



**TOXICOLOGICAL REVIEW**

**OF**

**CHLOROPRENE**

(CAS No. 126-99-8)

**In Support of Summary Information on the  
Integrated Risk Information System (IRIS)**

*September 2009*

**NOTICE**

This document is an **External peer review draft**. This information is distributed solely for the purpose of pre-dissemination peer review under applicable information quality guidelines. It has not been formally disseminated by EPA. It does not represent and should not be construed to represent any Agency determination or policy. It is being circulated for review of its technical accuracy and science policy implications.

U.S. Environmental Protection Agency  
Washington, DC

## **DISCLAIMER**

1           This document is a preliminary draft for review purposes only. This information is distributed  
2 solely for the purpose of pre-dissemination peer review under applicable information quality  
3 guidelines. It has not been formally disseminated by EPA. It does not represent and should not be  
4 construed to represent any Agency determination or policy. Mention of trade names or commercial  
5 products does not constitute endorsement or recommendation for use.

## TABLE OF CONTENTS

LIST OF TABLES.....	v
LIST OF FIGURES.....	viii
LIST OF ABBREVIATIONS AND ACRONYMS.....	ix
FOREWORD.....	xi
AUTHORS, CONTRIBUTORS, AND REVIEWERS.....	xii
<b>1. INTRODUCTION.....</b>	<b>1-1</b>
<b>2. CHEMICAL AND PHYSICAL INFORMATION.....</b>	<b>2-1</b>
<b>3. TOXICOKINETICS.....</b>	<b>3-1</b>
3.1. ABSORPTION.....	3-1
3.2. DISTRIBUTION.....	3-1
3.3. METABOLISM.....	3-2
3.4. ELIMINATION.....	3-7
3.5. PHYSIOLOGICALLY BASED TOXICOKINETIC MODELS.....	3-7
<b>4. HAZARD IDENTIFICATION.....</b>	<b>4-1</b>
4.1. STUDIES IN HUMANS—EPIDEMIOLOGY, CASE REPORTS, CLINICAL CONTROLS...4-1	
4.1.1. Chloroprene Exposure and Cancer Effects.....	4-1
4.1.1.1. Overview.....	4-1
4.1.1.2. Individual Occupational Studies.....	4-1
4.1.1.3. Summary and Discussion of Relevant Methodological Issues.....	4-15
4.1.2. Chloroprene Exposure and Noncancer Effects.....	4-19
4.1.2.1. Acute-, Short-, and Subchronic-Duration Noncancer Effects.....	4-19
4.1.2.2. Chronic Noncancer Effects.....	4-20
4.2. SUBCHRONIC AND CHRONIC STUDIES AND CANCER BIOASSAYS IN ANIMALS— ORAL AND INHALATION.....	4-21
4.2.1. Oral Exposure.....	4-21
4.2.2. Inhalation Exposure.....	4-23
4.3. REPRODUCTIVE/DEVELOPMENTAL STUDIES—ORAL AND INHALATION.....	4-44
4.4. OTHER DURATION- OR ENDPOINT-SPECIFIC STUDIES.....	4-50
4.4.1. Acute and Subchronic Studies.....	4-50
4.4.2. Immunotoxicity.....	4-52
4.5. MECHANISTIC DATA AND OTHER STUDIES IN SUPPORT OF MODE OF ACTION...4-53	
4.5.1. Mode-of-Action Studies.....	4-53
4.5.2. Genotoxicity Studies.....	4-56
4.5.2.1. Bacterial Mutagenicity Assays.....	4-57
4.5.2.2. Mammalian Cell Assays.....	4-58
4.5.2.3. In Vivo Bioassays.....	4-59
4.5.3. Structural Alerts.....	4-60
4.6. SYNTHESIS OF MAJOR NONCANCER EFFECTS.....	4-61
4.6.1. Animal Studies.....	4-62

4.6.1.1. Oral Exposure .....	4-62
4.6.1.2. Inhalation Exposure .....	4-62
4.7. EVALUATION OF CARCINOGENICITY .....	4-65
4.7.1. Summary of Overall Weight of Evidence .....	4-66
4.7.2. Synthesis of Human, Animal, and Other Supporting Evidence .....	4-68
4.7.2.1. Human .....	4-68
4.7.2.1.1. Evidence for Causality .....	4-70
4.7.2.2. Laboratory Animal .....	4-72
4.7.3. Mode-of-Action Information .....	4-73
4.7.3.1. Hypothesized Mode of Action .....	4-73
4.7.3.2. Experimental Support for the Hypothesized Mode of Action .....	4-73
4.7.3.3. Conclusions about the Hypothesized Mode of Action .....	4-76
4.8. SUSCEPTIBLE POPULATIONS AND LIFE STAGES .....	4-78
4.8.1. Possible Childhood Susceptibility .....	4-78
4.8.2. Possible Gender Differences .....	4-79
<b>5. DOSE-RESPONSE ASSESSMENTS .....</b>	<b>5-1</b>
5.1. ORAL REFERENCE DOSE (RfD) .....	5-1
5.2. INHALATION REFERENCE CONCENTRATION (RfC) .....	5-1
5.2.1. Choice of Principal Study and Critical Effect(s) .....	5-1
5.2.2. Methods of Analysis .....	5-3
5.2.3. Exposure Duration and Dosimetric Adjustments .....	5-4
5.2.4. RfC Derivation—Including Application of Uncertainty Factors .....	5-7
5.2.5. Previous RfC Assessment .....	5-8
5.2.6. RfC Comparison Information .....	5-8
5.3. UNCERTAINTIES IN THE INHALATION REFERENCE CONCENTRATION .....	5-9
5.4. CANCER ASSESSMENT .....	5-12
5.4.1. Choice of Study/Data—with Rationale and Justification .....	5-12
5.4.2. Dose-Response Data .....	5-12
5.4.3. Dose Adjustments and Extrapolation Methods .....	5-14
5.4.4. Oral Slope Factor and Inhalation Unit Risk .....	5-17
5.4.5. Application of Age-Dependent Adjustment Factors .....	5-21
5.4.6. Previous Cancer Assessment .....	5-22
5.4.7. Uncertainties in Cancer Risk Values .....	5-22
<b>6. MAJOR CONCLUSIONS IN CHARACTERIZATION OF HAZARD AND DOSE RESPONSE .....</b>	<b>6-1</b>
6.1. HUMAN HAZARD POTENTIAL .....	6-1
6.2. DOSE RESPONSE .....	6-4
<b>7. REFERENCES .....</b>	<b>7-1</b>
APPENDIX A. Summary of External Peer Review and Public Comments and Disposition .....	A-1
APPENDIX B. Benchmark Dose Modeling Results for the Derivation of the RfC .....	B-1
APPENDIX C. Cancer Dose-Response Modeling Results .....	C-1

## LIST OF TABLES

Table 2-1. Physical properties and chemical identity of chloroprene .....	2-3
Table 3-1. Tissue-to-air partition coefficients for chloroprene .....	3-2
Table 3-2. Liver microsomal metabolites as a percentage of 1-butanol internal standard.....	3-3
Table 3-3. Stereochemical comparison of relative amounts (percentages) of R- and S-enantiomers of the major chloroprene metabolite (1-chloroethenyl)oxirane from liver microsomes compared across species, strains, gender, and chloroprene concentration (mM) .....	3-5
Table 3-4. Kinetic parameters used to describe the microsomal oxidation of chloroprene .....	3-6
Table 3-5. Metabolic parameters of chloroprene.....	3-7
Table 3-6. Physiological parameters used for chloroprene PBPK modeling .....	3-8
Table 4-1. Standardized mortality ratios (SMRs) for the DuPont Louisville Works cohort relative to general U.S. population rates.....	4-3
Table 4-2. Standardized mortality ratios (SMRs) for all cancers, liver and lung cancer among males exposed to chloroprene relative to general Chinese population rates .....	4-5
Table 4-3. Standardized mortality ratios (SMRs) for selected cancer risks relative to general population rates of Moscow, Russia.....	4-7
Table 4-4. Selected relative risk (RRs) estimates for the high exposure group relative to unexposed factory workers .....	4-7
Table 4-5. Internal relative risks (RRs) by duration of employment in the high-exposure category.....	4-8
Table 4-6. Selected standardized incidence ratios (SIRs) for chloroprene monomer cohort relative to the general Armenian population. ....	4-9
Table 4-7. Standardized incidence ratios (SIRs) for elevated cancer risks for plant workers relative to general population rates of Isère, France.....	4-11
Table 4-8. Standardized mortality ratios (SMRs) at each of four chloroprene production facilities .....	4-13
Table 4-9. Relative risks (RRs) for respiratory cancers by cumulative chloroprene exposure .....	4-14
Table 4-10. Epidemiologic summary results of respiratory system cancers: Overall standardized mortality ratios (SMRs) and SMRs for intermediate and high chloroprene exposures relative to external population comparison .....	4-16
Table 4-11. Epidemiologic summary results of liver/biliary passage cancers: Total cohort standardized mortality ratios (SMRs) and relative risk (RRs) for intermediate and high chloroprene exposures .....	4-17
Table 4-12. Frequency of chromosomal aberrations in lymphocyte culture cells from chloroprene production workers .....	4-21
Table 4-13. Tumor incidence in female BD IV rats treated orally with chloroprene (100 mg/kg) on GD17 and in their progeny treated (50 mg/kg) weekly for life (120 weeks).....	4-22

Table 4-14. Distribution of tumors in female BD IV rats treated orally with chloroprene (100 mg/kg) on GD17 and their progeny treated (50mg/kg) weekly for life (120 weeks).....	4-23
Table 4-15. Survival and body weights of rats in the 16-day inhalation study of chloroprene.....	4-24
Table 4-16. Incidences of selected nonneoplastic lesions in rats in the 16-day inhalation study of chloroprene.....	4-25
Table 4-17. Survival and body weights of mice in the 16-day inhalation study of chloroprene.....	4-26
Table 4-18. Survival and body weights of rats in the 13-week inhalation study of chloroprene.....	4-26
Table 4-19. Incidences of selected nonneoplastic lesions in rats in the 13-week inhalation study of chloroprene.....	4-28
Table 4-20. Survival and body weights of mice in the 13-week inhalation study of chloroprene.....	4-28
Table 4-21. Incidences of forestomach lesions in mice in the 13-week inhalation study of chloroprene.....	4-29
Table 4-22. 2-Year survival probability estimates for F344/N rats chronically exposed (2 years) to chloroprene by inhalation.....	4-30
Table 4-23. Incidence and severity of non-neoplastic lesions in F344/N rats chronically exposed (2 years) to chloroprene by inhalation.....	4-31
Table 4-24. Incidence of neoplasms in F344/N rats chronically exposed (2 years) to chloroprene by inhalation.....	4-32
Table 4-25. 2-Year survival probabilities for B6C3F1 mice chronically exposed (2 years) to chloroprene by inhalation.....	4-34
Table 4-26. Incidence and severity of non-neoplastic lesions in B6C3F1 mice chronically exposed (2 years) to chloroprene by inhalation.....	4-35
Table 4-27. Incidence of neoplasms in B6C3F1 mice chronically exposed (2 years) to chloroprene by inhalation.....	4-36
Table 4-28. Survival-adjusted neoplasm rates for mice in the 2-year inhalation study of chloroprene.....	4-38
Table 4-29. Selected mean relative organ weights of rats exposed for 24 months and hamsters exposed for 18 months to chloroprene vapor.....	4-40
Table 4-30. Incidence, site and type of tumor in selected organs and tissues of rats exposed to chloroprene for 24 months.....	4-42
Table 4-31. Incidence, site and type of tumor in selected organs and tissues of hamsters exposed to chloroprene for 18 months.....	4-43
Table 4-32. Summary of epididymal spermatozoal and estrous cycle parameters for rats and mice in the 13-week study of chloroprene.....	4-45
Table 4-33. Results of teratology and embryotoxicity studies in rats exposed to chloroprene by inhalation.....	4-47
Table 4-34. Incidence of anomalies in litters of rats exposed to chloroprene by inhalation.....	4-48
Table 4-35. Chloroprene-induced mortality in male rats.....	4-51
Table 4-36. Genotoxicity assays of chloroprene.....	4-56

Table 4-37. Sites of increased incidences of neoplasms in the 2 year inhalation studies of 1,3-butadiene, isoprene, and chloroprene in rats and mice.....	4-61
Table 4-38. Summary of animal and human tumor data and weight of evidence descriptor for chloroprene .....	4-67
Table 5-1. Incidences of nonneoplastic lesions statistically significantly increased at lowest exposure concentration resulting from chronic exposure (ppm) to chloroprene.....	5-3
Table 5-2. Human equivalent concentration estimates for best fitting models of the BMD from chronic exposure to chloroprene.....	5-6
Table 5-3. Summary of Uncertainties in the Chloroprene noncancer risk assessment .....	5-11
Table 5-4. Tumor incidence in female and male B6C3F1 mice exposed to chloroprene via inhalation .....	5-13
Table 5-5. Tumor incidence in female and male F344 rats exposed to chloroprene via inhalation .....	5-14
Table 5-6. Dose-response modeling summary for male mouse tumor sites associated with inhalation exposure to chloroprene.....	5-18
Table 5-7. Dose-response modeling summary for female mouse tumors associated with inhalation exposure to chloroprene.....	5-19
Table 5-8. Summary of uncertainties in chloroprene cancer unit risk estimate .....	5-23
Table B-1. Modeling Results for Alveolar Epithelial Hyperplasia in Male F344/N Rats .....	B-1
Table B-2. Modeling Results for Alveolar Epithelial Hyperplasia in Female F344/N Rats .....	B-4
Table B-3. Modeling Results for Bronchiolar Hyperplasia in Male B6C3F1 Mice.....	B-7
Table B-4. Modeling Results for Bronchiolar Hyperplasia in Female B6C3F1 Mice .....	B-10
Table B-5. Modeling Results for Histiocytic Cell Infiltration in Male B6C3F1 Mice .....	B-11
Table B-6. Modeling Results for Olfactory Chronic Inflammation in Male F344/N Rats .....	B-11
Table B-7. Modeling Results for Olfactory Atrophy in Male F344/N Rats.....	B-14
Table B-8. Modeling Results for Olfactory Necrosis in Male F344/N Rats .....	B-17
Table B-9. Modeling Results for Degenerative Nasal Lesions (olfactory atrophy or necrosis) in Male F344/N Rats.....	B-20
Table B-10. Modeling Results for Splenic Hematopoietic Cell Proliferation in Female B6C3F1 Mice .....	B-23
Table C-1. Summary of human equivalent overall cancer risk values estimated by R/BMD <sub>R</sub> , based on male and female mouse tumor incidence (NTP, 1998) .....	C-16

## LIST OF FIGURES

Figure 2-1. The chemical structure of chloroprene. ....	2-1
Figure 3-1. Proposed metabolism of chloroprene.....	3-4
Figure 5-1. Points of departure (in mg/m <sup>3</sup> ) for selected endpoints with corresponding applied uncertainty factors and derived sample RfCs (chosen RfC value is circled) .....	5-9
Figure B-1. Log-logistic model fit for alveolar epithelial hyperplasia in male F344/N rats .....	B-2
Figure B-2. Log-logistic model fit for alveolar epithelial hyperplasia in female F344/N rats.....	B-5
Figure B-3. Log-logistic model fit for bronchiolar hyperplasia in male B6C3F1 Mice .....	B-8
Figure B-4. Log-logistic model fit for olfactory chronic inflammation in male F344/N rats .....	B-12
Figure B-5. Logistic model fit for olfactory atrophy in male F344/N rats.....	B-14
Figure B-6. Logistic model fit for olfactory necrosis in male F344/N rats.....	B-18
Figure B-7. Logistic model fit for degenerative nasal lesions (olfactory atrophy or necrosis) in male F344/N rats.....	B-21
Figure B-8. Probit model fit for splenic hematopoietic cell proliferation in female B6C3F1 mice.....	B-24
Figure C-1. Female mice, hemangiomas and hemangiosarcomas in all organs; high dose dropped, ) hemangiosarcomas occurring before termination considered fatal.....	C-1
Figure C-2. Female mice, hemangiomas and hemangiosarcomas in all organs; high dose dropped, hemangiosarcomas occurring before termination considered fatal. Details below.....	C-2
Figure C-3. Female mice, alveolar/bronchiolar tumors. Details below.....	C-3
Figure C-4. Female mice, hepatocellular adenomas and carcinomas. Details below. ....	C-4
Figure C-5. Female mice, forestomach tumors. Details below. ....	C-5
Figure C-6. Female mice, Harderian gland tumors. Details below. ....	C-6
Figure C-7. Female mice, mammary gland tumors. Details below. ....	C-7
Figure C-8. Female mice, skin sarcomas. Details below.....	C-8
Figure C-9. Female mice, Zymbal's gland tumors. Details below.....	C-9
Figure C-10. Male mice, hemangiomas and hemangiosarcomas; hemangiosarcomas occurring before termination considered fatal. Details below. ....	C-10
Figure C-11. Male mice, alveolar/bronchiolar tumors. Details below. ....	C-12
Figure C-12. Male mice, forestomach tumors. Details below.....	C-13
Figure C-13. Male mice, Harderian gland tumors. Details below.....	C-14
Figure C-14. Male mice, renal tubule tumors. Details below.....	C-15



## LIST OF ABBREVIATIONS AND ACRONYMS

<b>ADAF</b>	age dependent adjustment factor
<b>AEH</b>	alveolar epithelial hyperplasia
<b>AIC</b>	Akaike Information Criterion
<b>ALP</b>	alkaline phosphatase
<b>ALT</b>	alanine aminotransferase
<b>BMC</b>	benchmark concentration
<b>BMCL</b>	lower bound on the benchmark concentration
<b>BMD</b>	benchmark dose
<b>BMDL</b>	lower confidence limit on the benchmark dose
<b>BMDS</b>	benchmark dose software
<b>BMR</b>	benchmark response
<b>CASRN</b>	Chemical Abstracts Service Registry Number
<b>CI</b>	confidence interval
<b>CNS</b>	central nervous system
<b>CYP</b>	cytochrome
<b>DAF</b>	dosimetric adjustment factor
<b>DMSO</b>	dimethyl sulfoxide
<b>DNA</b>	deoxyribonucleic acid
<b>EH</b>	epoxide hydrolases
<b>EPA</b>	U.S. Environmental Protection Agency
<b>GD</b>	gestational day
<b>GDH</b>	glutamine dehydrogenase
<b>GSH</b>	glutathione
<b>HEC</b>	human equivalent concentration
<b>IARC</b>	International Agency for Research on Cancer
<b>ICD</b>	International Classification of Diseases
<b>IPCS</b>	International Programme on Chemical Safety
<b>IRIS</b>	Integrated Risk Information System
<b>LOAEL</b>	lowest-observed-adverse-effect level
<b>LOH</b>	loss of heterozygosity
<b>M</b>	Molar
<b>MLE</b>	maximum likelihood estimate
<b>MOA</b>	mode of action
<b>MV</b>	minute volume
<b>NCEA</b>	National Center for Environmental Assessment
<b>NIOSH</b>	National Institute for Occupational Safety and Health
<b>NLM</b>	National Library of Medicine
<b>NOAEL</b>	no-observed-adverse-effect level
<b>NPSH</b>	nonprotein sulfhydryl
<b>NRC</b>	National Research Council
<b>NTP</b>	National Toxicology Program
<b>OECD</b>	Organisation for Economic Cooperation and Development
<b>OR</b>	odds ratio
<b>p</b>	probability value
<b>PBPK</b>	physiologically based pharmacokinetic (model)
<b>PCB</b>	polychlorinated biphenyl

<b>POD</b>	point of departure
<b>ppm</b>	parts per million
<b>PU</b>	pulmonary
<b>R</b>	level of risk
<b>RBC</b>	red blood cell
<b>RfC</b>	reference concentration
<b>RfD</b>	reference dose
<b>RGDR</b>	regional gas dose ratio
<b>RR</b>	relative risk
<b>SA</b>	surface area
<b>SD</b>	standard deviation
<b>SDH</b>	sorbitol dehydrogenase
<b>SIR</b>	standard incidence ratio
<b>SMR</b>	standardized mortality ratio
<b>UCL</b>	upper confidence limit
<b>UF</b>	uncertainty factor
<b>v/v</b>	volume/volume
<b><math>\chi^2</math></b>	chi squared

## FOREWORD

1           The purpose of this Toxicological Review is to provide scientific support and rationale for the  
2 hazard and dose-response assessment in IRIS pertaining to chronic exposure to chloroprene. It is not  
3 intended to be a comprehensive treatise on the chemical or toxicological nature of chloroprene.

4           The intent of Section 6, *Major Conclusions in the Characterization of Hazard and Dose*  
5 *Response*, is to present the major conclusions reached in the derivation of the reference dose, reference  
6 concentration and cancer assessment, where applicable, and to characterize the overall confidence in  
7 the quantitative and qualitative aspects of hazard and dose response by addressing the quality of data  
8 and related uncertainties. The discussion is intended to convey the limitations of the assessment and to  
9 aid and guide the risk assessor in the ensuing steps of the risk assessment process.

10           For other general information about this assessment or other questions relating to IRIS, the  
11 reader is referred to EPA's IRIS Hotline at (202) 566-1676 (phone), (202) 566-1749 (fax), or  
12 [hotline.iris@epa.gov](mailto:hotline.iris@epa.gov) (email address).

## **AUTHORS, CONTRIBUTORS, AND REVIEWERS**

### **CHEMICAL MANAGER**

J. Allen Davis M.S.P.H.  
National Center for Environmental Assessment  
U.S. Environmental Protection Agency  
Research Triangle Park, NC 27711

### **AUTHORS**

J. Allen Davis, M.S.P.H.  
Jeffrey Gift, Ph.D.  
Karen Hogan, M.S.  
Ines Pagan, D.V.M., Ph.D.  
John Stanek, Ph.D.  
National Center for Environmental Assessment  
Office of Research and Development  
U.S. Environmental Protection Agency  
Washington, D.C.

J. Michael Wright, Ph.D.  
National Center for Environmental Assessment  
Office of Research and Development  
U.S. Environmental Protection Agency  
Cincinnati, OH

Aparna M. Koppikar, M.D., Ph.D.  
E MAGE Inc.

### **CONTRACTOR SUPPORT**

Karla Thrall, Ph.D.  
Anthony Fristachi  
Nick Heyer, Ph.D.  
Paul Hinderliter, Ph.D.  
Jessica Sanford, Ph.D.  
Battelle Memorial Institute

## **REVIEWERS**

This document has been reviewed by EPA scientists and interagency reviewers from other federal agencies and White House offices.

### **INTERNAL EPA REVIEWERS**

Ila Cote, Ph.D.

National Center for Environmental Assessment  
Office of Research and Development

Lynn Flowers, Ph.D.

National Center for Environmental Assessment  
Office of Research and Development

Connie Meacham, M.S.

National Center for Environmental Assessment  
Office of Research and Development

John Vandenberg, Ph.D.

National Center for Environmental Assessment  
Office of Research and Development

Debra Walsh, M.S.

National Center for Environmental Assessment  
Office of Research and Development

Kate Guyton, Ph.D.

National Center for Environmental Assessment  
Office of Research and Development

Jennifer Jinot, Ph.D.

National Center for Environmental Assessment  
Office of Research and Development

## 1. INTRODUCTION

1 This document presents background information and justification for the Integrated Risk  
2 Information System (IRIS) Summary of the hazard and dose-response assessment of chloroprene.  
3 IRIS Summaries may include oral reference dose (RfD) and inhalation reference concentration (RfC)  
4 values for chronic and other exposure durations, and a carcinogenicity assessment.

5 The RfD and RfC, if derived, provide quantitative information for use in risk assessments for  
6 health effects known or assumed to be produced through a nonlinear (presumed threshold) mode of  
7 action. The RfD (expressed in units of mg/kg-day) is defined as an estimate (with uncertainty  
8 spanning perhaps an order of magnitude) of a daily exposure to the human population (including  
9 sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a  
10 lifetime. The inhalation RfC (expressed in units of mg/m<sup>3</sup>) is analogous to the oral RfD, but provides a  
11 continuous inhalation exposure estimate. The inhalation RfC considers toxic effects for both the  
12 respiratory system (portal of entry) and for effects peripheral to the respiratory system (extrapulmonary  
13 or systemic effects). Reference values are generally derived for chronic exposures (up to a lifetime),  
14 but may also be derived for acute ( $\leq 24$  hours), short-term ( $> 24$  hours up to 30 days), and subchronic  
15 ( $> 30$  days up to 10% of lifetime) exposure durations, all of which are derived based on an assumption  
16 of continuous exposure throughout the duration specified. Unless specified otherwise, the RfD and  
17 RfC are derived for chronic exposure duration.

18 The carcinogenicity assessment provides information on the carcinogenic hazard potential of  
19 the substance in question and quantitative estimates of risk from oral and inhalation exposure may be  
20 derived. The information includes a weight-of-evidence judgment of the likelihood that the agent is a  
21 human carcinogen and the conditions under which the carcinogenic effects may be expressed.  
22 Quantitative risk estimates may be derived from the application of a low-dose extrapolation procedure.  
23 If derived, the oral slope factor is a plausible upper bound on the estimate of risk per mg/kg-day of  
24 oral exposure. Similarly, an inhalation unit risk is a plausible upper bound on the estimate of risk per  
25  $\mu\text{g}/\text{m}^3$  air breathed.

26 Development of these hazard identification and dose-response assessments for chloroprene has  
27 followed the general guidelines for risk assessment as set forth by the National Research Council  
28 (NRC) (1983). EPA Guidelines and Risk Assessment Forum Technical Panel Reports that may have  
29 been used in the development of this assessment include the following: *Guidelines for the Health Risk*  
30 *Assessment of Chemical Mixtures* (U.S. EPA, 1986a), *Guidelines for Mutagenicity Risk Assessment*  
31 (U.S. EPA, 1986b), *Recommendations for and Documentation of Biological Values for Use in Risk*  
32 *Assessment* (U.S. EPA, 1988), *Guidelines for Developmental Toxicity Risk Assessment* (U.S. EPA,  
33 1991), *Interim Policy for Particle Size and Limit Concentration Issues in Inhalation Toxicity* (U.S.  
34 EPA, 1994a), *Methods for Derivation of Inhalation Reference Concentrations and Application of*  
35 *Inhalation Dosimetry* (U.S. EPA, 1994b), *Use of the Benchmark Dose Approach in Health Risk*  
36 *Assessment* (U.S. EPA, 1995), *Guidelines for Reproductive Toxicity Risk Assessment* (U.S. EPA, 1996),

1 *Guidelines for Neurotoxicity Risk Assessment* (U.S. EPA, 1998), *Science Policy Council Handbook:*  
2 *Risk Characterization* (U.S. EPA, 2000a), *Benchmark Dose Technical Guidance Document* (U.S. EPA,  
3 2000b), *Supplementary Guidance for Conducting Health Risk Assessment of Chemical Mixtures* (U.S.  
4 EPA, 2000c), *A Review of the Reference Dose and Reference Concentration Processes* (U.S. EPA,  
5 2002a), *Guidelines for Carcinogen Risk Assessment* (U.S. EPA, 2005a), *Supplemental Guidance for*  
6 *Assessing Susceptibility from Early-Life Exposure to Carcinogens* (U.S. EPA, 2005b), *Science Policy*  
7 *Council Handbook: Peer Review* (U.S. EPA, 2006a), and *A Framework for Assessing Health Risks of*  
8 *Environmental Exposures to Children* (U.S. EPA, 2006b).

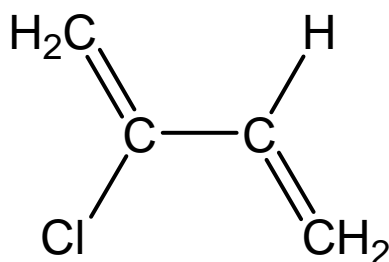
9         The literature search strategy employed for this compound was based on the Chemical  
10 Abstracts Service Registry Number (CASRN) and at least one common name. Any pertinent scientific  
11 information submitted by the public to the IRIS Submission Desk was also considered in the  
12 development of this document. The relevant literature was reviewed through August 2009.

## 2. CHEMICAL AND PHYSICAL INFORMATION

1 Beta-chloroprene ( $C_4H_5Cl$ ) (hereafter referred to as chloroprene) is a volatile, flammable liquid  
2 used primarily in the manufacture of polychloroprene or neoprene rubber. The latter is used to make  
3 diverse products, such as tires, wire coatings, and tubing. While 90% of chloroprene is used to make  
4 neoprene solid, polychloroprene, about 10% is converted to polychloroprene latex, a colloidal  
5 suspension of polychloroprene in water (International Agency for Research on Cancer [IARC], 1999).

6 In 1995, there was one commercial producer of chloroprene in the United States; other plants  
7 produced chloroprene for on-site use and processing, as a by-product of vinyl chloride production, or  
8 as a manufacturing impurity (National Toxicology Program [NTP], 2005). Used almost exclusively to  
9 produce polychloroprene, chloroprene is sold to only three U.S. companies for polychloroprene  
10 manufacture; less than 20 lb/yr is sold for research applications. The total estimated production of  
11 polychloroprene from 1986 to 1988 was approximately 250 to 300 million lb (113,000 to 136,000  
12 metric tons), and the volume from 1995 to 1996 was approximately 200 to 250 million lb (90,700 to  
13 113,000 metric tons).

14 There are no known natural occurrences of chloroprene in the environment. The main sources  
15 of releases to the environment are through effluent and emissions from facilities that use chloroprene  
16 to produce polychloroprene elastomers or transport of the product. In 1995, there were 14 facilities  
17 reporting releases of chloroprene to the atmosphere, eight of which reported individual atmospheric  
18 releases from 2 to 481,871 lbs (0.0009 to 218.6 Mg). Three plants in Kentucky, Texas, and Louisiana,  
19 each reporting atmospheric releases of > 100,000 lbs, accounted for most of the reported chloroprene  
20 releases. One of these sites produced chloroprene, while the other two converted chloroprene to  
21 polychloroprene (NTP, 2005). The chemical structure of chloroprene is shown in Figure 2-1.



**Figure 2-1. The chemical structure of chloroprene.**

22 The starting material for the synthesis of chloroprene is 1,3-butadiene. Chloroprene is also a  
23 structural analogue of isoprene (2-methyl 1,3-butadiene) and resembles vinyl chloride as far as having  
24 a chlorine bound to a double-bonded carbon (alkene) backbone. However, chloroprene contains four  
25 carbons arranged with two double bonds. The odor of chloroprene is described as pungent and ether-  
26 like (National Library of Medicine [NLM], 2008). Chloroprene is volatile and highly reactive; it is not



1 expected to bioaccumulate or persist in the environment (Organisation for Economic Cooperation and  
2 Development [OECD], 1998). Because of its high vapor pressure (215 mm Hg at 25°C), chloroprene  
3 is expected to readily volatilize from water and solid surfaces (NTP, 2005). Chloroprene vapor has an  
4 estimated ionization potential of  $8.95 \pm 0.05$  eV and an estimated half-life in the atmosphere of less  
5 than 20 hours (Grosjean, 1990). Reactions with  $\bullet\text{OH}$  (to produce formaldehyde),  $\text{O}_3$ , and  $\text{NO}_3$  are the  
6 expected pathways of removal, although no experimental data exist (Grosjean, 1991).

7         Of particular relevance to any toxicological studies involving chloroprene is its propensity to  
8 spontaneously oxidize and form dimers and other oxygenated species unless stabilizers or inhibitors  
9 are added. Uninhibited chloroprene must be stored under nitrogen at temperatures below 0°C (e.g., –  
10 20°C) to prevent spontaneous polymerization. When bulk chloroprene with 5% n-octane added as an  
11 internal standard was stored at 55°C for up to 6 hours, dimer content increased by 62% and  
12 chloroprene monomer decreased by 22% (NTP, 1996). Because these reaction products, if formed,  
13 may themselves account for any observed toxicity, toxicological studies that do not report storage or  
14 generation conditions may yield results that are questionable for their relevance to chloroprene  
15 monomer. A discussion of the polymerization process has been reported by Lynch (2001a), Kroshwitz  
16 and Howe-Grant (1993), Stewart (1971), and Nystrom (1948). Additional information on production  
17 and use has been reported by the International Agency for Research on Cancer (IARC, 1999).  
18 Structures have been proposed for some of the chloroprene dimers (Stewart, 1971); some dimers result  
19 upon reaction at room temperature while others result after prolonged heating.

20         In addition to volatilization, the potential fate of chloroprene that is released to soil is to leach  
21 into groundwater. Breakdown via hydrolysis is not likely, as it is only partially soluble in water  
22 (CambridgeSoft Corp., 2007). Chloroprene that is released to the water may only moderately adsorb  
23 to suspended sediments or particles, and there will be little bioaccumulation in aquatic organisms ( $K_{ow}$   
24 = 2.2). The occupational exposure potential to chloroprene is limited to facilities in the U.S., Europe,  
25 and Asia where chloroprene is produced and converted to polychloroprene (Lynch, 2001b). The  
26 physical and chemical properties of chloroprene are shown in Table 2-1.

**Table 2-1. Physical properties and chemical identity of chloroprene**

CHLOROPRENE		REFERENCE
CASRN	126-99-8	NLM (2008)
Synonyms	2-chlorobuta-1,3-diene; 2-chlorobutadiene; 2-chloroprene; alpha-chloroprene; beta-chlorobutadiene; beta-chloroprene; chlorobutadiene; chloroprene	CambridgeSoft Corp. (2007)
Registered trade name	Neoprene	CambridgeSoft Corp. (2007)
Melting point	-130°C	NLM (2008)
Boiling point	59.4°C	NLM (2008)
Density	0.956 at 20°C (relative to the density of H <sub>2</sub> O at 4°C)	NLM (2008)
Vapor pressure	215 mm Hg at 25°C	NLM (2008)
Vapor density	3.0 (air = 1)	NLM (2008)
Flashpoint (open cup)	-15.6°C	CambridgeSoft Corp. (2007)
Flammability limits	4-20% in air	NLM (2008)
Water solubility	2.115 g/L at 25°C	CambridgeSoft Corp. (2007)
Other solubilities	Miscible with ethyl ether, acetone, benzene; soluble in alcohol	NLM (2008)
Log K <sub>ow</sub>	2.2	OECD (1998)
Henry's law constant	$5.6 \times 10^{-2}$ atm/m <sup>3</sup> -mol at 25°C	NLM (2008)
Odor threshold	15 ppm (54 mg/m <sup>3</sup> )	U.S. EPA (2000d)
Molecular weight	88.54	NLM (2008)
Conversion factors (in air)	1 mg/m <sup>3</sup> = 0.276 ppm; 1 ppm = 3.62 mg/m <sup>3</sup> at 25°C, 760 torr	NLM (2008)
Empirical formula	C <sub>4</sub> H <sub>5</sub> Cl	CambridgeSoft Corp. (2007)

### 3. TOXICOKINETICS

1 No reports are available that address the toxicokinetics of chloroprene in humans by any route  
2 of exposure. Limited information is available for animals regarding the absorption and in vivo  
3 metabolism of chloroprene. No information regarding tissue distribution of chloroprene from animal  
4 studies is available. In vitro studies have been conducted to evaluate the metabolism of chloroprene in  
5 lung and liver tissue fractions from rat, mouse, hamster, and humans (Munter et al., 2007a, b, 2003;  
6 Himmelstein et al., 2004a, 2001a, 2001b; Cottrell et al., 2001; Summer and Greim, 1980). Hurst and  
7 Ali (2007) evaluated the kinetics of R- and S-enantiomers of the chloroprene metabolite  
8 (1-chloroethenyl)oxirane in mouse erythrocytes. A physiologically based pharmacokinetic (PBPK)  
9 model has been developed to describe changes in chamber chloroprene concentrations during  
10 exposures with mice, rats, and hamsters (Himmelstein et al. 2004a, 2004b). No in vivo time-course  
11 data for blood or tissue concentration are available for model validation.

#### 3.1. ABSORPTION

12 Quantitative data on the absorption of chloroprene from any route of exposure have not been  
13 reported. The Hazardous Substances Data Bank states that chloroprene is “rapidly absorbed by the  
14 skin” (Lefaux [1968] as cited in NLM [2008]). Chronic inhalation studies in B6C3F1 mice and  
15 F344/N rats suggest that chloroprene has multiple nonneoplastic and neoplastic targets (nose and lung,  
16 kidney, forestomach, Harderian gland, skin); therefore, the absorption and systemic distribution via the  
17 inhalation route can be inferred (NTP, 1998).

#### 3.2. DISTRIBUTION

18 No quantitative in vivo data on the tissue distribution of chloroprene have been reported. As  
19 indicated above, the widespread distribution of chloroprene in vivo following absorption can be  
20 inferred from effects in several target organs (NTP, 1998). Himmelstein et al. (2004b) determined  
21 partition coefficients for chloroprene in mouse, F344 rat, Wistar rat, and hamster tissues by using the  
22 vial equilibration method described by Gargas et al. (1989), as given in Table 3-1. These tissue-to-air  
23 ratios suggest that chloroprene will be preferentially distributed in adipose tissue, followed by lung,  
24 kidney, liver, and muscle. The partition coefficient values suggest there are no significant species  
25 differences expected in tissue distribution of chloroprene.

**Table 3-1. Tissue-to-air partition coefficients for chloroprene**

TISSUE	TISSUE-TO-AIR PARTITION COEFFICIENTS <sup>a</sup>				
	Mouse	F344 rat	Wistar rat	Hamster	Human <sup>b</sup>
Blood	7.8 ± 0.1	7.3 ± 0.1	8.0 ± 0.5	9.3 ± 0.3	4.5 ± 0.1
Lung	18.6 ± 5.1	13.5 ± 1.6	11.2 ± 0.5	9.7 ± 0.6	13.3 ± 4.1
Liver	9.8 ± 0.9	11.5 ± 0.3	10.9 ± 0.2	10.5 ± 0.5	10.7 ± 1.1
Fat	135.3 ± 1.6	124.0 ± 1.5	126.3 ± 1.4	130.1 ± 0.9	128.9 ± 2.7
Muscle	4.6 ± 0.8	4.4 ± 0.4	4.0 ± 0.3	5.0 ± 0.2	4.5 ± 1.0
Kidney	13.7 ± 0.6	16.7 ± 0.6	9.4 ± 0.4	8.2 ± 0.3	12.0 ± 0.9

<sup>a</sup> Mean ± standard error for three replicates per rodent tissue.

<sup>b</sup> Human blood values determined for nine replicates (three subjects, three replicates/subject); human tissue partition coefficient values were derived from rodents with standard error adjusted to account for the proportion of variation from each set of rodent data.

Source: Himmelstein et al. (2004b).

### 3.3. METABOLISM

1           The metabolism of chloroprene has been primarily evaluated in vitro with lung and liver tissue  
2 fractions from rat, mouse, hamster, and humans (Munter et al., 2007a, 2007b, 2003; Himmelstein et al.,  
3 2004a, 2001a, 2001b; Cottrell et al., 2001; Summer and Greim, 1980). In a 1978 review of the older  
4 literature, a number of reports suggested that chloroprene forms peroxides that interact with tissue thiol  
5 groups and that the disposition of chloroprene is likely similar to vinyl chloride and vinylidene  
6 chloride (Haley, 1978). This report was the first to postulate a metabolic profile of chloroprene,  
7 including formation of epoxides by cytochrome P450 (CYP450) enzymes that could give rise to  
8 aldehydes and eventually form mercapturic acid derivatives.

9           In studies using mouse and human liver microsomes, Bartsch et al. (1979) showed that  
10 2-chloro-2-ethynyloxirane and/or (1-chloroethenyl)oxirane could be intermediates in the  
11 biotransformation of chloroprene. This was based on the finding that 4-(4-nitrobenzyl)pyridine  
12 trapped a volatile metabolite produced during reaction of mouse liver microsomes with chloroprene.  
13 Summer and Greim (1980) reported that in vitro incubation of chloroprene with hepatocytes isolated  
14 from male Wistar rats produced a concentration-dependent decrease in cellular glutathione (GSH),  
15 suggesting a GSH-dependent detoxification pathway. A report by Himmelstein et al. (2001b) was the  
16 first to quantitatively identify (1-chloroethenyl)oxirane as an epoxide metabolite of chloroprene and  
17 confirmed the identify of the volatile metabolite reported by Bartsch et al. (1979). Himmelstein et al.  
18 (2001b) reported that the oxidation of chloroprene to (1-chloroethenyl)oxirane was evident in rodent  
19 and human liver microsomes and most likely involved CYP 2E1, as evidenced by nearly complete in  
20 vitro inhibition with 4-methylpyrazole hydrochloride. A comparison across species suggested that a  
21 greater amount of (1-chloroethenyl)oxirane was present in B6C3F1 mice and F344 rat liver  
22 microsomes, followed by the Wistar rat, then humans and hamsters (Table 3-2).

**Table 3-2. Liver microsomal metabolites as a percentage of 1-butanol internal standard**

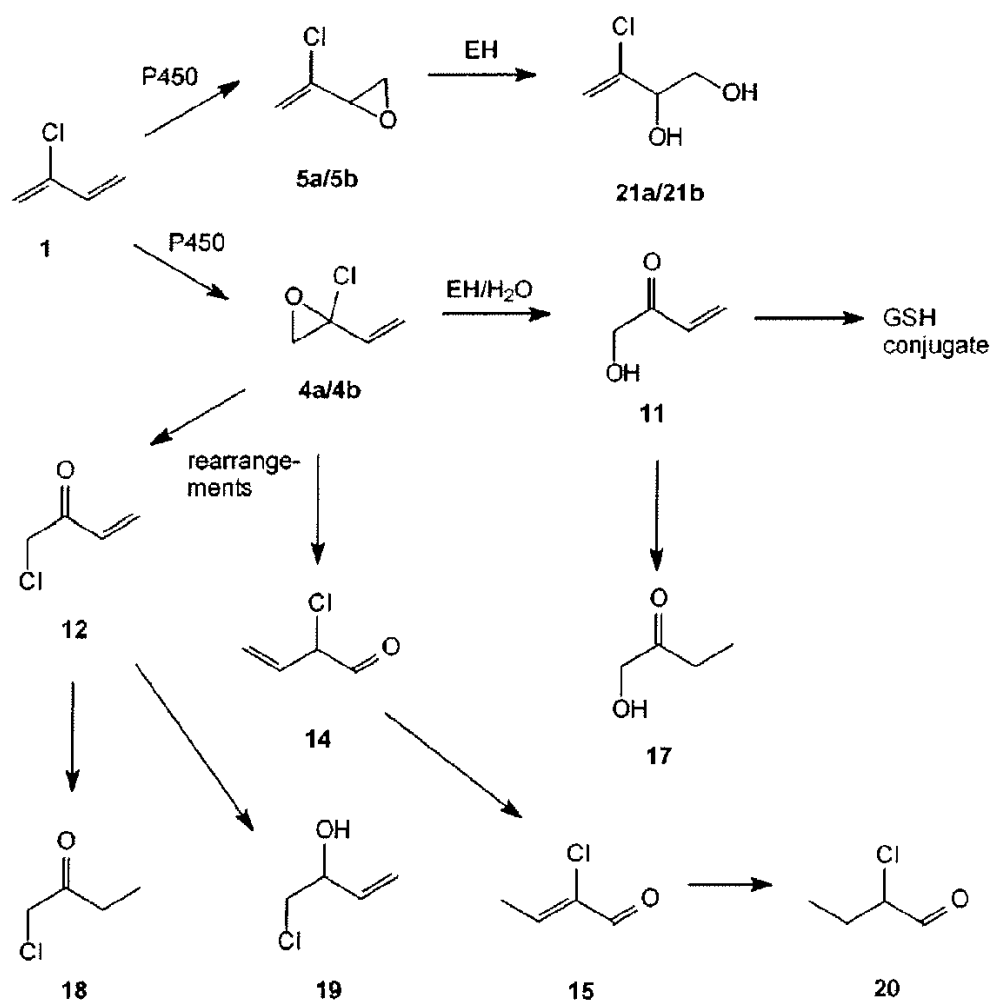
METABOLITE PEAK <sup>a</sup>	LIVER MICROSOMAL SUSPENSION				
	B6C3F1 mouse	F344 rat	Wistar rat	Hamster	Human
1	9.0	12.0	4.0	0.8	1.3
2	0.0	0.1	0.1	0.2	0.1
3	0.8	0.3	0.2	0.8	0.3
4	0.2	0.0	0.1	0.4	0.1
5	0.2	0.3	0.0	0.1	0.0
6	0.6	0.4	0.3	0.3	0.1

<sup>a</sup> Metabolite peak 1 = (1-chloroethenyl)oxirane. Metabolite peaks 2–5 had insufficient signal to obtain meaningful spectral data. A tentative spectral match for peak 6 was made as 3-chloro-2-butenal.

Source: Himmelstein et al. (2001b).

1 Further metabolism of (1-chloroethenyl)oxirane was observed in time-course evaluations with  
 2 liver microsomes (Himmelstein et al., 2001b). In mouse liver microsomes, the  
 3 (1-chloroethenyl)oxirane concentration showed an initial increase over 10 minutes that was followed  
 4 by a decline, attributable to either epoxide hydrolase-mediated hydrolysis or further oxidative  
 5 metabolism. Preliminary results indicated that the ranking of (1-chloroethenyl)oxirane hydrolysis in  
 6 liver microsomes was as follows: hamsters ~ humans > Wistar rats > B6C3F1 mice and F344 rats.

7 Studies by Cottrell et al. (2001) are in agreement with reports from Himmelstein et al. (2001a,  
 8 2001b) and further define the structures and stereochemistry of chloroprene metabolites from rodent  
 9 species and humans by comparison with synthetic reference standards. Based on these studies, the  
 10 metabolic pathway illustrated in Figure 3-1 was proposed.



**Figure 3-1. Proposed metabolism of chloroprene.**

Key: **1** = chloroprene; **5a/5b** = R- and S-enantiomers of (1-chloroethenyl)oxirane; **21a/b** = R- and S-enantiomers of 3-chlorobut-3-ene-1,2-diol; **4a/4b** = R- and S-enantiomers of 2-chloro-2-ethenyloxirane; **11** = 1-hydroxybut-3-en-2-one; **17** = 1-hydroxybutan-2-one; **14** = 2-chlorobut-3-en-1-al; **15** = 2-chlorobut-2-en-1-al; **20** = 2-chloro-butanal; **12** = 1-chlorobut-3-en-2-one; **18** = 1-chlorobutan-2-one; and **19** = 1-chloro-2-hydroxy-but-3-ene.

Source: Adapted from Cottrell et al. (2001).

1 Comparing metabolism between species, Cottrell et al. (2001) observed that qualitative profiles  
 2 of metabolites from liver microsomes obtained from B6C3F1 mice, Sprague-Dawley or F344 rats, and  
 3 humans were similar. In all species and either gender, (1-chloroethenyl)oxirane was the major  
 4 metabolite detected. An important difference among species was in the stereoselectivity of the  
 5 formation of R- and S-enantiomers of (1-chloroethenyl)oxirane (Table 3-3). For liver microsomes  
 6 from both male and female Sprague-Dawley and F344 rats, there was a distinct enantioselectivity in  
 7 the mono-epoxidation of chloroprene to preferentially form the R-enantiomer of (1-  
 8 chloroethenyl)oxirane. A further study by this group (Munter et al., 2003) verified significant

1 differences between species in the amounts of R- and S-enantiomers of (1-chloroethenyl)oxirane  
 2 formed in microsomal liver incubations, the order being mouse > rat > human.

**Table 3-3. Stereochemical comparison of relative amounts (percentages) of R- and S-enantiomers of the major chloroprene metabolite (1-chloroethenyl)oxirane from liver microsomes compared across species, strains, gender, and chloroprene concentration (mM)**

MALE				FEMALE			
Chloroprene(mM)	Species/strain <sup>a</sup>	% R	% S	Chloroprene(mM)	Species/strain <sup>a</sup>	% R	% S
5	Sprague-Dawley rat	58	42		Sprague-Dawley rat		
10		62	38	10		56	44
20		61	39	20		56	44
30		60	40	30		55	45
40		64	36	40		59	41
5	F344 rat	62	38		F344 rat		
10		62	38	10		56	46
20		62	38	20		54	46
30		60	40	30		53	47
40		64	36	40		54	46
5	B6C3F1 mouse	48	52		B6C3F1 mouse		
10		47	53	10		47	53
20		46	54	20		45	55
30		47	53	30		47	53
40		47	53	40		46	54
10	Human	43	57	10	Human	43	57
20		43	57	20		44	56
30		43	57	30		42	58

<sup>a</sup>Average of three samples per species/strain.

<sup>b</sup>Percentage estimated error  $\pm$  1%.

Source: Cottrell et al. (2001)

3 Himmelstein et al. (2004a) developed a two-compartment closed vial model to describe both  
 4 chloroprene and (1-chloroethenyl)oxirane metabolism in liver and lung fractions from rat (two strains,  
 5 F344 and Wistar), mouse, hamster, and humans. Estimates for  $V_{max}$  and  $K_m$  for oxidation of  
 6 chloroprene in liver microsomes ranged from 0.068–0.29  $\mu\text{mol}/\text{hour}/\text{mg}$  protein and 0.53–1.33  $\mu\text{M}$ ,  
 7 respectively. Oxidation ( $V_{max}/K_m$ ) of chloroprene in the liver was slightly faster in the mouse and  
 8 hamster than in rats or humans (Table 3-4). In lung microsomes,  $V_{max}/K_m$  was much greater for mice  
 9 compared with the other species. Conversely, hydrolysis ( $V_{max}/K_m$ ) of (1-chloroethenyl)oxirane in  
 10 liver and lung microsomes was faster for the human and hamster, than for rat or mouse. Glutathione S-  
 11 transferase-mediated metabolism of (1-chloroethenyl)oxirane in cytosolic tissue fractions was  
 12 described as a pseudo second-order reaction, with rates ranging from 0.0016–0.0068  $\text{hour}/\text{mg}$  cytosolic  
 13 protein in liver and 0.00056–0.0022  $\text{hour}/\text{mg}$  in lung.

**Table 3-4. Kinetic parameters used to describe the microsomal oxidation of chloroprene**

TISSUE	SPECIES	ACTIVITY OF MICROSOMAL OXIDATION		
		$V_{max}$	$K_m$	$V_{max}/K_m$
Liver	Mouse	0.23	1.03	224
	F344 rat	0.078	0.53	146
	Wistar rat	0.11	0.84	125
	Hamster	0.29	1.33	218
	Human	0.068	0.68	101
Lung	Mouse	0.10	1.5	66.7
	F344 rat	--	--	1.3 <sup>a</sup>
	Wistar rat	--	--	1.3 <sup>a</sup>
	Hamster	--	--	1.3 <sup>a</sup>
	Human	--	--	1.3 <sup>a</sup>

<sup>a</sup> The apparent rate of lung metabolism, over the range of biologically relevant concentrations tested, was linear and was estimated as  $V_{max}/K_m$

Source: Himmelstein et al. (2004a).

1 Hurst and Ali (2007) evaluated the kinetics of R- and S-enantiomers of the chloroprene  
 2 metabolite, (1-chloroethenyl)oxirane in mouse erythrocytes. These results implied that  
 3 S-(1-chloroethenyl)oxirane was much more quickly detoxified than the R-enantiomer when incubated  
 4 with mouse erythrocytes in vitro. The disappearance of S-(1-chloroethenyl)oxirane was blocked when  
 5 erythrocytes were preincubated with diethyl maleate, indicating dependence on cellular glutathione for  
 6 rapid removal. The study by Hurst and Ali (2007) suggested that the R-enantiomer of (1-  
 7 chloroethenyl)oxirane is potentially more toxic because of slower detoxification.

8 The limited in vivo rodent studies support the postulated metabolic pathway for chloroprene.  
 9 For example, male Wistar rats administered 100 or 200 mg/kg chloroprene by gavage demonstrated a  
 10 rapid depletion of hepatic GSH and a dose-dependent increase in excreted urinary thioethers  
 11 (presumably GSH-conjugates), which is consistent with in vitro studies using isolated liver  
 12 hepatocytes (Summer and Greim, 1980). Pretreatment of rats or hepatocytes with phenobarbital or a  
 13 polychlorinated biphenyl (PCB) mixture (Clophen A50) to induce the mixed-function oxidase enzymes  
 14 enhanced the GSH depletion effect.

15 Himmelstein et al. (2004b) conducted closed-chamber gas uptake exposures with rats (Wistar  
 16 and F344), mice, and hamsters to evaluate metabolism rates with and without metabolic inhibition by  
 17 using pretreatment with 4-methyl pyrazole. Initial exposure concentrations ranged from 160–240 parts  
 18 per million (ppm) chloroprene. A PBPK model was used to describe the decrease in chamber  
 19 chloroprene concentrations over time by using metabolic parameters ( $V_{max}$ ,  $K_m$ ) scaled from in vitro  
 20 studies (Himmelstein et al., 2004a). The in vitro scaling of total chloroprene metabolism (Table 3-5)  
 21 was sufficient to explain the in vivo gas uptake data.



**Table 3-5. Metabolic parameters of chloroprene**

BIOCHEMICAL PARAMETERS <sup>a</sup>		SPECIES			
		Mouse	F344 rat	Wistar rat	Hamster
Liver	V <sub>max</sub> (mg/kg-hour)	39.2	11.50	15.5	42.8
	K <sub>m</sub> (mg/L)	0.091	0.047	0.075	0.118
	V <sub>max</sub> /K <sub>m</sub> (L/kg-hour)	431.0	244.0	208.0	363.0
Lung	V <sub>max</sub> (mg/kg-hour)	1.02	---	---	---
	K <sub>m</sub> (mg/L)	0.13	---	---	---
	V <sub>max</sub> /K <sub>m</sub> (L/kg-hour)	7.67	0.14	0.14	0.14

<sup>a</sup>Scaled from Himmelstein et al. (2004a) using microsomal protein content.

Source: Himmelstein et al. (2004b).

### 3.4. ELIMINATION

1 Limited information is available regarding the elimination of chloroprene in rodents. Summer  
 2 and Greim (1980) administered male Wistar rats 100 or 200 mg/kg chloroprene by gavage and  
 3 observed a dose-dependent, nonlinear increase in excreted urinary thioethers (presumably glutathione  
 4 conjugates). The clearance of these thioethers reached a threshold at 24 hours after dosing, indicating  
 5 that elimination was rapid.

### 3.5. PHYSIOLOGICALLY BASED TOXICOKINETIC MODELS

6 Himmelstein et al. (2004b) published a physiologically based toxicokinetic model of  
 7 chloroprene. Construction of the mathematical model was based on physicochemical, physiological,  
 8 and metabolic parameters for chloroprene from mouse, rat, hamster, and humans (Table 3-6). The  
 9 model consisted of distinct compartments for liver and lung, as well as lumped compartments for fat  
 10 and slowly and rapidly perfused tissues. Metabolism of chloroprene was localized to the lung and  
 11 liver compartments and described by Michaelis-Menten type saturable kinetics. Although the model  
 12 was used to estimate the chloroprene concentration in each of the defined compartments, comparisons  
 13 of model predictions were limited to experimental determinations of chloroprene vapor uptake in  
 14 closed chambers. Inhibition of uptake was achieved with 4-methyl pyrazole pretreatment, indicating  
 15 that the decline of chloroprene chamber concentration was due to CYP450 monooxygenase-mediated  
 16 metabolism. The loss in chamber concentration in the presence of metabolic inhibition represented  
 17 uptake due to chemical distribution within the animal. A satisfactory model description for inhibition  
 18 was obtained by setting V<sub>max</sub> to zero for both liver and lung metabolism. No blood or tissue time-  
 19 course concentration data are available for model validation.

20

**Table 3-6. Physiological parameters used for chloroprene PBPK modeling**

PHYSIOLOGICAL PARAMETERS	SPECIES				
	Mouse	F344 rat	Wistar rat	Hamster	Human
Body weight (kg)	0.024–0.034	0.16–0.28	0.20–0.34	0.10–0.18	NA
Ventilation (L/kg-hour)	15	10.5	10.5	12	NA
Cardiac output (L/kg-hour)	15	9	9	12	NA
Tissue volumes (% body weight)					
Liver	5.5	4.0	4.0	4.0	2.6
Fat	5.0	7.0	7.0	7.0	21.4
Rapid perfused	3.5	5.0	5.0	5.0	7.7
Slow perfused	77.0	75.0	75.0	75.0	56.1
Lung	0.73	0.50	0.50	0.50	0.76
Blood flow (% cardiac output)					
Liver	16.1	18.3	18.3	18.3	22.7
Fat	7.0	7.0	7.0	7.0	5.2
Rapid perfused	51.0	51.0	51.0	51.0	47.2
Slow perfused	15.0	15.0	15.0	15.0	24.9

Source: Himmelstein et al. (2004b).

## 4. HAZARD IDENTIFICATION

### 4.1. STUDIES IN HUMANS—EPIDEMIOLOGY, CASE REPORTS, CLINICAL CONTROLS

1 Potential for human exposure to chloroprene primarily is via inhalation and perhaps by the  
2 dermal route. This section summarizes studies in occupationally-exposed populations from the period  
3 of 1978 to 2008.

#### 4.1.1. Chloroprene Exposure and Cancer Effects

##### 4.1.1.1. Overview

4 The NTP (1998, 2005) described chloroprene as *reasonably anticipated to be a human*  
5 *carcinogen* based on evidence of benign and malignant tumor formation at multiple sites in animals.  
6 Evidence in humans for the carcinogenicity was reported to be limited based on consideration of only  
7 two occupational epidemiological studies by Pell (1978) and Li et al. (1989). Rice and Boffetta (2001)  
8 and briefly examined evidence from five epidemiologic studies (Pell, 1978; Li et al., 1989; Bulbulyan  
9 et al., 1998; Bulbulyan et al., 1999; Colonna and Laydevant, 2001). Although several of these earlier  
10 epidemiological studies noted suggestive evidence of an association between chloroprene exposure  
11 and liver cancer risk, study limitations included possible bias from cohort enumeration, follow-up, and  
12 choice of reference population. Other study limitations noted included limited exposure assessment  
13 data, low statistical power and the possible confounding by unmeasured co-exposures (Rice and  
14 Boffetta, 2001). To date, there have been nine occupational epidemiological studies conducted  
15 covering 11 cohorts. This epidemiological database is reviewed in the following section.

##### 4.1.1.2. Individual Occupational Studies

16 Pell (1978) conducted a cohort mortality study in two neoprene (polychloroprene)  
17 manufacturing plants of DuPont. The first cohort (“Louisville Works Cohort”) consisted of 1,576 male  
18 workers identified from a roster of wage roll employees in 1957. All workers who were exposed to  
19 chloroprene were followed through December 31, 1974, accruing 26,939 person-years. Workers  
20 terminated before June 30, 1957 were excluded and 17 individuals were lost to follow-up. Causes of  
21 death were obtained from death certificates and coded according to the 7th and 8th revised editions of  
22 the “International Classification of Diseases” (ICD). Worker exposures to chloroprene were classified  
23 qualitatively as “high,” “moderate,” “low,” and “varied” based on job description. Statistical analyses  
24 were performed using Poisson probability distribution with statistical significance level at  $p < 0.05$ .  
25 The general U.S. male population and all male DuPont wage roll employees were used as external and  
26 internal comparison populations, respectively. The study’s primary objective was to examine  
27 respiratory system cancer mortality, but mortality from other site-specific cancers was also evaluated.

1           Among the 193 deaths detected in this cohort, 51 were due to cancer and 16 were due to cancer  
2 of the respiratory system. Compared to U.S. rates, the standardized mortality ratios (SMRs) for all-  
3 cause mortality, total cancer mortality and respiratory system cancer mortality were 69.0, 96.6, and  
4 98.4, respectively. Based on the internal comparison SMRs of 114.0 were detected for total cancer  
5 mortality and 109.6 for respiratory system cancer mortality. The internal comparison yielded SMRs of  
6 108.7 (15 cases) and 113.2 (12 cases) for respiratory cancer after 15- and 20-year latency periods,  
7 respectively. SMRs were lower for the same latency periods when compared with the U.S. general  
8 population. Thirteen of the 16 deaths due to respiratory system cancer occurred in smokers, while  
9 smoking history was unknown for the other three. Analyses by high exposure occupation did not show  
10 any significant change in SMRs or any statistically significant trend when analyzed by years since first  
11 exposure. Other cancer deaths that were detected included 19 of the digestive organs (SMR = 142.9  
12 using an internal comparison) and seven of the lymphatic and hematopoietic tissues (SMR = 155.6  
13 using an internal comparison). All the SMRs observed in this study were not statistically significant  
14 based on both internal (DuPont) and U.S. general population mortality rates.

15           These data were reanalyzed by the National Institute for Occupational Safety and Health  
16 (NIOSH) using a modified life-table analysis (Leet and Selevan, 1982). Workers were classified into  
17 high and low exposure categories based on a classification scheme developed by an industrial  
18 hygienist who worked at the plant. Eight hundred and fifty-one workers were allocated to the high  
19 exposure group and 823 to the low exposure group, with some workers contributing person-years in  
20 both categories when their exposures or job titles changed. A total of 26,304 person-years were  
21 accrued, with 13,606 person-years in the high-exposure and 12,644 in the low-exposure category.  
22 Compared to U.S. population rates, the overall SMR for the total cohort was 79. Excess deaths were  
23 observed for cancers of the digestive system (especially the biliary passages and liver), the lung, and  
24 the lymphatic/hematopoietic system. The only statistically significant SMR of biliary passage and  
25 liver was based on four cases, three from the high-exposure category (Table 4-1). Of these three  
26 deaths, one was due to liver cancer, and the other two to gall bladder cancer. Cancer mortality data  
27 were analyzed with respect to latency and duration of exposures stratified into 10-year intervals.  
28 Statistically significant trends were not observed in either the latency analysis or the years of presumed  
29 chloroprene exposure analysis, but these analyses were based on small numbers.

30           The main limitations of the Pell (1978) study and the NIOSH reanalysis (Leet and Selevan,  
31 1982) are lack of smoking history data, lack of adjustment for other potential risk factors, and absence  
32 of quantitative exposure information. Exclusion of workers terminated prior to June 30, 1957, might  
33 have also resulted in some unidentified cancer deaths that could have been associated with earlier  
34 higher exposures. Moreover, as pointed out by Leet and Selevan (1982), the statistical power of the  
35 study to detect a significant excess in mortality was low when the sub-cohort analyses were conducted.

**Table 4-1. Standardized mortality ratios (SMRs) for the DuPont Louisville Works cohort relative to general U.S. population rates.**

CAUSE OF DEATH	TOTAL COHORT CASES, SMR (95% CI) <sup>a</sup>	HIGH EXPOSURE CASES, SMR (95% CI)	LOW EXPOSURE CASES, SMR (95% CI)
All Causes	193, 79 (68–91)	91, 75 (61–92)	102, 82 (67–100)
All Cancers	51, 107 (80–141)	25, 107 (69–158)	26, 107 (70–157)
Digestive	19, 145 (87–227)	8, 125 (54–246)	11, 164 (82–294)
Biliary/liver	4, 571 (156–1463)	3, 750 (155–2192)	1, 250 (6–1393)
Trachea, bronchus, lung	17, 106 (62–170)	10, 128 (61–236)	7, 86 (35–178)
Lymphatic, hematopoietic	7, 140 (56–288)	4, 160 (44–410)	3, 120 (25–351)

<sup>a</sup>CI = confidence interval.

Source: Leet and Selevan (1982).

1 Pell (1978) also evaluated a second cohort that originally consisted of 270 males (“Chamber  
2 Works Cohort”) believed to be exposed between 1931 and 1948 in a neoprene manufacturing facility  
3 and followed through December 31, 1974. Follow up was complete for 240 workers. Since historical  
4 records were not complete for this cohort, efforts were made to assess exposures for former employees  
5 based largely on the recall of other employees. The observation period, during which latency in tumor  
6 induction could be analyzed, was 30–40 years from date of first exposure. Examination of mortality  
7 following a long latency period was considered a strength of this study.

8 A total number of 55 deaths were observed in this cohort. Study exclusions included thirteen of  
9 these deaths occurring prior to 1957 (the starting point of observation assuming a 15-year latency  
10 period) and three deaths occurring due to heart disease and malignant melanoma among former  
11 laboratory personnel who had little or no exposure. The 39 observed deaths that occurred from 1957 to  
12 1974 were slightly more than the 37.7 expected using the DuPont comparison population. The 12  
13 observed cancer deaths were also elevated (SMR = 140) but were not statistically significant. There  
14 were three deaths due to digestive cancer compared to 2.7 expected and were four deaths due to lung  
15 cancer compared to 3.0 expected. The five observed cancers of the urinary system (3 bladder and 2  
16 kidney) were significantly elevated (SMR = 300 compared to the DuPont population and SMR = 250  
17 compared to the U.S. general population:  $p < 0.01$  for both). The authors attributed the bladder cancers  
18 to beta-naphthylamine exposure. Biliary and liver cancers were not examined in this study. Small  
19 cohort size, low statistical power, and lack of quantitative exposure data were limitations of this  
20 analysis.

21 Li et al. (1989) conducted a cohort mortality study of Chinese employees who worked in one of  
22 three shops with chloroprene exposure (a chloroprene monomer workshop, a neoprene workshop, and  
23 a laboratory) within a larger chemical plant. A cohort of 1,258 employees who had worked for at least  
24 one year of chloroprene-related work prior to June 30, 1980 were identified from an employee roster.  
25 The follow-up period for cancer deaths was from July 1, 1969 through June 30, 1983. Cancer mortality  
26 was assessed by searching the death registries at the plant’s hospital and the police substation; cancer  
27 diagnoses were verified by review of medical records at the city general hospitals and cancer hospitals.

1 Exposures were assigned to occupations based upon measured concentrations in air at work sites and  
2 duration of exposure at different sites. When these levels were not available, exposures were  
3 determined through interviews with workers and administrators. Exposure assignments took into  
4 account movement between exposure areas and were designed to roughly represent time-weighted  
5 average exposure values. Follow up was achieved for 1,213 (96%) cohort members (955 males and  
6 258 females) and SMRs were calculated using sex- and age-specific mortality in the local area. A total  
7 of 721 (75%) males and 131 (51%) females were exposed for more than 15 years, while 131 (14%)  
8 males and 9 (3%) females were exposed for more than 25 years. Statistically significant differences ( $p$   
9  $< 0.005$ ) in exposure to chloroprene were detected in males compared to females based on  $> 15$  years  
10 and  $> 25$  years of exposure.

11 Person-years were computed by 5-year categories for the total cohort and for the subgroup  
12 starting from July 1, 1969 or when the individual first started working with chloroprene through June  
13 30, 1983 for live individuals or until their date of death.<sup>1</sup> SMRs were calculated using sex- and age-  
14 specific local area rates in 1973-1975. The results presented below are for male workers only as all  
15 sixteen cancer deaths were reported among male workers (Table 4-2). The all-cancer SMR for the  
16 male workers was 271 ( $p < 0.01$ ). Of 955 males, 464 (49%) were employed in occupations with high  
17 exposures such as maintenance mechanics and monomer/polymer operators. The SMRs for male  
18 workers in several high exposure areas were statistically significant for liver and lung cancer mortality.  
19 An increased SMR for liver cancer was observed, with four deaths occurring among monomer workers  
20 and two deaths occurring in polymer mechanics. Half of the cancers in the monomer shop were  
21 primary liver cancers (4 observed, SMR = 482,  $p < 0.01$ ), with two occurring among the maintenance  
22 mechanics (SMR = 1667,  $p < 0.05$ ).

---

<sup>1</sup> Person-years accrued were not reported in the paper.

**Table 4-2. Standardized mortality ratios (SMRs) for all cancers, liver and lung cancer among males exposed to chloroprene relative to general Chinese population rates**

EXPOSURE AREA	NUMBER OF DEATHS/SMR		
	ALL CAUSE	LIVER CANCER	LUNG CANCER
Total cohort	16/271*	6/242	2/513
Monomer workshop	8/377	4/482**	1/714
Vinylacetylene operator <sup>a</sup>	0/---	0/---	0/---
Monomer operator	4/450**	2/465	0/---
Maintenance mechanic <sup>a</sup>	4/1,290**	2/1667**	1/5000**
Neoprene workshop	5/176	2/165	1/556
Polymer operator <sup>a</sup>	5/394**	0/---	
Final treatment	0/---	0/---	
Maintenance <sup>a</sup> mechanic	0/---	2/357	1/1250
Laboratory	3/319	0/---	0/---
Quality monitor <sup>a</sup>	1/129	0/---	0/---
Researcher	21,176**	0/---	0/---

Statistical significance: \* p < 0.01; \*\* p < 0.05.

<sup>a</sup>: High Exposure Area

Source: Li et al. (1989)

1           One of the limitations of the Li et al. (1989) study include insufficient mortality data especially  
2 since only three years of local area data were available to calculate SMRs. If these years are not  
3 representative of the entire study period, then the SMRs could be biased. For example, if the general  
4 population experienced higher mortality during the times periods not examined (i.e., 1969-1972 &  
5 1976-1983) then the SMRs would be underestimated due to a lower expected number of deaths. If the  
6 mortality was lower during the other time periods, the SMRs would be overestimated. Lack of  
7 quantitative exposure information precluded conducting internal analyses by latency or duration of  
8 exposure. Additionally, there was no data on alcohol use or smoking history and limited information  
9 was available on other potential confounders such as co-exposures to chloroprene oligomers. The  
10 authors did consider potential confounding exposures due to benzene and anti-ager D (N-phenyl-Z-  
11 naphthylamine) but determined that these exposures were limited and not likely to influence the  
12 results.

13           Li et al. (1989) also conducted a case-control study for the entire plant. Of 55 observed cancer  
14 deaths, 54 were matched with the same number of non-cancer deaths among plant workers based upon  
15 gender, age ( $\pm 2$  years) and date of death ( $\pm 2$  years). The authors observed that 16 of the cancer deaths  
16 (30%) were among workers exposed to chloroprene compared to only four of the non-cancer deaths  
17 (7%), yielding an odds ratio of 13 (p < 0.005). Although the average age at death was 12.7 years less  
18 for the exposed cancer cases relative to the unexposed cancer cases (p < 0.001), these findings are  
19 limited by lack of data on co-exposures and other potential confounders.

20           Bulbulyan et al. (1998) examined cancer mortality at a Moscow shoe factory with exposures to  
21 chloroprene from glue and from polychloroprene latex (a colloidal suspension of polychloroprene in  
22 water). The cohort consisted of 5,185 workers (4,569 women and 616 men) employed for at least two

1 years during 1960–1976 at specific production departments (i.e., cutting, fitting, lasting and making,  
2 and finishing). Auxiliary departments and management employees were excluded. Work histories  
3 were obtained from the personnel department, and subjects were assigned exposure levels based on  
4 department and job; industrial hygiene measurements of exposure levels were conducted in the 1970s.  
5 The authors provided detailed exposure data by job and department, ranging from a high of 20 mg/m<sup>3</sup>  
6 (gluers in the finishing department) to an intermediate level of 0.4–1 mg/m<sup>3</sup> (all other jobs in the  
7 finishing department and all jobs in the lasting and making department) to the unexposed (all jobs in  
8 the cutting and fitting departments).

9 The authors concluded that the industrial hygiene data were not systematic enough to assign  
10 quantitative exposures to each worker since the collection of samples varied by locations and by  
11 different years. They, therefore, devised a relative exposure system, where workers in the high-  
12 exposure assignment was assigned a level of 10, intermediate-exposure - a level of 1, and unexposed -  
13 a level of 0. Cumulative exposures for individual workers were calculated by multiplying years of  
14 exposure by the level of exposure, taking into account changes in job and department. In addition,  
15 workers were classified by their highest exposure category. The authors considered confounding  
16 exposures, including benzene exposures (6-20 ppm) in the high polychloroprene exposure group  
17 during the 1950s, but did not adjust for those exposures in their analysis.

18 Mortality follow up was conducted from 1979-1993 which included 70,328 (62,492 in females  
19 and 7,836 in males) person-years of observation. Thirty-seven percent of cohort members contributing  
20 26,063 (female and male distribution was not provided) person-years were unexposed. Death  
21 certificates were acquired from the National Registry Office Card Index and causes of deaths were  
22 classified using ICD-9. Mortality rates of general population of Moscow were used for comparison.  
23 For the general population, mortality data for five cancers (liver, kidney, bladder, pancreas, and  
24 malignant neoplasm of mediastinum and rhabdomyosarcoma of the heart) were only available for  
25 1992-1993. Therefore, the number of expected deaths among these sites during 1992-1993 was  
26 applied to the entire cohort for the entire period of observation. A Poisson distribution was used to  
27 calculate the 95% CIs. One hundred thirty-one (2.5%) workers were lost to follow up. SMRs were  
28 calculated for the entire cohort and separately for females and males. Among the total cohort, SMRs  
29 were statistically significant for all cancers, liver cancer and leukemia (Table 4-3). Cancer-specific  
30 SMRs for liver cancer and leukemia were statistically significant in females but not in males, while the  
31 SMR for lung cancer was significant in males only.



**Table 4-3. Standardized mortality ratios (SMRs) for selected cancer risks relative to general population rates of Moscow, Russia.**

CAUSE OF DEATH	TOTAL COHORT CASES, SMR (95% CI)	MEN CASES, SMR (95% CI)	WOMEN CASES, SMR (95% CI)
All causes	900; 103 (97–110)	181; 121 (104–140)	719; 100 (93–107)
All cancers	265; 122 <sup>a</sup> (107–137)	56; 158 (119–205)	209; 115 (100–131)
Liver cancer	10; 240 <sup>a</sup> (110–430)	2; 240 (30–860)	8; 230 <sup>a</sup> (100–460)
Lung cancer	31; 140 (90–200)	17; 170 <sup>a</sup> (100–270)	14; 110 (60–190)
Leukemia	13; 190 <sup>a</sup> (100–330)	2; 190 (20–700)	11; 190 <sup>a</sup> (100–350)

<sup>a</sup> Statistical significance  $p < 0.05$ .

Source: Bulbulyan et al. (1998).

1 Internal relative risk (RR) analyses (controlling for gender, age, and calendar period) were  
 2 conducted for selected cancers by using multivariate Poisson regression models, with trends evaluated  
 3 with the Mantel-extension test. Estimates for liver cancer were relatively imprecise since only one  
 4 liver cancer death was observed in the no-exposure category (a low number since this category  
 5 included 29% of all observed deaths). Stratified analyses by gender were not reported. Internal  
 6 analyses comparing the high exposure group to the unexposed resulted in statistically significant RRs  
 7 for all causes of death (Table 4-4). Although they were not statistically significant largely due to a  
 8 small number of cases, elevated RRs ranging from 2.2-4.9 were detected for leukemia, and cancers of  
 9 the liver, kidney and colon.

**Table 4-4. Selected relative risk (RRs) estimates for the high exposure group relative to unexposed factory workers**

CAUSE OF DEATH	CASES	HIGH-EXPOSURE RR (95% CI) <sup>a</sup>
All causes	194	1.23 <sup>b</sup> (1.02–1.49)
Liver cancer	3	4.9 (0.5–47)
Colon cancer	8	2.6 (0.8–7.9)
Kidney cancer	2	3.3 (0.3–37)
Leukemia	5	2.2 (0.6–8.4)

<sup>a</sup> Reference group is defined as workers with no chloroprene exposure.

<sup>b</sup> Statistical significance  $p < 0.05$ .

Source: Bulbulyan et al., (1998).

10 Although there were only a few deaths in each group, RR analysis by duration of employment  
 11 in the highest exposure categories (1–9 years, 10–19 years, 20+ years) relative to no exposure showed  
 12 a significant trend for liver cancer but not for leukemia mortality (Table 4-5). The cumulative  
 13 exposure analysis indicated an increased risk of liver cancer mortality based upon six deaths in the  
 14 intermediate exposure category (RR = 7.1, 95% CI: 0.8-61) and three deaths in the highest exposure  
 15 category (RR = 4.4, 95% CI: 0.4-44). Kidney cancer was increased in all categories but none of the  
 16 RRs were statistically significant and no overall trend was observed.

**Table 4-5. Internal relative risks (RRs) by duration of employment in the high-exposure category.**

CAUSE OF DEATH	1-9 YEARS CASES; RR (95% CI)	10-19 YEARS CASES; RR (95% CI)	20+ YEARS CASES; RR (95% CI)	TREND
Liver cancer	1; 2.7 (0.2-45)	1; 8.3 (0.5-141)	1; 45.0 (2.2-903)	p = 0.02
Leukemia	2; 1.3 (0.2-7.3)	2; 3.4 (0.6-19)	1; 8.8 (0.7-66)	p = 0.07

Source: Bulbulyan et al. (1998).

1 The most prominent finding in the Bulbulyan et al. (1998) cohort was 10 deaths occurring from  
 2 liver cancer. The authors detected 11 deaths (3 in males and 8 in females) due to cirrhosis, a precursor  
 3 of primary liver cancer, but did not adjust for this as a potential confounder. Increased mortality due to  
 4 leukemia was observed in all categories for both cumulative exposure and duration of employment  
 5 (with high exposure) but neither trend was statistically significant. The authors suspected a causal role  
 6 of chloroprene in the leukemia deaths but could not rule out a possible role of exposure to benzene. A  
 7 significant increase in lung cancer was observed among males only, which may have been due to  
 8 confounding by smoking. Potential confounding by smoking could not be examined due to lack of  
 9 data for this cohort. Pancreatic cancer, which may be smoking related, was also observed in males  
 10 only. No excess risk for lung cancer was observed in females or in the total cohort. Lack of precise  
 11 quantitative exposure information, no adjustment for confounding risk factors, and exclusion of deaths  
 12 prior to 1979 resulting in relatively low statistical power were some of the limitations of this study.  
 13 Similar to Li et al study, the minimal data on observed deaths for some cancers among the general  
 14 population may have also resulted in biased SMR values if these years were not representative of  
 15 mortality during the entire study period.

16 Bulbulyan et al. (1999) conducted a retrospective cohort study of 2,314 workers (1,897 males,  
 17 417 females) who had been employed in production departments of a chloroprene monomer  
 18 production plant in Yerevan, Armenia, for at least two months between 1940 and 1988 and were alive  
 19 as of 1979. Mortality was followed from 1979-1988, and vital status was accessed through the  
 20 Yerevan Address Bureau. Death certificates were coded by using ICD-9 revision. Sixty-three (3%)  
 21 individuals were lost to follow-up. Industrial hygiene exposure measurements of chloroprene were  
 22 available both before and after 1980, when production changes led to a dramatic decrease in exposures.  
 23 Before 1980, exposures averaged 5.59-69.80 mg/m<sup>3</sup> (1.54-19.3 ppm) during the summer and 2.30-  
 24 249.5 mg/m<sup>3</sup> (0.63-68.9 ppm) during the winter. After 1980, for the same seasons, these averages  
 25 were 0.80-3.60 mg/m<sup>3</sup> (0.22-0.99 [summer] ppm) and 0.55-2.10 mg/m<sup>3</sup> (0.15-0.58 [winter] ppm),  
 26 respectively. Work histories were obtained from the personnel department, including the start and end  
 27 of each job, and from the departments of employment. Relative exposure values were assigned based  
 28 on either high exposure (production operators: six units before 1980, three units after 1980) or low  
 29 exposure (other production workers: two units before 1980 and one unit after 1980). Unexposed  
 30 workers were assigned a relative exposure value score of zero. SMRs and standardized incidence  
 31 ratios (SIRs) were calculated based on comparison rates for the entire Armenian population, and 95%

1 CIs were also calculated by using a Poisson distribution assumption. Internal RR estimates were  
2 calculated by using multivariate Poisson regression models and adjusting for age, calendar period, and  
3 gender.

4 A total of 21,107 person-years were contributed by the study population. There were 20 deaths  
5 during the observation period with four due to stomach cancers and three each resulting from liver and  
6 lung cancers. The SMR was statistically significant for liver cancer only (SMR = 339, 95% CI 109–  
7 1050). Two liver and two lung cancer deaths were identified among males, while one liver cancer  
8 death and one lung cancer death were identified in females. No internal comparisons were included in  
9 the SMR analysis. Cancer incidence data was examined from 1979–1990 through the Armenian  
10 Cancer Registry. Several types of cancers (37 cases) were identified with six liver and six lung cancers  
11 (five each in males) being the most prevalent (Table 4-6). The SIRs for liver cancer were statistically  
12 significant for the total cohort (SIR = 327, 95% CI 147–727) and for males (SIR = 303, 95% CI 126–  
13 727) when stratified by gender. SIRs below 100 were observed for lung cancer among both the total  
14 cohort as well as among males only.

**Table 4-6. Selected standardized incidence ratios (SIRs) for chloroprene monomer cohort relative to the general Armenian population.**

CANCER TYPE	OBSERVED	SIR (95% CI)
All cancers	37	0.68 (0.49–0.94)
Lung cancer	6	0.53 (0.24–1.19)
Liver cancer	6	3.27 <sup>a</sup> (1.47–7.27)

<sup>a</sup> Statistical significance  $p < 0.05$ .

Source: Bulbulyan et al. (1999).

15 Internal trend analyses of plant workers only showed increasing incidence of liver cancer by  
16 duration of employment with a statistically significant relative risk among chloroprene production  
17 workers who were employed for more than 20 years (4 cases, SIR =3.45, 95% CI: 1.29-9.20).  
18 Evaluation of liver cancer incidence by duration of employment (<1 year, 1-9 years and 10+ years) in  
19 the high chloroprene exposure groups resulted in a statistically significant SIR in the 10+ years  
20 category (SIR = 6.1; 95% CI: 2.3-16.3). Similar findings were noted when analyzed using cumulative  
21 exposure with a statistically significant SIR of 4.9 (95% CI: 2.0-11.7) among the five cases in highest  
22 cumulative exposure of 40+ units. All six cases of liver cancer in this study occurred among highly  
23 exposed operators. These internal analyses suggested a possible dose-response relationship between  
24 chloroprene exposure and liver cancer incidence.

25 The authors discussed the strong healthy worker effect observed in this study. In particular,  
26 they suggested that the low SMRs might be due, in part, to potential loss of early cases resulting from  
27 not beginning the follow-up period until 1979. In addition to the incomplete enumeration of outcomes  
28 among the workers, the authors acknowledged that there might be misclassification as well as  
29 incomplete registration of liver cancers in the Armenian registry. Furthermore, although measurements

1 of chloroprene levels were available, investigators were unable to develop quantitative estimates and  
2 assigned exposure units to the workers depending upon their job description. The role of potential  
3 confounding by alcohol use and smoking could not be examined due to lack of data. The high  
4 incidence (27 in males and 5 in females) of liver cirrhosis, a precursor for liver cancer, is an unlikely  
5 confounder as it is likely an intermediate in the causal pathway precluding statistical adjustment. There  
6 was also little evidence that several other co-exposures (i.e., vinyl acetate, toluidine, talc, and  
7 mercaptans) that were not adjusted for either in mortality or incidence analyses are liver carcinogens.

8 Romazini et al. (1992) investigated cancer mortality in a retrospective cohort study of 660.  
9 French chloroprene polymer manufacturing workers (599 males, 61 females) employed for at least two  
10 years at a polychloroprene plant. The follow-up period was from 1966-1989 with 32 observed deaths  
11 included in the study; an additional 18 potential study subjects were lost to follow up. No excess  
12 mortality was observed compared to regional rates. In a nested case-control study comparing time of  
13 employment, the authors found that workers exposed to conditions prior to 1977 had a much higher  
14 risk of death compared to those exposed to chloroprene after 1977. Similar to other studies, the small  
15 size of this cohort and inability to control for smoking and other potential confounders limited the  
16 conclusions that could be drawn from this study.

17 Colonna and Laydevant (2001) conducted a cohort cancer incidence study among 533 males  
18 who worked a chloroprene production plant in Isère, France, for at least two years between January  
19 1966 (when the plant opened) and December, 1997. Cancer incidence cases were traced through the  
20 Isère cancer registry from 1979 (when the registry was founded) through 1997. Workers who died  
21 before 1979 or who left the area were not traced (the number of untraced incident cancers was not  
22 estimated). Work histories were collected and jobs were classified into low, intermediate, and high  
23 chloroprene exposure groups based on estimated exposure of < 2 ppm, 2-5 ppm, and > 5 ppm  
24 respectively. Exposure duration was divided into three groups of  $\leq 10$  years, 11-20 years and > 20  
25 years. The cohort was divided into two groups, workers employed prior to 1977 and those employed in  
26 1977 or later, based on lower anticipated exposures following significant changes in worker protection.  
27 SIRs were calculated using the general population rates of Isère as a reference and confidence intervals  
28 were calculated using a Poisson distribution.

29 A total of 7,950 person-years were accrued. Of the 34 incident cancers, 32 occurred prior to  
30 1977. There were nine lung cancers, nine cancers of the head and neck (including three laryngeal  
31 cancers), and one liver cancer. SIRs were calculated for various cancers including those occurring in  
32 the head and neck, larynx, lung, liver and colon/rectum (Table 4-7). With the exception of  
33 colon/rectum, all of the SIRs exceeded 100 with most of the cases and higher SIRs noted for earlier  
34 periods of first employment (i.e., before 1977).

**Table 4-7. Standardized incidence ratios (SIRs) for elevated cancer risks for plant workers relative to general population rates of Isère, France.**

CANCER TYPE	TOTAL COHORT CASES, SIR (95% CI)	BEFORE 1977 CASES, SIR (95% CI)
All Cancers	34, 1.26 (0.88-1.77)	32, 1.46 (1.00-2.06)
Head and Neck	9, 1.89 (0.87-3.59)	8, 2.09 (0.90-4.11)
Larynx	3, 2.43 (0.50-7.13)	3, 2.97 (0.61-8.68)
Lung	9, 1.84 (0.84-3.49)	8, 1.99 (0.86-3.91)
Liver	1, 1.36 (0.04-7.63)	1, 1.64 (0.05-9.13)
Colon/Rectum	2, 0.66 (0.08-2.39)	2, 0.79 (0.10-2.87)

Source: Colonna and Laydevant, (2001).

1 Although none of the SIRs were statistically significant, a significant trend was observed when  
 2 the data were analyzed by duration of exposure. Five lung cancers were found in workers with > 20  
 3 years of exposure (SIR = 2.57), 3 in 11-20 years exposure (SIR = 1.49) and 1 in  $\leq$ 10 years exposure  
 4 (SIR = 1.06). No significant excesses were observed in head and neck cancer by duration of exposure.  
 5 No trend was detected for lung cancer incidence in relation to intensity of exposure with SIRs of 4.63  
 6 (95% CI: 1.27-11.91), 1.25 (95% CI: 0.15-4.51), and 1.23 (95% CI: 0.26-3.61) reported for the low,  
 7 intermediate and high exposure categories, respectively.

8 Increased lung cancer and laryngeal cancer were observed in this study. Given that smoking is  
 9 strongly associated with lung cancer, and since seven of the eight lung cancer cases were smokers, the  
 10 investigators concluded that the lung cancers excess was unlikely to be due to chloroprene exposure.  
 11 Although smoking and alcohol consumption was discussed as strongly associated with laryngeal  
 12 cancer, no additional information was provided in the paper. This study found only one incident liver  
 13 cancer but noted that liver cancer incidence was likely under-estimated due to difficulties in case  
 14 enumeration. Study limitations included lack of precise quantitative exposure information, low cancer  
 15 incidence, and reduced power because of elimination of workers who had died or left the area prior to  
 16 1979.

17 More recently, Marsh et al. (2007a) evaluated mortality patterns of four chloroprene production  
 18 facilities by using external regional rates and using internal comparisons (Marsh et al., 2007b). This  
 19 study attempted to address the problems identified with earlier studies by conducting a detailed  
 20 exposure assessment for both the chloroprene and a potential confounding co-exposure, vinyl chloride  
 21 monomer (Esmen et al., 2007a, 2007b, 2007c; Hall et al., 2007). As described in detail by Esmen et al.  
 22 (2007c), a historical review of processes at all four plants led to the assignment of exposures to 257  
 23 unique tasks. Taking into account shared tasks or rotation between tasks, job title-based exposures to  
 24 chloroprene were assigned to one of seven categories, including unexposed (< 0.0005 ppm). Vinyl

1 chloride exposures were assigned to one of five categories, including unexposed (< 0.01 ppm) (Esmen  
2 et al., 2007b).

3 Two of the facilities evaluated were in the U.S. - DuPont/Dow plants at Louisville (L),  
4 Kentucky and Pontchartrain (P), Louisiana. The third one was in Northern Ireland - the Maydown (M)  
5 plant, and the fourth facility was in Grenoble (G), France - the Enichem Elastomer plant. These plant  
6 cohorts included 5,507 workers (L), 1,357 workers (P), 4,849 workers (M), and 717 workers (G).  
7 Median cumulative exposures to chloroprene at these plants were 18.35, 0.13, 0.084, and 1.01 ppm-  
8 years, respectively. Vinyl chloride exposures existed in only two plants, Louisville and Maydown.  
9 Their median cumulative vinyl chloride exposures were 1.54 and 0.094 ppm-years, respectively.

10 The study period for the cohorts encompassed 52 (L), 41(M), 39 (P), and 34 (G) years resulting  
11 in 197,919, 127,036, 30,660, and 17,057 person-years, respectively (Marsh et al., 2007a). Vital status  
12 was assessed using several different sources. A trained nosologist using the ICD codes in effect at the  
13 time of death coded the underlying cause of death. A total of 3,002 deaths had occurred during the  
14 follow-up period in the chloroprene cohort and cause of death was ascertained for 2,850 individuals  
15 (95%). A modified Occupational Cohort Mortality Program was used to conduct statistical analyses.  
16 Independent analyses were conducted for the four facilities for total cancer deaths and certain site-  
17 specific deaths. Person-years at risk were computed for each individual by race, sex, age group,  
18 calendar time, duration of employment, and the time since first employment. SMRs and 95% CIs were  
19 calculated for the total cohort and selected sub-cohorts for each plant.

20 All cause combined mortality was significantly reduced (compared to local county rates) for  
21 each of the four cohorts (Table 4-8). In addition, each cohort had significantly reduced mortality for all  
22 cancers, and the largest cohort, Louisville, had significantly reduced mortality from respiratory  
23 cancers. The total number of cancer deaths observed at each of the four plants was 652 (L), 128 (M),  
24 34 (P), and 20 (G). Reported lung cancer deaths were 266, 48, 12, and 10, while liver cancer deaths  
25 were 17, 1, 0, and 1 for L, M, P, and G, respectively. Compared to the local population rates, fewer  
26 deaths from liver cancer were observed in the Louisville (SMR = 90, 95% CI: 52-144) cohort than  
27 expected. All other sites had no more than one death due to liver cancer. Similar to the healthy worker  
28 effect observed in other studies, fewer cancer deaths were reported in the occupational cohorts  
29 when compared to general population estimates. When chloroprene exposed and unexposed workers  
30 were analyzed separately, the SMRs for all cancers were all significantly reduced for exposed workers  
31 at each plant, while they were generally higher (at or above expected levels for all plants except at  
32 Grenoble) for unexposed workers. Given that there were few unexposed workers in these cohorts,  
33 these values are unstable and are also difficult to interpret given the healthy worker effect bias.

**Table 4-8. Standardized mortality ratios (SMRs) at each of four chloroprene production facilities**

CAUSE OF DEATH	LOUISVILLE (L) CASES, SMR (95% CI)	MAYDOWN (M) CASES, SMR (95% CI)	PONTCHARTRAIN (P) CASES, SMR (95% CI)	GRENOBLE (G) CASES, SMR (95% CI)	TOTAL CASES, SMR (95% CI)
All Causes	2403 74 (71-77)	435 60 (55-67)	102 53 (43-65)	62 65 (50-83)	3002 70 (67-73)
All Cancers	652 75 (69-80)	128 68 (56-80)	34 68 (47-95)	20 59 (36-91)	834 73 (68-78)
Respiratory Cancers	266 75 (66-85)	48 79 (58-105)	12, 62 (32-109)	10 85 (41-156)	336 75 (68-74)
All Cancers: Exposed	651 74 (69-80)	114 62 (51-75)	26 57 (37-84)	15 59 (33-97)	806 71 (66-76)
Unexposed	1 99 (3-551)	14 126 (69-212)	8 144 (62-285)	5 61 (20-142)	28 108 (72-156)

Source: Marsh et al. (2007a).

1 In their companion paper (Marsh et al., 2007b), the authors conducted internal RR analyses at  
 2 each of these four plants. Exposure-response trends across categories of exposures (based on quartiles)  
 3 were examined using a forward stepwise regression modeling approach to adjust for potential  
 4 confounding. Analyses were conducted by considering 5- and 15-year lagged exposures and using  
 5 white/blue collar as a surrogate for lifetime smoking. Absolute mortality rates were estimated by  
 6 calculating exposure category-specific SMRs using external mortality rates. The internal analyses for  
 7 all cancers showed increasing RRs with duration of exposure (< 10, 10-19, 20+ years) to chloroprene  
 8 in plants L and M, but a statistically significant trend ( $p < 0.007$ ) was only noted for Plant M. Relative  
 9 to less than 10 years of exposure, increased RRs were noted for 10-19 years (RR = 1.53; 95% CI =  
 10 1.00-2.34) and 20+ years (RR = 1.78; 95% CI = 1.11-2.84) of exposure. The external comparison  
 11 consistently showed SMRs less than the internal analysis (and mostly below 1) for both the plants  
 12 suggestive of bias due to the healthy worker effect.

13 The internal analysis for liver cancer could only be conducted in the Louisville cohort, which  
 14 contained 17 of the 19 observed deaths and also had the highest chloroprene levels. Despite the limited  
 15 number of deaths, these data show some evidence of a dose-response effect across the four exposure  
 16 levels ( $p = 0.09$ ). Although the individual RRs were not statistically significant, the range for the  
 17 highest three exposure levels was from 1.9-5.1.

18 The results of the internal analyses for respiratory cancers at the three plants (M, P, G) without  
 19 worker status adjustment showed higher RRs with increasing cumulative exposure (Table 4-9). The  
 20 observed trends were not statistically significant but were based on a small number of respiratory  
 21 cancers. In contrast, the plant with the most cases (L) showed little evidence of an exposure-response  
 22 relationship. The investigators adjusted for the potential confounding by smoking status in the analyses  
 23 of lung cancer mortality at Louisville only (due to small numbers at the other plants) using the

1 employment status as a surrogate of blue versus white collar workers. This decision was justified by  
 2 the authors based upon this variable being a surrogate for variables associated with smoking such as  
 3 education and socio-economic status. It is impossible, however, to discern whether this surrogate  
 4 resulted in control for smoking or resulted in an over-adjustment since work status is so highly  
 5 correlated with chloroprene exposures.

**Table 4-9. Relative risks (RRs) for respiratory cancers by cumulative chloroprene exposure**

PLANT	LEVEL 1 <sup>a</sup> (LOWEST) N	LEVEL 2 N, RR (95% CI)	LEVEL 3 N, RR (95% CI)	LEVEL 4 N, RR (95% CI)	TREND
Louisville (L)	62, Reference	67, 1.00 (0.71-1.43)	77, 1.32 (0.94-1.88)	60, 0.85 (0.58-1.23)	p = 0.71
Maydown (M)	14, Reference	9, 1.65 (0.66-4.15)	12, 1.89 (0.72-4.96)	13, 2.28 (0.86-6.01)	p = 0.10
Pontchartrain (P)	3, Reference	3, 1.60 (0.20-12.8)	2, 2.90 (0.20-34.1)	4, 2.32 (0.30-21.8)	p = 0.34
Grenoble (G)	2, Reference	1, 0.61 (0.05-6.76)	4, 2.87 (0.35-39.7)	3, 3.14 (0.30-48.0)	p = 0.17

<sup>a</sup>Chloroprene exposure (in ppm years) levels varied by plant: L (<4.7->164.1); M (<0.04->24.5); P (<0.02->16.2); G (<0.05->23.9).

Source: Marsh et al. (2007b)

6 The authors also conducted internal analyses of cancer mortality and vinyl chloride exposure  
 7 (the primary co-exposure in this study) at the Louisville plant. They found an inverse association  
 8 (many of them statistically significant) between risk of both respiratory and liver cancer in relation to  
 9 vinyl chloride exposures. In fact, the vast majority of respiratory and liver cancers occurred among  
 10 workers who were unexposed to vinyl chloride. If vinyl chloride is a negative confounder of the  
 11 association between chloroprene and liver cancer, then the reported association between chloroprene  
 12 and liver cancer would be an underestimate of the association adjusted for vinyl chloride. Given this, it  
 13 is highly unlikely that confounding by vinyl chloride could explain the associations observed between  
 14 chloroprene and these cancers. In addition, the authors reported that there was no correlation between  
 15 cumulative exposures to vinyl chloride and chloroprene among these workers.

16 The Marsh et al. (2007a, 2007b) study is one of the more comprehensive studies to date, largely  
 17 due to exposure assessment data which allowed for internal comparisons. Although the authors  
 18 concluded that their study provided no evidence of cancer risk associated with chloroprene exposures,  
 19 the data on chloroprene exposure and liver cancer risk was not inconsistent with previous findings.  
 20 While the authors stated that “chance alone does not appear to be an explanation for the cancer deficits  
 21 observed among unexposed workers,” they rejected the healthy worker effect as a plausible  
 22 explanation. Instead, they postulated “some heretofore unknown selection factors for low cancer  
 23 incidence or mortality were operating on the unexposed subjects” (Marsh et al., 2007b). This is  
 24 inconsistent with the data that Marsh et al. (2007b) presented on cancer mortality among exposed and



1 unexposed workers (Table 4-9). It can be concluded that the explanations for observed associations  
2 between chloroprene exposure and cancer, especially liver and respiratory cancers, given by Marsh et  
3 al. (2007b) are not entirely consistent with the data presented. Despite the study limitations including  
4 small numbers, this study is informative given the findings of the internal analysis including the data  
5 on cumulative exposure and liver cancer risk.

#### 4.1.1.3. *Summary and Discussion of Relevant Methodological Issues*

6 Nine studies covering 11 cohorts were reviewed to assess the relationship between exposure to  
7 chloroprene and cancer incidence and mortality. Four cohorts had less than 1000 workers, while the  
8 remaining cohorts had sample sizes less than 6000. The most consistent finding was excess liver  
9 (Bulbulyan et al. 1999, 1998; Li et al., 1989; Leet and Selevan, 1982) and lung/respiratory system  
10 (Marsh et al., 2007b; Colonna and Laydevant, 2001; Bulbulyan et al. 1999, 1998; Leet and Selevan,  
11 1982; Pell et al., 1978) cancer incidence or mortality (Tables 4-10 and 4-11). The limitations of each of  
12 the aforementioned studies are discussed in this section. Most occupational cohort studies are  
13 historical in nature gathering human subject information from existing records and going back many  
14 years. In general, the constructed databases do not include detailed information on the workers'  
15 individual habits (e.g., tobacco use, alcohol consumption) and usually only have limited exposure  
16 information. These limitations often limit the ability to control for bias due to confounding variables  
17 and to assess the potential for misclassification of exposure.

18 One of the limitations of the occupational epidemiologic studies examining chloroprene  
19 exposure is the potential for the healthy worker effect to influence the results. Since occupational  
20 studies involve workers who are healthier than the general population, a reduced mortality risk is often  
21 observed among these populations when compared to external populations. This potential bias was  
22 likely reduced in some studies by using internal comparisons or other study designs such as a nested  
23 case-control study.

24 Another concern in these occupational studies is the reliance on death certificates for outcome  
25 ascertainment especially in the mortality studies. Although misclassification of cause of death can be  
26 minimized by the review of medical records or by histological confirmation, this was not done in any  
27 of the studies. Incomplete enumeration of incident cases was another limitation of several of the  
28 studies. This may limit the ability to detect associations as it directly reduces statistical power through  
29 reduced sample sizes. Outcome misclassification can also bias the measures of associations that were  
30 examined, but it is difficult to gauge the potential impact of this bias on the reported findings.

31 Finally, the lack of quantitative exposure assessment is clearly a limiting factor of most  
32 occupational studies; however, they still are able to contribute to the overall qualitative weight of  
33 evidence considerations. In many cases where exposure data were missing or insufficient to provide  
34 quantitative assessments, exposure levels were differentiated based upon job titles and industrial  
35 hygiene knowledge of the processes involved. Although measurement error is present in all studies to

1 varying degrees, there is no evidence that this error differed by outcome (i.e., was non-differential) in  
 2 these studies. Although there are rare exceptions, non-differential misclassification of workers'  
 3 exposures due to lack of information usually results in an underestimate of the association between  
 4 exposure and outcome.

**Table 4-10. Epidemiologic summary results of respiratory system cancers: Overall standardized mortality ratios (SMRs) and SMRs for intermediate and high chloroprene exposures relative to external population comparison**

STUDY	TOTAL COHORT SMR (95% CI)	HIGH EXPOSURE <sup>A</sup> SMR (95% CI)	INTERMEDIATE EXPOSURE <sup>A</sup> SMR (95% CI)
Bulbulyan et al., 1998	140 (90-200)	0.8 (0.3–2.4) <sup>c,d</sup>	1.0 (0.4–2.5) <sup>c,d</sup>
Bulbulyan et al., 1999	50 (16-155)	-----	-----
Colonna and Laydevant, 2001	184 (84-349) <sup>e</sup>	123 (26-361) <sup>e</sup>	125 (15–451) <sup>e</sup>
Leet and Sullivan, 1982	106 (62-170)	128 (61-236)	86 (35-178) <sup>b</sup>
Marsh et al., 2007a,b-Louisville	75 (66-85)	65 (50-85) <sup>d,e</sup>	92 (73-115) <sup>d,e</sup>
Marsh et al., 2007a,b-Maydown	79 (58-105)	113 (60-192) <sup>d,e</sup>	97 (50-169) <sup>d,e</sup>
Marsh et al., 2007a,b-Pontchartrain	62 (32-109)	85 (23-218) <sup>d,e</sup>	96 (12-348) <sup>d,e</sup>
Marsh et al., 2007a,b-Grenoble	85 (41-156)	128 (26-373) <sup>d,e</sup>	119 (32-304) <sup>d,e</sup>

<sup>a</sup>Relative to Low or Unexposed Groups

<sup>b</sup>Low Exposure Group

<sup>c</sup>Relative Risk of Death from Lung Cancer

<sup>d</sup>Cumulative Chloroprene Exposures

<sup>e</sup>Standardized Incidence Ratios

**Table 4-11. Epidemiologic summary results of liver/biliary passage cancers: Total cohort standardized mortality ratios (SMRs) and relative risk (RRs) for intermediate and high chloroprene exposures**

STUDY	TOTAL COHORT SMR <sup>A</sup> (95% CI)	HIGH EXPOSURE <sup>B</sup> RR (95% CI)	INTERMEDIATE EXPOSURE <sup>B</sup> RR (95% CI)
Bulbulyan et al., 1998	240 (110-430)	4.4 (0.4-44) <sup>c,d</sup>	7.1 (0.8-61) <sup>c,d</sup>
Bulbulyan et al., 1999	339 (109-1050)	4.9 (2.02-11.7) <sup>d,e</sup>	2.9 (0.41-20.8) <sup>d,e</sup>
Colonna and Laydevant, 2001	136 (4-763) <sup>e</sup>	-----	-----
Leet and Sullivan, 1982	571 (156-1463)	750 (155-2192) <sup>f</sup>	250 (6-1393) <sup>f</sup>
Li et al, 1989	482 (N/R, p < 0.01)	-----	-----
Marsh et al., 2007a,b-Louisville	90 (52-144)	3.3 (0.5, 39.3) <sup>d</sup>	5.1 (0.9, 54.5) <sup>d</sup>
Marsh et al., 2007a,b-Maydown	24 (1-134)	-----	-----
Marsh et al., 2007a,b-Pontchartrain	-----	-----	-----
Marsh et al., 2007a,b-Grenoble	56 (1-312)	-----	-----

N/R: Not Reported

<sup>a</sup>Relative to External Population Rates

<sup>b</sup>Relative to Low or Unexposed Groups

<sup>c</sup>Relative Risk of Death from Liver Cancer

<sup>d</sup>Cumulative Chloroprene Exposures

<sup>e</sup>Standardized Incidence Ratio

<sup>f</sup>Standardized Mortality Ratio

### ***Lung Cancer Summary***

1 An increased risk of lung cancer incidence and mortality was observed in a few studies  
2 (Colonna and Laydevant, 2001; Bulbulyan et al., 1998; Pell et al., 1978; Li et al., 1989), although few  
3 statistically significant associations were reported. None of the studies adjusted for smoking because  
4 the investigators either did not have this information available or because the majority of their lung  
5 cancer cases were observed in smokers. Marsh et al. (2007b) used white/blue collar as a surrogate for  
6 smoking habits assuming that blue collar workers smoked more than white collar workers. But due to  
7 small number of deaths in white collar workers the authors reportedly only adjusted the lung cancer  
8 risk for worker type in the Louisville, Kentucky plant. Since worker pay type is a crude surrogate of  
9 smoking status, it is difficult to rule out the potential confounding effects of smoking. Worker pay  
10 status is also a marker of chloroprene exposure. Therefore, inclusion of this variable in regression  
11 models may result in over-adjustment distorting the relationship between cancer mortality and  
12 chloroprene exposure. A few studies noted higher SMRs for lung cancer among workers exposed to  
13 chloroprene; however, there was no evidence of an exposure-response relationship across various  
14 chloroprene exposure categories.

## ***Liver Cancer Summary***

1 Statistically significant excesses of liver cancers were detected in four of the cohorts that were  
2 examined (Bulbulyan et al. 1999, 1998; Li et al., 1989; Leet and Selevan, 1982). Although no  
3 statistically significant increase in risk of liver cancer was detected in the Louisville plant (Marsh et  
4 al., 2007b), the relative risk increased with increasing cumulative exposures indicating a dose-response  
5 trend. In three of the cohorts, there was only one case of liver cancer or mortality from liver cancer  
6 (Marsh et al., 2007a, 2007b and Colonna and Laydevant, 2001) detected, while the Pontchartrain  
7 cohort study had no reported liver cancer deaths (Marsh et al., 2007b). This precluded meaningful  
8 examination especially in the latter studies with more detailed exposure information.

9 Confounding by occupational co-exposures is addressed in some studies but few of these  
10 included direct adjustments for the possible confounders. Some studies have selected workers from  
11 several different processes where the co-exposures might have been different or non-existent in some  
12 processes to help address the potential for confounding. Bulbulyan et al. (1999, 1998) discussed other  
13 possible exposures and concluded that confounding was unlikely, since none of the known co-exposure  
14 chemicals were known to be associated with liver cancer. Marsh et al. (2007b) conducted a separate  
15 analysis with vinyl chloride in the Louisville plant and found that 15 out of 17 liver cancer cases were  
16 found in workers that were not exposed to vinyl chloride. The authors also reported that there was no  
17 correlation between cumulative exposures to vinyl chloride and chloroprene among these workers.  
18 Given these data, it is highly unlikely that confounding by vinyl chloride could explain the association  
19 observed between chloroprene and these cancers. No adjustments for other risk factors for liver  
20 cancer, such as alcohol consumption, were performed in any of the cohorts observing statistically  
21 significant increases in liver cancer mortality. If alcohol consumption was associated with chloroprene  
22 exposure this might be a source of residual confounding. Further limitations in these cohorts include  
23 the lack of precise quantitative exposure information, limited statistical power to detect effects due to  
24 insufficient general population mortality data, and incomplete ascertainment of health outcomes.  
25 Studies that relied upon comparisons to external population mortality rates are also susceptible to the  
26 healthy worker effect although the potential impact on cancer mortality in these populations is unclear  
27 (see above).

28 Primary liver cancer is relatively rare in the U.S. It accounts for approximately 1.3% of new  
29 cancer cases and 2.6% of cancer deaths (Jemal et al., 2003). There are few identified chemicals that  
30 have been associated with primary liver cancer. The observation of an increased risk of liver cancer  
31 mortality is reasonably consistent and there is some evidence of an exposure-response relationship  
32 among workers exposed to chloroprene in different cohorts in different continents (i.e. U.S., China,  
33 Russia, and Armenia).

## 4.1.2. Chloroprene Exposure and Noncancer Effects

### 4.1.2.1. *Acute-, Short-, and Subchronic-Duration Noncancer Effects*

1 Nystrom (1948) reported effects associated with the levels (not specified) of chloroprene  
2 exposure experienced during the start-up of chloroprene production in Sweden. The author noted a  
3 high level of symptoms among workers in two departments, chloroprene distillation and  
4 polymerization, in both the pilot plant and early period of regular production. Over the time period  
5 from 1944–1997, the author conducted a series of employee medical examinations. In the distillation  
6 department of the production plant, 19 of 21 workers (90%) complained of fatigue and pressure or  
7 pains over the chest, with much fewer numbers (3–6 employees) complaining of palpitations,  
8 giddiness, irritability, and dermatitis. No workers experienced loss of hair.

9 In the polymerization department of the production plant, temporary hair loss affected 11 of 12  
10 workers or 90%. The author attributed this to systemic rather than direct skin exposure (which was  
11 carefully controlled). Dermatitis was present in four workers (30%), and all other symptoms evaluated  
12 were limited to no more than one worker.

13 Guided by animal studies and reports from other companies, Nystrom (1948) evaluated  
14 employees for impaired renal and liver function, basal metabolism, and pulmonary and cardiovascular  
15 abnormalities by conducting general body examination, clinical chemistry of the urine and blood, and  
16 other tests referred to as “special investigations” (including X-rays, electrocardiograms, and  
17 hypoxemia and stress tests). The results of these evaluations were reported in an anecdotal manner  
18 with no qualitative or quantitative (e.g., statistical significance of results) details. Except for increased  
19 symptoms with exercise right after exposure (among distillation department workers), no clear  
20 pathologies were observed. In the pilot plant, where exposures were less controlled, Nystrom (1948)  
21 noted anemia among exposed workers. The author also observed that, when the workers were  
22 educated about the dangers and safety precautions were enforced, the symptoms decreased.

23 In a Russian review of the effects of chloroprene, Sanotskii (1976) noted that medical  
24 examinations of chloroprene production workers had found changes in the nervous system, hepatic and  
25 renal function, cardiovascular system, and hematology. Assessment of exposures in Russian latex and  
26 rubber manufacturing plants showed that chloroprene was the main hazard and that exposures ranged  
27 from 1–7 mg/m<sup>3</sup> in exposed work areas.

28 One of the studies reported in this review included medical exams of 12 men and 53 women, of  
29 whom two-thirds had been employed in a chloroprene production plant for less than 5 years.  
30 Cardiovascular examinations found muffled heart sounds in 30 workers, reduced arterial pressure in  
31 14, and tachycardia in 9. There was also a reduction in RBC counts, with hemoglobin substantially  
32 below the limit of physiological variation. Erythrocytopenia, leucopenia, and thrombocytopenia were  
33 observed. Increases in vestibular function disturbance were associated with duration of work.

1 In another study reviewed by Sanotskii (1976), women aged 19–23 and employed in jobs with  
2 chloroprene exposure for 2–4 years had abnormal diurnal variation in arterial pressure, with reduced  
3 systolic and diastolic components at the end of the workday when compared with controls. Their pulse  
4 rates were considerably higher than those of controls ( $p < 0.01$ ). Central nervous system (CNS)  
5 function was also affected with lengthening of sensorimotor response to visual cues compared with  
6 controls. Olfactory thresholds increased with duration of employment.

#### 4.1.2.2. *Chronic Noncancer Effects*

7 Chronic effects in exposed workers at an electrical engineering plant were also reported in the  
8 review by Sanotskii (1976). When compared to 118 unexposed controls, the chloroprene-exposed  
9 cohort (143 workers) exhibited an increased incidence of disturbances of spermatogenesis after 6–10  
10 years of work and morphological disturbances after 11 years or more. A questionnaire showed that  
11 cases of spontaneous abortion in the wives of chloroprene workers occurred more than three times as  
12 frequently as in the control group. This study presents interpretational difficulties concerning the level  
13 of participation of the exposed workers and their wives, the quantitative interpretation of the reported  
14 sperm abnormalities, and the appropriate matching of exposed and control populations. In an earlier  
15 evaluation of this study, U.S. EPA (1985) concluded that recall bias associated with a retrospective  
16 questionnaire, such as was used in the study reviewed by Sanotskii (1976), was likely, and the  
17 likelihood that the study would have discovered a real increase in the rate of spontaneous abortions  
18 was remote, as embryos with chromosomal abnormalities are spontaneously aborted early in  
19 pregnancy. Many pregnancies are lost spontaneously often before a woman recognizes that she is  
20 pregnant, and the clinical signs of miscarriage are often mistaken for a heavy or late menses (Griebel et  
21 al., 2005). Thus, U.S. EPA (1985) concluded that it was not reasonable to draw conclusions on the  
22 possible effect of chloroprene on early fetal losses based on the Sanotskii (1976) review. In addition,  
23 the EPA suggested that the low participation of male volunteers available for sperm analysis (9.5%  
24 participation, 15/143 workers) indicated that a large degree of selection bias may have been present. If  
25 males with reproductive deficits self-selected themselves for participation, the meaningful  
26 interpretation of the study results may be limited.

27 The final conclusion of the EPA analysis was that it is not possible to interpret the results in the  
28 Sanotskii (1976) review with any degree of reliability (U.S. EPA, 1985). Savitz et al. (1994) and  
29 Schrag and Dixon (1985) separately reviewed the study and also concluded that insufficient  
30 methodological details were available to critically evaluate the observation reported by Sanotskii  
31 (1976).

32 Sanotskii (1976) also reported a study of chromosome aberrations in leukocyte culture cells of  
33 chloroprene production employees. The occurrence of chromosomal aberrations were significantly  
34 higher ( $p < 0.001$ ) in the exposed group compared to the control group, as well as elevated compared to  
35 reported levels among healthy persons. Similar results were reported for a different study of two sets

1 of female employees: (1) 20 women aged 19–23 and exposed to 3–7 mg/m<sup>3</sup> (0.83–1.93 ppm)  
 2 chloroprene for 1–4 years; and (2) 8 women aged 19–50 and exposed to 1–4 mg/m<sup>3</sup> (0.28–1.1 ppm) for  
 3 1–20 years. The results of these two studies are shown in Table 4-12.

**Table 4-12. Frequency of chromosomal aberrations in lymphocyte culture cells from chloroprene production workers**

CHLOROPRENE EXPOSURE	# EXAMINED	YEARS EXPOSED	AGE RANGE	# CELLS ANALYZED	PERCENT ABERRANT (+/-)	PERCENT TYPE ABERRANT	
						Chromatid	Chromosome
Chloroprene Workers	18	----	----	1,666	4.77 (0.57) <sup>a</sup>	74.4	25.6
Control	9	----	----	572	0.65 (0.56)	100	0
1–4 mg/m <sup>3</sup>	8	1–20	19–50	648	2.5 (0.49) <sup>b</sup>	----	----
3–7 mg/m <sup>3</sup>	20	1–4	19–23	1,748	3.49 (0.51) <sup>a</sup>	----	----
Population Control	181	----	----	28,386	1.19 (0.06)	50.3	49.7

<sup>a</sup> p < 0.001. All values means ± SE

<sup>b</sup> p < 0.05

Source: Sanotskii (1976).

## 4.2. SUBCHRONIC AND CHRONIC STUDIES AND CANCER BIOASSAYS IN ANIMALS—ORAL AND INHALATION

### 4.2.1. Oral Exposure

4 The only available long-term animal study using the oral route of administration was part of a  
 5 developmental/reproductive study. Ponomarkov and Tomatis (1980) administered chloroprene  
 6 dissolved in olive oil by stomach tube to 17 female BD IV rats at a single dose (100 mg/kg body  
 7 weight) on gestational day (GD) 17. Progeny from treated females (81 males and 64 females) were  
 8 treated weekly with 50 mg/kg body weight by stomach tube from the time of weaning for life (120  
 9 weeks). A control group of 14 female rats was treated with 0.3 mL olive oil. The purity of the  
 10 chloroprene was reported as 99% with 0.8% 1-chlorobutadiene; storage conditions were not reported.  
 11 All survivors were sacrificed at 120 weeks or when moribund and autopsied. Major organs, as well as  
 12 those that showed gross abnormalities, were examined histologically.

13 Litter sizes and preweaning mortality, survival rates, and body weights did not differ between  
 14 chloroprene-treated animals and controls. Animals treated with chloroprene that died within the first  
 15 23–35 weeks of treatment showed severe congestion of the lungs and kidneys. Some animals (number  
 16 not specified) autopsied 80–90 weeks after the onset of treatment showed multiple liver necroses.  
 17 Animals that died after 90 weeks and some survivors euthanized at 120 weeks showed degenerative  
 18 lesions of the liver parenchymal cells (large cells with clear cytoplasm in nodular arrangements).

1 Tumor incidences and distribution reported in this study are summarized in Tables 4-13 and 4-  
 2 14. No statistically significant differences were reported between treated and control rats. However,  
 3 several tumors observed in males (intestinal leiomyosarcoma, osteoma, kidney mesenchymal tumor,  
 4 bone hemangioma, neurinoma of the optic nerve, transition-cell carcinoma of urinary bladder, and  
 5 forestomach papilloma.) and females (ovarian and mammary tumors) treated weekly with chloroprene  
 6 were not seen in the vehicle control group. Subcutaneous fibromas were more numerous in  
 7 chloroprene-treated male rats than in controls.

**Table 4-13. Tumor incidence in female BD IV rats treated orally with chloroprene (100 mg/kg) on GD17 and in their progeny treated (50 mg/kg) weekly for life (120 weeks)**

GROUP	NUMBER <sup>a</sup>	TUMOR BEARING RATS		NUMBER OF TUMORS		ANIMALS WITH MORE THAN ONE TUMOR	
		n	%	Total	Per rat	n	%
Treated females	16	9	56.2	14	0.9	5	31.3
Treated progeny							
Males	54	15	27.8	18	0.3	3	5.6
Females	62	33	53.2	37	0.6	4	6.5
Control females	14	5	35.7	7	0.5	2	14.3
Control progeny							
Males	49	16	32.7	16	0.3	---	---
Females	47	24	51.1	29	0.6	5	10.6

<sup>a</sup>Survivors at the time the first tumors were observed.

Source: Ponomarkov and Tomatis (1980).



**Table 4-14. Distribution of tumors in female BD IV rats treated orally with chloroprene (100 mg/kg) on GD17 and their progeny treated (50mg/kg) weekly for life (120 weeks)**

GROUP	ORAL CAVITY		MAMMARY		OVARY		THYROID		SOFT TISSUE		PITUITARY		OTHER	
	n	%	n	%	n	%	n	%	n	%	n	%	n	%
Treated	1	6.3	6	37.5	2	12.5	---	---	---	---	1	6.3	4 <sup>a</sup>	25.0
Treated														
Males	---	---	---	---	---	---	1	1.9	7	13.0	2	3.7	8 <sup>b</sup>	14.8
Females	---	---	25	40.3	9	14.5	1	1.6	---	---	2	3.2	---	---
Control	1	7.1	4	28.6	---	---	---	---	1	7.1	---	---	1 <sup>c</sup>	7.1
Control														
Males	2	4.1	---	---	---	---	---	---	4	8.2	2	4.1	8 <sup>d</sup>	16.3
Females	1	2.1	22	46.8	3	6.4	---	---	---	---	1	---	3 <sup>e</sup>	6.4

<sup>a</sup> 1 each: uterine squamous cell carcinoma; lung reticulosarcoma; forestomach papilloma; sebaceous basal cell carcinoma.

<sup>b</sup> 1 each: intestinal leiomyosarcoma; osteoma; kidney mesenchymal tumor; bone hemangioma; neurinoma of the optic nerve; adrenal cortical adenoma; transition-cell carcinoma of urinary bladder; forestomach papilloma.

<sup>c</sup> Adrenal cortical adenoma.

<sup>d</sup> 2 lymphomas; 1 each: lung epidermoid carcinoma; spleen hemangioma; osteosarcoma; mediastinal sarcoma; meningioma; adrenal cortical adenoma.

<sup>e</sup> 1 each: stomach fibrosarcoma; lymphoma; uterine adenoma.

Source: Ponomarkov and Tomatis (1980).

#### 4.2.2. Inhalation Exposure

1           The NTP conducted 16-day, 13-week, and 2-year inhalation exposure studies with chloroprene  
2 in F344/N rats and B6C3F1 mice (NTP, 1998). Results of the 13-week study were reported by  
3 Melnick et al. (1996), while the cancer results of the 2-year study were discussed separately by  
4 Melnick et al. (1999) in relation to observations noted with 1,3-butadiene in mice. All experimental  
5 regimes consisted of 6 hours per day, 5 days per week whole-body exposures. Group sizes were 10  
6 animals/sex/group in the 16-day and 13-week studies and 50 animals/sex/group in the 2-year study.  
7 Overall purity of the bulk chloroprene was determined to be approximately 96% by gas  
8 chromatography. Vapor was generated in the 13-week and 2-year studies from chloroprene in an  
9 evaporation flask kept at 66°C (72°C in the 16-day studies) followed by a temperature-controlled  
10 condenser column (to remove less volatile impurities such as chloroprene dimers); the chloroprene  
11 reservoir was kept at dry ice temperature (16-day study) or under nitrogen (13-week and 2-year  
12 studies). The actual concentrations generated from the evaporator flask were within 99% of target  
13 concentrations at the beginning of the exposures and were 95% pure at the end of the exposure period.  
14 Chloroprene was dragged from the evaporator by a metered flow of nitrogen before being injected  
15 into the mixer column, where it was diluted with HEPA- and charcoal-filtered air. Impurities more  
16 volatile than chloroprene, such as chlorobutene, never exceeded more than 0.6% of the desired  
17 chloroprene concentration when sampled from the distribution line, the last sampling point upstream  
18 from the actual exposure chambers. Histopathology was performed by a study pathologist and  
19 reviewed by a quality assurance pathologist and the Pathology Working Group.

1 In the 16-day study, rats were exposed to 0, 32, 80, 200, or 500 ppm chloroprene (NTP, 1998).  
 2 On day 4, rats were placed in metabolism cages for 16-hour urine collection. A necropsy was  
 3 performed on all animals, and histopathological examinations were performed on controls, 80 ppm  
 4 female rats, and 200 and 500 ppm male and female rats. Tissues and organs examined included brain,  
 5 liver, kidney, lung, bone marrow, thymus, spleen, and testes. Sperm morphology and vaginal cytology  
 6 were not evaluated.

7 Survival and body weights of rats are given in Table 4-15. Only one male in the high-exposure  
 8 group (500 ppm) survived. Females in the high-exposure group had a higher survival (7/10) with a  
 9 significantly decreased body weight (-6% compared with controls). Significantly decreased body  
 10 weight gain was also observed in males and females at 200 ppm, and in females at 500 ppm.

**Table 4-15. Survival and body weights of rats in the 16-day inhalation study of chloroprene**

SEX	EXPOSURE (ppm)	SURVIVAL	MEAN BODY WEIGHT (g)		
			Initial	Final	Change
Male	0	7/10	115 ± 4	139 ± 5	+ 20 ± 2
	32	10/10	113 ± 4	134 ± 6	+ 20 ± 2
	80	10/10	118 ± 5	136 ± 5	+ 18 ± 1
	200	9/10	114 ± 4	127 ± 5	+ 11 ± 2**
	500	1/10	114 ± 4	104	4 <sup>a</sup>
Female	0	9/10	100 ± 2	110 ± 3	+ 9 ± 1
	32	9/10	100 ± 2	109 ± 3	+ 8 ± 1
	80	9/10	103 ± 2	112 ± 2	+ 9 ± 1
	200	3/10	101 ± 2	101 ± 4	+ 4 ± 1**
	500	7/10	102 ± 2	103 ± 3	- 1 ± 1**

<sup>a</sup> No standard error calculated due to high mortality

\*\* Significantly different ( $p \leq 0.01$ ) from the chamber control group by Williams' or Dunnett's test

Source: NTP (1998)

11 The incidences of minimal to mild olfactory epithelial degeneration in all exposed groups of  
 12 males and females were significantly greater than those in the chamber control groups (Table 4-16).  
 13 Mild to moderate centrilobular hepatocellular necrosis was observed in male and female rats exposed  
 14 to 200 or 500 ppm. Hematological and clinical chemistry parameters indicated increased serum  
 15 alanine aminotransaminase (ALT), glutamine dehydrogenase (GDH), and sorbitol dehydrogenase  
 16 (SDH) activities, as well as anemia and thrombocytopenia (decreased platelet count) in the 200 and  
 17 500 ppm groups, on day 4 only. In females, significant increases in kidney weights (right kidney only)  
 18 were seen at 80 and 500 ppm, and significantly increased liver weights were seen at 200 and 500 ppm.

**Table 4-16. Incidences of selected nonneoplastic lesions in rats in the 16-day inhalation study of chloroprene**

	CONTROL	32 ppm	80 ppm	200 ppm	500 ppm
<i>Male</i>					
Nose <sup>a</sup>	10/10	10/10	10/10	10/10	10/10
Degeneration, olfactory epithelium	1/10	10/10 <sup>c</sup>	10/10 <sup>c</sup>	10/10 <sup>c</sup>	10/10 <sup>c</sup>
Metaplasia, squamous, olfactory epithelium	0/10	0/10	0/10	1/10	4/10 <sup>b</sup>
Metaplasia, respiratory, olfactory epithelium	0/10	2/10	5/10 <sup>b</sup>	6/10 <sup>b</sup>	1/10
Metaplasia, squamous, olfactory epithelium	1/10	1/10	0/10	0/10	7/10
Liver <sup>a</sup>	10/10	1/10	10/10	10/10	10/10
Necrosis, centrilobular	0/10	0/10	0/10	1/10	9/10 <sup>c</sup>
Inflammation, chronic	0/10	0/10	0/10	0/10	1/10
<i>Female</i>					
Nose <sup>a</sup>	10/10	10/10	10/10	10/10	10/10
Degeneration, olfactory epithelium	0/10	9/10 <sup>c</sup>	10/10 <sup>c</sup>	10/10 <sup>c</sup>	10/10 <sup>c</sup>
Metaplasia, squamous, olfactory epithelium	0/10	1/10	1/10	4/10 <sup>b</sup>	0/10
Metaplasia, respiratory, olfactory epithelium	0/10	7/10 <sup>c</sup>	8/10 <sup>c</sup>	3/10	7/10 <sup>c</sup>
Metaplasia, squamous, olfactory epithelium	1/10	1/10	0/10	0/10	4/10
Liver <sup>a</sup>	10/10	3/10	10/10	10/10	10/10
Necrosis, centrilobular	0/10	0/10	0/10	7/10 <sup>c</sup>	3/10
Inflammation, chronic	0/10	0/10	0/10	2/10	5/10 <sup>b</sup>

<sup>a</sup> Number of animals with tissue examined microscopically.

<sup>b</sup>  $p \leq 0.05$ .

<sup>c</sup> Significantly different ( $p \leq 0.01$ ) from the chamber control group by the Fisher's exact test.

Source: NTP (1998)

1           In the mouse portion of the 16-day NTP (1998) study, exposure levels were 0, 12, 32, 80, and  
2 200 ppm. Additional groups of 10 male and 10 female mice designated for day 5 hematology and  
3 clinical chemistry analyses were exposed to the same chloroprene concentrations. Histopathology  
4 examinations were performed on chamber controls and 80 and 200 male and female mice as well as on  
5 selected target organs in other groups. Tissues and organs examined were identical to those described  
6 for the rat. Survival and body weights for mice are given in Table 4-17. All male and female animals  
7 in the high-concentration group died, exhibiting signs of narcosis, hepatocellular and thymic necrosis,  
8 and hypertrophy of the myocardium. Significantly decreased body weight gain (compared with  
9 controls) was seen in males at 32 and 80 ppm. There were no other clinical findings related to  
10 chloroprene exposure in the mouse.

**Table 4-17. Survival and body weights of mice in the 16-day inhalation study of chloroprene**

EXPOSURE (ppm)	SURVIVAL	MEAN BODY WEIGHT (g)		
		Initial	Final	Change
<i>Male</i>				
0	10/10	24.7 ± 0.5	27.0 ± 0.5	+ 2.3 ± 0.1
12	10/10	24.8 ± 0.5	27.1 ± 0.6	+ 2.3 ± 0.3
32	10/10	25.3 ± 0.3	26.5 ± 0.3	+ 1.2 ± 0.3 <sup>a</sup>
80	10/10	24.8 ± 0.5	26.1 ± 0.6	+ 1.3 ± 0.2 <sup>a</sup>
200	0/10	24.2 ± 0.4	---	---
<i>Female</i>				
0	10/10	19.5 ± 0.7	22.6 ± 0.5	+ 2.3 ± 0.3
12	10/10	20.4 ± 0.8	23.1 ± 0.4	+ 2.6 ± 0.3
32	10/10	19.9 ± 1.0	22.1 ± 0.2	+ 1.8 ± 0.3
80	10/10	20.1 ± 0.8	22.5 ± 0.3	+ 2.7 ± 0.3
200	0/10	20.0 ± 0.6	---	---

<sup>a</sup>Significantly different ( $p \leq 0.01$ ) from the chamber control group by Williams' or Dunnett's test.

Source: NTP (1998)

1 A range-finding 13-week inhalation study was conducted by NTP (1998) (reported by Melnick  
 2 et al., 1996), using both mice and rats. In the rat, exposure groups were 0, 5, 12, 32, 80, and 200 ppm.  
 3 Separate groups of 10 male and 10 female rats designated for coagulation studies were exposed to  
 4 these concentrations for 2 days. Rats designated for hematology and clinical chemistry tests were first  
 5 placed in metabolism cages for 16-hour urine collections. Sperm samples were collected from male  
 6 rats at the end of the studies. Samples of vaginal fluid and cells were collected for up to 7 consecutive  
 7 days prior to the end of the studies for cytology evaluations. Five male and five female rats were  
 8 exposed to 0, 5, 32 or 200 ppm for glutathione evaluations. At week 11, all male and female core  
 9 study rats were administered neurobehavioral tests measuring the following parameters:  
 10 forelimb/hind-limb grip strength, horizontal activity, rearing activity, total activity, tail-flick latency,  
 11 startle response latency, and startle response amplitude. Survival and body weights of rats are given in  
 12 Table 4-18. No effects on final mean body weights were seen.

**Table 4-18. Survival and body weights of rats in the 13-week inhalation study of chloroprene**

EXPOSURE (ppm)	SURVIVAL	MEAN BODY WEIGHT (g)		
		Initial	Final	Change
<i>Male</i>				
0	10/10	109 ± 4	311 ± 9	+ 202 ± 8
5	10/10	119 ± 2*	323 ± 11	+ 204 ± 10
12	10/10	116 ± 1	306 ± 9	+ 190 ± 8
32	10/10	117 ± 2	327 ± 11	+ 209 ± 10
80	10/10	116 ± 1	301 ± 8	+ 184 ± 7
200	9/10	116 ± 3	304 ± 8	+ 185 ± 7

EXPOSURE (ppm)	SURVIVAL	MEAN BODY WEIGHT (g)		
		Initial	Final	Change
<i>Female</i>				
0	10/10	102 ± 2	191 ± 4	+ 89 ± 3
5	10/10	101 ± 1	193 ± 4	+ 92 ± 3
12	10/10	102 ± 2	199 ± 5	+ 97 ± 4
32	10/10	101 ± 2	195 ± 4	+ 94 ± 4
80	10/10	103 ± 1	192 ± 3	+ 90 ± 3
200	10/10	102 ± 1	183 ± 3	+ 81 ± 3

Significantly different ( $p \leq 0.05$ ) from the chamber control group by Williams' or Dunnett's test.

Source: NTP (1998)

1 On day 2, minimal increases in hematocrit values, hemoglobin concentrations, and erythrocyte  
2 counts occurred in males exposed to  $\geq 32$  ppm and in females exposed to 200 ppm. At week 13, male  
3 and female rats in the 200 ppm groups demonstrated decreased hematocrit values, hemoglobin  
4 concentrations, and erythrocyte counts characterized as normocytic, normochromic anemia.  
5 Thrombocytopenia, evidenced by a reduction in circulating platelet numbers, occurred in the male and  
6 female rats in the 200 ppm groups on day 2 and in the females at 80 and 200 ppm on day 22. Platelet  
7 numbers rebounded at study termination in the highest exposure groups for both male and female rats.  
8 Activities of serum ALT, GDH, and SDH were elevated on day 22 in both sexes of the 200 ppm group.  
9 However, these increases were transient, and serum activities of the enzyme levels returned to control  
10 levels by the end of the exposure period. At week 13, an alkaline phosphatase (ALP) enzymeuria  
11 occurred in males exposed to  $\geq 32$  ppm and in females exposed to 200 ppm. In male rats in the 200  
12 ppm group, proteinuria was seen at week 13. Significant reductions in nonprotein sulfhydryl (NPSH)  
13 concentrations were observed in the livers from male rats exposed to 200 ppm for 1 day or 12 weeks,  
14 as well as in female rats exposed to 200 ppm for 12 weeks. Nonprotein sulfhydryl concentrations were  
15 reduced in the lung of 200 ppm female rats after 1 day but not after 12 weeks of exposure to 200 ppm.  
16 Significant increases in kidney weights were seen in both male and female rats at 200 ppm and in  
17 females at 80 ppm. In male rats exposed to 200 ppm, sperm motility was significantly less than that of  
18 the chamber control group. Of the neurobehavioral parameters, horizontal activity was increased in  
19 male rats exposed to  $\geq 32$  ppm compared with chamber control animals. Total activity was increased  
20 in male rats in the 32 and 200 ppm groups. There were no exposure-related effects on motor activity,  
21 forelimb/hind-limb grip strength, or startle response.

22 Increased incidences of minimal to mild olfactory epithelial degeneration and respiratory  
23 metaplasia occurred in male and female rats exposed to 80 or 200 ppm (Table 4-19). The incidence of  
24 olfactory epithelial degeneration in females exposed to 32 ppm was significantly greater than in the  
25 chamber control group. In female rats exposed to 200 ppm, the incidence of hepatocellular necrosis  
26 was significantly greater than in the chamber control group. Variably sized aggregates of yellow or  
27 brown material consistent with hemosiderin appeared in small vessels or lymphatics in or near portal  
28 triads or in Kupffer cells of male and female rats exposed to 200 ppm and were significantly increased  
29 compared with chamber controls.

**Table 4-19. Incidences of selected nonneoplastic lesions in rats in the 13-week inhalation study of chloroprene**

	CONTROL	5 ppm	12 ppm	32 ppm	80 ppm	200 ppm
<i>Male</i>						
Nose <sup>a</sup>	10/10	0/10	10/10	10/10	10/10	10/10
Degeneration, olfactory epithelium	0/10	---	0/10	3/10	10/10 <sup>c</sup>	10/10 <sup>c</sup>
Metaplasia, respiratory, olfactory epithelium	0/10	---	0/10	0/10	4/10 <sup>b</sup>	4/10 <sup>b</sup>
Liver <sup>a</sup>	10/10	2/10	1/10	1/10	10/10	10/10
Necrosis, centrilobular	0/10	0/10	0/10	01/10	0/10	3/10
Inflammation, chronic	0/10	1/10	0/10	0/10	1/10	2/10
Hemosiderin pigmentation	0/10	0/10	0/10	0/10	0/10	5/10 <sup>b</sup>
<i>Female</i>						
Nose <sup>a</sup>	10/10	0/10	10/10	10/10	10/10	10/10
Degeneration, olfactory epithelium	0/10	---	0/10	4/10 <sup>b</sup>	9/10 <sup>c</sup>	10/10 <sup>c</sup>
Metaplasia, respiratory, olfactory epithelium	0/10	---	0/10	0/10	8/10 <sup>c</sup>	9/10 <sup>c</sup>
Liver <sup>a</sup>	10/10	2/10	5/10	3/10	10/10	10/10
Necrosis, centrilobular	0/10	0/10	0/10	0/10	0/10	5/10 <sup>b</sup>
Inflammation, chronic	2/10	0/10	1/10	0/10	1/10	8/10 <sup>b</sup>
Hemosiderin pigmentation	3/10	0/10	1/10	0/10	0/10	9/10 <sup>c</sup>

<sup>a</sup> Number of animals with tissue examined microscopically.

<sup>b</sup> Significantly different (  $p \leq 0.05$ ) the chamber control group by Fisher's exact test.

<sup>c</sup> Significantly different (  $p \leq 0.01$ ) from the chamber control group by Fisher's exact test.

Source: NTP (1998)

1            In the mouse portion of the NTP 13-week inhalation study, exposure groups were 0, 5, 12, 32,  
 2 and 80 ppm. Survival and body weights are given in Table 4-20. There was no increased mortality in  
 3 any exposure group. Final mean body weights in 80 ppm males were significantly decreased  
 4 compared with controls.

**Table 4-20. Survival and body weights of mice in the 13-week inhalation study of chloroprene**

SEX	EXPOSURE (ppm)	SURVIVAL	MEAN BODY WEIGHT (g)		
			Initial	Final	Change (+)
Male	0	10/10	25.5 ± 0.4	35.9 ± 0.9	10.5 ± 0.7
	5	10/10	25.2 ± 0.3	35.1 ± 0.9	10.0 ± 0.7
	12	10/10	25.2 ± 0.2	34.9 ± 0.6	9.7 ± 0.6
	32	10/10	25.4 ± 0.2	36.0 ± 0.9	10.6 ± 0.9
	80	10/10	24.7 ± 0.3	32.7 ± 0.6 <sup>a</sup>	7.9 ± 0.5 <sup>a</sup>
Female	0	10/10	20.4 ± 0.2	30.3 ± 1.0	9.9 ± 0.9
	5	10/10	20.9 ± 0.3	32.2 ± 0.9	11.3 ± 0.9
	12	10/10	20.4 ± 0.3	30.1 ± 0.6	9.7 ± 0.6
	32	10/10	20.8 ± 0.2	32.6 ± 0.8	11.8 ± 0.7
	80	10/10	20.5 ± 0.2	30.2 ± 1.3	9.7 ± 1.2

<sup>a</sup>Significantly different (  $p \leq 0.05$ ) from the chamber control group by Williams' or Dunnett's test

Source: NTP (1998)

1 Hematology variables were similar to, although more mild than, in the 13-week rat study. A  
 2 minimal anemia, including decreased hematocrit values and erythrocyte counts, occurred in female  
 3 mice exposed to 32 and 80 ppm. Platelet counts were minimally increased in female mice exposed to  
 4 32 and 80 ppm, suggesting an increase in platelet production. No significant organ weight effects were  
 5 observed. Sperm morphology and vaginal cytology parameters were similar to those of the chamber  
 6 controls. Significantly increased incidences of squamous epithelial hyperplasia of the forestomach  
 7 were observed in male and female mice exposed to 80 ppm (Table 4-21).

**Table 4-21. Incidences of forestomach lesions in mice in the 13-week inhalation study of chloroprene**

	CONTROL	5 ppm	12 ppm	32 ppm	80 ppm
<i>Male</i>					
Number examined microscopically	10/10	3/10	0/10	10/10	10/10
Squamous epithelial hyperplasia	0/10	0/10	---	0/10	4/10 <sup>a</sup>
<i>Female</i>					
Number examined microscopically	10/10	0/10	0/10	10/10	10/10
Squamous epithelial hyperplasia	0/10	---	---	0/10	9/10 <sup>b</sup>

<sup>a</sup> Significantly different ( $p \leq 0.05$ ) from the chamber control group by Fisher's exact test.

<sup>b</sup>  $p \leq 0.01$ .

Source: NTP (1998)

8 In the 2-year NTP (1998) inhalation study of chloroprene in male and female rats, groups were  
 9 exposed to 0, 12.8, 32, and 80 ppm chloroprene. Estimates of 2-year survival probabilities are shown  
 10 in Table 4-22. Survival of males exposed to 32 or 80 ppm was significantly less than that of the  
 11 chamber control group.

**Table 4-22. 2-Year survival probability estimates for F344/N rats chronically exposed (2 years) to chloroprene by inhalation**

SEX	STATUS	CONTROL	12.8 ppm	32 ppm	80 ppm
Male	Animals initially in study	50	50	50	50
	Moribund	34	40	41	41
	Natural deaths	3	1	4	5
	Animals surviving to study termination	13	9	5	4
	Percent probability of survival at end of study	26	18	10	8
	Mean survival (days)	646	638	609	609
	Survival analysis <sup>a</sup>	p = 0.013	p = 0.615	p = 0.025	p = 0.025
Female	Animals initially in study	50	50	50	50
	Moribund	19	21	23	27
	Natural deaths	1	1	1	2
	Pregnant	1	0	0	0
	Animals surviving to study termination	29	28	26	21
	Percent probability of survival at end of study	59	56	52	42
	Mean survival (days)	686	685	672	673
	Survival analysis	p = 0.085	p = 1.000	p = 0.473	p = 0.151

<sup>a</sup> The result of the life table trend test (Tarone, 1975) is in the chamber control column, and the results of the life table pairwise comparisons (Cox, 1972) with the chamber controls are in the exposed group columns

Source: NTP (1998)

1 All animals were observed twice daily, and body weights were recorded initially, weekly  
2 through week 12, approximately every 4 weeks from week 15 through week 91, and every 2 weeks  
3 until the end of the study. Clinical findings were recorded initially at weeks 4, 8, 12, and 15, every 4  
4 weeks through week 91, and every 2 weeks until the end of the study. Complete necropsy and  
5 microscopic examinations were performed on all rats. In addition to gross lesions and tissue masses,  
6 the following tissues were examined: adrenal gland, bone and marrow, brain, clitoral gland, esophagus,  
7 heart, large intestine (cecum, colon, and rectum), small intestine (duodenum, jejunum, and ileum),  
8 kidney, liver, lung, lymph nodes (bronchial, mandibular, mediastinal, and mesenteric), mammary  
9 gland, nose, ovary, pancreas, parathyroid gland, pituitary gland, preputial gland, prostate gland,  
10 salivary gland, spleen, stomach (forestomach and glandular stomach), testis with epididymis and  
11 seminal vesicle, thymus, thyroid gland, trachea, urinary bladder, and uterus. Sperm morphology and  
12 vaginal cytology evaluations, clinical pathology evaluations, glutathione evaluations, coagulation  
13 studies, and neurobehavioral evaluations were not performed.

14 The incidences of nonneoplastic and neoplastic lesions observed in rats following 2-year  
15 inhalation exposures to chloroprene are given in Tables 4-23 and 4-24 (NTP, 1998). The incidences of  
16 squamous cell papilloma and combined squamous cell papilloma and squamous cell carcinoma of the  
17 oral cavity (oral mucosa, tongue, pharynx, and gingiva) in male rats exposed to 32 ppm and male and  
18 female rats exposed to 80 ppm were significantly greater than those in the chamber controls and  
19 exceeded historical control ranges. Squamous hyperplasia was observed in three male rats exposed to



1 80 ppm chloroprene, and was characterized by focal thickening and folding of the squamous  
 2 epithelium.

**Table 4-23. Incidence and severity of non-neoplastic lesions in F344/N rats chronically exposed (2 years) to chloroprene by inhalation**

TISSUE SITE/LESION TYPE	LESION INCIDENCE (SEVERITY)							
	Males (ppm)				Females (ppm)			
	0	12.8	32	80	0	12.8	32	80
Oral cavity Squamous Cell Hyperplasia	0/50	0/50	0/50	3/50 (2.7) <sup>a</sup>	--	--	--	--
Thyroid gland Follicular Cell Hyperplasia	0/50	2/50 (2.0)	4/49 <sup>b</sup> (1.8)	1/50 (1.0)	0/49	0/50	0/50	2/50 (2.5)
Lung Alveolar Hyperplasia	5/50 (1.4)	16/50 <sup>c</sup> (1.4)	14/49 <sup>b</sup> (1.9)	25/50 <sup>c</sup> (1.4)	6/49 (1.8)	22/50 <sup>c</sup> (1.4)	22/50 <sup>c</sup> (1.5)	34/50 <sup>c</sup> (1.3)
Kidney (renal tubules) Hyperplasia	14/50 (2.0)	20/50 (2.6)	28/50 <sup>c</sup> (2.1)	34/50 <sup>c</sup> (2.9)	6/49 (1.3)	6/50 (1.8)	11/50 (2.1)	21/50 <sup>c</sup> (2.0)
Olfactory Atrophy <sup>d</sup>	3/50 (1.7)	12/50 <sup>b</sup> (1.8)	46/49 <sup>c</sup> (2.2)	48/49 <sup>c</sup> (3.6)	0/49	1/50 (1.0)	40/50 <sup>c</sup> (1.3)	50/50 <sup>c</sup> (2.9)
Basal Cell Hyperplasia	0/50	0/50	38/49 <sup>c</sup> (1.6)	46/49 <sup>c</sup> (2.2)	0/49	0/50	17/50 <sup>c</sup> (1.1)	49/50 <sup>c</sup> (2.3)
Metaplasia	6/50 1.7	5/50 (1.0)	45/49 <sup>c</sup> (1.8)	48/49 <sup>c</sup> (3.1)	0/49	1/50 (1.0)	35/50 <sup>c</sup> (1.0)	50/50 <sup>c</sup> (2.7)
Necrosis <sup>e</sup>	0/50	11/50 <sup>b</sup> (2.0)	26/49 <sup>c</sup> (2.0)	19/49 <sup>c</sup> (2.2)	0/49	0/50	8/50 <sup>c</sup> (2.0)	12/50 <sup>c</sup> (1.3)
Chronic Inflammation	0/50	5/50 <sup>c</sup> (1.0)	9/49 <sup>c</sup> (1.6)	49/49 <sup>c</sup> (2.7)	0/49	0/50	2/50 (1.0)	33/50 <sup>c</sup> (2.0)

<sup>a</sup> Severity of lesions graded as: 1= minimal, 2 = mild, 3 = moderate, 4 = marked, average severity reported in parenthesis

<sup>b</sup>  $p \leq 0.05$ , ps correspond to the pairwise comparisons between the chamber controls and that exposed group. The logistic regression test regards lesions in animals dying prior to terminal kill as nonfatal

<sup>c</sup>  $p \leq 0.01$

<sup>d</sup> Severity of atrophic lesions: Males: control –1 minimal, 2 mild; 12.8 ppm –6 minimal, 3 mild, 3 moderate; 32 ppm – 10 minimal, 19 mild, 15 moderate, 2 marked; 80 ppm – 1 mild, 18 moderate, 29 marked. Females: control –all 0; 12.8 ppm – 1 minimal; 32 ppm – 31 minimal, 7 mild, 2 moderate; 80 ppm – 10 mild, 33 moderate, 7 marked.

<sup>e</sup> Severity of necrotic lesions: Males: control –all 0, 12.8 ppm – 5 minimal, 1 mild, 5 moderate; 32 ppm – 8 minimal, 10 mild, 8 moderate; 80 ppm – 6 minimal, 4 mild, 8 moderate, 1 marked. Females: control –all 0; 12.8 ppm – all 0; 32 ppm – 3 minimal, 2 mild, 3 moderate; 80 ppm – 8 minimal, 4 mild.

Source: NTP (1998)

3 The incidences of thyroid gland follicular cell adenoma or carcinoma (combined) in male rats  
 4 exposed to 32 or 80 ppm were significantly greater than those in the chamber control group and  
 5 exceeded historical control ranges. The incidences of follicular cell adenoma and follicular cell  
 6 adenoma or carcinoma combined in female rats exposed to 80 ppm were increased but not significantly  
 7 greater than those in the chamber controls, although they did exceed the historical control range.

1 Follicular cell carcinomas destroyed the thyroid gland and occasionally invaded the capsule or  
 2 adjacent structures. The incidence of follicular cell hyperplasia was significantly increased in male  
 3 rats exposed to 32 ppm. Hyperplasia was characterized by one or a few enlarged follicles with several  
 4 much smaller follicles inside and to one side.

**Table 4-24. Incidence of neoplasms in F344/N rats chronically exposed (2 years) to chloroprene by inhalation**

TISSUE SITE/TUMOR TYPE	TUMOR INCIDENCE							
	Males (ppm)				Females (ppm)			
	0	12.8	32	80	0	12.8	32	80
Oral cavity Papillomas or carcinomas	0/50	2/50	5/50 <sup>a</sup>	12/50 <sup>b</sup>	1/49	3/50	5/50	11/50 <sup>b</sup>
Thyroid gland Adenomas or carcinomas	0/50	2/50	4/49 <sup>a</sup>	5/50 <sup>a</sup>	1/49	1/50	1/50	5/50
Lung Adenomas or carcinomas <sup>c</sup>	2/50	2/50	4/49	6/50	1/49	0/50	0/50	3/50
Kidney (renal tubules) Adenomas or carcinomas (extended and standard evaluations combined)	1/50	8/50 <sup>a</sup>	6/50 <sup>b</sup>	8/50 <sup>b</sup>	0/49	0/50	0/50	4/50
Mammary gland Fibroadenomas	---	---	---	---	24/49	32/50	36/50 <sup>a</sup>	36/50 <sup>b</sup>

<sup>a</sup>  $p \leq 0.05$ , ps correspond to the pairwise comparisons between the chamber controls and that exposed group. The logistic regression test regards lesions in animals dying prior to terminal kill as nonfatal

<sup>b</sup>  $p \leq 0.01$

<sup>c</sup> Adenomas only in females

Source: NTP (1998)

5 The incidences of alveolar/bronchiolar carcinoma and alveolar/bronchiolar adenoma or  
 6 carcinoma (combined) in males exposed to 80 ppm were slightly greater than those in the chamber  
 7 control group. Although the increase in neoplasms was not statistically significantly increased relative  
 8 to control, the incidences exceeded the historical control range. The incidence of alveolar/bronchiolar  
 9 adenoma only was increased, though not significantly, in female rats exposed to 80 ppm chloroprene.  
 10 Alveolar/bronchiolar carcinomas were solid or papillary, obliterated normal pulmonary structure, and  
 11 sometimes invaded the pleura and other adjacent areas. The incidences of alveolar epithelial  
 12 hyperplasia (AEH) were significantly greater in all exposed groups of males and females compared  
 13 with the chamber control groups.

14 Renal tubule adenoma and hyperplasia were observed in male and female rats. Because renal  
 15 tubule neoplasms are rare in chamber control F344/N rats, additional kidney sections from male and  
 16 female control and exposed groups were examined to provide a clearer indication of the potential  
 17 effects of chloroprene on the kidney. The combined single- and step-section incidences of renal tubule  
 18 hyperplasia in males exposed to 32 and 80 ppm and in females exposed to 80 ppm and the incidences  
 19 of adenoma and adenoma or carcinoma combined in all exposed males were significantly greater than  
 20 those in the chamber controls.

1 The incidences of multiple fibroadenoma of the mammary gland in all exposed groups of  
2 female rats were greater than in the chamber control group. The incidences of fibroadenoma in  
3 females exposed to 32 and 80 ppm were significantly greater than in the chamber control group.  
4 However, the incidences of fibroadenomas in all exposed females and the chamber control exceeded  
5 the historical control range.

6 A slight increase in the incidence of transitional epithelium carcinoma of the urinary bladder  
7 was observed in females exposed at 80 ppm. In addition, one male exposed at 32 ppm had a  
8 transitional epithelium carcinoma and one male exposed at 80 ppm had a transitional cell papilloma.  
9 No urinary bladder neoplasms have been observed historically in chamber control male or female  
10 F344/N rats.

11 The incidences of atrophy, basal cell hyperplasia, metaplasia, and necrosis of the olfactory  
12 epithelium in males and females exposed to 32 and 80 ppm and of atrophy and necrosis in males  
13 exposed to 12.8 ppm were significantly greater than those in the chamber control groups. The  
14 incidences of chronic inflammation were significantly increased in males exposed to 12.8 or 32 ppm  
15 and in females exposed to 80 ppm. The incidences of fibrosis and adenomatous hyperplasia in males  
16 and females exposed to 80 ppm were significantly greater than those in the chamber controls. Lesions  
17 of the nasal cavity were generally minimal to moderate in average severity. Necrosis of the olfactory  
18 epithelium was characterized by areas of karyorrhexis and sloughing of olfactory epithelium with cell  
19 debris in the lumen of the dorsal meatus. Atrophy of the olfactory epithelium was characterized by  
20 decreased numbers of layers of olfactory epithelium and included loss of Bowman's glands and  
21 olfactory axons in more severe cases. Metaplasia was characterized by replacement of olfactory  
22 epithelium with ciliated, columnar, respiratory-like epithelium. Basal cell hyperplasia was  
23 characterized by proliferation or increased thickness of the basal cell layer in the turbinate and septum.

24 In the NTP 2-year mouse study, exposure concentrations were 0, 12.8, 32, and 80 ppm. All  
25 animals were observed twice daily and body weights were recorded initially, weekly through week 12,  
26 approximately every 4 weeks from week 15 through week 91, and every 2 weeks until the end of the  
27 study. Clinical findings were recorded initially, at weeks 4, 5, 8, 12, every 4 weeks through week 91,  
28 and every 2 weeks until the end of the study. A complete necropsy and microscopic examination were  
29 performed on all mice as described for the rat portion of the 2-year study. Estimates of 2-year survival  
30 probabilities are shown in Table 4-25.

**Table 4-25. 2-Year survival probabilities for B6C3F1 mice chronically exposed (2 years) to chloroprene by inhalation**

		<b>CONTROL</b>	<b>12.8 ppm</b>	<b>32 ppm</b>	<b>80 ppm</b>
<b>Male</b>	Animals initially in study	50	50	50	50
	Moribund	15	16	26	34
	Natural deaths	3	7	10	3
	Animals surviving to study termination	27	27	14	13
	Percent probability of survival at end of study	54	54	28	26
	Mean survival (days)	689	683	646	646
	Survival analysis <sup>a</sup>	p < 0.001	p = 1.000	p = 0.007	p = 0.003
<b>Female</b>	Animals initially in study	50	50	50	50
	Accidental death	0	1	0	1
	Moribund	13	27	38	41
	Natural deaths	2	6	11	5
	Animals surviving to study termination	35	16	1	3
	Percent probability of survival at end of study	70	33	2	6
	Mean survival (days)	686	641	558	562
	Survival analysis	p < 0.001	p < 0.001	p < 0.001	p < 0.001

<sup>a</sup> the result of the life table trend test (Tarone, 1975) is in the chamber control column, and the results of the life table pairwise comparisons (Cox, 1972) with the chamber controls are in the exposed group columns

Source: NTP (1998)

1 Survival of males exposed to 32 or 80 ppm and of all exposed female groups was significantly  
 2 less than that of the chamber controls. The mean body weights of females exposed to 80 ppm were  
 3 significantly less than those of the chamber control group after week 75.

4 The incidences of non-neoplastic and neoplastic lesions observed in mice with 2-year  
 5 inhalation exposure to chloroprene are given in Tables 4-26 and 4-27. The incidences of  
 6 alveolar/bronchiolar neoplasms in the lungs of all groups of exposed males and females were  
 7 significantly greater than in the chamber control group and generally exceeded the historical control  
 8 ranges. The incidences of multiple alveolar/bronchiolar adenoma and alveolar/bronchiolar carcinoma  
 9 were increased in all exposed males and females. The morphology of lung neoplasms was similar in  
 10 control and exposed groups. The incidences of bronchiolar hyperplasia in all exposed groups of males  
 11 and females were significantly greater than in the chamber control groups. Bronchiolar hyperplasia  
 12 was characterized by diffuse thickening of the cuboidal cells lining the terminal bronchioles and in  
 13 some cases caused papillary projections into the lumen. The incidences of histiocytic cell infiltration  
 14 in males exposed to 80 ppm and in all exposed females were significantly increased relative to  
 15 chamber controls. This change consisted of histiocytes within alveolar lumens, usually adjacent to  
 16 alveolar/bronchiolar neoplasms.

**Table 4-26. Incidence and severity of non-neoplastic lesions in B6C3F1 mice chronically exposed (2 years) to chloroprene by inhalation**

TISSUE SITE/LESION TYPE	LESION INCIDENCE (SEVERITY)							
	Males (ppm)				Females (ppm)			
	0	12.8	32	80	0	12.8	32	80
Lung								
Bronchiolar Hyperplasia	0/50	10/50 <sup>c</sup> (2.0)	18/50 <sup>c</sup> (1.7)	23/50 <sup>c</sup> (2.2)	0/50	15/49 <sup>c</sup> (2.0)	12/50 <sup>c</sup> (2.2)	30/50 <sup>c</sup> (2.2)
Histiocytic Cell Infiltration	7/50 (1.6)	8/50 (3.3)	11/50 (2.5)	22/50 <sup>c</sup> (2.9)	1/50 (3.0)	14/49 <sup>c</sup> (2.0)	18/50 <sup>c</sup> (2.3)	23/23 <sup>c</sup> (2.4)
Kidney (renal tubule)								
Hyperplasia	0/50	4/49 (1.3)	5/50 <sup>b</sup> (1.2)	5/50 <sup>b</sup> (1.4)	--	--	--	--
Mammary Gland								
Hyperplasia	--	--	--	--	0/49	1/49 (1.0)	1/50 (1.0)	3/50 (2.0)
Forestomach								
Epithelial Hyperplasia	4/50 (3.0)	6/48 (1.8)	7/49 (2.3)	29/50 <sup>c</sup> (2.2)	4/50 (2.0)	3/49 (3.7)	8/49 (1.6)	27/50 <sup>c</sup> (2.7)
Olfactory								
Suppurative Inflammation	2/50 (2.0)	1/48 (1.0)	4/50 (1.0)	6/50 (1.5)	0/50	1/49 (1.0)	3/49 <sup>b</sup> (1.7)	4/50 <sup>c</sup> (1.5)
Atrophy	7/50 (1.1)	8/48 (1.4)	7/50 (1.1)	49/50 <sup>c</sup> (2.5)	6/50 (1.2)	5/49 (1.2)	4/49 (1.3)	47/50 <sup>c</sup> (2.0)
Metaplasia	6/50 (1.0)	5/50 (1.4)	5/50 (1.0)	49/50 <sup>c</sup> (2.5)	2/50 (1.0)	3/49 (91.0)	1/49 (92.0)	44/50 <sup>c</sup> (2.0)
Spleen								
Hematopoietic Proliferation	26/50	22/49	35/50 <sup>d</sup>	31/50 <sup>d</sup>	13/50	25/49 <sup>d</sup>	42/49 <sup>d</sup>	39/50 <sup>d</sup>

<sup>a</sup> Severity of lesions graded as: 1= minimal, 2 = mild, 3 = moderate, 4 = marked, average severity reported in parenthesis, average severity not reported for splenic hematopoietic proliferation

<sup>b</sup>  $p \leq 0.05$ , ps correspond to the pairwise comparisons between the chamber controls and that exposed group. The logistic regression test regards lesions in animals dying prior to terminal kill as nonfatal

<sup>c</sup>  $p \leq 0.01$

<sup>d</sup> Significantly increased relative to controls, level of significance not reported

Source: NTP (1998)

1

2           The incidences of olfactory epithelial atrophy, adenomatous hyperplasia, and metaplasia in  
3 males and females exposed to 80 ppm were significantly greater than those in the chamber controls.  
4 The incidence of suppurative inflammation in females exposed to 32 and 80 ppm was significantly  
5 greater than controls. Atrophy and metaplasia of the olfactory epithelium was similar to lesions  
6 observed in rats exposed to chloroprene. Adenomas of the respiratory epithelium were present in one  
7 female exposed to 32 ppm and one male exposed to 80 ppm.

8           In male mice, a pattern of nonneoplastic liver lesions along with silver-staining helical  
9 organisms within the liver was observed, consistent with *Helicobacter hepaticus* infection.  
10 Polymerase chain reaction-restriction fragment length polymorphism based assay confirmed an

1 organism compatible with *H. hepaticus*. Historically, NTP studies with *H. hepaticus* associated  
 2 hepatitis showed increased incidences of hemangiosarcoma in male mice. Therefore,  
 3 hemangiosarcomas of the liver were excluded from the analyses of circulatory neoplasms in the males  
 4 in the chloroprene 2-year study. However, even with this exclusion, the combined occurrence of  
 5 hemangioma or hemangiosarcoma at other sites was significantly increased in all males exposed to  
 6 chloroprene and in females exposed to 32 ppm. The incidences of neoplasms at other sites were not  
 7 considered to have been significantly impacted by the infection with *H. hepaticus* or its associated  
 8 hepatitis. The incidences of hepatocellular carcinoma in all exposed female mice and hepatocellular  
 9 adenoma or carcinoma combined in females exposed to 32 and 80 ppm were significantly greater than  
 10 in the chamber control

**Table 4-27. Incidence of neoplasms in B6C3F1 mice chronically exposed (2 years) to chloroprene by inhalation**

TISSUE SITE/TUMOR TYPE	TUMOR INCIDENCE							
	Males (ppm)				Females (ppm)			
	0	12.8	32	80	0	12.8	32	80
Lung Adenomas or carcinomas	13/50	28/50 <sup>c</sup>	36/50 <sup>c</sup>	43/50 <sup>c</sup>	4/50	28/49 <sup>c</sup>	34/50 <sup>c</sup>	42/50 <sup>c</sup>
All Organs Hemangiomas or hemangiosarcomas	3/50	14/50 <sup>b</sup>	23/50 <sup>c</sup>	21/50 <sup>c</sup>	4/50	6/50	18/50 <sup>b</sup>	8/50
Harderian gland Adenomas or carcinomas	2/50	5/50	10/50 <sup>a</sup>	12/50 <sup>b</sup>	2/50	5/50	3/50	9/50 <sup>a</sup>
Kidney (renal tubules) Adenomas or carcinomas (extended and standard evaluations combined)	0/50	2/49	3/50 <sup>a</sup>	9/50 <sup>b</sup>	---	---	---	---
Mammary gland Carcinomas	---	---	---	---	3/50	4/50	7/50	12/50 <sup>a</sup>
Forestomach Papillomas or carcinomas	1/50	0/50	2/50	4/50	1/50	0/50	0/50	4/50
Liver Adenomas or carcinomas	---	---	---	---	20/50	26/49	20/50 <sup>a</sup>	30/50 <sup>c</sup>
Skin Sarcoma	---	---	---	---	0/50	11/50 <sup>b</sup>	11/50 <sup>c</sup>	18/50 <sup>c</sup>
Mesentery Sarcomas	---	---	---	---	0/50	4/50	8/50 <sup>b</sup>	3/50
Zymbal's gland Carcinomas	---	---	---	---	0/50	0/50	0/50	3/50

<sup>a</sup> p < 0.05, ps correspond to the pairwise comparisons between the chamber controls and that exposed group. The logistic regression test regards lesions in animals dying prior to terminal kill as nonfatal

<sup>b</sup> p < 0.01

<sup>c</sup> p < 0.001

Source: NTP (1998)

11 The incidences of Harderian gland adenoma and Harderian gland adenoma or carcinoma  
 12 combined in males exposed to 32 or 80 ppm and females exposed to 80 ppm were significantly greater  
 13 than in the chamber controls. The incidences of Harderian gland adenoma or carcinoma combined in  
 14 these groups exceeded the historical control range.

1 Although not significantly increased, the incidence of renal tubule adenoma in males exposed  
2 to 80 ppm was greater than in the chamber control group. The incidence of this rare neoplasm  
3 exceeded the historical control range. The incidences of renal tubule hyperplasia in males exposed to  
4 32 or 80 ppm were significantly greater than in the chamber controls. The combined single- and step-  
5 section incidence of renal tubule adenoma in males exposed to 80 ppm and the combined incidences of  
6 renal tubule hyperplasia in all groups of exposed male mice were greater than in the chamber controls.

7 The incidences of mammary gland carcinoma in females exposed to 80 ppm were significantly  
8 greater than in the chamber control group. The incidences of mammary gland carcinoma in females  
9 exposed to 32 and 80 ppm exceeded the historical control range. Mammary gland hyperplasia was  
10 present in a few females exposed to chloroprene, but was not significantly increased relative to  
11 chamber controls.

12 The incidence of forestomach squamous cell papilloma in females exposed to 80 ppm was  
13 greater than in the chamber controls but statistically not significant. The incidence observed exceeded  
14 the historical control range. In male and female mice exposed to 80 ppm, the incidences of hyperplasia  
15 of the forestomach epithelium were significantly greater than in chamber controls, and the lesions were  
16 similar to those seen in the 13-week study. Hyperplasia was a focal to multifocal change characterized  
17 by an increase in the number of cell layers in the epithelium.

18 The incidences of sarcoma of the skin were significantly greater in all exposed female mice  
19 compared with chamber controls. The incidences of sarcomas of the mesentery were increased in all  
20 exposed female mice, with only the mice in the 32 ppm exposure group exhibiting a significant  
21 increase.

22 Carcinomas of Zymbal's gland were observed in three females exposed to 80 ppm, and two  
23 carcinomas had metastasized to the lung. Zymbal's gland carcinomas have not been reported in the  
24 NTP historical database for control female mice.

25 Single papillary adenomas were detected in the trachea of one male exposed to 12.8 ppm and in  
26 one male exposed to 32 ppm. These adenomas have not been documented in the NTP historical  
27 database.

28 The incidences of splenic hematopoietic proliferation in males exposed to 32 and 80 ppm and  
29 in all exposed groups of females were significantly greater than in the chamber controls.

30 Because of a large number of early deaths of mice exposed to chloroprene for 2-years, survival-  
31 adjusted neoplasm rates were estimated by NTP by using the poly-3 survival-adjusted quantal response  
32 method of Portier and Bailer (1989). This adjustment accounts for the impact of early mortality on the  
33 expression of late-developing neoplasms and provides a clearer indication of exposure-response  
34 relationships for neoplasms induced by chloroprene (Table 4-28). The neoplasm incidence values  
35 provided represent the ratio of the number of animals in an exposure group bearing the specific  
36 neoplasm relative to the adjusted number of animals at risk.

**Table 4-28. Survival-adjusted neoplasm rates for mice in the 2-year inhalation study of chloroprene**

	MALES (%)				FEMALES (%)			
	0	12.8	32	80	0	12.8	32	80
Lung								
Adenoma or carcinoma	14.1 <sup>b</sup>	28.3	56.9 <sup>b</sup>	66.4 <sup>b</sup>	4.6 <sup>b</sup>	35.6 <sup>b</sup>	53.8 <sup>b</sup>	76.0 <sup>b</sup>
Alveolar/bronchiolar adenoma or carcinoma	29.8 <sup>b</sup>	63.7 <sup>b</sup>	79.2 <sup>b</sup>	92.9 <sup>b</sup>	9.1 <sup>b</sup>	68.3 <sup>b</sup>	85.8 <sup>b</sup>	96.1 <sup>b</sup>
All Organs								
Hemangioma or hemangiosarcoma	2.4 <sup>b</sup>	28.2 <sup>b</sup>	45.2 <sup>b</sup>	43.6 <sup>b</sup>	9.0 <sup>a</sup>	16.0	53.1 <sup>b</sup>	27.7 <sup>a</sup>
Harderian gland								
Adenoma or carcinoma	4.7 <sup>b</sup>	12.0	26.3 <sup>b</sup>	32.0 <sup>b</sup>	4.5 <sup>b</sup>	13.5	11.7	31.2 <sup>b</sup>
Kidney (renal tubules)								
Adenoma								
(single section)	0 <sup>a</sup>	2.4	2.8	8.2	---	---	---	---
(single + step section)	0 <sup>b</sup>	4.8	8.3	23.9 <sup>a</sup>	---	---	---	---
Mammary gland								
Adenoacanthoma or carcinoma	---	---	---	---	6.7 <sup>b</sup>	12.9	33.7 <sup>b</sup>	42.5 <sup>b</sup>
Forestomach								
Squamous cell papilloma or carcinoma	2.4 <sup>b</sup>	0	5.6	13.3	2.3 <sup>b</sup>	0	0	14.6
Liver								
Carcinoma	---	---	---	---	9.0 <sup>b</sup>	28.4 <sup>a</sup>	47.5 <sup>b</sup>	58.2 <sup>b</sup>
Adenoma or carcinoma	---	---	---	---	44.8	62.9	63.3	79.7 <sup>b</sup>
Skin								
Sarcoma	---	---	---	---	0 <sup>a</sup>	27.5 <sup>b</sup>	39.0 <sup>b</sup>	52.6 <sup>b</sup>
Mesentery								
Sarcoma	---	---	---	---	0	10.7 <sup>a</sup>	28.9 <sup>b</sup>	11.0

In the chamber control column, <sup>a</sup> indicates a significant trend ( $p < 0.05$ ) across all exposure groups by the Poly-3 quantal response test; <sup>b</sup> indicates a significant trend at  $p < 0.01$

In the exposed group columns, <sup>a</sup> indicates a significant difference ( $p < 0.05$ ) from the chamber control group by pairwise comparison; <sup>b</sup> indicates a significant difference at  $p < 0.01$ .

Source: NTP (1998)

1           In another chronic inhalation study, Trochimowicz et al. (1998) exposed three groups of 100  
2 Wistar rats and Syrian hamsters of each sex to chloroprene at 0, 10, or 50 ppm for 6 hours/day, 5  
3 days/week for up to 18 months (hamsters) or 24 months (rats). Chemical purity of the bulk  
4 chloroprene was reported to be 99.6%, with less than 50 ppm of dimers as determined by gas  
5 chromatography. Bottles of test material were received weekly and were stored under nitrogen at –  
6 20°C. Phenothiazine (0.01%) was added to prevent oxidation. A fresh sample of chloroprene from  
7 cold storage was used for each day's exposure. To generate the test atmospheres, sufficient quantities  
8 of the bulk material were vaporized with dried and filtered nitrogen at 0°C; vaporization at this  
9 temperature was performed to inhibit the formation of degradation products. The saturated  
10 chloroprene/nitrogen mixture was then directed into the inhalation chamber inlet, where it was mixed  
11 with the main air flow to generate the desired exposure concentration. All animals were observed  
12 daily and clinical signs and mortality were recorded. Rats and hamsters were weighed immediately  
13 before the first exposure, weekly for the first 8 weeks, and at 4-week intervals thereafter. During the  
14 last 6 months of each study, all animals were palpated monthly for the presence of tumors. Time of  
15 tumor appearance, size, location, and progression were recorded. At study termination, both hamsters



1 and rats were sacrificed by exsanguination of the abdominal aorta. A postmortem examination was  
2 conducted during which all major organs/tissues were examined for gross abnormalities. Gross  
3 pathological examinations were conducted on all animals, including those that died intercurrently or  
4 were killed in extremis, unless advanced autolysis or cannibalism prevented this. The following  
5 organs were weighed: adrenals, brain (hamster), heart, kidneys, liver, lungs with trachea and larynx,  
6 ovaries, pituitary, spleen, testes, and thyroid (rat). The following organs/tissues were preserved and  
7 examined microscopically: all gross lesions, adipose tissue, aorta (rat), epididymides, external auditory  
8 canal with Zymbal's glands, eyes, exorbital lachrymal glands, femur (with knee joint), gastrointestinal  
9 tract (esophagus, stomach, duodenum, jejunum, ileum, cecum, and colon), lungs, lymph nodes  
10 (auxiliary, cervical, and mesenteric), mammary glands, nasal cavity (four transverse sections),  
11 pancreas, parotid salivary glands, preputial glands, prostate, sciatic nerve, seminal vesicles, skeletal  
12 muscle, skin, spinal cord, sternum (bone marrow), sublingual and submaxillary salivary glands,  
13 thymus, thyroid with parathyroid (hamster), urinary bladder, and uterus. Microscopic examinations  
14 were performed on all organs from all control and high-exposure animals, and on the liver, spleen,  
15 pituitary gland, thyroid glands, adrenals, and all grossly visible tumors and tumor-like lesions from the  
16 low-exposure animals.

17 Mortality rate for rats was relatively low in all groups up to week 72, ranging from 1–3%.  
18 During week 72, however, 87 males and 73 females of the 10 ppm exposure group died overnight from  
19 suffocation resulting from accidental failure of the exposure chamber ventilation system. For  
20 hamsters, the mortality rate was negatively correlated with the concentration of chloroprene exposure.  
21 After 18 months of exposure, survival rates in the 0, 10, and 50 ppm groups were 88, 92, and 93% in  
22 males and 63, 75, and 72% in females, respectively.

23 A slight but consistent growth retardation was found in male rats (~10%) and female rats (~5%)  
24 in the 50 ppm exposure group. Both male and female hamsters showed a slight growth depression in  
25 the 50 ppm group throughout the study. Appearance and behavior of the rats were not affected by  
26 exposure to chloroprene, except that alopecia occurred more frequently in the 50 ppm group than in the  
27 10 ppm group or in the controls. The alopecia varied from small, focal, mostly bilateral bald areas to  
28 severe, diffuse, generalized hair loss. Alopecia was first observed after an exposure period of about 10  
29 weeks, but by 25 weeks the incidence and degree of alopecia gradually decreased and in many animals  
30 complete re-growth of hair was observed. No abnormalities were observed in hamsters; alopecia was  
31 occasionally seen in each group during the first 64 weeks of study, regardless of exposure.

32 Body weights are given in Table 4-29. In both male and female rats, mean relative lung  
33 weights were significantly lower in both exposure groups than in controls. In females exposed to 50  
34 ppm, the mean relative spleen and thyroid weights were significantly lower. The kidney and pituitary  
35 weights in males exposed to 10 ppm were significantly increased compared with controls, although  
36 this was not observed in the 50 ppm exposure group. In hamsters, both male and female animals

1 exposed to 50 ppm had significantly higher brain weights compared with controls. Relative lung  
 2 weight was significantly higher in males exposed to 50 ppm than in controls.

**Table 4-29. Selected mean relative organ weights of rats exposed for 24 months and hamsters exposed for 18 months to chloroprene vapor**

GROUP (ppm)	NUMBER <sup>1</sup>	BW (g)	ADRENALS	BRAIN	KIDNEYS	LIVER	LUNGS	SPLEEN	THYROID
<i>Rats</i>									
<i>Males</i>									
0	77	494	---	---	0.61	3.09	0.45	0.154	0.0056
10	9	500	---	---	0.68 <sup>a</sup>	3.31	0.37 <sup>b</sup>	0.172	0.0056
50	76	496	---	---	0.64	3.15	0.38 <sup>b</sup>	0.146	0.0056
<i>Females</i>									
0	81	308	---	---	0.64	3.00	0.53	0.180	0.0080
10	19	309	---	---	0.65	3.23 <sup>a</sup>	0.45 <sup>a</sup>	0.176	0.0073
50	75	307	---	---	NR <sup>2</sup>	3.13 <sup>a</sup>	0.45 <sup>a</sup>	0.164 <sup>b</sup>	0.0070 <sup>b</sup>
<i>Hamsters</i>									
<i>Males</i>									
0	86	101	0.0311	1.10	1.25	5.11	0.85	0.197	---
10	92	101	0.0279 <sup>a</sup>	1.11	1.17 <sup>b</sup>	4.75 <sup>a</sup>	0.84	0.190	---
50	92	93	0.0294	1.19 <sup>c</sup>	1.22	4.91	0.90 <sup>b</sup>	0.174 <sup>b</sup>	---
<i>Females</i>									
0	60	99	0.0340	1.13	1.48	6.73	1.01	0.253	---
10	74	98	0.0356	1.16	1.50	6.54	0.97	0.269	---
50	72	90	0.0383	1.24 <sup>c</sup>	1.50	6.37	1.01	0.286	---

<sup>1</sup> Number at sacrifice

<sup>2</sup> Not recorded

<sup>a</sup> Significant,  $0.1 \leq p < 0.005$

<sup>b</sup> Significant,  $0.001 \leq p < 0.01$

<sup>c</sup> Significant,  $p < 0.001$

Source : Trochimowicz et al. (1998)

3  
 4 Gross pathology revealed that lungs from rats exposed at 10 and 50 ppm had markedly lower  
 5 incidences of nodular pleural surfaces, consolidation, and gross changes consistent with, and  
 6 characterized as chronic respiratory disease, than did controls. Morphologic indicators of chronic  
 7 respiratory disease were seen in 28 of 196 controls, 0 of 37 in the 10 ppm group, and 4 of 200 in the 50  
 8 ppm group. The incidence of tumors or tumor-like lesions of the mammary glands was slightly higher  
 9 in the exposed animals terminated at the end of the study (10/24 and 34/100 in 10 and 50 ppm,  
 10 respectively) compared with controls (23/99); however, these differences were not statistically  
 11 significant unless animals that were moribund or dead before the terminal sacrifice were included in  
 12 the analysis. No other remarkable differences in gross pathology were seen in rats. Macroscopic  
 13 examination of hamsters revealed a slight, concentration-related decrease in the incidence of pale  
 14 adrenal glands in males.

15 The only nonneoplastic lesions in rats were observed in liver and lungs (only the livers of  
 16 animals that died accidentally due to a failure in the ventilation system were available for microscopic

1 examination). The number of female and male rats with one or more small foci of cellular alteration in  
2 the liver was significantly increased in the 50 ppm group than in controls. Mild changes, such as  
3 lymphoid aggregates around bronchi, bronchiole, and blood vessels, were observed in males and  
4 females exposed to 50 ppm. Acute inflammatory processes in the lungs were found in the 50 ppm  
5 exposure group and control animals to a similar extent.

6 The only nonneoplastic change seen in hamsters was a generalized amyloidosis (in the liver,  
7 kidneys, spleen, and adrenals) that was lower in incidence in the 50 ppm exposed group compared with  
8 controls.

9 Tumor incidences for rats and hamsters are shown in Tables 4-30 and 4-31, respectively. With  
10 the exception of mammary gland tumors and squamous cell carcinomas, no individual organ or tissue  
11 in rats exposed to chloroprene showed a statistically significant excess of tumors compared with  
12 controls. The number of females bearing mammary tumors in the 50 ppm group was significantly  
13 increased ( $p < 0.05$ ). The observed increase in mammary tumors in the high dose animals was due to  
14 the inclusion in the analysis of animals that were moribund or dead before the terminal sacrifice. No  
15 difference was observed between control and test group animals that were sacrificed at the end of the  
16 study. The number of mammary tumors per rat was not different between the 50 ppm group and the  
17 control group. The increased incidence of mammary tumors was almost entirely due to the relatively  
18 high number of animals of the test groups bearing benign fibroadenomas. Squamous cell carcinomas  
19 involving the nasal cavity, sinus maxillaries, subcutis, and skin were found in 3 of 100 males of the 50  
20 ppm group and in 1 of 99 females of the control group. Neither macroscopic nor microscopic  
21 examination could clarify the exact origin of these tumors. If they originated as skin tumors, the total  
22 number of squamous-cell carcinomas of the skin would have been 5/100 in the 50 ppm group, which  
23 would be a statistically significant ( $p < .05$ ) increase over controls (1/97).

24 In the hamster, the incidences of cystadenomatous polyps of the gallbladder and  
25 pheochromocytoma were slightly, but significantly, elevated in the males exposed to 10 ppm. All other  
26 tumors observed were about equally distributed among test and control groups or occurred in only one  
27 or two hamsters.

28 Sanotskii (1976) provided a review of numerous Russian subchronic inhalation studies of  
29 chloroprene (chemical purity and exposure regimen not specified) in rats and mice. According to  
30 Sanotskii (1976), the studies evaluated the systemic effects of chloroprene exposure in white rats  
31 exposed for 4.5 months to 0.051, 0.15, and 1.69 mg/m<sup>3</sup> (0.014, 0.041, and 0.47 ppm) or C57BL/6 mice  
32 exposed for 2 months to concentrations as high as 35 mg/m<sup>3</sup> (9.7 ppm). Several “signs of systemic  
33 effect” in male rats were reported at 1.69 ± 0.087 mg/m<sup>3</sup>, including an increase in a “summation  
34 threshold index” (not defined) after 2.5 and 4.5 months, a decrease in the synthesis of hippuric acid  
35 from sodium benzoate (Quick’s test) at 4.5 months, and an inhibition of gas exchange after 4.5 months.  
36 Chloroprene was reported to have had no effect on “the indicators used in the tests” (i.e., summation

1 threshold index, hippuric acid synthesis, and inhibition of gas exchange) in mice at concentrations as  
 2 high as  $35 \pm 0.7 \text{ mg/m}^3$  (9.7 ppm).

**Table 4-30. Incidence, site and type of tumor in selected organs and tissues of rats exposed to chloroprene for 24 months**

Site and type of tumor <sup>a</sup>	MALES			FEMALES		
	0 ppm	10 ppm	50 ppm	0 ppm	10 ppm	50 ppm
Initial number of rats	100	100	100	100	100	100
Number examined	97	13	100	99	24	100
Number tumor-bearing <sup>b</sup>	51	6	57	66	12	74
Total number primary tumors <sup>b</sup>	73/51	6/6	77/57	100/66	13/12	96/71
Hematopoietic system						
Lymphoid leukemia	1	0	2	0	0	1
Monocytic leukemia	0	0	1	0	0	0
Kidneys						
Lipoma	0	0	1	1	0	1
Adenocarcinoma	0	0	1	0	0	0
Liver						
Unidentified	0	0	0	1	0	0
Lungs						
Anaplastic carcinoma	0	0	0	1	0	0
Mammary glands						
Adenoma	---	---	---	3	1	7
Fibroadenoma	---	---	---	24	6	36
Adenocarcinoma	---	---	---	5	0	3
Papillary carcinoma	---	---	---	1	0	0
Unidentified tumor	---	---	---	1	2	0
Skin						
Squamous cell carcinoma	0	0	2	0	0	0
Skin, nasal cavity, maxillary sinus,						
Squamous cell carcinoma	0	0	3	1	0	0
Spleen						
Hemangiosarcoma	0	0	1	0	0	0
Subcutis, nasal cavity, or maxillary sinus						
Reticulum cell sarcoma	0	0	0	0	0	1
Testes						
Leydig cell tumor	2	2	4	---	---	---
Testes/epididymides						
Mesothelioma	1	0	0	---	---	---
Thyroid gland						
Parafollicular cell adenoma						
Small	6	0	8	11	0	14
Medium/large	3	1	3	3	1	4
Parafollicular cell carcinoma						
Small	1	0	0	0	0	0
Large	1	0	0	0	0	0
Follicular adenoma						
Small	2	0	2	0	0	3
Large	2	0	1	0	0	0
Papillary carcinoma	0	0	0	0	0	2

Site and type of tumor <sup>a</sup>	MALES			FEMALES		
	0 ppm	10 ppm	50 ppm	0 ppm	10 ppm	50 ppm
Urinary bladder Transitional cell carcinoma (metastasizing)	0	0	1	0	0	0
Zymbal's gland Adenoma	0	0	0	0	0	1

<sup>a</sup> Multiple tumors at one site were counted as one tumor

<sup>b</sup> Some animals had more than one tumor

Source: Trochimowicz et al. (1998)

**Table 4-31. Incidence, site and type of tumor in selected organs and tissues of hamsters exposed to chloroprene for 18 months**

	MALES			FEMALES		
	0 ppm	10 ppm	50 ppm	0 ppm	10 ppm	50 ppm
Initial number of hamsters	100	100	100	100	100	100
Number examined	100	97	97	94	93	97
Number tumor bearing <sup>a</sup>	14	17	20	10	11	15
Total number primary tumors <sup>a</sup>	15/14	18/17	23/20	11/11	11/11	18/15
Kidney	2	0	0	0	0	0
Cortical adenocarcinoma						
Liver						
Neoplastic (hepatocellular) nodule	0	1	0	0	0	0
Unidentified tumor-like lesion	0	1	0	0	0	1
Lung tumors	0	0	0	0	0	0
Gallbladder	1	6 <sup>a</sup>	1	1	2	3
Cystadenomatous polyp						
Pancreas						
Islet-cell adenoma	1	0	2	0	0	0
Islet-cell adenocarcinoma	0	0	0	1	0	1
Stomach						
Papilloma	0	0	2	0	0	0
Unidentified papilloma-like lesion	1	1	1	1	2	0
Testes	1	0	0	---	---	---
Leydig-cell tumor						
Colon	0	0	0	2	0	0
Adenomatous polyp						
Pituitary	0	0	1	2	0	0
Adenoma						
Thyroid gland						
Parafollicular cell adenoma	2	0	0	0	2	1
Cystadenoma	1	0	0	0	0	0
Papillary adenoma	0	1	1	1	0	2
Follicular adenoma	2	1	0	1	2	2
Parathyroid	0	0	0	0	1	0
Adenoma						
Adrenals						
Cortical adenoma	4	1	10	0	0	3
Cortical carcinoma	0	1	0	1	0	1
Pheochromocytoma	0	4 <sup>b</sup>	2	0	0	0
Malignant pheochromocytoma	0	0	2	0	0	0
Ovaries	---	---	---	0	2	1
Granulosa-theca-cell tumor						

	MALES			FEMALES		
	0 ppm	10 ppm	50 ppm	0 ppm	10 ppm	50 ppm
Parotid salivary glands Adenoma	0	0	0	0	0	1
Skin Unidentified tumor-like lesion	0	1	0	0	0	0
Zymbal's gland Sebaceous adenoma	0	0	1	0	0	0
Depot fat Lipoma	0	0	0	0	0	1
Nose						
Adenoma of Bowman's glands	0	0	0	1	0	0
Adenocarcinoma of Bowman's glands	0	0	0	0	0	1
Bone (ribs) Osteosarcoma	0	0	0	1	0	0
Abdominal cavity Reticulum cell sarcoma	1	0	0	0	0	0

<sup>a</sup> Some animals had more than one tumor

<sup>b</sup> Significant,  $p < 0.05$  by chi-squared test

Source: Trochimowicz et al. (1998)

#### 4.3. REPRODUCTIVE/DEVELOPMENTAL STUDIES—ORAL AND INHALATION

1 Ponomarkov and Tomatis (1980) administered chloroprene dissolved in olive oil by stomach  
2 tube to 17 female BD IV rats at a single dose (100 mg/kg body weight) on gestational day (GD) 17.  
3 Progeny from treated females (81 males and 64 females) were treated weekly with 50 mg/kg body  
4 weight by stomach tube from the time of weaning for life (120 weeks). A control group of 14 female  
5 rats was treated with 0.3 mL olive oil. Litter sizes and preweaning mortality, survival rates, and body  
6 weights did not differ between chloroprene-treated animals and controls (see Section 4.2.1 for further  
7 study details).

8 NTP (1998) evaluated sperm morphology and vaginal cytology in rats exposed to 0, 5, 32, or  
9 200 ppm and mice exposed to 0, 12, 32, 80 ppm chloroprene for 13 weeks. Methods used were those  
10 described in the NTP's sperm morphology and vaginal cytology evaluations protocol (NTP, 1985).  
11 Table 4-32 is a summary of measured epididymal spermatozoal and estrous cycle parameters from  
12 these 13-week studies. The sperm motility of male rats exposed to 200 ppm was significantly less than  
13 that of controls. This was the only reproductive tissue or estrous cycle parameter affected, compared  
14 with controls, in rats or mice at any exposure level.

**Table 4-32. Summary of epididymal spermatozoal and estrous cycle parameters for rats and mice in the 13-week study of chloroprene**

	RATS				MICE			
	0 ppm	5 ppm	32 ppm	200 ppm	0 ppm	12 ppm	32 ppm	80 ppm
n	10	10	9	9	7	8	10	10
<i>Epididymal spermatozoa - males<sup>a</sup></i>								
Motility (%)	86.73 ± 1.04	83.62 ± 1.93	82.16 ± 1.84	80.04 ± 1.99 <sup>d</sup>	79.09 ± 1.20	81.07 ± 1.13	80.08 ± 1.19	80.04 ± 1.47
Abnormal sperm (%)	0.70 ± 0.05	0.78 ± 0.11	0.73 ± 0.11	1.02 ± 0.14	1.49 ± 0.42	1.30 ± 0.22	0.98 ± 0.10	1.36 ± 0.22
Sperm concentration (10 <sup>6</sup> /g cauda epididymidis)	698 ± 40	722 ± 62	689 ± 46	683 ± 25	1,632 ± 138	1,447 ± 122	1,575 ± 104	1,672 ± 134
<i>Estrous cycle - females<sup>a</sup></i>								
Length (days)	5.00 ± 0.15	4.67 ± 0.17 <sup>b</sup>	5.00 ± 0.27 <sup>c</sup>	5.33 ± 0.17 <sup>b</sup>	4.00 ± 0.00	4.30 ± 0.21	4.22 ± 0.15 <sup>b</sup>	4.13 ± .13 <sup>c</sup>
Diestrus stage (% of cycle)	42.9	35.7	44.3	45.7	31.4	31.4	30.0	35.7
Proestrus stage (% of cycle)	15.7	18.6	11.4	17.1	20.0	20.0	22.9	25.7
Estrus stage (% of cycle)	18.6	22.9	20.0	15.7	24.3	24.3	25.7	20.0
Metestrus stage (% of cycle)	22.9	22.9	24.3	20.0	24.3	24.3	21.4	18.6
Uncertain diagnosis stage (% of cycle)	0.0	0.0	0.0	1.4	----	----	----	----

<sup>a</sup> Epididymal spermatozoal parameters, and estrous cycle lengths are presented as mean ± standard error. Differences from the control group are not significant by Dunn's test (epididymal spermatozoal abnormality and concentration, estrous cycle length). By multivariate analysis of variance, exposed females do not differ significantly from the chamber control females in relative length of time spent in the estrous stages.

<sup>b</sup> Estrous cycle was longer than 12 days or unclear in 1 of 10 animals.

<sup>c</sup> Estrous cycle was longer than 12 days or unclear in 2 of 10 animals.

<sup>d</sup> Significantly different ( $p \leq 0.01$ ) from the control group by Shirley's test.

Source: NTP, (1998).

1

2 Sanotskii (1976) reviewed several Russian studies that exposed white rats (strain unknown) to  
3 various concentrations of chloroprene in order to determine the effect on reproductive and  
4 developmental parameters. In male rats exposed for 4.5 months to 1.7 mg/m<sup>3</sup> (0.5 ppm) of  
5 chloroprene, reductions in the number of normal spermatogonia, increases in the percentage of dead  
6 spermatozoa, and decreases in spermatozoal motility were reported. These effects were not observed  
7 by NTP (1998) in F344 rats at much higher concentrations (Table 4-32). Sanotskii (1976) also  
8 reported an increase in the number of seminiferous tubules with desquamating epithelium in male  
9 C57BL/6 mice exposed to 0.32 mg/m<sup>3</sup> (0.09 ppm) for 2 months and increased dominant lethal  
10 mutations in germ cells of male and female C57BL/6 mice exposed to 3.5 mg/m<sup>3</sup> (1 ppm) for 2  
11 months.

12 Sanotskii (1976) also reported on an embryotoxicity study in which pregnant white rats were  
13 exposed during their "whole period of pregnancy." Exposure to 4 mg/m<sup>3</sup> (1.1 ppm) chloroprene was  
14 reported to have resulted in an increase of embryonic mortality, a decrease in fetal weight, and a  
15 disturbance in vascular permeability as evidenced by hemorrhaging into body cavities. Exposure to  
16 0.13 mg/m<sup>3</sup> (~ 0.04 ppm) chloroprene was reported to have resulted in increased postnatal mortality.

1 Exposure to 4 mg/m<sup>3</sup> (1.1 ppm) chloroprene at various times during pregnancy was reported to have  
2 resulted in cerebral hernia and hydrocephalus.

3 Culik et al. (1978) evaluated the embryotoxic, teratogenic, and reproductive toxicity of  
4 chloroprene in rats. Culik et al. (1978) exposed pregnant CD rats to chloroprene by inhalation at 0, 1,  
5 10, or 25 ppm (0.28, 2.8, or 6.9 mg/m<sup>3</sup>) for 4 hours daily, either on GDs 1–12 (embryotoxicity study)  
6 or GDs 3–20 (teratology study). Pregnant rats in these embryotoxicity and teratology studies were  
7 sacrificed and their litters examined on GDs 17 and 21, respectively. Male rats in a separate  
8 reproduction study were exposed to 0 or 25 ppm (0 or 6.9 mg/m<sup>3</sup>) 4 hours daily for 22 days and bred  
9 with untreated females for 8 consecutive weeks. The embryotoxicity study included 200 female rats  
10 (50 per exposure group), the teratology study included 100 primigravida rats (25 per exposure group),  
11 and the male reproduction study involved 10 male rats (5 per exposure group) and 3 virgin females per  
12 male. The test material was reported to be > 99.9% pure and was stored under nitrogen at –20°C in  
13 small glass bottles holding one day's supply for generating atmospheres. No chemical decomposition  
14 was observed during the experiment.

15 In both the embryotoxicity and teratogenicity studies, litter size, average numbers of  
16 implantation sites per litter, and preimplantation losses among exposed females did not differ  
17 significantly from those of the controls (Table 4-33). In the teratology study, there was an increase in  
18 the percentage of litters with resorptions that was statistically significant ( $p \leq 0.05$ , Fisher's exact test)  
19 only in the 10 ppm exposure group (62% compared to 29% in the control group). The percentage of  
20 litters with resorptions was also elevated in the 25 ppm group (59%), although this increase in effect  
21 failed to achieve statistical significance. There was no effect on percentage of litters with resorptions  
22 in any exposure group in the larger embryotoxicity study; all groups had approximately 50% of their  
23 litters exhibiting resorption. The number of resorptions per litters with resorptions was not affected in  
24 either study. The more frequently investigated endpoint of number of resorptions per litter (total) was  
25 not reported by the study, but was calculated from the reported data and included in Table 4-33 for  
26 reference. There was a slight, but statistically significant ( $p < 0.05$ ), increase in the average body  
27 weight of fetuses from dams exposed to chloroprene at 25 ppm in the teratology study. Fetuses from  
28 dams in the teratology study exposed to 10 and 25 ppm chloroprene were significantly ( $p < 0.05$ )  
29 longer than the control fetuses. The incidence of minor anomalies (minute subcutaneous hematomas  
30 and petechial hemorrhages) in fetuses from exposed dams was similar to that found in control fetuses  
31 (Table 4-34). No major compound-induced or concentration-related skeletal or soft tissue anomalies  
32 were found. The number of unossified sternbrae and unossified thoracic vertebral centers were  
33 similar in all groups regardless of treatment. The combined results of weekly matings for the 8-week  
34 reproduction test indicated that there were no significant effects on reproduction due to chloroprene  
35 exposure: the mating index, average number of pups per litter, viability index, and lactation index  
36 were similar for exposed and control animals.



**Table 4-33. Results of teratology and embryotoxicity studies in rats exposed to chloroprene by inhalation**

PARAMETER	CONCENTRATION OF CHLOROPRENE (ppm)			
	0	1	10	25
<b>Teratology Study</b>				
Number of litters	21	24	21	19
Pregnancy rate, %	84 (21/25)	96 (24/25)	84 (21/25)	76 (19/25)
Corpora lutea/dam	13 ± 3	12 ± 2	12 ± 2	13 ± 2
Implantation sites/dam	10 ± 2	9 ± 3	9 ± 2	11 ± 1
Median preimplantation loss, %	14.7	29.5	20.0	10.0
Live fetuses/litter	9 ± 2	8 ± 3	8 ± 3	10 ± 1
Litters with resorption, %	29 (6/21)	29 (7/24)	62 (13/21) <sup>a</sup>	59 (11/19)
Litters totally resorbed	0	0	0	0
Median postimplantation loss in litters with resorption, %	11.8	16.7	22.0	16.7
Resorptions/litters with Resorptions	1.3 (8/6)	2.0 (14/7)	1.9 (25/13)	1.6 (17/11)
Resorptions/litters total	0.38 (8/21)	0.58 (14/24)	1.19 (25/21)	0.89 (17/19)
Fetal body weight, g	3.76 ± 0.28	3.94 ± 0.46	3.96 ± 0.26	4.04 ± 0.27 <sup>b</sup>
Fetal crown-rump length, mm	32.9 ± 1.4	33.7 ± 1.6	33.8 ± 0.7 <sup>b</sup>	34.1 ± 1.2 <sup>b</sup>
<b>Embryotoxicity Study</b>				
Number of litters	45	43	43	48
Pregnancy rate, %	90 (45/50)	86 (43/50)	88 (43/49)	94 (48/51)
Corpora lutea/dam	15 ± 3	14 ± 3	14 ± 2	13 ± 3
Implantation sites/dam	11 ± 3	11 ± 4	10 ± 4	10 ± 3
Median preimplantation loss, %	20.0	16.2	17.7	16.0
Live fetuses/litter	10 ± 3	9 ± 4	10 ± 3	10 ± 3
Litters with resorption, %	51 (23/45)	51 (22/43)	53 (23/43)	50 (24/48)
Litters totally resorbed	0	1	0	0
Median postimplantation loss in litters with resorption, %	9.1	12.9	8.3	9.1
Resorptions/litters with resorptions	1.7 (39/23)	2.1 (47/22)	1.6 (37/23)	1.4 (34/24)
Resorptions/litters total	0.87 (39/45)	1.09 (47/43)	0.86 (37/43)	0.71 (34/48)

<sup>a</sup> Significantly different ( $p \leq 0.05$ ) from the control group by Fisher's exact test.

<sup>b</sup> Significantly different ( $p \leq 0.05$ ) from the control group by an analysis of variance and least significant difference (LSD) test

Source: Culik et al. (1978)

1 Culik et al. (1978) concluded that the statistically significant increase in litters with resorptions  
2 observed in the teratology study at 10 ppm was not biologically significant because the increase at 25  
3 ppm was not statistically significant and the effect was not observed in the embryotoxicity study,  
4 which had larger numbers of animals per exposure group and was specifically designed to observe  
5 such an effect. Further, the control group for the teratology study is the only group in either study  
6 (embryotoxicity or teratology) that is far outside of the historical control range for number of  
7 resorptions per litter ( $0.83 \pm 0.34$ ) for this strain of rat (Charles River Laboratories, 1996); the  
8 corresponding control group in the embryotoxicity study had a response rate equivalent to historical  
9 controls. Therefore, if the control group response in the teratology study is abnormally low, this may  
10 indicate that the statistically significant increase seen in the 10 ppm group may be a spurious

1 observation. Chloroprene exerts an effect on fetal weight and size, as evidenced by increases in both at  
 2 higher exposure levels. However, in the absence of other definitive markers of developmental toxicity,  
 3 the importance or adversity of this finding remains unclear. Given the lack of a defined dose-response  
 4 for litters with resorptions in either the embryotoxicity or teratology study, and that the control group  
 5 in the teratology study may be a statistical outlier compared to historic control data, there is no  
 6 compelling evidence that chloroprene displays developmental effects in CD rats at exposure levels up  
 7 to 25 ppm. Therefore, 25 ppm is identified as the NOAEL for this study.

**Table 4-34. Incidence of anomalies in litters of rats exposed to chloroprene by inhalation**

	CONCENTRATION OF CHLOROPRENE (ppm)			
	0	1	10	25
	Number of litters (fetuses) examined			
Gross anomalies	21 (192)	24 (191)	21 (172)	19 (184)
Soft tissue anomalies	21 (66)	24 (69)	21 (60)	19 (62)
Skeletal anomalies	21 (126)	24 (122)	21 (112)	19 (122)
	Number of litters (fetuses) affected			
Gross anomalies				
Runts <sup>a</sup>	1 (1)	0	1 (1)	1 (1)
Small subcutaneous hematomas	5 (5)	9 (9)	4 (4)	6 (10)
Petechial hemorrhages	5 (5)	2 (6)	3 (3)	2 (2)
Soft tissue anomalies				
Hydronephrosis	8 (9)	4 (6)	1 (1)	5 (7)
Subcutaneous edema	0	1 (1)	0	0
Skeletal anomalies				
Delayed ossification of one or more sternebrae	17 (58)	15 (39)	13 (33)	14 (45)
14th rudimentary ribs(s) or spur(s)	20 (91)	22 (76)	20 (67)	19 (77)
Wavy ribs	4 (4)	4 (5)	2 (3)	3 (4)
Bipartite thoracic centra	2 (2)	2 (3)	2 (2)	4 (8)

<sup>a</sup> Body weight less than control mean weight minus 3 standard deviations

Source: Culik et al. (1978)

8 Mast et al. (1994) exposed groups of 15-16 pregnant New Zealand white rabbits by inhalation  
 9 to 10, 40, or 175 ppm chloroprene (36.2 144.8, or 633.5 mg/m<sup>3</sup>) for 6 hours/day on gestational days 6-  
 10 28. Maternal body weights were measured on days 0, 6, 15, 22, and 29 and animals were observed  
 11 twice daily (7 days/week) during the exposure period for signs of illness or mortality. On GD29, dams  
 12 were sacrificed and examined for gross tissue abnormalities. Maternal kidneys and liver were removed  
 13 and weighed. The uterus was removed and weighed, and the number, position, and status (live,  
 14 resorbed, or dead) of implants were recorded. Live fetuses were weighed and examined from gross,  
 15 visceral, and skeletal defects. Bulk chemical analysis was performed using infrared spectroscopy to  
 16 confirm test material identity. Purity and dimer determinations were conducted by gas chromatography.  
 17 Exposure atmospheres were generated by immersing an evaporation flask containing bulk material in  
 18 a 150° F water bath and passing a metered flow of nitrogen through the flask to a condenser. The  
 19 condenser's temperature was maintained at -2° C in order to control the chloroprene vapor

1 concentration, and to remove low volatility impurities from the vapor. From the condenser, the  
2 chloroprene vapor was mixed with an appropriate amount of compressed air in order to achieve the  
3 desired exposure concentration. The normal exposure concentrations in the study were between 98-  
4 100% target concentrations, and there was no evidence of degradation products greater than 0.1%  
5 target concentration.

6 There were no signs of maternal toxicity due to exposure to chloroprene. A few dams in each  
7 group exhibited nasal discharge, vaginal bleeding, and loose stools at various times during the  
8 exposure period. The overall pregnancy rate was 89%, with a range of 80-94% for each exposure  
9 group. The incidence of clinical signs of toxicity was low during the exposure, and dams appeared to  
10 be in excellent health at termination. No exposure-related effects on maternal weight change were  
11 noted. Exposure to chloroprene had no effect on the number of implantations, live pups, or  
12 resorptions. Fetal body, liver, and kidney weights were not affected by exposure. The incidence of  
13 fetal malformations was not affected by exposure to chloroprene. The results of this study indicate that  
14 exposure to chloroprene on GD6-28 in rabbits results in no observable developmental toxicity,  
15 therefore the high exposure group, 175 ppm, was identified as the NOAEL for this study.

16 In an unpublished report, Appelman and Dreef van der Meulen (1979) exposed two successive  
17 generations (F<sub>0</sub> or F<sub>1</sub>) of Wistar rats to 0, 10, 33, or 100 ppm (0, 36.2, 119.5, or 362 mg/m<sup>3</sup>)  
18 chloroprene. In the F<sub>0</sub>-generation, groups of 25 males and females were exposed to chloroprene for 6  
19 hours/day, 5 days/week for 13 weeks. After the termination of the exposure, the treated animals were  
20 caged and mated with untreated stock animals for 20 days (1 male per 1 female). After the mating  
21 period, the animals were separated: males were sacrificed and their testes were collected and  
22 examined whereas females were caged individually and allowed to birth and rear their litters. After  
23 their litters were weaned, the females were sacrificed and their uteri were collected and examined for  
24 implantation sites. The number of pups in each litter was recorded at birth, as well as the total number  
25 of survivors and total litter weight at days 1, 3, 14, and 28. Litters containing more than 8 siblings  
26 were randomly culled to that number at day 4. From the F<sub>1</sub>-litters, 20 males and females were selected  
27 randomly from each exposure group one week after weaning and exposed to the same concentrations  
28 of chloroprene from 10 weeks (6 hours/day, 5 days/week). In both the F<sub>0</sub> and F<sub>1</sub> rats, the general  
29 condition, behavior, and signs of possible intoxication were checked daily and all signs of illness or  
30 reaction to exposure were recorded. Individual body weights were recorded weekly during exposure.  
31 In the F<sub>1</sub> rats, blood samples were collected from 15 rats/sex/exposure group at an age of 4 weeks and  
32 analyzed for hemoglobin concentration. At the end of the exposure period, 10 F<sub>1</sub> rats/sex/exposure  
33 group were sacrificed and their liver, lungs, and gonads were weighed and examined. Test  
34 atmospheres were generated by evaporating bulk material with a metered flow of filtered and dried  
35 nitrogen at 0° C. The chloroprene-saturated chloroprene was then mixed with air to achieve the  
36 desired test concentration. Nominal concentrations were within 98-100% target concentrations.

1 The general condition and behavior of F<sub>0</sub> rats did not differ between exposure groups. At 100  
2 ppm, slight (less than 10% decrease relative to control), but significant, growth retardation was  
3 observed in males in weeks 3, 6, 7, 8, and 10 and in females from week 2 to termination of exposure (p  
4 < 0.05). There were statistically significant decreases in body weights in both sexes at various time  
5 points in the low and mid-exposure groups compared to controls, but no consistent exposure-related  
6 pattern was observed. No data on food consumption were provided, but the authors note that decreases  
7 in body weight were most likely attributable to occasional shortages in food availability. The  
8 percentage of females (exposed and non-exposed) that successfully mated was not affected by  
9 chloroprene exposure. Sex ratios, mortality during lactation, and resorption quotients were not  
10 significantly altered in any exposure group. The body weight of offspring descended from treated  
11 females and untreated males was statistically reduced in the high exposure group. Body weights of  
12 offspring descended from treated males and untreated females were not affected.

13 The general condition and behavior of F<sub>1</sub> rats did not differ between exposure groups.  
14 Statistically significant decreases in body weight (greater than 10% reduction compared to control)  
15 were observed in females descended from treated females during week 1 of exposure (p < 0.01), in  
16 males descended from treated males during weeks 4, 6, 7, and 10 (p < 0.01), and in females descended  
17 from treated males during weeks 5 and 6 (p < 0.01). Again, no food consumption data were provided,  
18 precluding a determination of whether these decreases in body weight were related to exposure.  
19 Hemoglobin levels were similar in all groups. The relative weights of testes from F<sub>1</sub> males were  
20 statistically increased in all exposure groups in males descended from treated females (p < 0.05 at 10  
21 and 33 ppm, p < 0.01 at 100 ppm) and at 33 and 100 ppm in males descended from treated males (p <  
22 0.05). F<sub>1</sub> females descended from treated males and exposed to 100 ppm chloroprene had significantly  
23 increased liver (p < 0.01), ovary (p < 0.001), and lung (p < 0.05) weights. Gross and microscopic  
24 histopathological examinations revealed no treatment-related abnormalities in these organ systems.  
25 Given the lack of histopathological findings in any examined organ system, the significant increases in  
26 lung, liver, and gonad weights in F<sub>1</sub> males and females are not considered to be adverse.

27 The NOAEL for this study was identified as 33 ppm based on decreases in body weight during  
28 lactation in pups descended from treated females and untreated males.

#### **4.4. OTHER DURATION- OR ENDPOINT-SPECIFIC STUDIES**

##### **4.4.1. Acute and Subchronic Studies**

29 Clary et al. (1978) conducted a study to investigate chloroprene's acute and subchronic toxicity  
30 and to determine the dose range for a 2 year chronic inhalation study (chronic study by Trochimowicz  
31 et al., 1998) in rats and hamsters. Groups of six male albino rats (from Charles River laboratories)  
32 were exposed to chloroprene by the dermal (200 mg/kg), oral (50 mg/kg), or inhalation (2 mg/L [~550  
33 ppm]) routes for 4 hours and sacrificed for histological examinations 14 days after exposure. This  
34 exposure protocol was referred to as a "modified Class B poison test" (extension of sacrifice from 2–

1 14 days after exposure). A lethal concentration test was also conducted by exposing male rats to 0,  
 2 530, 1,690, 2,280, 3,535, or 3,610 ppm (0, 146, 467, 630, 976, or 997 mg/m<sup>3</sup>). The approximate lethal  
 3 concentration by inhalation (4 hours) in rats was determined to be 2,280 ppm (Table 4-35). In the  
 4 4-week range-finding inhalation study, Wistar rats were exposed to chloroprene at 0, 50, 200, or 800  
 5 ppm (actual mean concentrations were 0, 39, 161, or 625 ppm [0, 11, 44, or 173 mg/m<sup>3</sup>], respectively).  
 6 A similar study was conducted (after completion of the 4-week rat study) with Syrian golden hamsters  
 7 exposed to 0, 40, 160, or 625 ppm (actual mean concentrations were 0, 39, 162, or 630 ppm [0, 11, 45,  
 8 or 174 mg/m<sup>3</sup>], respectively). The purity of chloroprene used in this study was 99.9% with 0.01%  
 9 phenothiazine added as a polymerization inhibitor. Test atmospheres were generated by low  
 10 temperature (0°C) vaporization in nitrogen.

**Table 4-35. Chloroprene-induced mortality in male rats**

CONCENTRATION (ppm)	MORTALITY (DEAD/TOTAL)
530	0/6
1,690	0/6
2,280	1/6
3,535	2/6
3,610	2/6

Source: Clary et al. (1978)

11 Clary et al. (1978) reported no deaths from dermal, oral, or inhalation administration in the  
 12 standard Class B poison test (sacrifice 2 days after the 4-hour exposure period). There were mild to  
 13 moderate skin irritation and erythema after the dermal exposure. Irregular respiration, mild  
 14 lacrimation, and slight initial weight loss were reported after the inhalation exposure. For the modified  
 15 Class B poison test (sacrifice 14 days after the 4-hour exposure period), 2/6 and 3/6 animals died on  
 16 the sixth and seventh days, respectively.

17 In the 4-week range-finding study, exposure to 625 ppm chloroprene was associated with eye  
 18 irritation, restlessness, lethargy, nasal discharge, and orange-colored urine in rats and hamsters. Hair  
 19 loss was observed in female rats exposed to the two highest exposure groups (161 and 625 ppm).  
 20 Increased mortality in rats was observed at the two highest concentrations starting in week 1 (5/10  
 21 males and 3/10 females died at 625 ppm; 3/10 males died at 161 ppm at the end of the exposure period,  
 22 4 weeks). Mortality was 100% for male and female hamsters in the highest dose group (630 ppm) by  
 23 the end of week 1, and 1/10 males and 3/10 females at the mid-exposure (162 ppm) by the end of week  
 24 4. 1 male hamster died in the low exposure (39 ppm) group by week 4. Decreases in body weight  
 25 were observed at all concentrations in rats and at 162 ppm in hamsters. There were changes in the  
 26 relative weights of all organs except for the heart. The relative organ weights for kidneys were  
 27 increased at the 162 ppm exposure level for both male and female hamsters, the 625 ppm level for  
 28 male rats, and the 161 and 625 ppm level for female rats. Liver weights were increased in the high  
 29 exposure group in both species except for female hamsters. Male rats exhibited decreased liver

1 weights at 39 and 161 ppm. Relative lung weights were increased at 625 ppm for male and female  
2 rats. Clary et al. (1978) noted that these increases in the relative weight of the kidneys, liver, and lungs  
3 may have indicated a direct effect of chloroprene exposure, whereas weight changes in other organs  
4 (spleen, brain, thyroid, and adrenal glands) may have been secondary to decreases in body weight.

5 In rats, gross pathological examination of the animals that died during exposure revealed dark,  
6 swollen livers and grayish lungs with hemorrhagic areas. Dark swollen livers were also observed in  
7 several animals exposed to the highest concentration when they were sacrificed at the end of the study.  
8 Microscopic examination revealed slight to severe centrilobular liver degeneration in all male rats and  
9 in 8/10 of the females at the high concentration. This change was also observed in 2/3 male rats  
10 exposed to 161 ppm that died during the study. The kidneys of male and female rats exposed to 625  
11 ppm had enlarged tubular epithelial cells. In addition, one male and one female rat exposed to 625  
12 ppm showed foci of necrotic tubules in the intramedullary area of the kidneys.

13 In hamsters, the lungs of most of the animals that died within the first 24 hours of exposure (all  
14 animals died after a single exposure to 630 ppm and 1/10 males and 1/10 females at 162 ppm) showed  
15 gray-reddish edematous areas. Fecal and urinary incontinence were observed in 1/10 male and 3/10  
16 females at 630 ppm. The heart of 1/2 females that died on the second day of exposure was pale with  
17 severe myocarditis, and the thoracic cavity contained a considerable amount of fluid. The other female  
18 had a small spleen and a pale liver with a pronounced lobular pattern. Significant body weight  
19 decreases were observed only in the 162 ppm group. Histopathology examinations revealed necrosis  
20 and midzonal degeneration of hepatocytes in most of the survivors of the 162 ppm group. Several  
21 males and females (number not specified) exposed to either 39 or 162 ppm showed irritation of the  
22 mucous membranes of the nasal cavity. This irritation was described as a slight flattening and thinning  
23 of the layer of the olfactory epithelium in the dorsomedial part of the cavity.

#### 4.4.2. Immunotoxicity

24 There are some laboratory animal data suggesting potential immunomodulatory effects in of  
25 chloroprene; however the data are from standard toxicological studies and no targeted  
26 immunotoxicological studies of chloroprene were identified. The studies discussed below were  
27 described in detail previously in the assessment and only the relevant immune data are presented here.  
28 NTP (1998) observed that thymus weights in adult male and female B6C3F1 mice exposed to 80 ppm  
29 chloroprene for 16 days were significantly decreased compared to controls ( $p < 0.01$ ) and thymic  
30 necrosis, characterized by karyorrhexis of thymic lymphocytes, was observed in both sexes at 200  
31 ppm. No changes in thymus weight or histopathology were reported in mice after chloroprene  
32 exposure for a longer period (i.e., 13-week exposure) as part of the same NTP (1998) study.  
33 Alterations in differential white blood cell counts (i.e., increased leukocyte, neutrophil, and monocyte  
34 numbers) were observed at 500 ppm in male rats after 16 days exposure and segment neutrophils were  
35 decreased in male rats at 200 ppm after 13 weeks of exposure. In the 2-year chronic portion of the  
36 NTP study, splenic hematopoietic cell proliferation was significantly increased over controls in male

1 mice at 32 and 80 ppm, and in all exposed females (level of significance not reported). Hyperplasia of  
2 the mediastinal lymph node was observed in females exposed to 32 or 80 ppm (significance not  
3 stated).

4 Trochimowicz et al. (1998) observed that mean relative spleen and thymus weights were  
5 significantly ( $p < 0.01$ ) lower in female Wistar rats exposed to 50 ppm chloroprene for 2 years, but did  
6 not report any accompanying histopathological changes in either organ. Clary et al. (1978) also  
7 observed small spleens in hamsters (qualitative description) and decreased spleen weights (possibly  
8 secondary to decreased body weights) in rats exposed to 625-630 ppm chloroprene for 4 weeks.  
9 Sanotskii (1976) reported that chromosomal aberrations were observed in the bone marrow of mice  
10 exposed to chloroprene and in leukocyte cultures of exposed chloroprene production workers.

11 These findings provide some evidence of immunomodulatory effects of chloroprene in  
12 laboratory animals. The immune-related data for chloroprene include altered lymphoid organ weights  
13 and histopathology, and chromosomal aberrations in bone marrow. However, it has been shown that  
14 changes in lymphoid organ weights and genotoxicity observed in lymphoid organs are both poor  
15 predictors of compound-related changes in immune function (Luster et al., 1992). The changes in  
16 thymic histopathology reported after 16 days of exposure were not observed with longer exposure,  
17 suggesting no chronic effects. The remaining data on increased hematopoietic cell proliferation and  
18 lymph node hyperplasia are nonspecific effects that are difficult to interpret as potential immunotoxicity  
19 of chloroprene. They may be related to general hematopoietic effects of chloroprene rather than an  
20 effect on the immune system or immune function. In general, measures such as these (i.e.,  
21 morphological disturbances) are not clear measures of a chemical's potential to cause changes in  
22 immune function (Putman et al., 2003). Direct measures of immune function, such as antibody  
23 production to a T-cell dependent antigen, are usually preferred to delineate a chemical's immunotoxic  
24 potential (Luster et al., 1992; Putman et al., 2003).

#### **4.5. MECHANISTIC DATA AND OTHER STUDIES IN SUPPORT OF MODE OF ACTION**

##### **4.5.1. Mode-of-Action Studies**

25 Many of the available studies addressing the mode of action (MOA) of chloroprene have  
26 focused on investigating the metabolic profile for chloroprene including identifying epoxide  
27 metabolites, their reactivity with DNA, and adduct formation in vitro (Munter et al., 2002; Hurst and  
28 Ali, 2007). Other studies have used molecular analysis to study alterations in ras proto- oncogenes  
29 from lung and Harderian gland tumors identified in the NTP (1998) chronic bioassay that may indicate  
30 events in chloroprene-induced neoplasia (Ton et al., 2007; Sills et al., 1999).

31 The metabolism of chloroprene into reactive epoxides has been primarily evaluated in vitro  
32 with liver and lung tissue fractions from rat, mouse, hamster, and humans. Only a limited number of  
33 studies have investigated the in vivo metabolism of chloroprene. In studies using mouse and human

1 liver microsomes, Bartsch et al. (1979) showed that 2-chloro-2-ethynyloxirane and/or (1-  
2 chloroethenyl)oxirane could be intermediates in the biotransformation of chloroprene. Metabolism of  
3 chloroprene into (1-chloroethenyl)oxirane was confirmed by Himmelstein et al. (2001b); oxidation of  
4 chloroprene to (1-chloroethenyl)oxirane was evident in rodent and human liver microsomes and most  
5 likely involved CYP2E1, as evidenced by the near complete in vitro inhibition with 4-methylpyrazole.  
6 A comparison across species suggested that a greater amount of (1-chloroethenyl)oxirane was present  
7 in B6C3F1 mice and F344 rat liver microsomes, followed by the Wistar rat, then humans and  
8 hamsters. A maximum concentration of (1-chloroethenyl)oxirane of 0.01-0.02  $\mu\text{M}$  was detected in  
9 mouse liver microsomes between 5-10 minutes after initiation of exposure with 0.05  $\mu\text{M}$  chloroprene.  
10 Preliminary data also showed that hydrolysis of (1-chloroethenyl)oxirane was slowest in the liver  
11 microsomes of B6C3F1 mice. Further comparing metabolism between species, Cottrell et al. (2001)  
12 observed that qualitative profiles of metabolites from liver microsomes obtained from B6C3F1 mice,  
13 Sprague-Dawley or F344 rats, and humans were similar, with (1-chloroethenyl)oxirane being the  
14 major metabolite in all species and genders. Himmelstein et al. (2004a) developed a two-compartment  
15 closed vial model to describe both chloroprene and (1-chloroethenyl)oxirane metabolism in liver and  
16 lung fractions from rat (two strains, F344 and Wistar), mouse, hamster, and humans. Estimates for  
17  $V_{\text{max}}$  and  $K_{\text{m}}$  for oxidation of chloroprene (into (1-chloroethenyl)oxirane) in liver microsomes ranged  
18 from 0.068–0.29  $\mu\text{mol}/\text{hour}/\text{mg}$  protein and 0.53–1.33  $\mu\text{M}$ , respectively. Oxidation ( $V_{\text{max}}/K_{\text{m}}$ ) of  
19 chloroprene in the liver was slightly faster in the mouse and hamster than in rats or humans. In lung  
20 microsomes,  $V_{\text{max}}/K_{\text{m}}$  was much greater for mice compared with the other species. Conversely,  
21 hydrolysis ( $V_{\text{max}}/K_{\text{m}}$ ) of (1-chloroethenyl)oxirane in liver and lung microsomes was faster for the  
22 human and hamster, than for rat or mouse. The observation that mice generally metabolized  
23 chloroprene into its epoxide metabolite at equal or faster rates than other species and hydrolyzed the  
24 epoxide more slowly may, in part, explain why mice were observed to be the most sensitive species in  
25 regards to chloroprene's observed carcinogenicity.

26 The in vivo rodent studies support the postulated metabolic pathway for chloroprene. For  
27 example, male Wistar rats administered 100 or 200 mg/kg chloroprene by gavage demonstrated a rapid  
28 depletion of hepatic GSH and a dose-dependent increase in excreted urinary thioethers (presumably  
29 GSH-conjugates), which is consistent with in vitro studies using isolated liver hepatocytes (Summer  
30 and Greim, 1980). Pretreatment of rats or hepatocytes with phenobarbital or a polychlorinated  
31 biphenyl (PCB) mixture (Clophen A50) to induce the mixed-function oxidase enzymes enhanced the  
32 GSH depletion effect.

33 Munter et al. (2002) investigated the reactivity of the chloroprene metabolite  
34 (1-chloroethenyl)oxirane towards DNA nucleosides and calf thymus DNA. The adducts were isolated  
35 by reverse-phase chromatography and characterized by their mass spectrometric features. The reaction  
36 of (1-chloroethenyl)oxirane with the nucleoside 2'-deoxyguanosine yielded one major adduct derived  
37 by nucleophilic attack of N-7 guanine on C-3' of the epoxide. In addition, another chloroprene



1 metabolite 2-chlorobut-2-en-1-al (See Figure 1, metabolite labeled as number 15) described as an  
2 unsaturated aldehyde, yielded 2 major adducts. The reaction of (1-chloroethenyl)oxirane with double  
3 stranded calf thymus DNA yielded N7-(3-chloro-2-hydroxy-3-buten-1-yl)-guanine (dGI) as the major  
4 adduct, the same adduct seen when the chloroprene metabolite was incubated with 2'-deoxyguanosine  
5 individually. N3-(3-chloro-2-hydroxy-b-buten-1-yl)-2'-deoxyuridine (dCI) was also detected. The  
6 reaction of (1-chloroethenyl)oxirane with deoxycytidine in DNA may be significant because such  
7 adducts are difficult to repair and may therefore be implicated in mutagenesis (Koskinen et al., 2000).

8 The in vitro reactivity of (1-chloroethenyl)oxirane with hemoglobin (adduct formation) and  
9 enantiomer detoxification (i.e., disappearance of R- vs. S-enantiomer from the test system) in vitro  
10 have been investigated by Hurst and Ali (2007). Mouse (C57BL/6) erythrocytes (RBCs) were  
11 incubated with the R- and S-enantiomers of (1-chloroethenyl)oxirane in vitro. The authors reported a  
12 greater persistence of the R- over the S-enantiomer upon incubation with RBCs in the in vitro system  
13 tested. The authors also reported a greater amount of globin adducts formed with the R- than with the  
14 S-enantiomer.

15 As part of the 2-year bioassay of chloroprene, NTP (1998) evaluated possible oncogene-  
16 activating mechanisms for lung and Harderian gland neoplasms in the B6C3F1 mouse at 0, 12.8, 32,  
17 and 80 ppm. The results were published by Sills et al. (1999). After isolation and amplification of  
18 DNA from the neoplasms, H-ras and K-ras mutations were identified. A higher frequency (80%) of K-  
19 ras mutations was detected in chloroprene-induced lung neoplasms than in spontaneous neoplasms of  
20 control mice (30%). The predominant mutation was an A→T transversion (CAA→CTA) at K-ras  
21 codon 61: 80% (8/10) of low dose, 71% (10/14) of mid dose, and 18% (4/22) of high dose lung tumors  
22 were observed to have this mutation). This specific mutation was not observed in spontaneously  
23 occurring lung neoplasms. A similar pattern of ras mutations was observed also with isoprene-induced  
24 lung neoplasms but not in those induced by butadiene. Rare point mutations, not seen in spontaneous  
25 lung neoplasms, were detected at codon 12. No consistent morphological pattern (papillary, solid, or  
26 mixed) or type (benign or malignant) of neoplasm was co-observed with specific K-ras mutations.  
27 Although definitive evidence is currently unavailable, there are a number of factors that may explain  
28 the observation of the lower frequency of codon 61 CTA transversions in lung tumors of high dose  
29 animals. In the lung, the lower frequencies in CTA transversions at high doses may be due to non-ras  
30 mutation mechanisms of genotoxicity or carcinogenicity. Alternatively, differences in DNA-adduct  
31 formation or induction of repair or removal mechanisms may explain the pattern observed.

32 A high incidence (100%) of both K-ras and H-ras mutations was detected in chloroprene-  
33 induced Harderian gland neoplasms, compared with 56% in spontaneous Harderian gland tumors in  
34 control mice, 100% in neoplasms from isoprene-exposed mice, or 69% in neoplasms from butadiene-  
35 exposed mice. The predominant mutation was also a CAA→CTA transversion at K-ras codon 61  
36 (93%), which only occurred in 7% (2/27) spontaneously occurring Harderian gland neoplasms. The  
37 concentration-response was similar across exposure groups. It was suggested that the large number of

1 ras mutations at A:T base pairs after exposure to chloroprene, isoprene, or butadiene indicated an  
 2 interaction with DNA to form adenine adducts that may be important for tumor induction. Sills et al.  
 3 (2001) reported higher frequencies of K- and H-ras mutations (57%) in chloroprene-induced  
 4 forestomach tumors in B6C3F1 mice compared to spontaneous tumors (36%). The A→T transversion  
 5 (CAA→CTA) in H-ras codon 61 was identified in 29% of the chemically induced forestomach  
 6 neoplasms, but was not observed in spontaneous control tumors. Mutations at K-ras codon 61 were  
 7 not observed in chloroprene-induced forestomach tumors.

8 Ton et al. (2007) evaluated mutations in the K-ras oncogenes and loss of heterozygosity in the  
 9 region of K-ras on distal chromosome 6 in lung tumor samples collected from mice exposed to  
 10 chloroprene in the NTP 2-year inhalation study. DNA analysis included isolation from formalin fixed  
 11 tissue sections, and amplification, cycle sequencing of ras gene and analysis for loss of heterozygosity  
 12 (LOH). Chloroprene-induced mouse lung tumors had a high frequency of LOH on chromosome 6 in  
 13 the region of K-ras. The correlation between K-ras mutation and loss of the wildtype allele was high in  
 14 the tumors examined: of the 19 lung tumors with LOH from B6C3F1 mice exposed to chloroprene, 16  
 15 (84%) of them also had K-ras mutations.

#### 4.5.2. Genotoxicity Studies

16 This section presents the findings of several genotoxicity studies that are summarized in Table  
 17 4-36.

**Table 4-36. Genotoxicity assays of chloroprene**

TEST SYSTEM	CELLS/STRAIN	TESTED CONCENTRATIONS	RESULTS <sup>a</sup>	REFERENCE
<i>Bacterial assays</i>				
<i>Salmonella typhimurium</i>	TA100	0.5 to 8% (volume/volume) in air	+	Bartsch et al. (1979)
	TA100, TA1535		+	Willems (1980)
	TA98		-	Willems (1980)
	TA100, TA1535	10,000-40,000 ppm	+	Willems (1978)
	TA98, TA1537, TA1538	10,000-40,000 ppm	-	Willems (1978)
	TA100, TA1535, TA1537, TA98	up to 3,333 µg/plate	-	NTP (1998)
	TA100	0-5 µmol/plate	-	Westphal et al. (1994)
	TA100	0-5 µmol/plate <sup>b</sup>	+	Westphal et al. (1994)
	TA100, TA1535, TA97A, TA98	0 to 69 mM <sup>c</sup>	+	Himmelstein et al. (2001a)
<i>Mammalian cell assays</i>				
Micronucleus	Chinese hamster V79	10% (v/v)	-	Drevon and Kuroki (1979)
Micronucleus	Chinese hamster V79	0.175 mM <sup>a</sup>	-	Himmelstein et al. (2001a)

TEST SYSTEM	CELLS/STRAIN	TESTED CONCENTRATIONS	RESULTS <sup>a</sup>	REFERENCE
<i>In vivo bioassays</i>				
Sex-linked recessive lethal mutation	Drosophila (Canton-S)		–	Foureman et al. (1994)
Sex-linked recessive lethal mutation	Drosophila (Berlin-K)		+	Vogel (1979)
Sister chromatid exchange: bone marrow	B6C3F1 mice	12.8, 32, 80 ppm	–	NTP (1998); Shelby (1990); Tice (1988a, 1988b)
Chromosomal aberration: bone marrow	B6C3F1 mice	12.8, 32, 80 ppm	–	NTP (1998)
Chromosomal aberration: bone marrow	C57BL/6 mice	up to 1 ppm	+	Sanotskii (1976)
Micronucleus: peripheral blood	B6C3F1 mice	12.8, 32, 80 ppm	–	NTP (1998)
Micronucleus: bone marrow	B6C3F1 mice		–	Shelby and Witt (1995)

<sup>a</sup> For bacterial assays, tests were performed in the absence or presence of the exogenous S9 metabolism system. In all cases of positive mutagenicity (except Westphal et al., 1994), addition of S9 mixture enhanced the observed mutagenicity

<sup>b</sup> Aged chloroprene distillates tested (in the absence of the exogenous S9 metabolism system).

<sup>c</sup> Epoxide metabolite (1-chloroethenyl)oxirane tested.

#### 4.5.2.1. Bacterial Mutagenicity Assays

1 Both positive and nonpositive mutagenic responses have been observed in bacterial mutagenic  
2 assays.

3 Bartsch et al. (1979) exposed *Salmonella typhimurium* strain TA100 to 0.5–8%  
4 (volume/volume [v/v]) of chloroprene within sealed desiccators for 4 hours at 37°C in the absence or  
5 presence of the exogenous S9 metabolism system. Batch solutions were freshly prepared before use  
6 and kept at –20°C. Chloroprene purity was 99% and contained a negligible amount of dimers. A  
7 positive mutagenic response that was concentration-dependent was observed without S9 fraction; this  
8 response increased threefold when S9 fractions from either phenobarbital-pretreated or untreated mice  
9 were used.

10 Willems (1978, 1980) found that chloroprene (purity not stated, but sample was “freshly  
11 supplied”) was mutagenic with *S. typhimurium* strains TA100 and TA1535 in the presence or absence  
12 of S9 (mutagenicity was more pronounced in the presence of the S9 fraction), indicating base pair  
13 substitution mutations. Chloroprene, however, was not mutagenic in *S. typhimurium* strains TA98,  
14 TA1537, and TA1538 indicating a lack of frameshift mutations. Petri plates were incubated at 37°C in  
15 desiccators for either 48 or 24 hours, removed, and then incubated for another 24 hours. Positive  
16 controls were used. Four dimers (chemical characterization not stated) were also tested under the same  
17 conditions. Three of the four were mutagenic against both salmonella base pair substitution strains  
18 (TA100 and TA1535).

19 Westphal et al. (1994) investigated the mutagenicity of chloroprene with respect to the  
20 compound stability and reactivity with solvents used in the test system. The Ames test was performed  
September 2009

1 using the *S. typhimurium* (strain TA100) with or without S9, in gas-tight chambers to prevent  
2 chloroprene volatilization. Chloroprene was freshly distilled from a 50% xylene solution. The  
3 distillates were stored at  $-20^{\circ}\text{C}$  and checked for purity immediately before testing. The authors noted  
4 that 2–5% xylenes remained in the chloroprene distillates. Another set of distillates were prepared in  
5 the same manner and stored either under air or under argon and kept at room temperature (referred to  
6 as aging) for 1, 2, or 3 days. Chromatographic analysis of the aged chloroprene revealed the presence  
7 of decomposition products reported to be cyclic dimers. The influence of solvents was also tested in  
8 this study by using either ethanol or dimethyl sulfoxide (DMSO) as vehicles. Propylene oxide (a  
9 volatile direct mutagen) and benzo(a)pyrene were used as positive controls.

10 Freshly distilled chloroprene dissolved in either DMSO or ethanol as vehicles, with or without  
11 S9, was not mutagenic in TA100. Aged chloroprene had a mutagenic effect on TA100 that increased  
12 linearly with increasing age of the chloroprene distillates. Westphal et al. (1994) confirmed these  
13 findings by obtaining positive results with 10 additional distillates containing different proportions  
14 (quantitative details not specified) of the decomposition products, without S9. The mutagenicity of the  
15 distillates correlated with the proportion of the decomposition products (which increased over time in  
16 the aged samples). The mutagenicity of aged chloroprene towards TA100 was the same whether  
17 chloroprene was stored under air or under an inert gas. The authors speculated that the mutagenic  
18 products in aged chloroprene were less volatile than those in the fresh distillates, thus remaining in the  
19 test medium long enough to cause toxicity.

20 Addition of GSH, both with and without S9, reduced the mutagenicity of aged chloroprene but  
21 was less effective as the amount of decomposition products increased. Westphal et al. (1994) stated  
22 that chloroprene diluted in DMSO was markedly more toxic and more mutagenic than chloroprene  
23 dissolved in ethanol, although no data were provided to support this statement.

24 Chloroprene did not show any evidence of mutagenicity in any of four strains of *S.*  
25 *typhimurium* (TA98, TA100, TA1535, or TA1537) tested at concentrations up to 3,333  $\mu\text{g}/\text{plate}$ , in the  
26 presence or absence of aroclor-induced rat or hamster liver S9 fraction (NTP, 1998).

27 Chloroprene monoepoxide, (1-chloroethenyl)oxirane ( $> 98\%$  purity), was found to be  
28 mutagenic in salmonella strains TA100 and TA1535. Some activity was also observed in strains  
29 TA97A and TA98 without Aroclor-induced S9 activation (Himmelstein et al., 2001a); inclusion of S9  
30 had no effect in the mutagenic response in all tester strains. Test concentrations were  
31 0–69 mM in DMSO. Toxicity was noted at  $> 14$  mM in plates without S9 and at  $> 34$  mM in plates  
32 with S9.

#### 4.5.2.2. *Mammalian Cell Assays*

33 Chloroprene (99% pure) was evaluated for mutagenic potential in V79 Chinese hamster cells in  
34 the presence of a liver supernatant (S15 fraction) from phenobarbitone-pretreated rats and mice  
35 (Drevon and Kuroki, 1979). Cells were incubated at  $37^{\circ}\text{C}$  for 5 hours or longer in 2.5 mL of reaction

1 mixture with or without S15 fraction from mice pretreated with phenobarbitone, plus cofactors, either  
2 in liquid suspension or in 0.3 % agar. The petri dishes were placed in a desiccator and exposed to 0,  
3 0.2, 1, 2, and 10% (v/v) chloroprene vapors for 5 hours. Toxicity was evaluated as a measure of  
4 plating efficiency. Mutations were evaluated in terms of resistance to a purine analogue (8-  
5 azaguanine) and ouabain (inhibitor of adenosine triphosphatase in cell membranes). Chloroprene  
6 toxicity was observed at concentrations above 1%; this effect was enhanced with addition of the S15  
7 fraction. The authors noted that this suggested the formation of a toxic metabolite. No mutations were  
8 observed in the absence or presence of S15.

9 Himmelstein et al. (2001a) evaluated the clastogenic potential of the (1-chloroethenyl)oxirane  
10 (> 98% purity) using the cytochalasin-B blocked micronucleus test in Chinese hamster V79 cells  
11 without metabolic activation. The V79 cells plated on tissue culture slides were placed inside sterile  
12 bottles filled with culture medium followed by injection of  
13 0–0.943 mM (1-chloroethenyl)oxirane dissolved in DMSO into the bottles and incubation for 3 hours.  
14 Cells were then transferred to fresh medium containing cytochalasin-B and incubated for an additional  
15 16 hours. A minimum of 500 binucleated cells were scored for micronuclei. Cytotoxicity, reported as  
16 a reduction in the number of binucleated cells, and altered cell morphology were observed starting at  
17 0.175 mM. No clastogenic response was noted at concentrations up to 0.175 mM.

#### 4.5.2.3. *In Vivo Bioassays*

18 Vogel (1979) evaluated chloroprene (99% pure with negligible dimer content) dissolved in  
19 DMSO (final DMSO concentration = 1%) in an experiment for induction of recessive lethal mutations  
20 on the X chromosome of male *Drosophila melanogaster* (Berlin-K). Storage conditions and the  
21 elapsed time between receipt and use were not reported. After mating, the F<sub>3</sub> generation was evaluated  
22 for recessive lethality. The increase in the percentage of observed recessive-lethal mutations was  
23 marginal in several experiments and was not concentration dependent. However, when the data from  
24 pooled samples from several experiments (53 lethals in 15,941 X chromosomes) were compared with  
25 seven control experiments, the difference was statistically significant at  $p < 0.01$ . The authors noted  
26 that the possible variation among samples could be related to the instability of chloroprene.

27 In a study by Foureman et al. (1994), chloroprene (purity not reported) dissolved in ethanol  
28 was nonpositive ( $p > 0.01$ ) for sex-linked recessive lethal mutations in postmeiotic and meiotic germ  
29 cells of adult male *D. melanogaster* (Canton-S) when exposed by either the injection or feeding route.  
30 The investigators suggested that the discrepancy between their nonpositive findings and those of Vogel  
31 (1979) may be due to (1) differences in purity of the chloroprene sample, (2) differences between the  
32 Berlin-K and Canton-S strains, (3) differences in sample sizes, and (4) possible genetic drift within the  
33 female populations used by the two groups of investigators. Another possibility for the conflicting  
34 results could be that chloroprene in ethanol is less genotoxic than if dissolved in DMSO (Westphal et  
35 al., 1994; Gahlmann, 1993).

1 Cytogenetic tests using chloroprene were nonpositive. In studies performed by Brookhaven  
2 National Laboratories for the NTP (1998), sister chromatid exchanges and chromosomal aberrations  
3 (bone marrow cells) and the frequency of micronuclei in peripheral blood erythrocytes were evaluated  
4 in male mice exposed by inhalation to chloroprene in the NTP (1998) bioassay. Results were  
5 published separately by Shelby (1990), Tice (1988), and Tice et al (1988). Mice were exposed by  
6 inhalation to chloroprene at 0, 12.8, 32, 80, or 200 ppm (0, 3.5, 8.8, 22, or 55 mg/m<sup>3</sup>) 6 hours/day for  
7 12 days. Mortality was 100% at 200 ppm. There were no exposure-related effects compared with  
8 controls in numbers of sister chromatid exchanges, chromosomal aberrations, or micronucleus  
9 frequency in polychromatic or normochromatic erythrocytes. Tice (1988) and Tice et al (1988) did  
10 report that the mitotic index (frequency of cells in metaphase) in mouse bone marrow cells was  
11 elevated in chloroprene-exposed animals, with the increase being significant in the 80 ppm group.  
12 Tice (1988), and Tice et al (1988) suggested that the lack of chloroprene-induced genotoxicity in bone  
13 marrow may imply that any carcinogenic activity attributable to chloroprene would likely be localized  
14 to tissues directly exposed to chloroprene (e.g., lung) or to tissues with a high metabolic activity that  
15 form reactive intermediates.

16 The frequency of micronucleated cells in peripheral blood erythrocytes was not affected when  
17 mice were exposed to chloroprene for 13 weeks to 0, 12.8, 32, or 80 ppm (0, 3.5, 8.8, or 22 mg/m<sup>3</sup>)  
18 (NTP, 1998; MacGregor et al., 1990).

19 Sanotskii (1976) reported on a study identifying an increase in chromosomal aberrations in  
20 bone marrow cells of mice exposed for 2 months to chloroprene concentrations of 3.5 mg/m<sup>3</sup> (1 ppm)  
21 and below. The protocol details and information about the purity and storage of chloroprene were not  
22 provided.

23 Shelby and Witt (1995) found nonpositive results in vivo in the mouse bone marrow  
24 micronucleus test and in chromosomal aberration tests when male B6C3F1 mice were injected  
25 intraperitoneally with chloroprene in corn oil, three times, at 24-hour intervals. Dose levels, protocol  
26 details, and information about the purity and storage of chloroprene were not provided.

27 Chloroprene was also tested in a dominant lethal assay with male Swiss mice (Immels and  
28 Willems, 1978). Groups of 12 males were exposed to 0, 10, or 100 ppm (0, 2.8, or 28 mg/m<sup>3</sup>)  
29 chloroprene 6 hours/day, 5 days/week for 2 weeks. Immediately after exposure, each male was mated  
30 with two virgin females for seven days. Females were replaced each week for 8 weeks. There was no  
31 sign of dominant lethal mutations or effects on mating performance or fertility.

#### 4.5.3. Structural Alerts

32 Chloroprene is the 2-chloro analog of 1,3-butadiene, a multiorgan, cross-species carcinogen,  
33 and is structurally similar to isoprene (2-methyl-1,3-butadiene). Inhalation studies have demonstrated  
34 that, similar to butadiene and isoprene, chloroprene is a multisite carcinogen in rats and mice.  
35 Butadiene and isoprene are both metabolized to epoxides and diepoxides that are known mutagens and

1 are believed to be responsible for their carcinogenicity. Chloroprene is also metabolized to an epoxide  
 2 intermediate that may mediate its carcinogenic effects; however, there is no evidence of diepoxide  
 3 formation in the metabolism of chloroprene. The similarities in the sites of tumor induction in rodents  
 4 (see Table 4-37) between butadiene, isoprene, and chloroprene provide further evidence for a similar  
 5 MOA for these epoxide-forming compounds. A comparative report of the carcinogenicity of these  
 6 compounds highlights the qualitative and quantitative concordance of their tumorigenic effects  
 7 (Melnick and Sills, 2001). The female mouse lung was the most sensitive site of carcinogenicity for  
 8 both chloroprene and butadiene.

**Table 4-37. Sites of increased incidences of neoplasms in the 2 year inhalation studies of 1,3-butadiene, isoprene, and chloroprene in rats and mice**

Site	Mice			Rats		
	Butadiene	Isoprene	Chloroprene	Butadiene	Isoprene	Chloroprene
Lymphatic/hematopoietic	M, F <sup>a</sup>	M	M, F			
Circulatory	M, F	M				
Lung	M, F	M	M, F			M
Liver	M, F	M	F			
Forestomach	M, F	M	M, F			
Harderian gland	M, F	M, F	M, F			
Mammary gland	F		F	F	M, F	F
Brain				M		
Thyroid				F		M, F
Pancreas				M		
Testis				M	M	
Zymbal's gland			F	F		
Kidney	M		M		M	M, F
Oral Cavity						M, F

<sup>a</sup> M = males ; F = females

Source: NTP (1998); Melnick et al. (1994); Placke et al. (1996); U.S. EPA (2002b)

#### 4.6. SYNTHESIS OF MAJOR NONCANCER EFFECTS

9 There is a limited body of information on the toxicological consequences to humans who are  
 10 exposed to chloroprene. In a summary by Nystrom (1948), chloroprene was reported to cause  
 11 respiratory, eye, and skin irritation, chest pains, temporary hair loss, dizziness, insomnia headache, and  
 12 fatigue in occupationally exposed workers. Chest pains accompanied by tachycardia and dyspnea  
 13 were also reported. In a Russian review (Sanotskii, 1976) of the effects of chloroprene, medical  
 14 examinations of chloroprene production workers revealed changes in the nervous system (lengthening  
 15 of sensorimotor response to visual cues and increased olfactory thresholds), cardiovascular system

1 (muffled heart sounds, reduced arterial pressure, and tachycardia), and hematology (reduction in RBC  
2 counts, decreased hemoglobin levels, erythrocytopenia, leucopenia, and thrombocytopenia). The  
3 ambient concentration of chloroprene in work areas ranged from 1–7 mg/m<sup>3</sup> (3.6–25 ppm).

#### 4.6.1. Animal Studies

##### 4.6.1.1. Oral Exposure

4 Chloroprene's toxic potential by the oral route has been assessed in only one study  
5 (Ponomarev and Tomatis, 1980). This was a reproductive study involving exposure of BDIV rats to a  
6 single dose (100 mg/kg) of chloroprene on the 17<sup>th</sup> day of pregnancy and of their progeny to weekly  
7 doses (50 mg/kg) for 120 weeks. Animals treated with chloroprene that died within the first 30 weeks  
8 of treatment showed severe congestion of the lungs and kidneys.

##### 4.6.1.2. Inhalation Exposure

9 The database for inhalation toxicity studies in animals on chloroprene includes two range-  
10 finding studies for 16 days and 13 weeks (NTP, 1998 [also reported by Melnick et al., 1999]), two  
11 chronic inhalation bioassays (NTP, 1998 [also reported by Melnick et al., 1999]; Trochimowicz et al.,  
12 1998) and four reproductive developmental studies (Mast et al., 1994; Culik et al., 1978; Appelman  
13 and Dreef van der Meulen, 1979; Sanotskii, 1976). These studies associate chloroprene inhalation  
14 exposure with respiratory, kidney, liver, spleen, forestomach, reproductive, and developmental effects.

15 Inhalation exposure for 16 days (first range-finding study for the NTP [1998] chronic bioassay)  
16 to chloroprene was associated with a range of effects. In rats, there were increased mortality at the  
17 high exposure concentration (500 ppm) and decreased body weight starting at 200 ppm. Minimal to  
18 mild olfactory epithelial degeneration was observed in all exposed groups (males and females). Mild  
19 to moderate centrilobular hepatocellular necrosis was observed in male and female rats exposed to 200  
20 or 500 ppm. Hematological and clinical chemistry parameters indicated increased serum enzyme  
21 (ALT, GDH, and SDH) activities, as well as anemia and thrombocytopenia (decreased platelet count)  
22 in the 200 and 500 ppm groups on day 4 only. In females, significant increases in kidney weights  
23 (right kidney only) were seen at 80 and 500 ppm, and significantly increased liver weights were seen at  
24 200 and 500 ppm.

25 In mice, all male and female animals in the high-exposure (200 ppm) group died, exhibiting  
26 signs of narcosis, hepatocellular and thymic necrosis, and hypertrophy of the myocardium.  
27 Significantly decreased body weight gains were seen in males at 32 and 80 ppm. There were no other  
28 clinical findings related to chloroprene exposure in the mouse.

29 In the second (13-week) range-finding study, inhalation to chloroprene was associated with a  
30 range of effects across several organ systems. In rats, on day 2, minimal increases in hematocrit values,  
31 hemoglobin concentrations, and erythrocyte counts occurred in males exposed to 32 ppm or higher and



1 in females exposed to 200 ppm. At week 13, male and female rats in the 200 ppm group demonstrated  
2 decreased hematocrit values, decreased hemoglobin concentrations, and decreased erythrocyte counts  
3 characterized as normocytic, normochromic anemia. Thrombocytopenia, evidenced by a reduction in  
4 circulating platelet numbers, occurred in the male and female rats in the 200 ppm group on day 2 and  
5 in the females at 80 and 200 ppm on day 22. Transient increases in platelet numbers were observed at  
6 80 and 200 ppm in treated males and females. Transient increases in activities of serum enzymes  
7 (ALT, GDH, and SDH) were also observed on day 22 in both sexes at 200 ppm. Alkaline phosphatase  
8 enzymeuria was observed in males at  $\geq 32$  ppm and in females at 200 ppm. In male rats proteinuria  
9 was observed at 200 ppm. Reductions in liver NPSH levels were observed in both sexes of rats at 200  
10 ppm. Nonprotein sulfhydryl concentrations were also reduced in the lungs of female rats at 200 ppm.  
11 Increases in kidney weights were seen in both male and female rats at 200 ppm and in females at 80  
12 ppm. In male rats, sperm motility was decreased at 200 ppm. Of the neurobehavioral parameters  
13 tested, horizontal activity was increased in male rats exposed to  $\geq 32$  ppm. Total activity was  
14 increased in male rats at 32 and 200 ppm. There were no exposure-related effects on motor activity,  
15 forelimb/hind-limb grip strength, or startle response.

16 Increased incidences of minimal to mild olfactory epithelial degeneration and respiratory  
17 metaplasia occurred in male and female rats at 80 or 200 ppm. Olfactory epithelial degeneration was  
18 observed in females at 32 ppm. The incidence of hepatocellular necrosis was increased in female rats  
19 at 200 ppm. Variably sized aggregates of yellow or brown material, consistent with hemosiderin  
20 accumulation, appeared in small vessels or lymphatics in or near portal triads or in Kupffer cells of  
21 male and female rats exposed to 200 ppm.

22 In mice, the hematological changes were similar to those observed in rats; however, they were  
23 less severe. Minimal anemia, including decreased hematocrit values, erythrocyte counts, and platelet  
24 counts were observed in females at 32 and 80 ppm. Sperm morphology and vaginal cytology  
25 parameters were similar to those of the chamber controls. Significantly increased incidences of  
26 squamous epithelial hyperplasia of the forestomach were observed in male and female mice at 80 ppm.

27 Exposure to chloroprene for 2 years (NTP, 1998) was associated with effects to the respiratory  
28 tract (lung and nose) in rats and mice. The forestomach was also a target for chloroprene-induced  
29 effects in mice.

30 In rats, the incidences of atrophy, basal cell hyperplasia, metaplasia, and necrosis of the  
31 olfactory epithelium in males and females were increased at 32 and 80 ppm; atrophy and necrosis were  
32 also increased in males at 12.8 ppm. The incidence of chronic inflammation was increased in males  
33 exposed to 12.8 ppm and greater and in females exposed to 80 ppm. The incidences of fibrosis and  
34 adenomatous hyperplasia of the olfactory epithelium were increased in males and females at 80 ppm.  
35 The incidence of alveolar/bronchiolar hyperplasia was statistically significantly increased in males and  
36 females in every exposure group.

1 In mice, there was increased mortality in males at 32 or 80 ppm and in females at all  
2 concentrations tested. A decrease in mean body weights was observed in females at 80 ppm. Increases  
3 in the incidences of olfactory epithelial atrophy, adenomatous hyperplasia, and metaplasia were  
4 observed in males and females at 80 ppm. An increase in the incidence of forestomach epithelial  
5 hyperplasia was observed at 80 ppm. Bronchiolar hyperplasia was increased in males and females at  
6 doses 12.8 ppm and greater, whereas pulmonary histiocytic cellular infiltration was increased in every  
7 dose group in females only. Hematopoietic cell proliferation was increased in males at 12.8 ppm and  
8 greater. Renal tubule hyperplasia was observed in males at 32 and 80 ppm.

9 In the study by Trochimowicz et al. (1998), the only remarkable nonneoplastic lesions in rats  
10 were observed in liver and lungs. The number of rats with one or more small foci of cellular alteration  
11 in the liver was higher in the 50 ppm group than in controls. In males, there was an increased  
12 incidence of hepatocellular lesions described as one or several small clear cell foci in the 50 ppm  
13 group. Mild changes, such as lymphoid aggregates around bronchi, bronchioles, and blood vessels,  
14 were observed in males and females exposed to 50 ppm. Acute inflammatory processes in the lungs  
15 were found in the 50 ppm group and control animals to a similar extent. In hamsters, the only  
16 exposure-related effect was a generalized amyloidosis (liver, kidney, spleen, and adrenal glands) that  
17 was lower in incidence in the 50 ppm exposed group compared with controls.

18 Culik et al. (1978) exposed pregnant rats by inhalation to chloroprene at 0, 1, 10, or 25 ppm 4  
19 hours/day on days 1–12 (embryotoxicity study) or days 3–20 (teratology study). In the teratology  
20 study, an increase in the percentage of litters with resorptions was observed at 10 and 25 ppm, with  
21 only the change in the 10 ppm group achieving statistical significance ( $p \leq 0.05$ ) relative to controls.  
22 An increase in the percentage of litters with resorptions was not observed by Culik et al. (1978) in the  
23 larger embryotoxicity portion of the study, which was specifically designed to detect such effects. The  
24 equally high numbers of litters with resorptions (~50%) in all experimental groups, including controls,  
25 in the embryotoxicity study correspond well to the level of response observed at 10 ppm and 25 ppm in  
26 the teratology study (62% and 59%, respectively). The observation that the control rates of litters with  
27 resorptions differ so much between the teratology and embryotoxicity portions of the Culik et al.  
28 (1978) warrants further consideration. When the potential increase in resorptions is expressed in  
29 numbers of resorbed fetuses per litter, the control group for the teratology study is the only exposure  
30 group which falls far outside of the historical control range for this strain of rat (Charles Rivers  
31 Laboratories, 1976). This suggests that the control group response in the teratology study may be a  
32 statistical outlier and that the finding of a statistically significant increase of litters with resorptions at  
33 10 ppm is spurious. Chloroprene exposure did result in statistically significant increases in average  
34 body weight of fetuses in the 25 ppm group ( $p < 0.05$ ) and in the length of fetuses from dams in the 10  
35 and 25 ppm groups ( $p < 0.05$ ). No major compound-induced or dose-related skeletal or soft tissue  
36 anomalies were found.

1 Mast et al. (1994) exposed groups of 15-16 pregnant New Zealand white rabbits by inhalation  
2 to 10, 40, or 175 ppm chloroprene (36.2, 144.8, or 633.5 mg/m<sup>3</sup>) for 6 hours/day on gestational days  
3 6-28. There were no signs of maternal toxicity due to exposure to chloroprene. A few dams in each  
4 group exhibited nasal discharge, vaginal bleeding, and loose stools at various times during the  
5 exposure period. The overall pregnancy rate was 89%, with a range of 80-94% for each exposure  
6 group. The incidence of clinical signs of toxicity was low during the exposure, and dams appeared to  
7 be in excellent health at termination. No exposure-related effects on maternal weight change were  
8 noted. Exposure to chloroprene had no effect on the number of implantations, live pups, or  
9 resorptions. Fetal body, liver, and kidney weights were not affected by exposure. The incidence of  
10 fetal malformations was not affected by exposure to chloroprene.

11 Appelman and Dreef van der Meulen (1979, unpublished report) exposed two successive  
12 generations (F<sub>0</sub> or F<sub>1</sub>) of Wistar rats to 0, 10, 33, or 100 ppm (0, 36.2, 119.5, or 362 mg/m<sup>3</sup>)  
13 chloroprene via inhalation. The F<sub>0</sub> generation was exposed for 13 weeks and then allowed to mate  
14 with untreated animals. After weaning, the F<sub>1</sub> was exposed for an additional 10 weeks. There were  
15 statistically significant decreases in body weight reported in the F<sub>0</sub> animals, however, concurrent food  
16 consumption data was not reported and the authors report that the observed decreases were most likely  
17 related to inadequacies in food availability. There were no reported effects on resorptions, sex ratio,  
18 or mortality during lactation, although F<sub>1</sub> pups from treated females had reduced body weights at birth  
19 and weaning compared to controls. The exposed F<sub>1</sub> rats also had decreased body weights relative to  
20 controls, but as with the F<sub>0</sub> animals, no concurrent food consumption data were available to assess  
21 whether those decreases were treatment-related. Exposed F<sub>1</sub> males had significantly smaller testes and  
22 females had larger ovaries, livers, and lungs compared to controls, but no histopathological changes  
23 were observed in those organs.

24 The general lack of effects in the Mast et al. (1994), Culik et al. (1978) and Appelman and  
25 Dreef van der Meulen (1979) studies are not consistent with the many positive effects seen in previous  
26 Russian studies reviewed in Sanotskii (1976). Similar to other conflicting results in the chloroprene  
27 toxicity database, the differences in the results in the reproductive and developmental studies may be  
28 attributed to the purity of the test substance, differences in the species and strains used, and  
29 experimental design and parameters evaluated in the individual studies.

#### 4.7. EVALUATION OF CARCINOGENICITY

30 Under the *Guidelines for Carcinogen Risk Assessment* (U.S. EPA, 2005a), there is evidence that  
31 chloroprene is “likely to be carcinogenic to humans” based on (1) statistically significant and dose-  
32 related information from an NTP (1998) chronic inhalation bioassay demonstrating the early  
33 appearance of tumors, development of malignant tumors, and the occurrence of multiple tumors within  
34 and across animal species; (2) evidence of an association between liver cancer risk and occupational  
35 exposure to chloroprene; (3) some evidence of an association between lung cancer risk and

1 occupational exposure; (4) the proposed mutagenic mode of action; and (5) structural similarities  
2 between chloroprene and known human carcinogens, butadiene and vinyl chloride (see Table 4-38).

3 U.S. EPA's *Guidelines for Carcinogen Risk Assessment* (2005a) indicate that for tumors  
4 occurring at a site other than the initial point of contact, the weight of evidence for carcinogenic  
5 potential may apply to all routes of exposure that have not been adequately tested at sufficient doses.  
6 An exception occurs when there is convincing toxicokinetic data that absorption does not occur by  
7 other routes. Information available on the carcinogenic effects of chloroprene via the inhalation route  
8 demonstrates that tumors occur in tissues remote from the site of absorption. Information on the  
9 carcinogenic effects of chloroprene via the oral and dermal routes in humans or animals is limited or  
10 absent. Data regarding the absorption via any route of exposure are unavailable. However, based on  
11 the observance of systemic tumors following inhalation exposure, and in the absence of information to  
12 indicate otherwise, it is assumed that an internal dose will be achieved regardless of the route of  
13 exposure. Therefore, chloroprene is considered "likely to be carcinogenic to humans" by all routes of  
14 exposure.

#### 4.7.1. Summary of Overall Weight of Evidence

15 According to NTP (1998), there is clear evidence of carcinogenicity in the F344/N rat and  
16 B6C3F1 mouse due to lifetime inhalation exposure to chloroprene. In rats, increased incidences of  
17 neoplastic lesions primarily occurred in the oral cavity and lung (males only), kidney, and mammary  
18 gland (females). In mice, increased incidences in neoplasms occurred in the lungs, circulatory system  
19 (all organs), Harderian gland, forestomach, liver, skin and mesentery (females only), and kidney  
20 (males only).

21 In the current document, a total of nine studies covering 11 cohorts of human subjects exposed to  
22 chloroprene were reviewed to assess the occurrence of cancer. The most consistent findings across the  
23 database were excess cancers of the liver (Bulbulyan et al., 1999, 1998; Li et al., 1989; Leet and  
24 Selevan, 1982) and lung (Marsh et al., 2007b; Colonna and Laydevant, 2001; Bulbulyan et al., 1999,  
25 1998; Leet and Selevan, 1982; Pell, 1978). The epidemiologic evidence for increased lung cancer  
26 mortality due to chloroprene exposures is limited. The few studies that reported increased risk were  
27 not statistically significant. In addition to lack of a consistent association and the small increased risks  
28 that were detected, other study limitations, such as lack of smoking data, limit the ability to determine  
29 possible causal associations between lung cancer and humans exposed occupationally to chloroprene  
30 based on the available data.

**Table 4-38. Summary of animal and human tumor data and weight of evidence descriptor for chloroprene**

<p><b>Statistically Significant Tumor Types</b></p>	<ul style="list-style-type: none"> <li>• In male F344/n rats, increased incidence of kidney (renal tubule) adenoma or carcinoma in all dose groups, and oral papilloma or carcinoma and thyroid adenoma or carcinoma at the two highest dose groups</li> <li>• In female F344/n rats, increased incidence of mammary fibroadenoma at the two highest dose groups and oral papilloma or carcinoma at the highest dose</li> <li>• In male B6C3F1 mice, increased incidence of lung adenoma or carcinoma and hemangioma/hemangiosarcoma in all organs in all dose groups, and harderian gland adenoma or carcinoma and kidney (renal tubule) adenoma or carcinoma at the two highest dose groups</li> <li>• In female male B6C3F1 mice, increased incidence of lung adenoma or carcinoma and skin sarcoma in all dose groups, liver adenoma or carcinoma at the two highest dose groups, and harderian gland adenoma or carcinoma and mammary gland fibroadenomas at the highest dose. Hemangiomas/hemangiosarcomas in all organs and mesentery sarcomas were observed in the middle dose.</li> <li>• In humans, significant increases in liver cancer mortality were observed in 4 occupational epidemiology studies (out of 9 total studies). Relative risk estimates for liver cancer (while not statistically significant) increased with increasing exposure, indicating a dose-response trend.</li> </ul>
<p><b>Rare Tumors</b></p>	<ul style="list-style-type: none"> <li>• Statistically significant increase in rare kidney (renal tubule) adenoma in male rats and mice. Non-statistical increase in females at the high dose.</li> <li>• Statistically significant increases in primary (assumed) liver cancer in four cohort studies and lung cancer mortality in two studies in workers occupationally exposed to chloroprene</li> </ul>
<p><b>Multiple Studies</b></p>	<ul style="list-style-type: none"> <li>• Animals – NTP (1998)</li> <li>• Humans – Leet and Sullivan (1982), Li et al. (1989), Bulbulyan et al. (1989), and Bulbulyan et al. (1999)</li> </ul>
<p><b>Conclusions</b></p>	<ul style="list-style-type: none"> <li>• Tumors in both sexes of rats and mice</li> <li>• Decreased time to tumor in both sexes of rats and mice</li> <li>• Tumors in occupationally exposed workers</li> <li>• Methodological limitations of the occupational epidemiology studies (e.g., no available data for some potential confounders which precluded adjustment, limited statistical power due to small sample sizes, and lack of precise quantitative exposure ascertainment) make it difficult to draw firm conclusions regarding the human cancer data</li> <li>• Rare tumors (kidney renal tubule adenomas in animals, primary liver cancer in humans)</li> <li>• Metabolites include DNA-reactive epoxides and a mutagenic mode of action is proposed.</li> </ul>
<p><b>Weight of Evidence characterization</b></p>	<ul style="list-style-type: none"> <li>• Likely to be carcinogenic to humans</li> </ul>

---

1           There was a statistically significant excess of liver cancers in four of the cohorts reviewed  
2 (Bulbulyan et al., 1999, 1998; Li et al., 1989; Leet and Selevan, 1982), with a two- to more than five-  
3 fold increased risk in the SMR seen among these studies. Although no statistically significant increase  
4 in risk of liver cancer was detected in the most recent and comprehensive cohort study involving  
5 workers at four plants (Marsh et al., 2007b), the observed RR increased with increasing cumulative  
6 exposure in the plant with the highest exposure levels, indicating a dose-response trend. Similar to the  
7 Colonna and Laydevant (2001) study, there was only one case of liver cancer in the other three plants  
8 included in this study (Marsh et al., 2007a, 2007b). Limitations in the existing epidemiological  
9 database included the lack of information on individual workers' habits (i.e., alcohol consumption)  
10 needed to control for potential confounding, incomplete enumeration of incidence and mortality cases,  
11 and potential for biases that may lead to an underestimation of the risk (e.g., the healthy worker effect).  
12 These limitations are further discussed in Section 4.7.2.1.

#### **4.7.2. Synthesis of Human, Animal, and Other Supporting Evidence**

##### **4.7.2.1. *Human***

13           A number of occupational cohort studies have examined cancer mortality and incidence among  
14 workers exposed to chloroprene monomer and/or polychloroprene latex in the United States, Russia  
15 (Moscow), Armenia, France, China, and Ireland (Marsh et al., 2007a, 2007b; Colonna and Laydevant,  
16 2001; Bulbulyan et al., 1999, 1998; Romazini et al., 1992; Li et al., 1989; Leet and Selevan, 1982; and  
17 Pell, 1978). Concern that exposure to chloroprene may result in liver cancer derives principally from  
18 its structural similarity to vinyl chloride, a chemical known to cause liver angiosarcoma in humans.  
19 Exposed workers have included those involved in chloroprene monomer production using both the  
20 acetylene process in which exposure to vinyl chloride was possible and the more recent butadiene  
21 process which does not involve vinyl chloride exposure. Other workers were involved with  
22 handling/sampling of partially finished products such as polychloroprene latex which contains various  
23 amounts of dissolved monomer. Some studies span eras in which little or no worker safety protection  
24 measures were likely used in contrast with years in which process improvements and concern for  
25 worker safety were gradually instituted. Therefore, it is difficult to compare results across studies  
26 given a wide range of exposure variability within and between these cohorts.

27           Despite these differences in occupational exposure to chloroprene and other chemicals, four of  
28 the cohorts with observed liver/biliary passage cancer cases showed statistically significant  
29 associations (i.e., two- to five-fold increased risk) with chloroprene exposure. Four mortality studies  
30 reported SMRs of 571, 482, 240, and 339 when compared to external populations (Bulbulyan et al.,  
31 1999, 1998; Li et al, 1989; and Leet and Selevan, 1982). Although sample size and statistical power  
32 were limited (thus limiting the precision of risk estimates), Bulbulyan et al. (1999, 1998) observed

1 significantly elevated relative risk estimates for liver cancer incidence and mortality among  
2 intermediate and highly exposed workers. The study involving four plants by Marsh et al. (2007b),  
3 which had the largest sample size and most extensive exposure assessment, also observed increased  
4 relative risk estimates for liver cancer in relation to cumulative exposure in the plant with the highest  
5 exposure levels (trend p-value = 0.09, RRs 1.0, 1.90, 5.10, and 3.33 across quartiles of exposure, based  
6 on 17 total cases). Although not statistically significant, these findings were comparable to results (RR  
7 range: 2.9-7.1) detected in two other studies for high and intermediate cumulative exposures  
8 (Bulbulyan et al., 1999, 1998). Though several studies noted higher SMRs for lung cancer among  
9 workers exposed to chloroprene, the evidence was not considered as strong as liver cancer. This was  
10 mostly due to the inability to adequately control for confounding by smoking status, a strong risk  
11 factor for lung cancer. There was also no evidence of exposure-response relationship across various  
12 chloroprene exposure categories.

13 One of the strengths of several of the more recent epidemiologic studies was improved  
14 exposure assessment data. These studies utilized industrial hygiene information to determine which  
15 areas or jobs were most likely to have received higher chloroprene exposures. This allowed for  
16 examination of various exposure contrasts and helped reduce the potential for exposure  
17 misclassification. As such, valid internal analyses were conducted which were less impacted by bias  
18 due to the healthy worker effect. Despite these improvements, several study limitations added to the  
19 uncertainty in addressing the weight of evidence of the epidemiologic data.

20 A key limitation of most of the chloroprene studies (and other occupational studies) is the  
21 potential for bias due to the healthy worker effect. Although this may be less of a concern for cancer  
22 mortality outcomes, SMR analyses are based on external comparisons to the general population and  
23 will often result in reduced SMR values for the occupational cohort. Two studies with more advanced  
24 chloroprene exposure assessment conducted internal analyses to reduce this source of bias (Bulbulyan  
25 et al., 1999; Marsh et al., 2007b). Among these studies, only Bulbulyan et al. (1999) observed a  
26 statistically significant association between chloroprene exposure and liver cancer mortality. As with  
27 most epidemiological research, the potential for bias due to residual confounding is another limitation  
28 that exists in these studies. With respect to liver cancer, the lack of data on alcohol consumption is a  
29 key limitation which precludes its examination, although there is no direct evidence that alcohol is  
30 related to the exposure of interest (i.e., chloroprene). Given the nature of the work environment for  
31 most of the study participants in these occupational studies, there is also a high likelihood of co-  
32 exposures which may be confounders. Despite this potential, there is little evidence of substantial  
33 exposure to liver carcinogens in these populations. One study with data on a co-exposure (vinyl  
34 chloride) reported evidence of negative confounding (Marsh et al., 2007b). This would result in an  
35 underestimate of the reported association between chloroprene and liver cancer if adjusted for vinyl  
36 chloride which suggests that this co-exposure was unlikely to explain the association observed  
37 between chloroprene and liver cancer in that population.

1 An additional limitation in several studies was incomplete enumeration of both incident cases  
2 and deaths. In some studies, there were many workers who were exposed during time periods when  
3 chloroprene levels were relatively high who could not be identified or located for inclusion in the  
4 studies. This raises the possibility that the actual number of liver cancer cases might have been higher  
5 than indicated from the data on the subset of individuals that were included in the studies. Another  
6 concern in these occupational studies is the reliance on death certificates for outcome ascertainment in  
7 the mortality analyses. Although misclassification of cause of death can be minimized by the review of  
8 medical records or by histological confirmation, this was not done in any of the studies. The lack of  
9 histological review of the liver cancer cases is an important limitation of the available studies using  
10 internal controls.

11 These epidemiologic study results, when examined in the context of different plant operating  
12 and worker exposure conditions over different time periods and a low number of incident liver cancers,  
13 offer evidence of an association for exposure to chloroprene with an increase of liver cancer in  
14 humans. Despite various limitations (e.g., healthy worker bias, potential co-exposure, and incomplete  
15 enumeration of cases), internal and external comparisons showed consistent evidence of an association  
16 between chloroprene exposures and liver cancer. The associations detected in some studies add  
17 support to the cancer weight of evidence determination.

#### 4.7.2.1.1. Evidence for Causality

18 The evidence for causality for cancer from the human studies is summarized in the paragraphs  
19 that follow and is based on recommendations from the EPA (2005a) guidelines for carcinogen risk  
20 assessment. It should be noted that there exists a number of methodological limitations of the  
21 epidemiologic studies that may preclude drawing firm conclusions regarding the following criteria.  
22 These limitations include lack of control of personal confounders and risk factors associated with the  
23 outcomes in question, imprecise exposure ascertainment resulting in crude exposure categories,  
24 incorrect enumeration of cases leading to misclassification errors, limited sample sizes, and the healthy  
25 worker effect.

26 **Temporality** – exposure must precede the effect for causal inference. Furthermore, and  
27 particularly with cancers, exposure must precede the effect with a sufficient latency to be considered  
28 causal. In all the occupational studies reviewed the chloroprene exposure has preceded effect (either  
29 incidence of or mortality due to liver cancer) with sufficient latency to be considered causally  
30 associated. Several of the studies have specifically evaluated latencies of 15 to 20 years (Marsh et al.,  
31 2007a, 2007b; Colonna and Laydevant, 2001; Bulbulyan et al., 1998; and Pell, 1978).

32 **Strength of Association** – refers to the magnitude of measures of association such as the ratio  
33 of incidence or mortality (e.g., SMRs, SIRs, RRs or odds ratios) irrespective of statistical significance.  
34 Studies reporting large, precise risks are less likely to be doing so due to chance, bias, or confounding.  
35 Reports of modest risk, however, do not preclude a causal association and may reflect lower levels of



1 exposure or an agent of lower potency. When compared to external populations, there was a  
2 statistically significant two- to five-fold increased risk of liver cancer in four cohort studies in China (Li  
3 et al, 1989), United States (Leet and Selevan, 1982), Russia (Bulbulyan et al., 1998) and Armenia  
4 (Bulbulyan et al., 1999) despite evidence of healthy worker effect bias. Despite relatively small  
5 numbers, there were also suggestive data from the Louisville cohort (Marsh et al., 2007b) which found  
6 RRs ranging from 1.9-5.1 (not statistically significant) for cumulative exposures to chloroprene and  
7 liver cancer mortality. These data were consistent in magnitude to two other studies (Bulbulyan et al.  
8 1999, 1998) examining intermediate and high cumulative exposures to chloroprene and liver cancer  
9 incidence (RRs = 2.9-4.9, statistically significant) and mortality (RRs = 4.4-7.1, not statistically  
10 significant), respectively.

11 **Consistency** – the observation of the same site-specific effect across several independent study  
12 populations strengthens an inference of causality. Four different studies have shown an association  
13 between chloroprene exposure and liver cancer incidence and mortality (Bulbulyan et al. 1998, 1999;  
14 Li et al., 1989; Leet and Selevan, 1982), while a fifth study showed evidence suggesting an association  
15 when examined in relation to detailed exposure data (Marsh et al, 2007b). Larger effect estimates for  
16 liver cancer risk have been observed in diverse populations working in chloroprene monomer and  
17 polymer production, neoprene manufacturing, and manufacturing utilizing polychloroprene products in  
18 the U.S., China, Armenia, and Russia. The studies with internal comparisons showed consistently  
19 elevated liver cancer relative risk estimates for intermediate (RR range: 2.9-7.1) and high cumulative  
20 risk exposures (Range: 3.3-4.9) as noted above.

21 **Specificity** – as originally intended, this refers to increased inference of causation if a single  
22 site effect as opposed to multiple effects is observed and associated with exposure. Based on current  
23 understanding, this is now considered one of the weaker guidelines for causality (for example, many  
24 agents cause respiratory disease and respiratory disease has multiple causes). However, when  
25 specificity of effect is found, it strengthens causal inference. Chloroprene exposure has been found to  
26 be associated specifically with increased risk of liver cancer in four cohorts (Bulbulyan et al. 1998,  
27 1999; Li et al., 1989; Leet and Selevan, 1982).

28 **Biological Gradient** – refers to the presence of a dose-response and/or duration-response  
29 between a health outcome and exposure of interest. The aforementioned internal analyses for  
30 chloroprene (Bulbulyan et al., 1999; Marsh et al., 2007b) show a biological gradient by comparing  
31 highly exposed workers to low or unexposed workers. This has also been observed in comparisons  
32 between long-term employees and short-term employees

33 **Biological Plausibility** – refers to the observed effect having some biological link to the  
34 exposure. Chloroprene has been found to be metabolized by humans and other species to epoxides,  
35 which are known genotoxic metabolites, and has been shown to be a potent (early appearance,  
36 multiplicity, malignancy of observed tumors) carcinogen in mice and rats. In addition, the structurally

1 related carcinogen, butadiene, is also metabolized to epoxides and produces a tumor profile resembling  
2 that observed with chloroprene.

3 In summary, the temporality of exposure prior to occurrence of liver cancer, strength of  
4 association, consistency, biological gradient, and biological plausibility provide some evidence for  
5 chloroprene's carcinogenicity in humans.

#### 4.7.2.2. *Laboratory Animal*

6 According to the NTP (1998), there is clear evidence of carcinogenicity in the F344/N rat and  
7 B6C3F1 mouse due to lifetime inhalation exposure to chloroprene. The mouse is regarded as the most  
8 sensitive species because tumor incidence and multisite distribution were greater than with the rat.  
9 There was decreased survival in chloroprene-exposed rats and mice, and survival in mice was  
10 significantly associated with the burden of neoplastic lesions. Mortality in rats was likely due to overt  
11 toxicity across many organ systems. In rats, increased incidences of neoplastic lesions primarily  
12 occurred in the oral cavity and lung (males only), kidney, and mammary gland (females). In mice,  
13 increased incidences in neoplasms occurred in the lungs, circulatory system (all organ, Harderian  
14 gland, forestomach, liver, skin and mesentery (females only), and kidney (males only). In contrast to  
15 the neoplastic findings in the F334/N rat, only small numbers of neoplastic lesions were observed in  
16 Wistar rats or Syrian golden hamsters (Trochimowicz et al., 1998). There is no unequivocal  
17 explanation for why the results for the rat differ between these two studies. The stability of the bulk  
18 material in the NTP (1998) study was monitored by gas chromatography, and the material was  
19 analyzed for peroxide content. In addition, stabilizer concentrations were in an acceptable range and  
20 no dimer peaks were found in the distribution lines leading to the exposure chamber. Concentrations  
21 of volatile degradation products (e.g., 1-chlorobutadiene) never exceeded 0.6% of the atmospheric  
22 concentration of chloroprene when sampled from either the distribution line or exposure chamber. In  
23 the study in the Wistar rat by Trochimowicz et al. (1998), there was no evidence of degradation of the  
24 freshly distilled chloroprene, and dimer concentrations were stated to be less than the limit of  
25 detection. Thus, it is unlikely that the bulk materials or generated atmospheres differed to an extent  
26 that would have caused the differences in results. The discrepancy between the carcinogenicity of  
27 chloroprene observed in the two studies may be due to species and/or strain differences. Himmelstein  
28 et al. (2001b) observed that liver microsomes from B6C3F1 mice and the F344 rats, the two species  
29 used in the NTP (1998) study, produced more (1-chloroethenyl)oxirane than those from hamsters or  
30 Wistar rats, the two species used in the Trochimowicz et al. (1998) study. These differences in  
31 production of (1-chloroethenyl)oxirane were as great as 15-fold greater (F344 rats vs. hamsters).

32 The inhalation study by Dong et al. (1989) found that a 7-month exposure of the Kunming  
33 strain of albino mice, a strain reported to have a low spontaneous rate of lung tumor formation,  
34 resulted in a chloroprene-associated increase in lung tumors. Although quality assurance procedures

1 regarding histopathology were not reported, these study results are considered to support the findings  
2 in the B6C3F1 mice in the NTP (1998) chronic bioassay.

3 In the only long-term oral cancer study (an F1 generation of inbred BD IV rats given weekly  
4 doses of 50 mg/kg chloroprene by gavage), no significant neoplastic effects were reported  
5 (Ponomarkov and Tomatis, 1980). The number of tumor-bearing animals was similar to controls.

### 4.7.3. Mode-of-Action Information

#### 4.7.3.1. Hypothesized Mode of Action

6 The proposed hypothesis is that chloroprene acts via a mutagenic mode of action involving  
7 reactive epoxide metabolites formed at target sites. DNA-epoxide adduct formation is an effect  
8 observed for a number of carcinogens structurally related to chloroprene, including those with a known  
9 mutagenic mode of action (i.e., vinyl chloride; EPA, 2005b, 2000f) and those for which a  
10 preponderance of evidence strongly suggests a mutagenic mode of action (i.e., isoprene and 1,3-  
11 butadiene) (Begemann et al., 2004; EPA, 2002b; Sills et al., 1999). This hypothesized mode of action  
12 is presumed to apply to all tumor types. Mutagenicity is a well-established cause of carcinogenicity.

#### 4.7.3.2. Experimental Support for the Hypothesized Mode of Action

13 Compelling evidence for the hypothesized mutagenic mode of action for chloroprene includes:  
14 1) chloroprene, like butadiene and isoprene, is metabolized to epoxide intermediates and both  
15 compounds are carcinogens; 2) chloroprene forms DNA adducts via its epoxide metabolite, and is a  
16 point mutagen in vitro (in some but not all bacterial assays) and in vivo (in carcinogenicity bioassays,  
17 with mutations occurring in proto-oncogenes); 3) observation of the genetic alterations (base-pair  
18 transversions) in proto-oncogenes in chloroprene-induced lung, Harderian gland, and forestomach  
19 neoplasms in mice and positive results in *Salmonella typhimurium* strains that test for base-pair  
20 substitution mutations ; and 4) similarities in tumor sites and sensitive species between chloroprene  
21 and butadiene in chronic rodent bioassays (NTP 1998 and 1999, respectively). These lines of evidence  
22 are elaborated on below.

23 Evidence for the formation of reactive epoxide metabolites following exposure to chloroprene  
24 has been observed in both genders of multiple species. Currently, *in vivo* data are unavailable for  
25 blood or tissue-specific epoxide metabolism rates or concentrations. However, in studies using mouse  
26 and human liver microsomes, Bartsch et al. (1979) showed that 2-chloro-2-ethynylloxirane and/or  
27 (1-chloroethenyl)oxirane could be intermediates in the biotransformation of chloroprene. Himmelstein  
28 et al. (2001b) confirmed the identity of the volatile metabolite reported by Bartsch et al. (1979) as the  
29 epoxide (1-chloroethenyl)oxirane. Himmelstein et al. (2001b) reported that the oxidation of  
30 chloroprene to (1-chloroethenyl)oxirane was evident in rodent and human liver microsomes and most  
31 likely involved CYP 2E1. The oxidation of chloroprene to (1-chloroethynyl)oxirane is more prevalent

1 in B6C3F1 mice and F344 rat liver microsomes than in Wistar rats, humans, or hamsters. Comparing  
2 metabolism between species, Cottrell et al. (2001) confirmed the results of Himmelstein et al. (2001b),  
3 and further showed that the quantitative profiles of metabolites from liver microsomes obtained from  
4 mice, rats, and humans were similar. In all species and either gender, (1-chloroethynyl)oxirane was the  
5 major metabolite detected. One distinct difference between species was the stereospecificity of  
6 epoxide metabolites formed. In 2 strains of rats (Sprague-Dawley and F344), the R-enantiomer was  
7 preferentially formed, whereas this enantioselectivity was not observed in mice or humans. Hurst and  
8 Ali (2007) reported that the S-(1-chloroethynyl)oxirane enantiomer was more quickly detoxified in  
9 mouse erythrocytes than the R-enantiomer, suggesting that the R-enantiomer may be more toxic due to  
10 its slower elimination. 1,3-butadiene exhibits similar biotransformation to reactive epoxide  
11 metabolites. Oxidation of 1,3-butadiene to 1,2-epoxy-3-butene has been observed in hepatic, lung, and  
12 kidney microsomes, as well as lung tissue and bone marrow, in rats, mice, and humans (EPA, 2002b).  
13 Further oxidation of 1,2-epoxy-3-butene to 1,2,3,4-diepoxybutane has been observed rat, mouse, and  
14 human liver microsomes, as well as in blood and tissues of mice and rats exposed by inhalation to 1,3-  
15 butadiene (EPA, 2002b). Vinyl chloride and isoprene are also readily converted into their reactive  
16 epoxide metabolites; vinyl chloride is converted to chloroethylene epoxide in rats and isoprene to  
17 (2,2')-2-methylbioxirane in rats and mice (Watson et al., 2001; EPA, 2002f).

18 Chloroprene's metabolites have been shown to form DNA adducts when reacted with  
19 nucleosides and double stranded DNA in vitro. Reaction of (1-chloroethenyl)oxirane with the  
20 nucleoside 2'-deoxyguanosine yielded one major adduct derived by nucleophilic attack of N-7 guanine  
21 on C-3' of the epoxide, whereas another metabolite, 2-chlorobut-2-en-1-al, yielded 2 major adducts  
22 (Munter et al., 2002). The reaction of (1-chloroethenyl)oxirane with double stranded calf thymus DNA  
23 yield the same adduct observed when the chloroprene metabolite was incubated with  
24 2'-deoxyguanosine individually. (1-chloroethenyl)oxirane also reacted with deoxycytidine in double  
25 stranded DNA to yield an adduct which may be significant as such adducts are difficult to repair and  
26 may therefore be implicated in mutagenesis (Koskinen et al., 2000).

27 Evidence for the mutagenic potential of chloroprene has been shown in molecular analysis of  
28 the genetic alteration of cancer genes including the ras proto-oncogenes (Sills et al., 1999, 2001; Ton et  
29 al., 2007), which are alterations commonly observed in human cancers. Tissues from lung,  
30 forestomach, and Harderian gland tumors from mice exposed to chloroprene in the NTP chronic  
31 bioassay (1998) were shown to have a higher frequency of mutations in K- and H-ras proto-oncogenes  
32 than in spontaneous occurring tumors (Sills et al., 1999, 2001). Further, there was a high correlation  
33 between K-ras mutations and loss of heterozygosity in the same chromosome in chloroprene-induced  
34 lung neoplasms in mice (Ton et al., 2007). Similar increases in the frequencies of K-ras mutations in  
35 rodents were observed in isoprene-induced lung neoplasms and vinyl chloride-induced hepatocellular  
36 carcinomas (NTP, 1998; U.S. EPA, 2002f). Activated K-ras oncogenes were observed in lung tumors,  
37 hepatocellular carcinomas, and lymphomas in B6C3F1 mice exposed to 1,3-butadiene (EPA, 2002b).

1 Activated K-ras oncogenes have not been found in spontaneously occurring liver tumors or  
2 lymphomas, and are found in only 1/10 spontaneous forming lymphomas in B6C3F1 mice (EPA,  
3 2002b).

4 Although the genetic toxicity database for chloroprene includes numerous studies covering a  
5 range of standard test batteries, their results have been conflicting. In general, bacterial base pair  
6 substitution mutation (*Salmonella typhimurium* strains TA100 and TA 1535) assays have been positive  
7 (Willems 1980; Bartsch et al., 1979) while the bacterial frame shift (*S. typhimurium* strains TA 97 and  
8 TA 98) assays have been nonpositive (NTP, 1998; Willems 1980; Willems 1978). The observation of  
9 positive results in bacterial base pair substitution assays is in concordance with the finding that  
10 mutations in H- and K-ras oncogenes in select neoplasms of exposed mice manifest in base pair  
11 tranversions (Sills et al., 1999, 2001). In contrast, other studies (NTP, 1998) have reported nonpositive  
12 results for all bacterial strains. Westphal et al. (1994) suggested that decomposition products of  
13 chloroprene may be responsible for the mutagenicity seen in positive tests. Westphal et al. (1994)  
14 exposed bacteria directly to liquid chloroprene in solution and observed no increase in mutagenicity,  
15 whereas positive tests (Willem 1978, 1980; Bartsch et al., 1979) were conducted by exposure of  
16 bacteria to chloroprene in the air. Atmospheric exposures of chloroprene may result in more  
17 degradation products being formed, thereby increasing the mutagenicity of the parent compound. A  
18 positive result with all bacterial strains was observed when exposed to chloroprene's epoxide  
19 metabolite (1-chloroethenyl)oxirane in solution (Himmelstein et al., 2001).

20 Conflicting results (positive in Vogel, 1979; nonpositive in Foureman et al., 1994) have also  
21 been reported for the in vivo *Drosophila melanogaster* sex-linked lethal mutation assay. Differences  
22 observed may be due to differences in purity, strain susceptibilities, and sample size. Chloroprene has  
23 been primarily nonpositive in the in vitro micronucleus assay (Himmelstein et al., 2001; Drevon and  
24 Kuroki, 1979), in vivo chromosomal damage (NTP 1998) assay, and bone marrow micronucleus assays  
25 (NTP 1998; Shelby and Witt, 1995). The lack of genotoxic damage induced in bone marrow or blood  
26 by chloroprene suggests that the carcinogenic activity of this chemical may be site specific. The *in*  
27 *vivo* uptake of chloroprene involves a balance of reactive epoxide formation and glutathione- or  
28 epoxide hydrolase-dependent detoxification pathways. These pathways may be enhanced or more  
29 active in some tissues, thus limiting DNA damage in those tissues. Bone marrow was not a target for  
30 cancer in the chronic carcinogenicity bioassays (NTP, 1998), and the endpoints for chromosomal  
31 damage in this tissue were nonpositive. Evidence for target organ-dependent mutagenicity is further  
32 supported by the findings of K- and H-ras oncogene mutations in lung, forestomach, and Harderian  
33 gland neoplasms in B6C3F1 mice (Sills et al., 1999, 2001). However, a positive result with all  
34 bacterial strains was observed with chloroprene's epoxide intermediate (1-chloroethenyl)oxirane  
35 (Himmelstein et al., 2001).

36 A comparative analysis by Melnick and Sills (2001) has shown that chloroprene, isoprene, and  
37 butadiene share several tumor sites in rats (mammary gland, thyroid, and kidney) and mice

1 (hemangiomas and hemangiosarcomas [all organs], lung, liver, forestomach, Harderian gland, and  
2 mammary gland). Similar to butadiene, the female mouse lung was the most sensitive site of  
3 chloroprene carcinogenicity (see Section 4.5.3 and Tables 4-24 and 4-27). There are also remarkable  
4 similarities in the potency and shape of the dose response between both compounds. Detailed  
5 quantitative analysis (Melnick and Sills, 2001) has rated butadiene as being of slightly greater or equal  
6 in potency at some of the common sites of tumor induction (mammary gland and Harderian gland),  
7 and more importantly, of equal potency in the induction of the most sensitive tumor, lung neoplasms in  
8 female mice.

9 In summary, the evidence supports the hypothesized mutagenic mode of action for chloroprene  
10 . A mutagenic mode of carcinogenic action of chloroprene is supported by chloroprene's epoxide  
11 metabolite formation, DNA-adduct formation, observation of in vivo and in vitro mutagenicity, and the  
12 well known structure-activity relationship of similar epoxide-forming carcinogens. Chloroprene has  
13 been found to be metabolized to epoxides by humans and rodents. The hypothesized mutagenic mode  
14 of action is supported by evidence of base pair substitution mutations seen in H- and K-ras proto-  
15 oncogenes in chloroprene-induced lung, forestomach, and Harderian gland neoplasms observed in the  
16 NTP (1998) study.

#### 4.7.3.3 *Conclusions about the Hypothesized Mode of Action*

17 As noted above, the hypothesis is that chloroprene carcinogenicity has a mutagenic mode of  
18 action. This hypothesized mode of action is presumed to apply to all of the tumor types. The *key*  
19 *events* in the hypothesized mutagenic mode of action are metabolism to reactive epoxide intermediates  
20 followed by binding to DNA, which leading to mutation. Epoxide-forming agents are generally  
21 capable of forming DNA adducts which in turn have the potential to cause genetic damage, including  
22 mutations; mutagenicity, in turn, is a well-established cause of carcinogenicity. This chain of key  
23 events is consistent with current understanding of the biology of cancer. Further, the mutagenic mode  
24 of action hypothesis is strongly supported by analogy with another epoxide-forming compound,  
25 1,3-butadiene. In addition, alternative or additional modes of action for chloroprene carcinogenicity  
26 have not been hypothesized or have supporting evidence.

27 **Strength, Consistency, Specificity of Association** – Data from NTP (1998) and Sills et al.  
28 (1999, 2001) show codon-specific (codons 12, 13, and 61) mutations in the H- and K-ras proto-  
29 oncogenes in chloroprene-induced lung, forestomach, and Harderian gland neoplasms. The high  
30 incidence of ras proto-oncogene activation (37/46 lung, 27/27 Harderian gland, 4/7 forestomach) in  
31 tumors in treated animals, in contrast with the lower incidence of oncogene activation in spontaneously  
32 occurring tumors (25/82 lung, 15/27 Harderian gland, 4/11 forestomach), provides support for the role  
33 of mutation in the ras oncogene as a precursor to tumor formation in animals treated with chloroprene.  
34 Similar findings of ras oncogene activation for isoprene (11/11 lung, 30/30 Harderian gland, 7/10  
35 forestomach) and 1,3-butadiene (6/9 lung, 20/29 Harderian gland, 20/24 forestomach) were observed

1 in tumors from animals treated with these structurally-related compounds (Sills et al., 2001, 1999).  
2 These findings provide additional support for the importance of ras proto-oncogene activation via  
3 mutation in the carcinogenesis of chloroprene and related compounds.

4 **Dose-Response Concordance** – High frequencies of K-ras codon 61 CTA mutations were  
5 observed in lung tumors from animals exposed to the low- and mid-dose of chloroprene, but not the  
6 high dose. Similarly high frequencies of K-ras mutations were observed at all doses in Harderian  
7 gland tumors. There are a number of factors that might explain such observations. The higher  
8 frequency of mutations at lower doses in lung neoplasms may indicate the saturation of one or more  
9 metabolic pathways at higher doses or may suggest that non-ras mechanisms of genotoxicity are  
10 operating at those doses. Dose-dependent differences in the mutation profile in the lung and Harderian  
11 gland may be explained by differences in DNA-adduct formation or repair in low doses vs high doses.

12 **Temporal Relationships** – In mice exposed to chloroprene, tumors were observed in a  
13 significant fraction of the exposed animals after 2 years of exposure. DNA-adduct formation and  
14 subsequent ras mutations were most likely early mutagenic events in the development of lung,  
15 Harderian gland, and forestomach neoplasms. The observation that ras mutations occurred in benign  
16 neoplasms in these organ systems (lung and Harderian gland adenomas and forestomach papillomas) is  
17 supportive evidence of this. Additionally, in mice exposed to isoprene for 6 months and then allowed a  
18 6 month recovery period, forestomach neoplasm with ras mutations did not regress (Melnick et al.,  
19 1994). This suggests that ras mutations may have transformed forestomach epithelial cells at an early  
20 time point and that the transformed cells progressed to neoplasia even after chemical exposure had  
21 been terminated.

22 **Biological Plausibility and Coherence** – The biological plausibility of a mutagenic mode of  
23 action for chloroprene is supported by evidence of mutations leading to ras proto-oncogene activation  
24 in tumors from mice treated with chloroprene (Sills et al., 2001, 1999; NTP, 1998). These studies  
25 provide the critical link between the in vitro evidence of mutagenicity (positive results in  
26 *S. typhimurium* strains 100 and 1535 that test for point mutations) and tumor formation in a specific  
27 species. Similar findings with the structurally related chemicals 1,3-butadiene and isoprene and the  
28 lower incidence of spontaneously occurring tumors displaying ras mutations in untreated animals (Sills  
29 et al., 2001, 1999) enhance the database supporting this particular mode of action for chloroprene.

30 Additional evidence for the association between mutagenesis and tumor formation is the  
31 observation that chloroprene exposure caused tumors in a wide variety of mouse tissues, including  
32 lung, kidney, Harderian gland, mammary gland, forestomach, liver, skin, mesentery, and Zymbal's  
33 gland (NTP, 1998). Tumors were also observed in a number of rat tissues, including oral cavity,  
34 thyroid, lung, kidney, and mammary gland. Induction of tumors at multiple sites and in different  
35 species is characteristic of carcinogens acting via mutagenesis (US EPA, 2005a).

36 **Early-Life Susceptibility** – According to the *Supplemental Guidance for Assessing*  
37 *Susceptibility from Early-Life Exposures to Carcinogens* (U.S. EPA, 2005b) those exposed to

1 carcinogens with a mutagenic mode of action are assumed to have increased early-life susceptibility.  
2 Data on chloroprene are not sufficient to develop separate risk estimates for childhood exposure.  
3 There are no data comparing the carcinogenicity of chloroprene after exposure during early life with  
4 the carcinogenicity after exposure during adulthood. Exposure to chloroprene commenced at about  
5 6 weeks of age in mice and rats, and continued through adulthood in the 2-year chronic assay  
6 (NTP, 1998).

7 Therefore, because the weight of evidence supports a mutagenic mode of action for  
8 chloroprene carcinogenicity (see Section 4.7.3.2), and in the absence of chemical-specific data to  
9 evaluate differences in susceptibility, early-life susceptibility should be assumed and the age-  
10 dependent adjustment factors (ADAFs) should be applied, in accordance with the Supplemental  
11 Guidance.

12 In conclusion, *the weight of evidence supports a mutagenic mode of action for chloroprene*  
13 *carcinogenicity and application of ADAFs to address assumed early-life susceptibility.*

## 4.8. SUSCEPTIBLE POPULATIONS AND LIFE STAGES

### 4.8.1. Possible Childhood Susceptibility

14 No direct evidence has been found that indicates children are more susceptible to the toxic  
15 effects of chloroprene exposure than adults: exposures of children have not been reported and the  
16 metabolic fate of chloroprene in humans has not been sufficiently characterized. However, there are a  
17 number of issues that, when considered together, suggest that childhood may represent a lifestage with  
18 increased susceptibility to chloroprene effects.

19 There are indications of reduced metabolic capacity and elimination in children relative to  
20 adults that may be a source of susceptibility. Glutathione levels are rapidly depleted in response to in  
21 vitro (rat hepatocytes) and in vivo (Wistar rats) chloroprene exposures, suggesting a GSH-dependent  
22 detoxification pathway (Summer and Greim, 1980). Additionally, chloroprene's major metabolite, (1-  
23 chloroethenyl)oxirane, is rapidly detoxified via epoxide hydrolase-mediated hydrolysis in mouse liver  
24 microsomes (Himmelstein et al., 2001b). The levels of both epoxide hydrolase and glutathione  
25 transferase (GST) have been shown to be lower in infants than adults (Ginsberg et al., 2004). Epoxide  
26 hydrolase is active at birth, but only at 50% of adult function for as long as 2 years. Evidence,  
27 although limited, suggests that two forms of GST (GSTmu and  $\alpha_{B2}$ ) may be deficient (40-60% of adult  
28 levels) in early life. This decrement in GST activity is especially relevant as GSTmu is critical to  
29 epoxide conjugation to glutathione. Therefore, as both epoxide hydrolase and certain forms of GST  
30 exhibit decreased activity in early life, newborns and young infants may experience higher and more  
31 persistent blood concentrations of chloroprene and/or its metabolite than adults at similar dose levels.  
32 Compensating mechanisms (i.e., other GST isozymes such as GSTpi) may be active in early life.  
33 Reduced renal clearance in children may be another important source of potential susceptibility.



1 Excretion of chloroprene in exposed rats occurs through the elimination of urinary thioesters  
2 (presumably glutathione conjugates) (Summer and Greim, 1980). Data indicating reduced renal  
3 clearance for infants up to 2 months of age may suggest a potential to affect chloroprene excretion,  
4 thus prolonging its toxic effects.

5 Further, a mutagenic mode of action is proposed for chloroprene's observed carcinogenicity  
6 (See Section 4.7.3). In the absence of chemical-specific data to evaluate the differences between  
7 adults and children, chemicals with such a mode of action are assumed to have increased early-life  
8 susceptibility and age-dependent adjustment factors (ADAFs) should be applied, in accordance with  
9 EPA's *Supplemental Guidance for Assessing Susceptibility From Early-Life Exposure to Carcinogens*  
10 (U.S. EPA, 2005b).

#### **4.8.2. Possible Gender Differences**

11 In lifetime studies conducted in the rat, mouse, and hamster, chloroprene was not shown to  
12 exhibit any remarkable gender-related differences in effects with the exception of a more pronounced  
13 neoplastic response in B6C3F1 female mice compared to males.

## 5. DOSE-RESPONSE ASSESSMENTS

### 5.1. ORAL REFERENCE DOSE (RfD)

1           The available data are inadequate to derive an oral RfD for chloroprene. There are no human  
2 data involving oral exposure. The only lifetime oral study exposed rats to chloroprene at one dose (50  
3 mg/kg/day) and only qualitatively reported non-cancer effects (Ponomarkov and Tomatis, 1980).

4           In summary, this study identifies the liver (multiple liver necroses and degenerative lesions of  
5 parenchymal cells), lung (severe congestion), and kidney (severe congestion) as potential target organs  
6 for the oral toxicity of chloroprene; although, the available information is insufficient to characterize  
7 toxicity outcomes or dose-response relationships. An RfD was not derived due to the significant  
8 uncertainty associated with the oral database for chloroprene.

### 5.2. INHALATION REFERENCE CONCENTRATION (RfC)

9           RfCs are derived for exposures via the inhalation route. In general, the RfC is an estimate of a  
10 daily exposure to the human population (including susceptible subgroups) that is likely to be without  
11 an appreciable risk of adverse health effects over a lifetime. It is derived from a statistical lower  
12 confidence limit on the benchmark dose (BMDL), a no-observed-adverse-effect level (NOAEL), a  
13 lowest-observed-adverse-effect level (LOAEL), or another suitable point of departure (POD), with  
14 uncertainty/variability factors applied to reflect limitations of the data used. The inhalation RfC is  
15 analogous to the oral RfD but provides a continuous inhalation exposure estimate. The inhalation RfC  
16 considers toxic effects for both the respiratory system (portal-of-entry) effects and systems peripheral  
17 to the respiratory system (extra-respiratory or systemic effects). It is generally expressed in mg/m<sup>3</sup>.

#### 5.2.1. Choice of Principal Study and Critical Effect(s)

18           While literature exists on the carcinogenic potential of chloroprene exposure in humans, no  
19 human studies are available that would allow for the quantification of sub-chronic or chronic non-  
20 cancer effects. Two inhalation studies investigating portal-of-entry (nasal and pulmonary) and  
21 systemic effects were identified in the literature and considered for the principal study for derivation of  
22 an RfC: a 2-year chronic study in B6C3F1 mice and F344 rats (NTP, 1998), and a 2-year chronic study  
23 in Wistar rats and Syrian gold hamsters (Trochimowicz et al., 1998).

24           The chronic NTP inhalation bioassay (1998) exposed groups of 50 mice and rats of each sex to  
25 0, 12.8, 32 or 80 ppm chloroprene for 6 hours/day, 5 days/week for 2 years. This study observed a  
26 range of chloroprene-induced nonneoplastic effects across several organ systems including the  
27 respiratory tract (from the nose to the alveolar region) in both mice and rats, the kidneys of rats and  
28 male mice, the forestomach of male and female mice and the spleen of male and female mice (NTP,  
29 1998). In addition, many histopathological lesions were significantly increased compared to controls  
30 at the lowest level tested (12.8 ppm), including alveolar epithelial hyperplasia in male and female rats,

1 bronchiolar hyperplasia in male and female mice, lung histiocytic cell infiltration in female mice,  
2 hematopoietic cell proliferation in the spleen in female mice, and atrophy, necrosis, and chronic  
3 inflammation of the nasal olfactory epithelium in male rats.

4 Trochimowicz et al. (1998) exposed three groups of 100 Wistar rats and Syrian hamsters of  
5 each sex to chloroprene at 0, 10, or 50 ppm for 6 hours/day, 5 days/week for up to 18 months  
6 (hamsters) or 24 months (rats). Unlike the NTP (1998) study, this study did not observe a wide range  
7 of nonneoplastic effects in multiple organ systems. Gross pathology revealed that the lungs from rats  
8 exposed at 10 and 50 ppm had markedly lower incidences of pathological changes consistent with, and  
9 characterized as, chronic respiratory disease than did controls. Male hamsters exhibited a  
10 concentration-related decrease in the incidence of pale adrenal glands. The only remarkable  
11 nonneoplastic lesions statistically increased in male and female rats were observed in the liver and  
12 lungs at 50 ppm: an increase in foci of cellular alteration in the liver and mild changes, such as  
13 lymphoid aggregates around the bronchi, bronchiole, and blood vessels, in the lungs. Accidental  
14 failure of the exposure chamber ventilation system suffocated 87 males and 73 females in the low  
15 exposure (10 ppm) group during week 72 of exposure, and limited the histopathological examinations  
16 performed in this study. Only the livers of rats that died accidentally were processed for microscopic  
17 examination. No morphological disturbances were noted in the liver of low exposure group animals.  
18 The only nonneoplastic change seen in hamsters was a generalized amyloidosis (in the liver, kidneys,  
19 spleen, and adrenals) that was lower in incidence in the 50 ppm exposed group compared with  
20 controls.

21 The chronic NTP (1998) study was chosen as the principal study for the derivation of the RfC.  
22 Based on the non-cancer database for chloroprene, this study demonstrated exposure concentration-  
23 related effects more extensively than any other study. It was a well conducted study that utilized 50  
24 animals per sex, per exposure group, a range of exposure concentrations based on the results of  
25 preliminary, shorter-duration studies (16 day and 13 weeks), and thoroughly examined chloroprene's  
26 observed toxicity in two species. Trochimowicz et al. (1998) was not chosen as the principal study  
27 primarily due to the lack of observed effects at similar exposure levels as the NTP (1998) study  
28 (Trochimowicz et al., 1998; see Section 4.7.2.2 for discussion of potential causes of differences in  
29 observed toxicity between the NTP and Trochimowicz studies). Concerns regarding the abnormally  
30 high mortality in the low dose animals in the Trochimowicz et al. (1998) also influenced the choice to  
31 disregard it as the principal study.

32 From the NTP (1998) study, all portal-of-entry and systemic nonneoplastic lesions that were  
33 statistically increased at the lowest exposure concentration (12.8 ppm), compared to chamber controls,  
34 were considered candidates for the critical effect. The candidate endpoints included bronchiolar  
35 hyperplasia, pulmonary histiocytic cell infiltration, and splenic hematopoietic cell proliferation in  
36 mice, and alveolar epithelial hyperplasia, nasal chronic inflammation, olfactory necrosis, and olfactory  
37 epithelium atrophy in rats (Table 5-1).

1 The incidence data for atrophic and necrotic olfactory epithelial lesions in male rats were  
 2 mostly coincident, suggesting an interdependence between these two lesions. In the 12 ppm group, 10  
 3 of the 13 males affected with one of these lesions showed the other as well, and all male rats with  
 4 necrosis at higher exposures also showed atrophy. Because both are degenerative lesions and not  
 5 enough information was available to establish if one lesion was a precursor for the other (e.g., atrophy  
 6 progressing to necrosis), these lesions were combined and considered as one critical effect,  
 7 degenerative nasal lesions. In addition, with the exception of one high concentration male rat, all rats  
 8 with nasal chronic inflammation showed nasal atrophy.

**Table 5-1. Incidences of nonneoplastic lesions statistically significantly increased at lowest exposure concentration resulting from chronic exposure (ppm) to chloroprene**

SPECIES	TISSUE	ENDPOINT	MALE				FEMALE			
			0	12.8	32	80	0	12.8	32	80
Mice	Lung	Bronchiolar hyperplasia	0/50	10/50 <sup>b</sup>	18/50 <sup>b</sup>	23/50 <sup>b</sup>	0/50	15/49 <sup>b</sup>	12/50 <sup>b</sup>	30/50 <sup>b</sup>
		Histiocytic cell infiltration	--	--	--	--	1/50	14/49 <sup>b</sup>	18/50 <sup>b</sup>	23/50 <sup>b</sup>
	Spleen	Hematopoietic cell proliferation	--	--	--	--	13/50	25/49 <sup>c</sup>	42/49 <sup>c</sup>	39/50 <sup>c</sup>
Rats	Nose	Inflammation, chronic	0/50	5/50 <sup>a</sup>	9/49 <sup>b</sup>	49/49 <sup>b</sup>	--	--	--	--
		Atrophy	3/50	12/50 <sup>a</sup>	46/49 <sup>b</sup>	48/49 <sup>b</sup>	--	--	--	--
		Necrosis	0/50	11/50 <sup>b</sup>	26/49 <sup>b</sup>	19/49 <sup>b</sup>	--	--	--	--
		Atrophy or Necrosis <sup>d</sup>	3/50	13/50	47/49	48/49	--	--	--	--
	Lung	Alveolar epithelial hyperplasia	5/50	16/50 <sup>b</sup>	14/49 <sup>a</sup>	25/50 <sup>b</sup>	6/49	22/50 <sup>b</sup>	22/50 <sup>b</sup>	34/50 <sup>b</sup>

<sup>a</sup> p < 0.05

<sup>b</sup> p < 0.01

<sup>c</sup> Reported as significantly greater than controls, but level of significance not reported

<sup>d</sup> Combination of two separately reported endpoints

-- Endpoint not observed

Source: NTP (1998)

### 5.2.2. Methods of Analysis

9 This assessment uses benchmark dose (BMD) methodology to estimate a POD for the  
 10 derivation of an RfC for chloroprene. The use of the BMD approach improves the assessment by  
 11 including consideration of the shape of the dose-response curve, providing independence from  
 12 experimental doses, and providing estimation of the experimental variability associated with the  
 13 calculated dose-response relationship. Use of BMD methods involves fitting mathematical models to  
 14 dose-response data and provides a BMD and its 95% lower confidence limit (BMDL) associated with a

1 predetermined benchmark response (BMR). The BMDL is then used as the POD for deriving the RfC.  
2 The suitability of these methods to determine a POD is dependent on the nature of the toxicity  
3 database for a specific chemical. Alternatively, the NOAEL/LOAEL approach was used when the data  
4 could not be appropriately modeled.

5 A BMR of 10% extra risk was chosen for these endpoints under the assumption that it  
6 represents a minimal biologically significant change. In any case, a 10% increase in incidence relative  
7 to controls is recommended for the BMR when using dichotomous models, to facilitate a consistent  
8 basis of comparison across assessments and endpoints (U.S. EPA, 2000b). All available dichotomous  
9 models in the EPA BMD software (BMDS) (version 2.0) were fit to the incidence data for lung, spleen,  
10 and nasal effects in rats and mice (Table 5-1). Details of the BMD modeling analysis are included in  
11 Appendix B1.

12 The models selected for a particular endpoint were chosen based on global and local goodness-  
13 of-fit criteria (Akaike Information Criterion [AIC] and chi-square [ $\chi^2$ ] residual values, respectively)  
14 and visual inspection. The BMDs and BMDLs associated with an extra risk of 10% for the best-fitting  
15 models for each endpoint are shown in Table 5-2. NOAELs and LOAELs were used as potential  
16 PODs for the bronchiolar hyperplasia and splenic hematopoietic cell proliferation endpoints in female  
17 mice that could not be modeled adequately.

### 5.2.3. Exposure Duration and Dosimetric Adjustments

18 Because an RfC is a measure that assumes continuous human exposure over a lifetime, data  
19 derived from animal studies need to be adjusted to account for the noncontinuous exposure protocols  
20 used in animal studies. In the NTP (1998) study, rats were exposed to chloroprene for 6 hours/day, 5  
21 days/week for 2 years. Therefore, the duration-adjusted PODs for lung, nasal, and spleen lesions in  
22 rats and mice are calculated as follows:

$$\text{POD}_{\text{ADJ}} (\text{ppm}) = \text{POD} (\text{ppm}) \times \text{hours exposed per day}/24 \text{ hours} \times \text{days exposed per week}/7 \text{ days}$$

23  
24  
25  
26 RfCs are typically expressed in units of  $\text{mg}/\text{m}^3$ ; the above ppm value needs to be converted  
27 using the chemical specific conversion factor of  $1 \text{ ppm} = 3.62 \text{ mg}/\text{m}^3$  (see Table 2-1) for chloroprene.  
28 Therefore, the final  $\text{POD}_{\text{ADJ}}$  values are calculated as follows:

$$\text{POD}_{\text{ADJ}} (\text{mg}/\text{m}^3) = \text{POD}_{\text{ADJ}} (\text{ppm}) \times 3.62 \text{ mg}/\text{m}^3/1 \text{ ppm}$$

29  
30  
31  
32 Finally, this  $\text{POD}_{\text{ADJ}}$  value must be converted to a human equivalent concentration (HEC).  
33 Chloroprene is a relatively water-insoluble, non-reactive gas that primarily induces nasal (i.e.,  
34 olfactory atrophy) and thoracic (i.e., bronchiolar/alveolar hyperplasia) non-cancer effects. Water-  
35 insoluble, non-reactive chemicals typically do not partition greatly into the aqueous mucus coating of  
36 the upper respiratory system. Rather, they tend to distribute to the lower portions of the respiratory

1 tract where larger surface areas and the thin alveolar-capillary barrier facilitate uptake (Medinsky and  
2 Bond, 2001). However, the pattern of respiratory effects seen following chloroprene exposure is  
3 consistent with what is known about its metabolism and the expression of cytochrome P450 enzymes  
4 in the olfactory and respiratory mucosa in rats. The proposed mode of action of chloroprene involves  
5 the conversion of the parent compound into its reactive epoxide metabolite by P450 isoform CYP2E1.  
6 The olfactory and respiratory mucosa of rats have been shown to specifically express CYP2E1  
7 (Thornton-Manning and Dahl, 1997). Further, the olfactory mucosa of rats contains levels of P450s  
8 that are more similar to hepatic levels than any other non-hepatic tissue examined and respiratory  
9 mucosa P450 concentrations are approximately 25% that of the olfactory mucosa. Conversion of  
10 chloroprene into its reactive epoxide metabolite in the olfactory and respiratory epithelia may facilitate  
11 its uptake in those regions.

12 Therefore, in accordance with the U.S. EPA (1994b) RfC methods, chloroprene is characterized  
13 as a Category 1 gas for portal-of-entry effects, and as such the HECs for lung and nasal lesions in rats  
14 and mice were calculated by the application of a dosimetric adjustment factor (DAF). DAFs are ratios  
15 of animal and human physiologic parameters, and are dependent on the nature of the contaminant  
16 (particle or gas) and the target site (e.g., respiratory tract or remote to the portal-of-entry) (U.S. EPA,  
17 1994b). For gases with extrathoracic portal-of-entry effects (i.e. nasal), the DAF is the regional gas  
18 dose ratio (RGDR<sub>ET</sub>) and is expressed (in this particular case, for male rats) as follows:

$$19 \quad \text{RGDR}_{\text{ET}} = (\text{MV}_r / \text{S}_{\text{ET}_r}) / (\text{MV}_h / \text{S}_{\text{ET}_h})$$

20 where:

$$21 \quad \text{MV}_r = \text{F344/N male rat minute volume (0.294 L/min)}^2$$

$$22 \quad \text{MV}_h = \text{human minute volume, (13.8 L/min)}$$

$$23 \quad \text{S}_{\text{ET}_r} = \text{surface area of the extrathoracic region in rats (15 cm}^2\text{)}$$

$$24 \quad \text{S}_{\text{ET}_h} = \text{surface area of the extrathoracic region in humans (200 cm}^2\text{)},$$

$$25 \quad \text{RGDR}_{\text{ET}} = (.294/15)/(13.8/200)$$

$$26 \quad \text{RGDR}_{\text{ET}} = 0.28$$

27 Therefore, the HEC for portal-of-entry effects in male rats is calculated as follows:

$$28 \quad \text{HEC (mg/m}^3\text{)} = \text{POD}_{\text{ADJ}} \text{ (mg/m}^3\text{)} \times \text{DAF}$$

$$29 \quad \quad \quad = \text{POD}_{\text{ADJ}} \text{ (mg/m}^3\text{)} \times 0.28$$

30 The calculated HEC values for all considered endpoints are presented in the last column of  
31 Table 5-2.

---

<sup>2</sup> Calculated according to U.S. EPA (1994b):  $\ln(\text{MV}_r) = b_0 + b_1 \times \ln(\text{BW})$ . Default minute volume is in L/min;  $b_0$  and  $b_1$  = species-specific (rat) intercept and coefficient used; body weight in kg. Time-weighted average body weight was 0.456, kg for male rats

**Table 5-2. Human equivalent concentration estimates for best fitting models of the BMD from chronic exposure to chloroprene**

Endpoint	Species/ Sex	NOAEL (ppm)	LOAEL (ppm)	Model <sup>a</sup>	BMD <sub>10</sub> <sup>b</sup> (ppm)	BMDL <sub>10</sub> <sup>b</sup> (ppm)	POD <sub>adj</sub> <sup>c</sup> (mg/m <sup>3</sup> )	DAF <sup>d,e</sup>	POD <sub>HEC</sub> (mg/m <sup>3</sup> )
<i>Lung</i>									
Alveolar epithelial hyperplasia	Rat/male	n/a	12.8	Log-logistic	11.4	7.1	4.6	3.4	15.6
	Rat/female	n/a	12.8	Log-logistic	4.9	3.3	2.1	2.3	4.9
Bronchiolar hyperplasia	Mouse/ male	n/a	12.8	Log-logistic	7.5	5.6	3.6	4.1	14.8
	Mouse/ female	n/a	12.8	f	--	--	8.3	4.1	33.9
Histiocytic cell infiltration	Mouse/ female	n/a	12.8	f	--	--	8.3	4.1	33.9
<i>Nasal</i>									
Chronic Inflammation	Rat/male	n/a	12.8	Log-logistic <sup>g</sup>	14.6	9.3	6.0	0.28	1.7
Atrophy	Rat/male	n/a	12.8	Logistic <sup>g</sup>	7.7	6.0	3.9	0.28	1.1
Necrosis	Rat/male	n/a	12.8	Log-probit <sup>g</sup>	7.9	6.4	4.1	0.28	1.2
Atrophy or Necrosis	Rat/male	n/a	n/a	Logistic <sup>g</sup>	7.4	5.7	3.7	0.28	1.0
<i>Systemic Effects</i>									
Hematopoietic proliferation	Mouse/ female	n/a	12.8	Probit <sup>g</sup>	4.0	3.3	2.1	1.0	2.1

<sup>a</sup>Best fitting model as determined by goodness-of-fit statistics. Bold numbers indicate which value (NOAEL, LOAEL, or BMDL) is used in determination of POD<sub>HEC</sub>.

<sup>b</sup>At BMR = 10% extra risk.

<sup>c</sup>Duration adjusted POD [mg/m<sup>3</sup>] (POD<sub>adj</sub>) = POD [ppm] × (3.62 mg/m<sup>3</sup>/ppm) × (5 days/7 days) × (6 hours/24 hours), in accordance with EPA policy (2002a)

<sup>d</sup>DAF = dosimetric adjustment factor.

<sup>e</sup> For portal-of-entry effects (lung and nasal effects) the DAF = the regional gas dose ratio (RGDR) and is expressed as: (MV/SA)<sub>animals</sub> / (MV/SA)<sub>human</sub>, where MV = minute volume and SA = respiratory surface area. F344/N male rat MV = 0.294 L/min, F344/N female rat MV = 0.203 L/min, B6C3F1 male mouse MV = 0.052L/min, B6C3F1 female mouse MV = 0.053 L/min, human minute volume = 13.8 L/min. Surface area of the pulmonary region in F344/N rats = 0.34 m<sup>2</sup>, surface area of the pulmonary region in B6C3F1 mice = 0.05 m<sup>2</sup>, surface area of the pulmonary region in humans = 54 m<sup>2</sup>, surface area of the extrathoracic region in rats = 15 cm<sup>2</sup>, surface area of the extrathoracic region in humans = 200 cm<sup>2</sup>. Minute volumes were calculated according to U.S. EPA 1994b using the following time-weighted average body weights: 0.456, 0.290, 0.0437, and 0.0443 kg for male rats, female rats, male mice, and female mice, respectively. For systemic effects (splenic effects) the DAF is expressed as the ratio of animal to human blood:air partition coefficients. As given in Table 3-1, the blood:air partition coefficients for rats are in the range of 7.3-8.0, while that for humans is 4.5. A default value of 1 is substituted when the laboratory animal value exceeds the human.

<sup>f</sup> No model fits appropriately according fit statistics or visual inspection. Therefore, the NOAEL/LOAEL approach is recommended to determine a POD

<sup>g</sup> High dose group was dropped in order to obtain adequate model fit.

Source: NTP (1998)

1 The BMD modeling indicated that degenerative nasal lesions were the most sensitive endpoint,  
2 when comparing the BMD<sub>10S</sub> and BMDL<sub>10S</sub>. Selection of the most relevant BMR for this endpoint to  
3 use for developing the RfC involved evaluating the relative biological significance of the degenerative  
4 nasal lesions. The nasal lesion data for chloroprene over the range of exposure concentrations tested  
5 (NTP, 1998) indicate a progression in both incidence and severity from no necrosis and minimal  
6 atrophy in the controls to manifestations of cellular injury and diminished tissue function at the highest  
7 exposures (see Table 4-23 for severity grade details). Considering the mild to moderate degenerative  
8 nasal lesions observed in 26% of male rats exposed to 12.8 ppm (average severity 1.8 for atrophy and  
9 2.0 for necrosis), a BMR of 10% extra risk was selected for the POD based on the assumption that a  
10 10% increase in incidence of this effect (with presumably less than moderate severity) is minimally  
11 biologically significant. Therefore, 1.0 mg/m<sup>3</sup> was selected to serve as the human equivalent POD for  
12 the derivation of the RfC.

#### 5.2.4. RfC Derivation—Including Application of Uncertainty Factors

13 A POD<sub>HEC</sub> value of 1.0 mg/m<sup>3</sup> for increased incidence of degenerative nasal lesions in male  
14 F344/N rats (NTP, 1998) was used as the POD to derive the chronic RfC for chloroprene because it  
15 was the lowest POD<sub>HEC</sub> calculated after duration and dosimetric adjustments. A total UF of 100 was  
16 applied to this POD as described below:

- 17 • A 3-fold UF<sub>A</sub> was used to account for uncertainty in extrapolating from laboratory animals to  
18 humans (i.e., interspecies variability). This uncertainty factor is comprised of two separate  
19 and equal areas of uncertainty to account for differences in the toxicokinetics and  
20 toxicodynamics of animals and humans. In this assessment, toxicokinetic uncertainty was  
21 accounted for by the calculation of a human equivalent concentration by the application of a  
22 dosimetric adjustment factor as outlined in the RfC methodology (U.S. EPA, 1994b). As the  
23 toxicokinetic differences are thus accounted for, only the toxicodynamic uncertainties  
24 remain, and a UF of 3 is retained to account for this residual uncertainty.
- 25 • A default 10-fold UF<sub>H</sub> was used to account for variation in susceptibility among members of  
26 the human population (i.e., interindividual variability). Limited information is available to  
27 predict potential variability in human susceptibility.
- 28 • An UF<sub>S</sub> was not needed to account for subchronic-to-chronic extrapolation because a chronic  
29 inhalation study is being used to derive the chronic RfC.
- 30 • An UF for LOAEL-to-NOAEL extrapolation was not applied because the current approach is  
31 to address this factor as one of the considerations in selecting a BMR for benchmark dose  
32 modeling. In this case, a BMR of 10% change in degenerative nasal lesions was selected  
33 under an assumption that it represents a minimal biologically significant change.



- A 3-fold UF was used to account for deficiencies in the database. The major strength of the database is the observation of exposure-response effects in multiple organ systems in a well-designed chronic inhalation study that utilized 50 animals per sex per dose group, a range of doses based on the results of preliminary, shorter-duration studies (16 day and 13 weeks), and thoroughly examined chloroprene's observed toxicity in two species (rat and mouse). The database further contains another chronic inhalation bioassay investigating outcomes in another species (hamster), and well-designed embryotoxicity, teratological, and reproductive toxicity studies. The database also contains subchronic studies and chronic studies observing potential neurotoxic and immunotoxic effects. A limitation in the database is the lack of a two-generation reproductive toxicity study.

Application of this 100-fold composite uncertainty factor yields the calculation of the chronic RfC for chloroprene as follows:

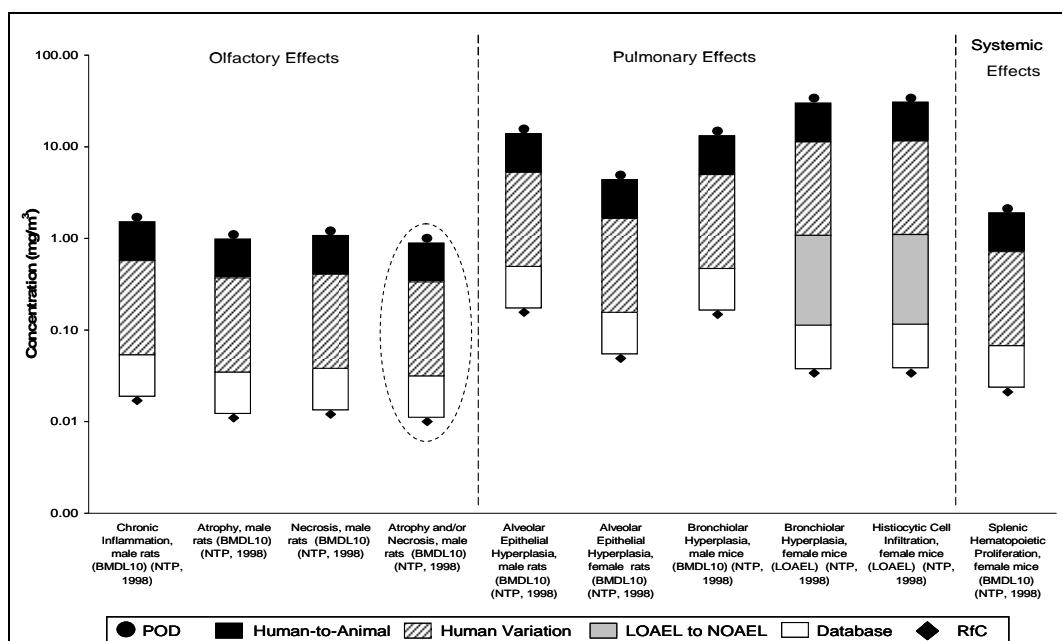
$$\text{RfC} = \text{POD}_{\text{HEC}} \div \text{UF} = 1.0 \text{ mg/m}^3 \div 100 = 1.0 \times 10^{-2} \text{ mg/m}^3$$

#### 5.2.5. Previous RfC Assessment

The IRIS Program has not previously evaluated the noncancer inhalation toxicity of chloroprene.

#### 5.2.6. RfC Comparison Information

Figure 5-1 presents PODs, applied UFs, and derived sample RfCs for all of the endpoints from the chronic inhalation NTP (1998) study that were considered for the critical effect for determination of an RfC. Of the considered studies, the NTP (1998) study was considered the most suitable to derive an RfC. The endpoints considered for the critical effects from the NTP (1998) study included any histopathological lesion that was significantly increased in the lowest dose group relative to controls. The PODs are either based on the best fit models from BMD models or the LOAEL of 12.8 ppm and were adjusted for duration and dosimetry before applications of uncertainty factors.



**Figure 5-1. Points of departure (in  $\text{mg}/\text{m}^3$ ) for selected endpoints with corresponding applied uncertainty factors and derived sample RfCs (chosen RfC value is circled).**

### 5.3. UNCERTAINTIES IN THE INHALATION REFERENCE CONCENTRATION

1 As presented earlier in the previous section, the UF approach, following EPA practices and RfC  
 2 guidance (U.S. EPA, 1994b), was applied to the  $\text{POD}_{\text{HEC}}$  in order to derive the chronic RfC. Factors  
 3 accounting for uncertainties associated with a number of steps in the analyses were adopted to account  
 4 for extrapolating from an animal bioassay to human exposure, a diverse population of varying  
 5 susceptibilities, POD determination methodologies, and to account for database deficiencies. The  
 6 following is a more extensive discussion of the uncertainties associated with the RfC for chloroprene  
 7 beyond which is described quantitatively in Section 5.2.4. A summary is provided in Table 5-3.

8 *Choice of endpoint.* Sample RfCs considered from the NTP (1998) chronic inhalation study  
 9 ranged from  $1.0 \times 10^{-2}$  to  $3.4 \times 10^{-1} \text{ mg}/\text{m}^3$ . Sample RfC values primarily depended on whether  
 10 olfactory or pulmonary effects were considered. The chosen critical effect, increased incidence of  
 11 degenerative nasal lesions in male rats, is considered to be the most sensitive endpoint because it  
 12 returned the lowest  $\text{POD}_{\text{HEC}}$  value compared to all other considered endpoints. Its portal-of-entry  
 13 nature is consistent with the other portal-of-entry effects (e.g., nasal chronic inflammation, alveolar  
 14 epithelial hyperplasia, etc.) observed in the NTP (1998) study. The location of the effect is also  
 15 consistent with what is currently proposed for chloroprene's metabolism: conversion of chloroprene  
 16 into its reactive metabolite (1-chloroethenyl)oxirane by CYP2E1. The olfactory mucosa of rats has  
 17 been shown to specifically express CYP2E1 (Thornton-Manning and Dahl, 1996) and levels of total  
 18 P450 enzymes most similar to hepatic levels than any other non-hepatic tissue examined. Choice of

1 other olfactory effects (chronic inflammation, necrosis or atrophy considered separately) as the critical  
2 effect would not appreciably alter the derived RfC ( $1.7 \times 10^{-2}$  for chronic inflammation,  $1.2 \times 10^{-2}$  for  
3 olfactory necrosis, or  $1.1 \times 10^{-2}$  for olfactory atrophy) relative to degenerative nasal lesions (i.e.,  
4 atrophy and necrosis considered together). Choice of degenerative nasal lesions as the critical effect is  
5 supported as the RfC derived is marginally lower than RfCs for other olfactory effects, and thus this  
6 value is presumed to be protective for any individual lesion type. Choice of pulmonary effects (e.g.,  
7 alveolar epithelial hyperplasia) as the critical effect would result in RfC values up to 30-fold higher  
8 than the RfC for degenerative nasal lesions. Choice of the only systemic effect considered from the  
9 NTP (1998) study, splenic hematopoietic proliferation, would result in an RfC approximately 2-fold  
10 higher than the RfC for degenerative nasal lesions.

11 *Choice of model for BMDL derivation.* The logistic model fit the data for degenerative nasal  
12 lesions in male rats adequately (global goodness of fit p-value = 0.231). Data points are well-predicted  
13 near the BMD ( $\chi^2$  residual = 0.905). Use of sample models would either increase the RfC by  
14 approximately 50% or decrease the RfC by approximately 3-fold. However, the logistic model was  
15 chosen over these models based on current BMD technical guidance (U.S. EPA, 2000b).

16 *Choice of BMR.* There is uncertainty in the selection of the benchmark response (BMR) level.  
17 For increased incidence of degenerative nasal lesions in male rats, definitive data do not exist to  
18 further inform the selection of what the appropriate BMR should be; therefore a BMR of 10% extra  
19 risk was chosen based on the assumption that a 10% increase in incidence of this effect (with  
20 presumably less than moderate severity) is minimally biologically significant.

21 *Statistical uncertainty at POD.* For the logistic model applied to degenerative nasal lesions in  
22 male rats, there is a reasonably small degree of statistical uncertainty at the 10% extra risk level (the  
23 point of departure for derivation of the RfC), with the BMDL being about 25% below the BMD.

24 *Choice of bioassay.* The NTP (1998) chronic inhalation study was used for development of the  
25 RfC because it was a well designed study that was conducted in 2 relevant species, used 50 animals per  
26 sex per exposure group, and thoroughly examined a wide-range of appropriate toxicological endpoints.  
27 The other bioassays were discounted for use as the principal study due either a general lack of effects  
28 at similar exposure levels (i.e., Trochimowicz et al., 1998) or interpretational difficulties in respect to  
29 the observed effects (i.e., Culik et al., 1978).

30 *Choice of species.* The RfC was based on increased incidence of degenerative nasal lesions in  
31 male rats exposed to chloroprene via inhalation for 2 years. Use of other effects that occurred in  
32 another species, B6C3F1 mice, would result in RfCs approximately 2-30 times greater than the current  
33 RfC.

34 *Human population variability.* The extent of inter-individual variation of chloroprene  
35 metabolism in humans has not been well characterized. However, a number of issues, including lower  
36 enzyme levels and renal clearance in children, potential distribution of chloroprene to breast milk, and  
37 chloroprene's proposed mutagenic mode of action suggest that childhood may represent a potentially

- 1 susceptible lifestage to chloroprene's toxicity. The 10-fold default uncertainty value is applied to the  
 2  $POD_{HEC}$  primarily due to the limited data on human variability or potential susceptible subpopulations.

**Table 5-3. Summary of Uncertainties in the Chloroprene noncancer risk assessment**

<b>CONSIDERATION</b>	<b>POTENTIAL IMPACT<sup>a</sup></b>	<b>DECISION</b>	<b>JUSTIFICATION</b>
Choice of endpoint	Use of other endpoints could ↑ RfC by up to 30-fold	RfC is based on the endpoint with the lowest $POD_{HEC}$ , increased incidence of degenerative nasal lesions in male rats,	Chosen endpoint is considered to be the most sensitive (based on $POD_{HEC}$ values). Its portal-of-entry nature is consistent with other portal-of-entry effects observed in the NTP (1998) study.
Choice of model for BMDL derivation	Other models would ↑ or ↓ RfC	Logistic model used	U.S. EPA (2000b) BMD technical guidance used to choose model based on global and local measures of model fit
Choice of BMR	Other BMRs would ↑ or ↓ RfC	BMR of 10% extra risk chosen	BMR of 10% extra risk was chosen based on the assumption that a 10% increase in incidence of this effect (with presumably less than moderate severity) is minimally biologically significant
Statistical uncertainty at POD	RfC would be ~ 25% higher if BMD (vs. BMDL) were used	BMDL used as POD per U.S. EPA guidance (2000b)	Size of bioassay results in sampling variability; lower bound is 95% confidence interval on administered exposure
Choice of bioassay	Other bioassays could ↑ or ↓ RfC	NTP (1998) used as critical study	Other bioassays were available but were discounted as principal study due to lack of effects or interpretational difficulties. The chosen bioassay was well-conducted and reported and resulted in the lowest BMDL for derivation of RfC
Choice of species	RfC would ↑ if based on another species	Rats chosen	RfC is based on the most sensitive endpoint (incidence of degenerative nasal lesions) in the most sensitive species (rat), based on $POD_{HEC}$
Human population variability	RfC could ↑ or ↓ if a non-default value of UF was used	10-fold uncertainty factor applied to derived the RfC	10-fold UF, the default value, is applied principally because of limited data on human variability or potential susceptible subpopulations

<sup>a</sup> ↑ = increase, ↓ = decrease

## 5.4. CANCER ASSESSMENT

### 5.4.1. Choice of Study/Data—with Rationale and Justification

1           The NTP (1998) study was used for development of an inhalation unit risk. This was a well-  
2 designed study, conducted in both sexes of two species with 50 animals per sex per dose group and  
3 with examination of appropriate toxicological endpoints in both sexes of rats and mice. Tumor  
4 incidences were elevated with increasing exposure level at numerous sites across all sex/species  
5 combinations, involving point of contact in the respiratory system and more distant locations. The  
6 Trochimowicz et al. (1998) was not considered for quantification purposes, primarily due to the  
7 general lack of observed neoplastic effects at similar exposure levels as the NTP (1998) study (see  
8 Section 4.2.2. for study details).

### 5.4.2. Dose-Response Data

9           In the NTP (1998) study, groups of 50 male and female F344 rats and B6C3F1 mice were  
10 exposed via inhalation to 0, 12.8, 32, or 80 ppm chloroprene for 6 hours/day, 5 days/week for 2 years.  
11 These data are summarized in Tables 5-4 (mice) and 5-5 (rats).

12           Mice were the more sensitive species, with statistically significant increases in tumor incidence  
13 observed at multiple sites: all organs (hemangiomas, hemangiosarcomas), lung (bronchiolar/alveolar  
14 adenomas and carcinomas), forestomach, Harderian gland (adenomas and carcinomas), kidney  
15 (adenomas [males]), skin and mesentery (sarcomas), liver, and mammary gland (females). These  
16 tumors generally appeared earlier with increasing exposure levels and showed statistically significantly  
17 increasing trends with increasing exposure level (by life table test or logistic regression,  $p \leq 0.001$ ).  
18 Etiologically similar tumor types, benign and malignant tumors of the same cell type, were combined  
19 for these tabulations because of the possibility that the benign tumors could progress to the malignant  
20 form (U.S. EPA, 2005a). Survival for all chloroprene-exposed female mice and for male mice in the  
21 two higher exposed groups was statistically significantly lower than for the corresponding control  
22 mice.

**Table 5-4. Tumor incidence in female and male B6C3F1 mice exposed to chloroprene via inhalation**

TISSUE	CUMULATIVE INCIDENCE; TIME OF FIRST OCCURRENCE	ADMINISTERED CHLOROPRENE CONCENTRATION (ppm)			
		Control	12.8	32	80
<i>Females</i>					
All organs: hemangioma or hemangiosarcoma	Unadjusted	4/50	6/49	18/50	8/50
	KM (%)	11%	26%	100%	50.8%
	First incidence (days)	541	482	216	523
Lung: alveolar/bronchiolar adenoma or carcinoma	Unadjusted	4/50	28/49	34/50	42/50
	KM <sup>a</sup> (%)	11%	84%	100%	100%
	First incidence (days)	706	447	346	324
Liver: hepatocellular adenoma or carcinoma	Unadjusted	20/50	26/49	20/50	30/50
	KM (%)	52%	82%	100%	100%
	First incidence (days)	493	440	503	384
Skin or mesentery: sarcoma	Unadjusted	0/50	15/49	18/50	19/50
	KM (%)	0%	63%	100%	72%
	First incidence (days)	-	285	463	443
Mammary gland: adenocarcinoma, carcinoma or adenoacanthoma	Unadjusted	3/50	6/49	11/50	14/50
	KM (%)	7.4%	23%	42%	61%
	First incidence (days)	527	440	394	336
Forestomach: squamous cell papilloma or carcinoma	Unadjusted	1/50	0/49	0/50	4/50
	KM (%)	2.9%	0%	0%	19%
	First incidence (days)	734	-	-	576
Harderian gland: adenoma or carcinoma	Unadjusted	2/50	5/49	3/50	9/50
	KM (%)	5%	24%	12%	77%
	First incidence (days)	527	621	524	427
Zymbal's gland: carcinoma	Unadjusted	0/50	0/50	0/50	3/50
	KM (%)	0%	0%	0%	11%
	First incidence (days)	-	-	-	565
<i>Males</i>					
All organs: hemangioma or hemangiosarcoma	Unadjusted	3/50	14/50	23/50	21/50
	KM (%)	11%	42%	71%	74%
	First incidence (days)	733	659	495	454
Lung: alveolar/bronchiolar adenoma or carcinoma	Unadjusted	13/50	28/50	36/50	43/50
	KM (%)	39%	79%	89%	100%
	First incidence (days)	635	530	382	523
Forestomach: squamous cell papilloma or carcinoma	Unadjusted	1/50	0/50	2/50	4/50
	KM (%)	4%	0%	14%	15%
	First incidence (days)	733	-	733	587
Harderian gland: adenoma or carcinoma	Unadjusted	2/50	5/49	10/50	12/50
	KM (%)	5.8%	18%	42%	58%
	First incidence (days)	596	701	596	589
Kidney: renal tubule adenomas or carcinomas (extended and standard evaluations combined)	Unadjusted	0/50	2/49	3/50	9/50
	KM (%)	0%	7.1%	20%	41%
	First incidence (days)	-	722	715	567

<sup>a</sup> Kaplan-Meier estimated neoplasm incidence rate at the end of the study, involving adjustment for intercurrent mortality and under the assumption that the observed tumors were fatal.

Source: NTP (1998).

**Table 5-5. Tumor incidence in female and male F344 rats exposed to chloroprene via inhalation**

TISSUE	CUMULATIVE INCIDENCE; TIME OF FIRST OCCURRENCE	ADMINISTERED CHLOROPRENE CONCENTRATION (ppm)			
		Control	12.8	32	80
<i>Females</i>					
Oral cavity: papillomas or carcinomas	Unadjusted	1/49	3/50	5/50	11/50
	KM <sup>a</sup> (%)	3.0%	9.2%	17%	41%
	First incidence (days)	687	681	588	660
Thyroid gland: follicular cell adenomas or carcinomas	Unadjusted	1/49	1/50	1/50	5/50
	KM (%) <sup>a</sup>	3.4%	3.2%	3.8%	17%
	First incidence (days)	733	721	733	617
Mammary gland: fibroadenomas	Unadjusted	24/49	32/50	36/50	36/50
	KM (%)	65%	86%	85%	90%
	First incidence (days)	366	302	470	433
Kidney: renal tubule adenomas or carcinomas (extended and standard evaluations combined)	Unadjusted	0/49	0/50	0/50	4/50
	KM (%)	0%	0%	0%	10%
	First incidence (days)	-	-	-	609
<i>Males</i>					
Oral cavity: papillomas or carcinomas	Unadjusted	0/50	2/50	5/50	12/50
	KM (%)	0%	14%	28%	75%
	First incidence (days)	-	701	609	539
Thyroid gland: follicular cell adenomas or carcinomas	Unadjusted	0/50	2/50	4/49	5/50
	KM (%)	0%	14%	30%	36%
	First incidence (days)	-	597	569	307
Lung: alveolar/bronchiolar adenoma or carcinoma	Unadjusted	2/50	2/50	4/49	6/50
	KM (%)	6.9%	18%	20%	59%
	First incidence (days)	616	702	505	540
Kidney: renal tubule adenomas or carcinomas (extended and standard evaluations combined)	Unadjusted	1/50	8/50	6/50	8/50
	KM (%)	7.7%	43%	53%	71%
	First incidence (days)	733	600	679	625

<sup>a</sup> Kaplan-Meier estimated neoplasm incidence rate at the end of the study, involving adjustment for intercurrent mortality and under the assumption that the observed tumors were fatal.

Source: NTP (1998).

### 5.4.3. Dose Adjustments and Extrapolation Methods

1 The current EPA *Guidelines for Carcinogen Risk Assessment* (EPA, 2005a) emphasize that the  
2 method used to characterize and quantify cancer risk from a chemical is determined by what is known  
3 about the MOA of the carcinogen and the shape of the cancer dose-response curve. The dose response  
4 is assumed to be linear in the low dose range when evidence supports a mutagenic MOA because of  
5 DNA reactivity or if another MOA that is anticipated to be linear is applicable. A mutagenic mode of  
6 carcinogenic action of chloroprene is supported by chloroprene's epoxide metabolite formation, DNA-  
7 adduct formation, observation of in vivo and in vitro mutagenicity, and the well known structure-  
8 activity relationship of similar epoxide-forming carcinogens. The determination of a mutagenic mode  
9 of action is also supported by evidence of base pair substitution mutations seen in H- and K-ras proto-

1 oncogenes in chloroprene-induced lung, forestomach, and Harderian gland neoplasms observed in the  
2 NTP (1998) study.

3 . For these reasons, a linear low-dose extrapolation approach was used to estimate human  
4 carcinogenic risk associated with chloroprene exposure. Because the weight of evidence supports a  
5 mutagenic mode of action for chloroprene carcinogenicity, and in the absence of chemical-specific  
6 data on early-life susceptibility, increased early-life susceptibility should be assumed and, if there is  
7 early-life exposure, the age-dependent adjustment factors (ADAFs) should be applied, as appropriate,  
8 in accordance with EPA's *Supplemental Guidance for Assessing Susceptibility From Early-Life*  
9 *Exposure to Carcinogens* (U.S. EPA, 2005b).

10 Due to the occurrence of multiple tumor types, earlier occurrence with increasing exposure, and  
11 increased mortality with increasing exposure level, methods that can reflect the influence of competing  
12 risks and intercurrent mortality on site-specific tumor incidence rates are preferred. EPA has generally  
13 used the multistage Weibull model, because it incorporates the time at which death-with-tumor  
14 occurred. The multistage Weibull model has the following form:

$$P(d) = 1 - \exp[-(q_0 + q_1d + q_2d^2 + \dots + q_kd^k) \times (t - t_0)^z]$$

15  
16 where  $P(d)$  represents the lifetime risk (probability) of cancer at dose  $d$  (i.e., human equivalent  
17 exposure in this case); parameters  $q_i \geq 0$ , for  $i = 0, 1, \dots, k$ ;  $t$  is the time at which the tumor was  
18 observed; and  $z$  is a parameter estimated in fitting the model, which characterizes the change in  
19 response with age. The parameter  $t_0$  represents the time between when a potentially fatal tumor  
20 becomes observable and when it causes death and is generally set to 0 because of a lack of data to  
21 estimate the time reliably. The dose-response analyses were conducted using the computer software  
22 program TOX\_RISK, version 5.3 (ICF, Fairfax, VA), which is based on Weibull models drawn from  
23 Krewski et al. (1983). Parameters were estimated using the method of maximum likelihood estimate  
24 (MLE).

25 Other characteristics of the observed tumor types were considered prior to modeling, including  
26 allowance for different, although possibly unidentified, MOAs and for relative severity of tumor types.  
27 First, etiologically different tumor types were not combined across sites prior to modeling in order to  
28 allow for the possibility that different tumor types can have different dose-response relationships  
29 because of varying time courses or other underlying mechanisms or factors. Consequently, all of the  
30 tumor types listed separately in Table 5-4 were modeled separately. A further consideration allowed by  
31 the software program is the distinction between tumor types as being either fatal or incidental in order  
32 to adjust for competing risks. Incidental tumors are those tumors thought not to have caused the death  
33 of an animal, while fatal tumors are thought to have resulted in animal death.

34 Specific multistage Weibull models were selected for the individual tumor types for each sex,  
35 based on the values of the log-likelihoods according to the strategy used by EPA (U.S. EPA, 2002b). If  
36 twice the difference in log-likelihoods was less than a  $\chi^2$  with degrees of freedom equal to the



1 difference in the number of stages included in the models being compared, the models were considered  
2 comparable, and the most parsimonious model (i.e., the lowest-stage model) was selected contingent  
3 on visual fits of the data as follows. For incidental tumors, plots of model fits compared with Hoel-  
4 Walburg estimates of cumulative incidence were also examined for goodness of fit in the lower  
5 exposure region of the observed data (Gart et al., 1986). For fatal tumors, plots of model fits were  
6 compared with Kaplan-Meier estimates of cumulative incidence. If a model with one more stage fitted  
7 the low-dose data better than the most parsimonious model, then the model with one higher stage was  
8 selected.

9 Tumor types were categorized by tumor context as either fatal or incidental tumors. Incidental  
10 tumors are those tumors thought not to have caused the death of an animal, and fatal tumors are  
11 thought to have resulted in animal death. Hemangiosarcomas were treated as fatal tumors, unless  
12 observed at an interim or terminal sacrifice, in which case they were considered incidental.  
13 Furthermore, these fatal tumors were deemed rapidly fatal, and  $t_0$  was set equal to 0 (the data were  
14 considered insufficient to reliably estimate  $t_0$  in any event, without any interim sacrifices for example).  
15 Tumors at all other sites were treated as incidental. This is consistent with the tumor context  
16 determinations in the IRIS assessment of 1,3-butadiene (US EPA, 2002b)

17 PODs for estimating low-dose risk were identified at doses at the lower end of the observed  
18 data, generally corresponding to 10% extra risk, defined as the extra risk over the background tumor  
19 rate,  $[P(d) - P(0)]/[1 - P(0)]$ . PODs were converted to continuous human-equivalent exposure levels  
20 by multiplying by  $(6 \text{ hours})/(24 \text{ hours}) \times (5 \text{ days})/(7 \text{ days})$ , or 0.178. Additionally, in accordance with  
21 the U.S. EPA (1994b) RfC methodology, the HECs for the various tumors were calculated by the  
22 application of DAFs (see section 5.2.3 and Table 5-2 footnote f for explanations of derivation). With  
23 the exception of the lung tumors, all tumors were treated as systemic effects. For these sites a DAF of  
24 1.0 was applied as the value for the rat blood:air partition coefficient exceeded the human value. For  
25 alveolar/bronchiolar tumors, the HEC was calculated treating the neoplasms alternatively as portal-of-  
26 entry effects or systemic effects. As there is evidence that chloroprene and/or its metabolite are  
27 distributed systemically (i.e., the observation of tumors in multiple organ systems), there is the  
28 potential that chloroprene is redistributed to the lungs. In this manner, chloroprene may induce lung  
29 tumors as a systemically delivered carcinogen in addition to inducing tumors via inhalation. However,  
30 the contribution of either route of delivery (i.e., inhalation vs. bloodstream) to the induction of lung  
31 tumors is currently unknown. Therefore, chloroprene-induced lung tumors were treated as either  
32 point-of-entry lesions using a DAF of 4.1, or as systemic lesions using a DAF of 1.0 due to a lack of  
33 data clarifying whether one or both modes were more likely to be operating.

34 The lifetime continuous inhalation unit risk for humans is defined as the slope of the line from  
35 the lower 95% bound on the exposure at the POD. This 95% upper confidence limit represents a  
36 plausible upper bound on the true risk. Unit risks for each tumor site were calculated by dividing the

1 BMR level (usually 10%) by its corresponding lower bound on the benchmark concentration  
2 (BMDL<sub>10</sub>).

#### 5.4.4. Oral Slope Factor and Inhalation Unit Risk

3 In the absence of any data on the carcinogenicity of chloroprene via the oral route, or a suitable  
4 PBPK model allowing route-to-route extrapolation, no oral slope factor was derived. An inhalation  
5 unit risk was derived based on the carcinogenic effects of chloroprene via the inhalation route. The  
6 results of applying the multistage Weibull models to the male and female mouse tumor incidence data  
7 are provided in Tables 5-6 and 5-7, respectively. Human equivalent unit risks estimated from the  
8 mouse tumor sites with statistically significant increases ranged from  $7.2 \times 10^{-6}$  to  $1.7 \times 10^{-4}$  per  
9  $\mu\text{g}/\text{m}^3$ , approximately a 25-fold range. The highest unit risk ( $1.7 \times 10^{-4}$  per  $\mu\text{g}/\text{m}^3$ ) corresponded to  
10 lung tumors (treated as systemic lesions) in female mice; the highest unit risk in male mice was  
11 associated with lung tumors (treated as systemic lesions) at  $8.5 \times 10^{-5}$  per  $\mu\text{g}/\text{m}^3$ . Lung tumors were  
12 the most sensitive response in mice for 1,3-butadiene as well. Alternatively, if the lung tumors resulted  
13 strictly from portal-of-entry processes, the estimated risks associated with this site would be four-fold  
14 lower, and the highest unit risk estimates come from hemangiomas and hemangiosarcomas, at  $8.3 \times$   
15  $10^{-5}$  per  $\mu\text{g}/\text{m}^3$  for female mice and  $6.6 \times 10^{-5}$  per  $\mu\text{g}/\text{m}^3$  for male mice.

16 Given the multiplicity of tumor sites, however, basing the unit risk on one tumor site may  
17 underestimate the carcinogenic potential of chloroprene. An approach suggested in the cancer  
18 guidelines would be to estimate cancer risk from tumor-bearing animals. EPA traditionally used this  
19 approach until the document *Science and Judgment in Risk Assessment* (National Research Council  
20 [NRC], 1994) made a case that this approach would tend to underestimate overall risk when tumor  
21 types occur in a statistically independent manner. In addition, application of one model to a composite  
22 data set does not accommodate biologically relevant information that may vary across sites or may  
23 only be available for a subset of sites. For instance, the time courses of the multiple tumor types  
24 evaluated varied substantially, as is suggested by the variation in estimates of  $z$  (see Tables 5-6 and 5-  
25 7) which shows an association of increasing incidence with time, from about 1.0–10 for female mice  
26 and from about 2–10 for male mice. Fitting a model like the multisage-Weibull with mechanism-  
27 related parameters to composite data would not characterize the evident range of variation. A simpler  
28 empirical model could be used for the composite data, such as the multistage model, but available  
29 biological information (time of tumor observation) would then be ignored.

**Table 5-6. Dose-response modeling summary for male mouse tumor sites associated with inhalation exposure to chloroprene**

TUMOR TYPE*	MLE COEFFICIENTS <sup>a</sup>	POINT OF DEPARTURE <sup>b</sup> (µg/m <sup>3</sup> )				UNIT RISK <sup>d</sup> (µg/m <sup>3</sup> ) <sup>-1</sup>	OVERALL UNIT RISK <sup>e</sup> (µg/m <sup>3</sup> ) <sup>-1</sup>
		Modeled from bioassay		Continuous, human equivalent <sup>c</sup>			
		BMDL <sub>10</sub>	BMD <sub>10</sub>	BMDL <sub>10</sub>	BMD <sub>10</sub>		
Lung: alveolar/ bronchiolar adenoma or carcinoma <sup>f</sup>	q <sub>0</sub> = 4.01 × 10 <sup>-8</sup> q <sub>1</sub> = 4.46 × 10 <sup>-9</sup> z = 3.5	6.64 × 10 <sup>3</sup>	9.08 × 10 <sup>3</sup>	<i>1.18 × 10<sup>3</sup></i> <i>4.84 × 10<sup>3</sup></i>	<i>1.62 × 10<sup>3</sup></i> <i>6.62 × 10<sup>3</sup></i>	8.5 × 10 <sup>-5</sup> 2.01 × 10 <sup>-5</sup>	1.7 × 10 <sup>-4</sup> 1.1 × 10 <sup>-4</sup>
All organs: hemangiosarcomas, hemangiomas	q <sub>0</sub> = 8.38 × 10 <sup>-22</sup> q <sub>1</sub> = 1.16 × 10 <sup>-22</sup> z = 10	8.50 × 10 <sup>3</sup>	1.10 × 10 <sup>4</sup>	1.51 × 10 <sup>3</sup>	1.95 × 10 <sup>3</sup>	6.6 × 10 <sup>-5</sup>	
Forestomach: squamous cell papilloma or carcinoma	q <sub>0</sub> = 3.03 × 10 <sup>-6</sup> q <sub>1</sub> = 2.34 × 10 <sup>-7</sup> z = 1.8	1.68 × 10 <sup>5</sup>	4.01 × 10 <sup>5</sup>	2.99 × 10 <sup>3</sup>	7.14 × 10 <sup>4</sup>	3.3 × 10 <sup>-5</sup>	
Harderian gland: adenoma or carcinoma	q <sub>0</sub> = 3.26 × 10 <sup>-13</sup> q <sub>1</sub> = 3.60 × 10 <sup>-14</sup> z = 5.6	3.86 × 10 <sup>4</sup>	6.15 × 10 <sup>4</sup>	6.87 × 10 <sup>3</sup>	1.10 × 10 <sup>4</sup>	1.5 × 10 <sup>-5</sup>	
Kidney: renal tubule adenomas or carcinomas (extended and standard evaluations combined)	q <sub>1</sub> = 2.03 × 10 <sup>-15</sup> z = 6.1	6.07 × 10 <sup>4</sup>	9.85 × 10 <sup>4</sup>	1.08 × 10 <sup>4</sup>	1.75 × 10 <sup>4</sup>	9.3 × 10 <sup>-6</sup>	

<sup>a</sup> Model: multistage-Weibull:  $P(d) = 1 - \exp[-(q_0 + q_1d + q_2d^2 + \dots + q_kd^k) \times (t - t_0)^z]$ , coefficients estimated in terms of ppm as administered in bioassay; lower stage q<sub>i</sub> not listed were estimated to be zero.

<sup>b</sup> BMD<sub>10</sub> = Concentration at 10% extra risk; BMDL<sub>10</sub> = 95% lower bound on concentration at 10% extra risk.

<sup>c</sup> Continuous equivalent estimated by multiplying exposures by (6 hr)/(24 hr) × (5 days)/(7 days).

<sup>d</sup> Unit risk estimated by dividing the BMR (0.1) by the BMDL<sub>10</sub>.

<sup>e</sup> Overall unit risk estimate, across all sites listed; see text for method.

<sup>f</sup> Values in italics indicate BMD/BMDL when lung tumors are treated as systemic lesions

\* Tumor incidence data from NTP (1998)

**Table 5-7. Dose-response modeling summary for female mouse tumors associated with inhalation exposure to chloroprene**

TUMOR TYPE*	MLE COEFFICIENTS <sup>a</sup>	POINT OF DEPARTURE <sup>b</sup> (µg/m <sup>3</sup> )				UNIT RISK <sup>d</sup> /(µg/m <sup>3</sup> )	OVERALL UNIT RISK <sup>e</sup> /(µg/m <sup>3</sup> )
		Modeled from bioassay		Continuous, Human equivalent <sup>c</sup>			
		BMDL <sub>10</sub>	BMD <sub>10</sub>	BMDL <sub>10</sub>	BMD <sub>10</sub>		
Lung: alveolar/ bronchiolar adenoma or carcinoma <sup>f</sup>	q <sub>0</sub> = 5.95 × 10 <sup>-10</sup> q <sub>2</sub> = 5.76 × 10 <sup>-10</sup> z = 4.1	3.38 × 10 <sup>3</sup>	4.22 × 10 <sup>3</sup>	<i>6.02 × 10<sup>2</sup></i> <i>2.47 × 10<sup>3</sup></i>	<i>7.51 × 10<sup>2</sup></i> <i>3.08 × 10<sup>3</sup></i>	<i>1.7 × 10<sup>-4</sup></i> <i>4.1 × 10<sup>-5</sup></i>	<i>3.3 × 10<sup>-4</sup></i> <i>2.1 × 10<sup>-4</sup></i>
Skin: sarcoma	q <sub>1</sub> = 7.40 × 10 <sup>-7</sup> z = 2.1	2.54 × 10 <sup>4</sup>	3.91 × 10 <sup>4</sup>	4.53 × 10 <sup>3</sup>	6.95 × 10 <sup>3</sup>	2.2 × 10 <sup>-5</sup>	
All organs: hemangiosarcomas, hemangiomas	q <sub>0</sub> = 1.35 × 10 <sup>-15</sup> q <sub>2</sub> = 1.97 × 10 <sup>-17</sup> z = 6.8	1.97 × 10 <sup>4</sup>	3.56 × 10 <sup>4</sup>	3.51 × 10 <sup>3</sup>	6.34 × 10 <sup>3</sup>	8.3 × 10 <sup>-5</sup>	
Mammary gland: adenocarcinoma, carcinoma or adenoacanthoma	q <sub>0</sub> = 6.82 × 10 <sup>-4</sup> q <sub>1</sub> = 4.97 × 10 <sup>-5</sup> z = 1.0	4.88 × 10 <sup>4</sup>	7.52 × 10 <sup>4</sup>	8.69 × 10 <sup>3</sup>	1.34 × 10 <sup>4</sup>	1.2 × 10 <sup>-5</sup>	
Liver: hepatocellular adenoma or carcinoma	q <sub>0</sub> = 1.15 × 10 <sup>-10</sup> q <sub>1</sub> = 5.27 × 10 <sup>-12</sup> z = 4.8	9.74 × 10 <sup>3</sup>	1.30 × 10 <sup>4</sup>	1.73 × 10 <sup>3</sup>	2.31 × 10 <sup>3</sup>	5.78 × 10 <sup>-5</sup>	
Forestomach: squamous cell papilloma or carcinoma	q <sub>0</sub> = 6.98 × 10 <sup>-23</sup> q <sub>1</sub> = 1.33 × 10 <sup>-23</sup> z = 10	6.07 × 10 <sup>4</sup>	1.97 × 10 <sup>5</sup>	1.08 × 10 <sup>4</sup>	3.51 × 10 <sup>4</sup>	9.3 × 10 <sup>-6</sup>	
Harderian gland: adenoma or carcinoma	q <sub>0</sub> = 4.68 × 10 <sup>-14</sup> q <sub>1</sub> = 6.62 × 10 <sup>-15</sup> z = 5.9	4.81 × 10 <sup>4</sup>	6.05 × 10 <sup>4</sup>	8.56 × 10 <sup>3</sup>	1.08 × 10 <sup>4</sup>	1.2 × 10 <sup>-5</sup>	
Zymbal's gland: carcinoma	q <sub>3</sub> = 2.22 × 10 <sup>-27</sup> z = 10	7.86 × 10 <sup>4</sup>	2.52 × 10 <sup>5</sup>	1.40 × 10 <sup>4</sup>	4.49 × 10 <sup>4</sup>	7.2 × 10 <sup>-6</sup>	

<sup>a</sup> Model: multistage-Weibull:  $P(d) = 1 - \exp[-(q_0 + q_1d + q_2d^2 + \dots + q_kd^k) \times (t - t_0)^z]$ , coefficients estimated in terms of ppm as administered in bioassay; lower stage q<sub>i</sub> not listed were estimated to be zero.

<sup>b</sup> BMD<sub>10</sub> = Concentration at 10% extra risk; BMDL<sub>10</sub> = 95% lower bound on concentration at 10% extra risk.

<sup>c</sup> Continuous equivalent estimated by multiplying exposures by (6 hours)/(24 hours) × (5 days)/(7 days).

<sup>d</sup> Unit risk estimated by dividing the BMR (0.1) by the BMDL<sub>10</sub>.

<sup>e</sup> Overall unit risk estimate, across all sites listed; see text for method.

<sup>f</sup> Values in italics indicate BMD/BMDL when lung tumors are treated as systemic lesions

\* Tumor incidence data from NTP (1998)

1 Following the recommendations of the NRC (1994) and the current *Guidelines for Carcinogen*  
 2 *Risk Assessment* (U.S. EPA, 2005a) to consider total risk, a statistically-based upper bound on total risk  
 3 was estimated in order to gain some understanding of the total risk from multiple tumor sites in female  
 4 and male B6C3F1 mice. Note that this upper bound estimate of overall risk describes the risk of  
 5 developing any combination of the tumor types considered, not just the risk of developing all  
 6 simultaneously. Statistical methods which can accommodate the underlying distribution of slope  
 7 factors are optimal, such as through maximum likelihood estimation or through bootstrapping or  
 8 Bayesian analysis. However, these methods have not yet been extended to models such as the  
 9 multistage-Weibull model. Consequently, this analysis used the same method as in several previous

1 assessments (e.g., 1,3-butadiene (US EPA, 2002b), 1,2-dibromoethane (US EPA, 2005)) which  
2 involves assuming that variability in slope factors can be characterized by a normal distribution. Each  
3 overall risk estimate involved the following steps (detailed in Appendix C):

- 4 • It was assumed that the tumor types associated with chloroprene exposure were statistically  
5 independent - that is, that the occurrence of a hemangiosarcoma, say, was not dependent on  
6 whether there was a forestomach tumor. This assumption cannot currently be verified and if  
7 not correct could lead to an overestimate of risk from summing across tumor sites. However,  
8 NRC (1994) argued that a general assumption of statistical independence of tumor-type  
9 occurrences within animals was not likely to introduce substantial error in assessing  
10 carcinogenic potency from rodent bioassay data.
  
- 11 • The models previously fitted to estimate the BMDs and BMDLs were used to extrapolate to a  
12 lower level of risk (R) where the BMDs and BMDLs were in a linear range. For these data a  
13  $10^{-2}$  risk was generally the lowest risk necessary. Although this step appears to differ from the  
14 explicit recommendation of the cancer guidelines (U.S. EPA, 2005a) to estimate cancer risk  
15 from a POD “near the lower end of the observed range, without significant extrapolation to  
16 lower doses,” this method is recommended in the cancer guidelines as a method for combining  
17 multiple extrapolations. A sensitivity analysis considering risks nearer the lower end of the  
18 observed ranges for each tumor type was also considered and is described below with the  
19 results. The unit risk for each site was then estimated by  $R/BMDL_R$ , as for the estimates for  
20 each tumor site above.
  
- 21 • The central tendency estimates of unit potency (that is, risk per unit of exposure) at each  
22  $BMD_R$ , estimated by  $R/BMD_R$ , were summed across the sites listed in Table 5-6 for male mice  
23 and similarly across the sites for female mice listed in Table 5-7.
  
- 24 • An estimate of the 95% upper bound on the overall unit risk was calculated by assuming a  
25 normal distribution for the individual risk estimates and deriving the variance of the risk  
26 estimate for each tumor site from its 95% upper confidence limit (UCL) according to the  
27 following formula:

$$28 \quad 95\% \text{ UCL} = \text{MLE} + 1.645 \times \text{SD} \quad (1)$$

29 rearranged to:

$$30 \quad \text{SD} = (\text{UCL} - \text{MLE})/1.645 \quad (2)$$

31 where 1.645 is the t-statistic corresponding to a one-sided 95% confidence interval and > 120 degrees  
32 of freedom, and the standard deviation (SD) is the square root of the variance of the MLE. The  
33 variances (variance =  $SD^2$ ) for each site-specific estimate were summed across tumor sites to obtain

1 the variance of the sum of the MLEs. The 95% UCL on the sum of the individual MLEs was  
2 calculated from expression (1) using the variance of the MLE to obtain the relevant SD (SD =  
3 variance<sup>1/2</sup>).

4 The resulting combined unit risk for all tumor types for female mice was  $3.3 \times 10^{-4}$  per  $\mu\text{g}/\text{m}^3$   
5 (with lung tumors treated as a systemic effect). Overall, the consideration of the other tumor sites  
6 increased the unit risk by two-fold from the highest unit risk for any individual tumor type,  $1.7 \times 10^{-4}$   
7 per  $\mu\text{g}/\text{m}^3$  for lung tumors treated as a systemic lesion. The increase was due largely to the  
8 hemangiosarcomas and liver tumors, with little contribution from the other tumor sites. A sensitivity  
9 analysis (not included in this document) showed that the overall risk was essentially the same (to 2  
10 significant digits) whether or not the individual risks were estimated in the region of  $10^{-2}$  risk or near  
11 the PODs.

12 For male mice the combined unit risk for all tumor types was  $1.7 \times 10^{-4}$  per  $\mu\text{g}/\text{m}^3$  (with lung  
13 tumors treated as a systemic lesion), a 2-fold increase compared to the highest unit risk for any  
14 individual tumor type,  $8.5 \times 10^{-5}$  per  $\mu\text{g}/\text{m}^3$  for lung tumors treated as a systemic lesion. The increase  
15 was due almost entirely to the risk associated with the hemangiosarcomas. As with the overall risk for  
16 female mice, there was a trivial difference whether or not the individual risks were estimated in the  
17 region of  $10^{-2}$  risk or near the PODs.

18 For estimates in both species, if the lung tumors are primarily site of contact lesions, the  
19 estimated overall risk decreases to  $2.1 \times 10^{-4}$  per  $\mu\text{g}/\text{m}^3$  (females) and  $1.1 \times 10^{-4}$  per  $\mu\text{g}/\text{m}^3$  (males).  
20 Based on the relatively high fat:air partition coefficients (see Section 3.2.) in rodents and humans,  
21 chloroprene is likely to be absorbed rapidly (U.S. EPA, 1994), consistent with the possibility that the  
22 lung tumors are both portal-of-entry and systemic lesions.

23 Based on the analyses discussed above, the recommended upper bound estimate on human  
24 extra cancer risk from continuous lifetime exposure to chloroprene is  $3 \times 10^{-4}$  per  $\mu\text{g}/\text{m}^3$ , rounding the  
25 overall risk for female mice above to one significant digit. This unit risk should not be used with  
26 continuous lifetime exposures greater than  $600 \mu\text{g}/\text{m}^3$  ( $0.6 \text{ mg}/\text{m}^3$ ), the human equivalent POD for the  
27 female lung tumors, because the observed dose-response relationships do not continue linearly above  
28 this level and the fitted dose-response models better characterize what is known about the  
29 carcinogenicity of chloroprene. The recommended unit risk estimate reflects the time-to-tumor  
30 dimension of the responses as well as the exposure-response relationships for the multiple tumor sites  
31 in both sexes of mice.

#### 5.4.5 Application of Age-Dependent Adjustment Factors

32 Because a mutagenic mode of action for chloroprene carcinogenicity is sufficiently supported  
33 by *in vivo* and *in vitro* data and relevant to humans (see Section 4.7.3.1), and in the absence of  
34 chemical-specific data to evaluate the differences in susceptibility, increased early-life susceptibility is  
35 assumed and the age-dependent adjustment factors (ADAFs) should be applied, as appropriate, along  
36 with specific exposure data in accordance with EPA's *Supplemental Guidance for Assessing*

1 *Susceptibility From Early-Life Exposure to Carcinogens* (U.S. EPA, 2005b). The inhalation unit risk  
2 of  $3 \times 10^{-4}$  per  $\mu\text{g}/\text{m}^3$ , calculated from data for adult exposures, does not reflect presumed early-life  
3 susceptibility for this chemical. Example evaluations of cancer risks based on age at exposure are  
4 given in Section 6 of the *Supplemental Guidance*.

5 The *Supplemental Guidance* establishes ADAFs for three specific age groups. The current  
6 ADAFs and their age groupings are 10 for <2 years, 3 for 2 to <16 years, and 1 for 16 years and above  
7 (U.S. EPA, 2005b). The 10-fold and 3-fold adjustments in slope factor are to be combined with age  
8 specific exposure estimates when estimating cancer risks from early life (<16 years age) exposure to  
9 chloroprene.

10 To illustrate the use of the ADAFs established in the *Supplemental Guidance* (U.S. EPA,  
11 2005b), sample calculations are presented for a lifetime risk estimate for continuous exposure from  
12 birth with a life expectancy of 70 years. The ADAFs are first applied to obtain risk estimates for  
13 continuous exposure over the three age groups:

- 14 • Risk for birth through < 2 yr =  $3 \times 10^{-4}$  per  $\mu\text{g}/\text{m}^3 \times 10 \times 2\text{yr}/70\text{yr} = 8.6 \times 10^{-5}$  per  $\mu\text{g}/\text{m}^3$
- 15 • Risk for ages 2 through < 16 =  $3 \times 10^{-4}$  per  $\mu\text{g}/\text{m}^3 \times 3 \times 14\text{yr}/70\text{yr} = 1.8 \times 10^{-4}$  per  $\mu\text{g}/\text{m}^3$
- 16 • Risk for ages 16 until 70 =  $3 \times 10^{-4}$  per  $\mu\text{g}/\text{m}^3 \times 1 \times 54\text{yr}/70\text{yr} = 2.3 \times 10^{-4}$  per  $\mu\text{g}/\text{m}^3$

17 To calculate the lifetime risk estimate for continuous exposure from birth for a population with  
18 default life expectancy of 70 years, the risk associated with each of the three relevant time periods is  
19 summed:

$$20 \bullet \text{Risk} = 8.6 \times 10^{-5} + 1.8 \times 10^{-4} + 2.3 \times 10^{-4} = 5.0 \times 10^{-4} \text{ per } \mu\text{g}/\text{m}^3$$

21 Using the above full lifetime unit risk estimate of  $5 \times 10^{-4}$  per  $\mu\text{g}/\text{m}^3$  for continuous exposure  
22 from birth to 70 years, the lifetime chronic exposure level of chloroprene corresponding to an extra  
23 risk of  $1 \times 10^{-6}$  can be estimated as follows:

$$24 \quad 1 \times 10^{-6} \div 5 \times 10^{-4} \text{ per } \mu\text{g}/\text{m}^3 = 0.002 \mu\text{g}/\text{m}^3$$

#### 5.4.6. Previous Cancer Assessment

25 The carcinogenicity of chloroprene has not been evaluated previously for the IRIS program.

#### 5.4.7. Uncertainties in Cancer Risk Values

26 A number of uncertainties underlie the cancer unit risk for chloroprene. These are discussed in  
27 the following paragraphs. Specifically addressed is the impact on the assessment of issues such as the  
28 use of models and extrapolation approaches, the use of other bioassay data, and the choices made and  
29 the data gaps identified. In addition, the use of assumptions, particularly those underlying the  
30 *Guidelines for Carcinogen Risk Assessment* (U.S. EPA, 2005a) is explained and the decision

1 concerning the preferred approach is given and justified. Principal uncertainties are discussed below  
 2 and summarized in Table 5-8.

**Table 5-8. Summary of uncertainties in chloroprene cancer unit risk estimate**

<b>Consideration</b>	<b>Potential Impact<sup>a</sup></b>	<b>Decision</b>	<b>Justification</b>
Human population variability in metabolism and response/ sensitive subpopulations	Low-dose risk could ↑ or ↓ to an unknown extent	Considered qualitatively	No data to support range of human variability/sensitivity. Mutagenic MOA indicates potentially increased early-life susceptibility.
Low-dose extrapolation procedure	Unknown; not clear what departure from Cancer Guidelines would be plausible	Multistage-Weibull model to determine POD, linear low-dose extrapolation from POD	Multistage-Weibull model addresses competing risks from other tumors and intercurrent mortality. Mutagenic MOA supports linear low-dose extrapolation.
Dose metric	Alternatives could ↑ or ↓ low-dose risk per unit concentration by an unknown extent	Used administered concentration	Experimental evidence supports a role for metabolism in toxicity, but actual responsible metabolites are neither clearly identified nor quantifiable. Use of administered concentration provides an unbiased estimate if proportional to the actual carcinogen(s).
Bioassay	Others unavailable	NTP study	Standard design, well conducted, extensively peer reviewed; carcinogenic response consistently observed across all 4 species/sex combinations.
Species /gender combination	Human risk could ↓ or ↑, depending on relative sensitivity	Multiple sites in female mice	Unit risk is based on the most sensitive endpoint (risk of any tumor type) in the most sensitive species and gender (female mouse), based on POD <sub>HEC</sub> . It was assumed that humans are as sensitive as the most sensitive rodent gender/species tested; true correspondence is unknown. Site concordance for liver tumors for humans and female mice was observed, but human data not sufficient to rule out other types seen in mice or rats.
Cross-species extrapolation	Alternatives for lung tumors differ by 4-fold: human risk for any site could ↓ or ↑. Low-dose risk would ↓ approximately 40% if lung tumors were treated as portal-of-entry effects	RfC methodology: Equal risk per unit of air concentration for all sites; for lung also considered relative surface areas of affected region. Treat lung tumors as systemic effects.	There are no data to support other alternatives. There is evidence that chloroprene is distributed systematically (observation of tumors at multiple sites), and correspondingly the possibility that chloroprene is redistributed to the lungs. The contribution of one route of delivery (i.e., inhalation vs. bloodstream) to the induction of lung tumors is currently unknown, therefore the derivation approach that returns the highest unit risk was used



Consideration	Potential Impact <sup>a</sup>	Decision	Justification
Statistical uncertainty at POD	↓ risk per unit concentration 1.2-fold if BMD <sub>10</sub> used rather than BMDL <sub>10</sub>	BMCL (default approach for calculating plausible upper bound)	Limited size of bioassay results in sampling variability; lower bound is 95% confidence interval on concentration.

<sup>a</sup> ↑ = increase, ↓ = decrease

1            *Human population variability.* The extent of inter-individual variability in chloroprene  
2 metabolism has not been characterized. A separate issue is that the human variability in response to  
3 chloroprene is also poorly understood. The effect of metabolic variation, including potential  
4 implications for differential toxicity, has not been well studied. Although a mutagenic MOA indicates  
5 increased early-life susceptibility, there are no data exploring whether there is differential sensitivity to  
6 chloroprene carcinogenicity across human life stages. This lack of understanding about potential  
7 differences in metabolism and susceptibility across exposed human populations thus represents a  
8 source of uncertainty.

*Choice of low-dose extrapolation approach.* The MOA is a key consideration in clarifying how risks should be estimated for low-dose exposure. A multistage Weibull time-to-tumor model was the preferred model because it can account for differences in mortality and other competing risks between the exposure groups in the mouse bioassay; however, it is unknown how well this model predicts low-dose extrapolated risks for chloroprene.

*Dose metric.* Chloroprene is metabolized to intermediates with carcinogenic potential, most likely an epoxide. However, data sufficient to estimate quantities were not available. Under the assumption that the carcinogenic form(s) of chloroprene are produced in proportion to low exposures of chloroprene, the derived unit risk is an unbiased estimate.

*Choice of bioassay/species/gender.* The NTP inhalation bioassay followed an accepted protocol, was well conducted, and extensively peer reviewed. The carcinogenic response occurs in both species and sexes of rodents as well as in humans. The calculated combined unit risk is based on the most sensitive endpoint (risk of any tumor type) in the most sensitive species and gender (female mouse). There is no information on chloroprene to indicate that the observed rodent tumors are not relevant to humans. Further, no data exist to guide quantitative adjustment for differences in sensitivity among rodents and humans. While site concordance generally is not assumed across species, e.g., due to potential differences in pharmacokinetics, DNA repair, other protective systems across species and tissues (U.S. EPA, 2005a), it is notable that human-mouse site concordance was observed for liver tumors. In addition, rat and mouse tumor types overlapped but included different tumor types observed for each species/sex combination. Human data were insufficient to rule out the occurrence of these additional tumor types in humans.

9            *Cross-species scaling.* Another source of uncertainty comes from the interspecies extrapolation  
10 of risk from mouse to human. The two rodent species for which bioassay data were available— mouse

1 and rat—vary in their carcinogenic responses to chloroprene, in terms of both site specificity and  
2 magnitude of response (see Chapter 4). Ideally, a PBPK model for the internal dose(s) of the reactive  
3 metabolite(s) would decrease some of the quantitative uncertainty in interspecies extrapolation;  
4 however, current PBPK models are inadequate for this purpose (Chapter 3). Existing pharmacokinetic  
5 models cannot yet adequately explain the species differences in carcinogenic response, and it is  
6 possible that there are pharmacodynamic as well as pharmacokinetic differences between the mouse  
7 and rat with respect to their sensitivities to chloroprene.

8 While concordance of specific sites between rodents and humans (e.g., liver tumors) tends to  
9 support the relevance of rodent species to humans, lack of specific site concordance (other tumors)  
10 does not diminish concern for human carcinogenic potential. The mouse was the more sensitive  
11 species to the carcinogenic effects of chloroprene exposure. Although the derivation took into account  
12 some known differences between mice and humans in tissue dosimetry (US EPA, 1994), differences in  
13 anatomy of the upper respiratory tract and resulting differences in absorption or in local respiratory  
14 system effects are sources of uncertainty.

*Statistical uncertainty at the Point of Departure (POD).* Parameter uncertainty within the chosen model reflects the limited sample size of the cancer bioassay. For the multistage-Weibull model applied to this data set, there is a reasonably small degree of uncertainty at the 10% extra risk level (the POD for linear low-dose extrapolation). Central estimates of risk differed from their upper bounds by about 1.2-fold for lung tumors and for the overall risk estimates.

*HEC derivation.* A source of uncertainty in the derivation of the HEC comes from whether or not chloroprene induces lung tumors due to portal-of-entry or systemic effects. Systemic distribution of chloroprene is evidenced by the induction of tumors in multiple organs and suggests that chloroprene may be redistributed back to the lungs and may potentially act as a systemically delivered carcinogen rather than, or in addition to, a portal-of-entry toxicant. However, the contribution of either route of delivery (i.e., inhalation vs. bloodstream) to the induction of lung tumors is currently unknown. Treating lung tumors as systemic effects returns the highest combined unit risk (approximately 60% greater than if lung tumors are treated as portal-of-entry effects).

## 6. MAJOR CONCLUSIONS IN CHARACTERIZATION OF HAZARD AND DOSE RESPONSE

### 6.1. HUMAN HAZARD POTENTIAL

1 Chloroprene (C<sub>4</sub>H<sub>5</sub>Cl, 2-chloro-1,3-butadiene, CASRN 126-99-8) is a volatile and flammable  
2 liquid monomer that can be produced by dimerization of acetylene and addition of hydrogen chloride  
3 or by chlorination of 1,3-butadiene. Chloroprene is polymerized to form elastomers for use in the  
4 manufacture of belts, hoses, gloves, wire coatings, tubing, solvents, and adhesives. Chloroprene is  
5 also a structural analogue of isoprene (2-methyl-1,3-butadiene) and resembles vinyl chloride as far as  
6 having a chlorine bound to a double-bonded carbon (alkene) backbone.

7 Toxicokinetic information on the absorption, distribution, and in vivo metabolism and excretion  
8 of chloroprene and/or its metabolites is nonexistent for humans and limited for animals. Several in  
9 vitro studies have focused on chloroprene metabolism in lung and liver tissue fractions from rat,  
10 mouse, hamster, and humans (Hurst and Ali, 2007; Munter et al., 2007a, b, 2003; Himmelstein et al.,  
11 2004a, 2001a, 2001b; Cottrell et al., 2001; Summer and Greim, 1980). These studies suggest that  
12 chloroprene is metabolized via the CYP450 enzyme system to monoepoxides [(1-  
13 chloroethenyl)oxirane and 2-chloro-2-ethynyloxirane], further metabolized to aldehydes and ketone  
14 intermediates and subsequent mercapturic acid derivatives, and cleared via hydrolysis and/or  
15 glutathione conjugation reactions. Similar to 1,3-butadiene, the epoxide metabolite is considered to be  
16 the toxic moiety. The metabolic profile for chloroprene is qualitatively similar across species.  
17 However, in vitro kinetic studies using tissues from rodents and humans suggest quantitative species  
18 and tissue-specific differences that, if operative in vivo, could contribute to the species, strain, and  
19 gender differences observed in chloroprene-induced effects.

20 Limited information exists on the noncancer effects of chloroprene due to oral ingestion. In  
21 rats, oral exposures from weaning until death (at 120 weeks) resulted in indices of liver toxicity (liver  
22 necroses and degenerative lesions of the parenchymal cells). No information is available on  
23 chloroprene's oral toxicity in humans.

24 Limited information exists on the noncancer effects of chloroprene via the inhalation route in  
25 humans. Chloroprene was reported to cause respiratory, ocular, and dermal irritation, chest pains,  
26 temporary hair loss, dizziness, insomnia, headache, and fatigue. Chest pains accompanied by  
27 tachycardia and dyspnea were also reported. In a Russian review of the effects of chloroprene,  
28 Sanotskii (1976) reported that medical examinations of chloroprene production workers revealed  
29 changes in the nervous system (lengthening of sensorimotor response to visual cues and increased  
30 olfactory thresholds), cardiovascular system (muffled heart sounds, reduced arterial pressure, and  
31 tachycardia), and hematology (reduction in red blood cell (RBC) counts, decreased hemoglobin levels,  
32 erythrocytopenia, leucopenia, and thrombocytopenia). The ambient concentration of chloroprene  
33 associated with these effects ranged from 1–7 mg/m<sup>3</sup>.

1 Chloroprene's toxic and carcinogenic potential by the inhalation route has been assessed in  
2 several laboratory animal studies, including a rat and mouse subchronic (16 days and 13 weeks) and  
3 chronic inhalation bioassays conducted by NTP (1998), a subchronic range-finding and a chronic study  
4 in rats and hamsters conducted by Trochimowicz et al. (1998), an embryotoxicity and a teratology  
5 study by Culik et al. (1978), and a series of Russian reproductive and developmental toxicity studies  
6 reviewed by Sanotskii (1976). These studies associate chloroprene inhalation exposure with  
7 respiratory, kidney, liver, forestomach, reproductive, and developmental effects. The pulmonary  
8 (alveolar hyperplasia) and nasal (olfactory epithelium) lesions were the most sensitive endpoints in  
9 chronically exposed test animals, having been observed at all the doses tested (12.8–80 ppm) in the  
10 NTP (1998) study of rats and mice. In the chronic study by Trochimowicz et al. (1998), lesions in  
11 lungs (inflammation, lymphoid aggregates around the bronchi, bronchiole, and blood vessels) and  
12 livers (small foci of cellular alteration) of rats were observed at 50 ppm. Embryotoxicity and fetal  
13 resorptions were reported in the inhalation developmental toxicity study (Culik et al., 1978). However,  
14 interpretational difficulties obscure whether this effect is an actual outcome or rather a statistical  
15 artifact of an abnormally low background rate in control animals.

16 Chloroprene's carcinogenic potential in humans has been assessed in a number of occupational  
17 epidemiologic studies among workers exposed to chloroprene monomer and/or polychloroprene latex  
18 conducted in 11 cohorts from the United States, Russia, Armenia, France, China, and Ireland. Five  
19 cohorts with sufficient numbers of liver/biliary passage cancer cases showed some evidence of  
20 association with occupational chloroprene exposure. Four mortality studies reported elevated SMRs  
21 when compared to external populations (Marsh et al., 2007a; Bulbulyan et al., 1999; Li et al., 1989;  
22 Leet and Selevan, 1982). These measures of association were strong, especially in the presence of the  
23 healthy worker effect bias. Several studies were able to use more advanced exposure assessments and  
24 internal reference populations, which should reduce this bias. These studies showed relatively  
25 consistent elevated relative risk estimates among intermediate and highly exposed workers, despite  
26 limited sample size and statistical power (Marsh et al., 2007a; Bulbulyan et al., 1999, 1998). Several  
27 studies also reported higher SMRs for lung cancer among workers exposed to chloroprene. These  
28 associations are not considered as strong as those with liver cancer due to the inability to control for  
29 confounding by smoking status, a strong indicator of lung cancer.

30 Chloroprene has been shown to induce multisite, malignant tumors in rats and mice in the 2-  
31 year NTP (1998) bioassay. Dose-related increasing trends in tumors were noted in rats at the following  
32 sites: oral cavity, thyroid gland, lung, kidney, mammary gland. Dose related increasing trends in  
33 tumors were noted in mice at the following sites: lung, all organs (hemangiomas and  
34 hemangiosarcomas), Harderian gland, forestomach, kidney, skin, liver, mammary gland, mesentery,  
35 Zymbal's gland. All of these tumor sites showed statistically significantly positive trends with  
36 increasing exposure level (Cochran-Armitage test for trend  $p < 0.05$ , most with  $p \leq 0.001$ ). In

1 addition, many early deaths and moribund sacrifices were associated with chloroprene-induced  
2 neoplasms.

3 The genetic toxicity database includes numerous studies covering a range of standard genotoxicity test  
4 batteries; however, the results have been conflicting, making it difficult to ascertain the mutagenic  
5 potential of chloroprene. In general, bacterial base pair substitution (*S. typhimurium* strains TA100  
6 and TA 1535) mutation assays have been positive (Willems, 1980; Bartsch et al., 1979), while the  
7 bacterial frame shift (*S. typhimurium* strains TA97 and TA98) mutation assays have been nonpositive  
8 (NTP, 1998; Willems, 1980). In contrast, other studies (NTP, 1998) have reported nonpositive results  
9 for all bacterial strains. A positive result with all bacterial strains was observed with chloroprene's  
10 epoxide intermediate epoxide (1-chloroethenyl)oxirane (Himmelstein et al., 2001a). Chloroprene has  
11 been primarily nonpositive in in vitro micronucleus assays (Himmelstein et al., 2001a; Drevon and  
12 Kuroki, 1979), in vivo chromosomal damage assays (NTP, 1998), and bone marrow micronucleus  
13 assays (NTP, 1998; Shelby and Witt, 1995). Conflicting results (positive in Vogel [1979]; nonpositive  
14 in Foureman et al. [1994]) have been reported for the in vivo drosophila sex-linked lethal mutation  
15 assay. Further in vivo evidence for chloroprene's mutagenicity is the observation that tissues from  
16 lung, forestomach, and Harderian gland tumors from mice exposed to chloroprene in the NTP chronic  
17 bioassay (1998) were shown to have a higher frequency of mutations in K- and H-ras proto-oncogenes  
18 than in spontaneous occurring tumors (Stills et al., 1999, 2001). There was also a high correlation  
19 between K-ras mutations and loss of heterozygosity in the same chromosome in chloroprene-induced  
20 lung neoplasms in mice (Ton et al., 2007). Possible explanations for the conflicting mutagenic  
21 responses of chloroprene in standard genotoxicity assays include methods of exposure that do not  
22 control for the high volatility of chloroprene (i.e., chloroprene is not present in the test system), the  
23 presence of more stable (perhaps more toxic) chloroprene dimers, the use of microsomal inducers that  
24 did not elicit a broad range of metabolic enzymes (specifically, in bacterial assays), and the reactivity  
25 (perhaps deactivation) of chloroprene with treatment vehicle (e.g., DMSO vs. ethanol).

26 The likely MOA for chloroprene is via mutagenicity involving epoxide metabolites formed at  
27 the target sites. The MOA determination is supported by chloroprene's epoxide metabolite formation,  
28 DNA-adduct formation, observation of in vivo and in vitro mutagenicity, and the well known  
29 structure-activity relationship of similar epoxide-forming carcinogens. Chloroprene has been found to  
30 be metabolized to epoxides by humans and rodents. The hypothesized mutagenic mode of action is  
31 supported by evidence of base pair substitution mutations seen in H- and K-ras proto-oncogenes in  
32 chloroprene-induced lung, forestomach, and Harderian gland neoplasms observed in the NTP (1998)  
33 study.

34 In addition, chloroprene is the 2-chloro analog of 1,3-butadiene. Inhalation studies have  
35 demonstrated that, similar to 1,3-butadiene and isoprene, chloroprene is a multisite carcinogen in rats  
36 and mice. Butadiene and isoprene are metabolized to epoxides and diepoxides which are believed to  
37 be responsible for their carcinogenicity. Chloroprene is also metabolized to epoxide intermediates

1 that, similarly to butadiene, may mediate its carcinogenic effects. The similarities in the sites of tumor  
2 induction in rodents (mammary gland and thyroid gland in rats, lung, Harderian gland, forestomach,  
3 kidney, and liver in mice) between butadiene and chloroprene provide further evidence for a similar  
4 MOA for these epoxide-forming compounds. In addition, the mouse lung was the most sensitive site  
5 of carcinogenicity for both chloroprene and butadiene. Similar to butadiene, DNA reactivity and  
6 adduct formation have been described for chloroprene. Areas of uncertainty exist in the data  
7 supporting a mutagenic MOA for chloroprene carcinogenicity, more specifically in the genotoxicity  
8 database. There is conflicting evidence in the bacterial genotoxicity assays and generally nonpositive  
9 findings in mammalian in vivo tests, but these results are weighed against the base pair substitution  
10 mutations seen in H- and K-ras proto-oncogenes in chloroprene-induced lung, forestomach, and  
11 Harderian gland neoplasms observed in the NTP (1998) study.

## 6.2. DOSE RESPONSE

12 The chronic inhalation study conducted by NTP (1998) was considered as the principal study  
13 for both the non-neoplastic and neoplastic effects of chloroprene exposure.

14 The respiratory system is the primary targets of chloroprene-induced non-neoplastic effects via  
15 inhalation. A range of portal-of-entry non-neoplastic effects from the NTP study (1998), including  
16 alveolar epithelial hyperplasia, bronchiolar hyperplasia, pulmonary histiocytic cell infiltration,  
17 olfactory epithelial atrophy, chronic inflammation, and necrosis were considered as candidates for the  
18 selection of the critical effect for derivation of the RfC. BMD modeling was used to determine  
19 potential PODs for deriving the chronic RfC by estimating the effective dose at a specified level of  
20 response (benchmark concentration [BMD<sub>10</sub>]) and its BMDL<sub>10</sub> for each selected chloroprene-induced  
21 respiratory and systemic effect (see Table 5-2). The HEC for each of the selected endpoints was then  
22 estimated for the best fitting models of the BMD at a BMR of 10% extra risk. Degenerative nasal  
23 lesions in male rats (characterized by atrophy or necrosis of the olfactory epithelium) resulted in the  
24 lowest POD<sub>(HEC)</sub> value of approximately 1.0 mg/m<sup>3</sup>. This POD was then divided by a 100-fold UF (3  
25 for uncertainty associated with animal to human differences, 10 for consideration of human variability,  
26 and 3 for database deficiencies) to obtain a chronic RfC of  $1 \times 10^{-2}$  mg/m<sup>3</sup>.

27 Statistically significant increases in tumor incidence were observed at multiple sites in the  
28 mouse (the most sensitive species) in the NTP study: all organs (hemangiomas and  
29 hemangiosarcomas), lung (bronchiolar/alveolar adenomas and carcinomas), forestomach, Harderian  
30 gland (adenomas and carcinomas), kidney (adenomas), skin and mesentery, liver, and mammary  
31 glands. These tumors generally appeared earlier with increasing exposure level and showed  
32 statistically significantly increasing trends with increasing exposure level (by life table test or logistic  
33 regression,  $p \leq 0.001$ ). Dose-response modeling was used to determine potential PODs for deriving  
34 the inhalation unit risk by estimating the effective dose at a specified level of response (benchmark  
35 concentration [BMD<sub>10</sub>]) and its BMDL<sub>10</sub> for each selected chloroprene-induced tumor (see Tables 5-6

1 and 5-7). Lung tumors, treated as a systemic lesion (see Section 5.4.3 and 5.4.7 for details), in female  
2 mice resulted in the highest inhalation unit risk ( $1.7 \times 10^{-4}$  per  $\mu\text{g}/\text{m}^3$ ) when modeled as an individual  
3 lesion. When etiologically different tumors were considered together (given the multiplicity of the  
4 tumor sites, basing unit risk on only one tumor site may underestimate the carcinogenic potential of  
5 chloroprene), the resulting combined inhalational unit risk for female mice was  $3.3 \times 10^{-4}$  per  $\mu\text{g}/\text{m}^3$   
6 (when lung tumors were considered systemic lesions). Based on these modeling results, the upper  
7 bound estimate on human extra lifetime cancer risk from continuous lifetime (adult) exposure to  
8 chloroprene is  $3 \times 10^{-4}$  per  $\mu\text{g}/\text{m}^3$ . Application of the ADAFs to account for early-life susceptibility to  
9 chloroprene's proposed mutagenic mode of action yields an adjusted human lifetime cancer risk of  $5 \times$   
10  $10^{-4}$  per  $\mu\text{g}/\text{m}^3$ .

11 Confidence in the principal study (NTP, 1998) is judged to be high as it was a well-designed  
12 study using two test species (rats and mice) with 50 animals per dose group. This study appropriately  
13 characterizes a range of chloroprene-induced non-neoplastic and neoplastic lesions. In addition, the  
14 key histopathological lesions observed are appropriately described, and suitable statistical analysis is  
15 applied to all animal data.

16 Confidence in the critical non-cancer effect identified in the principal study is medium to high.  
17 The critical non-cancer effect, increased incidence of degenerative nasal lesions in male rats, is  
18 consistent with what is known about chloroprene's metabolism and the expression of cytochrome p450  
19 enzymes in the olfactory and respiratory mucosa of rats, as well as the effects of structurally analogous  
20 chemicals (i.e. 1,3-butadiene).

21 Confidence in the overall database specific to chloroprene is medium to high. The major  
22 strength of the database is the observation of dose-response effects in multiple organ systems in a well-  
23 designed chronic inhalation study that utilized 50 animals per sex per dose group, a range of doses  
24 based on the results of preliminary, shorter-duration studies (16 day and 13 weeks), and thoroughly  
25 examined chloroprene's observed toxicity in two species (rat and mouse). The database further  
26 contains another chronic inhalation bioassay investigating outcomes in another species (hamster), and  
27 well-designed embryotoxicity, teratological, and reproductive toxicity studies. The database also  
28 contains subchronic studies and chronic studies observing potential neurotoxic and immunotoxic  
29 effects. A major limitation in the database is the lack of a two-generation reproductive toxicity study.  
30 Therefore, confidence in the RfC is judged to be medium to high.

## 7. REFERENCES

- 1 Appelman, LM and Dreef van der Meulen HC. (1979) Reproduction study with  $\beta$ -chloroprene vapor in rats. Report no. R  
2 6225. Produced by the Central Institute for Nutrition and Food Research (CIVO), The Netherlands, submitted by DuPont  
3 Chemical, Wilmington, DE, under TSCA Section 8D; EPA Document No. 878215005; NTIS No. OTS0206752.
- 4 Bartsch, H; Malaveille, C; Barbin, A; et al. (1979) Mutagenic and alkylating metabolites of halo-ethylenes,  
5 chlorobutadienes and dichlorobutenes produced by rodent or human liver tissues. Evidence for oxirane formation by P450-  
6 linked microsomal mono-oxygenases. Arch Toxicol 41(4):249–277.
- 7 Begemann, P; Christova-Georgieva, NI; Sangaiah, R; et al (2004) Synthesis, characterization, and identification of N7-  
8 guanine adducts of isoprene monoepoxides in vitro. Chem Res Toxicol 17: 929-936.
- 9 Bulbulyan, MA; Changuina, OV; Zaridze, DG; et al. (1998) Cancer mortality among Moscow shoe workers exposed to  
10 chloroprene (Russia). Cancer Causes Control 9(4):381–387.
- 11 Bulbulyan, MA; Margaryan, AG; Ilychova, SA; et al. (1999) Cancer incidence and mortality in a cohort of chloroprene  
12 workers from Armenia. Int J Cancer 81(1):31–33.
- 13 CambridgeSoft Corp. (2007) Chloroprene. ChemFinder. CambridgeSoft Corporation, Cambridge, MA. Available online at  
14 <http://chemfinder.cambridgesoft.com>.
- 15 Charles River Laboratories. (1996) Historical control data (1992-1994) for developmental and reproductive toxicity studies  
16 using the CrI:CD (SD)BR rat. Compiled by the Middle Atlantic Reproduction and Teratology Association. Available on-  
17 line at: [http://www.criver.com/sitecollectiondocuments/rm\\_rm\\_r\\_tox\\_studies\\_crlcd\\_sd\\_br\\_rat.pdf](http://www.criver.com/sitecollectiondocuments/rm_rm_r_tox_studies_crlcd_sd_br_rat.pdf)
- 18 Clary, JJ; Feron, VJ; Reuzel, PG. (1978) Toxicity of beta-chloroprene (2-chlorobutadiene-1,3): acute and subacute toxicity.  
19 Toxicol Appl Pharmacol 46(2):375–384.
- 20 Colonna, M; Laydevant, G. (2001) A cohort study of workers exposed to chloroprene in the department of Isère, France.  
21 Chem Biol Interact 135-136:505–514.
- 22 Corrao, G; Bagnardi, V; Zambon, A; La Vecchia, CA. (2004) A meta-analysis of alcohol consumption and the risk of 15  
23 diseases. Prev Med, 38:613-619.
- 24 Cottrell, L; Golding, BT; Munter, T; et al. (2001) In vitro metabolism of chloroprene: species differences, epoxide  
25 stereochemistry and a de-chlorination pathway. Chem Res Toxicol 14(11):1552–1562.
- 26 Cox, DR. (1972) Regression models and life-tables. J R Stat Soc B34: 187-220.
- 27 Crump, KS. (1984) A new method for determining allowable daily intakes. Fundam Appl Toxicol 4:854–871.
- 28 Crump, KS. (1995) Calculation of benchmark doses from continuous data. Risk Anal 15:79–89.
- 29 Culik, R; Kelly, DP; Clary, JJ. (1978) Inhalation studies to evaluate the teratogenic and embryotoxic potential of beta-  
30 chloroprene (2-chlorobutadiene-1,3). Toxicol Appl Pharmacol 44(1):81–88.
- 31 Dong, QA; Xiao, BL; Hu, YH; et al. (1989) Short-term test for the induction of lung tumor in mouse by chloroprene.  
32 Biomed Environ Sci 2(2):150–153.
- 33 Drevon, C; Kuroki, T. (1979) Mutagenicity of vinyl chloride, vinylidene chloride and chloroprene in V79 Chinese hamster  
34 cells. Mutat Res 67(2):173–182.
- 35 Esmen, NA; Hall, TA; Phillips, ML; et al. (2007a) Chemical process based reconstruction of exposures for an  
36 epidemiological study. I. Theoretical and methodological issues. Chem Biol Interact 166(1-3):254–263.



- 1 Esmen, NA; Hall, TA; Phillips, ML; et al. (2007b) Chemical process-based reconstruction of exposures for an  
2 epidemiological study. Part II. Estimated exposures to chloroprene and vinyl chloride. *Chem Biol Interact* 166(1-3):264–  
3 276.
- 4 Esmen, NA; Kennedy, KJ; Hall, TA; et al. (2007c) Classification of worker exposures. *Chem Biol Interact* 166(1-3):245–  
5 253.
- 6 Foureman, P; Mason, JM; Valencia, R; et al. (1994) Chemical mutagenesis testing in drosophila. X. Results of 70 coded  
7 chemicals tested for the National Toxicology Program. *Environ Mol Mutagen* 23(3):208–227.
- 8 Gahlmann, R. (1993) Pros and cons of transgenic mouse mutagenesis test systems. *J Exp Anim Sci* 35(5-6):232–243.
- 9 Gargas, ML; Burgess, RJ; Voisard, DE; et al. (1989) Partition coefficients of low-molecular-weight volatile chemicals in  
10 various liquids and tissues. *Toxicol Appl Pharmacol* 98(1):87–99.
- 11 Gart, JJ; Krewski, D; Lee, PN; et al. (1986) Statistical methods in cancer research. Volume III. The design and analysis of  
12 long-term animal experiments. *IARC Sci Publ* 79:1–219.
- 13 Ginsberg, G; Slikker Jr., W; Bruckner, J; Sonawane, B. (2004) Incorporating children's toxicokinetics into a risk  
14 framework. *Environ Health Perspect* 112(2): 272-283.
- 15 Griebel, CP; Halvorsen, J; Golemon, TB; et al. (2005) Management of spontaneous abortion. *Am Fam Physician*  
16 72(7):1243–1250.
- 17 Grosjean, D. (1990) Atmospheric chemistry of toxic contaminants 1. Reaction rates and atmospheric persistence. *J Air*  
18 *Waste Manag Assoc* 40:1397–1402.
- 19 Grosjean, D. (1991) Atmospheric chemistry of toxic contaminants 5. Unsaturated halogenated aliphatics: allyl chloride,  
20 chloroprene, hexachlorocyclopentadiene, vinylidene chloride. *J Air Waste Manag Assoc* 41:182–189.
- 21 Haley, TJ. (1978) Chloroprene (2-chloro-1, 3-butadiene)--what is the evidence for its carcinogenicity? *Clin Toxicol*  
22 13(2):153–170.
- 23 Hall, TA; Esmen, NA; Jones, EP; et al. (2007) Chemical process based reconstruction of exposures for an epidemiological  
24 study. III. Analysis of industrial hygiene samples. *Chem Biol Interact* 166(1-3):277–284.
- 25 Hill, AB. (1965) The environment and disease: Association or causation? *Proc R Soc Med* 58:295–300.
- 26 Himmelstein, MW; Gladnick, NL; Donner, EM; et al. (2001a) In vitro genotoxicity testing of (1-chloroethenyl)oxirane, a  
27 metabolite of beta-chloroprene. *Chem Biol Interact* 135-136:703–713.
- 28 Himmelstein, MW; Carpenter, SC; Hinderliter, PM; et al. (2001b) The metabolism of beta-chloroprene: Preliminary in-vitro  
29 studies using liver microsomes. *Chem Biol Interact* 135-136:267–284.
- 30 Himmelstein, MW; Carpenter, SC; Hinderliter, PM. (2004a) Kinetic modeling of beta-chloroprene metabolism: I. In vitro  
31 rates in liver and lung tissue fractions from mice, rats, hamsters, and humans. *Toxicol Sci* 79(1):18–27.
- 32 Himmelstein, MW; Carpenter, SC; Evans, MV; et al. (2004b) Kinetic modeling of beta-chloroprene metabolism: II. The  
33 application of physiologically based modeling for cancer dose response analysis. *Toxicol Sci* 79(1):28–37.
- 34 Hurst, HE; Ali, MY. (2007) Analyses of (1-chloroethenyl)oxirane headspace and hemoglobin N-valine adducts in  
35 erythrocytes indicate selective detoxification of (1-chloroethenyl)oxirane enantiomers. *Chem Biol Interact* 166(1-3):332–  
36 340.
- 37 IARC (International Agency for Research on Cancer). (1999) IARC monographs on the evaluation of carcinogenic risks of  
38 chemicals to humans. Vol. 71. Re-evaluation of some organic chemicals, hydrazine, and hydrogen peroxide. Lyon, France:  
39 International Agency for Research on Cancer. Available online at  
40 <http://monographs.iarc.fr/ENG/Monographs/vol71/volume71.pdf>.

- 1 Immels, H; Willems, M. (1978) Initial submission: Dominant lethal assay with beta-chloroprene in male mice with cover  
2 letter dated 09/01/92. Produced by the Central Institute for Nutrition and Food Research (CIVO), The Netherlands; Report  
3 No. 5756; submitted by Dupont Chemical, Wilmington, DE, under TSCA Section 8ECP; EPA Document No. 88-  
4 920008417; NTIS No. OTS0570699.
- 5 Jemal, A; Murray, T; Samuels, A; et al. (2003) Cancer statistics, 2003. *CA Cancer J Clin* 53:5–26.
- 6 Koskinen, M; Calebiro, Davide; Hemminki, K. (2000) Styrene oxide-induced 2'-deoxycytidine adducts: implications for  
7 the mutagenicity of styrene oxide. *Chem Biol Interact* 126:201-213.
- 8 Krewski, D; Crump, KS; Farmer, J; et al. (1983) A comparison of statistical methods for low dose extrapolation utilizing  
9 time-to-tumor data. *Fundam Appl Toxicol* 3(3):140–160.
- 10 Kroshwitz, JI; Howe-Grant, M; eds. (1993) Chloroprene. *Kirk-Othmer encyclopedia of chemical technology*. Vol. 6. 4<sup>th</sup>  
11 edition. New York, NY: Wiley; pp. 70–78.
- 12 Leet, T; Selevan, S. (1982) Mortality analysis of workers exposed to chloroprene [final report]. E.I. du Pont de Nemours  
13 and Co., Inc., Wilmington, DE. Available from the National Technical Information Service, Springfield, VA; PB83-193581.
- 14 Lefaux, R; ed. (1968) Chloroprene. In: *Practical toxicology of plastics*. London: Iliffe Books, Ltd.; pp. 69–71.
- 15 Li, SQ; Dong, QN; Liu, YQ; et al. (1989) Epidemiologic study of cancer mortality among chloroprene workers. *Biomed*  
16 *Environ Sci* 2(2):141–149.
- 17 Luster, MI; Portier, C; Pait, DG; White, Jr., KL; Gennings, G; Munson, AE; Rosenthal, GJ. (1992) Risk assessment in  
18 immunotoxicity. I. Sensitivity and predictability of immune tests. *Fundam Appl Toxicol* 8:200-210.
- 19 Lynch, J. (2001a) BD monomer and elastomer production processes. *Chem Biol Interact* 135–136:147–153.
- 20 Lynch, M. (2001b) Manufacture and use of chloroprene monomer. *Chem Biol Interact* 135–136:155–167.
- 21 MacGregor, JT; Wehr, CM; Henika, PR; et al. (1990) The in vivo erythrocyte micronucleus test: measurement at steady  
22 state increases assay efficiency and permits integration with toxicity studies. *Fundam Appl Toxicol* 14(3):513–522.
- 23 Marsh, GM; Youk, AO; Buchanich, JM; et al. (2007a) Mortality patterns among industrial workers exposed to chloroprene  
24 and other substances. I. General mortality patterns. *Chem Biol Interact* 166(1-3):285–300.
- 25 Marsh, GM; Youk, AO; Buchanich, JM; et al. (2007b) Mortality patterns among industrial workers exposed to chloroprene  
26 and other substances. II. Mortality in relation to exposure. *Chem Biol Interact* 166(1-3): 301–316.
- 27 Mast, TJ; Evanhoff, JJ; Westerberg, RL; et al. (1994) Inhalation developmental toxicology studies: developmental toxicity  
28 of chloroprene vapors in New Zealand white rabbits. Prepared by Battelle Pacific Northwest Laboratories, Richland, WA,  
29 for the National Institute of Environmental Health Sciences, U.S. Department of Health and Human Services, Research  
30 Triangle Park, NC; PNL-7458. Available from the National Technical Information Service, Springfield, VA; DE94012384.
- 31 Medinsky, MA and Bond, JA. (2001) Sites and mechanisms for uptake of gases and vapors in the respiratory tract.  
32 *Toxicology* 160: 165-172.
- 33 Melnick, RL; Sills, RC. (2001) Comparative carcinogenicity of 1,3-butadiene, isoprene, and chloroprene in rats and mice.  
34 *Chem Biol Interact* 135-136:27–42.
- 35 Melnick, RL; Elwell, MR; Roycroft, JH; et al. (1996) Toxicity of inhaled chloroprene (2-chloro-1,3-butadiene) in F344 rats  
36 and B6C3F(1) mice. *Toxicology* 108(1–2):79–91.
- 37 Melnick, RL; Sills, RC; Portier, CJ; et al. (1999) Multiple organ carcinogenicity of inhaled chloroprene (2-chloro-1,3-  
38 butadiene) in F344/N rats and B6C3F1 mice and comparison of dose-response with 1,3-butadiene in mice. *Carcinogenesis*  
39 20(5):867–878.

- 1 Melnick, RL; Sills, RC; Roycroft, JH; Chou, BJ; Ragan, HA; Miller, RA (1994) Isoprene, an endogenous hydrocarbon and  
2 industrial chemical, induces multiple organ neoplasia in rodents after 26 weeks of inhalation exposure. *Can Res* 54: 5333-  
3 5339.
- 4 Munter, T; Cottrell, L; Ghai, R; et al. (2007a) The metabolism and molecular toxicology of chloroprene. *Chem Biol*  
5 *Interact* 166(1-3):323-331.
- 6 Munter, T; Cottrell, L; Ghai, R; et al. (2007b) Erratum to “The metabolism and molecular toxicology of chloroprene”  
7 [Chem Biol Interact 2007; 166(1-3):323-331]. *Chem Biol Interact* 168(2):169.
- 8 Munter, T; Cottrell, L; Golding, BT; et al. (2003) Detoxication pathways involving glutathione and epoxide hydrolase in the  
9 in vitro metabolism of chloroprene. *Chem Res Toxicol* 16(10):1287-1297.
- 10 Munter, T; Cottrell, L; Hill, S; et al. (2002) Identification of adducts derived from reactions of (1-chloroethenyl)oxirane  
11 with nucleosides and calf thymus DNA. *Chem Res Toxicol* 15: 1549-1560.
- 12 NLM (National Library of Medicine). (2008) 2-Chloro-1,3-butadiene. HSDB (Hazardous Substances Data Bank). National  
13 Institutes of Health, U.S. Department of Health and Human Services, Bethesda, MD. Available online at  
14 <http://toxnet.nlm.nih.gov>.
- 15 NRC (National Research Council). (1983) Risk assessment in the federal government: Managing the process. Washington,  
16 DC: National Academy Press.
- 17 NRC (National Research Council). (1994) Science and judgement in risk assessment. Washington, DC:National Academy  
18 Press.
- 19 NTP (National Toxicology Program). (1985) Technical protocol for sperm morphology and vaginal cytology evaluations in  
20 toxicity testing for rats and mice, 10/31/82 version (updated March 1985). Public Health Service, U.S. Department of  
21 Health and Human Services. Available from the National Institute of Environmental Health Sciences, Research Triangle  
22 Park, NC.
- 23 NTP (National Toxicology Program). (1996) Toxicology and carcinogenesis studies of chloroprene (CAS No. 126-99-8) in  
24 F344/N rats and B6C3F1 mice (inhalation studies) [draft]. Public Health Service, U.S. Department of Health and Human  
25 Services; NTP TR-467. Available from the National Institute of Environmental Health Sciences, Research Triangle Park,  
26 NC.
- 27 NTP (National Toxicology Program). (1998) Toxicology and carcinogenesis studies of chloroprene (CAS No. 126-99-8) in  
28 F344/N rats and B6C3F1 mice (inhalation studies). Public Health Service, U.S. Department of Health and Human Services;  
29 NTP TR-467. Available from the National Institute of Environmental Health Sciences, Research Triangle Park, NC, and  
30 online at [http://ntp.niehs.nih.gov/ntp/htdocs/LT\\_rpts/tr467.pdf](http://ntp.niehs.nih.gov/ntp/htdocs/LT_rpts/tr467.pdf).
- 31 NTP (National Toxicology Program). (2000) 9th Report on carcinogens. Public Health Service, U.S. Department of Health  
32 and Human Services, Research Triangle Park, NC.
- 33 NTP (National Toxicology Program). (2005) 11th Report on carcinogens. Public Health Service, U.S. Department of  
34 Health and Human Services, Research Triangle Park, NC. Available online at [http://ntp.niehs.nih.gov/?objectid=035E5806-  
35 F735-FE81-FF769DFE5509AF0A](http://ntp.niehs.nih.gov/?objectid=035E5806-F735-FE81-FF769DFE5509AF0A).
- 36 Nystrom, A. (1948) Health hazards in the chloroprene rubber industry and their prevention. *Acta Med Scand* 132(Suppl.  
37 219):1-125.
- 38 OECD (Organisation for Economic Co-operation and Development). (1998) Chloroprene. Screening Information DataSet  
39 (SIDS) High Production Volume Chemicals. United Nations Environment Programme (UNEP) Publications, Nairobi,  
40 Kenya. Available online at <http://www.inchem.org/documents/sids/sids/Chloroprene.pdf>.
- 41 Pell, S. (1978) Mortality of workers exposed to chloroprene. *J Occup Med* 20(1):21-29.

- 1 Placke, ME; Griffs, L; Bird, M; Bus, J; Persing, RL; Cox Jr, AC (1996) Chronic inhalation oncogenicity study of isoprene  
2 in B6C3F1 mice. *Toxicology* 110: 253-262.
- 3 Ponomarkov, V; Tomatis, L. (1980) Long-term testing of vinylidene chloride and chloroprene for carcinogenicity in rats.  
4 *Oncology* 37(3):136–141.
- 5 Portier, CJ; Bailer, AJ. (1989) Testing for increased carcinogenicity using a survival-adjusted quantal response test.  
6 *Fundam Appl Toxicol* 12(4):731–737.
- 7 Putman, E; van der Laan, JW; van Loveren, H. (2003) Assessing immunotoxicity: guidelines. *Fund Clinical Pharamcol*  
8 17(5): 615-626.
- 9 Rice, JM; Boffetta, P. (2001) 1,3-Butadiene, isoprene and chloroprene: Reviews by the IARC monographs programme,  
10 outstanding issues, and research priorities in epidemiology. *Chem Biol Interact* 135-136:11–26.
- 11 Romazini, S; Laydevant, G; Lutz, J; et al. (1992) Mortality study in occupational exposure to chloroprene. *Arch Mal Prof*  
12 8:721–725.
- 13 Rothman, K. (1986) *Modern epidemiology*. Boston, MA: Little, Brown and Co.
- 14 Sanotskii, IV. (1976) Aspects of the toxicology of chloroprene: Immediate and long-term effects. *Environ Health Perspect*  
15 17:85–93.
- 16 Savitz, DA; Sonnenfeld, NL; Olshan, AF. (1994) Review of epidemiologic studies of paternal occupational exposure and  
17 spontaneous abortion. *Am J Ind Med* 25(3):361–383.
- 18 Schrag, SD; Dixon, RL. (1985) Occupational exposures associated with male reproductive dysfunction. *Annu Rev*  
19 *Pharmacol Toxicol* 25:567–592.
- 20 Shelby, MD. (1990) Results of NTP-sponsored mouse cytogenetic studies on 1,3-butadiene, isoprene, and chloroprene.  
21 *Environ Health Perspect* 86:71–73.
- 22 Shelby, MD; Witt, KL. (1995) Comparison of results from mouse bone marrow chromosome aberration and micronucleus  
23 tests. *Environ Mol Mutagen* 25(4):302–313.
- 24 Sills, RC; Hong, HL; Boorman, GA; et al. (2001) Point mutations of K-ras and H-ras genes in forestomach neoplasm from  
25 control B6C3F1 mice and following exposure to 1,3-butadiene, isoprene or chloroprene for up to 2-years. *Chem Bio Inter*  
26 135-136: 373–386.
- 27 Sills, RC; Hong, HL; Melnick, RL; et al. (1999) High frequency of codon 61 K-ras A-->T transversions in lung and  
28 Harderian gland neoplasms of B6C3F1 mice exposed to chloroprene (2-chloro-1,3-butadiene) for 2 years, and comparisons  
29 with the structurally related chemicals isoprene and 1,3-butadiene. *Carcinogenesis* 20(4):657–662.
- 30 Stewart, KJ. (1971) Dimerization of chloroprene and related dimers. *J Am Chem Soc* 93:4815–4821.
- 31 Summer, KH; Greim, H. (1980) Detoxification of chloroprene (2-chloro-1,3-butadiene) with glutathione in the rat.  
32 *Biochem Biophys Res Commun* 96(2):566–573.
- 33 Tarone, RE. (1975) Tests for trend in lifre table analysis. *Biometrika* 62: 679-682.
- 34 Thornton-Manning, JR and Dahl, AR. (1997) Metabolic capacity of nasal tissue: interspecies comparisons of xenobiotic-  
35 metabolizing enzymes. *Mutat Res* 380: 43-59.
- 36 Tice, RR. (1988) The cytogenetic evaluation of in vivo genotoxic and cytotoxic activity using rodent somatic cells. *Cell*  
37 *Biol Toxicol* 4(4):475–486.
- 38 Tice, RR; Boucher, R; Luke, CA; et al. (1988) Chloroprene and isoprene: cytogenetic studies in mice. *Mutagenesis*  
39 3(2):141–146.

- 1 Ton, TV; Hong, HH; Devereux, TR; et al. (2007) Evaluation of genetic alterations in cancer-related genes in lung and brain  
2 tumors from B6C3F1 mice exposed to 1,3-butadiene or chloroprene. *Chem Biol Interact* 166(1-3):112–120.
- 3 Trochimowicz, H; Loser, E; Feron, V; et al. (1998) Chronic inhalation toxicity and carcinogenicity studies on beta-  
4 chloroprene in rats and hamsters. *Inhal Toxicol* 10:443–472.
- 5 U.S. EPA, (Environmental Protection Agency). (1985) Summary overview of health effects associated with chloroprene.  
6 Environmental Criteria and Assessment Office, Office of Health and Environmental Assessment
- 7 U.S. EPA (Environmental Protection Agency). (1986a) Guidelines for the health risk assessment of chemical mixtures.  
8 Federal Register 51(185):34014–34025. Available online at <http://www.epa.gov/ncea/raf/rafguid.htm>.
- 9 U.S. EPA (Environmental Protection Agency). (1986b) Guidelines for mutagenicity risk assessment. Federal Register  
10 51(185):34006–34012. Available online at <http://www.epa.gov/ncea/raf/rafguid.htm>.
- 11 U.S. EPA (Environmental Protection Agency). (1988) Recommendations for and documentation of biological values for use  
12 in risk assessment. Environmental Criteria and Assessment Office, Office of Health and Environmental Assessment,  
13 Cincinnati, OH; EPA/600/6-87/008. Available from the National Technical Information Service, Springfield, VA, PB88-  
14 179874/AS, and online at <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=34855>.
- 15 U.S. EPA (Environmental Protection Agency). (1991) Guidelines for developmental toxicity risk assessment. Federal  
16 Register 56(234):63798–63826. Available online at <http://www.epa.gov/ncea/raf/rafguid.htm>.
- 17 U.S. EPA (Environmental Protection Agency). (1994a) Interim policy for particle size and limit concentration issues in  
18 inhalation toxicity: Notice of availability. Federal Register 59(206):53799. Available online at <http://www.epa.gov/EPA-PEST/1994/October/Day-26/pr-11.html>.
- 20 U.S. EPA (Environmental Protection Agency). (1994b) Methods for derivation of inhalation reference concentrations and  
21 application of inhalation dosimetry. Environmental Criteria and Assessment Office, Office of Health and Environmental  
22 Assessment, Cincinnati, OH; EPA/600/8-90/066F. Available from the National Technical Information Service, Springfield,  
23 VA, PB2000-500023, and online at <http://cfpub.epa.gov/ncea/raf/recordisplay.cfm?deid=71993>.
- 24 U.S. EPA (Environmental Protection Agency). (1995) Use of the benchmark dose approach in health risk assessment. Risk  
25 Assessment Forum, Washington, DC; EPA/630/R-94/007. Available from the National Technical Information Service,  
26 Springfield, VA, PB95-213765, and online at  
27 [http://cfpub.epa.gov/ncea/raf/raf\\_pubtitles.cfm?detype=document&excCol=archive](http://cfpub.epa.gov/ncea/raf/raf_pubtitles.cfm?detype=document&excCol=archive).
- 28 U.S. EPA (Environmental Protection Agency). (1996) Guidelines for reproductive toxicity risk assessment. Federal  
29 Register 61(212):56274–56322. Available online at <http://www.epa.gov/ncea/raf/rafguid.htm>.
- 30 U.S. EPA (Environmental Protection Agency). (1998) Guidelines for neurotoxicity risk assessment. Federal Register  
31 63(93):26926–26954. Available online at <http://www.epa.gov/ncea/raf/rafguid.htm>.
- 32 U.S. EPA (Environmental Protection Agency). (2000a) Science policy council handbook: Risk characterization. Office of  
33 Science Policy, Office of Research and Development, Washington, DC. EPA/100-B-00-002. Available online at  
34 <http://www.epa.gov/OSA/spc/pdfs/prhandbk.pdf>.
- 35 U.S. EPA (Environmental Protection Agency). (2000b) Benchmark dose technical guidance document [external review  
36 draft]. Risk Assessment Forum, Washington, DC; EPA/630/R-00/001. Available online at <http://cfpub.epa.gov/ncea/cfm/nceapublication.cfm?ActType=PublicationTopics&detype=DOCUMENT&subject=BENCHMARK+DOSE&subtype=TITLE&excCol=Archive>.
- 39 U.S. EPA (Environmental Protection Agency). (2000c) Supplementary guidance for conducting health risk assessment of  
40 chemical mixtures. Risk Assessment Forum, Washington, DC; EPA/630/R-00/002. Available online at  
41 [http://cfpub.epa.gov/ncea/raf/chem\\_mix.cfm](http://cfpub.epa.gov/ncea/raf/chem_mix.cfm).

- 1 U.S. EPA (Environmental Protection Agency). (2000d) Chloroprene (2-chloro-1,3-butadiene). Hazard summary,  
2 Technology Transfer Network Air Toxics Web Site. Office of Air and Radiation, Washington, DC. Available online at  
3 <http://www.epa.gov/ttn/atw/hlthef/chloropr.html>.
- 4 U.S. EPA (Environmental Protection Agency). (2000e) Guidance for data quality assessment: Practical methods for data  
5 analysis. Office of Environmental Information, Washington, DC; EPA/600/R-96/084.
- 6 U.S. EPA (Environmental Protection Agency). (2000f) Toxicological review of vinyl chloride. Integrated Risk Information  
7 System. National Center for Environmental Assessment. Washington, DC: EPA/635R-00/004. Available online at:  
8 <http://www.epa.gov/ncea/iris/toxreviews/1001-tr.pdf>
- 9 U.S. EPA (Environmental Protection Agency). (2002a) A review of the reference dose concentration and reference  
10 concentration processes. Risk Assessment Forum, Washington, DC; EPA/630/P-02/002F. Available online at  
11 [http://cfpub.epa.gov/ncea/raf/raf\\_pubtitles.cfm?detype=document&excCol=archive](http://cfpub.epa.gov/ncea/raf/raf_pubtitles.cfm?detype=document&excCol=archive).
- 12 U.S. EPA (Environmental Protection Agency). (2002b) Health assessment of 1,3-butadiene. National Center for  
13 Environmental Assessment. Washington, DC: EPA/600/P-98/001F. Available online at  
14 <http://www.epa.gov/ncea/iris/supdocs/buta-sup.pdf>
- 15 U.S. EPA (Environmental Protection Agency). (2005a) Guidelines for carcinogen risk assessment. Federal Register  
16 70(66):17765–18717. Available online at <http://www.epa.gov/cancerguidelines>.
- 17 U.S. EPA (Environmental Protection Agency). (2005b) Supplemental guidance for assessing susceptibility from early-life  
18 exposure to carcinogens. Risk Assessment Forum, Washington, DC; EPA/630/R-03/003F. Available online at  
19 <http://www.epa.gov/cancerguidelines>.
- 20 U.S. EPA (Environmental Protection Agency). (2006a) Science policy council handbook: Peer review. 3rd edition. Office  
21 of Science Policy, Office of Research and Development, Washington, DC; EPA/100/B-06/002. Available online at  
22 <http://www.epa.gov/OSA/spc/2peerrev.htm>.
- 23 U.S. EPA (Environmental Protection Agency). (2006b) A framework for assessing health risk of environmental exposures  
24 to children. National Center for Environmental Assessment, Washington, DC; EPA/600/R-05/093F. Available online at  
25 <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=158363>.
- 26 Vogel, E. (1979) Mutagenicity of chloroprene, 1-chloro-1,3-trans-butadiene, 1-4-dichlorobutene-2 and 1,4-dichloro-2,3-  
27 epoxybutane in *Drosophila melanogaster*. *Mutat Res* 67(4):377–381.
- 28 Watson, WP; Cottrell, L; Zhang, D; Golding, BT (2001) Metabolism and molecular toxicology of isoprene. *Chem-Biol*  
29 *Inter* 135-136: 223-238.
- 30 Westphal, GA; Blaszkewicz, M; Leutbecher, M; et al. (1994) Bacterial mutagenicity of 2-chloro-1,3-butadiene  
31 (chloroprene) caused by decomposition products. *Arch Toxicol* 68(2):79–84.
- 32 Willems, M. (1978) Evaluation of beta-chloroprene and five dimmers in the Salmonella/microsome mutagenicity test.  
33 Report no. R 6392. Produced by the Central Institute for Nutrition and Food Research (CIVO), The Netherlands; submitted  
34 by Dupont Chemical, Wilmington, DE, under TSCA Section 8ECP
- 35 Willems, M. (1980) Evaluation of beta-chloroprene and 4-chloroprene dimers in the Ames test by atmospheric exposure of  
36 the tester strains with cover letter dated 090192. Produced by the Central Institute for Nutrition and Food Research (CIVO),  
37 The Netherlands; submitted by Dupont Chemical, Wilmington, DE, under TSCA Section 8ECP; EPA Document No. 88-  
38 920008421; NTIS No. OTS0570703.

**APPENDIX A. SUMMARY OF EXTERNAL PEER REVIEW AND PUBLIC COMMENTS  
AND DISPOSITION**

1  
2  
3  
4

[page intentionally left blank]

## APPENDIX B. BENCHMARK DOSE MODELING RESULTS FOR THE DERIVATION OF THE RFC

1 Benchmark Dose (BMD) modeling was performed to identify the point of departure for the  
 2 derivation of the chronic RfC for chloroprene. The modeling was conducted in accordance with the  
 3 draft EPA guidelines (U.S. EPA, 2000b) using Benchmark Dose Software Version 2.0 (BMDS). The  
 4 BMDS model outputs for the derivation of the chronic RfC are attached.

5 The following critical effects were modeled using BMDS: alveolar epithelial hyperplasia,  
 6 bronchiolar hyperplasia, lung histiocytic cell infiltration, nasal epithelial chronic inflammation, nasal  
 7 epithelium atrophy, nasal epithelial necrosis, and splenic hematopoietic cell proliferation. The  
 8 endpoint being modeled specified which set of models, continuous (linear, polynomial, power, and  
 9 Hill) or dichotomous (gamma, logistic, multi-stage, probit, quantal-linear, quantal-quadratic, Weibull,  
 10 and dichotomous Hill), would be utilized. Model eligibility was determined by assessing the  
 11 goodness-of-fit using a value of  $\alpha = 0.1$  (when appropriate), visual fit, and ranking by Akaike  
 12 Information Criterion (AIC).

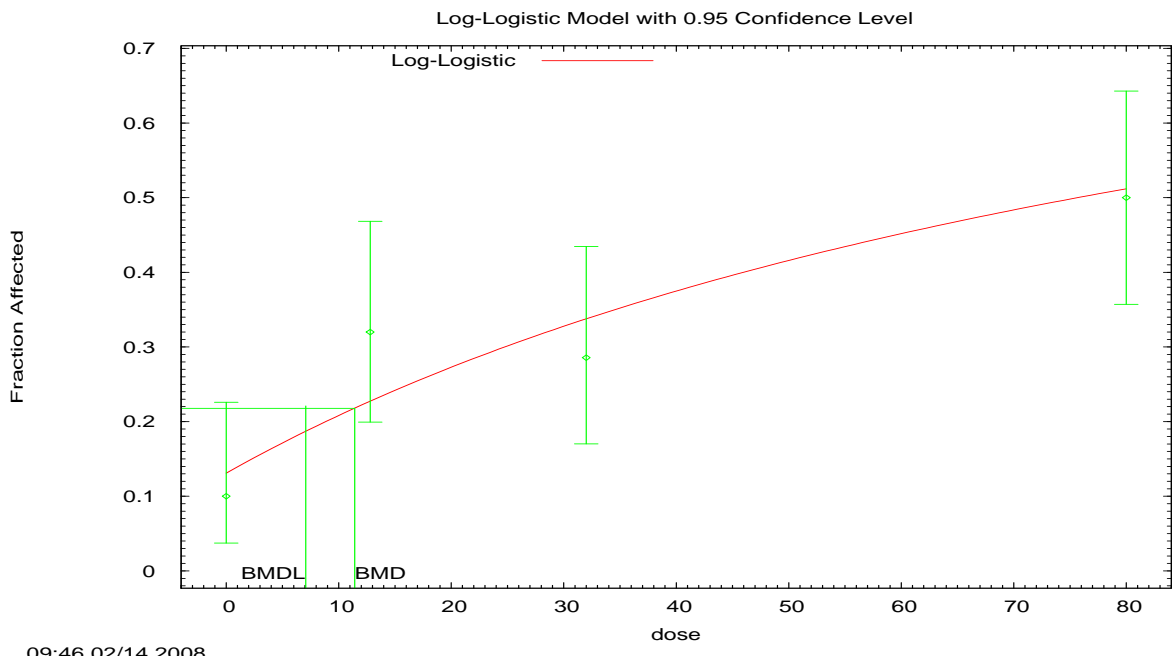
13 The critical endpoint selected for the derivation of the chronic RfC was increased incidence of  
 14 degenerative nasal lesions in male rats. The logistic model provided the best fit for this data set. The  
 15 following tables (B-1 through B-9) are summaries of the modeling results for all considered endpoints.  
 16 The best fitting model for each endpoint is indicated in **bold** and the model plot and output are  
 17 included immediately after the table.

**Table B-1. Modeling Results for Alveolar Epithelial Hyperplasia in Male F344/N Rats**

<b>Model:</b>	<b>Gamma</b>	<b>Logistic</b>	<b>Log-Logistic</b>	<b>Log-Probit</b>	<b>Probit</b>	<b>Weibull</b>	<b>Quantal-Linear</b>	<b>Hill</b>
<b>Restricted:</b>	Yes		Yes	Yes		Yes		Yes
<b>BMR:</b>	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
<b>BMR Type:</b>	Extra Risk	Extra Risk	Extra Risk	Extra Risk	Extra Risk	Extra Risk	Extra Risk	Extra Risk
<b>BMD</b>	14.8657	24.4838	11.4228	28.604	23.3986	14.866	14.866	3.54712
<b>BMDL</b>	10.0883	19.1571	7.06934	19.5927	18.2584	10.0883	10.0883	9.05E-08
<b>Chi<sup>2</sup></b>	4.05	5.12	3.48	6.63	5.02	4.05	4.05	1.989357
<b>Goodness-of-fit p-value</b>	0.1317	0.0775	0.1753	0.0363	0.0813	0.1317	0.1317	NA
<b>AIC</b>	231.042	232.34	230.479	233.859	232.209	231.042	231.042	233.164
<b>Fitted Log-Likelihood</b>	-113.521	-114.17	-113.24	-114.93	-114.104	-113.521	-113.521	-112.582
<b>Fitted p-value</b>	0.1421	0.0743	0.1883	0.03475	0.07933	0.1421	0.1421	NA



Scaled Residuals:								
0	-0.928	-0.928	-0.649	-1.676	-1.427	-0.928	-0.928	-0.1573
12.8	1.698	1.698	1.566	1.939	1.711	1.698	1.698	0.6599
32	-0.509	-0.509	-0.763	-0.087	-0.126	-0.509	-0.509	-1.122
80	-0.224	-0.224	-0.16	-0.23	-0.198	-0.224	-0.224	0.5197



09:46 02/14 2008

**Figure B-1. Log-logistic model fit for alveolar epithelial hyperplasia in male F344/N rats**

```

=====
1
2 Logistic Model. (Version: 2.10; Date: 09/23/2007)
3 Input Data File: U:\Chloroprene\Male_F344_rat\alv_hyper_loglog.(d)
4 Gnuplot Plotting File: U:\Chloroprene\Male_F344_rat\alv_hyper_loglog.plt
5 Thu Feb 14 09:46:06 2008
6
7 =====
8 BMDS Model Run
9 ~~~~~
10 The form of the probability function is:
11 P[response] = background+(1-background)/[1+EXP(-intercept-slope*Log(dose))]
12 Dependent variable = alveolar_hyper
13 Independent variable = DOSE
14 Slope parameter is restricted as slope >= 1
15 Total number of observations = 4
16 Total number of records with missing values = 0
17 Maximum number of iterations = 250
18 Relative Function Convergence has been set to: 1e-008
19 Parameter Convergence has been set to: 1e-008
20 User has chosen the log transformed model
21
22 Default Initial Parameter Values
23 background = 0.1

```

1 intercept = -4.4782  
2 slope = 1

3  
4 Asymptotic Correlation Matrix of Parameter Estimates

5  
6 ( \*\*\* The model parameter(s) -slope  
7 have been estimated at a boundary point, or have been specified by the user,  
8 and do not appear in the correlation matrix )  
9 background intercept

10  
11 background 1 -0.66  
12 intercept -0.66 1

13  
14 Parameter Estimates

15  
16 95.0% Wald Confidence Interval  
17 Variable Estimate S td. Err. Lower Conf. Limit Upper Conf. Limit  
18 background 0.130984 \* \* \*  
19 intercept -4.63283 \* \* \*  
20 slope 1 \* \* \*

21  
22 \* - Indicates that this value is not calculated.

23  
24 Analysis of Deviance Table

25  
26 Model Log(likelihood) # Param's Deviance Test d.f. P-value  
27 Full model -111.57 4  
28 Fitted model -113.24 2 3.33902 2 0.1883  
29 Reduced model -121.815 1 20.4898 3 0.0001343

30  
31 AIC: 230.479

32  
33 Goodness of Fit

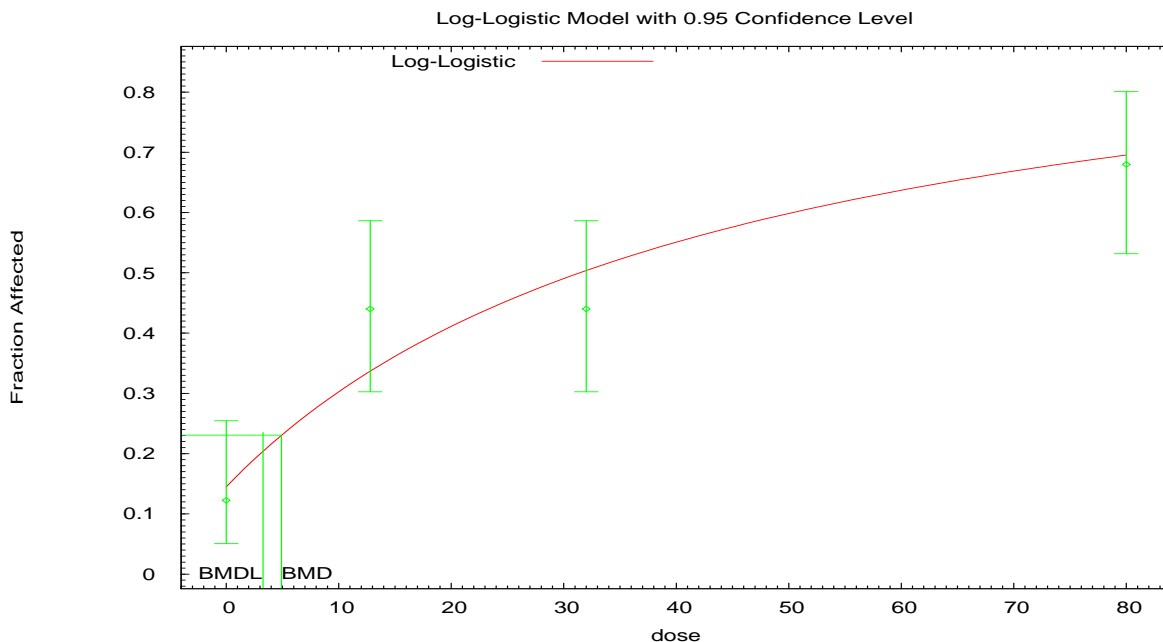
34 Scaled  
35 Dose Est\_Prob. Expected Observed Size Residual  
36 -----  
37 0.0000 0.1310 6.549 5 50 -0.649  
38 12.8000 0.2272 11.360 16 50 1.566  
39 32.0000 0.3373 16.526 14 49 -0.763  
40 80.0000 0.5113 25.564 25 50 -0.160

41  
42 Chi^2 = 3.48 d.f. = 2 P-value = 0.1753

43  
44  
45 Benchmark Dose Computation  
46 Specified effect = 0.1  
47 Risk Type = Extra risk  
48 Confidence level = 0.95  
49 BMD = 11.4228  
50 BMDL = 7.06934

**Table B-2. Modeling Results for Alveolar Epithelial Hyperplasia in Female F344/N Rats**

<b>Model:</b>	<b>Gamma</b>	<b>Logistic</b>	<b>Log-Logistic</b>	<b>Log-Probit</b>	<b>Probit</b>	<b>Weibull</b>	<b>Quantal-Linear</b>	<b>Hill</b>
<b>Restricted:</b>	Yes		Yes	Yes		Yes		Yes
<b>BMR:</b>	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
<b>BMR Type:</b>	Extra Risk	Extra Risk	Extra Risk	Extra Risk	Extra Risk	Extra Risk	Extra Risk	Extra Risk
<b>BMD</b>	8.0322	14.8564	4.90719	15.342	14.4844	8.03223	8.03223	1.42027
<b>BMDL</b>	5.89582	11.9857	3.27097	10.7468	11.8082	5.89582	5.89582	0.001489
<b>Chi<sup>2</sup></b>	5.59	8.24	3.45	9.68	8.14	5.59	5.59	1.853207
<b>Goodness-of-fit p-value</b>	0.0612	0.0163	0.1779	0.0079	0.0171	0.0612	0.0612	0.1734
<b>AIC</b>	245.78	248.949	243.677	249.954	248.806	245.78	245.78	244.161
<b>Fitted Log-Likelihood</b>	-120.89	-122.475	-119.839	-122.977	-122.403	-120.89	-120.89	-119.081
<b>Fitted p-value</b>	0.06481	0.01328	0.1854	0.00804	0.01427	0.06481	0.06481	0.1733
<b>Scaled Residuals:</b>								
<b>0</b>	-1.098	-2.002	-0.453	-1.77	-1.96	-1.098	-1.098	-0.05399
<b>12.8</b>	1.998	1.99	1.536	2.446	2.006	1.998	1.998	0.6151
<b>32</b>	-0.328	0.271	-0.91	-0.201	0.275	-0.328	-0.328	-1.089
<b>80</b>	-0.531	-0.442	-0.246	-0.723	-0.439	-0.531	-0.531	0.5347



13:10 02/14 2008

**Figure B-2. Log-logistic model fit for alveolar epithelial hyperplasia in female F344/N rats**

```

1  =====
2  Logistic Model. (Version: 2.10; Date: 09/23/2007)
3  Input Data File: U:\Chloroprene\Female_F344_rat\alv_hyper_loglog(d)
4  Gnuplot Plotting File: U:\Chloroprene\Female_F344_rat\alv_hyper_loglog.plt
5                                     Thu Feb 14 13:10:35 2008
6  =====
7
8  BMDS Model Run
9  ~~~~~
10
11  The form of the probability function is:
12  P[response] = background+(1-background)/[1+EXP(-intercept-slope*Log(dose))]
13  Dependent variable = alveolar_hyper
14  Independent variable = DOSE
15  Slope parameter is restricted as slope >= 1
16  Total number of observations = 4
17  Total number of records with missing values = 0
18  Maximum number of iterations = 250
19  Relative Function Convergence has been set to: 1e-008
20  Parameter Convergence has been set to: 1e-008
21  User has chosen the log transformed model
22
23  Default Initial Parameter Values
24  background = 0.122449
25  intercept = -3.74532
26  slope = 1
27
28
29  Asymptotic Correlation Matrix of Parameter Estimates
30
31  ( *** The model parameter(s) -slope
32  have been estimated at a boundary point, or have been specified by the user,
33  and do not appear in the correlation matrix )

```

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45

background intercept

background	1	-0.62
intercept	-0.62	1

Parameter Estimates

Variable	Estimate	Std. Err.	95.0% Wald Confidence Interval	
			Lower Conf. Limit	Upper Conf. Limit
background	0.145252	*	*	*
intercept	-3.78793	*	*	*
slope	1	*	*	*

\* - Indicates that this value is not calculated.

Analysis of Deviance Table

Model	Log(likelihood)	# Param's	Deviance	Test d.f.	P-value
Full model	-118.153	4			
Fitted model	119.839	2	3.37005	2	0.1854
Reduced model	-135.512	1	34.7167	3	<.0001

AIC: 243.677

Goodness of Fit

Dose	Est._Prob.	Expected	Observed	Size	Scaled Residual
0.0000	0.1453	7.117	6	49	-0.453
12.8000	0.3373	16.866	22	50	1.536
32.0000	0.5044	25.218	22	50	-0.910
80.0000	0.6960	34.799	34	50	-0.246

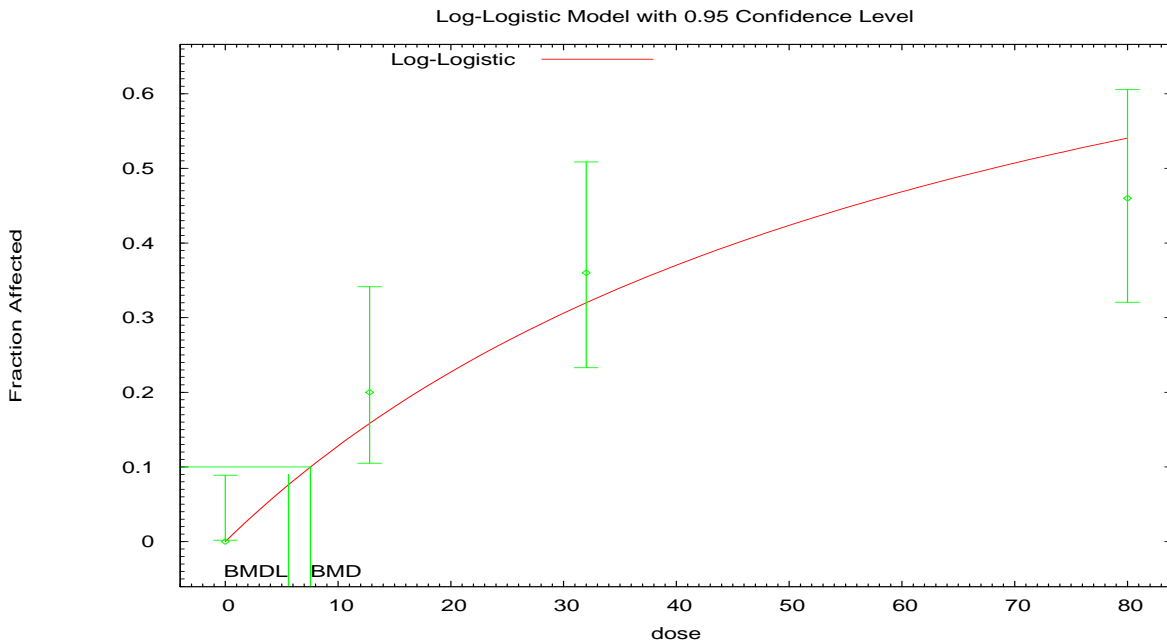
Chi^2 = 3.45 d.f. = 2 P-value = 0.1779

Benchmark Dose Computation

Specified effect = 0.1  
 Risk Type = Extra risk  
 Confidence level = 0.95  
 BMD = 4.90719  
 BMDL = 3.27097

**Table B-3. Modeling Results for Bronchiolar Hyperplasia in Male B6C3F1 Mice**

<b>Model:</b>	<b>Gamma</b>	<b>Logistic</b>	<b>Log-Logistic</b>	<b>Log-Probit</b>	<b>Probit</b>	<b>Weibull</b>	<b>Quantal-Linear</b>	<b>Hill</b>
<b>Restricted:</b>	Yes		Yes	Yes		Yes		Yes
<b>BMR:</b>	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
<b>BMR Type:</b>	Extra Risk	Extra Risk	Extra Risk	Extra Risk	Extra Risk	Extra Risk	Extra Risk	Extra Risk
<b>BMD</b>	9.962	25.582	7.54241	18.0076	23.8731	9.962	9.962	6.46897
<b>BMDL</b>	7.95025	20.9208	5.60381	12.7086	19.6205	7.95025	7.95025	0.13456
<b>Chi<sup>2</sup></b>	6.24	12.55	2.32	13.97	12.13	6.24	6.24	0
<b>Goodness-of-fit p-value</b>	0.1003	0.0019	0.5085	0.0009	0.0023	0.1003	0.1003	0.9997
<b>AIC</b>	192.219	206.147	188.645	203.779	205.312	192.219	192.219	190.376
<b>Fitted Log-Likelihood</b>	-95.1094	-101.073	-93.3224	-99.8893	-100.656	-95.1094	-95.1094	-92.1882
<b>Fitted p-value</b>	0.1195	0.000138	0.5186	0.000452	0.00021	0.1195	0.1195	0.9997
<b>Scaled Residuals:</b>								
<b>0</b>	0	-2.549	0	-1.669	-2.442	0	0	0
<b>12.8</b>	1.561	0.897	0.8	2.278	0.992	1.561	1.561	-0.0003
<b>32</b>	1.139	2.136	0.6	1.259	2.094	1.139	1.139	-0.00015
<b>80</b>	-1.585	-0.826	-1.149	-2.098	-0.891	-1.585	-1.585	0.000113



**Figure B-3. Log-logistic model fit for bronchiolar hyperplasia in male B6C3F1 Mice**

```

1  =====
2  Logistic Model. (Version: 2.10; Date: 09/23/2007)
3  Input Data File: U:\Chloroprene\Male_B6C3F1_mouse\bronc_hyper_loglog.(d)
4  Gnuplot Plotting File: U:\Chloroprene\Male_B6C3F1_mouse\bronc_hyper_loglog.plt
5  Wed Feb 20 07:46:23 2008
6  =====
7
8  BMDS Model Run
9  ~~~~~
10 The form of the probability function is:
11 P[response] = background+(1-background)/[1+EXP(-intercept-slope*Log(dose))]
12 Dependent variable = bronchiolar_hyper
13 Independent variable = DOSE
14 Slope parameter is restricted as slope >= 1
15 Total number of observations = 4
16 Total number of records with missing values = 0
17 Maximum number of iterations = 250
18 Relative Function Convergence has been set to: 1e-008
19 Parameter Convergence has been set to: 1e-008
20 User has chosen the log transformed model
21
22
23 Default Initial Parameter Values
24 background = 0
25 intercept = -4.24694
26 slope = 1
27
28
29 Asymptotic Correlation Matrix of Parameter Estimates
30
31 ( *** The model parameter(s) -background -slope
32 have been estimated at a boundary point, or have been specified by the user,
33 and do not appear in the correlation matrix )
34
35 intercept

```

1 intercept 1

2

3 Parameter Estimates

4

5 95.0% Wald Confidence Interval

6 Variable	Estimate	Std. Err.	Lower Conf. Limit	Upper Conf. Limit
7 background	0	*	*	*
8 intercept	-4.21777	*	*	*
9 slope	1	*	*	*

10

11 \* - Indicates that this value is not calculated.

12

13 Analysis of Deviance Table

14

15 Model	Log(likelihood)	# Param's	Deviance	Test d.f.	P-value
16 Full model	-92.1882	4			
17 Fitted model	-93.3224	1	2.26827	3	0.5186
18 Reduced model	-113.552	1	42.7283	3	<.0001

19

20 AIC: 188.645

21

22

23 Goodness of Fit

24

25 Dose	Est_Prob.	Expected	Observed	Size	Scaled Residual
27 0.0000	0.0000	0.000	0	50	0.000
28 12.8000	0.1586	7.932	10	50	0.800
29 32.0000	0.3204	16.019	18	50	0.600
30 80.0000	0.5410	27.049	23	50	-1.149

31

32 Chi^2 = 2.32 d.f. = 3 P-value = 0.5085

33

34

35 Benchmark Dose Computation

36 Specified effect	=	0.1
37 Risk Type	=	Extra risk
38 Confidence level	=	0.95
39 BMD	=	7.54241
40 BMDL	=	5.60381



**Table B-4. Modeling Results for Bronchiolar Hyperplasia in Female B6C3F1 Mice**

<b>Model:</b>	<b>Gamma</b>	<b>Logistic</b>	<b>Log-Logistic</b>	<b>Log-Probit</b>	<b>Probit</b>	<b>Weibull</b>	<b>Quantal-Linear</b>	<b>Hill</b>
<b>Restricted:</b>	Yes		Yes	Yes		Yes		Yes
<b>BMR:</b>	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
<b>BMR Type:</b>	Extra Risk	Extra Risk	Extra Risk	Extra Risk	Extra Risk	Extra Risk	Extra Risk	Extra Risk
<b>BMD</b>	8.36521	21.7233	6.16449	16.922	20.2623	8.36519	8.36519	2.97514
<b>BMDL</b>	6.74162	17.9832	4.6013	11.5061	16.905	6.74162	6.74162	0.149667
<b>Chi<sup>2</sup></b>	11.72	14.42	7.96	18.88	14.34	11.72	11.72	5.982981
<b>Goodness-of-fit p-value</b>	0.0084	0.0007	0.0469	0.0001	0.0008	0.0084	0.0084	0.0502
<b>AIC</b>	194.774	205.342	192.407	206.563	204.825	194.774	194.774	192.953
<b>Fitted Log-Likelihood</b>	-96.387	-100.671	-95.2036	-101.282	-100.412	-96.387	-96.387	-94.4763
<b>Fitted p-value</b>	0.01856	9.29E-05	0.05422	5.04E-05	0.00012	0.01856	0.01856	0.04552
<b>Scaled Residuals:</b>								
<b>0</b>	0	-2.5	0	-2.04	-2.409	0	0	0
<b>12.8</b>	3.092	2.835	2.128	3.615	2.889	3.092	3.092	1.122
<b>32</b>	-1.377	-0.285	-1.847	-1.163	-0.359	-1.377	-1.377	-1.956
<b>80</b>	-0.513	-0.235	0.137	-0.549	-0.249	-0.513	-0.513	0.9482

Note: No model fits appropriately. Therefore, recommend using the NOAEL/LOAEL approach to determining a POD

**Table B-5. Modeling Results for Histiocytic Cell Infiltration in Male B6C3F1 Mice**

<b>Model:</b>	<b>Gamma</b>	<b>Logistic</b>	<b>Log-Logistic</b>	<b>Log-Probit</b>	<b>Probit</b>	<b>Weibull</b>	<b>Quantal-Linear</b>	<b>Hill</b>
<b>Restricted:</b>	Yes		Yes	Yes		Yes		Yes
<b>BMR:</b>	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
<b>BMR Type:</b>	Extra Risk	Extra Risk	Extra Risk	Extra Risk	Extra Risk	Extra Risk	Extra Risk	Extra Risk
<b>BMD</b>	11.1361	24.8436	7.44347	22.6862	23.4156	11.1363	11.1363	
<b>BMDL</b>	8.17864	19.8574	5.28235	15.5226	18.7645	8.17864	8.17864	
<b>Chi<sup>2</sup></b>	8.97	12.27	5.38	14.62	12.04	8.97	8.97	
<b>Goodness-of-fit p-value</b>	0.0113	0.0022	0.0679	0.0007	0.0024	0.0113	0.0113	
<b>AIC</b>	215.559	222.023	211.84	223.144	221.531	215.559	215.559	1615.32
<b>Fitted Log-Likelihood</b>	-105.78	-109.012	-103.92	-109.572	-108.765	-105.78	-105.78	-807.661
<b>Fitted p-value</b>	0.01235	0.000488	0.07927	0.000278	0.000624	0.01235	0.01235	1.31E-304
<b>Scaled Residuals:</b>								
<b>0</b>	-1.224	-2.606	-0.49	-2.356	-2.524	-1.224	-1.224	
<b>12.8</b>	2.188	1.653	1.762	2.379	1.714	2.188	2.188	
<b>32</b>	0.816	1.488	0.222	1.188	1.458	0.817	0.817	
<b>80</b>	-1.421	-0.733	-1.409	-1.414	-0.779	-1.421	-1.421	

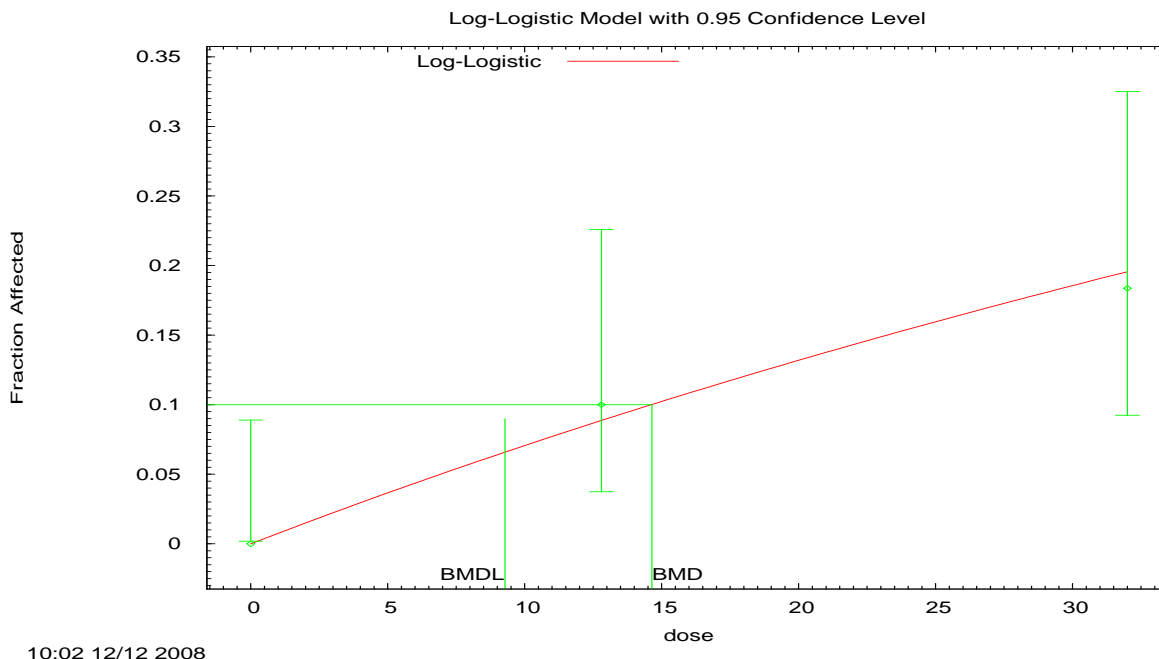
Note: No model fits appropriately. Therefore, recommend using the NOAEL/LOAEL approach to determining a POD

**Table B-6. Modeling Results for Olfactory Chronic Inflammation in Male F344/N Rats**

<b>Model:</b>	<b>Gamma</b>	<b>Logistic</b>	<b>Log-Logistic</b>	<b>Log-Probit</b>	<b>Probit</b>	<b>Weibull</b>	<b>Quantal-Linear</b>	<b>Hill</b>
<b>Restricted:</b>	Yes		Yes	Yes		Yes		Yes
<b>BMR:</b>	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
<b>BMR Type:</b>	Extra Risk	Extra Risk	Extra Risk	Extra Risk	Extra Risk	Extra Risk	Extra Risk	Extra Risk
<b>BMD</b>	15.2489	23.8087	14.6428	17.7991	15.2489	15.2489	15.2489	--
<b>BMDL</b>	10.1164	18.9473	9.27776	13.7362	10.1164	10.1164	10.1164	--
<b>Chi<sup>2</sup></b>	0.22	2.83	0.12	3.08	0.22	0.22	0.22	--
<b>Goodness-of-fit p-value</b>	0.8964	0.0925	0.9398	0.2144	0.8964	0.8964	0.8964	--
<b>AIC</b>	81.4586	87.0594	81.3682	83.9766	81.4586	81.4586	81.4586	--
<b>Fitted Log-Likelihood</b>	-39.7293	-41.5297	-39.4291	-40.9883	-41.3298	-39.7293	-39.7293	--
<b>Fitted p-value</b>	0.8993	0.05085	0.9409	0.2553	0.06467	0.8993	0.8993	--

Scaled Residuals:								
0	0.000	-1.120	<b>0.000</b>	0.000	-1.027	0.000	0.000	--
12.8	0.390	1.221	<b>0.286</b>	1.458	1.195	0.390	0.390	--
32	-0.258	-0.291	<b>-0.207</b>	-0.976	-0.345	-0.258	-0.258	--

Note: High dose group was dropped in order to obtain adequate model fit



**Figure B-4. Log-logistic model fit for olfactory chronic inflammation in male F344/N rats**

```

1  =====
2  Logistic Model. (Version: 2.12; Date: 05/16/2008)
3  Input Data File: M:\Chloroprene\Male_F344_rat\ntp_inflammation_hdd_loglog.(d)
4  Gnuplot Plotting File: M:\Chloroprene\Male_F344_rat\ntp_inflammation_hdd_loglog.plt
5  Fri Dec 12 08:22:05 2008
6  =====
7
8  BMDS Model Run
9  ~~~~~
10 The form of the probability function is:
11 P[response] = background+(1-background)/[1+EXP(-intercept-slope*Log(dose))]
12 Dependent variable = Col3
13 Independent variable = Col1
14 Slope parameter is restricted as slope >= 1
15 Total number of observations = 3
16 Total number of records with missing values = 0
17 Maximum number of iterations = 250
18 Relative Function Convergence has been set to: 1e-008
19 Parameter Convergence has been set to: 1e-008
20 User has chosen the log transformed model
21

```

```

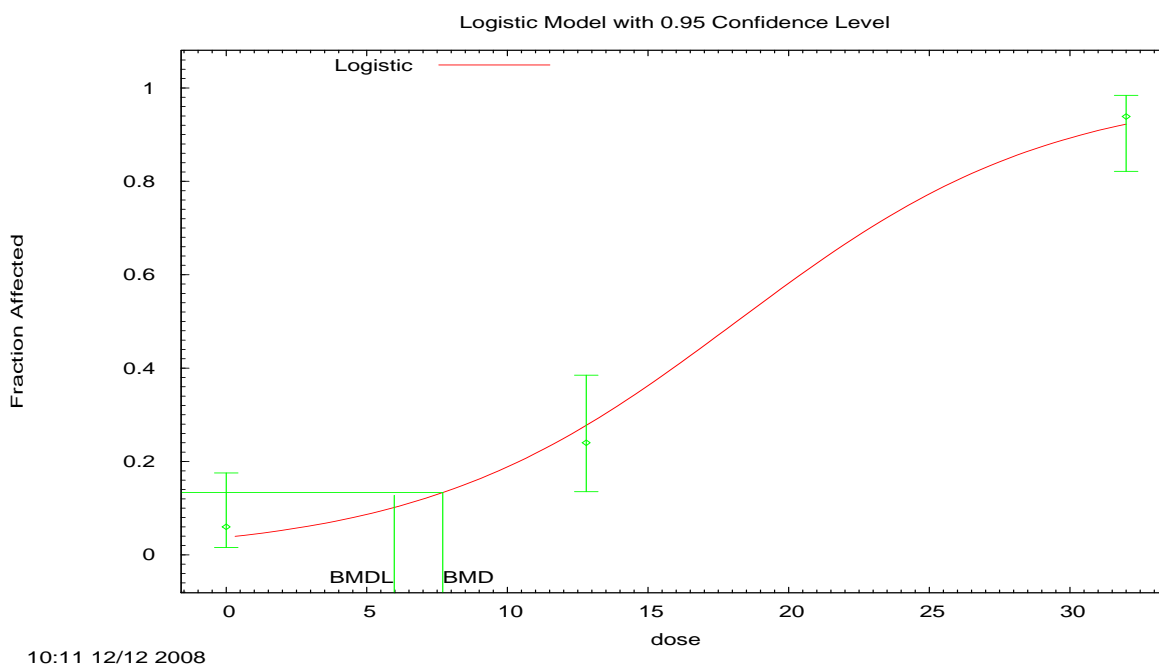
1 Default Initial Parameter Values
2 background =      0
3 intercept =  -4.79799
4 slope =      1
5
6
7 Asymptotic Correlation Matrix of Parameter Estimates
8
9 ( *** The model parameter(s) -background -slope
10 have been estimated at a boundary point, or have been specified by the user,
11 and do not appear in the correlation matrix )
12
13 intercept
14 intercept      1
15
16 Parameter Estimates
17
18                               95.0% Wald Confidence Interval
19 Variable      Estimate   Std. Err.  Lower Conf. Limit  Upper Conf. Limit
20 background      0           *           *                 *
21 intercept     -4.88117      *           *                 *
22 slope          1           *           *                 *
23
24 * - Indicates that this value is not calculated.
25
26 Analysis of Deviance Table
27
28 Model          Log(likelihood) # Param's  Deviance Test d.f. P-value
29 Full model      -39.6231      3
30 Fitted model    39.6841      1      0.121914  2      0.9409
31 Reduced model   -46.4291      1      13.6119  2      0.001107
32
33 AIC:      81.3682
34
35
36 Goodness of Fit
37
38 Dose          Est._Prob.  Expected  Observed  Size  Scaled
39 -----
40 0.0000        0.0000    0.000    0.000    50   0.000
41 12.8000       0.0885    4.426    5.000    50   0.286
42 32.0000       0.1954    9.574    9.000    49  -0.207
43
44 Chi^2 = 0.12  d.f. = 2    P-value = 0.9398
45
46
47 Benchmark Dose Computation
48 Specified effect =      0.1
49 Risk Type      =  Extra risk
50 Confidence level =      0.95
51 BMD      =  14.6428
52 BMDL     =  9.27776

```

**Table B-7. Modeling Results for Olfactory Atrophy in Male F344/N Rats**

Model:	Gamma	Logistic	Log-Logistic	Log-Probit	Probit	Weibull	Quantal-Linear	Hill
Restricted:	Yes		Yes	Yes		Yes		Yes
BMR:	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
BMR Type:	Extra Risk	Extra Risk	Extra Risk	Extra Risk	Extra Risk	Extra Risk	Extra Risk	Extra Risk
BMD	10.6003	7.70048	10.81	10.9386	6.91725	9.95012	2.28431	--
BMDL	7.99938	5.97454	8.62799	8.79455	5.40111	7.06875	1.80011	--
Chi <sup>2</sup>	0.00	1.24	0.00	0.00	2.02	0.00	18.03	--
Goodness-of-fit p-value	NA	0.2655	NA	NA	0.1555	NA	0.0000	--
AIC	106.376	105.53	106.376	106.376	106.283	106.376	125.166	--
Fitted Log-Likelihood	-50.1882	-50.7651	-50.1882	-50.1882	-51.1417	-50.1882	-60.5831	--
Fitted p-value	NA	0.2828	NA	NA	0.1673	NA	5.12E-006	--
<b>Scaled Residuals:</b>								
	--							
0	-0.000	0.847	0.000	0.000	0.977	0.000	0.459	--
12.8	-0.000	-0.597	0.000	-0.000	-0.901	0.000	-3.280	--
32	0.000	0.406	-0.000	0.000	0.502	-0.000	2.658	--

Note: High dose group was dropped in order to obtain adequate model fit



**Figure B-5. Logistic model fit for olfactory atrophy in male F344/N rats**

```

1  =====
2  Logistic Model. (Version: 2.12; Date: 05/16/2008)
3  Input Data File: M:\Chloroprene\Male_F344_rat\ntp_atrophy_hdd_logistic.(d)
4  Gnuplot Plotting File: M:\Chloroprene\Male_F344_rat\ntp_atrophy_hdd_logistic.plt
5  Fri Dec 12 08:51:22 2008
6  =====

```

```

7
8  BMD5 Model Run
9  ~~~~~

```

```

10 The form of the probability function is:
11 P[response] = 1/[1+EXP(-intercept-slope*dose)]
12 Dependent variable = Col3
13 Independent variable = Col1
14 Slope parameter is not restricted
15 Total number of observations = 3
16 Total number of records with missing values = 0
17 Maximum number of iterations = 250
18 Relative Function Convergence has been set to: 1e-008
19 Parameter Convergence has been set to: 1e-008
20

```

```

21
22 Default Initial Parameter Values
23 background =      0 Specified
24 intercept =  -2.84277
25 slope =      0.164779
26

```

```

27
28 Asymptotic Correlation Matrix of Parameter Estimates
29
30 ( *** The model parameter(s) -background
31 have been estimated at a boundary point, or have been specified by the user,
32 and do not appear in the correlation matrix )
33

```

	intercept	slope
intercept	1	-0.85
slope	-0.85	1

```

34
35
36
37
38
39
40 Parameter Estimates
41
42
43
44
45
46
47
48

```

Variable	Estimate	Std. Err.	95.0% Wald Confidence Interval	
			Lower Conf. Limit	Upper Conf. Limit
intercept	-3.25094	0.484263	-4.20007	-2.3018
slope	0.179356	0.0262753	0.127857	0.230855

```

49 Analysis of Deviance Table
50
51
52
53
54
55
56
57
58

```

Model	Log(likelihood)	# Param's	Deviance	Test d.f.	P-value
Full model	-50.1882	3			
Fitted model	-50.7651	2	1.15379	1	0.2828
Reduced model	-100.819	1	101.262	2	<.0001

```

56 AIC:      105.53
57

```

```

59 Goodness of Fit
60
61
62
63
64

```

Dose	Est_Prob.	Expected	Observed	Size	Scaled Residual
0.0000	0.0373	1.865	3.000	50	0.847
12.8000	0.2778	13.892	12.000	50	-0.597

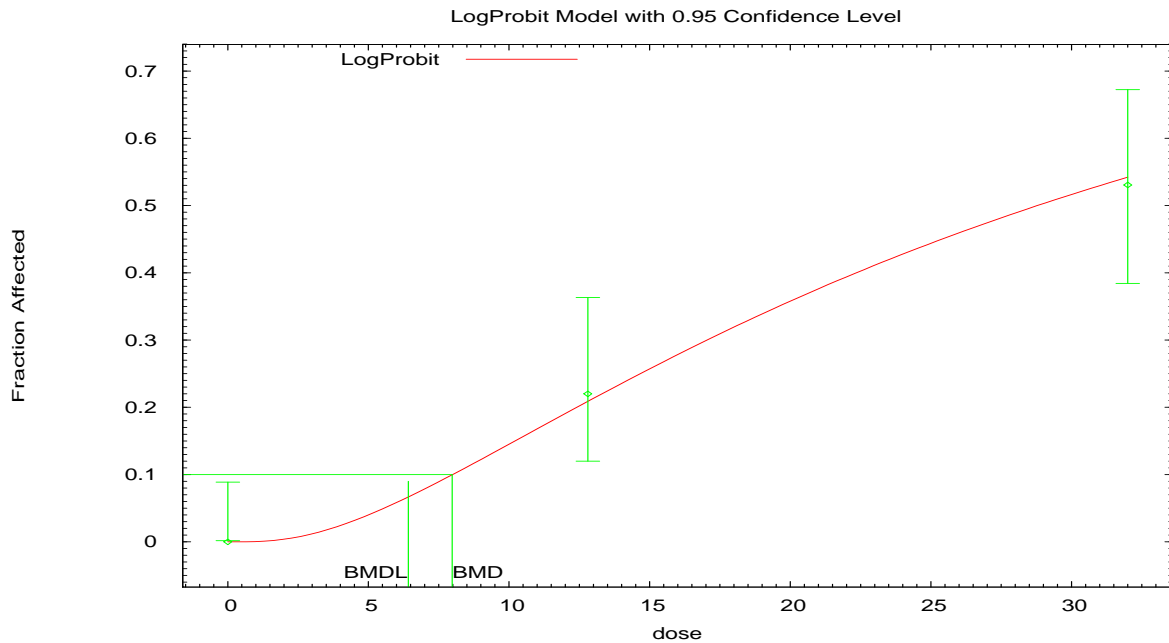
1 32.0000 0.9233 45.243 46.000 49 0.406  
2  
3 Chi<sup>2</sup> = 1.24 d.f. = 1 P-value = 0.2655  
4  
5  
6 Benchmark Dose Computation  
7 Specified effect = 0.1  
8 Risk Type = Extra risk  
9 Confidence level = 0.95  
10 BMD = 7.70048  
11 BMDL = 5.97454

**Table B-8. Modeling Results for Olfactory Necrosis in Male F344/N Rats**

<b>Model:</b>	<b>Gamma</b>	<b>Logistic</b>	<b>Log-Logistic</b>	<b>Log-Probit</b>	<b>Probit</b>	<b>Weibull</b>	<b>Quantal-Linear</b>	<b>Hill</b>
<b>Restricted:</b>	Yes		Yes	Yes		Yes		Yes
<b>BMR:</b>	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
<b>BMR Type:</b>	Extra Risk	Extra Risk	Extra Risk	Extra Risk	Extra Risk	Extra Risk	Extra Risk	Extra Risk
<b>BMD</b>	6.46561	12.1684	6.92124	7.98173	11.3581	6.31726	4.75407	--
<b>BMDL</b>	3.70666	9.77545	2.96263	6.41755	9.13936	3.70666	3.65317	--
<b>Chi<sup>2</sup></b>	0.00	4.56	0.00	0.06	3.86	0.00	0.30	--
<b>Goodness-of-fit p-value</b>	1.0000	0.0328	1.0000	0.9686	0.0494	1.0000	0.8622	--
<b>AIC</b>	124.435	130.942	124.435	122.499	129.762	124.435	122.737	--
<b>Fitted Log-Likelihood</b>	-60.2177	-63.4712	-60.2177	-60.2494	-62.881	-60.2177	-60.3685	--
<b>Fitted p-value</b>	1.00	0.01075	1.00	0.9688	0.021	1.00	0.86	--
<b>Scaled Residuals:</b>								
<b>0</b>	0.000	-1.510	0.000	0.000	-1.313	0.000	0.000	--
<b>12.8</b>	-0.000	1.450	0.000	0.188	-0.461	-0.000	-0.443	--
<b>32</b>	0.000	-0.418	-0.000	-0.169	1.387	0.000	0.317	--

Note: High dose group was dropped in order to obtain adequate model fit





1 10:14 12/12 2008

**Figure B-6. Logistic model fit for olfactory necrosis in male F344/N rats**

```

2 =====
3 Probit Model. (Version: 3.1; Date: 05/16/2008)
4 Input Data File: M:\Chloroprene\Male_F344_rat\ntp_necrosis_hdd_logprobit.(d)
5 Gnuplot Plotting File: M:\Chloroprene\Male_F344_rat\ntp_necrosis_hdd_logprobit.plt
6 Fri Dec 12 09:00:57 2008
7 =====
8
9 BMDS Model Run ~~~~~
10
11 The form of the probability function is:
12 P[response] = Background + (1-Background) * CumNorm(Intercept+Slope*Log(Dose)),
13 where CumNorm(.) is the cumulative normal distribution function
14 Dependent variable = Col3
15 Independent variable = Col1
16 Slope parameter is restricted as slope >= 1
17 Total number of observations = 3
18 Total number of records with missing values = 0
19 Maximum number of iterations = 250
20 Relative Function Convergence has been set to: 1e-008
21 Parameter Convergence has been set to: 1e-008
22 User has chosen the log transformed model
23
24
25 Default Initial (and Specified) Parameter Values
26 background = 0
27 intercept = -3.33803
28 slope = 1
29
30
31 Asymptotic Correlation Matrix of Parameter Estimates
32 (***) The model parameter(s) -background -slope
33 have been estimated at a boundary point, or have been specified by the user,
34 and do not appear in the correlation matrix )
35
36 intercept

```

1 intercept 1

2

3

4

5 Parameter Estimates

6

7 95.0% Wald Confidence Interval

8 Variable	Estimate	Std. Err.	Lower Conf. Limit	Upper Conf. Limit
9 background	0	NA		
10 intercept	-3.35871	0.133307	-3.61998	-3.09743
11 slope	1	NA		

12

13 NA - Indicates that this parameter has hit a bound  
 14 implied by some inequality constraint and thus  
 15 has no standard error.

16 Analysis of Deviance Table

19 Model	Log(likelihood)	# Param's	Deviance	Test d.f.	P-value
20 Full model	-60.2177	3			
21 Fitted model	-60.2494	1	0.063351	2	0.9688
22 Reduced model	-83.5122	1	46.5889	2	<.0001

23

24 AIC: 122.499

25 Goodness of Fit

27 Dose	Est_Prob.	Expected	Observed	Size	Scaled Residual
28 0.0000	0.0000	0.000	0.000	50	0.000
29 12.8000	0.2092	10.459	11.000	50	0.188
30 32.0000	0.5426	26.588	26.000	49	-0.169

31

32

33

34  $\chi^2 = 0.06$  d.f. = 2 P-value = 0.9686

35

36 Benchmark Dose Computation

37 Specified effect = 0.1

38 Risk Type = Extra risk

39 Confidence level = 0.95

40 BMD = 7.98173

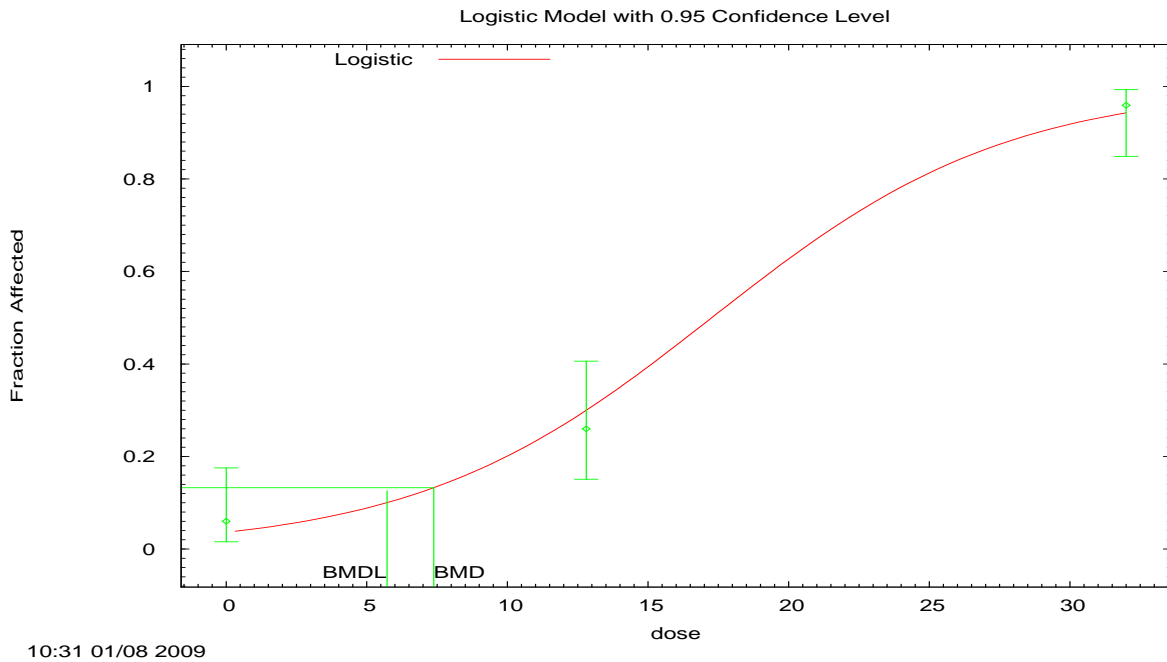
41 BMDL = 6.41755

42

**Table B-9. Modeling Results for Degenerative Nasal Lesions (olfactory atrophy or necrosis) in Male F344/N Rats**

<b>Model:</b>	<b>Gamma</b>	<b>Logistic</b>	<b>Log-Logistic</b>	<b>Log-Probit</b>	<b>Probit</b>	<b>Weibull</b>	<b>Quantal-Linear</b>	<b>Hill</b>
<b>Restricted:</b>	Yes		Yes			Yes		Yes
<b>BMR:</b>	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
<b>BMR Type:</b>	Extra Risk	Extra Risk	Extra Risk	Extra Risk	Extra Risk	Extra Risk	Extra Risk	Extra Risk
<b>BMD</b>	10.3392	7.38383	10.6373	10.7236	6.61322	9.55894	2.13213	--
<b>BMDL</b>	7.89967	5.71667	8.62242	8.71969	5.14757	6.8742	1.68322	--
<b>Chi<sup>2</sup></b>	0	1.44	0	0	2.11	0	18.61	--
<b>Goodness-of-fit p-value</b>	n/a	0.2309	n/a	n/a	0.1460	n/a	0.0	--
<b>AIC</b>	102.417	102.053	102.714	102.714	102.721	102.714	122.619	--
<b>Fitted Log-Likelihood</b>	-48.3572	-49.0267	-48.3572	-48.3572	-49.3605	-48.3572	-59.3096	--
<b>Fitted p-value</b>	n/a	0.2472	n/a	n/a	0.1566	n/a	2.8E-006	--
<b>Scaled Residuals:</b>								
<b>0</b>	-0.0	0.905	0.0	0.0	0.993	-0.0	0.445	--
<b>12.8</b>	0.0	-0.614	0.0	-0.0	-0.903	0.0	-3.304	--
<b>32</b>	-0.0	0.490	-0.0	0.0	0.558	0.0	2.738	--

Note: High dose group was dropped in order to obtain adequate model fit



**Figure B-7. Logistic model fit for degenerative nasal lesions (olfactory atrophy or necrosis) in male F344/N rats**

```

1 =====
2 Logistic Model. (Version: 2.12; Date: 05/16/2008)
3 Input Data File: M:\Chloroprene\Male_F344_rat\olfactory_logistic_hdd(d)
4 Gnuplot Plotting File: M:\Chloroprene\Male_F344_rat\olfactory_logistic_hdd.plt
5 Tue Jan 06 12:25:14 2009
6 =====
7
8 BMDS Model Run
9 ~~~~~
10
11 The form of the probability function is:
12 P[response] = 1/[1+EXP(-intercept-slope*dose)]
13 Dependent variable = Col3
14 Independent variable = Col1
15 Slope parameter is not restricted
16 Total number of observations = 3
17 Total number of records with missing values = 0
18 Maximum number of iterations = 250
19 Relative Function Convergence has been set to: 1e-008
20 Parameter Convergence has been set to: 1e-008
21
22
23 Default Initial Parameter Values
24 background =      0 Specified
25 intercept =     -2.85849
26 slope =         0.176122
27
28 Asymptotic Correlation Matrix of Parameter Estimates
29 ( *** The model parameter(s) -background
30 have been estimated at a boundary point, or have been specified by the user,
31 and do not appear in the correlation matrix )

```

```

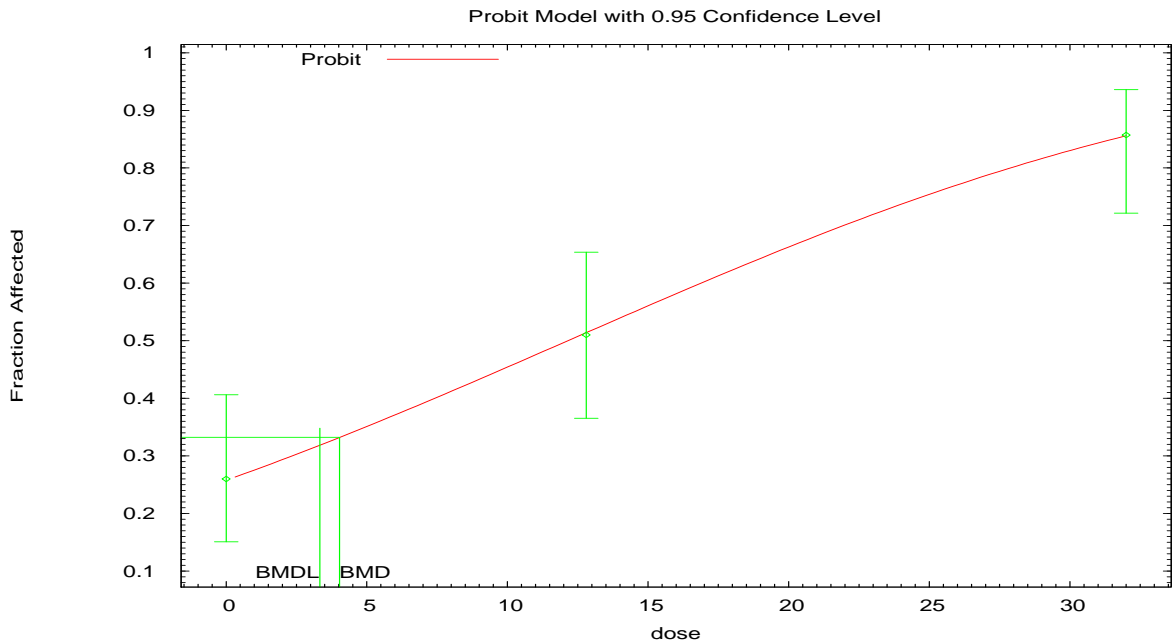
1
2 intercept slope
3 intercept 1 -0.85
4 slope -0.85 1
5
6 Parameter Estimates
7
8 Variable Estimate Std. Err. 95.0% Wald Confidence Interval
9 intercept -3.28386 0.49695 Lower Conf. Limit Upper Conf. Limit
10 slope 0.190277 0.0288302 0.133771 0.246783
11
12
13 Analysis of Deviance Table
14
15 Model Log(likelihood) # Param's Deviance Test d.f. P-value
16 Full model -48.3572 3
17 Fitted model -49.0267 2 1.33895 1 0.2472
18 Reduced model -101.497 1 106.279 2 <.0001
19
20 AIC: 102.053
21
22 Goodness of Fit
23
24 Dose Est_Prob. Scaled Expected Observed Size Residual
25 -----
26 0.0000 0.0361 1.806 3.000 50 0.905
27 12.8000 0.2998 14.989 13.000 50 -0.614
28 32.0000 0.9429 46.204 47.000 49 0.490
29
30 Chi^2 = 1.44 d.f. = 1 P-value = 0.2309
31
32
33 Benchmark Dose Computation
34 Specified effect = 0.1
35 Risk Type = Extra risk
36 Confidence level = 0.95
37 BMD = 7.38383
38 BMDL = 5.71667

```

**Table B-10. Modeling Results for Splenic Hematopoietic Cell Proliferation in Female B6C3F1 Mice**

<b>Model:</b>	<b>Gamma</b>	<b>Logistic</b>	<b>Log-Logistic</b>	<b>Log-Probit</b>	<b>Probit</b>	<b>Weibull</b>	<b>Quantal-Linear</b>	<b>Hill</b>
<b>Restricted:</b>	Yes		Yes	Yes		Yes		Yes
<b>BMR:</b>	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
<b>BMR Type:</b>	Extra Risk	Extra Risk	Extra Risk	Extra Risk	Extra Risk	Extra Risk	Extra Risk	Extra Risk
<b>BMD</b>	5.73584	4.06642	6.5828	6.91076	4.03306	5.17994	2.34557	--
<b>BMDL</b>	1.90919	3.28512	2.43228	3.48982	3.33147	1.90919	1.7616	--
<b>Chi<sup>2</sup></b>	0.00	0.02	0.00	0.00	0.00	0.00	1.35	--
<b>Goodness-of-fit p-value</b>	NA	0.8993	NA	NA	0.9466	NA	0.2455	--
<b>AIC</b>	171.405	169.421	171.405	171.405	169.41	171.405	171.405	--
<b>Fitted Log-Likelihood</b>	-82.7026	-82.7106	-82.7026	-82.7026	-82.7048	-82.7026	-82.7026	--
<b>Fitted p-value</b>	NA	0.8993	NA	NA	0.9466	NA	NA	--
<b>Scaled Residuals:</b>								
0	0.000	0.064	0.000	0.000	0.033	-0.000	-0.000	--
12.8	-0.001	-0.095	0.000	0.000	-0.052	0.000	0.000	--
32	0.000	0.054	-0.000	0.000	0.026	-0.000	-0.000	--

Note High dose group was dropped in order to obtain adequate model fit



10:17 12/12 2008

**Figure B-8. Probit model fit for splenic hematopoietic cell proliferation in female B6C3F1 mice**

```

1
2
3
4 =====
5 Probit Model. (Version: 3.1; Date: 05/16/2008)
6 Input Data File: M:\Chloroprene\Female_B6C3F1_mouse\ntp_hemato_prolif_hdd_probit(d)
7 Gnuplot Plotting File: M:\Chloroprene\Female_B6C3F1_mouse\ntp_hemato_prolif_hdd_probit.plt
8 Fri Dec 12 09:20:03 2008
9 =====
10
11 BMDS Model Run
12 ~~~~~
13 The form of the probability function is:
14 P[response] = CumNorm(Intercept+Slope*Dose),
15 where CumNorm(.) is the cumulative normal distribution function
16 Dependent variable = Col3
17 Independent variable = Col1
18 Slope parameter is not restricted
19 Total number of observations = 3
20 Total number of records with missing values = 0
21 Maximum number of iterations = 250
22 Relative Function Convergence has been set to: 1e-008
23 Parameter Convergence has been set to: 1e-008
24
25
26 Default Initial (and Specified) Parameter Values
27 background = 0 Specified
28 intercept = -0.643083
29 slope = 0.0528681
30
31
32 Asymptotic Correlation Matrix of Parameter Estimates

```

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47

( \*\*\* The model parameter(s) -background  
have been estimated at a boundary point, or have been specified by the user,  
and do not appear in the correlation matrix )

	intercept	slope
intercept	1	-0.73
slope	-0.73	1

Parameter Estimates

Variable	Estimate	Std. Err.	95.0% Wald Confidence Interval	
			Lower Conf. Limit	Upper Conf. Limit
intercept	-0.649733	0.16595	-0.97499	-0.324476
slope	0.0534876	0.00913534	0.0355826	0.0713925

Analysis of Deviance Table

Model	Log(likelihood)	# Param's	Deviance	Test d.f.	P-value
Full model	-82.7026	3			
Fitted model	-82.7048	2	0.00449095	1	0.9466
Reduced model	-102.099	1	38.7924	2	<.0001

AIC: 169.41

Goodness of Fit

Dose	Est._Prob.	Expected	Observed	Size	Scaled Residual
0.0000	0.2579	12.897	13.000	50	0.033
12.8000	0.5139	25.182	25.000	49	-0.052
32.0000	0.8559	41.937	42.000	49	0.026

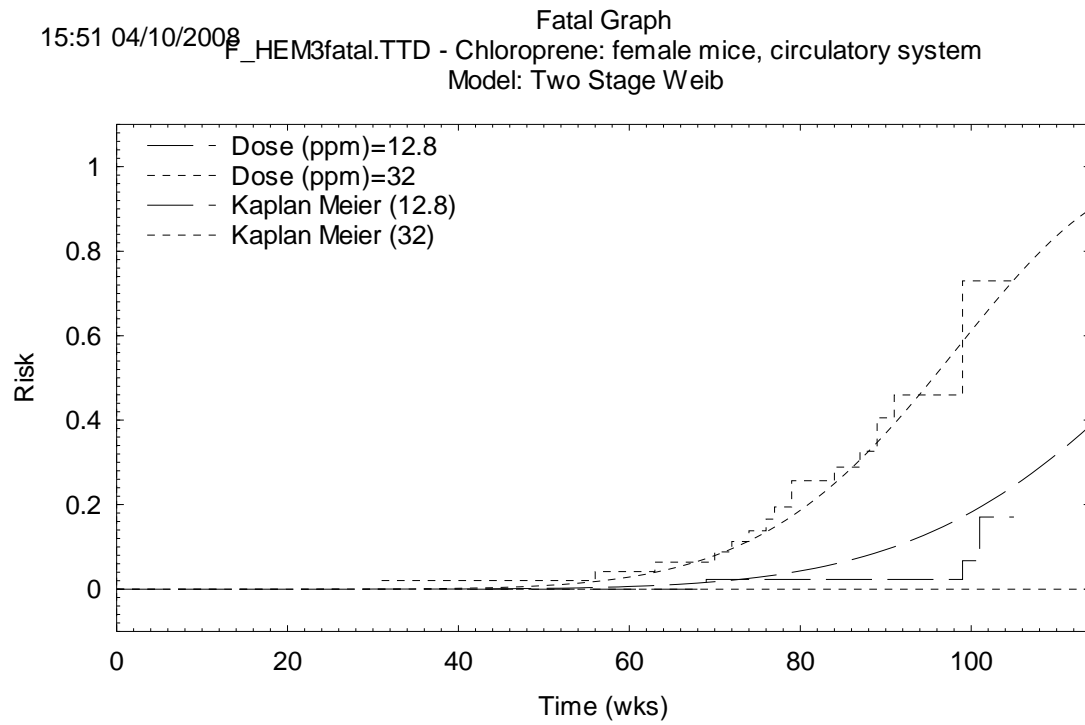
Chi^2 = 0.00 d.f. = 1 P-value = 0.9466

Benchmark Dose Computation

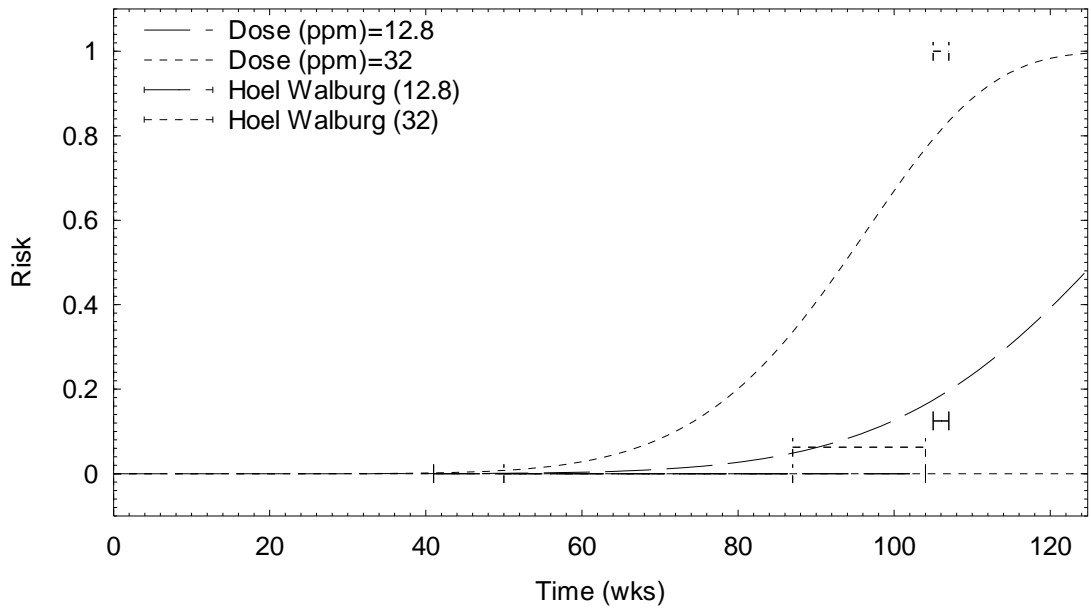
Specified effect = 0.1  
Risk Type = Extra risk  
Confidence level = 0.95  
BMD = 4.03306  
BMDL = 3.33147



## APPENDIX C. CANCER DOSE-RESPONSE MODELING RESULTS



**Figure C-1. Female mice, hemangiomas and hemangiosarcomas in all organs; high dose dropped, ) hemangiosarcomas occurring before termination considered fatal**



**Figure C-2. Female mice, hemangiomas and hemangiosarcomas in all organs; high dose dropped, hemangiosarcomas occurring before termination considered fatal. Details below.**

Model: Two Stage Weib      Dataset: M:\\_ToxRiskData\Chloroprene\F\_HEM3fatal.TTD  
 Functional form:  $1 - \text{EXP}[-Q_0 - Q_1 * D - Q_2 * D^2] * (T - T_0)^Z$   
 Maximum Log-Likelihood = -1.431146e+002

Parameter Estimates :

Q 0	=	1.352245E-015	
Q 1	=	0.000000E+000	
Q 2	=	1.970859E-017	
Z	=	6.820986E+000	
T0	=	0.000000E+000	Set by User

Avg. Doses (ppm)	Number		
	of animals	with fatal tumors	with incidental tumors
0	50	1	3
12.80	50	4	2
32	50	16	2

Exposure Pattern  
 Model: Two Stage Weib      Age Begins: 0      Age Ends: 70  
 Target Species: Human      Weeks/Year: 52      Days/Week: 7  
 Route: Air      Hours/Day : 24

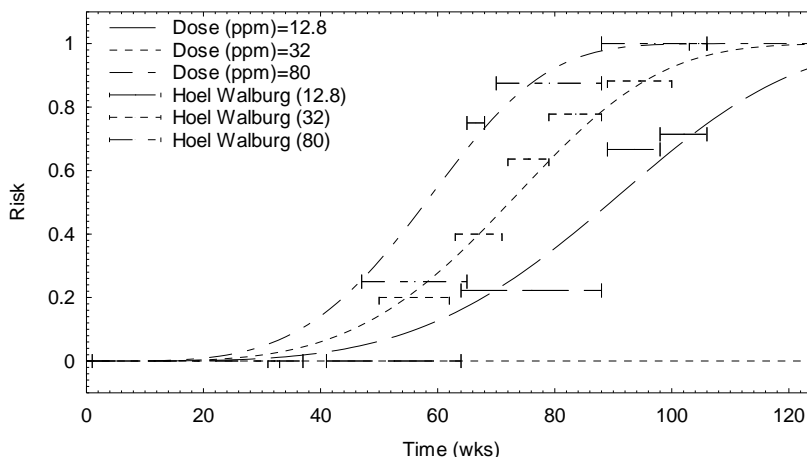
Animal to human conversion method: PPM IN AIR

Human Equivalent Dose Estimates (ug/m<sup>3</sup>)

Incid Extra Risk	Time (yr)	95.00 %		MLE	95.00 %	
		Lower Bound	Upper Bound		Lower Bound	Upper Bound
1.0000E-006	70.00	6.3992E-002	8.5868E-002	8.5868E-002	Not Reqstd	
1.0000E-005	70.00	6.3992E-001	8.5868E-001	8.5868E-001	Not Reqstd	
0.0001	70.00	6.3995E+000	8.5872E+000	8.5872E+000	Not Reqstd	
0.0010	70.00	6.4024E+001	8.5911E+001	8.5911E+001	Not Reqstd	
0.01	70.00	6.4314E+002	8.6300E+002	8.6300E+002	Not Reqstd	
0.10	70.00	6.7422E+003	9.0471E+003	9.0471E+003	Not Reqstd	

16:45 04/10/2008

Incidental Graph  
 F\_LUNG.TTD - Alveolar/Bronch tumors, females  
 Model: Multistage Weib



**Figure C-3. Female mice, alveolar/bronchiolar tumors. Details below.**

Model: Three Stage Weib      Dataset: M:\\_ToxRiskData\Chloroprene\F\_LUNG.TTD  
 Functional form:  $1 - \text{EXP}[-Q_0 - Q_1 * D - Q_2 * D^2 - Q_3 * D^3] * (T - T_0)^Z$   
 Maximum Log-Likelihood = -8.624362e+001

Parameter Estimates :

Q 0 = 5.948316E-010  
 Q 1 = 5.755951E-010  
 Q 2 = 0.000000E+000  
 Q 3 = 0.000000E+000  
 Z = 4.067307E+000  
 T0 = 0.000000E+000      Set by User

Avg. Doses (ppm)	Number		
	of animals	with fatal tumors	with incidental tumors
0	50	0	4
12.80	50	0	28
32	50	0	34
80	50	0	42

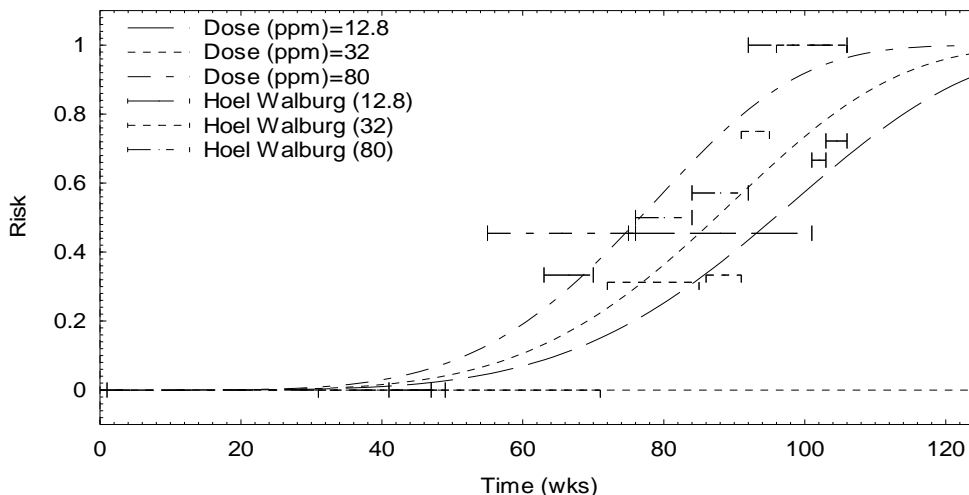
Exposure Pattern  
 Model: Three Stage Weib      Age Begins: 0      Age Ends: 70  
 Target Species: Human      Weeks/Year: 52      Days/Week: 7  
 Route: Air      Hours/Day : 24

Animal to human conversion method: PPM IN AIR

Human Equivalent Dose Estimates (ug/m<sup>3</sup>)

Incid Extra Risk	Time (yr)	95.00 %		
		Lower Bound	MLE	Upper Bound
1.0000E-006	70.00	3.2072E-002	4.0061E-002	Not Reqstd
1.0000E-005	70.00	3.2072E-001	4.0061E-001	Not Reqstd
0.0001	70.00	3.2074E+000	4.0063E+000	Not Reqstd
0.0010	70.00	3.2088E+001	4.0081E+001	Not Reqstd
0.01	70.00	3.2234E+002	4.0263E+002	Not Reqstd
0.10	70.00	3.3791E+003	4.2208E+003	Not Reqstd

16:53 04/10/2008 Incidental Graph  
 F\_LIV.TTD - Chloroprene: female mice, hep. carc. and aden.  
 Model: One Stage Weib



**Figure C-4. Female mice, hepatocellular adenomas and carcinomas. Details below.**

Model: One Stage Weib Dataset: M:\\_ToxRiskData\Chloroprene\F\_LIV.TTD  
 Functional form:  $1 - \text{EXP}[(-Q0 - Q1 * D) * (T - T0)^Z]$   
 Maximum Log-Likelihood = -1.233781e+002

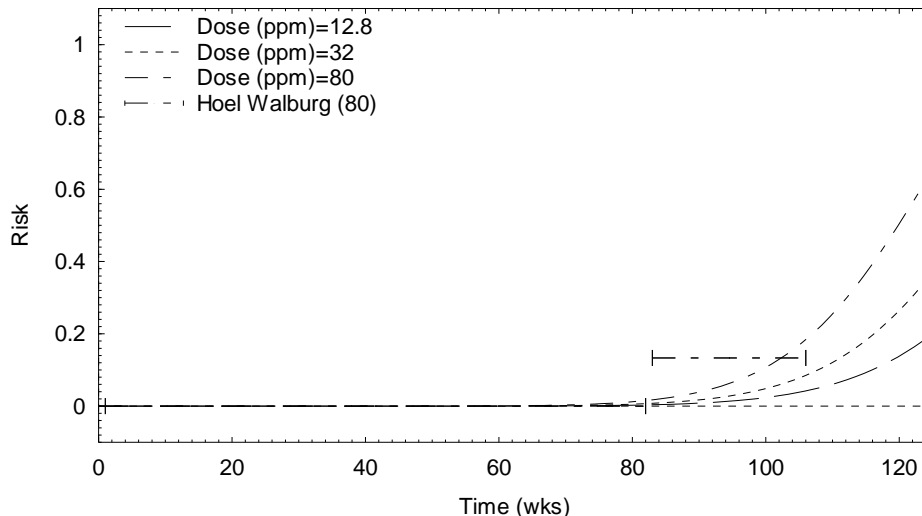
Parameter Estimates :

Q 0 = 1.153457E-010  
 Q 1 = 5.270331E-012  
 Z = 4.834857E+000  
 T0 = 0.000000E+000 Set by User

Avg. Doses (ppm)	Number		
	of animals	with fatal tumors	with incidental tumors
0	50	0	20
12.80	49	0	26
32	50	0	20
80	50	0	30

Exposure Pattern  
 Model: One Stage Weib Age Begins: 0 Age Ends: 70  
 Target Species: Human Weeks/Year: 52 Days/Week: 7  
 Route: Air Hours/Day : 24  
 Animal to human conversion method: PPM IN AIR

Incid Extra Risk	Time (yr)	Human Equivalent Dose Estimates (ug/m <sup>3</sup> )		
		95.00 % Lower Bound	MLE	95.00 % Upper Bound
1.0000E-006	70.00	9.2486E-002	1.2383E-001	Not Reqstd
1.0000E-005	70.00	9.2486E-001	1.2383E+000	Not Reqstd
0.0001	70.00	9.2490E+000	1.2384E+001	Not Reqstd
0.0010	70.00	9.2532E+001	1.2389E+002	Not Reqstd
0.01	70.00	9.2951E+002	1.2445E+003	Not Reqstd
0.10	70.00	9.7443E+003	1.3047E+004	Not Reqstd



**Figure C-5. Female mice, forestomach tumors. Details below.**

Model: One Stage Weib Dataset: M:\\_ToxRiskData\Chloroprene\F\_FORST.TTD  
 Functional form:  $1 - \text{EXP}[( -Q0 - Q1 * D ) * (T - T0)^Z]$   
 Maximum Log-Likelihood = -3.359600e+001

Parameter Estimates :

Q 0 = 6.983602E-023  
 Q 1 = 1.330500E-023  
 Z = 1.000000E+001  
 T0 = 0.000000E+000 Set by User

Avg. Doses (ppm)	Number		
	of animals	with fatal tumors	with incidental tumors
0	50	0	1
12.80	50	0	0
32	49	0	0
80	50	0	4

Exposure Pattern

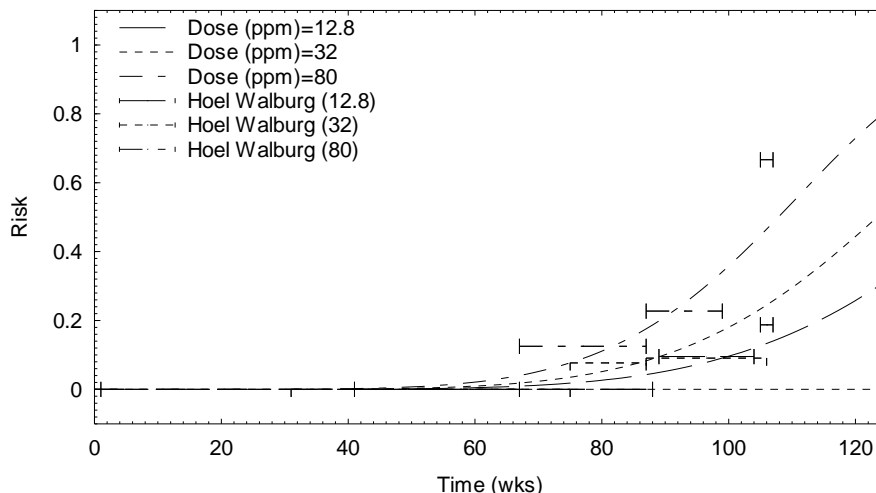
Model: One Stage Weib Age Begins: 0 Age Ends: 70  
 Target Species: Human Weeks/Year: 52 Days/Week: 7  
 Route: Air Hours/Day : 24

Animal to human conversion method: PPM IN AIR

Human Equivalent Dose Estimates (ug/m<sup>3</sup>)

Incid Extra Risk	Time (yr)	95.00 %		
		Lower Bound	MLE	Upper Bound
1.0000E-006	70.00	5.7604E-001	1.8723E+000	Not Reqstd
1.0000E-005	70.00	5.7604E+000	1.8723E+001	Not Reqstd
0.0001	70.00	5.7607E+001	1.8724E+002	Not Reqstd
0.0010	70.00	5.7632E+002	1.8733E+003	Not Reqstd
0.01	70.00	5.7894E+003	1.8818E+004	Not Reqstd
0.10	70.00	6.0692E+004	1.9727E+005	Not Reqstd

17:28 04/10/2008 Incidental Graph  
 F\_HARD.TTD - Chloroprene: female mice, hard.gland tumors  
 Model: One Stage Weib



**Figure C-6. Female mice, Harderian gland tumors. Details below.**

Model: One Stage Weib Dataset: M:\\_ToxRiskData\Chloroprene\F\_HARD.TTD  
 Functional form:  $1 - \text{EXP}[(-Q_0 - Q_1 * D) * (T - T_0)^Z]$   
 Maximum Log-Likelihood = -6.640761e+001

Parameter Estimates :

Q 0 = 4.680639E-014  
 Q 1 = 6.624162E-015  
 Z = 5.942561E+000  
 T0 = 0.000000E+000 Set by User

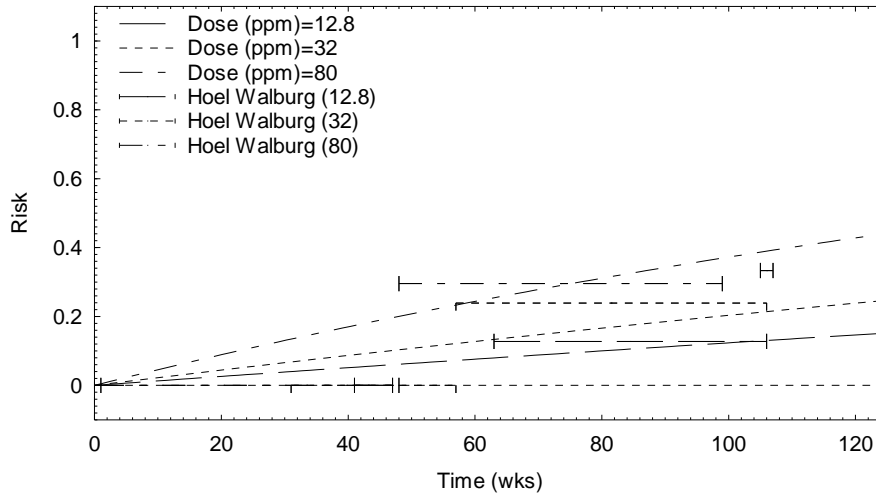
Avg. Doses (ppm)	Number		
	of animals	with fatal tumors	with incidental tumors
0	50	0	2
12.80	50	0	5
32	50	0	3
80	50	0	9

Model: One Stage Weib Age Begins: 0 Exposure Pattern  
 Target Species: Human Weeks/Year: 52 Age Ends: 70  
 Route: Air Days/Week: 7  
 Hours/Day : 24

Animal to human conversion method: PPM IN AIR

Human Equivalent Dose Estimates (ug/m<sup>3</sup>)

Incid Extra Risk	Time (yr)	95.00 %		
		Lower Bound	MLE	Upper Bound
1.0000E-006	70.00	4.5697E-001	5.7446E-001	Not Reqstd
1.0000E-005	70.00	4.5697E+000	5.7446E+000	Not Reqstd
0.0001	70.00	4.5699E+001	5.7449E+001	Not Reqstd
0.0010	70.00	4.5720E+002	5.7474E+002	Not Reqstd
0.01	70.00	4.5927E+003	5.7735E+003	Not Reqstd
0.10	70.00	4.8146E+004	6.0525E+004	Not Reqstd



**Figure C-7. Female mice, mammary gland tumors. Details below.**

Model: One Stage Weib      Dataset: M:\\_ToxRiskData\Chloroprene\F\_MAMM.TTD  
 Functional form:  $1 - \text{EXP}[(-Q0 - Q1 * D) * (T - T0)^Z]$   
 Maximum Log-Likelihood = -9.075190e+001

Parameter Estimates :

Q 0 = 6.820061E-004  
 Q 1 = 4.969301E-005  
 Z = 1.000000E+000  
 T0 = 0.000000E+000      Set by User

Avg. Doses (ppm)	Number		
	of animals	with fatal tumors	with incidental tumors
0	50	0	3
12.80	50	0	6
32	50	0	11
80	50	0	14

Exposure Pattern

Model: One Stage Weib      Age Begins: 0      Age Ends: 70  
 Target Species: Human      Weeks/Year: 52      Days/Week: 7  
 Route: Air      Hours/Day : 24

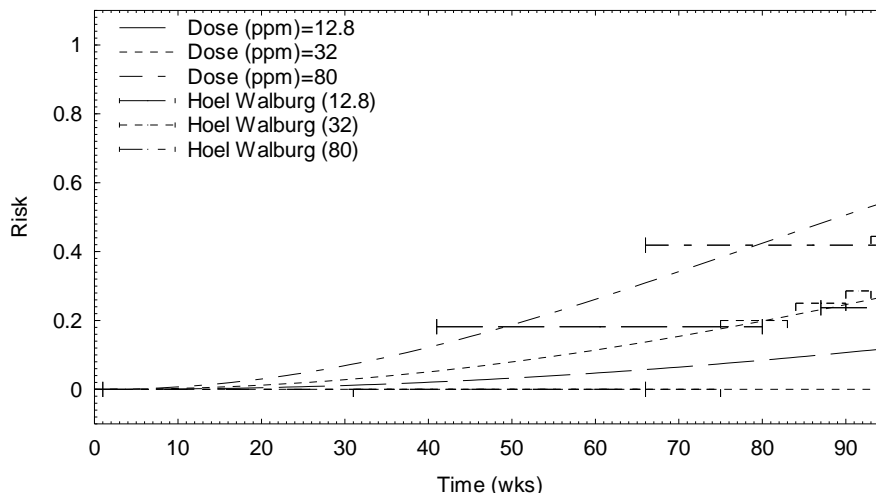
Animal to human conversion method: PPM IN AIR

Human Equivalent Dose Estimates (ug/m<sup>3</sup>)

Incid Extra Risk	Time (yr)	95.00 %		
		Lower Bound	MLE	Upper Bound
1.0000E-006	70.00	4.6346E-001	7.1352E-001	Not Reqstd
1.0000E-005	70.00	4.6347E+000	7.1352E+000	Not Reqstd
0.0001	70.00	4.6349E+001	7.1355E+001	Not Reqstd
0.0010	70.00	4.6369E+002	7.1387E+002	Not Reqstd
0.01	70.00	4.6580E+003	7.1711E+003	Not Reqstd
0.10	70.00	4.8831E+004	7.5176E+004	Not Reqstd

10:10 04/14/2008

Incidental Graph  
 F\_SKIN.TTD - Chloroprene: female mice, skin sarcomas  
 Model: One Stage Weib



**Figure C-8. Female mice, skin sarcomas. Details below.**

Model: One Stage Weib      Dataset: M:\\_ToxRiskData\Chloroprene\F\_SKIN.TTD  
 Functional form:  $1 - \text{EXP}[(-Q0 - Q1 * D) * (T - T0)^Z]$   
 Maximum Log-Likelihood = -9.120449e+001

Parameter Estimates :

Q 0 = 0.000000E+000  
 Q 1 = 7.398518E-007  
 Z = 2.086144E+000  
 T0 = 0.000000E+000      Set by User

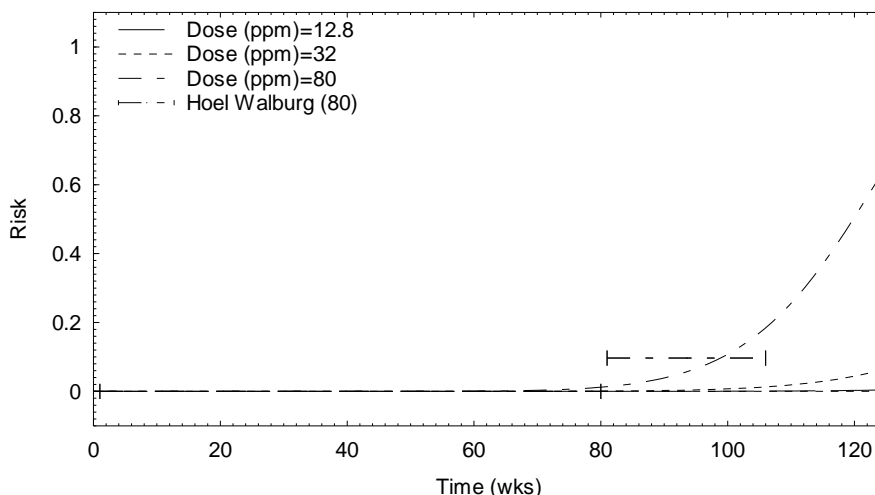
Avg. Doses (ppm)	Number		
	of animals	with fatal tumors	with incidental tumors
0	50	0	0
12.80	50	0	11
32	50	0	11
80	50	0	18

Exposure Pattern  
 Model: One Stage Weib      Age Begins: 0      Age Ends: 70  
 Target Species: Human      Weeks/Year: 52      Days/Week: 7  
 Route: Air      Hours/Day : 24

Animal to human conversion method: MG/KG BODY WEIGHT(3/4)/DAY

Incid Extra Risk	Time (yr)	Human Equivalent Dose Estimates (ug/m <sup>3</sup> )		
		95.00 % Lower Bound	MLE	95.00 % Upper Bound
1.0000E-006	70.00	2.4134E-001	3.7066E-001	Not Reqstd
1.0000E-005	70.00	2.4134E+000	3.7066E+000	Not Reqstd
0.0001	70.00	2.4135E+001	3.7068E+001	Not Reqstd
0.0010	70.00	2.4146E+002	3.7085E+002	Not Reqstd
0.01	70.00	2.4255E+003	3.7253E+003	Not Reqstd
0.10	70.00	2.5428E+004	3.9053E+004	Not Reqstd





**Figure C-9. Female mice, Zymbal's gland tumors. Details below.**

Model: Three Stage Weib Dataset: M:\\_ToxRiskData\Chloroprene\F\_Zymb.TTD  
 Functional form:  $1 - \text{EXP}[( -Q0 - Q1 * D - Q2 * D^2 - Q3 * D^3 ) * (T - T0)^Z]$   
 Maximum Log-Likelihood = -2.897667e+001

Parameter Estimates :

Q 0 = 0.000000E+000  
 Q 1 = 0.000000E+000  
 Q 2 = 0.000000E+000  
 Q 3 = 2.224776E-027  
 Z = 1.000000E+001  
 T0 = 0.000000E+000 Set by User

Avg. Doses (ppm)	Number		
	of animals	with fatal tumors	with incidental tumors
0	50	0	0
12.80	50	0	0
32	49	0	0
80	50	0	3

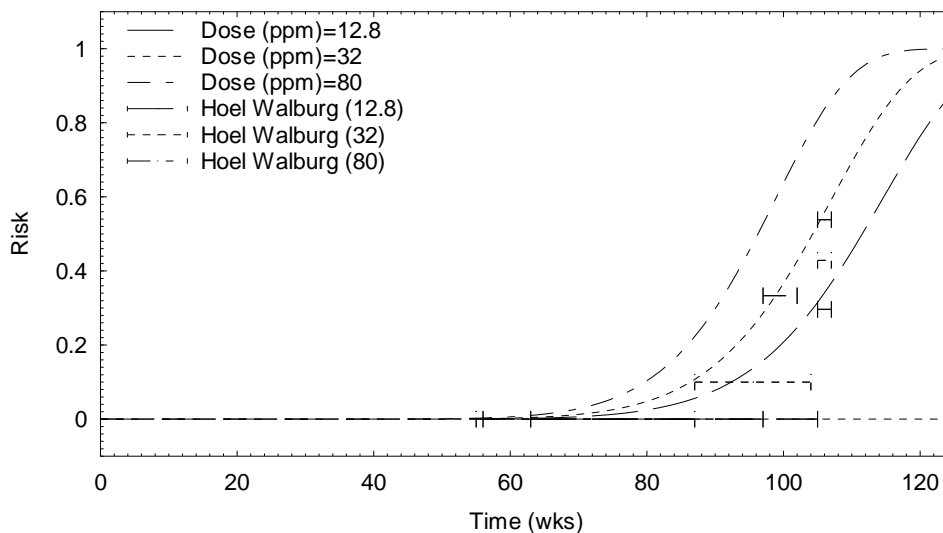
Exposure Pattern

Model: Three Stage Weib Age Begins: 0 Age Ends: 70  
 Target Species: Human Weeks/Year: 52 Days/Week: 7  
 Route: Air Hours/Day : 24

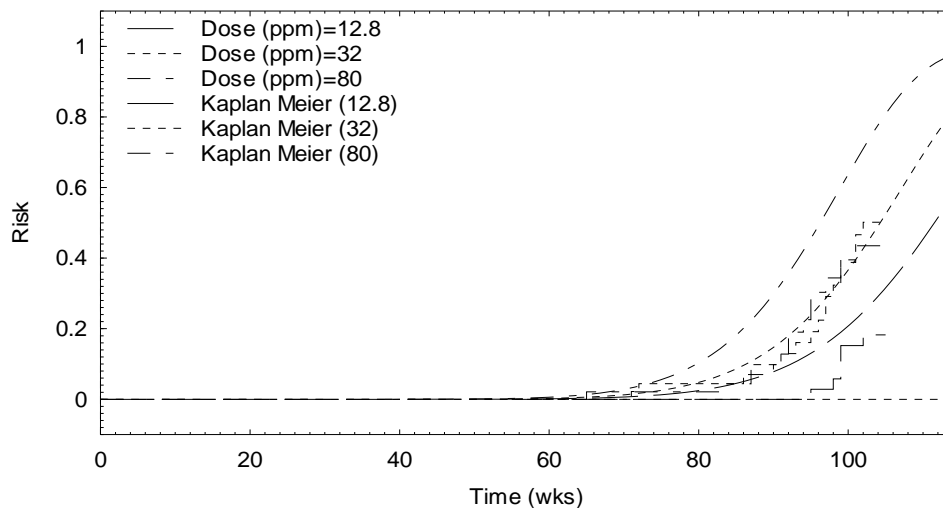
Animal to human conversion method: PPM IN AIR

Incid Extra Risk	Time (yr)	Human Equivalent Dose Estimates (ug/m <sup>3</sup> )		
		95.00 % Lower Bound	MLE	95.00 % Upper Bound
1.0000E-006	70.00	4.8038E-001	5.3398E+003	Not Reqstd
1.0000E-005	70.00	4.8039E+000	1.1504E+004	Not Reqstd
0.0001	70.00	4.8041E+001	2.4786E+004	Not Reqstd
0.0010	70.00	4.8062E+002	5.3407E+004	Not Reqstd
0.01	70.00	1.1261E+004	1.1524E+005	Not Reqstd
0.10	70.00	7.8634E+004	2.5220E+005	Not Reqstd

17:40 04/10/2008 Incidental Graph  
 M\_HEM.TTD - Chloroprene: Male mice, circulatory system  
 Model: One Stage Weib



17:47 04/10/2008 Fatal Graph  
 M\_HEM.TTD - Chloroprene: Male mice, circulatory system  
 Model: One Stage Weib



**Figure C-10. Male mice, hemangiomas and hemangiosarcomas; hemangiosarcomas occurring before termination considered fatal. Details below.**

Model: One Stage Weib                    Dataset: M:\\_ToxRiskData\Chloroprene\M\_HEM.TTD  
 Functional form: 1 - EXP[( -Q0 - Q1 \* D ) \* (T - T0)^Z]  
 Maximum Log-Likelihood = -2.022502e+002

Parameter Estimates :  
 Q 0 = 8.379828E-022  
 Q 1 = 1.163863E-022  
 Z = 1.000000E+001  
 T0 = 0.000000E+000     Set by User

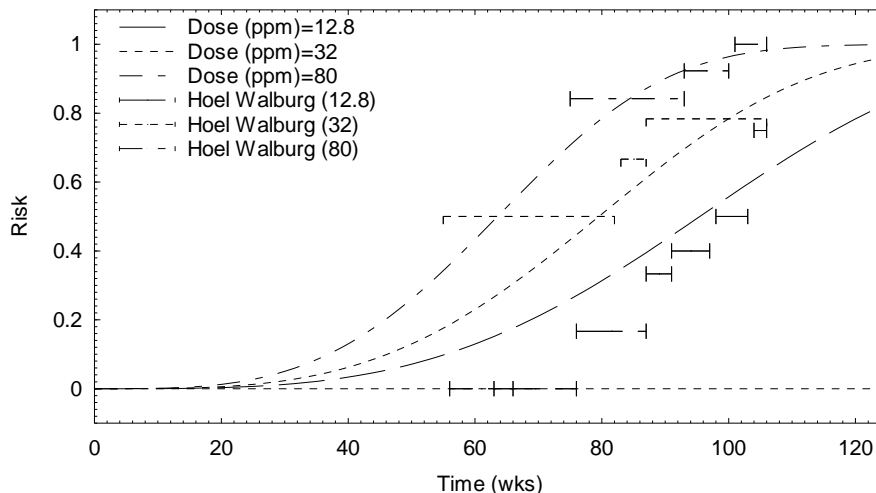
Avg. Doses (ppm)	Number		
	of animals	with fatal tumors	with incidental tumors
0	50	0	3
12.80	50	6	8
32	50	16	7
80	50	13	8

Exposure Pattern  
 Model: One Stage Weib                    Age Begins: 0     Age Ends: 70  
 Target Species: Human                    Weeks/Year: 52    Days/Week: 7  
 Route: Air                                    Hours/Day : 24

Animal to human conversion method: PPM IN AIR

Human Equivalent Dose Estimates (ug/m<sup>3</sup>)

IncidExtra Risk	Time (yr)	95.00 %		
		Lower Bound	MLE	Upper Bound
1.0000E-006	70.00	8.0694E-002	1.0423E-001	Not Reqstd
1.0000E-005	70.00	8.0694E-001	1.0423E+000	Not Reqstd
0.0001	70.00	8.0698E+000	1.0424E+001	Not Reqstd
0.0010	70.00	8.0734E+001	1.0428E+002	Not Reqstd
0.01	70.00	8.1100E+002	1.0475E+003	Not Reqstd
0.10	70.00	8.5019E+003	1.0982E+004	Not Reqstd



**Figure C-11. Male mice, alveolar/bronchiolar tumors. Details below.**

Model: One Stage Weib Dataset: M:\\_ToxRiskData\Chloroprene\M\_LUNG.TTD  
 Functional form:  $1 - \text{EXP}[(-Q0 - Q1 * D) * (T - T0)^Z]$   
 Maximum Log-Likelihood = -1.049275e+002  
 Parameter Estimates :  
 Q 0 = 4.009395E-008  
 Q 1 = 4.460491E-009  
 Z = 3.461551E+000  
 T0 = 0.000000E+000 Set by User

Avg. Doses (ppm)	Number		
	of animals	with fatal tumors	with incidental tumors
0	50	0	13
12.80	50	0	28
32	50	0	36
80	50	0	43

Generating Extrapolated Doses Table ---  
 TITLE: Chloroprene: Alv/Bronch tumors, males

Dataset: M:\\_ToxRiskData\Chloroprene\M\_LUNG.TTD  
 Exposure Pattern  
 Model: One Stage Weib Age Begins: 0 Age Ends: 70  
 Target Species: Human Weeks/Year: 52 Days/Week: 7  
 Route: Air Hours/Day : 24

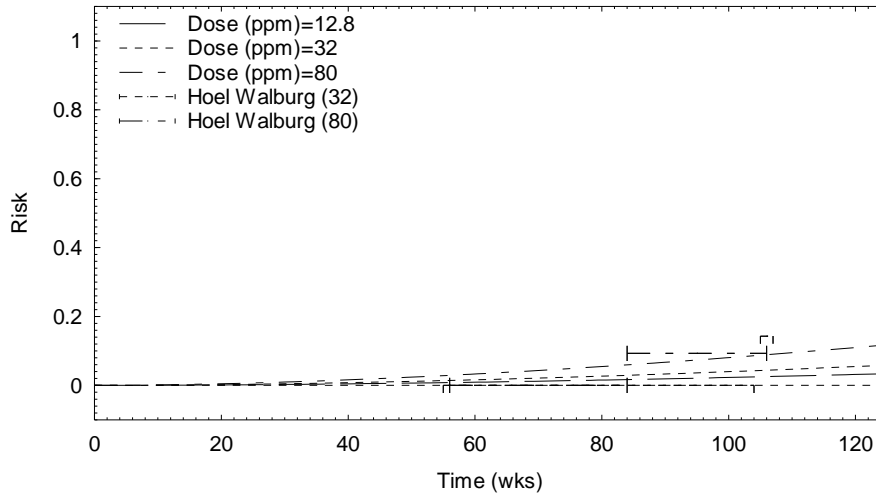
Animal to human conversion method: PPM IN AIR

Incid Extra Risk	Time (yr)	Human Equivalent Dose Estimates (ug/m <sup>3</sup> )		
		95.00 % Lower Bound	MLE	95.00 % Upper Bound
1.0000E-006	70.00	6.2992E-002	8.6156E-002	Not Reqstd
1.0000E-005	70.00	6.2992E-001	8.6157E-001	Not Reqstd
0.0001	70.00	6.2995E+000	8.6160E+000	Not Reqstd
0.0010	70.00	6.3024E+001	8.6199E+001	Not Reqstd
0.01	70.00	6.3309E+002	8.6590E+002	Not Reqstd
0.10	70.00	6.6369E+003	9.0774E+003	Not Reqstd

17:54 04/10/2008

Incidental Graph

M\_FORST.TTD - Chloroprene: Male mice, forestomach papillomas  
Model: One Stage Weib



**Figure C-12. Male mice, forestomach tumors. Details below.**

Model: One Stage Weib      Dataset: M:\\_ToxRiskData\Chloroprene\M\_FORST.TTD  
Functional form:  $1 - \text{EXP}[(-Q0 - Q1 * D) * (T - T0)^Z]$   
Maximum Log-Likelihood = -2.831876e+001

Parameter Estimates :

Q 0 = 3.027002E-006  
Q 1 = 2.341463E-007  
Z = 1.793090E+000  
T0 = 0.000000E+000      Set by User

Avg. Doses (ppm)	Number		
	of animals	with fatal tumors	with incidental tumors
0	50	0	1
12.80	50	0	0
32	50	0	2
80	50	0	4

Exposure Pattern

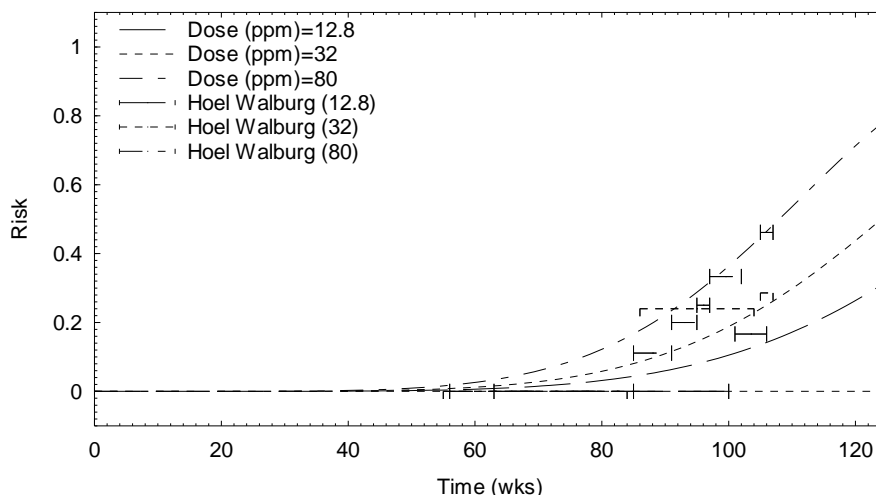
Model: One Stage Weib      Age Begins: 0      Age Ends: 70  
Target Species: Human      Weeks/Year: 52      Days/Week: 7  
Route: Air      Hours/Day : 24

Animal to human conversion method: PPM IN AIR

Human Equivalent Dose Estimates (ug/m<sup>3</sup>)

Incid Extra Risk	Time (yr)	95.00 %		
		Lower Bound	MLE	Upper Bound
1.0000E-006	70.00	1.5961E+000	3.8065E+000	Not Reqstd
1.0000E-005	70.00	1.5961E+001	3.8065E+001	Not Reqstd
0.0001	70.00	1.5962E+002	3.8067E+002	Not Reqstd
0.0010	70.00	1.5969E+003	3.8084E+003	Not Reqstd
0.01	70.00	1.6041E+004	3.8256E+004	Not Reqstd
0.10	70.00	1.6816E+005	4.0105E+005	Not Reqstd

17:56 04/10/2008  
 M\_HARD.TTD - Chloroprene: Male mice, harderian gland tumors  
 Model: One Stage Weib



**Figure C-13. Male mice, Harderian gland tumors. Details below.**

Generating Model Fit Table ---  
 TITLE: Chloroprene: Male mice, Harderian gland tumors  
 Model: One Stage Weib Dataset: M:\\_ToxRiskData\Chloroprene\M\_HARD.TTD  
 Functional form:  $1 - \text{EXP}[-Q_0 - Q_1 * D] * (T - T_0)^Z$   
 Maximum Log-Likelihood = -7.366394e+001  
 Parameter Estimates :

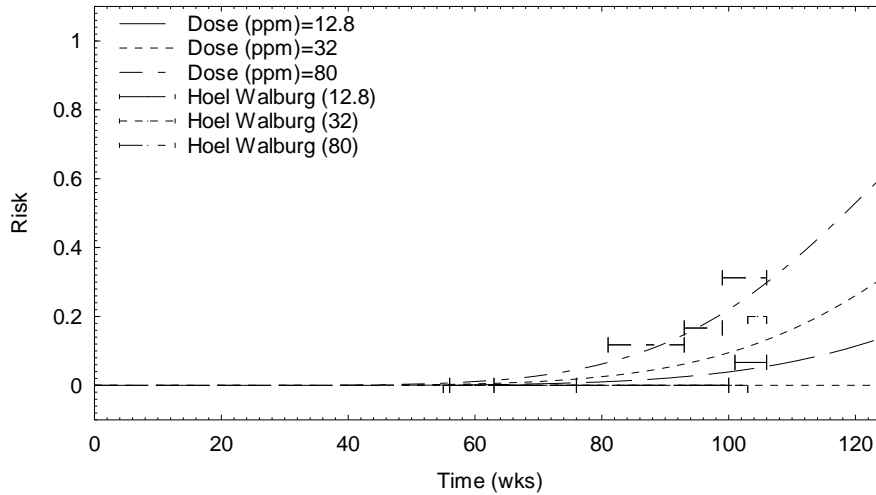
Avg. Doses (ppm)	Number		
	of animals	with fatal tumors	with incidental tumors
0	50	0	2
12.80	50	0	5
32	50	0	10
80	50	0	12

Generating Extrapolated Doses Table ---  
 TITLE: Chloroprene: Male mice, Harderian gland tumors  
 Dataset: M:\\_ToxRiskData\Chloroprene\M\_HARD.TTD  
 Exposure Pattern  
 Model: One Stage Weib Age Begins: 0 Age Ends: 70  
 Target Species: Human Weeks/Year: 52 Days/Week: 7  
 Route: Air Hours/Day : 24  
 Animal to human conversion method: PPM IN AIR

Unit Potency [ per mg/kg/day ] (computed for Risk of 1.0E-6)  
 Lower Bound = Not Reqstd MLE = 5.9938E-003 Upper Bound(q1\*) = 9.5529E-003

Induction Time (T0) Set by User to 0

Incid	Extra Risk	Time (yr)	Human Equivalent Dose Estimates (ug/m <sup>3</sup> )		
			95.00 % Lower Bound	MLE	95.00 % Upper Bound
1.0000E-006		70.00	3.6653E-001	5.8417E-001	Not Reqstd
1.0000E-005		70.00	3.6653E+000	5.8417E+000	Not Reqstd
0.0001		70.00	3.6655E+001	5.8420E+001	Not Reqstd
0.0010		70.00	3.6671E+002	5.8446E+002	Not Reqstd
0.01		70.00	3.6837E+003	5.8711E+003	Not Reqstd
0.10		70.00	3.8618E+004	6.1548E+004	Not Reqstd



**Figure C-14. Male mice, renal tubule tumors. Details below.**

Model: One Stage Weib      Dataset: M:\\_ToxRiskData\Chloroprene\M\_KIDN.TTD  
Functional form:  $1 - \text{EXP}[( -Q0 - Q1 * D ) * (T - T0)^Z]$   
Maximum Log-Likelihood = -4.100330e+001  
Parameter Estimates :  
Q 0 = 0.000000E+000  
Q 1 = 2.031241E-015  
Z = 6.092308E+000  
T0 = 0.000000E+000      Set by User

Avg. Doses (ppm)	Number		
	of animals	with fatal tumors	with incidental tumors
0	50	0	0
12.80	50	0	2
32	50	0	3
80	50	0	9

Exposure Pattern

Model: One Stage Weib      Age Begins: 0      Age Ends: 70  
Target Species: Human      Weeks/Year: 52      Days/Week: 7  
Route: Air      Hours/Day : 24

Animal to human conversion method: PPM IN AIR

Human Equivalent Dose Estimates (ug/m<sup>3</sup>)

Incid Extra Risk	Time (yr)	95.00 %		
		Lower Bound	MLE	Upper Bound
1.0000E-006	70.00	5.7583E-001	9.3451E-001	Not Reqstd
1.0000E-005	70.00	5.7583E+000	9.3451E+000	Not Reqstd
0.0001	70.00	5.7586E+001	9.3455E+001	Not Reqstd
0.0010	70.00	5.7612E+002	9.3498E+002	Not Reqstd
0.01	70.00	5.7873E+003	9.3921E+003	Not Reqstd
0.10	70.00	6.0670E+004	9.8460E+004	Not Reqstd

**Table C-1. Summary of human equivalent overall cancer risk values estimated by R/BMD<sub>R</sub>, based on male and female mouse tumor incidence (NTP, 1998)**

Tumor site	Assumed Dosimetry	Risk, R	BMD <sub>R</sub> , μg/m <sup>3</sup>	BMDL <sub>R</sub> , μg/m <sup>3</sup>	Unit Risk at BMD <sub>R</sub> <sup>a</sup> , per μg/m <sup>3</sup>	Unit risk <sup>b</sup> , per μg/m <sup>3</sup>	SD	SD <sup>2</sup>	Proportion of total variance	
<b>Female Mice</b>										
Lung	Systemic	0.01	3.22 × 10 <sup>2</sup>	4.03 × 10 <sup>2</sup>	3.10 × 10 <sup>-5</sup>	2.48 × 10 <sup>-5</sup>	3.76 × 10 <sup>-6</sup>	1.41 × 10 <sup>-11</sup>		0.55
	Portal-of-Entry	0.01	1.32 × 10 <sup>3</sup>	1.65 × 10 <sup>3</sup>	7.57 × 10 <sup>-6</sup>	6.06 × 10 <sup>-6</sup>	9.17 × 10 <sup>-7</sup>	8.41 × 10 <sup>-13</sup>	0.07	
Skin	Systemic	0.01	2.43 × 10 <sup>3</sup>	3.73 × 10 <sup>3</sup>	4.12 × 10 <sup>-6</sup>	2.68 × 10 <sup>-6</sup>	8.74 × 10 <sup>-7</sup>	7.65 × 10 <sup>-13</sup>	0.06	0.03
All hemangiomas, hemangiosarcomas	Systemic	0.01	6.43 × 10 <sup>2</sup>	8.63 × 10 <sup>2</sup>	1.55 × 10 <sup>-5</sup>	1.16 × 10 <sup>-5</sup>	2.41 × 10 <sup>-6</sup>	5.80 × 10 <sup>-12</sup>	0.46	0.22
Mammary adenomas, carcinomas, adenocarcinomas	Systemic	0.01	4.66 × 10 <sup>3</sup>	7.17 × 10 <sup>3</sup>	2.15 × 10 <sup>-6</sup>	1.39 × 10 <sup>-6</sup>	4.57 × 10 <sup>-7</sup>	2.09 × 10 <sup>-13</sup>	0.02	0.01
Hepatocellular tumors	Systemic	0.01	9.30 × 10 <sup>2</sup>	1.24 × 10 <sup>3</sup>	1.08 × 10 <sup>-5</sup>	8.04 × 10 <sup>-6</sup>	1.66 × 10 <sup>-6</sup>	2.74 × 10 <sup>-12</sup>	0.22	0.11
Forestomach	Systemic	0.01	5.79 × 10 <sup>3</sup>	1.88 × 10 <sup>4</sup>	1.73 × 10 <sup>-6</sup>	5.31 × 10 <sup>-7</sup>	7.27 × 10 <sup>-7</sup>	5.29 × 10 <sup>-13</sup>	0.04	0.02
Harderian gland	Systemic	0.01	4.59 × 10 <sup>3</sup>	5.77 × 10 <sup>3</sup>	2.18 × 10 <sup>-6</sup>	1.73 × 10 <sup>-6</sup>	2.71 × 10 <sup>-7</sup>	7.33 × 10 <sup>-14</sup>	0.01	0.00
Zymbal's gland	Systemic	0.001	4.81 × 10 <sup>2</sup>	5.34 × 10 <sup>4</sup>	2.08 × 10 <sup>-6</sup>	1.87 × 10 <sup>-8</sup>	1.25 × 10 <sup>-6</sup>	1.57 × 10 <sup>-12</sup>	0.13	0.06
Sum, MLE Cancer Risks <sup>c</sup> :					5.08 × 10 <sup>-5c</sup> 3.20 × 10 <sup>-5</sup>		Sum, SD <sup>2</sup> :	2.58 × 10 <sup>-11</sup> 1.25 × 10 <sup>-11</sup>		
Upper Bound on Sum of MLE Risk Estimates <sup>e</sup> :						5.92 × 10 <sup>-5</sup> 3.79 × 10 <sup>-5</sup>	Overall SD <sup>d</sup> :	5.08 × 10 <sup>-6</sup> 3.54 × 10 <sup>-6</sup>		
Continuous Human Equivalent Overall Unit Risk <sup>f</sup> :						3.32 × 10 <sup>-4</sup> 2.13 × 10 <sup>-4</sup>				



Tumor site	Assumed Dosimetry	Risk, R	BMD <sub>R</sub> , μg/m <sup>3</sup>	BMDL <sub>R</sub> , μg/m <sup>3</sup>	Unit risk at BMD <sub>R</sub> <sup>a</sup> , per μg/m <sup>3</sup>	Unit risk <sup>b</sup> , per μg/m <sup>3</sup>	SD	SD <sup>2</sup>	Proportion of total variance	
<b>Male Mice</b>										
Lung	Systemic	0.01	6.33 × 10 <sup>2</sup>	8.66 × 10 <sup>2</sup>	1.58 × 10 <sup>-5</sup>	1.15 × 10 <sup>-5</sup>	2.58 × 10 <sup>-6</sup>	6.67 × 10 <sup>-12</sup>		0.66
	Portal-of-Entry	0.01	2.60 × 10 <sup>3</sup>	3.55 × 10 <sup>3</sup>	3.85 × 10 <sup>-6</sup>	2.82 × 10 <sup>-6</sup>	6.30 × 10 <sup>-7</sup>	3.96 × 10 <sup>-13</sup>	0.10	
All hemangiomas, hemangiosarcomas	Systemic	0.01	8.11 × 10 <sup>2</sup>	1.05 × 10 <sup>3</sup>	1.23 × 10 <sup>-5</sup>	9.55 × 10 <sup>-6</sup>	1.69 × 10 <sup>-6</sup>	2.86 × 10 <sup>-12</sup>	0.74	0.28
Forestomach	Systemic	0.01	1.60 × 10 <sup>4</sup>	3.83 × 10 <sup>4</sup>	6.23 × 10 <sup>-7</sup>	2.61 × 10 <sup>-7</sup>	2.20 × 10 <sup>-7</sup>	4.84 × 10 <sup>-14</sup>	0.01	0.00
Harderian gland	Systemic	0.01	3.68 × 10 <sup>3</sup>	5.87 × 10 <sup>3</sup>	2.71 × 10 <sup>-6</sup>	1.70 × 10 <sup>-6</sup>	6.15 × 10 <sup>-7</sup>	3.78 × 10 <sup>-13</sup>	0.10	0.04
Kidney	Systemic	0.01	5.79 × 10 <sup>3</sup>	9.39 × 10 <sup>3</sup>	1.73 × 10 <sup>-6</sup>	1.06 × 10 <sup>-6</sup>	4.03 × 10 <sup>-7</sup>	1.63 × 10 <sup>-13</sup>	0.04	0.02
Sum, MLE Cancer Risks <sup>c</sup> :					2.41 × 10 <sup>-5</sup>		Sum, SD <sup>2</sup> :	1.01 × 10 <sup>-11</sup>		
Upper Bound on Sum of Risk Estimates <sup>e</sup> :					1.54 × 10 <sup>-5</sup>		Over all SD <sup>d</sup> :	3.85 × 10 <sup>-12</sup>		
Continuous Human Equivalent Overall Unit Risk <sup>f</sup> :								2.94 × 10 <sup>-5</sup>		
								1.86 × 10 <sup>-5</sup>	1.96 × 10 <sup>-6</sup>	
								1.65 × 10 <sup>-4</sup>		
								1.05 × 10 <sup>-4</sup>		

<sup>a</sup> R/BMD<sub>R</sub>

<sup>b</sup> R/BMDL<sub>R</sub>

<sup>c</sup> Summary statistics in italics were calculated using the “systemic” entries. The other summary statistics were calculated using the “portal-of-entry” estimate for lung tumors and all entries for the other tumor sites.

<sup>d</sup> Overall SD = (Sum, SD<sup>2</sup>)<sup>0.5</sup>

<sup>e</sup> Upper bound on the overall risk estimate = Sum of MLE cancer risks + 1.645 × Overall SD.

<sup>f</sup> Adjusted for continuous exposure by multiplying unit risk in previous line by 6/24 (hours) × 5/7 (days) = 5.6.