TRIM (.15)	0.45	0.42	0.44	0.44	-1.16	-2.82	-1.35	-1.27
HAMPEL	0.46	0.42	0.44	0.44	-1.05	-1.4	-1.28	-1.17
BWEIGHT	0.41	0.38	0.39	0.4	-1.07	-0.48	-1.29	-1.19
W STATISTIC	0.68	0.72	0.7	0.7	0.82	0.74	0.86	0.85
SIG. LEVEL	0	0	0	0	0.0017	0.0001	0.0084	0.006
MAXIMUM VALUE	3.3	3.3	3.3	3.3	1.1	1.19	1.19	1.19
Z-SCORE	3.05	3	3.03	3.04	1.77	1.05	1.68	1.77
MINIMUM VALUE	0.1	0.0001	0.05	0.0707	-2.3	-9.21	-3	-2.65
Z-SCORE	-0.67	-0.73	-0.7	-0.69	-1.03	-1.4	-1.16	-1.1
SKEWNESS	1.86	1.76	1.81	1.83	0.19	-0.62	0.04	0.14
SKEWNESS/S.E.	3.3	3.13	3.22	3.25	0.33	-1.1	0.07	0.25
KURTOSIS	2.69	2.41	2.55	2.61	-1.56	-1.56	-1.6	-1.56
KURTOSIS/S.E.	2.4	2.14	2.27	2.32	-1.39	-1.39	-1.43	-1.39
STD. DEV.	0.86	0.88	0.87	0.87	1.21	4.25	1.47	1.34
VARIANCE	0.74	0.78	0.76	0.75	1.48	18.07	2.16	1.8
LCL	0.26	0.22	0.24	0.25	-1.64	-5.29	-1.99	-1.82
UCL	1.09	1.07	1.08	1.09	-0.47	-1.2	-0.57	-0.53
QUARTILE 1	0.1	0.0001	0.05	0.07	-2.3	-9.21	-3	-2.65
QUARTILE 3	0.8	0.8	0.8	0.8	-0.2	-0.22	-0.22	-0.22
DATA POINTS					19			

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 45, 1975 DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.55	0.46	0.51	0.52	-0.96	-4.23	-1.27	-1.12
STANDARD ERROR	0.08	0.09	0.08	0.08	0.1	0.59	0.14	0.13
MEDIAN	0.25	0.25	0.25	0.25	-1.4	-1.41	-1.41	-1.41
STANDARD ERROR	0.06	0.12	0.09	0.07	0.2	2.39	0.4	0.3
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.36	0.29	0.33	0.34	-1.13	-4.17	-1.42	-1.28
HAMPEL	0.23	0.27	0.26	0.26	-1.4	-3.02	-1.32	-1.25
BWEIGHT	0.22	0.26	0.26	0.21	-1.46	-4.17	-1.3	-1.18
W STATISTIC	0.64	0.73	0.69	0.67	0.79	0.7	0.84	0.82
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	3.1	3.1	3.1	3.1	1.1	1.13	1.13	1.13
Z-SCORE	4.22	3.99	4.11	4.15	2.67	1.22	2.26	2.45
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
Z-SCORE	-0.58	-0.7	-0.65	-0.62	-0.82	-1.14	-0.98	-0.91
SKEWNESS	2.34	2	2.17	2.25	0.9	-0.23	0.49	0.71
SKEWNESS/S.E.	7.16	6.1	6.65	6.86	2.75	-0.71	1.49	2.16
KURTOSIS	5.45	4.03	4.74	5.03	-0.35	-1.92	-1.06	-0.71
KURTOSIS/S.E.	8.32	6.15	7.24	7.69	-0.53	-2.93	-1.62	-1.09
STD. DEV.	0.6	0.66	0.63	0.62	0.77	4.39	1.06	0.92
VARIANCE	0.37	0.44	0.4	0.38	0.6	19.27	1.13	0.85
LCL	0.39	0.29	0.34	0.36	-1.17	-5.4	-1.55	-1.36
UCL	0.71	0.64	0.68	0.69	-0.76		-0.98	-0.87
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
QUARTILE 3	0.6	0.6	0.6	0.6	-0.5	-0.51	-0.51	-0.51
DATA POINTS					56			

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 45, 1976 DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.21	0.03	0.12	0.16	-1.55	-8.42	-2.19	-1.87
STANDARD ERROR	0.007	0.01	0.01	0.009	-0.02	0.31	0.047	0.034
MEDIAN	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
STANDARD ERROR	0	0	0	0	0	0	0	0
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
HAMPEL	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
BWEIGHT	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
W STATISTIC	0.32	0.35	0.35	0.34	0.32	0.34	0.35	0.35
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	0.5	0.5	0.5	0.5	-0.6	-0.69	-0.69	-0.69
Z-SCORE	5.3	4.29	4.68	4.9	5.07	3.19	4	4.31
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
Z-SCORE	-0.27	-.31	-0.3	-0.29	.28	-0.32	-0.32	-0.31
SKEWNESS	3.83	3.02	3.28	3.47	3.63	2.67	2.93	3.12
SKEWNESS/S.E.	12.32	9.71	10.55	11.15	11.68	8.58	9.41	10.02
KURTOSIS	14.48	7.92	9.96	11.42	12.7	5.22	7.13	8.51
KURTOSIS/S.E.	23.28	12.73	16.01	18.36	20.42	8.4	11.45	13.67
STD. DEV.	0.05	0.11	0.08	0.07	0.19	2.42	0.37	0.27
VARIANCE	0.003	0.01	0.006	0.005	0.04	5.87	0.14	0.07
LCL	0.2	0.006	0.1	0.14	-1.6	-9.04	-2.28	-1.94
UCL	0.23	0.061	0.14	0.18	-1.5	-7.81	-2.09	-1.8
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
QUARTILE 3	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
DATA POINTS				62				

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 45, 1977 DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.24	0.14	0.19	0.21	-1.44	-5.255	-1.8	-1.62
STANDARD ERROR	0.019	0.05	0.03	0.026	0.07	1.2	0.16	0.11
MEDIAN	0.2	0.1	0.15	0.17	-1.6	-5.41	-1.96	-1.78
STANDARD ERROR	0.029	0.09	0.06	0.046	0.11	2.3	0.32	0.22
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.23	0.13	0.18	0.2	-1.5	-5.3	-1.85	-1.68
HAMPEL	0.2	0.13	0.16	0.17	-1.6	-5.25	-1.83	-1.73
BWEIGHT	0.2	0.14	0.19	0.16	-1.6	-5.25	-1.81	-1.64
W STATISTIC	0.67	0.8	0.8	0.79	0.68	0.68	0.79	0.79
SIG. LEVEL	0.0003	0.0069	0.0091	0.0055	0.0003	0.0003	0.0059	0.0071
MAXIMUM VALUE	0.4	0.4	0.4	0.4	-0.9	-0.92	-0.92	-0.92
Z-SCORE	2.37	1.65	1.92	2.09	2.2	1.05	1.58	1.8
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-0.23	-1.96
Z-SCORE	-0.62	-0.91	-0.85	-0.79	-0.64	-0.96	-0.91	-0.85
SKEWNESS	1.11	0.27	0.54	0.74	0.94	0.01	0.26	0.49
SKEWNESS/S.E.	1.57	0.39	0.76	1.05	1.33	0.007	0.37	0.69
KURTOSIS	-0.13	-1.78	-1.36	-0.99	-0.72	-2.15	-1.83	-1.53
KURTOSIS/S.E.	-0.09	-1.26	-0.96	-0.7	-0.51	-1.52	-1.3	-1.08
STD. DEV.	0.07	0.16	0.11	0.09	0.25	4.14	0.56	0.39
VARIANCE	0.004	0.02	0.01	0.008	0.06	17.13	0.31	0.15
LCL	0.2	0.04	0.12	0.16	-1.6	-7.88	-2.15	-1.87
UCL	0.28	0.24	0.26	0.27	-1.28	-2.62	-1.44	-1.37
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
QUARTILE 3	0.3	0.3	0.3	0.3	-1.2	-1.2	-1.2	-1.2
DATA POINTS				12				

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 50, ALL DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.21	0.06	0.13	0.17	-1.54	-7.56	-2.1	-1.83
STANDARD ERROR	0.005	0.017	0.01	0.009	0.021	0.49	0.06	0.04
MEDIAN	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
STANDARD ERROR	0	0	0	0	0	0	0	0
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.2	0.017	0.11	0.15	-1.6	-8.57	-2.24	-1.93
HAMPEL	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
BWEIGHT	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
W STATISTIC	0.41	0.52	0.51	0.5	0.41	0.5	0.52	0.51
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	0.3	0.3	0.3	0.3	-1.2	-1.2	-1.2	-1.2
Z-SCORE	2.45	2.18	2.29	2.36	2.45	1.96	2.2	2.3
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
Z-SCORE	-0.4	-0.5	-0.49	-0.47	-0.4	-0.51	-0.5	-0.48
SKEWNESS	2.01	1.5	1.65	1.78	2.01	1.38	1.53	1.68
SKEWNESS/S.E.	5.38	4.01	4.4	4.76	5.38	3.7	4.09	4.51
KURTOSIS	2.08	0.4	0.95	1.41	2.08	-0.09	0.5	1.09
KURTOSIS/S.E.	2.79	0.54	1.27	1.88	2.79	-0.12	0.68	1.46
STD. DEV.	0.035	0.11	0.07	0.06	0.14	3.24	0.41	0.27
VARIANCE	0.001	0.013	0.005	0.003	0.02	10.51	0.17	0.07
LCL	0.2	0.021	0.11	0.15	-1.59	-8.56	-2.22	-1.91
UCL	0.22	0.09	0.16	0.18	-1.5	-6.57	-1.98	-1.74
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
QUARTILE 3	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
DATA POINTS					43			

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 50, ALL DAYSHIFT DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.22	0.06	0.14	0.17	-1.54	-7.63	-2.1	-1.83
STANDARD ERROR	0.006	0.018	0.012	0.009	0.023	0.51	0.065	0.044
MEDIAN	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
STANDARD ERROR	0	0	0	0	0	0	0	0
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.2	0.014	0.11	0.15	-1.6	-8.67	-2.25	-1.93
HAMPEL	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
BWEIGHT	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
W STATISTIC	0.43	0.5	0.5	0.49	0.43	0.49	0.5	0.5
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	0.3	0.3	0.3	0.3	-1.2	-1.2	-1.2	-1.2
Z-SCORE	2.35	2.17	2.24	2.29	2.35	2	2.18	2.26
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
Z-SCORE	-0.42	-0.49	-0.48	-0.46	-0.42	-0.49	-0.48	-0.47
SKEWNESS	1.89	1.54	1.64	1.74	1.89	1.45	1.56	1.67
SKEWNESS/S.E.	4.87	3.97	4.24	4.47	4.87	3.73	4.02	4.31
KURTOSIS	1.6	0.48	0.87	1.17	1.6	0.1	0.56	0.96
KURTOSIS/S.E.	2.07	0.62	1.12	1.52	2.07	0.13	0.72	1.25
STD. DEV.	0.036	0.11	0.07	0.057	0.14	3.2	0.41	0.28
VARIANCE	0.001	0.013	0.005	0.003	0.02	10.26	0.17	0.08
LCL	0.2	.021	0.11	0.15	-1.58	-8.65	-2.23	-1.91
UCL	0.23	0.09	0.16	0.19	-1.49	-6.6	-1.97	-1.74
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
QUARTILE 3	0.2	0.0001	0.1	0.14	-1.6	9.21	-2.3	-1.96
DATA POINTS					40			

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 65, ALL DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.6	0.5	0.55	0.57	-1.02	-4.52	-1.34	-1.18
STANDARD ERROR	0.11	0.11	0.11	0.11	0.08	0.41	0.1	0.09
MEDIAN	0.2	0.2	0.2	0.2	-1.6	-1.61	-1.61	-1.61
STANDARD ERROR	0.03	0.09	0.06	0.05	0.12	2.31	0.32	0.22
MODE	0.2	.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.33	0.24	0.29	0.31	-1.21	-4.58	-1.53	-1.38
HAMPEL	0.2	0.21	0.19	0.19	-1.6	-3.69	-1.47	-1.52
BWEIGHT	0.2	0.16	0.14	0.16	-1.6	-4.49	-1.43	-1.32
W STATISTIC	0.39	0.44	0.42	0.41	0.74	0.71	0.82	0.8
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	9.7	9.7	9.7	9.7	2.2	2.27	2.27	2.27
Z-SCORE	8.01	7.87	7.96	7.99	3.95	1.55	3.37	3.67
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
Z-SCORE	-0.35	-0.43	-0.39	-0.38	-0.72	-1.07	-0.9	-0.82
SKEWNESS	5.77	5.5	5.67	5.72	1.48	-0.11	0.9	1.19
SKEWNESS/S.E.	25.36	24.21	24.95	25.16	6.49	-0.47	3.95	5.25
KURTOSIS	38.42	35.84		38	2.03	-1.91	0.2	1.04
KURTOSIS/S.E.	84.47	78.79	82.41	83.47	4.47	-4.2	0.43	2.29
STD. DEV.	1.13	1.17	1.15	1.14	0.81	4.36	1.07	0.94
VARIANCE	1.29	1.37	1.32	1.31	0.66	19.1	1.15	0.89
LCL	0.39	0.28	0.34	0.36	-1.17	-5.32	-1.54	-1.36
UCL	0.81	0.71	0.76	0.78	-0.87	-3.71	-1.14	-1.01
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
QUARTILE 3	0.58	0.5	0.58	0.58	-0.53	-0.69	-0.56	-0.56
DATA POINTS				116				

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 65, ALL DAYSHIFT DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.56	0.47	0.52	0.54	-1.04	-4.44	-1.36	-1.2
STANDARD ERROR	0.1	0.11	0.11	0.11	0.08	0.43	0.1	0.09
MEDIAN	0.2	0.2	0.2	0.2	-1.6	-1.61	-1.61	-1.61
STANDARD ERROR	0.029	0.09	0.06	0.05	0.12	2.31	0.32	0.22
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.33	0.24	0.28	0.3	-1.22	-4.47	-1.54	-1.39
HAMPEL	0.2	0.21	0.2	0.19	-1.6	-3.5	-1.48	-1.51
BWEIGHT	0.2	0.2	0.13	0.16	-1.6	-4.41	-1.44	-1.33
W STATISTIC	0.37	0.44	0.4	0.39	0.75	0.7	0.83	0.81
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	9.7	9.7	9.7	9.7	2.2	2.27	2.27	2.27
Z-SCORE	8.59	8.4	8.5	8.54	4.17	1.55	3.48	3.82
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
Z-SCORE	-0.34	-0.43	-0.39	-0.37	-0.72	-1.1	-0.9	-0.83
SKEWNESS	6.67	6.25	6.47	6.55	1.47	-0.15	0.87	1.17
SKEWNESS/S.E.	27.62	25.89	26.81	27.16	6.07	-0.63	3.58	4.87
KURTOSIS	51.6	47.02	49.43	50.36	2.14	-1.91	0.14	1.06
KURTOSIS/S.E.	106.89	97.4	102.39	104.32	4.43	-3.95	0.28	2.2
STD. DEV.	1.06	1.1	1.08	1.07	0.78	4.34	1.04	0.91
VARIANCE	1.13	1.21	1.17	1.15	0.6	18.88	1.09	0.83
LCL	0.35	0.26	0.31	0.33	-1.19	-5.29	-1.56	-1.38
UCL	0.77	0.69	0.73	0.75	-0.89	-3.6	-1.15	-1.03
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
QUARTILE 3	0.5	0.5	0.5	0.5	-0.6	-0.69	-0.69	-0.69
DATA POINTS				103				

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO
DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 65, 1975 DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	1.1	1.08	1.09	1.09	-0.41	-1.24	-0.49	-0.45
STANDARD ERROR	0.25	0.25	0.25	0.25	0.13	0.43	0.15	0.14
MEDIAN	0.6	0.6	0.6	0.6	-0.45	-0.53	-0.52	-0.52
STANDARD ERROR	0.12	0.12	0.12	0.12	0.2	0.2	0.2	0.2
MODE				NOT UNIQ				
TRIM (.15)	0.69	0.69	0.69	0.69	-0.48	-0.49	-0.49	-0.49
HAMPEL	0.64	0.63	0.63	0.63	-0.51	-0.35	-0.5	-0.5
BWEIGHT	0.65	0.62	0.64	0.64	-0.52	-0.38	-0.52	-0.52
W STATISTIC	0.52	0.54	0.53	0.52	0.92	0.62	0.95	0.95
SIG. LEVEL	0	0	0	0	0.0058	0	0.092	0.057
MAXIMUM VALUE	9.7	9.7	9.7	9.7	2.2	2.27	2.27	2.27
Z-SCORE	5.13	5.11	5.12	5.13	2.98	1.2	2.7	2.84
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
Z-SCORE	-0.54	-0.64	-0.59	-0.57	-1.36	-2.73	-1.78	-1.57
SKEWNESS	3.64	3.58	3.62	3.63	0.82	-2.07	0.28	0.57
SKEWNESS/S.E.	10.09	9.93	10.02	10.05	2.26	-5.74	0.77	1.58
KURTOSIS	14.18	13.85	14.03	14.09	0.67	3.11	0.29	0.37
KURTOSIS/S.E.	19.64	19.18	19.42	19.51	0.93	4.3	0.4	0.52
STD. DEV.	1.68	16.9	1.68	1.68	0.88	2.93	1.02	0.96
VARIANCE	2.81	2.85	2.83	2.82	0.77	8.56	1.04	0.92
LCL	0.6	0.58	0.59	0.6	-0.67	-2.11	-0.79	-0.73
UCL	1.6	1.58	1.59	1.59	-0.15	-0.37	-0.18	-0.17
QUARTILE 1	0.3	0.3	0.3	0.3	-1.2	-1.2	-1.2	-1.2
QUARTILE 3	1.1	1.1	1.1	1.1	0	0.1	0.1	0.1
DATA POINTS					46			

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO
DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 65, 1976 DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.23	0.09	0.16	0.19	-1.5	-6.9	-2	-1.75
STANDARD ERROR	0.01	0.02	0.018	0.016	0.04	0.49	0.07	0.05
MEDIAN	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
STANDARD ERROR	0	0	0	0	0	0	0	0
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.2	0.04	0.12	0.15	-1.6	-7.68	-2.16	-1.89
HAMPEL	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
BWEIGHT	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
W STATISTIC	0.39	0.62	0.55	0.5	0.42	0.58	0.63	0.59
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	0.8	0.8	0.8	0.8	-0.2	-0.22	-0.22	-0.22
Z-SCORE	5.57	4.22	4.86	5.17	4.49	1.83	3.36	3.91
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
Z-SCORE	-0.32	-0.54	-0.47	-0.42	-0.36	-0.63	-0.57	-0.52
SKEWNESS	3.86	2.07	2.84	3.27	2.94	0.91	1.58	2.11
SKEWNESS/S.E.	11.69	6.27	8.59	9.9	8.89	2.75	4.77	6.39
KURTOSIS	16.31	4.51	9.1	11.93	8.2	-1.17	1.51	3.96
KURTOSIS/S.E.	24.69	6.83	13.77	18.07	12.42	-1.78	2.28	5.99
STD. DEV.	0.1	0.17	0.13	0.12	0.29	3.65	0.53	0.39
VARIANCE	0.01	0.03	0.02	0.014	0.08	13.32	0.28	0.15
LCL	0.21	0.05	0.13	0.16	-1.57	-7.89	-2.14	-1.86
UCL	0.26	0.14	0.2	0.22	-1.42	-5.91	-1.86	-1.65
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
QUARTILE 3	0.2	0.2	0.2	0.2	-1.6	-1.61	-1.61	-1.61
DATA POINTS					55			

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 70, ALL DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.33	0.24	0.29	0.31	-1.24	-4.8	-1.58	-1.42
STANDARD ERROR	0.037	0.05	0.04	0.04	0.08	0.62	0.12	0.09
MEDIAN	0.2	0.2	0.2	0.2	-1.6	-1.61	-1.61	-1.61
STANDARD ERROR	0.029	0.09	0.06	0.05	0.12	2.31	0.32	0.22
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.26	0.17	0.22	0.24	-1.37	-4.82	-1.7	-1.54
HAMPEL	0.2	0.19	0.21	0.21	-1.6	-2.42	-1.6	-1.53
BWEIGHT	0.2	0.19	0.21	0.16	-1.6	-0.95	-1.61	-1.48
W STATISTIC	0.59	0.76	0.7	0.66	0.74	0.68	0.82	0.81
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	1.6	1.6	1.6	1.6	0.4	0.47	0.47	0.47
Z-SCORE	5.06	4.33	4.7	4.85	3.26	1.26	2.63	2.99
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
Z-SCORE	-0.53	-0.77	-0.67	-0.62	-0.72	-1.05	-0.93	-0.86
SKEWNESS	3.14	1.98	2.54	2.79	1.31	-0.11	0.56	0.9
SKEWNESS/S.E.	8.61	5.41	6.96	7.65	3.58	-0.29	1.55	2.47
KURTOSIS	12.12	5.56	8.52	9.96	0.92	-2	-0.84	-0.05
KURTOSIS/S.E.	16.6	7.61	11.66	13.64	1.26	-2.74	-1.15	-0.07
STD. DEV.	0.25	0.31	0.28	0.27	0.5	4.19	0.78	0.63
VARIANCE	0.06	0.1	0.08	0.07	0.25	17.54	0.61	0.4
LCL	0.26	0.15	0.2	0.23	-1.39	-6.06	-1.81	-1.61
UCL	0.41	0.33	0.37	0.39	-1.09	-3.54	-1.34	-1.23
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
QUARTILE 3	0.4	0.4	0.4	0.4	-0.9	-0.92	-0.92	-0.92
DATA POINTS					45			

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 70, ALL DAYSHIFT DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.31	0.22	0.27	0.29	-1.25	-4.79	-1.59	-1.43
STANDARD ERROR	0.03	0.04	0.03	0.03	0.07	0.65	0.11	0.09
MEDIAN	0.2	0.2	0.2	0.2	-1.6	-1.61	-1.61	-1.61
STANDARD ERROR	0.03	0.09	0.06	0.46	0.12	2.31	0.32	0.22
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.26	0.18	0.22	0.24	-1.36	-4.78	-1.68	-1.53
HAMPEL	0.2	0.2	0.22	0.21	-1.6	-1.95	-1.6	-1.51
BWEIGHT	0.2	0.21	0.24	0.21	-1.6	-0.98	-1.61	-1.46
W STATISTIC	0.72	0.82	0.8	0.78	0.76	0.67	0.81	0.81
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	0.8	0.8	0.8	0.8	-0.2	-0.22	-0.22	-0.22
Z-SCORE	2.96	2.4	2.66	2.78	2.34	1.1	1.87	2.1
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
Z-SCORE	-0.67	-0.91	-0.83	-0.78	-0.77	-1.01	-0.97	-0.91
SKEWNESS	1.45	0.69	1.02	1.19	0.96	-0.13	0.32	0.56
SKEWNESS/S.E.	3.79	1.79	2.67	3.12	2.52	-0.33	0.83	1.47
KURTOSIS	1.05	-0.71	-0.01	0.39	-0.45	-2.01	-1.48	-1.13
KURTOSIS/S.E.	1.37	-0.92	-0.01	0.5	-0.58	-2.63	-1.93	-1.48
STD. DEV.	0.16	0.24	0.2	0.18	0.45	4.17	0.73	0.58
VARIANCE	0.03	0.06	0.04	0.03	0.2	17.37	0.54	0.33
LCL	0.26	0.14	0.2	0.23	-1.4	-6.11	-1.82	-1.61
UCL	0.36	0.3	0.33	0.34	-1.11	-3.48	-1.36	-1.24
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.32	-1.96
QUARTILE 3	0.4	0.4	0.4	0.4	-0.9	-0.92	-0.92	-0.92
DATA POINTS					41			

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 70, 1975 DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.37	0.33	0.35	0.36	-1.07	-2.5	-1.22	-1.16
STANDARD ERROR	0.03	0.04	0.04	0.04	0.09	0.63	0.12	0.1
MEDIAN	0.3	0.3	0.3	0.3	-1.2	-1.2	-1.2	-1.2
STANDARD ERROR	0.03	0.03	0.03	0.03	0.9	0.08	0.08	0.08
MODE	NOT UNIQ.	0.3	0.3	0.3	NOT UNIQ.	-1.2	-1.2	-1.2
TRIM (.15)	0.34	0.33	0.33	0.33	-1.12	-1.52	-1.17	-1.16
HAMPEL	0.34	0.32	0.32	0.32	-1.09	-0.98	-1.15	-1.15
BWEIGHT	0.36	0.32	0.34	0.34	-1.08	-0.99	-1.18	-1.15
W STATISTIC	0.85	0.93	0.91	0.90	0.88	0.57	0.9	0.92
SIG. LEVEL	.0007	0.087	0.035	0.011	0.005	0	0.06	0.059
MAXIMUM VALUE	0.8	0.8	0.8	0.8	-0.2	-0.22	-0.22	-.22
Z-SCORE	2.43	2.07	2.25	2.33	1.9	0.69	1.55	1.74
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
Z-SCORE	-0.96	-1.48	-1.27	-1.15	-1.14	-2.05	-1.68	-1.49
SKEWNESS	0.91	0.18	0.57	0.72	0.39	-1.49	-0.43	-0.04
SKEWNESS/S.E.	1.94	0.39	1.2	1.54	0.82	-3.15	-0.91	-0.1
KURTOSIS	-0.34	-0.73	-0.63	-0.53	-1.17	0.3	-0.89	-1.12
KURTOSIS/S.E.	-0.36	-0.77	-0.67	-0.56	-1.24	0.31	-0.94	-1.19
STD. DEV.	0.18	0.23	0.2	0.19	0.46	3.28	0.64	0.54
VARIANCE	0.03	0.05	0.04	0.04	0.21	10.76	0.41	0.29
LCL	0.3	0.24	0.27	0.28	-1.26	-3.8	-1.48	-1.37
UCL	0.44	0.42	0.43	0.43	0.89	-1.2	-0.97	-0.95
QUARTILE 1	0.2	0.2	0.2	0.2	-1.6	-1.61	-1.61	-1.61
QUARTILE 3	0.5	0.5	0.5	0.5	-0.6	-0.69	-0.69	-0.69
DATA POINTS				27				

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 70 1976 DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.28	0.1	0.19	0.23	-1.49	-8.25	-2.11	-1.8
STANDARD ERROR	0.08	0.09	0.08	0.08	0.11	0.66	0.16	0.14
MEDIAN	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
STANDARD ERROR	0	0	0	0	0	0	0	0
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
HAMPEL	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
BWEIGHT	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
W STATISTIC	0.25	0.3	0.28	0.27	0.25	0.38	0.33	0.3
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	1.6	1.6	1.6	1.6	0.4	0.47	0.47	0.47
Z-SCORE	4.01	3.98	4	4	4.01	3.1	3.88	4
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
Z-SCORE	-0.24	-0.27	-0.25	-0.25	-0.24	-0.34	-0.29	-0.27
SKEWNESS	3.56	3.48	3.54	3.55	3.56	2.34	3.26	3.45
SKEWNESS/S.E.	6.17	6.02	6.13	6.15	6.17	4.06	5.64	5.98
KURTOSIS	11.32	10.88	11.2	11.28	11.32	3.83	9.67	10.75
KURTOSIS/S.E.	9.81	9.43	9.7	9.77	9.81	3.32	8.38	9.31
STD. DEV.	0.33	0.38	0.35	0.34	0.47	2.82	0.66	0.57
VARIANCE	0.11	0.14	0.12	0.11	0.22	7.93	0.44	0.33
LCL	0.11	-0.09	0.01	0.05	-1.72	-9.65	-2.44	-2.09
UCL	0.44	0.29	0.36	0.4	-1.25	-6.85	-1.78	-1.52
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
QUARTILE 3	2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
DATA POINTS					18			

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 80, ALL DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.39	0.3	0.34	0.36	-1.18	-4.75	-1.52	-1.36
STANDARD ERROR	0.062	0.07	0.066	0.065	0.089	0.62	0.13	0.11
MEDIAN	0.2	0.2	0.2	0.2	-1.6	-1.61	-1.61	-1.61
STANDARD ERROR	0.029	0.087	0.058	0.046	0.12	2.31	0.32	0.22
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.27	0.18	0.23	0.25	-1.34	-4.81	-1.68	-1.52
HAMPEL	0.2	0.2	0.2	0.2	-1.6	-3.69	-1.58	-1.54
BWEIGHT	0.2	0.18	0.18	0.16	-1.6	-4.73	-1.58	-1.47
W STATISTIC	0.5	0.64	0.58	0.55	0.73	0.69	0.83	0.8
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	2.8	2.8	2.8	2.8	1	1.03	1.03	1.03
Z-SCORE	5.6	5.2	5.42	5.5	3.58	1.36	2.9	3.23
MINIMUM VALUE	0 2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
Z-SCORE	-0.45	-0.62	-0.54	-0.5	-0.68	-1.05	-0.89	-0 81
SKEWNESS	3.98	3.19	3.6	3.77	1.48	-0.09	0.78	1.13
SKEWNESS/S.E.	11.13	8.93	10.08	10.54	4.16	-0.24	2.18	3.15
KURTOSIS	18.47	13.12	15.83	16.95	1.81	-1.98	-0.3	0.64
KURTOSIS/S.E.	25.85	18.37	22.15	23.72	2.53	-2.77	-0.41	0.9
STD. DEV.	0.43	0.48	0.45	0.44	0.61	4.25	0.88	0.74
VARIANCE	0.18	0.23	0.21	0.2	0.37	18.09	0.77	0.55
LCL	0.27	0.16	0.21	0.23	-1.36	-6	-1.78	-1.57
UCL	0.52	0.44	0.48	0.49	-1	-3.5	-1.26	-1.14
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1 96
QUARTILE 3	0.4	0.4	0.4	0.4	-0.9	0.92	-0.92	-0 92
DATA POINTS					47			

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 80, ALL DAYSHIFT DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.39	0.29	0.34	0.36	-1.2	-4.75	-1.53	-1.37
STANDARD ERROR	0.065	0.072	0.068	0.067	0.089	0.63	0.13	0.11
MEDIAN	0.2	0.2	0.2	0.2	-1.6	-1.61	-1.61	-1.61
STANDARD ERROR	0.029	0.087	0.058	0.046	0.12	2.31	0.32	0.22
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.27	0.18	0.22	0.24	-1.35	-4.81	-1.68	-1.53
HAMPEL	0.2	0.19	0.2	0.2	-1.6	-3.69	-1.59	-1.54
BWEIGHT	0.2	0.17	0.19	0.16	-1.6	-4.73	-1.6	-1.49
W STATISTIC	0.49	0.62	0.56	0.53	0.72	0.7	0.82	0.8
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	2.8	2.8	2.8	2.8	1	1.03	1.03	1.03
Z-SCORE	5.56	5.18	5.38	5.46	3.65	1.36	2.94	3.29
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
Z-SCORE	-0.43	-0.61	-0.53	-0.49	-0.67	-1.05	-0.89	-0.81
SKEWNESS	4.05	3.28	3.69	3.84	1.58	-0.09	0.82	1.2
SKEWNESS/S.E.	11.08	8.99	10.1	10.53	4.33	-0.25	2.26	3.27
KURTOSIS	18.71	13.54	16.18	17.26	2.25	-1.98	-0.13	0.93
KURTOSIS/S.E.	25.62	18.54	22.16	23.64	3.08	-2.71	-0.18	1.27
STD. DEV.	0.43	0.48	0.46	0.45	0.6	4.24	0.87	0.73
VARIANCE	0.19	0.23	0.21	0.2	0.36	18	0.76	0.53
LCL	0.26	0.15	0.2	0.23	-1.38	-6.03	-1.79	-1.59
UCL	0.52	0.44	0.48	0.49	-1.01	-3.48	-1.26	-1.15
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1 96
QUARTILE 3	0.4	0.4	0.4	0.4	-0.9	-0.92	-0.92	-0.92
DATA POINTS				45				

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 80, 1975 DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.42	0.38	0.4	0.41	-1.01	-2.6	-1.17	-1.1
STANDARD ERROR	0.05	0.06	0.054	0.05	0.11	0.64	0.14	0.12
MEDIAN	0.3	0.3	0.3	0.3	-1.2	-1.2	-1.2	-1.2
STANDARD ERROR	0.058	0.06	0.057	0.058	0.2	0.2	0.2	0.2
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.35	0.34	0.35	0.35	-1.09	-1.73	-1.17	-1.14
HAMPEL	0.33	0.33	0.36	0.35	-1.06	0.89	-1.14	-1.13
BWEIGHT	0.36	0.33	0.34	0.34	-1.03	0.89	-1.15	-1.11
W STATISTIC	0.79	0.9	0.86	0.84	0.88	0.62	0.93	0.93
SIG. LEVEL	0	0.012	0.0012	0.0003	0.0027	0	0.056	0.068
MAXIMUM VALUE	1.2	1.2	1.2	1.22	0.1	0.18	0.18	0.18
Z-SCORE	2.88	2.61	2.76	2.81	2.02	0.8	1.8	1.99
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
Z-SCORE	-0.82	-1.21	-1.03	-0.95	-1.06	-1.91	-1.51	-1.33
SKEWNESS	1.41	0.86	1.16	1.27	0.44	-1.31	-0.13	0.22
SKEWNESS/S.E.	3.1	1.88	2.55	2.8	0.98	-2.88	-0.28	0.48
KURTOSIS	1.22	0.28	0.72	0.93	-1.12	-0.19	-1.01	-1.03
KURTOSIS/S.E.	1.35	0.3	0.79	1.02	-1.24	-0.21	-1.12	-1.13
STD. DEV.	0.27	0.31	0.29	0.28	0.55	3.47	0.75	0.65
VARIANCE	0.07	0.1	0.08	0.08	0.31	12.02	0.56	0.42
LCL	0.32	0.26	0.29	0.3	-1.22	-3.92	-1.46	-1.35
UCL	0.52	0.5	0.51	0.52	-0.8	-1.28	-0.89	-0.85
QUARTILE 1	0.2	0.2	0.2	0.2	-1.6	-1.61	-1.61	-1.61
QUARTILE 3	0.5	0.5	0.5	0.5	-0.6	-0.69	-0.69	-0.69
DATA POINTS					29			

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 80, 1976 DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.34	0.17	0.26	0.29	-1.46	-8.22	-2.08	-1.77
STANDARD ERROR	0.14	0.16	0.15	0.15	0.14	0.69	0.19	0.17
MEDIAN	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
STANDARD ERROR	0	0	0	0	0	0	0	0
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
HAMPEL	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
BWEIGHT	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
W STATISTIC	0.25	0.28	0.27	0.26	0.25	0.38	0.32	0.29
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	2.8	2.8	2.8	2.8	1	1.03	1.03	1.03
Z-SCORE	4.01	4	4	4.01	4.01	3.17	3.92	3.98
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
Z-SCORE	-0.24	0.25	-0.25	-0.24	-0.24	-0.34	-0.28	-0.26
SKEWNESS	3.56	3.53	3.55	3.56	3.56	2.38	3.34	3.49
SKEWNESS/S.E.	6.17	6.12	6.16	6.16	6.17	4.11	5.79	6.04
KURTOSIS	11.32	11.18	11.29	11.31	11.32	4.06	10.15	10.94
KURTOSIS/S.E.	9.81	9.68	9.77	9.8	9.81	3.52	8.79	9.48
STD. DEV.	0.61	0.66	0.64	0.63	0.61	2.92	0.79	0.7
VARIANCE	0.38	0.43	0.4	0.39	0.38	8.53	0.63	0.5
LCL	0.04	-0.16	-0.06	-0.02	-1.76	-9.67	-2.47	-2 12
UCL	0.65	0.49	0.57	0.6	-1.15	-6.76	-1.68	-1.42
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
QUARTILE 3	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
DATA POINTS					18			

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 85, ALL DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.43	0.33	0.38	0.4	-1.16	-4.96	-1.51	-1.34
STANDARD ERROR	0.04	0.046	0.043	0.04	0.07	0.411	.096	0.082
MEDIAN	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
STANDARD ERROR	0.03	0.089	0.06	.046	0.12	2.31	0.32	0.22
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.3	0.2	0.25	0.27	-1.29	-5.16	-1.66	-1.48
HAMPEL	0.2	0.0001	0.13	0.17	-1.6	-9.21	-1.6	-1.58
BWEIGHT	0 2	0.0001	0.13	0.15	-1.6	-9.21	-1.59	-1.84
W STATISTIC	0.66	0.72	0.7	0.68	0.83	0.68	0.86	0.85
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	2.3	2.3	2.3	2.3	0.8	0.83	0.83	0.83
Z-SCORE	4.41	4.06	4.24	4.31	2.74	1.34	2.33	2.53
MINIMUM VALUE	0.1	0.0001	0.05	0.0707	-2.3	-9.21	-3	-2.65
Z-SCORE	-0.77	-0.68	-0.73	-0.74	-1.6	-0.98	-1.47	-1.52
SKEWNESS	2.29	1.85	2.08	2.17	0.86	0.05	0.56	0.73
SKEWNESS/S.E.	9.83	7.97	8 93	9.31	3.69	0.23	2.43	3.14
KURTOSIS	5.15	3.32	4.22	4.6	-0.13	-1.97	-0.9	-0.5
KURTOSIS/S.E.	11.08	7.13	9.07	9.9	-0.27	-4.23	-1.94	-1.07
STD. DEV.	0.43	0.48	0.45	0.44	0.72	4.33	1.01	0.86
VARIANCE	0.18	0.24	0.21	0.19	0.51	18.77	1.01	0.74
LCL	0.35	0.24	0.29	0.32	-1.29	-5.78	-1.7	-1.5
UCL	0.5	0.42	0.46	0.48	-1.02	-4.15	-1.32	-1.18
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
QUARTILE 3	0.5	0.5	0.5	0.5	-0.6	-0.69	-0.69	-0.69
DATA POINTS					111			

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 85, ALL DAYSHIFT DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.44	0.35	0.39	0.41	-1.14	-4.8	-1.48	-1.31
STANDARD ERROR	0.04	0.05	0.05	0.04	0.07	0.42	0.1	0.09
MEDIAN	0.2	0.2	0.2	0.2	-1.6	-1.61	-1.61	-1.61
STANDARD ERROR	0.03	0.09	0.06	0.05	0.12	2.31	0.32	0.22
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.31	0.21	0.26	0.28	-1.26	-4.93	-1.61	-1.45
HAMPEL	0.2	0.1	0.19	0.18	-1.6	-4.66	-1.56	-1.56
BWEIGHT	0.2	0.15	0.13	0.15	-1.6	-4.79	-1.54	-1.85
W STATISTIC	0.67	0.74	0.71	0.7	0.84	0.68	0.87	0.87
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	2.3	2.3	2.3	2.3	0.8	0.83	0.83	0.83
Z-SCORE	4.29	3.96	4.13	4.2	2.65	1.3	2.27	2.46
MINIMUM VALUE	0.1	0.0001	0.05	0.0707	-2.3	-9.21	-3	-2.65
Z-SCORE	-0.78	-0.71	-0.74	-0.76	-1.6	-1.02	-1.49	-1.53
SKEWNESS	2.2	1.78	1.99	2.08	0.78	-0.02	0.49	0.66
SKEWNESS/S.E.	9.18	7.44	8.34	8.7	3.26	-0.08	2.07	2.75
KURTOSIS	4.68	3	3.82	4.18	-0.29	-1.97	-0.98	-0.62
KURTOSIS/S.E.	9.79	6.27	8	8.74	-0.6	-4.12	-2.06	-1.29
STD. DEV.	0.43	0.49	0.46	0.45	0.73	4.34	1.02	0.87
VARIANCE	0.19	0.24	0.21	0.2	0.53	18.82	1.04	0.76
LCL	0.36	0.25	0.3	0.33	-1.28	-5.63	-1.68	-1.48
UCL	0.52	0.44	0.48	0.5	-0.99	-3.96	-1.28	-1.14
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
QUARTILE 3	0.5	0.5	0.5	0.5	-0.6	-0.69	-0.69	-0.69
DATA POINTS					105			

*MDL = Minimum detection limit

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 85, 1974 DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.86	0.83	0.84	0.85	-0.67	-2.73	-0.86	-0.76
STANDARD ERROR	0.15	0.16	0.16	0.16	0.26	0.98	0.33	0.3
MEDIAN	0.75	0.75	0.75	0.75	-0.25	-0.29	-0.29	-0.29
STANDARD ERROR	0.23	0.23	0.23	0.23	0.29	0.32	0.32	0.32
MODE	0.1	0.0001	0.05	0.0707	-2.3	-9.21	-3	-2.65
TRIM (.15)	0.77	0.75	0.76	0.77	-0.59	-2.07	-0.74	-0.67
HAMPEL	0.83	0.81	0.82	0.83	-0.45	0.05	-0.43	-0.46
BWEIGHT	0.83	0.81	0.82	0.83	-0.61	0.06	-0.77	-0.69
W STATISTIC	0.91	0.92	0.91	0.91	0.82	0.66	0.79	0.81
SIG. LEVEL	0.067	0.086	0.078	0.073	0.0011	0	0.0004	0.0008
MAXIMUM VALUE	2.3	2.3	2.3	2.3	0.8	0.83	0.83	0.83
Z-SCORE	2.09	2.03	2.06	2.08	1.26	0.81	1.14	1.19
MINIMUM VALUE	0.1	0.0001	0.05	0.0707	-2.3	-9.21	-3	-2.65
Z-SCORE	-1.09	-1.14	-1.12	-1.12	-1.4	-1.48	-1.43	-1.41
SKEWNESS	0.46	0.37	0.41	0.44	-0.5	-0.78	-0.58	-0.52
SKEWNESS/S.E.	0.85	0.67	0.76	0.8	-0.91	-1.42	-1.05	-0.96
KURTOSIS	-1.01	-1.09	-1.05	-1.04	-1.5	-1.42	-1.48	-1.5
KURTOSIS/S.E.	-0.92	-1	-0.96	-0.95	-1.37	-1.3	-1.36	-1.37
STD. DEV.	0.69	0.73	0.71	0.7	1.17	4.37	1.49	1.34
VARIANCE	0.48	0.53	0.5	0.49	1.36	19.13	2.23	1.79
LCL	0.53	0.49	0.51	0.52	-1.21	-4.78	-1.56	-1.39
UCL	1.18	1.16	1.17	1.17	-0.12	-0.68	-0.17	-0.13
QUARTILE 1	0.1	0.0001	0.5	0.0707	-2.3	-9.21	-3	-2.65
QUARTILE 3	1.35	1.35	1.35	1.35	0.25	0.29	0.3	0.29
DATA POINTS				20				

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 85, 1975 DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.44	0.4	0.42	0.43	-0.99	2.71	-1.16	1.08
STANDARD ERROR	0.05	0.06	0.06	0.05	0.091	0.57	0.12	0.11
MEDIAN	0.35	0.35	0.35	0.35	-1.05	-1.06	-1.06	-1.06
STANDARD ERROR	0.03	0.03	0.03	0.03	0.09	0.08	0.08	0.08
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	2.3	1.96
TRIM (.15)	0.37	0.35	0.36	0.36	-1.06	-1.89	-1.15	1.12
HAMPEL	0.37	0.33	0.36	0.36	-1.01	-0.84	-1.14	1.11
BWEIGHT	0.38	0.34	0.36	0.37	-1.01	-0.86	-1.15	1.1
W STATISTIC	0.74	0.86	0.81	0.79	0.88	0.63	0.92	0.93
SIG. LEVEL	0	0.0001	0	0	0.0003	0	0.0111	0.0146
MAXIMUM VALUE	1.8	1.8	1.8	1.8	0.5	0.59	0.59	0.59
Z-SCORE	4.22	3.85	4.04	4.12	2.58	0.92	2.21	2.46
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
Z-SCORE	-0.75	-1.09	-0.94	-0.87	-1.06	-1.82	-1.45	-1.29
SKEWNESS	2.18	1.52	1.87	2.01	0.53	-1.2	-0.06	0.28
SKEWNESS/S.E.	5.63	3.94	4.84	5.19	1.37	-3.11	-0.16	0.73
KURTOSIS	5.85	3.46	4.63	5.14	-0.7	-0.46	-0.91	-0.78
KURTOSIS/S.E.	7.55	4.47	5.97	6.63	-0.91	-0.59	-1.17	1.01
STD. DEV.	0.32	0.36	0.34	0.33	0.58	3.58	0.79	0.68
VARIANCE	0.1	0.13	0.11	0.11	0.33	12.81	0.62	0.46
LCL	0.34	0.28	0.31	0.32	-1.17	-3.86	-1.41	-1.3
UCL	0.55	0.51	0.53	0.53	0.81	-1.57	-0.9	-0.86
QUARTILE 1	0.2	0.2	0.2	0.2	-1.6	-1.61	-1.61	-1.61
QUARTILE 3	0.6	0.6	0.6	0.6	-0.5	-0.51	-0.51	0.51
DATA POINTS				40				

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 85, 1976 DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.25	0.09	0.17	0.2	-1.48	-7.6	-2.05	-1.77
STANDARD ERROR	0.02	0.03	0.03	0.03	0.05	0.46	0.08	0.06
MEDIAN	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
STANDARD ERROR	0	0	0	0	0	0	0	0
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.2	0.013	0.11	0.15	-1.6	-8.71	-2.26	-1.93
HAMPEL	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
BWEIGHT	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
W STATISTIC	0.33	0.46	0.41	0.38	0.4	0.5	0.52	0.49
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	1.3	1.3	1.3	1.3	0.2	0.26	0.26	0.26
Z-SCORE	6.15	5.36	5.76	5.93	4.77	2.38	3.99	4.44
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
Z-SCORE	-0.28	-0.38	-0.34	-0.32	-0.34	-0.49	-0.44	-0.41
SKEWNESS	4.84	3.51	4.14	4.43	3.16	1.51	2.26	2.69
SKEWNESS/S.E.	14.1	10.23	12.08	12.93	9.22	4.4	6.59	7.84
KURTOSIS	25.54	14.26	19.45	21.95	9.91	0.32	4.46	7.07
KURTOSIS/S.E.	37.23	20.78	28.35	31.99	14.45	0.47	6.51	10.31
STD. DEV.	0.17	0.23	0.2	0.19	0.35	3.3	0.58	0.46
VARIANCE	0.03	0.05	0.04	0.03	0.12	10.88	0.33	0.21
LCL	0.2	0.02	0.11	0.15	-1.58	-8.53	-2.21	-1 9
UCL	0.3	0.15	0.22	0.25	-1.38	-6.67	-1.89	-1.64
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
QUARTILE 3	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
DATA POINTS					51			

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 95, ALL DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.34	0.25	0.29	0.32	-1.28	-4.84	-1.61	-1.45
STANDARD ERROR	0.04	0.04	0.04	0.04	0.06	0.43	0.08	0.07
MEDIAN	0.2	0.2	0.2	0.2	-1.6	-1.61	-1.61	-1.61
STANDARD ERROR	0	0.06	0.03	0.02	0	2.19	0.2	0.1
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.25	0.16	0.2	0.22	-1.43	-4.89	-1.76	-1.6
HAMPEL	0.2	0.17	0.2	0.2	-1.6	-3.78	-1.67	-1.59
BWEIGHT	0.2	0.15	0.19	0.16	-1.6	-4.82	-1.69	-1.59
W STATISTIC	0.44	0.61	0.54	0.5	0.66	0.68	0.81	0.77
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	2.6	2.6	2.6	2.6	0.9	0.96	0.96	0.96
Z-SCORE	6.22	5.73	6	6.1	4.11	1.4	3.26	3.69
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
Z-SCORE	-0.39	-0.6	-0.51	-0.46	-0.6	-1.06	-0.87	-0.77
SKEWNESS	4.38	3.47	3.97	4.16	1.98	-0.09	1	1.49
SKEWNESS/S.E.	17.17	13.58	15.53	16.27	7.76	-0.36	3.92	5.84
KURTOSIS	21.5	15.04	18.42	19.77	3.96	-1.96	0.53	2.12
KURTOSIS/S.E.	42.09	29.44	36.06	38.71	7.76	-3.84	1.04	4.15
STD. DEV.	0.36	0.41	0.38	0.37	0.53	4.14	0.79	0.65
VARIANCE	0.13	0.17	0.15	0.14	0.28	17.12	0.62	0.43
LCL	0.27	0.16	0.22	0.24	-1.39	-5.7	-1.78	-1.59
UCL	0.42	0.33	0.37	0.39	-1.17	-3.99	-1.45	-1.32
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
QUARTILE 3	0.38	0.38	0.38	0.38	-0.98	-0.99	-0.99	-0.99
DATA POINTS					92			

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 95, ALL DAYSHIFT DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.36	0.28	0.32	0.34	-1.24	-4.34	-1.53	-1.39
STANDARD ERROR	0.04	0.048	0.045	0.044	0.061	0.45	0.089	0.074
MEDIAN	0.2	0.2	0.2	0.2	-1.6	-1.61	-1.61	-1.61
STANDARD ERROR	0.03	0.09	0.058	0.046	0.115	2.31	0.317	0.217
MODE	0.2	0.0001	0.1	0.141	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.258	0.184	0.221	0.236	-1.39	-4.19	-1.65	-1.53
HAMPEL	0.2	0.195	0.212	0.211	-1.6	-1.35	-1.58	-1.52
BWEIGHT	0.2	0.187	0.213	0.222	-1.6	-1.05	-1.58	-1.49
W STATISTIC	0.47	0.63	0.558	0.524	0.7	0.69	0.84	0.804
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	2.6	2.6	2.6	2.6	0.9	0.955	0.956	0.956
Z-SCORE	5.85	5.43	5.66	5.74	3.87	1.3	3.11	3.5
MINIMUM VALUE	0.2	0.0001	0.1	0.141	-1.6	-9.21	-2.3	-1.956
Z-SCORE	-0.42	-0.65	-0.545	-0.5	-0.655	-1.19	-0.967	-0.848
SKEWNESS	4.1	3.29	3.73	3.9	1.8	-0.33	0.85	1.34
SKEWNESS/S.E.	15.05	12.09	13.71	14.32	6.6	-1.2	3.12	4.91
KURTOSIS	18.59	13.37	16.13	17.21	3.15	-1.85	0.28	1.64
KURTOSIS/S.E.	34.15	24.56	29.63	31.63	5.79	-3.4	0.52	3.02
STD. DEV.	0.38	0.428	0.4	0.394	0.553	4.09	0.8	0.67
VARIANCE	0.15	0.183	0.162	0.155	0.305	16.71	0.64	0.448
LCL	0.28	0.184	0.231	0.249	-1.36	-5.25	-1.71	-1.54
UCL	0.45	0.37	0.409	0.424	-1.12	-3.44	-1.35	-1.24
QUARTILE 1	0.2	0.0001	0.1	0.141	-1.6	-9.21	-2.3	-1 96
QUARTILE 3	0.4	0.4	0.4	0.4	0.9	-0.92	-0.92	-0.92
DATA POINTS	81							

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 95, 1975 DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.36	0.24	0.3	0.33	-1.28	-5.91	-1.71	-1.5
STANDARD ERROR	0.09	0.1	0.1	0.09	0.12	0.88	0.18	0.15
MEDIAN	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
STANDARD ERROR	0.03	0.09	0.06	0.05	0.12	2.31	0.32	0.22
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.24	0.11	0.18	0.21	-1.44	-6.43	-1.9	-1.68
HAMPEL	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
BWEIGHT	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
W STATISTIC	0.42	0.54	0.49	0.46	0.63	0.67	0.72	0.69
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	2.2	2.2	2.2	2.2	0.7	0.79	0.79	0.79
Z-SCORE	4.27	4.04	4.16	4.21	3.4	1.58	2.86	3.14
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
Z-SCORE	-0.37	-0.49	-0.44	-0.41	-0.55	-0.78	-0.68	-0.63
SKEWNESS	3.44	2.9	3.19	3.3	2.01	0.45	1.23	1.59
SKEWNESS/S.E.	6.74	5.68	6.24	6.46	3.94	0.88	2.41	3.1
KURTOSIS	11.62	8.72	10.23	10.83	3.65	-1.83	0.64	1.97
KURTOSIS/S.E.	11.38	8.53	10.01	10.6	3.57	-1.79	0.63	1.93
STD. DEV.	0.43	0.49	0.46	0.45	0.58	4.23	0.87	0.73
VARIANCE	0.19	0.24	0.21	0.2	0.34	17.98	0.76	0.53
LCL	0.17	0.03	0.1	0.13	-1.53	-7.74	-2.08	-1.81
UCL	0.55	0.45	0.5	0.52	-1.03	-4.08	-1.33	-1.18
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
QUARTILE 3	0.4	0.4	0.4	0.4	-0.9	0.92	-0.92	-0.91
DATA POINTS				23				

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 95, 1976 DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.33	0.25	0.29	0.31	-1.29	-4.54	-1.6	-1.45
STANDARD ERROR	0.04	0.05	0.04	0.04	0.06	0.49	0.09	0.08
MEDIAN	0.2	0.2	0.2	0.2	-1.6	-1.61	-1.61	-1.61
STANDARD ERROR	0	0.06	0.03	0.02	0	2.19	0.2	0.1
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.24	0.16	0.2	0.22	-1.44	-4.45	-1.72	-1.59
HAMPEL	0.2	0.18	0.2	0.2	-1.6	-1.71	-1.64	-1.57
BWEIGHT	0.2	0.17	0.2	0.19	-1.6	-1.11	-1.65	-1.56
W STATISTIC	0.44	0.62	0.54	0.5	0.67	0.69	0.84	0.79
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	2.6	2.6	2.6	2.6	0.9	0.96	0.96	0.96
Z-SCORE	6.62	6.07	6.37	6.48	4.26	1.35	3.36	3.83
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
Z-SCORE	-0.39	-0.64	-0.5	-0.47	-0.6	-1.14	-0.93	-0.81
SKEWNESS	4.72	3.67	4.25	4.47	1.99	-0.25	0.94	1.47
SKEWNESS/S.E.	15.9	12.37	14.31	15.04	6.69	-0.85	3.16	4.96
KURTOSIS	26.32	18.08	22.41	24.14	4.11	-1.91	0.53	2.17
KURTOSIS/S.E.	44.3	30.43	37.72	40.63	6.93	-3.21	0.89	3 66
STD. DEV.	0.34	0.39	0.36	0.35	0.52	4.08	0.76	0.63
VARIANCE	0.12	0.15	0.13	0.13	0.27	16.64	0.58	0.4
LCL	0.25	0.15	0.2	0.22	-1.42	-5.53	-1.78	-1.6
UCL	0.42	0.34	0.38	0.39	-1.17	-3.56	-1.41	-1.3
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1 96
QUARTILE 3	0.3	0.3	0.3	0.3	-1.2	-1.2	-1.2	-1.2
DATA POINTS				68				

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 110, ALL DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	1	0.97	0.99	0.99	-0.47	-1.65	-0.58	-0.53
STANDARD ERROR	0.11	0.11	0.11	0.11	0.08	0.29	0.09	0.09
MEDIAN	0.5	0.5	0.5	0.5	-0.6	-0.69	-0.69	-0.69
STANDARD ERROR	0.06	0.06	0.06	0.06	0.09	0.1	0.1	0.1
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	2.3	-1.96
TRIM (.15)	0.68	0.68	0.68	0.68	-0.55	-0.61	-0.57	-0.57
HAMPEL	0.58	0.61	0.63	0.61	-0.55	-0.32	-0.57	-0.57
BWEIGHT	0.6	0.56	0.58	0.59	-0.52	-0.3	-0.59	-0.58
W STATISTIC	0.61	0.64	0.63	0.62	0.92	0.64	0.95	0.94
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	9.5	9.5	9.5	9.5	2.2	2.25	2.25	2.25
Z-SCORE	6.48	6.4	6.44	6.46	2.98	1.17	2.64	2.81
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
Z-SCORE	-0.61	-0.73	-0.67	-0.65	-1.26	-2.27	-1.6	-1.44
SKEWNESS	3.69	3.56	3.63	3.65	0.53	-1.66	0.08	0.34
SKEWNESS/S.E.	17.57	16.93	17.27	17.4	2.52	-7.92	0.4	1.62
KURTOSIS	17.18	16.3	16.76	16.94	-0.31	1.18	-0.49	-0.46
KURTOSIS/S.E.	40.89	38.81	39.89	40.32	-0.75	2.81	-1.16	-1.11
STD. DEV.	1.31	1.33	1.32	1.32	0.9	3.33	1.07	0.99
VARIANCE	1.72	1.78	1.75	1.74	0.8	11.12	1.15	0.98
LCL	0.78	0.74	0.76	0.77	-0.63	-2.22	-0.77	-0.7
UCL	1.22	1.19	1.21	1.22	-0.32	-1.09	-0.4	-0.36
QUARTILE 1	0.3	0.3	0.3	0.3	-1.2	-1.2	-1.2	-1.2
QUARTILE 3	1.28	1.27	1.28	1.28	0.18	0.24	0.24	0.24
DATA POINTS					136			

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 110, ALL DAYSHIFT DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.99	0.96	0.97	0.98	-0.5	-1.72	-0.62	-0.56
STANDARD ERROR	0.12	0.13	0.12	0.12	0.08	0.31	0.1	0.09
MEDIAN	0.5	0.5	0.5	0.5	-0.6	-0.69	-0.69	-0.69
STANDARD ERROR	0.06	0.06	0.06	0.06	0.12	0.12	0.12	0.12
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.65	0.65	0.65	0.65	-0.59	-0.71	-0.61	-0.61
HAMPEL	0.56	0.59	0.61	0.59	-0.59	-0.36	-0.62	-0.62
BWEIGHT	0.56	0.54	0.55	0.56	-0.57	-0.33	-0.64	-0.64
W STATISTIC	0.59	0.62	0.61	0.6	0.92	0.65	0.95	0.94
SIG. LEVEL	0	0	0	0	0	0	0.0001	0
MAXIMUM VALUE	9.5	9.5	9.5	9.5	2.2	2.25	2.25	2.25
Z-SCORE	6.32	6.25	6.29	6.3	3	1.18	2.66	2.83
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
Z-SCORE	-0.59	-0.7	-0.64	-0.62	-1.22	-2.22	-1.57	-1.4
SKEWNESS	3.79	3.66	3.72	3.75	0.61	-1.61	0.15	0.41
SKEWNESS/S.E.	16.86	16.28	16.59	16.71	2.7	-7.18	0.65	1.82
KURTOSIS	17.55	16.7	17.15	17.32	-0.21	1	-0.45	-0.39
KURTOSIS/S.E.	39.09	37.19	38.18	38.57	-0.46	2.23	-1	-0.87
STD. DEV.	1.35	1.37	1.36	1.35	0.9	3.37	1.08	0.99
VARIANCE	1.81	1.87	1.84	1.82	0.81	11.37	1 16	0.99
LCL	0.74	0.71	0.73	0.73	-0.66	-2.33	-0 81	-0.74
UCL	1.23	1.2	1.21	1.22	-0.34	-1.11	-0.42	-0.38
QUARTILE 1	0.3	0.3	0.3	0.3	-1.2	-1.2	-1.2	-1.2
QUARTILE 3	1.2	1.2	1.2	1.2	0.1	-0.18	0.18	0.18
DATA POINTS				119				

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 110, 1974 DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	1.21	1.21	1.21	1.21	-0.19	-0.2	-0.2	-0.2
STANDARD ERROR	0.24	0.24	0.24	0.24	0.129	0.13	0.13	0.13
MEDIAN	0.75	0.75	0.75	0.75	-0.25	-0.29	-0.29	-0.29
STANDARD ERROR	0.087	0.087	0.087	0.087	0.115	0.12	0.12	0.12
MODE	0.5	0.5	0.5	0.5	-0.6	-0.69	-0.69	-0.69
TRIM (.15)	0.84	0.84	0.84	0.84	0.24	-0.26	-0.26	-0.26
HAMPEL	0.707	0.707	0.707	0.707	-0.27	-0.3	-0.3	-0.3
BWEIGHT	0.718	0.718	0.718	0.718	-0.29	-0.33	-0.33	-0.33
W STATISTIC	0.58	0.58	0.58	0.58	0.95	0.95	0.95	0.95
SIG. LEVEL	0	0	0	0	0.13	0.11	0.11	0.11
MAXIMUM VALUE	7.4	7.4	7.4	7.4	2	2	2	2
Z-SCORE	4.14	4.14	4.14	4.14	2.75	2.7	2.7	2.7
MINIMUM VALUE	0.2	0.2	0.2	0.2	-1.6	-1.61	-1.61	-1.61
Z-SCORE	-0.67	-0.67	-0.67	-0.67	-1.77	-1.72	-1.72	-1.72
SKEWNESS	3.01	3.01	3.01	3.01	0.65	0.69	0.69	0.69
SKEWNESS/S.E.	7.57	7.57	7.57	7.57	1.64	1.75	1.75	1.75
KURTOSIS	8.97	8.97	8.97	8.97	0.56	0.46	0.46	0.46
KURTOSIS/S.E.	11.29	11.29	11.29	11.29	0.704	0.57	0.57	0.57
STD. DEV.	1.49	1.49	1.49	1.49	0.8	0.82	0.82	0.82
VARIANCE	2.23	2.23	2.23	2.23	0.64	0.67	0.67	0.67
LCL	0.72	0.72	0.72	0.72	-0.45	-0.47	-0.47	-0.47
UCL	1.7	1.7	1.7	1.7	0.07	0.06	0.06	0.06
QUARTILE 1	0.5	0.5	0.5	0.5	-0.6	-0.69	-0.69	-0.69
QUARTILE 3	1.5	1.5	1.5	1.5	0.4	0.41	0.41	0.41
DATA POINTS				38				

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 110, 1975 DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	1.1	1.08	1.09	1.1	-0.37	-1.26	-0.44	-0.4
STANDARD ERROR	0.15	0.16	0.16	0.15	0.1	0.35	0.12	0.11
MEDIAN	0.6	0.6	0.6	0.6	-0.5	-0.52	-0.51	-0.51
STANDARD ERROR	0.12	0.12	0.12	0.12	0.14	0.17	0.17	0.17
MODE	NOT UNIQ	0.3	0.3	0.3	NOT UNIQ	-1.2	-1.2	-1.2
TRIM (.15)	0.8	0.8	0.8	0.8	-0.41	-0.41	-0.41	-0.41
HAMPEL	0.63	0.61	0.61	0.62	-0.41	-0.23	-0 41	-0.41
BWEIGHT	0.6	0.58	0.59	0.59	-0.39	-0.22	-0.44	-0.42
W STATISTIC	0.65	0.68	0.67	0.66	0.94	0.62	0.96	0.95
SIG. LEVEL	0	0	0	0	0.0018	0	0.032	0.0228
MAXIMUM VALUE	9.5	9.5	9.5	9.5	2.2	2.25	2.25	2.25
Z-SCORE	6.25	6.19	6.22	6.23	2.86	1.16	2.55	2.69
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
Z-SCORE	-0.67	-0.79	-0.73	-0.71	-1.38	-2.61	-1.76	-1.57
SKEWNESS	3.62	3.5	3.56	3.59	0.38	-2	-0.02	0.21
SKEWNESS/S.E.	12.87	12.46	12.68	12.76	1.37	-7.1	-0.08	0.76
KURTOSIS	18.12	17.32	17.73	17.89	-0.61	2.62	-0.54	-0.66
KURTOSIS/S.E.	32.24	30.81	31.55	31.84	-1.09	4.66	-0.97	-1.17
STD. DEV.	1.34	1.36	1.35	1.35	0.9	3.04	1.06	0.99
VARIANCE	1.81	1.85	1.82	1.82	0.81	9.25	1.11	0.98
LCL	0.8	0.77	0.78	0.79	-0.57	-1.96	-0.68	-0.63
UCL	1.41	1.39	1.4	1.4	-1.61	-0.57	-0.2	-0.18
QUARTILE 1	0.3	0.3	0.3	0.3	-1.2	-1.2	-1 2	-1.2
QUARTILE 3	1.48	1.48	1.48	1.48	0.38	-0.39	0.39	0.39
DATA POINTS					76			

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 110, 1976 DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.25	0.125	0.185	0.21	-1.44	-6.01	-1.87	-1.67
STANDARD ERROR	0.02	0.038	0.028	0.025	0.068	0.9	0.131	0.096
MEDIAN	0.2	0.0001	0.1	0.141	-1.6	-9.21	-2.3	-1.96
STANDARD ERROR	0	0.058	0.029	0.017	0	2.19	0.2	0.1
MODE	0.2	0.0001	0.1	0.141	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.21	0.085	0.15	0.18	-1.54	-6.44	-2	-1.77
HAMPEL	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
BWEIGHT	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
W STATISTIC	0.58	0.74	0.72	0.69	0.59	0.65	0.73	0.71
SIG. LEVEL	0	0.0001	0	0	0	0	0	0
MAXIMUM VALUE	0.5	0.5	0.5	0.5	-0.6	-0.693	-0.69	-0.69
Z-SCORE	2.88	2.19	2.48	2.64	2.74	1.32	2	2.25
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
Z-SCORE	-0.51	-0.73	-0.67	-0.62	-0.52	-0.8	-0.74	-0.68
SKEWNESS	1.65	0.82	1.15	1.35	1.51	0.39	0.75	1.02
SKEWNESS/S.E.	3	1.51	2.1	2.47	2.76	0.71	1.37	1.86
KURTOSIS	1.41	-0.9	-0.08	0.47	0.86	-1.93	-1.15	-0.55
KURTOSIS/S.E.	1.23	-0.82	-0.07	0.43	0.79	-1.76	-1.05	-0.51
STD. DEV.	0.089	0.171	0.127	0.11	0.31	4.02	0.59	0.43
VARIANCE	0.008	0.029	0.016	0.012	0.094	16.18	0.34	0.185
LCL	0.203	0.045	0.126	0.16	-1.58	-7.9	-2.14	-1.86
UCL	0.287	0.21	0.244	0.26	-1.3	-4.13	-1.59	-1.46
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
QUARTILE 3	0.275	0.275	0.275	0.275	-1.3	-1.31	-1.31	-1.31
DATA POINTS					20			

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 115, ALL DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.36	0.26	0.31	0.33	-1.29	-5.1	-1.65	-1.48
STANDARD ERROR	0.06	0.06	0.06	0.06	0.08	0.55	0.11	0.09
MEDIAN	0.2	0.1	0.15	0.17	-1.6	-5.41	-1.96	-1.78
STANDARD ERROR	0	0.06	0.03	0.02	0	2.19	0.2	0.1
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.23	0.13	0.18	0.2	-1.48	-5.29	-1.84	-1.66
HAMPEL	0.2	0.11	0.15	0.16	-1.6	-5.1	-1.88	-1.78
BWEIGHT	0.2	0.12	0.14	0.16	-1.6	-5.11	-1.81	-1.8
W STATISTIC	0.42	0.57	0.5	0.47	0.61	0.69	0.78	0.72
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	2.8	2.8	2.8	2.8	1	1.03	1.03	1.03
Z-SCORE	5.64	5.31	5.5	5.56	3.96	1.47	3.25	3.61
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
Z-SCORE	-0.36	-0.53	-0.45	-0.42	-0.53	-0.98	-0.79	-0.69
SKEWNESS	4.02	3.41	3.75	3.87	2.22	0.04	1.26	1.74
SKEWNESS/S.E.	12.49	10.61	11.66	12.04	6.9	0.14	3.92	5.42
KURTOSIS	17.28	13.31	15.46	16.27	4.62	-1.97	1.11	2.74
KURTOSIS/S.E.	26.86	20.69	24.03	25.29	7.18	-3.06	1.73	4.26
STD. DEV.	0.43	0.48	0.45	0.44	0.58	4.17	0.83	0.69
VARIANCE	0.19	0.23	0.21	0.2	0.34	17.41	0.68	0.48
LCL	0.24	0.13	0.19	0.21	-1.45	-6.2	-1.87	-1.66
UCL	0.47	0.38	0.42	0.44	-1.14	-4.01	-1.43	-1 29
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
QUARTILE 3	0.3	0.3	0.3	0.3	-1.2	-1.2	-1.2	-1.2
DATA POINTS				58				

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 115, ALL DAYSHIFT DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.36	0.26	0.31	0.33	-1.29	-5.1	-1.65	-1.47
STANDARD ERROR	0.059	0.065	0.062	0.06	0.078	0.56	0.11	0.09
MEDIAN	0.2	0.1	0.15	0.17	-1.6	-5.4	-1.96	-1.78
STANDARD ERROR	0	0.056	0.029	0.017	0	2.19	0.2	0.1
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.23	0.131	0.18	0.2	-1.48	-5.29	-1.84	-1.66
HAMPEL	0.2	0.112	0.147	0.16	-1.6	-5.1	-1.89	-1.79
BWEIGHT	0.2	0.117	0.143	0.16	-1.6	-5.11	-1.82	-1.81
W STATISTIC	0.425	0.57	0.5	0.47	0.6	0.69	0.78	0.73
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	2.8	2.8	2.8	2.8	1	1.03	1.03	1.03
Z-SCORE	5.54	5.2	5.4	5.46	3.9	1.47	3.21	3.56
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
Z-SCORE	-0.36	-0.53	-0.45	-0.42	-0.53	-0.984	-0.79	-0.69
SKEWNESS	3.94	3.35	3.68	3.8	2.18	0.05	1.26	1.73
SKEWNESS/S.E.	12.02	10.25	11.24	11.6	6.66	0.14	3.85	5.28
KURTOSIS	16.52	12.79	14.81	15.57	4.37	-1.97	1.06	2.62
KURTOSIS/S.E.	25.24	19.5	22.6	23.79	6.67	-3	1.63	4.01
STD. DEV.	0.44	0.49	0.46	0.45	0.59	4.18	0.83	0.7
VARIANCE	0.19	0.24	0.21	0.2	0.35	17.46	0.69	0.49
LCL	0.24	0.13	0.19	0.21	-1.45	-6.22	-1.87	-1.66
UCL	0.48	0.39	0.43	0.45	-1.13	-3.98	-1.42	-1.28
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
QUARTILE 3	0.3	0.3	0.3	0.3	-1.2	-1.2	-1.2	-1 2
DATA POINTS					56			

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 115, 1975 DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.27	0.18	0.23	0.24	-1.39	-4.73	-1.71	-1.56
STANDARD ERROR	0.04	0.05	0.05	0.04	0.1	1.02	0.16	0.12
MEDIAN	0.2	0.2	0.2	0.2	-1.6	-1.61	-1.61	-1.61
STANDARD ERROR	0.03	0.09	0.06	0.05	0.12	2.31	0.32	0.22
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.22	0.14	0.18	0.2	-1.51	-4.64	-1.8	-1.66
HAMPEL	0.2	0.16	0.19	0.2	-1.6	-1.55	-1.73	-1.62
BWEIGHT	0.2	0.15	0.18	0.19	-1.6	-1.26	-1.74	-1.64
W STATISTIC	0.52	0.79	0.7	0.64	0.61	0.7	0.84	0.8
SIG. LEVEL	0	0.0016	0.0001	0	0	0.0001	0.0101	0.0023
MAXIMUM VALUE	0.8	0.8	0.8	0.8	-0.2	-0.22	-0.22	-0.22
Z-SCORE	3.46	2.86	3.18	3.31	3.08	1.1	2.33	2.69
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
Z-SCORE	-0.45	-0.84	-0.69	-0.61	-0.53	-1.09	-0.93	-0.81
SKEWNESS	2.56	1.29	1.94	2.23	1.88	-0.21	0.64	1.18
SKEWNESS/S.E.	4.18	2.11	3.16	3.64	3.07	-0.34	1.05	1.93
KURTOSIS	5.98	1.45	3.56	4.62	2.88	-2.05	-0.62	0.66
KURTOSIS/S.E.	4.88	1.19	2.91	3.77	2.35	-1.67	-0.51	0.54
STD. DEV.	0.15	0.22	0.18	0.17	0.39	4.1	0.64	0.5
VARIANCE	0.02	0.05	0.03	0.03	0.15	16.77	0.41	0.25
LCL	0.19	0.07	0.13	0.15	-1.6	-6.91	-2.05	-1.82
UCL	0.35	0.3	0.32	0.33	-1.19	-2.55	-1.37	-1.29
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
QUARTILE 3	0.3	0.3	0.3	0.3	-1.2	-1.2	-1.2	-1.2
DATA POINTS					16			

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 115, 1976 DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.26	0.15	0.21	0.23	-1.4	-5.7	-1.81	-1.61
STANDARD ERROR	0.019	0.032	0.025	0.022	0.057	0.648	0.1	0.077
MEDIAN	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
STANDARD ERROR	0	0.058	0.029	0.017	0	2.19	0.2	0.1
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.22	0.101	0.16	0.185	-1.5	-6.03	-1.94	-1.74
HAMPEL	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
BWEIGHT	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
W STATISTIC	0.57	0.755	0.71	0.67	0.6	0.66	0.75	0.72
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	0.6	0.6	0.6	0.6	-0.5	-0.511	-0.51	-0.51
Z-SCORE	2.81	2.29	2.54	2.66	2.52	1.28	2.04	2.27
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.31	-1.96
Z-SCORE	-0.51	-0.754	-0.68	-0.62	-0.55	-0.87	-0.78	-0.72
SKEWNESS	1.89	0.99	1.39	1.6	1.56	0.26	0.77	1.1
SKEWNESS/S.E.	4.81	2.53	3.54	4.08	3.97	0.67	1.97	2.79
KURTOSIS	2.31	-0.27	0.79	1.4	1	-1.96	-0.92	-0.19
KURTOSIS/S.E.	2.95	-0.34	1.01	1.78	1.28	-2.5	-1.17	-0.245
STD. DEV.	0.12	0.197	0.156	0.14	0.36	4.05	0.64	0.484
VARIANCE	0.015	0.039	0.02	0.019	0.13	16.4	0.4	0.234
LCL	0.22	0.085	0.155	0.18	-1.52	-7.02	-2.01	-1.77
UCL	0.3	0.213	0.256	0.27	-1.29	-4.39	-1.6	-1.45
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1 96
QUARTILE 3	0.3	0.3	0.3	0.3	-1.2	-1.2	-1.2	-1.2
DATA POINTS					39			

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 120, ALL DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.32	0.24	0.28	0.3	-1.22	-4.45	-1.53	-1.39
STANDARD ERROR	0.03	0.04	0.03	0.03	0.06	0.61	0.11	0.08
MEDIAN	0.3	0.3	0.3	0.3	-1.2	-1.2	-1.2	-1.2
STANDARD ERROR	0.03	0.09	0.06	0.05	0.12	2.31	0.32	0.22
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.28	0.2	0.24	0.26	-1.31	-4.27	-1.59	-1.45
HAMPEL	0.29	0.22	0.26	0.27	-1.25	-0.99	-1.56	-1.41
BWEIGHT	0.28	0.22	0.25	0.27	-1.27	-0.98	-1.54	-1.41
W STATISTIC	0.67	0.81	0.77	0.74	0.81	0.66	0.82	0.84
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	1.2	1.2	1.2	1.2	0.1	0.18	0.18	0.18
Z-SCORE	4.88	3.84	4.33	4.55	3.06	1.12	2.38	2.78
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
Z-SCORE	-0.67	-0.94	-0.83	-0.77	-0.87	-1.15	-1.07	-1
SKEWNESS	2.77	1.22	1.88	2.23	0.94	-0.29	0.18	0 49
SKEWNESS/S.E.	7.6	3.35	5.16	6.11	2.59	-0.8	0.5	1.33
KURTOSIS	10.23	2.56	5.49	7.23	0.19	-1.94	-1.28	-0.67
KURTOSIS/S.E.	14	3.5	7.52	9.9	0.26	-2.65	-1.76	-0.92
STD. DEV.	0.18	0.25	0.21	0.2	0.43	4.12	0.72	0.57
VARIANCE	0.03	0.06	0.05	0.04	0.19	17.01	0.52	0.32
LCL	0.27	0.16	0.21	0.24	-1.35	-5.69	-1.75	-1.56
UCL	0.37	0.31	0.34	0.35	-1.09	-3.21	-1.32	-1.21
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
QUARTILE 3	0.4	0.4	0.4	0.4	-0.9	-0.92	-0.92	-0.92
DATA POINTS					45			

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 120, ALL DAYSHIFT DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.33	0.25	0.29	0.3	-1.21	-4.3	-1.51	-1.37
STANDARD ERROR	0.03	0.04	0.03	0.03	0.07	0.63	0.11	0.09
MEDIAN	0.3	0.3	0.3	0.3	-1.2	-1.2	-1.2	-1.2
STANDARD ERROR	0.03	0.09	0.06	0.05	0.12	2.31	0.32	0.22
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.29	0.21	0.25	0.26	-1.29	-4.06	-1.55	-1.42
HAMPEL	0.29	0.22	0.27	0.28	-1.22	-0.98	-1.53	-1.39
BWEIGHT	0.29	0.23	0.26	0.27	-1.24	-0.98	-1.51	-1.38
W STATISTIC	0.68	0.82	0.78	0.75	0.82	0.66	0.83	0.84
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	1.2	1.2	1.2	1.2	0.1	0.18	0.18	0.18
Z-SCORE	4.73	3.75	4.21	4.42	2.97	1.09	2.33	2.71
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
Z-SCORE	-0.68	-0.96	-0.86	-0.79	-0.89	-1.2	-1.1	-1.03
SKEWNESS	2.68	1.18	1.83	2.16	0.88	-0.36	0.13	0.44
SKEWNESS/S.E.	7.08	3.13	4.84	5.72	2.32	-0.95	0.35	1.15
KURTOSIS	9.48	2.42	5.16	6.75	0.02	-1.89	-1.29	-0.72
KURTOSIS/S.E.	12.54	3.2	6.82	8.93	0.03	-2.51	-1.71	-0.96
STD. DEV.	0.18	0.25	0.22	0.2	0.44	4.11	0.72	0.57
VARIANCE	0.03	0.06	0.05	0.04	0.19	16.87	0.53	0.33
LCL	0.27	0.17	0.22	0.24	-1.34	-5.58	-1.73	-1.54
UCL	0.38	0.32	0.35	0.37	-1.07	-3.02	-1.28	-1.19
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
QUARTILE 3	0.4	0.4	0.4	0.4	-0.9	-0.92	-0.92	-0.92
DATA POINTS					42			

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 120, 1975 DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.33	0.25	0.29	0.31	-1.2	-4.11	-1.48	-1.35
STANDARD ERROR	0.03	0.04	0.03	0.03	0.07	0.63	0.11	0.09
MEDIAN	0.3	0.3	0.3	0.3	-1.2	-1.2	-1.2	-1.2
STANDARD ERROR	0.03	0.09	0.06	0.05	0.12	2.31	0.32	0.22
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.29	0.22	0.26	0.27	-1.27	-3.79	-1.51	-1.4
HAMPEL	0.3	0.23	0.27	0.28	-1.22	-0.99	-1.51	-1.37
BWEIGHT	0.29	0.24	0.26	0.28	-1.23	-1	-1.48	-1.36
W STATISTIC	0.68	0.83	0.79	0.75	0.83	0.66	0.84	0.85
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	1.2	1.2	1.2	1.2	0.1	0.18	0.18	0.18
Z-SCORE	4.74	3.76	4.23	4.44	2.97	1.06	2.32	2.71
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
Z-SCORE	-0.7	-1	-0.89	-0.82	-0.92	-1.26	-1.15	-1.08
SKEWNESS	2.69	1.16	1.83	2.17	0.86	-0.46	0.06	0.39
SKEWNESS/S.E.	7.12	3.08	4.84	5.74	2.26	-1.21	0.17	1.03
KURTOSIS	9.61	2.51	5.28	6.89	0.05	-1.81	-1.25	-0.69
KURTOSIS/S.E.	12.72	3.32	6.99	9.12	0.07	-2.4	-1.65	-0.91
STD. DEV.	0.18	0.25	0.22	0.2	0.44	4.05	0.72	0.56
VARIANCE	0.03	0.06	0.05	0.04	0.19	16.47	0.51	0 32
LCL	0.27	0.17	0.22	0.24	-1.33	-5.37	-1.7	-1.52
UCL	0.39	0.33	0.36	0.37	-1.06	-2.85	-1.25	-1 17
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9 21	-2.3	-1.96
QUARTILE 3	0.4	0.4	0.4	0.4	-0.9	-0.92	-0.92	-0.92
DATA POINTS	42							

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 125, ALL DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.23	0.08	0.15	0.19	-1.51	-7.19	-2.04	-1.78
STANDARD ERROR	0.01	0.02	0.02	0.01	0.04	0.46	.07	0.05
MEDIAN	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
STANDARD ERROR	0	0	0	0	0	0	0	0
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.2	0.028	0.11	0.15	-1.6	-8.09	-2.21	-1.91
HAMPEL	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
BWEIGHT	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
W STATISTIC	0.48	0.59	0.54	0.53	0.55	0.55	0.57	0.6
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	0.7	0.7	0.7	0.7	-0.3	-0.36	-0.36	-0.36
Z-SCORE	5.29	3.97	4.57	4.87	4.2	1.95	3.28	3.71
MINIMUM VALUE	0.1	0.0001	0.1	0.1	-2.3	-9.21	-2.3	-2.3
Z-SCORE	-1.45	-0.51	-0.45	-0.81	-2.74	-0.58	-0.52	-1.36
SKEWNESS	3.29	1.96	2.53	2.86	1.98	1.12	1.67	1.95
SKEWNESS/S.E.	10.33	6.15	7.94	8.97	6.22	3.5	5.25	6.11
KURTOSIS	12.48	3.35	6.7	8.87	6.05	-0.75	1.5	3.03
KURTOSIS/S.E.	19.56	5.26	10.5	13.91	9.48	-1.17	2.35	4.74
STD. DEV.	0.09	0.16	0.12	0.11	0.29	3.5	0.51	0.38
VARIANCE	0.01	0.02	0.01	0.01	0.08	12.23	0.26	0.15
LCL	0.21	0.04	0.12	0.16	-1.59	-8.1	-2.17	-1.88
UCL	0.25	0.12	0.19	0.21	-1.44	-6.28	-1.9	-1.68
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
QUARTILE 3	0.2	0.1	0.1	0.14	-1.6	-2.3	-2.3	-1.96
DATA POINTS				59				

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 125, ALL DAYSHIFT DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.23	0.08	0.15	0.18	-1.52	-7.19	-2.04	-1.79
STANDARD ERROR	0.01	0.02	0.02	0.01	0.04	0.47	0.07	0.05
MEDIAN	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
STANDARD ERROR	0	0	0	0	0	0	0	0
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.2	0.03	0.11	0.15	-1.6	-8.09	-2.22	-1.91
HAMPEL	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
BWEIGHT	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
W STATISTIC	0.46	0.58	0.53	0.52	0.54	0.55	0.57	0.6
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	0.7	0.7	0.7	0.7	-0.3	-0.36	-0.36	-0.36
Z-SCORE	5.3	4.02	4.62	4.92	4.25	1.96	3.34	3.78
MINIMUM VALUE	0.1	0.0001	0.1	0.1	-2.3	-9.21	-2.3	-2.3
Z-SCORE	-1.43	-0.51	-0.45	-0.8	-2.74	-.58	-0 51	-1.37
SKEWNESS	3.46	2.04	2.66	3.02	2.07	1.11	1.72	2.03
SKEWNESS/S.E.	10.47	6.17	8.06	9.13	6.25	3.37	5.21	6.14
KURTOSIS	13.6	3.81	7.54	9.9	6.8	-0.75	1.76	3.52
KURTOSIS/S.E.	20.59	5.77	11.42	14.99	10.29	-1.14	2.66	5.33
STD. DEV.	0.09	0.15	0.12	0.11	0.29	3.49	0.51	0.38
VARIANCE	0.01	0.02	0.01	0.01	0.08	12.18	0.26	0.14
LCL	0.2	0.04	0.12	0.16	-1.59	-8.14	-2.18	-1.89
UCL	0.25	0.12	0.18	0.21	-1.44	-6.25	-1.91	-1.68
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
QUARTILE 3	0.2	0.1	0.1	0.14	-1.6	-2.3	-2.3	-1.96
DATA POINTS					55			

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 125, 1975 DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.26	0.17	0.22	0.23	-1.39	-4.82	-1.71	-1.55
STANDARD ERROR	0.02	0.04	0.03	0.03	0.07	0.91	0.13	0.1
MEDIAN	0.2	0.2	0.2	0.2	-1.6	-1.61	-1.61	-1.61
STANDARD ERROR	0.03	0.09	0.06	0.05	0.12	2.31	0.32	0.22
MODE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.24	0.15	0.19	0.21	-1.46	-4.73	-1.77	-1.62
HAMPEL	0.2	0.17	0.21	0.21	-1.6	-1.22	-1.71	-1.58
BWEIGHT	0.2	0.17	0.21	0.22	-1.6	-1.22	-1.72	-1.58
W STATISTIC	0.69	0.83	0.82	0.79	0.69	0.68	0.82	0.81
SIG. LEVEL	0	0	0.0013	0.0004	0	0	0.0011	0.001
MAXIMUM VALUE	0.5	0.5	0.5	0.5	-0.6	-0.69	-0.69	-0.69
Z-SCORE	2.55	1.89	2.18	2.33	2.4	1.01	1.69	1.93
MINIMUM VALUE	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
Z-SCORE	-0.64	-0.97	-0.88	-0.81	-0.66	-1.08	-0.98	-0.9
SKEWNESS	1.17	0.33	0.68	0.88	1.03	-0.18	0.25	0.54
SKEWNESS/S.E.	2.13	0.6	1.23	1.61	1.88	-0.32	0.45	0.99
KURTOSIS	-0.03	-1.47	-0.98	-0.64	-0.46	-2.05	-1.64	-1.34
KURTOSIS/S.E.	-0.03	-1.35	-0.9	-0.59	-0.42	-1.87	-1.5	-1.22
STD. DEV.	0.09	0.17	0.13	0.11	0.33	4.08	0.6	0.45
VARIANCE	0.01	0.03	0.02	0.01	0.11	16.67	0.36	0.2
LCL	0.22	0.09	0.15	0.18	-1.54	-6.73	-1.99	-1.76
UCL	0.3	0.25	0.28	0.29	-1.23	-2.91	-1.43	-1.35
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
QUARTILE 3	0.3	0.3	0.3	0.3	-1.2	-1.2	-1.2	-1.2
DATA POINTS					20			

*MDL = Minimum detection limit

ROCKY FLATS PLANT, GOLDEN, COLORADO

DESCRIPTIVE STATISTICS FROM BMDP FOR CARBON TETRACHLORIDE SAMPLES WITH SUBSTITUTIONS FOR CENSORED VALUES: AIR CONCENTRATION AND NATURAL LOG TRANSFORMATION OF AIR CONCENTRATION VALUES FOR BUILDING 707, MODULE C GLOVE BOX 125, 1976 DATA

	AIR CONCENTRATION (IN PARTS PER MILLION)				NATURAL LOG TRANSFORMED DATA			
	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED	MDL VALUE USED	0.0001 SUBSTITUTED	0.5(MDL) SUBSTITUTED	0.707(MDL) SUBSTITUTED
MEAN	0.2	0.01	0.11	0.15	-1.59	-8.79	-2:25	-1.93
STANDARD ERROR	0.003	0.01	0.006	0.005	0.01	0.29	0.03	0.02
MEDIAN	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
STANDARD ERROR	0	0	0	0	0	0	0	0
MODE	0 2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
TRIM (.15)	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
HAMPEL	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
BWEIGHT	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
W STATISTIC	0.17	0.25	0.25	0.24	0.17	0.25	0.25	0.25
SIG. LEVEL	0	0	0	0	0	0	0	0
MAXIMUM VALUE	0.3	0.3	0.3	0.3	-1.2	-1.2	-1.2	-1.2
Z-SCORE	5.92	4.9	5.28	5.55	5.92	4.24	4.98	5.36
MINIMUM VALUE	0.2	0.0001	0.1	0 14	-1.6	-9.21	-2.3	-1.96
Z-SCORE	-0.16	-0.23	-0.22	-0.21	-0.16	-0.24	-0.23	-0.22
SKEWNESS	5.6	4.04	4.4	4.79	5.6	3.79	4.1	4.51
SKEWNESS/S.E.	13.9	10.2	10.93	11.89	13.9	9.41	10.18	11.2
KURTOSIS	30.16	15.33	19.1	22.91	30.16	12.72	15.99	20.19
KURTOSIS/S.E.	37.45	19.03	23.71	28.45	37.45	15.8	19.86	25.07
STD. DEV.	0.02	0.06	0.04	0.03	0.07	1.79	0.21	0.13
VARIANCE	0.0003	0.003	0.001	0.0007	0.004	3.2	0.04	0.02
LCL	0.2	-0.005	0.1	0.14	-1.61	-9.39	-2.32	-1.97
UCL	0.21	0.03	0.12	0.16	-1.57	-8.19	-2.18	-1 88
QUARTILE 1	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1.96
QUARTILE 3	0.2	0.0001	0.1	0.14	-1.6	-9.21	-2.3	-1 96
DATA POINTS					37			

*MDL = Minimum detection limit

Appendix E

Results of Maximum Likelihood Estimate Program

MAXIMUM LIKELIHOOD ESTIMATE PROGRAM RESULTS FOR CARBON TETRACHLORIDE SAMPLES, BUILDING 707, MODULE C, GLOVE BOX 25, ROCKY FLATS PLANT, GOLDEN, COLORADO

	All Samples	Section 25A All Samples	Section 25B All Samples	Dayshift Samples	1974 All Samples	1974 Dayshift Samples
Number of Samples	140	70	70	131	52	47
Number of Censored Samples	53	18	35	48	5	3
Estimated Arithmetic Mean of Air Concentration (parts per million)	1.59	3	0.41	1.61	3.46	3.49
Estimated Arithmetic Standard Deviation of Air Concentration (parts per million)	7.39	13.59	0.85	7.03	12.01	8.5
Estimated Arithmetic Mean of Natural Logarithms of Air Concentration	-1.1	-0.44	-1.71	-1.02	-0.04	0.28
Estimated Arithmetic Standard Deviation of Natural Logarithms of Air Concentration	1.77	1.75	1.28	1.73	1.6	1.39
Estimated Geometric Mean of Natural Logarithms of Air Concentration (parts per million)	0.33	0.65	0.18	0.36	0.96	1.32
Estimated Geometric Standard Deviation of Natural Logarithms of Air Concentration (parts per million)	5.85	5.77	3.61	5.64	4.97	4.02

MAXIMUM LIKELIHOOD ESTIMATE PROGRAM RESULTS FOR CARBON TETRACHLORIDE SAMPLES, BUILDING 707, MODULE C, GLOVE BOX 25, ROCKY FLATS PLANT, GOLDEN, COLORADO (continued)

	1975 All Samples	1975 Dayshift Samples
Number of Samples	33	32
Number of Censored Samples	1	1
Estimated Arithmetic Mean of Air Concentration (parts per million)	0.8	0.8
Estimated Arithmetic Standard Deviation of Air Concentration (parts per million)	0.63	0.65
Estimated Arithmetic Mean of Natural Logarithms of Air Concentration	-0.47	-0.47
Estimated Arithmetic Standard Deviation of Natural Logarithms of Air Concentration	0.7	0.71
Estimated Geometric Mean of Natural Logarithms of Air Concentration (parts per million)	0.62	0.62
Estimated Geometric Standard Deviation of Natural Logarithms of Air Concentration (parts per million)	2.01	2.04

MAXIMUM LIKELIHOOD ESTIMATE PROGRAM RESULTS FOR CARBON TETRACHLORIDE SAMPLES, BUILDING 707, MODULE C, GLOVE BOX 30, ROCKY FLATS PLANT, GOLDEN, COLORADO

	All Samples	Dayshift Samples	1975 All Samples	1975 Dayshift Samples
Number of Samples	109	103	49	47
Number of Censored Samples	71	67	18	17
Estimated Arithmetic Mean of Air Concentration (parts per million)	0.19	0.19	0.25	0.26
Estimated Arithmetic Standard of Air Concentration (parts per million)	0.14	0.14	0.13	0.14
Estimated Arithmetic Mean of Natural Logarithms of Air Concentration	-1.9	-1.9	-1.49	-1.48
Estimated Arithmetic Standard Deviation of Natural Logarithms of Air Concentration	0.67	0.68	0.49	0.5
Estimated Geometric Mean of Natural Logarithms of Air Concentration (parts per million)	0.15	0.15	0.23	0.23
Estimated Geometric Standard Deviation of Natural Logarithms of Air Concentration (parts per million)	1.96	1.97	1.64	1.64

MAXIMUM LIKELIHOOD ESTIMATE PROGRAM RESULTS FOR CARBON TETRACHLORIDE SAMPLES, BUILDING 707, MODULE C, GLOVE BOX 45, ROCKY FLATS PLANT, GOLDEN, COLORADO

	All Samples	Section 45A All Samples	Section 45B All Samples	Dayshift Samples	Other shifts All Samples	1974 All Samples
Number of Samples	151	70	82	144	5	19
Number of Censored Samples	94	47	48	91	1	6
Estimated Arithmetic Mean of Air Concentration (parts per million)	0.32	0.37	0.28	0.31	0.59	0.26
Estimated Arithmetic Standard of Air Concentration (parts per million)	0.83	1.46	0.56	0.85	0.63	0.49
Estimated Arithmetic Mean of Natural Logarithms of Air Concentration	-2.18	-2.4	-2.05	-2.25	-0.92	-2.08
Estimated Arithmetic Standard Deviation of Natural Logarithms of Air Concentration	1.44	1.68	1.26	1.46	0.88	1.22
Estimated Geometric Mean of Natural Logarithms of Air Concentration (parts per million)	0.11	0.09	0.13	0.11	0.4	0.12
Estimated Geometric Standard Deviation of Natural Logarithms of Air Concentration (parts per million)	4.21	5.35	3.51	4.33	2.4	3.4

MAXIMUM LIKELIHOOD ESTIMATE PROGRAM RESULTS FOR CARBON TETRACHLORIDE SAMPLES, BUILDING 707, MODULE C, GLOVE BOX 45, ROCKY FLATS PLANT, GOLDEN, COLORADO (continued)

	1975 Dayshift Samples	1975 All Samples	1977 Dayshift Samples	1977 All Samples
Number of Samples	54	56	11	12
Number of Censored Samples	24	24	6	6
Estimated Arithmetic Mean of Air Concentration (parts per million)	0.47	0.5	0.19	0.2
Estimated Arithmetic Standard of Air Concentration (parts per million)	0.89	0.93	0.04	0.05
Estimated Arithmetic Mean of Natural Logarithms of Air Concentration	-1.5	-1.44	-1.67	-1.65
Estimated Arithmetic Standard Deviation of Natural Logarithms of Air Concentration	1.22	1.22	0.19	0.24
Estimated Geometric Mean of Natural Logarithms of Air Concentration (parts per million)	0.22	0.24	0.19	0.19
Estimated Geometric Standard Deviation of Natural Logarithms of Air Concentration (parts per million)	3.4	3.39	1.22	1.28

MAXIMUM LIKELIHOOD ESTIMATE PROGRAM RESULTS FOR CARBON TETRACHLORIDE SAMPLES, BUILDING 707, MODULE C, GLOVE BOX 60, ROCKY FLATS PLANT, GOLDEN, COLORADO

	All Samples
Number of Samples	4
Number of Censored Samples	2
Estimated Arithmetic Mean of Air Concentration (parts per million)	1.43
Estimated Arithmetic Standard of Air Concentration (parts per million)	11.62
Estimated Arithmetic Mean of Natural Logarithms of Air Concentration	-1.74
Estimated Arithmetic Standard Deviation of Natural Logarithms of Air Concentration	2.05
Estimated Geometric Mean of Natural Logarithms of Air Concentration (parts per million)	0.17
Estimated Geometric Standard Deviation of Natural Logarithms of Air Concentration (parts per million)	7.77

MAXIMUM LIKELIHOOD ESTIMATE PROGRAM RESULTS FOR CARBON TETRACHLORIDE SAMPLES, BUILDING 707, MODULE C, GLOVE BOX 65, ROCKY FLATS PLANT, GOLDEN, COLORADO

	All Samples	Section 65A All Samples	Section 65B All Samples	65 Dayshift Samples	Other shifts All Samples	1975 All Samples
Number of Samples	116	70	46	103	12	46
Number of Censored Samples	53	33	20	46	6	5
Estimated Arithmetic Mean of Air Concentration (parts per million)	0.48	0.6	0.36	0.45	0.81	0.86
Estimated Arithmetic Standard of Air Concentration (parts per million)	0.99	1.69	0.44	0.85	3.59	1.12
Estimated Arithmetic Mean of Natural Logarithms of Air Concentration	-1.55	-1.61	-1.46	-1.54	-1.73	-0.64
Estimated Arithmetic Standard Deviation of Natural Logarithms of Air Concentration	1.28	1.48	0.95	1.23	1.74	1.0
Estimated Geometric Mean of Natural Logarithms of Air Concentration (parts per million)	0.21	0.2	0.23	0.21	0.18	0.53
Estimated Geometric Standard Deviation of Natural Logarithms of Air Concentration (parts per million)	3.61	4.4	2.57	3.41	5.71	2.71

MAXIMUM LIKELIHOOD ESTIMATE PROGRAM RESULTS FOR CARBON TETRACHLORIDE SAMPLES, BUILDING 707, MODULE C, GLOVE BOX 65, ROCKY FLATS PLANT, GOLDEN, COLORADO (continued)

	1975 Dayshift Samples
Number of Samples	40
Number of Censored Samples	5
Estimated Arithmetic Mean of Air Concentration (parts per million)	0.86
Estimated Arithmetic Standard of Air Concentration (parts per million)	1.04
Estimated Arithmetic Mean of Natural Logarithms of Air Concentration	-0.61
Estimated Arithmetic Standard Deviation of Natural Logarithms of Air Concentration	0.95
Estimated Geometric Mean of Natural Logarithms of Air Concentration (parts per million)	0.55
Estimated Geometric Standard Deviation of Natural Logarithms of Air Concentration (parts per million)	2.59

MAXIMUM LIKELIHOOD ESTIMATE PROGRAM RESULTS FOR CARBON TETRACHLORIDE SAMPLES, BUILDING 707, MODULE C, GLOVE BOX 70, ROCKY FLATS PLANT, GOLDEN, COLORADO

	All Samples	Dayshift Samples	1975 All Samples	Other shifts All Samples
Number of Samples	45	41	27	4
Number of Censored Samples	21	19	5	2
Estimated Arithmetic Mean of Air Concentration (parts per million)	0.26	0.26	0.33	0.56
Estimated Arithmetic Standard of Air Concentration (parts per million)	0.2	0.19	0.19	1.65
Estimated Arithmetic Mean of Natural Logarithms of Air Concentration	-1.57	-1.58	-1.26	-1.71
Estimated Arithmetic Standard Deviation of Natural Logarithms of Air Concentration	0.69	0.67	0.53	1.5
Estimated Geometric Mean of Natural Logarithms of Air Concentration (parts per million)	0.21	0.21	0.28	0.18
Estimated Geometric Standard Deviation of Natural Logarithms of Air Concentration (parts per million)	1.98	1.95	1.7	4.5

MAXIMUM LIKELIHOOD ESTIMATE PROGRAM RESULTS FOR CARBON TETRACHLORIDE SAMPLES, BUILDING 707, MODULE C, GLOVE BOX 80, ROCKY FLATS PLANT, GOLDEN, COLORADO

	80 All Samples	Dayshift Samples	1975 All Samples	1975 Dayshift Samples
Number of Samples	47	45	29	28
Number of Censored Samples	22	21	6	6
Estimated Arithmetic Mean of Air Concentration (parts per million)	0.28	0.27	0.36	0.35
Estimated Arithmetic Standard of Air Concentration (parts per million)	0.27	0.24	0.25	0.25
Estimated Arithmetic Mean of Natural Logarithms of Air Concentration	-1.6	-1.6	-1.24	-1.27
Estimated Arithmetic Standard Deviation of Natural Logarithms of Air Concentration	0.8	0.77	0.64	0.64
Estimated Geometric Mean of Natural Logarithms of Air Concentration (parts per million)	0.2	0.2	0.29	0.28
Estimated Geometric Standard Deviation of Natural Logarithms of Air Concentration (parts per million)	2.23	2.16	1.9	1.9

MAXIMUM LIKELIHOOD ESTIMATE PROGRAM RESULTS FOR CARBON TETRACHLORIDE SAMPLES, BUILDING 707, MODULE C, GLOVE BOX 85, ROCKY FLATS PLANT, GOLDEN, COLORADO

	All Samples	Dayshift Samples	Section 85E All Samples	1975 All Samples	1975 Dayshift Samples
Number of Samples	111	105	12	40	38
Number of Censored Samples	56	51	6	9	7
Estimated Arithmetic Mean of Air Concentration (parts per million)	0.35	0.38	0.22	0.35	0.37
Estimated Arithmetic Standard of Air Concentration (parts per million)	0.65	0.72	0.15	0.25	0.25
Estimated Arithmetic Mean of Natural Logarithms of Air Concentration	-1.81	-1.75	-1.7	-1.25	-1.19
Estimated Arithmetic Standard Deviation of Natural Logarithms of Air Concentration	1.22	1.24	0.61	0.64	0.62
Estimated Geometric Mean of Natural Logarithms of Air Concentration (parts per million)	0.16	0.17	0.18	0.29	0.3
Estimated Geometric Standard Deviation of Natural Logarithms of Air Concentration (parts per million)	3.4	3.46	1.84	1.9	1.85

MAXIMUM LIKELIHOOD ESTIMATE PROGRAM RESULTS FOR CARBON TETRACHLORIDE SAMPLES, BUILDING 707, MODULE C, GLOVE BOX 95, ROCKY FLATS PLANT, GOLDEN, COLORADO

	All Samples	Dayshift Samples	Section 95E Al Samples	Section 95W All Samples	1975 All Samples	1975 Dayshift Samples
Number of Samples	92	81	23	34	23	16
Number of Censored Samples	43	33	6	18	14	7
Estimated Arithmetic Mean of Air Concentration (parts per million)	0.23	0.26	0.36	0.19	0.26	0.34
Estimated Arithmetic Standard of Air Concentration (parts per million)	0.18	0.22	0.27	0.05	0.43	0.46
Estimated Arithmetic Mean of Natural Logarithms of Air Concentration	-1.71	-1.6	-1.26	-1.7	-2.0	-1.59
Estimated Arithmetic Standard Deviation of Natural Logarithms of Air Concentration	0.7	0.72	0.68	0.26	1.14	1.02
Estimated Geometric Mean of Natural Logarithms of Air Concentration (parts per million)	0.18	0.2	0.28	0.18	0.14	0.2
Estimated Geometric Standard Deviation of Natural Logarithms of Air Concentration (parts per million)	2.02	2.05	1.97	1.3	3.14	2.77

MAXIMUM LIKELIHOOD ESTIMATE PROGRAM RESULTS FOR CARBON TETRACHLORIDE SAMPLES, BUILDING 707, MODULE C, GLOVE BOX 95, ROCKY FLATS PLANT, GOLDEN, COLORADO (continued)

	1976 All Samples	1976 Dayshift Samples
Number of Samples	68	65
Number of Censored Samples	29	26
Estimated Arithmetic Mean of Air Concentration (parts per million)	0.25	0.26
Estimated Arithmetic Standard of Air Concentration (parts per million)	0.2	0.2
Estimated Arithmetic Mean of Natural Logarithms of Air Concentration	-1.64	-1.6
Estimated Arithmetic Standard Deviation of Natural Logarithms of Air Concentration	0.7	0.69
Estimated Geometric Mean of Natural Logarithms of Air Concentration (parts per million)	0.19	0.2
Estimated Geometric Standard Deviation of Natural Logarithms of Air Concentration (parts per million)	2.01	1.99

MAXIMUM LIKELIHOOD ESTIMATE PROGRAM RESULTS FOR CARBON TETRACHLORIDE SAMPLES, BUILDING 707, MODULE C, GLOVE BOX 110, ROCKY FLATS PLANT, GOLDEN, COLORADO

	All Samples	Dayshift Samples	Other shifts All Samples	Section 110E All Samples	Section 110W All Samples	Section 110S All Samples
Number of Samples	136	119	12	16	9	8
Number of Censored Samples	21	19	3	9	3	0
Estimated Arithmetic Mean of Air Concentration (parts per million)	0.97	0.96	1.61	0.3	1.22	0.31
Estimated Arithmetic Standard of Air Concentration (parts per million)	1.45	1.43	4.85	0.38	2.7	0.11
Estimated Arithmetic Mean of Natural Logarithms of Air Concentration	-0.61	-0.62	-0.68	-1.66	-0.69	-1.22
Estimated Arithmetic Standard Deviation of Natural Logarithms of Air Concentration	1.08	1.08	1.52	0.97	1.33	0.34
Estimated Geometric Mean of Natural Logarithms of Air Concentration (parts per million)	0.54	0.54	0.51	0.19	0.5	0.3
Estimated Geometric Standard Deviation of Natural Logarithms of Air Concentration (parts per million)	2.95	2.95	4.57	2.63	3.79	1.4

MAXIMUM LIKELIHOOD ESTIMATE PROGRAM RESULTS FOR CARBON TETRACHLORIDE SAMPLES, BUILDING 707, MODULE C, GLOVE BOX 110, ROCKY FLATS PLANT, GOLDEN, COLORADO (continued)

	1974	1974 Day	1975 All Samples	1975 Dayshift Samples	1976 All Samples	1976 Dayshift Samples
Number of Samples	38	35	76	70	20	19
Number of Censored Samples	0	0	9	8	12	11
Estimated Arithmetic Mean of Air Concentration (parts per million)	1.13	1.07	1.0	1.05	0.19	0.19
Estimated Arithmetic Standard of Air Concentration (parts per million)	1.08	1.03	1.42	1.51	0.07	0.07
Estimated Arithmetic Mean of Natural Logarithms of Air Concentration	-0.21	-0.26	-0.55	-0.51	-1.73	-1.72
Estimated Arithmetic Standard Deviation of Natural Logarithms of Air Concentration	0.81	0.81	1.05	1.06	0.35	0.35
Estimated Geometric Mean of Natural Logarithms of Air Concentration (parts per million)	0.81	0.77	0.57	0.6	0.18	0.18
Estimated Geometric Standard Deviation of Natural Logarithms of Air Concentration (parts per million)	2.24	2.25	2.86	2.88	1.42	1.42

MAXIMUM LIKELIHOOD ESTIMATE PROGRAM RESULTS FOR CARBON TETRACHLORIDE SAMPLES, BUILDING 707, MODULE C, GLOVE BOX 115, ROCKY FLATS PLANT, GOLDEN, COLORADO

	All Samples	Dayshift Samples	1975 All Samples	1975 Dayshift Samples
Number of Samples	58	56	16	15
Number of Censored Samples	29	28	7	7
Estimated Arithmetic Mean of Air Concentration (parts per million)	0.23	0.23	0.24	0.23
Estimated Arithmetic Standard of Air Concentration (parts per million)	0.24	0.25	0.14	0.15
Estimated Arithmetic Mean of Natural Logarithms of Air Concentration	-1.81	-1.82	-1.6	-1.64
Estimated Arithmetic Standard Deviation of Natural Logarithms of Air Concentration	0.85	0.86	0.56	0.6
Estimated Geometric Mean of Natural Logarithms of Air Concentration (parts per million)	0.16	0.16	0.2	0.19
Estimated Geometric Standard Deviation of Natural Logarithms of Air Concentration (parts per million)	2.33	2.36	1.76	1.81

MAXIMUM LIKELIHOOD ESTIMATE PROGRAM RESULTS FOR CARBON TETRACHLORIDE SAMPLES, BUILDING 707, MODULE C, GLOVE BOX 120, ROCKY FLATS PLANT, GOLDEN, COLORADO

	All Samples	Dayshift Samples	1975 All Samples	1975 Dayshift Samples
Number of Samples	45	42	42	40
Number of Censored Samples	19	17	16	15
Estimated Arithmetic Mean of Air Concentration (parts per million)	0.24	0.24	0.24	0.25
Estimated Arithmetic Standard of Air Concentration (parts per million)	0.12	0.12	0.12	0.12
Estimated Arithmetic Mean of Natural Logarithms of Air Concentration	-1.56	-1.54	-1.52	-1.51
Estimated Arithmetic Standard Deviation of Natural Logarithms of Air Concentration	0.49	0.49	0.47	0.48
Estimated Geometric Mean of Natural Logarithms of Air Concentration (parts per million)	0.21	0.21	0.22	0.22
Estimated Geometric Standard Deviation of Natural Logarithms of Air Concentration (parts per million)	1.63	1.63	1.6	1.61

MAXIMUM LIKELIHOOD ESTIMATE PROGRAM RESULTS FOR CARBON TETRACHLORIDE SAMPLES, BUILDING 707, MODULE C, GLOVE BOX 125, ROCKY FLATS PLANT, GOLDEN, COLORADO

	All Samples	Dayshift Samples	1975 All Samples	1975 Dayshift Samples
Number of Samples	59	55	20	18
Number of Censored Samples	44	41	9	8
Estimated Arithmetic Mean of Air Concentration (parts per million)	0.15	0.15	0.21	0.21
Estimated Arithmetic Standard of Air Concentration (parts per million)	0.1	0.09	0.09	0.07
Estimated Arithmetic Mean of Natural Logarithms of Air Concentration	-2.06	-2.04	-1.64	-1.64
Estimated Arithmetic Standard Deviation of Natural Logarithms of Air Concentration	0.58	0.55	0.39	0.35
Estimated Geometric Mean of Natural Logarithms of Air Concentration (parts per million)	0.13	0.13	0.2	0.19
Estimated Geometric Standard Deviation of Natural Logarithms of Air Concentration (parts per million)	1.78	1.73	1.48	1.42

MAXIMUM LIKELIHOOD ESTIMATE PROGRAM RESULTS FOR CARBON TETRACHLORIDE SAMPLES, BUILDING 707, MODULE C, ROCKY FLATS PLANT, GOLDEN, COLORADO

	All Samples	Glove Box 25 Removed	Glove Box 110 Removed	Glove Boxes 25 and 110 Removed
Number of Samples	1177	1053	1041	901
Number of Censored Samples	580	527	537	490
Estimated Arithmetic Mean of Air Concentration (parts per million)	0.45	0.35	0.36	0.27
Estimated Arithmetic Standard of Air Concentration (parts per million)	0.96	0.62	0.76	0.38
Estimated Arithmetic Mean of Natural Logarithms of Air Concentration	-1.71	-1.77	-1.86	-1.88
Estimated Arithmetic Standard Deviation of Natural Logarithms of Air Concentration	1.33	1.19	1.3	1.06
Estimated Geometric Mean of Natural Logarithms of Air Concentration (parts per million)	0.18	0.17	0.16	0.15
Estimated Geometric Standard Deviation of Natural Logarithms of Air Concentration (parts per million)	3.78	3.29	3.67	2.89
Percent Censored	49.3	50	51.6	54.4

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