TOXICOLOGICAL PROFILE FOR 2-HEXANONE

Agency for Toxic Substances and Disease Registry
U.S. Public Health Service

September 1992

DISCLAIMER

The use of company or product name(s) is for identification only and does not imply endorsement by the Agency for Toxic Substances and Disease Registry.

FOREWORD

The Superfund Amendments and Reauthorization Act (SARA) of 1986 (Public Law 99-499) extended and amended the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA or Superfund). This public law directed the Agency for Toxic Substances and Disease Registry (ATSDR) to prepare toxicological profiles for hazardous substances which are most commonly found at facilities on the CERCLA National Priorities List and which pose the most significant potential threat to human health, as determined by ATSDR and the Environmental Protection Agency (EPA). The lists of the 250 most significant hazardous substances were published in the Federal Register on April 17, 1987; on October 20, 1988; on October 26, 1989; and on October 17, 1990. A revised list of 275 substances was published on October 17, 1991.

Section 104(i)(3) of CERCLA, as amended, directs the Administrator of ATSDR to prepare a toxicological profile for each substance on the lists. Each profile must include the following content:

(A) An examination, summary, and interpretation of available toxicological information and epidemiological evaluations on the hazardous substance in order to ascertain the levels of significant human exposure for the substance and the associated acute, subacute, and chronic health effects.

(B) A determination of whether adequate information on the health effects of each substance is available or in the process of development to determine levels of exposure which present a significant risk to human health of acute, subacute, and chronic health effects.

(C) Where appropriate, an identification of toxicological testing needed to identify the types or levels of exposure that may present significant risk of adverse health effects in humans.

This toxicological profile is prepared in accordance with guidelines developed by ATSDR and EPA. The original guidelines were published in the Federal Register on April 17, 1987. Each profile will be revised and republished as necessary.

The ATSDR toxicological profile is intended to characterize succinctly the toxicological and adverse health effects information for the hazardous substance being described. Each profile identifies and reviews the key literature (that has been peer-reviewed) that describes a hazardous substance's toxicological properties. Other pertinent literature is also presented but described in less detail than the key studies. The profile is not intended to be an exhaustive document; however, more comprehensive sources of specialty information are referenced.

Foreword

Each toxicological profile begins with a public health statement, which describes in nontechnical language a substance's relevant toxicological properties. Following the public health statement is information concerning levels of significant human exposure and, where known, significant health effects. The adequacy of information to determine a substance's health effects is described in a health effects summary. Data needs that are of significance to protection of public health will be identified by ATSDR, the National Toxicology Program (NTP) of the Public Health Service, and EPA. The focus of the profiles is on health and toxicological information; therefore, we have included this information in the beginning of the document.

The principal audiences for the toxicological profiles are health professionals at the federal, state, and local levels, interested private sector organizations and groups, and members of the public.

This profile reflects our assessment of all relevant toxicological testing and information that has been peer reviewed. It has been reviewed by scientists from ATSDR, the Centers for Disease Control, the NTP, and other federal agencies. It has also been reviewed by a panel of nongovernment peer reviewers. Final responsibility for the contents and views expressed in this toxicological profile resides with ATSDR.

William L. Roper, M.D., M.P.H.
Administrator
Agency for Toxic Substances and
Disease Registry

CONTENTS

FOREWORD iii

LIST OF FIGURES ix

LIST OF TABLES xi

1. PUBLIC HEALTH STATEMENT 1
   1.1 WHAT IS 2-HEXANONE? 1
   1.2 HOW MIGHT I BE EXPOSED TO 2-HEXANONE? 2
   1.3 HOW CAN 2-HEXANONE ENTER AND LEAVE MY BODY? 2
   1.4 HOW CAN 2-HEXANONE AFFECT MY HEALTH? 2
   1.5 IS THERE A MEDICAL TEST TO DETERMINE WHETHER I HAVE BEEN EXPOSED TO 2-HEXANONE? 3
   1.6 WHAT RECOMMENDATIONS HAS THE FEDERAL GOVERNMENT MADE TO PROTECT HUMAN HEALTH? 3
   1.7 WHERE CAN I GET MORE INFORMATION? 4

2. HEALTH EFFECTS 5
   2.1 INTRODUCTION 5
   2.2 DISCUSSION OF HEALTH EFFECTS BY ROUTE OF EXPOSURE 5
      2.2.1 Inhalation Exposure 6
         2.2.1.1 Death 6
         2.2.1.2 Systemic Effects 11
         2.2.1.3 Immunological Effects 13
         2.2.1.4 Neurological Effects 13
         2.2.1.5 Developmental Effects 17
         2.2.1.6 Reproductive Effects 17
         2.2.1.7 Genotoxic Effects 18
         2.2.1.8 Cancer 18
      2.2.2 Oral Exposure 18
         2.2.2.1 Death 18
         2.2.2.2 Systemic Effects 18
         2.2.2.3 Immunological Effects 23
         2.2.2.4 Neurological Effects 23
         2.2.2.5 Developmental Effects 24
         2.2.2.6 Reproductive Effects 24
         2.2.2.7 Genotoxic Effects 24
         2.2.2.8 Cancer 24
      2.2.3 Dermal Exposure 24
         2.2.3.1 Death 24
         2.2.3.2 Systemic Effects 24
         2.2.3.3 Immunological Effects 25
         2.2.3.4 Neurological Effects 25
         2.2.3.5 Developmental Effects 25
         2.2.3.6 Reproductive Effects 25
         2.2.3.7 Genotoxic Effects 25
         2.2.3.8 Cancer 25
   2.3 TOXICOKINETICS 25

2.3.1 Absorption 27
2.3.1.1 Inhalation Exposure 27
2.3.1.2 Oral Exposure 27
2.3.1.3 Dermal Exposure 27
2.3.2 Distribution 27
2.3.2.1 Inhalation Exposure 27
2.3.2.2 Oral Exposure 28
2.3.2.3 Dermal Exposure 28
2.3.3 Metabolism 28
2.3.4 Excretion 31
2.3.4.1 Inhalation Exposure 31
2.3.4.2 Oral Exposure 31
2.3.4.3 Dermal Exposure 31
2.4 RELEVANCE TO PUBLIC HEALTH 32
2.5 BIOMARKERS OF EXPOSURE AND EFFECT 36
2.5.1 Biomarkers Used to Identify and/or Quantify Exposure to 2-Hexanone 37
2.5.2 Biomarkers Used to Characterize Effects Caused by 2-Hexanone 37
2.6 INTERACTIONS WITH OTHER CHEMICALS 37
2.7 POPULATIONS THAT ARE UNUSUALLY SUSCEPTIBLE 38
2.8 MITIGATION OF EFFECTS 38
2.9 ADEQUACY OF THE DATABASE 40
2.9.1 Existing Information on Health Effects of 2-Hexanone . . 40
2.9.2 Data Needs 42
2.9.3 On-going Studies 47

3. CHEMICAL AND PHYSICAL INFORMATION 49
3.1 CHEMICAL IDENTITY 49
3.2 PHYSICAL AND CHEMICAL PROPERTIES 49

4. PRODUCTION, IMPORT, USE, AND DISPOSAL 53
4.1 PRODUCTION 53
4.2 IMPORT/EXPORT 53
4.3 USE 53
4.4 DISPOSAL 53

5. POTENTIAL FOR HUMAN EXPOSURE 55
5.1 OVERVIEW 55
5.2 RELEASES TO THE ENVIRONMENT 55
5.2.1 Air 55
5.2.2 Water 55
5.2.3 Soil 57
5.3 ENVIRONMENTAL FATE 57
5.3.1 Transport and Partitioning 57
5.3.2 Transformation and Degradation 58
5.3.2.1 Air 58
5.3.2.2 Water 58
5.3.2.3 Soil 58
5.4 LEVELS MONITORED OR ESTIMATED IN THE ENVIRONMENT 59
5.4.1 Air 59

5.4.2 Water 59
5.4.3 Soil 59
5.4.4 Other Environmental Media 60
5.5 GENERAL POPULATION AND OCCUPATIONAL EXPOSURE 60
5.6 POPULATIONS WITH POTENTIALLY HIGH EXPOSURES 60
5.7 ADEQUACY OF THE DATABASE 61
5.7.1 Data Needs 61
5.7.2 On-going Studies 63

6. ANALYTICAL METHODS 65
6.1 BIOLOGICAL MATERIALS 65
6.2 ENVIRONMENTAL SAMPLES 67
6.3 ADEQUACY OF THE DATABASE 67
6.3.1 Data Needs 67
6.3.2 On-going Studies 70

7. REGULATIONS AND ADVISORIES 71

8. REFERENCES 73

9. GLOSSARY 89

APPENDICES

A. USER'S GUIDE. A-1

B. ACRONYMS, ABBREVIATIONS, AND SYMBOLS. B-1

C. PEER REVIEW C-1

LIST OF FIGURES

2-1 Levels of Significant Exposure to 2-Hexanone - Inhalation 10

2-2 Levels of Significant Exposure to 2-Hexanone - Oral 21

2-3 Proposed Metabolic Pathway for 2-Hexanone 29

2-4 Existing Information on Health Effects of 2-Hexanone 41

5-1 Frequency of NPL Sites with 2-Hexanone Contamination 56

LIST OF TABLES

2-1 Levels of Significant Exposure to 2-Hexanone - Inhalation 7

2-2 Levels of Significant Exposure to 2-Hexanone - Oral 19

2-3 Levels of Significant Exposure to 2-Hexanone - Dermal 26

3-1 Chemical Identity of 2-Hexanone 50

3-2 Physical and Chemical Properties of 2-Hexanone 51

6-1 Analytical Methods for Determining 2-Hexanone in Biological Materials 66

6-2 Analytical Methods for Determining 2-Hexanone in Environmental Samples 68

7-1 Regulations and Guidelines Applicable to 2-Hexanone 72

1. PUBLIC HEALTH STATEMENT

This Statement was prepared to give you information about 2-hexanone and to emphasize the human health effects that may result from exposure to it. The Environmental Protection Agency (EPA) has identified 1,177 sites on its National Priorities List (NPL). 2-Hexanone has been found in at least 15 of these sites. However, we do not know how many of the 1,177 NPL sites have been evaluated for 2-hexanone. As EPA evaluates more sites, the number of sites at which 2-hexanone is found may change. This information is important for you to know because 2-hexanone may cause harmful health effects and because these sites are potential or actual sources of human exposure to 2-hexanone.

When a chemical is released from a large area, such as an industrial plant, or from a container, such as a drum or bottle, it enters the environment as a chemical emission. This emission, which is also called a release, does not always lead to exposure. You can be exposed to a chemical only when you come into contact with the chemical. You may be exposed to it in the environment by breathing, eating, or drinking substances containing the chemical or from skin contact with it.

If you are exposed to a hazardous chemical such as 2-hexanone, several factors will determine whether harmful health effects will occur and what the type and severity of those health effects will be. These factors include the dose (how much), the duration (how long), the route or pathway by which you are exposed (breathing, eating, drinking, or skin contact), the other chemicals to which you are exposed, and your individual characteristics such as age, sex, nutritional status, family traits, life style, and state of health.

1.1 WHAT IS 2-HEXANONE?

2-Hexanone, also known as methyl n-butyl ketone or MBK, is a clear, colorless liquid with a somewhat sharp odor. The liquid form can easily evaporate into the air as a vapor. It is a waste product of wood pulping, coal gasification, and oil shale operations. 2-Hexanone was formerly used in paint and paint thinner and in various chemical substances. However, since it was found to have harmful health effects, it is no longer made in the United States, and its uses have been restricted. There are no known major natural sources of 2-hexanone in the environment. When 2-hexanone is released to rivers or lakes, it dissolves very easily, and it may evaporate into the air in a few days. We do not know if 2-hexanone binds to soil. When 2-hexanone is released to the water, air, or soil, it is probably broken down into smaller products, possibly within a few days.

More information on the physical and chemical properties, uses, and releases of 2-hexanone and how it behaves in the environment can be found in Chapters 3, 4, and 5.

1. PUBLIC HEALTH STATEMENT

1.2 HOW MIGHT I BE EXPOSED TO 2-HEXANONE?

You can be exposed to 2-hexanone if you live near an industry or hazardous waste site that releases the liquid into wastewater or the gas form into the surrounding air. These industries include coal gasification plants, oil shale operations, and wood pulping mills. We have no information on background levels of 2-hexanone in the environment.

2-Hexanone has been found as a natural substance in foods such as cheese, nectarines, nuts, bread, and chicken muscle. We do not know the levels of 2-hexanone in these foods. 2-Hexanone has been found in milk and cream at levels up to 0.018 ppm (0.018 parts of 2-hexanone in one million parts of liquid). These levels are far below the levels that have caused harmful effects in animals. It has also been found in drinking water and soil near hazardous waste sites. Exposures at these sites may take place if you drink the contaminated water or bathe in it, if you get contaminated soil on your skin, or if you breathe the contaminated air.

More information on how you might be exposed to 2-hexanone is given in Chapter 5.

1.3 HOW CAN 2-HEXANONE ENTER AND LEAVE MY BODY?

2-Hexanone can enter your body when you breathe its vapors, eat food or drink water that contains it, or when you come in contact with it through your skin. When 2-hexanone is breathed in, about 75% of it is taken up and remains in the body unchanged or as a breakdown product for an unknown length of time. If it enters the body by mouth, about 65% of the chemical leaves the body slowly (in about a week), either unchanged or as breakdown products, in the breath and urine. The rest may either stay in the body or may leave the body slowly through the breath or urine. One of the breakdown products, called 2,5-hexanedione, may be responsible for the harmful effects on the nervous system (see Section 1.4). When 2-hexanone gets in through the skin, some leaves the body through the lungs and urine within a few hours. We have no information on how much stays in the body or for how long. If you live or work near a hazardous waste site, you may be exposed to 2-hexanone in the air that you breathe or in the water you drink or bathe in, if it contains small amounts of this chemical.

More information on how 2-hexanone enters and leaves the body is given in Chapter 2.

1.4 HOW CAN 2-HEXANONE AFFECT MY HEALTH?

The most important health concern for humans from exposure to 2-hexanone is its harmful effects on the nervous system. These effects were seen in workers who were exposed to 2-hexanone for almost a year. The major effects were weakness, numbness, and tingling in the skin of the hands and feet.

Similar effects were seen in animals that ate or breathed high levels of 2-hexanone; these effects included weakness, clumsiness, and paralysis.

We do not know whether 2-hexanone can cause cancer or birth defects. In one study, when pregnant rats were exposed to 2-hexanone in the air, fewer offspring lived after birth, and those that did survive had low birth weights.

Many of the studies in which the health effects of 2-hexanone in humans or animals were reported did not use pure 2-hexanone. Therefore, we do not know whether the results were caused by 2-hexanone itself or by the other chemicals in the mixture.

More information on health effects of 2-hexanone can be found in Chapter 2.

1.5 IS THERE A MEDICAL TEST TO DETERMINE WHETHER I HAVE BEEN EXPOSED TO 2-HEXANONE?

Tests can be used to find out whether you have recently been exposed to 2-hexanone. The tests measure levels of 2-hexanone or its breakdown products in blood or urine. These tests require special equipment and are done in a special laboratory, so they are usually not available in a doctor's office. However, these tests cannot be used to predict whether harmful effects will occur.

More information on how 2-hexanone can be measured in exposed humans is given in Chapters 2 and 6.

1.6 WHAT RECOMMENDATIONS HAS THE FEDERAL GOVERNMENT MADE TO PROTECT HUMAN HEALTH?

The federal government has set certain regulations and guidelines to help protect people from the possible health effects of 2-hexanone in the workplace. The Occupational Safety and Health Administration (OSHA) has set a limit of 5 ppm (5 parts of 2-hexanone in 1 million parts of air) as an average exposure level to this chemical over a 40-hour work week. The American Conference of Governmental Industrial Hygienists (ACGIH) has made the same recommendation. The National Institute for Occupational Safety and Health (NIOSH) recommends an even lower limit, 1 ppm, as an average exposure during a 10-hour period.

More information on governmental regulations regarding 2-hexanone can be found in Chapter 7.

1. PUBLIC HEALTH STATEMENT

1.7 WHERE CAN I GET MORE INFORMATION?

If you have any more questions or concerns not covered here, please contact your state health or environmental department or:

Agency for Toxic Substances and Disease Registry
Division of Toxicology
1600 Clifton Road, E-29
Atlanta, Georgia 30333

This agency can also provide you with information on the location of the nearest occupational and environmental health clinic. Such clinics specialize in recognizing, evaluating, and treating illnesses that result from exposure to hazardous substances.

2. HEALTH EFFECTS

2.1 INTRODUCTION

The primary purpose of this chapter is to provide public health officials, physicians, toxicologists, and other interested individuals and groups with an overall perspective of the toxicology of 2-hexanone and a depiction of significant exposure levels associated with various adverse health effects. It contains descriptions and evaluations of studies and presents levels of significant exposure for 2-hexanone based on toxicological studies and epidemiological investigations.

In the evaluation of studies described in this chapter, the purity of the test compound was considered. As shown in the text, tables, and figures, three general categories of 2-hexanone purity were indicated in the studies:

- Purity of 96% or more
- 70% purity (technical grade)
- Purity was not stated in the cited publication

In technical grade 2-hexanone, the 30% impurity was identified as methyl isobutyl ketone, and the possible implications of its presence in the test substance were discussed.

2.2 DISCUSSION OF HEALTH EFFECTS BY ROUTE OF EXPOSURE

To help public health professionals address the needs of persons living or working near hazardous waste sites, the information in this section is organized first by route of exposure--inhalation, oral, and dermal--and then by health effect--death, systemic, immunological, neurological, developmental, reproductive, genotoxic, and carcinogenic effects. These data are discussed in terms of three exposure periods --acute (less than 15 days), intermediate (15-364 days), and chronic (365 days or more).

Levels of significant exposure for each route and duration are presented in tables and illustrated in figures. The points in the figures showing noobserved- adverse-effect levels (NOAELS) or lowest-observed-adverse-effect levels (LOAELS) reflect the actual doses (levels of exposure) used in the studies. LOAELs have been classified into "less serious" or "serious" effects. These distinctions are intended to help the users of the document identify the levels of exposure at which adverse health effects start to appear. They should also help to determine whether or not the effects vary with dose and/or duration, and place into perspective the possible significance of these effects to human health.

The significance of the exposure levels shown in the tables and figures may differ depending on the user's perspective. For example, physicians concerned with the interpretation of clinical findings in exposed persons may be interested in levels of exposure associated with "serious" effects. Public health officials and project managers concerned with appropriate actions to

take at hazardous waste sites may want information on levels of exposure associated with more subtle effects in humans or animals (LOAEL) or exposure levels below which no adverse effects (NOAEL) have been observed. Estimates of levels posing minimal risk to humans (Minimal Risk Levels, MRLs) may be of interest to health professionals and citizens alike.

Estimates of exposure levels posing minimal risk to humans (MRLs) have been made, where data were believed reliable, for the most sensitive noncancer effect for each exposure duration. MRLs include adjustments to reflect human variability from laboratory animal data to humans.

Although methods have been established to derive these levels (Barnes et al. 1988; EPA 1989), uncertainties are associated with these techniques. Furthermore, ATSDR acknowledges additional uncertainties inherent in the application of the procedures to derive less than lifetime MRLs. As an example, acute inhalation MRLs may not be protective for health effects that are delayed in development or are acquired following repeated acute insults, such as hypersensitivity reactions, asthma, or chronic bronchitis. As these kinds of health effects data become available and methods to assess levels of significant human exposure improve, these MRLs will be revised.

2.2.1 Inhalation Exposure

Numerous studies have been conducted in which animals were exposed to 2-hexanone via inhalation. However, the purpose of many of these studies was to assess the potential effects of combined exposure to 2-hexanone and another substance (usually chloroform or methyl ethyl ketone [MEK]). Study design has consequently involved exposure to only one concentration of 2-hexanone as a control exposure. A single high dose of 2-hexanone was used in several other studies in order to elicit and study histopathological changes in the affected nervous tissue, In addition, the grade or purity of the 2-hexanone administered was not stated in many studies, or in some cases, hexanone with purity as low as 70% was used. As a result of these various complications, the usefulness of the available data is limited.

2.2.1.1 Death

The only lethality data available for inhalation exposure to 2-hexanone are from a study by Abdo et al. (1982) in which 1 of 5 hens exposed continuously to 200 ppm 2-hexanone (70% purity) died on day 72 of a 90-day study. At 400 ppm, 2 of 5 hens died by day 27. The cause of death was not stated. No deaths were observed in the groups exposed to 100 ppm and below.

The highest NOAEL value and a reliable LOAEL value for death in this species and duration category are recorded in Table 2-l and plotted in Figure 2-l.

TABLE 2-1. Levels of Significant Exposure to 2-Hexanone - Inhalation

Key to figure[a]	Species	Exposure frequency/ duration	System	NOAEL (ppm)	LOAEL (effect) Less serious (ppm)	LOAEL (effect) Serious (ppm)	Reference	Purity
INTERMEDIATE EXPOSURE								
Death								
1	Hen	90 d 24 hr/d		100		200 (death)	Abdo et al. 1982	T
Systemic								
2	Human	+10 mo (occup)	Other		9 (up to 60 lb weight loss)		Allen et al. 1975	U
3	Rat	6 mo 7d/wk 22hr/d	Other	100			Egan et al. 1980	P
4	Rat	6 mo 5d/wk 8hr/d	Hepatic Renal	50 50			Duckett et al. 1979	U
5	Rat	11 wk 72 hr/wk 18 hr/d	Hemato Other		700 (decreased weight gain)	700 (40% decrease in WBCs)	Katz et al. 1980	P
6	Rat	25-29 wk 5d/wk 6hr/d	Other	100	1000 (decreased body weight)		Johnson et al. 1977	U
7	Hen	90 d 24 hr/d	Other	50	200 (42% weight loss)		Abdo et al. 1982	T
Neurological								
8	Human	+10 mo (occup)			9 (neuropathy)		Allen et al. 1975	U
9	Rat	6 mo 5d/wk 8hr/d				50 (histopathology)	Duckett et al. 1979	U

TABLE 2-1 (Continued)

Key to figure[a]	Species	Exposure frequency/ duration	System	NOAEL (ppm)	LOAEL (effect) Less serious (ppm)	LOAEL (effect) Serious (ppm)	Reference	Purity
10	Rat	4 mo 5 d/wk 6 hr/d				1300 (nerve degeneration)	Spencer et al. 1975	U
11	Rat	6 mo 7d/wk 22hr/d				100 (histopathology)	Egan et al. 1980	P
12	Rat	6-9.5 wk 24hr/d				225 (paralysis, histopathology)	Saida et al. 1976	U
13	Rat	11 wk 72 hr/wk 18 hr/d				700 (neuropathy, histopathology)	Katz et al. 1980	P
14	Rat	29 wk 5d/wk 6hr/d			100 (neuropathy)		Johnson et al. 1977	U
15	Monkey	41 wk 5d/wk 6hr/d			100 (mild neuropathy)		Johnson et al. 1977	U
16	Hen	90 d 5 d/wk NDhr/d			100 (ataxia)		Abou-Donia et al. 1985a	T
17	Hen	90 d 24 hr/d		10	50 (ataxia)	200 (paralysis, histopathology)	Abdo et al. 1982	T
Developmental								
18	Rat	21 Gd 6hr/d				2000 (decreased pup survival and weight)	Peters et al. 1981	U
19	Rat	21 Gd 6hr/d			1000 (behavioral effects in offspring)		Peters et al. 1981	U

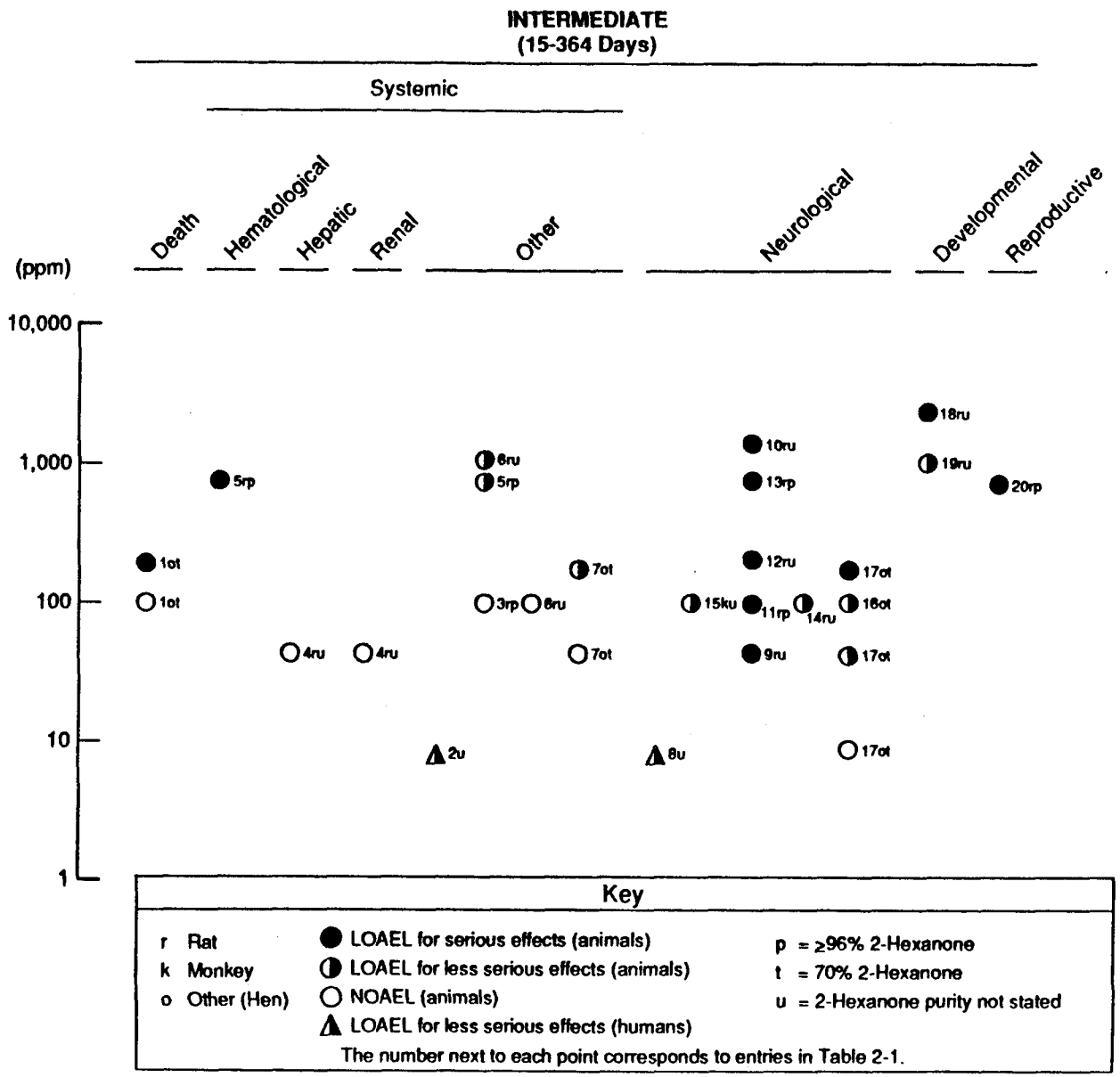
TABLE 2-1 (Continued)

Key to figure[a]	Species	Exposure frequency/ duration	System	NOAEL (ppm)	LOAEL (effect) Less serious (ppm)	LOAEL (effect) Serious (ppm)	Reference	Purity
Reproductive								
20	Rat	11 wk 72 hr/wk 18 hr/d				700 (decreased testes weight, histopathology)	Katz et al. 1980	P

[a]The number corresponds to entries in Figure 2-1.

d = day(s); Gd = gestation days; Hemato = hematological; hr = hour(s); lb = pounds; LOAEL = lowest-observed-adverse-effect level; mo = month(s); ND = no data; NOAEL = no-observed-adverse-effect level; occup = occupational; P = ≥96% 2-hexanone; T = 70% 2-hexanone; U = 2-hexanone purity not stated; WBC = white blood cells; wk = week(s)

FIGURE 2-1. Levels of Significant Exposure to 2-Hexanone – Inhalation



2.2.1.2 Systemic Effects

The systemic effects observed after inhalation exposure to 2-hexanone are discussed below. The NOAEL values and all reliable LOAEL values for systemic effects in each species and duration category are recorded in Table 2-l and plotted in Figure 2-1.

No studies were located regarding respiratory, cardiovascular, gastrointestinal, or dermal/ocular effects in humans or animals after inhalation exposure to 2-hexanone.

Hematological Effects. No studies were located regarding hematological effects in humans after inhalation exposure to 2-hexanone.

A reduction in total leukocyte counts to about 60% of control values($p<0.05$) was observed in rats intermittently exposed to 700 ppm 2-hexanone (96.1% purity) after 8 weeks of an ll-week study (Katz et al. 1980). Hemoglobin concentration, hematocrit, and differential white cell counts were similar to control values. Although the decrease in total white blood cell counts suggested an effect on bone marrow, the authors found no microscopic evidence of such damage. Therefore, the clinical significance of their findings was uncertain. In addition, only a single dosage level was used in the study.

Musculoskeletal Effects. No studies were located regarding musculoskeletal effects in humans or animals after inhalation exposure to 2-hexanone. Weakness and lack of coordination have been observed in several studies; however, these effects have been attributed to nerve damage (see Section 2.2.1.4).

Hepatic Effects. No studies were located regarding hepatic effects in humans after inhalation exposure to 2-hexanone.

There was no effect on hexobarbital-induced sleep times in rats exposed continuously to 225 ppm 2-hexanone (purity not stated) for 7 days (Couri et al. 1977). Thus, 2-hexanone exposure under these conditions does not seem to affect the hepatic microsomal enzyme activities associated with this response. No histopathological effects were seen in the livers of rats exposed to 50 ppm 2-hexanone (purity not stated) for 6 months (Duckett et al. 1979). However, no additional data on potential hepatic effects were found.

Renal Effects. No studies were located regarding renal effects in humans after inhalation exposure to 2-hexanone. No histopathological effects were seen in the kidneys of rats exposed to 50 ppm 2-hexanone (purity not stated) for 6 months (Duckett et al. 1979).

Other Systemic Effects. The most common systemic effect observed following inhalation exposure to 2-hexanone is weight loss or a decreased rate of weight gain in developing animals.

A 1973 outbreak of distal polyneuropathy involving 86 of 1,157 employees was reported in a plant that had been using 2-hexanone for about 10 months in the production of plastic-coated and color-printed fabrics (Allen et al. 1975; Billmaier et al. 1974). (Neurological effects associated with this exposure are discussed in Section 2.2.1.4.) Clinical evaluations indicated that of 10 workers whose body weight was recorded, weight loss ranging from 3 to 60 pounds was observed in the eight workers found to have moderate to severe neurological impairment (Allen et al. 1975). Of the milder cases, no significant weight change could be correlated with the presence of the disorder. Atmospheric sampling conducted after this incident indicated that 2-hexanone levels averaged 9.2 ppm in front of the printing machines and 36 ppm behind the machines. After the use of 2-hexanone was discontinued, weight gain was uniformly noted in those who had lost weight.

In animal studies involving 3-6 months of inhalation exposure to 2-hexanone, both weight loss and decreased rates of weight gain in developing animals were noted.

A progressive but not statistically significant loss of body weight was reported in monkeys, beginning 4 months after exposure to 1,000 ppm 2-hexanone (purity not stated) (Johnson et al. 1977). These effects were not seen at 100 ppm. Exposure of rats to 1,000 ppm 2-hexanone (purity not stated) resulted in statistically significant weight loss at weeks 2-10 and 20-24 (Johnson et al. 1977). No effects were seen at 100 ppm in that study or in a similar 6-month study in rats (Egan et al. 1980). Other available single-dose level studies in rats generally support these observations. A marked reduction in weight gain was observed in rats exposed to 700 ppm 2-hexanone (96.1% purity) within 3 days of exposure during an ll-week study (Katz et al.1980). Slow progressive weight loss (no details provided) in rats after 10 weeks of exposure to 1,300 ppm 2-hexanone (purity not stated) has also been reported (Spencer et al. 1975).

In hens, a clear dose-response relationship for effects on body weight resulting from inhalation of 2-hexanone was observed during a 13-week study by Abdo et al. (1982). No effects were seen at 10 or 50 ppm. Hens exposed to 100 ppm weighed about 92% of their initial weight at the end of 13 weeks of exposure. Hens exposed to 200 ppm weighed 58% of their initial weight after 10 weeks of exposure, and hens exposed to 400 ppm weighed 48% of their initial weight after 4 weeks of exposure. Hens exposed to 100 ppm 2-hexanone (70% purity) for 13 weeks had a nonsignificant increase in body weight (Abou-Donia et al. 1985a).

It is noteworthy that in three species (monkeys, rats, and hens), 3-6 months of exposure to 2-hexanone at 100 ppm resulted in little or no effect on body weight parameters. Levels measured in the epidemiological study of exposed workers, however, were only 9.2-36 ppm (Allen et al. 1975). However, these levels were measured after the incident. If these low levels of 2-hexanone are a reasonably accurate indication of the conditions of human exposure that resulted in the observed weight loss, humans may be a very sensitive species with regard to this parameter. It is not clear whether the affected individuals had decreased appetites and/or food consumption levels in conjunction with their weight loss.

2.2.1.3 Immunological Effects

No studies were located regarding immunological effects in humans after inhalation exposure to 2-hexanone.

A reduction in total white blood cell counts to 60% of control values ($p<0.05$), but no changes in differential white cell counts or evidence of bone marrow damage, was found in rats intermittently exposed to 700 ppm 2-hexanone after 8 weeks during an ll-week study (Katz et al. 1980). These findings, although inconclusive, suggest that immunological effects may warrant some consideration in future assessments of the potential toxicity of inhalation exposure to 2-hexanone.

2.2.1.4 Neurological Effects

In humans, the most important effect associated with inhalation exposure to 2-hexanone is neurological dysfunction, most commonly observed as peripheral neuropathy. Widespread attention was brought to this phenomenon after a 1973 outbreak of distal neuropathy in an Ohio fabric finishing plant that had introduced the use of 2-hexanone into its processing operations approximately 10 months before the first cases of neuropathy were reported. The screening of 1,157 employees resulted in the detection of 86 verified cases of neuropathy (Allen et al. 1975). Eleven of these cases were moderate to severe with both motor and sensory involvement; 38 were mild with sensory signs prevailing; and 37 were considered minimal, without clinical manifestations but with characteristic electrodiagnostic abnormalities. General characteristics of the neuropathy included muscle weakness, sensory loss (inability to discriminate pain, touch, temperature, or vibration) in the hands and feet, and diminution or loss of reflexes. Electromyographic (EMG) testing generally indicated that nerve conduction velocities (NCVs) were slower, especially in the ulnar, peroneal, tibial, and sural nerves, and the distal latencies (times to response) were prolonged in parallel to the reduction of the NCV. Other abnormalities included waves and fibrillations, especially in the more severe cases, and a decrease in the number and an increase in the size of motor unit potentials. No histological evidence of nerve damage was obtained in any of these patients. Atmospheric sampling conducted after this incident indicated that 2-hexanone levels in the

processing plant averaged 9.2 ppm in front of the printing machines and 36 ppm behind them. After the use of 2-hexanone was discontinued, marked improvement was seen in the affected employees during the next few months, including all of the moderate-to-severe cases and most of the mild and minimal cases. However, the authors stated that it was not possible to rule out a possible synergistic effect with methyl ethyl ketone or with other chemicals used at the plant.

This industrial incident apparently prompted most of the ensuing animal research on the effects of inhalation exposure to 2-hexanone. Several studies were conducted in rats in an attempt to describe the histopathological basis of the observed neuropathy, and several other studies were concerned with the ability of 2-hexanone exposure to potentiate the adverse effects of exposure to other agents. As described above, most of the animal neurotoxicity studies involved the use of only a single dose of 2-hexanone, usually as a control group for comparison with the effects of combined exposure to 2-hexanone and another compound, and several other studies used a single high dose of 2-hexanone in order to elicit neurotoxicity and assess the accompanying histopathological changes.

In all animals studied, including monkeys, cats, rats, and chickens, the clinical observations generally indicated a progression from weakness and ataxia to complete paralysis of the limbs. These clinical observations were accompanied or preceded by morphological changes in the peripheral nerves, including an increase in the number of neurofilaments in the nerve fibers, axonal swelling, and inpouchings and thinning of the myelin sheath. It is also important to note that 2,5-hexanedione, a metabolite of 2-hexanone in rats, guinea pigs, and humans (DiVincenzo et al. 1976, 1978; Eben et al. 1979) has been observed to elicit severe neuropathy following oral administration to rats (Krasavage et al. 1980) and following oral, dermal, or intraperitoneal administration to hens (Abou-Donia et al. 1982, 1985b). Comparative studies of the relative neurotoxicities of 2-hexanone, 2,5-hexanedione, and other compounds have concluded that 2,5-hexanedione is a more potent neurotoxicant than 2-hexanone (Abou-Donia et al. 1982; Krasavage et al. 1980).

Severe neurotoxicity was reported in rats as a result of 7 days of continuous inhalation exposure to 225 ppm 2-hexanone (Couri et al. 1977). However, no data for this toxic effect were given in the study. Paralysis was observed in rats exposed to 225 ppm 2-hexanone (purity not stated) for 9.5 weeks or to 400 ppm for 6 weeks (Saida et al. 1976). Inpouchings of the myelin sheath of the peripheral nerves occurred as early as 16 days at both dose levels. Other histopathological findings included denuded fibers and swollen axons. Continuous inhalation exposure of rats to 2-hexanone (purity not stated), initially at 600 ppm but lowered to 400 ppm to prevent weakness and weight loss, resulted in hind limb dragging at 11-12 weeks (Mendell et al. 1974b). Histopathological observations were axonal swelling and demyelination of nerve fibers. In rats exposed to 100 ppm 2-hexanone for 25-29 weeks, there was a progressive, statistically significant decrease in the maximum motor

conduction velocity (MCV) of the sciatic-tibial nerve at 29 weeks and of the ulnar nerve at 17 weeks. An effect on operant behavior, manifest as a reduced response rate in bar-pressing studies, was also reported. At 1,000 ppm exposure, these effects were seen earlier (Johnson et al. 1977). Rats exposed to 700 ppm 2-hexanone (96.1% purity) during an ll-week study developed clinical signs of neurotoxicity as early as the second week of exposure (Katz et al. 1980). Observations included reduced body muscle tone and weakened hind- and forelimb grasping of a wire mesh.

In a 6-month study, rats exposed to 100 ppm 2-hexanone (96.7% purity) did not demonstrate clinical signs of neuropathy. However, after 4 months of exposure, giant axonal swellings and demyelination were seen in fibers of the tibia1 nerves; by 6 months degeneration had ascended to the sciatic notch. In the central nervous system, 4-month observations included giant axonal swellings in the medulla oblongata and cerebellum. By 6 months the spinal cord had scattered fiber degeneration in the gracile tract and the lumbar region (Egan et al. 1980). In a 6-month study in rats, inhalation exposure to 50 ppm 2-hexanone (purity not stated) resulted in histopathological effects including demyelination of the sciatic nerve, and axonal hypertrophy and beading (Duckett et al. 1979). Rats exposed to 1,300 ppm during a 40-week study developed a pronounced symmetrical hindlimb footdrop, hindlimb and forelimb weakness, and nerve fiber swelling and degeneration (Spencer et al. 1975).

In a 10-month study, monkeys exposed to 1,000 ppm 2-hexanone had abnormal results in electrodiagnostic tests (Johnson et al. 1977). There was a progressive and statistically significant decrease in the maximum motor conduction velocity of the sciatic-tibia1 nerves starting at 4 months of exposure and a decrease in the maximum conduction velocity of the ulnar nerves starting at 1 month. Decreased amplitude of evoked muscle action potential was also seen at 1,000 ppm. Results of 100 ppm exposure were similar to those of controls except for a statistically significant decreased response in the ulnar nerve at the 1 and 3 month measurements and in the sciatic-tibia1 nerve only at 9 and 10 months. Recovery to pre-exposure values for motor conduction velocities took 2 months for the 100 ppm group and 6 months for the 1,000 ppm group.

Clinical signs of neuropathy were evident in cats after continuous inhalation exposure to 400-600 ppm 2-hexanone (purity not stated) for 5 weeks or more (Mendell et al. 1974b). (Initial exposure to 600 ppm was lowered to 400 ppm in order to prevent weakness and weight loss.) Hindlimb dragging was followed by forelimb weakness and eventual paralysis. The EMG studies showed a dramatic decrease (56%) in the ulnar nerve conduction velocity. Axonal swelling and demyelination of the nerve fibers were also observed. One of these cats was observed by Saida et al. (1976) for 4.5 months after exposure in order to assess recovery. The animal eventually regained the ability to walk, swollen axons were greatly reduced in number, and nerve fibers showed signs of remyelination.

2. HEALTH EFFECTS

Continuous inhalation exposure of hens to 2-hexanone (purity not stated) initially at 200 ppm, then lowered to 100 ppm to prevent weakness and weight loss, resulted in overt clinical signs of neuropathy at 4-5 weeks when the animals could no longer stand (Mendell et al. 1974b). Histopathological observations included axonal swelling and demyelination of nerve fibers. In a go-day inhalation study in hens followed by a 30-day recovery period, neurological effects were not apparent in the group exposed to 10 ppm 2-hexanone (70% purity) (Abdo et al. 1982). Mild ataxia (diminished leg movements and reluctance to walk) was seen with 4 weeks of exposure to 50 ppm; this progressed to near paralysis by 13 weeks. At higher levels, these effects were seen earlier. Exposure to 200 ppm resulted in mild ataxia after 2 weeks and paralysis after 10 weeks. Demyelination and axonal swelling were seen in the spinal cord at 50 ppm and in both the spinal cord and peripheral nerves at 100 ppm and above. During the 30-day recovery period, slight clinical improvement was seen in the 50 ppm group. In another go-day study, hens exposed to 100 ppm 2-hexanone (70% purity) had mild ataxia after 39 days of exposure but no evidence of histopathological changes in nerve tissue (Abou-Donia et al. 1985a).

As noted above, the test compound used in two of the studies in hens, Abdo et al. (1982) and Abou-Donia et al. (1985a), was technical grade 2-hexanone with a purity level of 70%. The other 30% component of this formulation was methyl isobutyl ketone. In a 90-day study in which hens were exposed to pure methyl isobutyl ketone at 1,000 ppm via inhalation, this compound failed to induce neurotoxicity (Abou-Donia et al. 1985c). However, in hens simultaneously exposed to 1,000 ppm n-hexane (which by itself was mildly neurotoxic), with increasing concentrations of methyl isobutyl ketone (l00-1,000 ppm) there was a dose-related response of increasingly severe ataxia progressing to paralysis. In addition, histopathological changes of the nervous system progressed to degeneration of the spinal cord and lesions in the peripheral nerves. These results are important to note because they serve to illustrate that a potential for synergistic interaction or potentiation exists with combined exposure to methyl isobutyl ketone and at least one other compound, n-hexane. It is, therefore, possible that combined exposure to 2-hexanone and methyl isobutyl ketone, as in the Abdo et al. (1982) and Abou-Donia et al. (1985a) studies can result in synergistic interaction or a potentiation effect (see Section 2.6).

In addition to the neurological effects in the studies described above, behavioral alterations were reported in the offspring of pregnant rats exposed to 1,000 ppm 2-hexanone (purity not stated) during and after gestation (Peters et al. 1981) (see Section 2.2.1.5).

The highest NOAEL value in hens and all reliable LOAEL values for neurological effects in each species in the intermediate-duration category are recorded in Table 2-l and plotted in Figure 2-l.

2.2.1.5 Developmental Effects

No studies were located regarding developmental effects in humans after inhalation exposure to 2-hexanone.

Behavioral alterations were reported in the offspring of pregnant rats exposed to 1,000 ppm or 2,000 ppm 2-hexanone (purity not stated) during 21 days of gestation (Peters et al. 1981). These effects consisted of reduced activity in the open field, increased activity in the running wheel, and deficits in avoidance conditioning. Offspring of treated dams (both dose levels) clung to an inclined screen longer than offspring of controls at all ages (newborn, weanling, puberty, and adult) except geriatric in which results were similar to those of controls. For offspring in the puberty and adult categories, pronounced sex differences were noted, with females in all exposure categories (including controls) clinging from 24% to 100% longer than males. However, the biological significance of this observation is unknown. There was a decreased rate of avoidance learning in puberty-aged females of treated dams and increased random movement in both puberty-aged and adult offspring of treated dams. Behavioral tests in most cases indicated that maternal exposure to 2-hexanone was associated with hyperactivity in the young and decreased activity in the geriatric stage, which the authors speculated to be due to premature aging resulting from the earlier hyperactivity. It is not clear whether these effects are the result of transplacental exposure to 2-hexanone or of postnatal exposure to 2-hexanone and/or its metabolites via the milk of the exposed dams.

In addition, decrements were observed in the weight gain of pregnant rats exposed to 1,000 ppm or 2,000 ppm 2-hexanone during 21 days of gestation (Peters et al. 1981). These decreases were 10% and 14%, respectively; statistical significance was not addressed. Rats in the 2,000 ppm exposure group were observed to eat less than did the controls. There was also a significant decrease in the number and weight of live offspring of dams in the 2,000 ppm exposure group.

The LOAEL values for developmental effects in rats in the intermediateduration category are recorded in Table 2-l and plotted in Figure 2-l.

2.2.1.6 Reproductive Effects

No studies were located regarding reproductive effects in humans after inhalation exposure to 2-hexanone.

Marked and significant reductions in absolute and relative testes weight and atrophy of testicular germinal epithelium were observed in male rats exposed to 700 ppm 2-hexanone for 11 weeks (Katz et al. 1980).

The LOAEL value for reproductive effects in rats for the intermediate-duration category is recorded in Table 2-l and plotted in Figure 2-l.

2.2.1.7 Genotoxic Effects

No studies were located regarding genotoxic effects in humans or animals after inhalation exposure to 2-hexanone.

2.2.1.8 Cancer

No studies were located regarding cancer effects in humans or animals after inhalation exposure to 2-hexanone.

2.2.2 Oral Exposure

Several studies were conducted in which only a single high dose of 2-hexanone was orally administered to rats in an attempt to induce and consequently study the resulting neurotoxic effects. In addition, only a few of the studies were conducted using 2-hexanone of a stated purity of 96% or better. Other studies used a formulation containing 70% 2-hexanone or the purity of the test substance was not stated. As a result, the usefulness of the existing data base using the oral route is limited.

2.2.2.1 Death

An LD_{50} of 2,590 mg/kg was calculated for a gavage administration of 2-hexanone (purity not stated) to rats (Smyth et al. 1954). One of 4 hens administered 2-hexanone (70% purity) at 2,000 mg/kg by gavage died (Abou-Donia et al. 1982). No lethality occurred in 24 hours in 6 male rats that received 2-hexanone (>99% purity) at 1,500 mg/kg by gavage (Hewitt et al. 1980a).

The highest NOAEL value, a reliable LOAEL value for death and an LD_{50} value for these species in the acute-duration category are recorded in Table 2-2 and plotted in Figure 2-2.

2.2.2.2 Systemic Effects

The systemic effects observed after oral exposure to 2-hexanone are discussed below. The highest NOAEL values and all reliable LOAEL values for systemic effects in each species and duration category are recorded in Table 2-2 and plotted in Figure 2-2.

No studies were located regarding respiratory, cardiovascular, gastrointestinal, hematological, musculoskeletal, or dermal/ocular effects in humans or animals after oral exposure to 2-hexanone.

Hepatic Effects. No studies were located regarding hepatic effects in humans after oral exposure to 2-hexanone.

TABLE 2-2. Levels of Significant Exposure to 2-Hexanone - Oral

Key to figure[a]	Species	Route	Exposure frequency/ duration	System	NOAEL (mg/kg/day)	LOAEL (effect) Less serious (mg/kg/day)	LOAEL (effect) Serious (mg/kg/day)	Reference	Purity
ACUTE EXPOSURE									
Death									
1	Rat	(G)	1x				2590 (LD50)	Smyth et al. 1954	U
2	Rat	(GO)	1x		1500			Hewitt et al. 1980a	P
3	Hen	(G)	1x				2000 (death of 1/4)	Abou-Donia et al. 1982	T
Systemic									
4	Rat	(G)	1x	Hepatic	1500			Hewitt et al. 1986	U
5	Rat	(GO)	1x	Hepatic Renal	1500 1500			Hewitt et al. 1980a	P
INTERMEDIATE EXPOSURE									
Systemic									
6	Rat	(G)	90 d 5d/wk 1x/d	Other		660 (weight loss)		Krasavage et al. 1980	P
7	Rat	(GW)	40 wk 1x/d	Hepatic Renal	400 400			Eben et al. 1979	P
Neurological									
8	Rat	(G)	90 d 5d/wk 1x/d				660 (paralysis, histopathology)	Krasavage et al. 1980	P
9	Gn pig	(W)	24 wk			600 (abnormal pupil response)		Abdel-Rahman et al. 1978	U

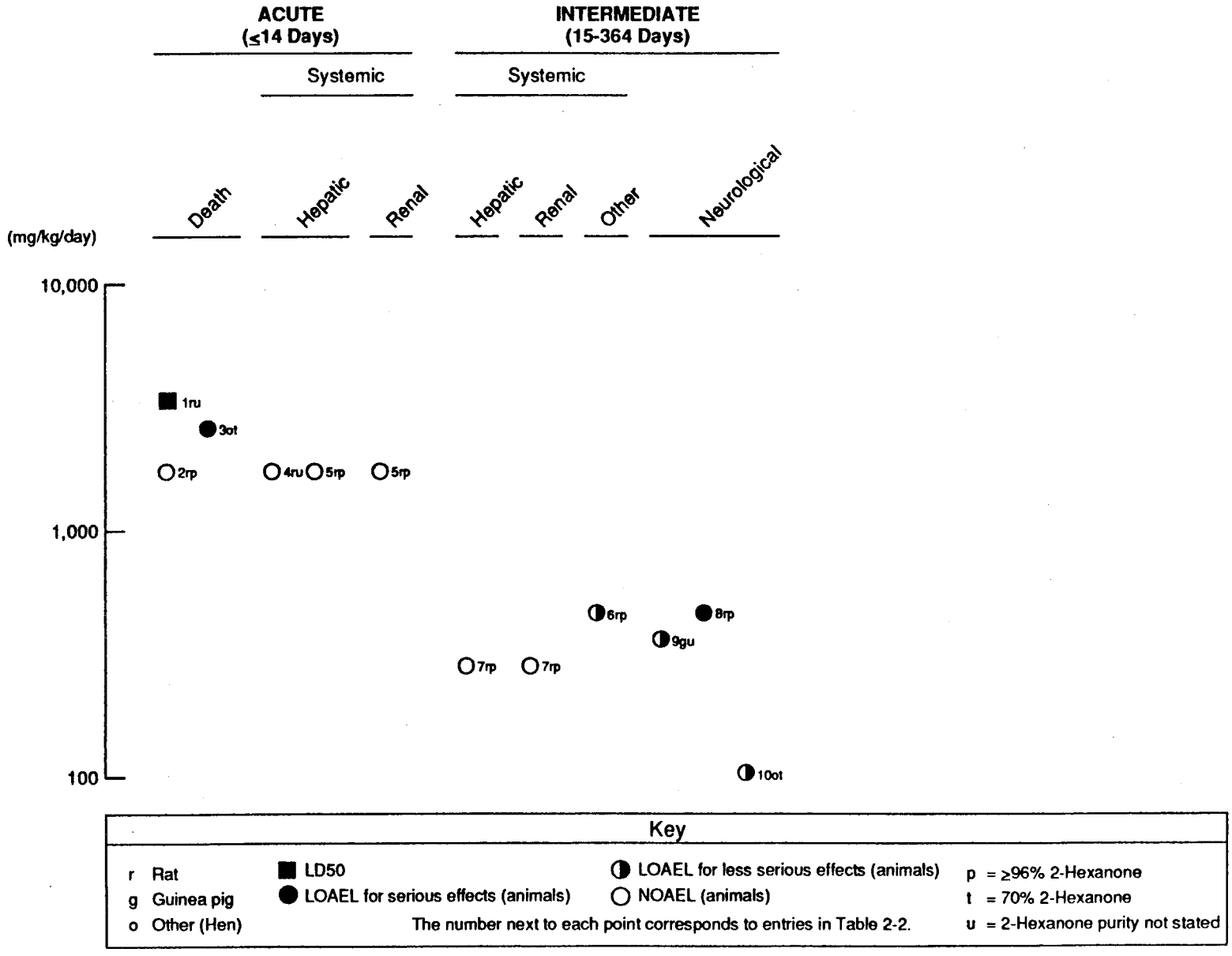
TABLE 2-2 (Continued)

Key to figure[a]	Species	Route	Exposure frequency/ duration	System	NOAEL (mg/kg/day)	LOAEL (effect) Less serious (mg/kg/day)	LOAEL (effect) Serious (mg/kg/day)	Reference	Purity
10	Hen	(G)	90 d 7d/wk 1x/d			100 (ataxia)		Abou-Donia et al. 1982	T

[a]The number corresponds to entries in Figure 2-2.

d = day(s); (G) = gavage; (GO) = gavage - oil; Gn pig = guinea pig; (GW) = gavage - water; Hemato = hematological; LD50 = lethal dose, 50% mortality; LOAEL = lowest-observed-adverse-effect level; NOAEL = no-observed-adverse-effect level; P = ≥96% 2-hexanone; T = 70% 2-hexanone; U = 2-hexanone purity not stated; (W) = water; wk = week(s); x = time(s)

FIGURE 2-2. Levels of Significant Exposure to 2-Hexanone – Oral



2. HEALTH EFFECTS

Various studies were conducted in rats in which the potential hepatic effects of oral administration of 2-hexanone combined with exposure to another agent were assessed. In rats given single doses of 2-hexanone up to 1,500 mg/kg by gavage, no effects were observed on liver histology, plasma glutamic-pyruvic transaminase levels (as a measure of centrilobular necrosis), measurements of the permeability of the biliary tree, malondialdehyde production (as a measure of lipid peroxidation), or total bilirubin levels in plasma (Cowlen et al. 1984b [2-hexanone purity not stated]; Hewitt et al. 1980a [2-hexanone purity >99%]; Hewitt et al. 1986]2-hexanone purity not stated]). Rapid depletion of hepatic glutathione (GSH) levels was observed in rats given a-single gavage dose of 2-hexanone (purity not stated) at 1,000 mg/kg (Cowlen et al. 1984a) and at 1,500 mg/kg (purity not stated) (Branchflower and Pohl 1981). The effect at 1,000 mg/kg was reported to be transient. Branchflower and Pohl (1981) postulated that this depletion might be associated with the potentiation of toxic effects from chloroform ($CHCl_2$) when coadministered with 2-hexanone, since depletion of hepatic GSH could allow more phosgene ($COCl_3$) (the toxic oxidation product of chloroform) to react with sensitive tissue components.

In a 40-week study in which rats were administered 2-hexanone at 400 mg/k/day, the levels of liver enzymes (alanine aminotransaminase and aspartate transaminase activities) measured at 4-week intervals were normal (Eben et al. 1979).

Renal Effects. No studies were located regarding renal effects in humans after oral exposure to 2-hexanone.

In studies in which rats were given a single gavage dose of 2-hexanone up to 1,500 mg/kg, no alterations were observed in renal morphology, renal cortical p-aminohippurate accumulation, plasma creatinine concentration (Brown and Hewitt 1984), blood urea nitrogen (BUN), renal GSH levels (Branchflower and Pohl 1981), ornithine carbamyl transferase (OCT) activities, or accumulation of p-aminohippurate (PAH) or tetraethylammonium (TEA) (Hewitt et al. 1980a). In male rats given 2-hexanone at 1,500 mg/kg, however, 9.6% of the renal tubules examined were degenerated (as compared with 1% of controls) (Hewitt et al. 1980a). The statistical significance of this finding was not addressed. Plasma urea concentrations were normal in rats that received daily gavage administrations of 2-hexanone at 400 mg/kg/day for 40 weeks (Eben et al. 1979). Other Systemic Effects. No studies were located regarding effects on body weight in humans after oral exposure to 2-hexanone.

Decreased weight gain was (specific data and statistical significance not provided) reported in rats given daily doses of 400 mg/kg/day for 40 weeks (Eben et al. 1979). Rats given 2-hexanone (undiluted) by gavage at

660 mg/kg/day in a 90-day study, weighed about 65% of control weights by 10 weeks of exposure (Krasavage et al. 1980). However, it is not clear from the data provided whether these rats were too weak or ataxic to eat.

2.2.2.3 Immunological Effects

No studies were located regarding immunological effects in humans or animals after oral exposure to 2-hexanone.

2.2.2.4 Neurological Effects

No studies were located regarding neurological effects in humans after oral exposure to 2-hexanone.

Neurological effects resulting from oral administration of 2-hexanone have been reported in three species of animals. In hens that received a single gavage dose of 2-hexanone at 2,000 mg/kg, mild weakness was observed on the day of administration, followed by apparent recovery in 4-5 days. Hens that received 100 mg/kg showed no signs of neurotoxicity (Abou-Donia et al. 1982). In a subchronic (90-day) phase of the same study, hens administered 2-hexanone at 100 mg/kg/day or higher developed severe ataxia or near paralysis. There was also evidence of histopathological changes including swelling or degeneration of thoracic and lumbar regions of the spinal cord. Some of the observations were described by the authors as equivocal.

Severe hindlimb dragging or paralysis was observed in all rats that received 2-hexanone (undiluted) by gavage at 660 mg/kg/day at about day 56 (8 weeks) of a go-day study (Krasavage et al. 1980). Morphologic changes indicative of "giant axonal" neuropathy included multifocal axonal swellings and myelin infolding and paranodal retraction. In rats that received 400 mg/kg/day in a 40 week study, there was a temporary weakness of the hindlimbs from 17 to 28 weeks of exposure (Eben et al. 1979). Improvement was observed after that period.

Abnormal pupillary responses to light (measured by changes in pupillary diameter) were observed in guinea pigs given 2-hexanone in drinking water at dosage levels of approximately 600 mg/kg/day during a 24-week study (Abdel-Rahman et al. 1978). Effects were seen from the first week of treatment.

It is important to note that 2,5-hexanedione, a metabolite in the blood and urine of rats and in the urine of guinea pigs orally administered 2-hexanone (DiVincenzo et al. 1976; Eben et al. 1979), has been demonstrated to elicit severe neurotoxicity following oral, dermal, or intraperitoneal administration to hens (Abou-Donia et al. 1982; 1985b) and following oral administration to rats (Krasavage et al. 1980).

Reliable LOAEL values for neurological effects in each species in the intermediate-duration category are recorded in Table 2-2 and plotted in Figure 2-2.

2.2.2.5 Developmental Effects

No studies were located regarding developmental effects in humans or animals after oral exposure to 2-hexanone.

2.2.2.6 Reproductive Effects

No studies were located regarding reproductive effects in humans after oral exposure to 2-hexanone.

Male rats that were given 2-hexanone at 660 mg/kg/day (undiluted) by gavage in a 90-day study were observed to develop atrophy of the germinal epithelium of the testes (Krasavage et al. 1980). However, the statistical significance of this observation was not addressed.

2.2.2.7 Genotoxic Effects

No studies were located regarding genotoxic effects in humans or animals after oral exposure to 2-hexanone.

2.2.2.8 Cancer

No studies were located regarding cancer effects in humans or animals after oral exposure to 2-hexanone.

2.2.3 Dermal Exposure

Very little information was located regarding health effects in humansor animals after dermal exposure to 2-hexanone.

2.2.3.1 Death

No studies were located regarding death in humans or animals afterdermal exposure to 2-hexanone.

2.2.3.2 Systemic Effects

No studies were located regarding respiratory, cardiovascular, gastrointestinal, hematological, musculoskeletal, hepatic, or renal effects in humans or animals after dermal exposure to 2-hexanone.

Dermal/Ocular Effects. No studies were located regarding dermaI/ocular effects in humans after dermal exposure to 2-hexanone.

Application of undiluted 2-hexanone to the skin of rabbits for 24 hours resulted in Grade 1 (least severe) irritation (Smyth et al. 1954). Ocular instillation resulted in Grade 3 (moderate) cornea1 necrosis.

2.2.3.3 Immunological Effects

No studies were located regarding immunological effects in humans or animals after dermal exposure to 2-hexanone.

2.2.3.4 Neurological Effects

No studies were located regarding neurological effects in humans after dermal exposure to 2-hexanone.

2-Hexanone (99% purity) applied to the backs of hens' necks at 100 mg/kg/day for 90 days resulted in gross ataxia (Abou-Donia et al. 1985b). Histological changes observed were swollen axons without obvious fragmentation of the axon or myelin sheath. No precautions against licking were mentioned in the study.

The LOAEL for neurological effects in hens in the intermediate-duration category is recorded in Table 2-3.

No studies were located regarding the following health effects in humans or animals after inhalation exposure to 2-hexanone:

2.2.3.5 Developmental Effects

2.2.3.6 Reproductive Effects

2.2.3.7 Genotoxic Effects

2.2.3.8 Cancer

2.3 TOXICOKINETICS

Data on the toxicokinetics of 2-hexanone, as described in this section, were derived from studies using 2-hexanone with purity of 97% or more. As discussed below, absorption of this compound has been demonstrated in humans, dogs, and rats after administration via inhalation, oral, or dermal exposure. Very little information is available on distribution. A metabolic pathway has been proposed based on the metabolites of 2-hexanone identified in the blood of guinea pigs and rats after intraperitoneal and oral administration, respectively. Expired breath and urine appear to be the main routes of excretion for 2-hexanone and its metabolites.

TABLE 2-3. Levels of Significant Exposure to 2-Hexanone - Dermal

Species	Route	Exposure frequency/ duration	System	NOAEL (mg/kg/day)	LOAEL (effect) Less serious (mg/kg/day)	LOAEL (effect) Serious (mg/kg/day)	Reference	Purity
INTERMEDIATE EXPOSURE								
Neurological								
Hen		90 d 7d/wk 1x/d			100 (ataxia)		Abou-Donia et al. 1985b	P

d = day(s); LOAEL = lowest-observed-adverse-effect level; NOAEL = no-observed-adverse-effect level; P = ≥96% 2-hexanone; wk = week(s); x = time(s)

2. HEALTH EFFECTS

2.3.1 Absorption

2.3.1.1 Inhalation Exposure

The available data indicate that 2-hexanone is well absorbed after administration via the inhalation route. An analysis of the expired breath of humans who inhaled 2-hexanone at 10 or 50 ppm for 7.5 hours or 100 ppm for 4 hours indicated that 75%-92% of the inhaled 2-hexanone vapor was absorbed by the lungs and respiratory tract (DiVincenzo et al. 1978).

Similarly, beagles that inhaled 2-hexanone at 50 or 100 ppm for 6 hours absorbed 65%-68% of the inhaled vapor (DiVincenzo et al. 1978).

2.3.1.2 Oral Exposure

2-Hexanone also appears to be well absorbed after oral administration. Humans who ingested a single capsule containing ^{14}C-2-hexanone at 0.1 mg/kg excreted about 40% of the ^{14}C in breath and 26% in urine during the next 8 days (DiVincenzo et al. 1978). This indicates that the absorbed amount averaged at least 66% of the administered dose.

Administration of 1-^{14}C-2-hexanone at 20 or 200 mg/kg by gavage to rats resulted in excretion of about 1.2% of the administered radioactivity in the feces, about 44% in the breath, 38% in urine, and 16% remaining in the carcass (DiVincenzo et al. 1977). The results were similar at either dosage level. These findings suggest that about 98% of the administered dose was absorbed.

2.3.1.3 Dermal Exposure

2-Hexanone is also absorbed after dermal application. The excretion of ^{14}C in the breath and urine of two human volunteers was measured after a 60-minute occlusive application of ^{14}C-2-hexanone to their shaved forearms (DiVincenzo et al. 1978). Calculated skin absorption rates were 4.8 and 8.0 pg/min/cm^2; however, the fraction of 2-hexanone that was absorbed was not calculated. ^{14}C-Hexanone was also applied to the clipped thorax of beagle dogs, and absorption was observed to be slow at first but increased dramatically after 20 minutes. At 60 minutes, 77 mg of 2-hexanone had penetrated the skin (DiVincenzo et al. 1978). The fraction of applied 2 hexanone that was absorbed was not calculated.

2.3.2 Distribution

2.3.2.1 Inhalation Exposure

No studies were located regarding distribution in humans or animals after inhalation exposure to 2-hexanone.

2.3.2.2 Oral Exposure

No studies were located regarding distribution in humans after oral exposure to 2-hexanone.

In rats administered a single dose of ^{14}C-2-hexanone at 200 mg/kg by gavage , tissue distribution was reported to be widespread with highest counts in the liver and blood. No quantitative data were given on tissue distribution (DiVincenzo et al. 1977). An analysis of subcellular distribution of the ^{14}C label in liver, brain, and kidney tissue indicated highest counts were associated with the crude lipid fraction and protein, with some recovery in DNA, and little or none in RNA.

2.3.2.3 Dermal Exposure

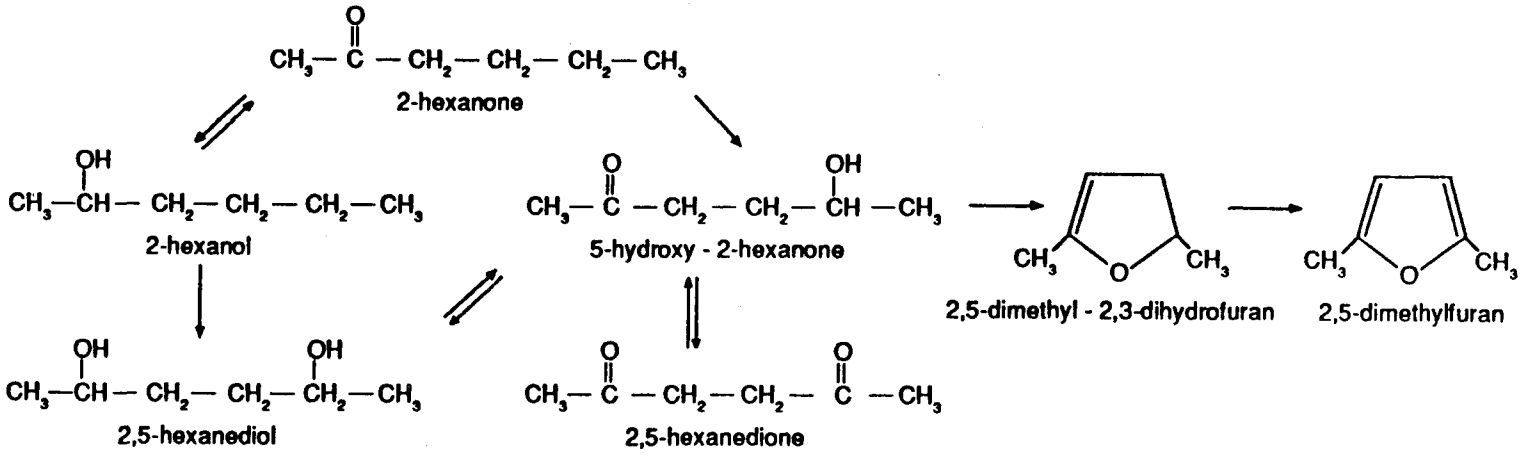
No studies were located regarding distribution in humans or animals after dermal exposure to 2-hexanone.

2.3.3 Metabolism

The proposed metabolic pathway for 2-hexanone, based on 2-hexanone metabolites identified in blood during intraperitoneal studies in guinea pigs (DiVincenzo et al. 1976) and oral studies in rats (DiVincenzo et al. 1977) is presented in Figure 2-3. Because inhalation exposure of humans to 2-hexanone has resulted in the appearance of carbon dioxide in expired air and 2,5-hexanedione in serum, DiVincenzo et al. (1978) have hypothesized that the metabolic pathway for 2-hexanone is similar in humans and experimental animals. The metabolism of aliphatic ketones has generally been found to proceed via reduction to the corresponding secondary alcohol, which accounts for the formation of 2-hexanol. An alternate pathway is oxidation of the 5-methylene group to the corresponding alcohol, 5-hydroxy-2-hexanone, which may be followed by further oxidation to the diketone 2,5-hexanedione. Another possibility in the metabolism of 2-hexanone is the cyclization of 5-hydroxy-2-hexanone to the corresponding dihydrofuran and oxidation to 2,5-dimethylfuran (DiVincenzo et al. 1977). However, the formation of these furan moieties may be the result of thermal dehydration and cyclization during gas chromatography (DiVincenzo et al. 1977). In addition, the gamma-valerolactone found in the urine (not shown in figure) is hypothesized to result from alphaoxidation of 5-hydroxy-2-hexanone to 2-keto-5-hydroxyhexanoic acid, decarboxylation and oxidation to 4-hydroxypentanoic acid, and lactonization to gamma-valerolactone (DiVincenzo et al. 1977).

A strong relationship has been noted between the concentration of 2,5-hexanedione in the urine and the onset of neuropathic symptoms (Eben et al. 1979). Similarly, 2,5-hexanedione was described as eliciting severe neurotoxic symptoms following oral, dermal, or intraperitoneal administration to hens (Abou-Donia et al. 1982, 1985b) and following oral administration to rats (Krasavage et al. 1980).

Figure 2-3. Proposed Metabolic Pathway for 2-Hexanone *



*Adapted from DiVincenzo et al. 1976, 1977

2. HEALTH EFFECTS

There are two major hypotheses related to the mechanism of neurotoxicity of 2,5-hexanedione: covalent binding with axonal components of nerve tissue and inhibition of enzymes associated with the production of energy in this tissue. In vitro studies in which 2,5-hexanedione was incubated with proteins demonstrated that this compound binds to the lysine ∈-amino group resulting in the formation of the substituted pyrrole adduct ∈-N-(2,5-dimethylpyrrolyl) norleucine (DeCaprio et al. 1982). Covalent binding of 2,5-hexanedione with axonal components leading to pyrrole formation and protein cross-linking was hypothesized as a possible initiation step leading to axonal degeneration and thus may account for the neurotoxic effects observed with exposure to gammadiketones in general (DeCaprio et al. 1982, 1988). In vivo confirmation of pyrrole formation was reported based on the presence of ∈-N-(2,5-dimethylpyrrolyl)norleucine in the hydrolyzed serum of a hen that had received 2,5-hexanedione at 200 mg/kg/day by gavage for two weeks (DeCaprio et al. 1982).

Other studies have demonstrated that both 2-hexanone and 2,5-hexanedione can inhibit sulfhydryl-dependent enzymes such as fructose-6-phosphate kinase (an enzyme in the pentose phosphate pathway) and glyceraldehyde-3-phosphate dehydrogenase (an enzyme in the glycolytic pathway) (Sabri et al. 1979b; Sabri 1984). Both of these neurotoxicants inhibited fructose-6-phosphate kinase crystallized from rabbit muscle or in rat brain homogenates; in each case, 2,5-hexanedione was the far more potent inhibitor (Sabri et al. 1979b). Preincubation with dithiothreitol protected this enzyme from inhibition, which suggests that these compounds interfere with the sulfhydryl groups required for fructose-6-phosphate kinase activity. However, dithiothreitol could not restore enzyme activity after these compounds had been added. In addition, fructose-6-phosphate kinase activity was also reduced in the brain homogenates of rats that had received 2,5-hexanedione at 0.5% of their drinking water for 10-12 weeks (Sabri et al. 1979b). Crystalline glyceraldehyde-3-phosphate dehydrogenase from rabbit muscle was also inhibited by both compounds; in this case, 2-hexanone was the more potent inhibitor (Sabri 1984). Levels of ATP were reduced in cat sciatic nerves treated with 2,5-hexanedione (Sabri 1984). 2-Hexanone was found to irreversibly inhibit rat brain and rabbit muscle creatine kinase and mouse brain adenylate kinase (Lapin et al. 1982).

In addition, oral administration of l-^{14}C-2-hexanone to humans or rats results in the appearance of $^{14}CO_2$ in the expired breath (DiVincenzo et al. 1977, 1978), indicating oxidation/cleavage of the alpha carbon. Administration of SKF525A (a mixed function oxidase inhibitor) to rats before oral administration of 2-hexanone resulted in a marked decrease in the excretion of respiratory $^{14}CO_2$ for the first 4 hours after administration, followed by a marked increase at 4-8 and 12-24 hours. This suggests that this oxidative step is mediated by a microsomal mixed function oxidase system (DiVincenzo et al. 1977).

2.3.4 Excretion

2.3.4.1 Inhalation Exposure

In humans exposed to 2-hexanone via inhalation at 10 or 50 ppm for 7.5 hours or to 100 ppm for 4 hours, unchanged 2-hexanone (but none of its metabolites) was found in expired air, and neither 2-hexanone nor any of its metabolites was found in urine during or after exposure (DiVincenzo et al. 1978). 2-Hexanone was not detected in the expired air 3 hours after exposure to 50 or 100 ppm. These results suggest slow clearance and possible accumulation of 2-hexanone in humans exposed by this route.

In beagle dogs exposed to 2-hexanone via inhalation at 50 or 100 ppm for 6 hours, 32% and 35%, respectively, of the inhaled vapor was excreted in the expired breath (DiVincenzo et al. 1978). By 3-5 hours after exposure, 2-hexanone was no longer detected in expired air. Excretion via other routes was not addressed.

2.3.4.2 Oral Exposure

In two humans who received a single oral dose of 1-^{14}C-2-hexanone, breath excretion of $^{14}CO_2$ CO, reached a peak within 4 hours, then decreased slowly over the next 3-5 days. Average overall recovery of the ^{14}C-label in 8 days was 40% in breath and 26% in urine. Feces were not analyzed (DiVincenzo et al. 1978).

In rats administered a single oral dose of 1-^{14}C-2-hexanone, DiVincenzo et al. (1977) observed similar results. Radioactivity in breath accounted for about 45% of the administered dose (5% was in unchanged 2-hexanone; 40% was in $^{14}C0_2$,); 35% was found in the urine; 1.5% was recovered in the feces; and about 15% remained in the carcass. In male rats that received daily gavage doses of 2-hexanone at 400 mg/kg/day for 40 weeks, very low concentrations of free 2-hexanone were detected in the urine from the third week. A maximum concentration of approximately 20 ug was reached in the 17th week (Eben et al. 1979). Similarly, free 2,5-hexanediol was found in the urine after 3 weeks and peaked in the 17th week. Free and conjugated 2,5-hexanedione were present in the urine from the 1st week of the study. The conjugated form peaked in the 7th week; whereas excretion levels of the free form were fairly consistent throughout the study. A strong correlation was observed in this study between the onset of neuropathy and the urinary concentration of 2,5-hexanedione when 2-hexanone, 2,5-hexanedione or 2,5-hexanediol was administered orally to rats at 400 mg/kg/day.

2.3.4.3 Dermal Exposure

^{14}C from l-^{14}C-2-hexanone applied to the forearms of two human volunteers was found in the breath and urine (DiVincenzo et al. 1978). In one subject,

excretion was similar by both routes; in the other subject, the levels were much higher (about 3:l) in the breath. Levels of radioactivity in feces were not measured.

2.4 RELEVANCE TO PUBLIC HEALTH

As discussed in Section 2.2, estimates of levels of exposure to 2-hexanone posing minimal risk to humans (MRLs) were to have been made, where data were believed reliable, for the most sensitive noncancer effect for each route and exposure duration. However, no MRLs could be derived for 2-hexanone. No data were located on effects of acute-duration or chronicduration inhalation exposure to 2-hexanone in humans or animals. Available information concerning effects of intermediate-duration inhalation exposure in humans and animals identifies neurological effects as the most sensitive indicator of toxicity, but this information does not reliably identify the threshold for this effect. Therefore, no inhalation MRLs were derived. Available information on acute-duration oral exposure in animals does not identify the most sensitive effect, and while available information on intermediate-duration oral exposure to 2-hexanone in animals suggests that neurotoxicity may be the most sensitive effect, data do not reliably identify the threshold for neurotoxicity. No information was located on effects of chronic-duration exposure to 2-hexanone in humans or animals. Therefore, no oral MRLs were derived. Acute-duration, intermediate-duration, and chronicduration dermal MRLs were not derived for 2-hexanone due to the lack of an appropriate methodology for the development of dermal MRLs.

As demonstrated in humans as well as in laboratory animals, the most important concern associated with exposure to 2-hexanone is neuropathy. In all species observed, this neurological effect is generally accompanied by effects on body weight. Based on the results of animal studies, other potential concerns are adverse hematological effects and effects on reproduction and fetal development.

Death. There are no data to suggest that lethality is a concern for humans exposed to 2-hexanone via any route. Lethality data in animals include an inhalation study by Abdo et al. (1982) in which 1 of 5 hens died after 72 days of continuous exposure to 200 ppm and 2 of 5 hens died by day 27 of exposure to 400 ppm. No deaths were recorded in hens exposed to 100 ppm for 90 days. An oral LD_{50} of 2,590 mg/kg has been reported for rats (Smyth et al. 1954). No lethality studies using the dermal route have been located. These findings suggest that lethality is possible with very high concentrations of 2-hexanone. However, it is unlikely that humans in any setting would be exposed to levels high enough to result in death.

Systemic Effects.

Hematological Effects. There is no evidence that adverse hematological effects occurred in workers exposed to 2-hexanone (Allen et al. 1975). The

potential hematological effects of exposure to 2-hexanone were investigated in an inhalation study by Katz et al. (1980) in which rats were exposed to 700 ppm 2-hexanone intermittently for 11 weeks. No effects were observed on hemoglobin concentration, hematocrit, or differential white blood cell counts. However, at about 8 weeks, total white cell counts were reduced to about 60% of control values. Since there was no evidence of a corresponding effect on bone marrow, the authors stated that the clinical significance of this finding was uncertain. However, it is possible that hematological effects may occur in humans exposed to 2-hexanone by inhalation.

Hepatic Effects. There are no data on hepatic effects occurring in humans exposed to 2-hexanone; however, these effects have been investigated in several studies in animals using inhalation or oral administration. No effect was found on hexobarbital-induced sleep times in rats continuously exposed to 2-hexanone via inhalation at 225 ppm for 7 days (Couri et al. 1977); no histopathological effects were found in the livers of rats exposed to 50 ppm for 6 months (Duckett et al. 1979). In studies conducted via the oral route, single-dose administration of 2-hexanone at levels up to 1,500 mg/kg did not result in effects on liver histology, plasma glutamic-pyruvic transaminase levels (as a measure of centrilobular necrosis), permeability of the biliary tree, malondialdehyde production (as a measure of lipoperoxidation), or total bilirubin levels in plasma (Cowlen et al. 1984b; Hewitt et al. 1980a, 1983, 1986). The results of liver enzyme measurements (alanine aminotransferase, aspartate aminotransferase) given at 4-week intervals were normal in rats receiving 2-hexanone at 400 mg/kg/day for 40 weeks (Eben et al. 1979). Hepatic effects were reported in two studies. The rapid depletion of glutathione (GSH) levels was observed in the livers of rats given a single dose of 2-hexanone at 1,500 mg/kg (Branchflower and Pohl 1981), and in another study, an increased liver to body weight ratio was found in rats given 2-hexanone at the same dose (Hewitt et al. 1983).

Based on the available data in animals, 2-hexanone does not appear to be hepatotoxic. However, there is evidence to indicate that it can greatly enhance the hepatotoxicity of other chemicals such as chloroform (see Section 2.6).

Renal Effects. There are no available data to suggest that renal effects are a potential risk associated with human exposure to 2-hexanone. No histopathological effects were seen in the kidneys of rats exposed to 50 ppm 2-hexanone via inhalation for 6 months (Duckett et al. 1979). Renal effects were also investigated in a study in which rats were administered a single gavage dose of 2-hexanone at 1,500 mg/kg. Degenerative changes were reported in 9.6% of the renal tubules in treated animals, as compared with a 1% incidence in controls (Hewitt et al. 1980a). The statistical significance of this finding was not addressed. However, these data do not support a concern for potential renal effects in humans exposed to 2-hexanone.

Dermal/Ocular Effects. 2-Hexanone applied to the skin of rabbits was minimally irritating; ocular instillation resulted in moderate cornea1 necrosis (Smyth et al. 1954). Human ocular contact with this chemical would, therefore, be of concern.

Other Effects. In both animals and humans, the most common systemic effect observed following inhalation or ingestion of 2-hexanone was weight loss or decreased weight gain in developing animals. Weight loss and decreased weight gain may be secondary to loss of appetite or inability to feed. Weight loss, ranging from 3 to 60 pounds was reported by Allen et al. (1975) in workers exposed to 2-hexanone for several months in a fabric-finishing plant. These losses were generally seen in the workers with more severe neurological impairment (peripheral neuropathy). Weight loss and decreased rates of weight gain in developing animals were reported in several species exposed via inhalation including rats (Johnson et al. 1977; Katz et al. 1980; Spencer et al. 1975), and hens (Abdo et al. 1982). In most of these studies, little or no effect on body weight was observed with exposure to 100 ppm or less. In oral studies, effects on body weight were also reported in rats (Krasavage et al. 1980). These observations indicate that weight loss in adults and decreased weight gains in children would be an area of concern associated with exposure to 2-hexanone.

Immunological Effects. There is no information on the immunological effects of human exposure to 2-hexanone. Reductions in total white blood cell count to 60% of control values were reported in rats intermittently exposed to 700 ppm 2-hexanone via inhalation for about 8 weeks (Katz et al. 1980). Because there were no effects on differential counts or evidence of bone marrow damage, the full implications of their findings to potential immunological effects in humans are not clear. It is interesting to note that in male mice given either single or 7 daily oral doses of 2,5-hexanedione, a metabolite of 2-hexanone, at a dose that was too low to elicit neurotoxicity (20% of the LD_{50}), there were reductions in the cellularity of the spleen, thymus, and mesenteric lymph nodes. Abnormal results in immune function tests such as delayed hypersensitivity reaction tests, plaque-forming cell assay, phagocytosis by adherent peritoneal exudate cells, and resistance to endotoxin shock were also reported (Upreti and Shanker 1987). In female rats given single or 7 daily oral doses of 2,5-hexanedione at l0%-50% of the LD_{50} decreased cellularity of various lymphoid organs was also observed (Upreti et al. 1986). These studies suggest that immunological effects may be an area of potential concern for humans exposed to 2-hexanone.

Neurological Effects. Neurological effects are the most likely public health concern associated with exposure to 2-hexanone. Peripheral neuropathy was reported in workers using 2-hexanone in fabric finishing operations (Allen et al. 1975). In animal studies, neuropathy progressing from mild ataxia to paralysis was reported in inhalation studies using cats (Mendell et al. 1974b; Saida et al. 1976), monkeys (Johnson et al. 1977), rats (Johnson et al. 1977; Saida et al. 1976), and hens (Abdo et al. 1982), and in oral studies using

rats (Eben et al. 1979; Krasavage et al. 1980), guinea pigs (Abdel-Rahman et al. 1978), and hens (Abou-Donia et al. 1982). Pathological alterations in hens, cats, and rats have been reported to be similar and the clinical manifestations in the experimental animals and the exposed workers were comparable (Mendell et al. 1974b).

Examination of the affected nerves in these test species indicated that demyelination and axonal swelling were generally associated with the observed clinical effects. A significant finding was that in rats that became paralyzed as a result of 2-hexanone exposure at 225 ppm for 9.5 weeks or to 400 ppm for 6 weeks, histopathological changes of the peripheral nerves occurred as early as 16 days at both exposure levels (Saida et al. 1976). In another study, no clinical signs of neuropathy were observed in rats exposed to 100 ppm 2-hexanone for 6 months, whereas histopathological changes of both peripheral nerves and tracts of the spinal cord were seen after 4 months of exposure (Egan et al. 1980). These findings suggest that nerve degeneration may also occur in exposed humans well before the characteristic symptoms of peripheral neuropathy (muscle weakness and sensory loss in the hands and feet) become apparent. Electromyographic testing, as used in some of the studies discussed in Sections 2.2.1.4 and 2.2.2.4, appears to be sensitive enough to detect abnormalities in the conduction characteristics of nerves before clinical manifestations occur.

Ultrastructural studies of nerve fibers in the peripheral and central nervous systems of exposed animals from several of their studies have led Spencer and Schaumberg (1977b) to the use of the term "dying-back" to describe the nature of the pathology. The most distal extremities of the longest and largest axons appear to be affected first; axonal degeneration seems to, Progress proximally to fibers in the central nervous system.

Developmental Effects. There are no available data on the developmental effects of human exposure to 2-hexanone. Concern that the offspring of women exposed to 2-hexanone during pregnancy may be at risk for developmental effects comes from an inhalation study in which behavioral alterations were seen in the offspring of pregnant rats exposed to 1,000 ppm 2-hexanone during gestation (Peters et al. 1981). These effects consisted of reduced activity in the open field, increased activity in the running wheel, and deficits in avoidance conditioning. There was also a decrease in the number and birth weight of live offspring of these rats. These findings suggest that neonate survival may be a concern for human exposure.

Reproductive Effects. There are no available data on the reproductive effects of human exposure to 2-hexanone. Reproductive effects may be a concern for women exposed to 2-hexanone based on the findings of an inhalation study in which there were decrements in the weight gain of pregnant rats exposed to 2,000 ppm 2-hexanone during gestation (Peters et al. 1981).

In addition, marked and significant reductions in absolute and relative testes weight and atrophy of testicular germinal epithelium were reported in male rats exposed to 700 ppm 2-hexanone via inhalation for 11 weeks (Katz et al. 1980), and atrophy of the testicular germinal epithelial was also observed in male rats that received 2-hexanone at 660 mg/kg/day by gavage during a 90-day study (Krasavage et al. 1980). Histological changes and reduced testicular weight have also been observed in rats that received 2,5-hexanedione for 4 weeks at 1% of their drinking water (about 1,400 mg/kg/day) (Boekelheide 1987). These observations suggest that effects on semen production and male fertility may be a concern for men exposed to 2-hexanone.

Genotoxic Effects. No studies were located regarding the potential genotoxic effects in humans or animals following any route of exposure to 2-hexanone. No in vitro studies have been located for 2-hexanone.

Cancer. No studies were located regarding the potential carcinogenic effects in humans or animals following any route of exposure to 2-hexanone.

2.5 BIOMARKERS OF EXPOSURE AND EFFECT

Biomarkers are broadly defined as indicators signaling events in biologic systems or samples. They have been classified as markers of exposure, markers of effect, and markers of susceptibility (NAS/NRC 1989).

A biomarker of exposure is a xenobiotic substance or its metabolite(s) or the product of an interaction between a xenobiotic agent and some target molecule(s) or cell(s) that is measured within a compartment of an organism (NAS/NRC 1989). The preferred biomarkers of exposure are generally the substance itself or substance-specific metabolites in readily obtainable body fluid or excreta. However, several factors can confound the use and interpretation of biomarkers of exposure. The body burden of a substance may be the result of exposures from more than one source. The substance being measured may be a metabolite of another xenobiotic substance (e.g., high urinary levels of phenol can result from exposure to several different aromatic compounds). Depending on the properties of the substance (e.g., biologic half-life) and environmental conditions (e.g., duration and route of exposure), the substance and all of its metabolites may have left the body by the time biologic samples can be taken. It may be difficult to identify individuals exposed to hazardous substances that are commonly found in body tissues and fluids (e.g., essential mineral nutrients such as copper, zinc, and selenium). Biomarkers of exposure to 2-hexanone are discussed in Section 2.5.1.

Biomarkers of effect are defined as any measurable biochemical, physiologic, or other alteration within an organism that, depending an magnitude, can be recognized as an established or potential health impairment or disease (NAS/NRC 1989). This definition encompasses biochemical or

cellular signals of tissue dysfunction (e.g., increased liver enzyme activity or pathologic changes in female genital epithelial cells), as well physiologic signs of dysfunction such as increased blood pressure or decreased lung capacity. Note that these markers are often not substance specific. They also may not be directly adverse, but can indicate potential health impairment (e.g., DNA adducts). Biomarkers of effects caused by 2-hexanone are discussed in Section 2.5.2.

A biomarker of susceptibility is an indicator of an inherent or acquired limitation of an organism's ability to respond to the challenge of exposure to a specific xenobiotic substance. It can be an intrinsic genetic or other characteristic or a preexisting disease that results in an increase in absorbed dose, biologically effective dose, or target tissue response. If biomarkers of susceptibility exist, they are discussed in Section 2.7, "POPULATIONS THAT ARE UNUSUALLY SUSCEPTIBLE."

2.5.1 Biomarkers Used to Identify and/or Quantify Exposure to 2-Hexanone

2-Hexanone and its various metabolic products (2-hexanol, 2,5-hexanedione, 5-hydroxy-2-hexanone, 2,5-dimethylfuran) can be measured in biological tissue, fluid, and excreta (Fedtke and Bolt 1986; Nomeir and Abou-Donia 1985; White et al. 1979). The currently available information, however, does not indicate whether the levels of these substances can be used to calculate or estimate corresponding levels of exposure to 2-hexanone. An additional complication is that because the same metabolites have been identified in the urine of rats orally exposed to n-hexane (Fedtke and Bolt 1986), the selection of a specific biomarker for exposure to 2-hexanone is thus unlikely.

2.5.2 Biomarkers Used to Characterize Effects Caused by 2-Hexanone

There are currently no subtle or sensitive biomarkers of effects associated with exposure to 2-hexanone. Electromyographic testing, however, may prove to be useful in the detection of nerve conduction abnormalities in their early stages, even before they are accompanied by clinical manifestations. Specific electrodiagnostic patterns associated with exposure to 2-hexanone have not been clearly delineated.

2.6 INTERACTIONS WITH OTHER CHEMICALS

Based on the results of several animal studies, exposure to 2-hexanone can result in the potentiation and exacerbation of adverse effects associated with the administration of other toxic compounds. Oral administration of 2-hexanone followed by intraperitoneal administration of chloroform to rats has resulted in a variety of hepatic and renal effects including decreased hepatic glutathione levels, increased plasma levels of glutamic pyruvic transaminase and blood urea nitrogen, and degeneration and necrosis of hepatic and renal tissue (Branchflower and Pohl 1981; Brown and Hewitt 1984; Cowlen et al. 1984a, 1984b; Hewitt et al. 1980a,b, 1983). Similarly, oral

administration of both 2-hexanone and chloroform to rats resulted in altered permeability of the biliary tree (Hewitt et al. 1986). In these studies, some or no effect on the end points of interest was observed after administration of 2-hexanone or chloroform alone; administration of both substances resulted in statistically significant and dramatic changes in these effects.

These authors have speculated that 2-hexanone potentiates the hepatic toxicity of chloroform by decreasing glutathione levels (Branchflower and Pohl 1981; Hewitt et al. 1980a) and by increasing the metabolism of chloroform to the potent hepatotoxicant, phosgene (Branchflower and Pohl 1981; Cowlen et al. 1984a, 1984b). Branchflower and Pohl (1981) have speculated that the metabolism of chloroform to phosgene may also be involved in the renal toxicity seen in these studies.

2-Hexanone has also been shown to potentiate the neurotoxic effects of some compounds.. In hens, dermal or inhalation exposure to 2-hexanone in combination with dermal application of the pesticide 0-ethyl-0-4-nitrophenyl phenylphosphonothioate (EPN) has resulted in earlier onset and far more severe clinical and histological manifestations of neurotoxic effects than with either chemical exposure alone (Abou-Donia et al. 1985a, 1985b). The authors speculated that this potentiation effect may have been due to induction of hepatic microsomal cytochrome P-450 by EPN, leading to increased metabolism of 2-hexanone to its neurotoxic metabolite, 2,5-hexanedione. An alternate explanation is that local trauma to the nervous tissue produced by 2-hexanone and EPN might increase vascular permeability and thus increase the entry of these compounds and their metabolites from circulation.

A study in which rats were exposed via inhalation to a combination of 2-hexanone and methyl ethyl ketone resulted in the potentiation of severe neurotoxic effects including paralysis and histopathological changes. These effects were either not observed or they occurred at much lower frequencies when either of the two compounds was administered separately (Saida et al. 1976).

These results suggest that persons living or working in the vicinity of hazardous waste sites or workers who are exposed to 2-hexanone in combination with any of the potentially toxic substances discussed above may be at special risk for the effects of exposure to the combination of chemicals.

2.7 POPULATIONS THAT ARE UNUSUALLY SUSCEPTIBLE

No population has been identified which is unusually susceptible to toxic effects resulting from 2-hexanone exposure.

2.8 MITIGATION OF EFFECTS

This section will describe clinical practice and research concerning methods for reducing toxic effects of exposure to 2-hexanone. However, because some

of the treatments discussed may be experimental and unproven, this section should not be used as a guide for treatment of exposures to 2-hexanone. When specific exposures have occurred, poison control centers and medical toxicologists should be consulted for medical advice.

Human exposure to 2-hexanone may occur by inhalation, ingestion, or dermal absorption (see Chapter 5). Dermal exposure to 2-hexanone may cause ocular and skin irritation. Exposure by any route may cause peripheral neuropathy, with nerve degeneration and paralysis (see Section 2.2).

Procedures for reducing toxic effects following acute, high level exposure to 2-hexanone include measures to reduce or eliminate further absorption. Following dermal or ocular exposure, these procedures include removing contaminated clothing and thoroughly washing the skin and eyes (Bronstein and Currance 1988; Stutz and Janusz 1988). Following acute, high level oral exposure, these procedures include emptying the stomach, using care to avoid aspiration of the gastric contents, followed by administration of activated charcoal and a cathartic to stimulate fecal excretion (Stutz and Janusz 1988).

The half-life of 2-hexanone and its metabolites in blood plasma has not been established; however, elimination from the body does appear to occur in less than 24 hours following both inhalation and ingestion exposures (DiVincenzo et al. 1977, 1978). 2-Hexanone is not known to accumulate over time in any tissues in the body (see section 2.3.4). While elimination enhancement through stimulation of metabolism of 2-hexanone may reduce some forms of toxicity, if used within the short time that 2-hexanone is retained in the body, there is the risk that these same metabolic reactions may form reactive metabolites such as 2,5-hexanedione. Furthermore, concurrent exposures to other substances may also occur for which stimulation of these same metabolic pathways is contraindicated. Therefore, the benefit of stimulating specific metabolic pathways to enhance 2-hexanone elimination is unclear and should be studied further.

The major toxic effect of exposure to 2-hexanone is neuropathy. Neuropathy can be caused by both 2-hexanone and its metabolite 2,5-hexanedione. A reduction of the neuropathy caused by exposure to 2-hexanone could theoretically be achieved through shunting of metabolism to less toxic metabolites. However, as discussed above, the toxicity of those other metabolites, and the effect of the treatment on metabolism of other potential toxicants, would have to be clearly assessed.

Two major hypotheses concerning the mechanism of action of either 2-hexanone or 2,5-hexanedione have been suggested (see section 2.3.3 Metabolism). These mechanisms are 1) inhibition of sulfhydryl dependent enzymes (Lapin et al. 1982; Sabri et al. 1979b; Sabri 1984), and 2) covalent binding to axonal components leading to pyrrole formation, protein crosslinking, and axonal degeneration (DeCaprio et al. 1982, 1988). Dithiothreitol has been shown to reduce the inhibition in one of the inhibited enzymes *in vitro*, suggesting

that blocking accessibility of the sulfhydryl groups may be an effective method of blocking toxic effects (Sabri et al. 1979b).

Interaction of 2-hexanone with EPN (Abou-Donia 1985a) and methyl ethyl ketone (Saida et al. 1976) may occur through the potentiation of the production of 2,5-hexanedione. An effective method of reducing the neurotoxic effects of combined exposures to these compounds would be to pharmacologically block the metabolic pathways that lead to the production of 2,5-hexanedione, given the same caveats presented for interference with metabolic pathways presented above. Increasing the breakdown or clearance of 2,5-hexanedione might also be effective.

2-Hexanone has been found to enhance the hepatotoxicity of chloroform in animals (Branchflower and Pohl 1981). This may occur in part through depletion of glutathione levels by 2-hexanone, and in part by a 2 hexanone-mediated increase in the production of phosgene from chloroform (Branchflower and Pohl 1981; Cowlen et al. 1984a). It is possible that ensuring sufficient glutathione stores in the body may reduce the chances of toxic effects following combined acute exposure to 2-hexanone and chloroform. Specific blockage of the production of phosgene, through the inhibition of liver cytochrome P450, might be an effective method of reducing liver damage. However, an analysis of the net effect of this inhibition on the toxicity of the combined exposure would need to be made prior to recommending this method as a mitigation treatment.

2.9 ADEQUACY OF THE DATABASE

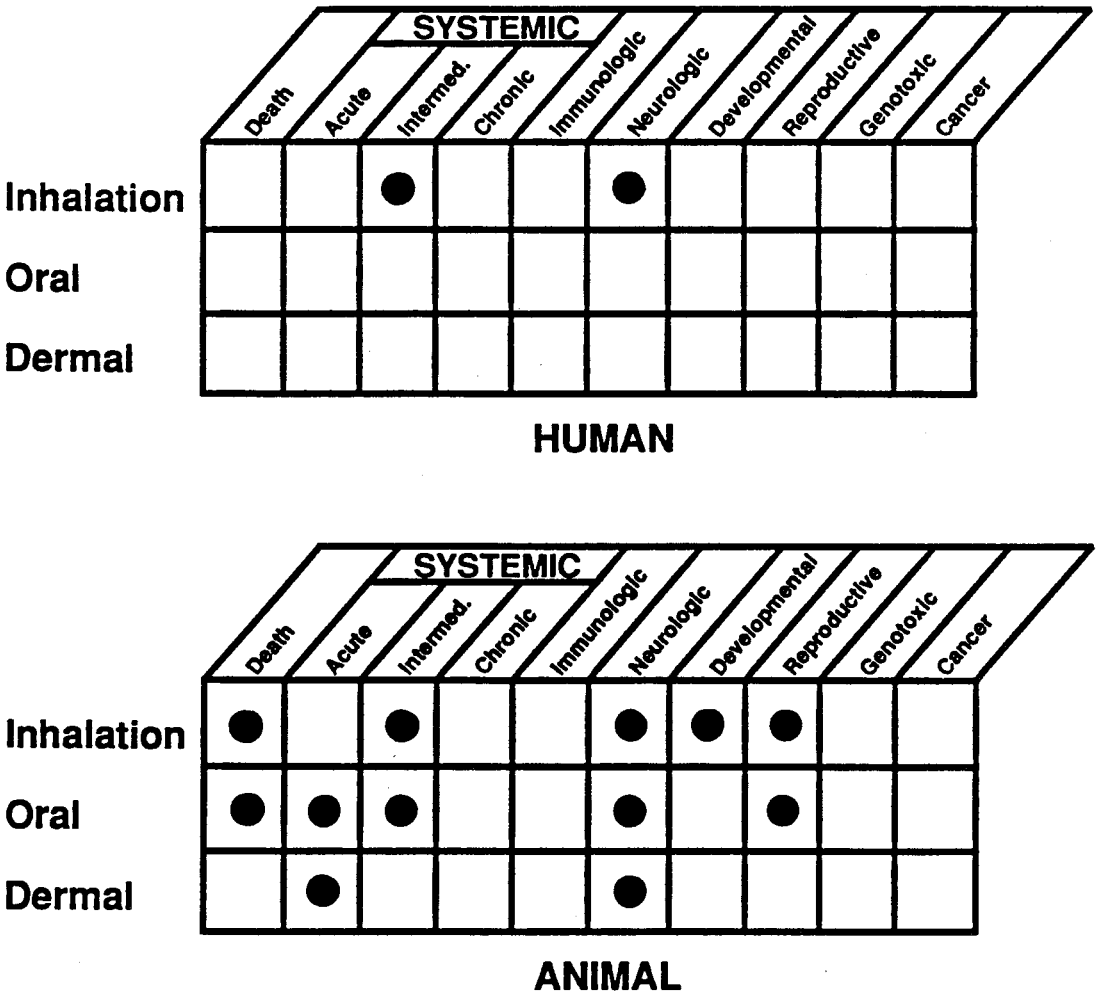
Section 104(i)(5) of CERCLA, as amended, directs the Administrator of ATSDR (in consultation with the Administrator of EPA and agencies and programs of the Public Health Service) to assess whether adequate information on the health effects of 2-hexanone is available. Where adequate information is not available, ATSDR, in conjunction with the National Toxicology Program (NTP), is required to assure the initiation of a program of research designed to determine the health effects (and techniques for developing methods to determine such health effects) of 2-hexanone.

The following categories of possible data needs have been identified by a joint team of scientists from ATSDR, NTP, and EPA. They are defined as substance-specific informational needs that, if met, would reduce or eliminate the uncertainties of human health assessment. In the future, the identified data needs will be evaluated and prioritized, and a substance-specific research agenda will be proposed.

2.9.1 Existing Information on Health Effects of 2-Hexanone

The existing data on health effects of inhalation, oral, and dermal exposure of humans and animals to 2-hexanone are summarized in Figure 2-4.

FIGURE 2-4. Existing Information on Health Effects of 2-Hexanone



● Existing Studies

The purpose of this figure is to illustrate the existing information concerning the health effects of 2-hexanone. Each dot in the figure indicates that one or more studies provide information associated with that particular effect. The dot does not imply anything about the quality of the study or studies. Gaps in this figure should not be interpreted as "data needs" information (i.e., data gaps that must necessarily be filled).

Figure 2-4 graphically depicts the information that currently exists on the health effects that have been observed or studied in humans or animals following exposure to 2-hexanone. Data on intermediate-duration systemic and neurologic effects in humans were derived from a single study of workers exposed to 2-hexanone for about 10 months. Although there is more information on animals, as discussed below, certain factors, such as the use of 2-hexanone of low or unknown purity or the use of a single dosage level in the test protocol, complicate the interpretation of these studies and limit their usefulness.

Some information is available from animal studies conducted via the inhalation route in several categories of toxicity including lethality, systemic effects resulting from intermediate-duration exposure, neurologic, reproductive, and developmental effects. In studies conducted via the oral route, some information is available on lethality, systemic effects resulting from acute- or intermediate-duration exposure, reproductive effects, and neurologic effects. Only two studies using the dermal route were available. These provided information on acute and neurologic effects.

2.9.2 Data Needs

As discussed in previous sections, many of the currently available studies on 2-hexanone used a single dose level of the test compound, the purity of the test compound was not stated in some studies or in some cases, the purity was stated to be as low as 70%. Therefore little or no dose-response information is available in the existing database. In addition, studies using 2-hexanone of low purity introduce the complications associated with exposures to multiple substances and the potential for chemical interactions. As a result, the available data are limited in their usefulness and must be interpreted with caution.

Acute-Duration Exposure. Currently, no data are available on humans for this exposure duration for any route of exposure. In addition, there is no information on acute toxicity in animals following inhalation exposure. Lethality data are available for the rat and hen via the oral route (Abou-Donia et al. 1982; Hewitt et al. 1980a; Smyth et al. 1954). Existing data are insufficient to derive an MRL for any route of exposure. Acute-duration studies for all routes of exposure using a range of exposure concentrations would be useful in determining potential target organs, especially the nervous system, to identify any dosage thresholds, and to establish dose-response relationships for these effects. Brief human exposure to 2-hexanone may occur

at hazardous waste sites, at the site of accidental spills, or in the workplace.

Intermediate-Duration Exposure. The currently available data on humans exposed to 2-hexanone for this duration period is based on a study of workers exposed to 2-hexanone for about 10 months (Allen et al. 1975). Peripheral neuropathy and weight loss were the major observations. Repeated-dose studies in rats, cats, monkeys, hens, and guinea pigs indicate that the nervous system is the primary target of 2-hexanone exposure via inhalation (Abdo et al. 1982; Abou-Donia et al. 1985a; Duckett et al. 1979; Egan et al. 1980; Johnson et al. 1977; Katz et al. 1980; Saida et al. 1976; Spencer et al. 1975), oral (Abdel-Rahman et al. 1978; Krasavage et al. 1980), or dermal (Abou-Donia et al. 1985b) exposure for this duration. In addition, decreased weight gain has been reported in rats and hens exposed via inhalation, decreased white blood cell counts in rats exposed via inhalation (Abdo et al. 1982; Johnson et al. 1977; Katz et al. 1980), and decreased weight gain in rats exposed via gavage (Krasavage et al. 1980). However, the data were not sufficient to derive an MRL for any route. Intermediate-duration (90-day) studies in animals via the inhalation and dermal routes would be useful in developing dose-response relationships, especially in relation to neurological effects. Such information would be valuable for predicting human health effects, because the potential exists for such exposure among populations in the vicinity of hazardous waste sites and in the workplace. In addition, because 2-hexanone has been found in surface water, groundwater, and drinking water in the vicinity of hazardous waste sites, a 90-day study using the oral route would also be useful. These studies should also include investigation of a number of endpoints including the potential hematological, immunological, developmental, and reproductive effects of exposure to 2-hexanone, because the available data indicate that these are areas of potential concern in humans.

Chronic-Duration Exposure and Cancer. There is currently no available information on humans or animals exposed to 2-hexanone for this duration period via any route of exposure. Chronic exposure studies using the inhalation, oral, and dermal routes would be useful, because chronic low level exposure via each of these routes is likely to occur in the vicinity of hazardous waste sites or in occupational settings. Data derived from 90-day studies would be useful in determining the dose levels to be used for the chronic-duration studies.

There is currently no information on the carcinogenic potential of 2-hexanone. Chronic-duration studies conducted via any route of exposure should assess this potential effect, since persons living in the vicinity of hazardous waste sites or in occupational settings may be chronically exposed to low levels of 2-hexanone via the oral, inhalation, and dermal routes.

Genotoxicity. There are currently no *in vivo* or *in vitro* studies that address the genotoxic potential of 2-hexanone. A battery of *in vitro* genotoxicity tests with 2-hexanone would be useful as a preliminary step in

assessing its mutagenic potential and determining if further genotoxicity tests would appear to be warranted.

Reproductive Toxicity. There is no information on the effects of 2-hexanone on reproductive parameters in exposed humans via any route of exposure. Available data in animals indicate that inhalation exposure of pregnant rats to 2-hexanone resulted in reduced maternal weight gain (Peters et al. 1981). In male rats, reduced testicular weights and atrophy of the testicular germinal epithelium were reported to result from inhalation exposure (Katz et al. 1980) and atrophy of the testicular germinal epithelium from oral exposure (Krasavage et al. 1980). Because of the limited data base for all routes of exposure, it would be useful to have 90-day studies for all three routes in order to investigate the potential dose-response relationship of exposure to this compound on a number of end points including sperm count and reproductive organ pathology. Because effects on reproduction have been observed, a multi-generation study would be helpful in assessing the potential impact of 2-hexanone exposure on the reproductive capacity of persons living in the vicinity of hazardous waste sites and exposed workers.

Developmental Toxicity. There is no information on the effects of exposure to 2-hexanone via any route on human development. There are no animal studies using the oral or dermal routes. The currently available data for animals is based on a single inhalation study in pregnant rats indicating that 2-hexanone exposure resulted in decreased litter size and pup weight (Peters et al. 1981). Additional studies investigating a number of developmental end points, and a dose-response relationship via inhalation, oral and dermal exposure would be useful in assessing the potential risks to persons exposed to 2-hexanone in the vicinity of hazardous waste sites or in the workplace.

Immunotoxicity. There are currently no data on the effects of 2-hexanone on the human immune system via any route of exposure. Animal data included an inhalation study in which there was a 40% decrease in peripheral white blood cells in rats exposed to 2-hexanone (Katz et al. 1980). In addition, 2,5-hexanedione, a metabolite of 2-hexanone, was shown to adversely affect lymphoid organs of the immune system in rats and to cause impairment of immunity in mice (Upreti and Shanker 1987). Immunological assessments, including analysis of peripheral blood components and effects on lymphoid tissue, conducted as part of intermediate- or chronic-duration studies and skin sensitization tests would be useful in developing a dose-response relationship and assessing the potential risk to chronically exposed persons in the vicinity of hazardous waste sites or to exposed workers.

Neurotoxicity. The nervous system has been clearly established as the major target for 2-hexanone in humans exposed via inhalation (Allen et al. 1975) and in animals exposed via any route of exposure (Abdel-Rahman et al. 1978; Abdo et al. 1982; Abou-Donia et al. 1982, 1985a,b; Duckett et al. 1979; Egan et al. 1980; Johnson et al. 1977; Katz et al. 1980; Krasavage et al.

1980; Saida et al. 1976; Spencer et al. 1975) and in the offspring of pregnant rats exposed via inhalation (Peters et al. 1981). However, most of the available information is derived from studies using 2-hexanone of low or unknown purity or using it at a single dosage level, its usefulness is limited. Animal data that would clearly establish dose-response relationships for neurological effects, including histopathological damage as well as clinical manifestations, as a result of exposure to pure 2-hexanone via all routes of exposure and using a range of exposure durations would be useful. This information would be valuable in assessing the potential risks of neurotoxicity in persons exposed to 2-hexanone in the vicinity of hazardous waste sites or at the workplace.

Epidemiological and Human Dosimetry Studies. The only epidemiological information that is currently available is the study of workers exposed to 2-hexanone for about a year (Allen et al. 1975). Humans may be exposed to 2-hexanone -through contaminated air in the workplace and in the vicinity of hazardous waste sites and consumption of and dermal contact with contaminated water, especially in the vicinity of hazardous waste sites. Epidemiological studies that followed populations exposed to 2-hexanone, either in the vicinity of hazardous waste sites or in the workplace, would be useful in assessing adverse health effects in humans. In any such studies, emphasis should be placed on neurological, hematological, immunological, reproductive, and developmental effects. Similarly, human dosimetry studies of these populations would be useful in associating 2-hexanone levels with the reported effects.

Biomarkers of Exposure and Effect. Measurement of 2-hexanone and its metabolites in blood or urine may not provide an adequate indication of exposure to this substance, since these metabolites may also result from exposure to n-hexane (Fedtke and Bolt 1986; Nomeir and Abou-Donia 1985; White et al. 1979). Further work in developing unequivocal evidence of exposure to 2-hexanone would be useful.

The major target organ of 2-hexanone in humans is the nervous system (Allen et al. 1975), and morphological effects may occur before clinical manifestations of toxicity (Egan et al. 1980). Therefore, the identification of sensitive nonmorphological effects of 2-hexanone exposure (such,as a certain pattern of responses in electromyographics testing) would be useful.

Absorption, Distribution, Metabolism, and Excretion. Although some information is available on each of these topics from studies conducted in several species, more information in each of these areas would be useful. In addition, because most of these studies were conducted by the same group of researchers, further studies in other laboratories in each of these areas would be useful in confirming the available data.

Available data indicate that 2-hexanone is readily absorbed by humans and various animal species after inhalation, oral, or dermal administration

(Di Vencenzo et al. 1977, 1978). However, information on the rates of absorption via the inhalation and oral routes, as well as estimates of the fraction of the applied dermal dose that is absorbed, would be useful in assessing potential absorption by exposed humans. In addition, information on potential determinants of absorption such as dose level and nutritional status would also be helpful.

Distribution data are limited to a single study in rats using the oral route (DiVincenzo et al. .1977); no quantitative information was provided. The use of multiple species and a comparison of tissue levels of 2-hexanone associated with multiple doses via each route of exposure would be useful in assessing the likelihood that 2-hexanone will reach various potential target organs in exposed humans.

The proposed metabolic pathway for 2-hexanone is based on blood metabolites identified during intraperitoneal studies in guinea pigs (DiVincenzo et al. 1976) and oral studies in rats (DiVincenzo et al. 1977). The metabolite 2,5-hexanedione has also been found in human serum after inhalation exposure (DiVincenzo et al. 1978). Because studies in rats exposed to 2-hexanone have indicated a strong relationship between the concentration of 2,5-hexanedione in the urine and the onset of neuropathic symptoms (Eben et al. 1979), it would be useful to also have this information for humans.

Limited excretion data are available in humans receiving 2-hexanone via inhalation, oral, and dermal.exposure, in dogs via inhalation exposure, and in rats via oral exposure (DiVincenzo et al. 1977, 1978). However, human data on excretion of 2-hexanone via feces are not available, and the available information in dogs concerns excretion via exhaled breath only. In these and any other studies, information on all routes of excretion would help to evaluate the potential for 2-hexanone clearance in the exposed species. Excretion data in rats receiving 2-hexanone via inhalation and dermal application and in other species receiving 2-hexanone via all three routes would be useful for comparison with the human data and to assess the comparative risks of exposure by each route. In addition, information on excretion rates in each species via each route would be helpful in understanding how long 2-hexanone and its metabolites may persist in the body.

Comparative Toxicokinetics. The toxicokinetic studies available in both humans and animals (dogs, rats, and guinea pigs) suggest that there may not be any major differences in the kinetics of this compound across certain species. Metabolites of 2-hexanone in the expired breath (carbon dioxide) of humans and rats exposed via the oral route and the presence of 2,5-hexanedione in the serum of humans exposed via inhalation, as well as in the blood and urine of orally exposed rats and the intraperitoneally exposed guinea pigs, suggest that there is a similar metabolic pathway in humans and experimental animals (DiVincenzo et al. 1976, 1977, 1978). Confirmation of this assumption would be useful. Similar toxic effects, neuropathy and weight loss, have been noted in several species (humans, monkeys, rats, cats, hens, and guinea pigs)

(Abdel-Rahman et al. 1978; Abdo et al. 1982; Abou-Donia et al 1982, 1985a,b; Allen et al. 1975; Duckett et al. 1979; Egan et al. 1980; Johnson et al. 1977; Katz et al. 1980; Krasavage et al. 1980; Saida et al. 1976; Spencer et al. 1975). Therefore, it would also be useful to investigate patterns of distribution, to identify target organs, and to measure rates of excretion in several species and to identify blood metabolites in humans in order to investigate interspecies similarities and differences. Studies in this area would be valuable for predicting toxic effects in humans and for studying the mechanisms of action of this chemical.

Mitigation of effects. Recommended methods for the mitigation of acute effects of 2-hexanone poisoning include prevention of absorption of 2-hexanone from the gastrointestinal tract by administration of emetics, binding agents and cathartics or administration of oxygen if exposure is by inhalation (Bronstein and Currance 1988; Stutz and Janusz 1988). No information was located concerning mitigation of effects of lower-level or longer-term exposure to 2-hexanone. Further information on techniques to mitigate such effects would be useful in determining the safety and effectiveness of possible methods for treating 2-hexanone-exposed populations surrounding hazardous waste sites.

2.9.3 On-going Studies

No research on the toxicity or toxicokinetics of 2-hexanone is known to be in progress.

There are, however, some studies currently in progress that are investigating the mechanism of neurotoxicity of the 2-hexanone metabolite, 2,5-hexanedione. A study is being conducted at the Oregon Health Sciences University, under the direction of Dr. Bruce Gordon Gold, to correlate the time course of any abnormal expression of phosphorylated neurofilament epitopes (a pathological alteration which occurs in several human neurofibrillary disorders including amyotrophic lateral sclerosis) and distal swellings and axonal degeneration in chronic 2,5-hexanedione neuropathy (in addition to other chemically-induced neuropathies). It is the intention of this study to establish a more universal marker for the presence of secondary changes in neuronal perikarya and to clarify the significance of these alterations in several human disorders such as amyotrophic lateral sclerosis.

In a study being conducted at Case Western Reserve University under the direction of Dr. Lawrence Sayre, trifluoromethyl-substituted analogs of 2,5-hexanedione will be synthesized, compared with the parent compound in chemical model studies, and evaluated for neurotoxicity in rats. This is part of an effort to address how gamma-diketone-induced pyrrole formation at neurofilament-based lysine epsilon-amino groups leads to neurofilament accumulations. Nuclear magnetic resonance (NMR) studies will provide direct visualization of the nature of chemical modification.

Other research being conducted at Case Western Reserve University under the direction of Dr. Lawrence Sayre is a study in which analogs of 2,5-hexanedione will be synthesized, studied chemically, and biologically evaluated in an effort to clarify the structural basis of toxicity, particularly in respect to the direct chemical modification of neurofilament proteins by these analogs or any of their metabolites.

A study to investigate the possible selective vulnerability of specific neuron types or neuronal components to 2,5-hexanedione, as well as to acrylamide, is being conducted at the Medical College of Georgia under the direction of Dr. Barry Goldstein. The aim of this project is to study the functional changes caused by these compounds in sensory and motor systems which either have different diameter axons or differing levels of adaptation. Electrophysiological studies will determine the time course and severity of involvement of various nociceptors, muscle spindles, and motor unit types to these chemicals. Axoplasmic transport changes will be examined in axons of varied diameter and in different motor unit types (and adaptation levels). The goal is to determine whether there is selective vulnerability of neurons to these toxicants, and if so, whether it is based on axonal diameter or on the functional ability to maintain discharge.

A project at Duke University, under the direction of Dr. Doyle Graham, is investigating the molecular pathogenesis of the neuropathy associated with 2,5-hexanedione. The goal is to synthesize novel analogs of 2,5-hexanedione and the putative crosslinking metabolites of other toxicants in order to test specific steps in the pathogenetic schemes and to define the identities of the crosslinking adducts. This project includes the synthesis of a series of gamma-diketones which, through the presence of electron-withdrawing or electron-donating groups, will enhance or impair the rate of pyrrole formation and retard or facilitate oxidation of the resulting pyrrole ring.

3. CHEMICAL AND PHYSICAL INFORMATION

3.1 CHEMICAL IDENTITY

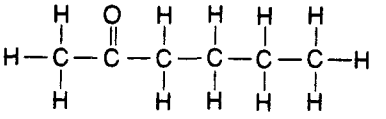
Table 3-1 lists common synonyms, trade names, and other pertinent identification information for 2-hexanone.

3.2 PHYSICAL AND CHEMICAL PROPERTIES

Table 3-2 lists important physical and chemical properties of 2-hexanone.

3. CHEMICAL AND PHYSICAL INFORMATION

TABLE 3-1. Chemical Identity of 2-Hexanone

Characteristic	Information	Reference
Chemical name	2-Hexanone	Sax 1984
Synonyms	Methyl n-butyl ketone; 2-oxohexane; n-butyl methyl ketone; propylacetone	NLM 1989; Sax and Lewis 1987
Trade names	No data	
Chemical formula	$C_6H_{12}O$	Windholz 1983
Chemical structure		ACGIH 1986
Identification numbers:		
CAS registry	591-78-6	Sax and Lewis 1987
NIOSH RTECS	MP1400000	Sax 1984
EPA hazardous waste	No data	
OHM/TADS	No data	
DOT/UN/NA/IMCO shipping	No data	
HSDB	543	HSDB 1989
NCI	No data	

CAS = Chemical Abstracts Service; DOT/UN/NA/IMCO = Department of Transportation/United Nations/North America/International Maritime Dangerous Goods Code; EPA = Environmental Protection Agency; HSDB = Hazardous Substances Data Bank; NCI = National Cancer Institute; NIOSH = National Institute for Occupational Safety and Health; OHM/TADS = Oil and Hazardous Materials/Technical Assistance Data System; RTECS = Registry of Toxic Effects of Chemical Substances

TABLE 3-2. Physical and Chemical Properties of 2-Hexanone

Property	Information	Reference
Molecular weight	100.16	Windholz 1983
Color	Colorless	Windholz 1983
Physical state	Liquid	Windholz 1983
Melting point	-57°C	Weast 1985
Boiling point	128°C	Weast 1985
Density at 20°C	0.83	Windholz 1983
Odor	Similar to acetone	EPA 1981
Odor threshold:		
Water	0.25 mg/L	Amoore and Hautala 1983
Air	0.076 ppm (0.31 mg/m^3)	Amoore and Hautala 1983
Solubility:		
Water at 20°C	20,000-35,000 mg/L	Morrison and Boyd 1974; Verschueren 1983
Organic solvents	Soluble in alcohol, ether, acetone	Weast 1985
Partition coefficients:		
Log octanol/water	1.38	EPA 1981
Log K_{oc}	No data	
Vapor pressure at 25°C	11.6 mmHg	Ambrose et al. 1975
Henry's law constant: at 20°C	No data	
Autoignition temperature	991°F (533°C)	Sax 1984
Flashpoint	95°F (35°C)(open cup)	Sax 1984
	163°F(73°C)(closed cup)	EPA 1981
Flammability limits	No data	
Conversion factors	1 ppm = 4.097 mg/m^3 (calculated)	
	1 mg/m^3 = 0.244 ppm (calculated)	
Explosive limits	1.2%-8%	Sax and Lewis 1987

4. PRODUCTION, IMPORT, USE, AND DISPOSAL

4.1 PRODUCTION

In 1977, the combined U.S. production and import of 2-hexanone was between 453 metric tons and 4,500 metric tons (EPA 1987b, 1981); no breakdown of these figures was provided. The only U.S. producer of 2-hexanone, the Tennessee Eastman Company division of Eastman Kodak, discontinued its production of 2-hexanone in 1979 and sold its remaining reserves by 1981 (EPA 1981, 1987b; HSDB 1989; Lande et al. 1976). 2-Hexanone was commercially produced by the catalyzed reaction of acetic acid and ethylene under pressure (EPA 1987b).

4.2 IMPORT/EXPORT

Currently, 2-hexanone is not produced or used in the United States, and consequently, there is no information on exports or imports (EPA 1987b; HSDB 1989).

4.3 USE

2-Hexanone is not currently manufactured, processed, or used for commercial purposes in the United States (EPA 1987b). 2-Hexanone had been used as a solvent for many materials, primarily in the lacquer industry as a solvent for lacquers and varnish removers. It had also been used as a solvent for ink thinners, resins, oils, fats, and waxes. 2-Hexanone had also been used as an intermediate in the synthesis of organic chemicals (ACGIH 1986; HSDB 1989).

4.4 DISPOSAL

No data were located regarding the disposal of 2-hexanone or on regulations and guidelines regarding its disposal. The favored method for disposal of ketones is incineration (Lande et al. 1976). No quantitative data were located regarding either the generation or disposal of 2-hexanone which may be produced as a degradation product of coal gasification, wood pulping, or oil shale processing.

5. POTENTIAL FOR HUMAN EXPOSURE

5.1 OVERVIEW

2-Hexanone is a volatile organic liquid that is very soluble in water. It is expected to be quite mobile in water and soils. Its rate of volatilization is likely to be moderately fast, but equilibration with sediments will be low. Biodegradation of 2-hexanone may occur slowly in water and soil, but bioconcentration is not expected.

Exposure of the general population to 2-hexanone is not likely to be high. However, persons living near hazardous waste sites or wood pulping, coal-gasification, or oil-shale processing plants may be exposed to 2 hexanone in contaminated environmental media. In the past, occupational exposures to 2-hexanone resulted from its manufacture and use. However, since 2-hexanone is not currently manufactured or used commercially in the United States, occupational exposures related to these activities are no longer of special concern.

The EPA has identified 1,177 NPL sites. 2-Hexanone has been found at 15 of the sites evaluated for the presence of this chemical. However, we do not know how many of the 1,177 NPL sites have been evaluated for the presence of 2-hexanone. As more sites are evaluated by the EPA, the number may change (View 1989). The frequency of these sites can be seen in Figure 5-1. Of these sites, 14 are located within the United States and 1 is located in the Commonwealth of Puerto Rico (not shown).

5.2 RELEASES TO THE ENVIRONMENT

Because 2-hexanone is not currently manufactured, imported, processed, or used for commercial purposes in the United States (EPA 1987b), releases to the environment are not likely to be high. Although it is reported to be released from wood pulping, coal-gasification, and oil-shale processing plants, levels resulting from these operations have been reported as being low. This compound is not listed in the Toxics Release Inventory (TRI).

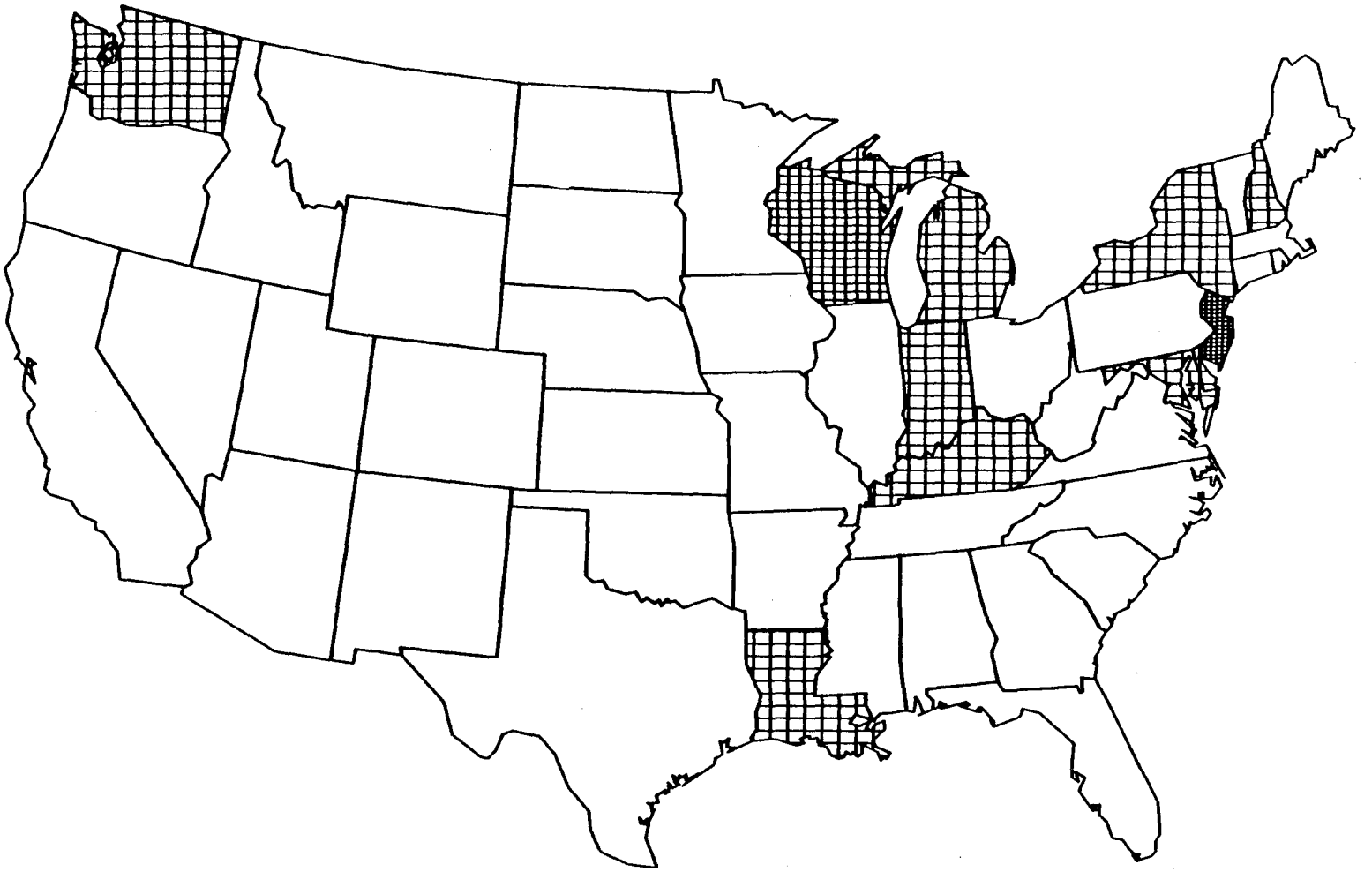
5.2.1 Air

No studies were located regarding the amount of 2-hexanone released to the atmosphere. However, since 2-hexanone is no longer produced in the United States (EPA 1987b) or used commercially (EPA 1987b; Lande et al. 1976; O'Donoghue 1985), atmospheric emissions from industrial sources are likely to be small.

5.2.2 Water

2-Hexanone is released to water by industrial facilities and at hazardous waste sites. 2-Hexanone was detected in 2 of 3 effluents from coal gasification plants and in 1 of 2 effluents from oil shale processing plants

FIGURE 5-1. FREQUENCY OF NPL SITES WITH 2-HEXANONE CONTAMINATION *



* Derived from View 1989

at mean concentrations ranging from 7 to 202 ppb (µg/L) (Pellizzarri et al. 1979). The compound has also been tentatively identified in 1 of 63 industrial effluents (Perry et al., 1979), the effluent from a chemical plant (Shackelford and Keith 1976), and in one municipal landfill leachate at 0.148 ppm (mg/L) in a study of leachates from 58 municipal and industrial landfills (Brown and Donnelly 1988).

2-Hexanone has also been detected in both groundwater and surface water at hazardous waste sites (CLPSD 1989) (see Section 5.4.2), indicating that this is a source of 2-hexanone release to the environment.

5.2.3 Soil

Soils or sediments may become contaminated with 2-hexanone by landfilling with 2-hexanone-containing solid wastes or by the discharge of contaminated water. 2-Hexanone has been detected in soil samples from hazardous waste sites (CLPSD 1989) (see Section 5.4.3).

5.3 ENVIRONMENTAL FATE

5.3.1 Transport and Partitioning

2-Hexanone exists in the atmosphere as a vapor. Liquid 2-hexanone is volatile; its vapor pressure has been measured as 1.53×10^{-2} atm (11.6 mmHg) at 25°C (Ambrose et al. 1975). Because 2-hexanone is very soluble in water, a large fraction of 2-hexanone released to the atmosphere, may dissolve in water vapor (such as clouds and rain drops). A Henry's law constant (H) estimates the tendency of a chemical to partition between its vapor phase and water. A value for H may be calculated by dividing the vapor pressure of 2-hexanone by its solubility in water at the same temperature (Mabey et al. 1982). In this case, an estimated value for H is 4.4-7.7x10-$^{-5}$ atm-m^3/mole at about 25°C. The magnitude of this value suggests that a large fraction of vapor-phase 2-hexanone will dissolve in water, and that precipitation may be an important physical removal mechanism. An analogous air-water partition coefficient measured for 2-hexanone at 37°C was approximately 2.3×10^{-4} atm-m^3/mole (Sato and Nakajima 1979), which indicates that precipitation will also be an important removal mechanism at this higher temperature.

2-Hexanone is very soluble in water, approximately 20-35 g/L (Morrison and Boyd 1974; Verschueren 1983). The magnitude of the estimated Henry's law constant ($4.4\text{-}7.7 \times 10^{-5}$ atm-m^3/mole) indicates that 2-hexanone will volatilize from water, with a half-life in river water of about 10-15 days (Mabey et al. 1982). Volatilization will be slower from lakes or ponds (Mabey et al. 1982). There is no information on whether 2-hexanone in water is expected to partition to soils and sediments.

5. POTENTIAL FOR HUMAN EXPOSURE

2-Hexanone will probably not be bioconcentrated by organisms in water. An octanol/water partition coefficient (K_{ow}) estimates the partitioning of a chemical between octanol and water. Octanol is believed to best imitate the fatty structures in plants and animal tissues. The K_{ow} of 2-hexanone is approximately 20-40, based on its solubility in water (Hassett et al. 1983). These low values suggest that 2-hexanone will not partition to fatty tissues.

A bioconcentration factor (BCF) relates the concentration of a chemical in plants or animals to the concentration of that chemical in the medium in which they live. A BCF of about 7 was calculated for 2-hexanone (Lande et al. 1976) using the empirical regression of Neely et al. (1974). This low BCF indicates that bioconcentration is probably not an important fate mechanism for 2-hexanone released into the environment. Biomagnification of 2-hexanone is also not expected to occur to any great extent (Lande et al. 1976). However, no experimental data on the biomagnification potential of 2-hexanone were located to corroborate these assumptions.

5.3.2 Transformation and Degradation

5.3.2.1 Air

The major fate mechanism of atmospheric 2-hexanone is photooxidation. This ketone is also degraded by direct photolysis (Calvert and Pitts 1966), but the reaction is estimated to be slow relative to reaction with hydroxyl radicals (Laity et al. 1973). The rate constant for the photochemicallyinduced transformation of 2-hexanone by hydroxyl radicals in the troposphere has been measured at 8.97×10^{-12} cm^3/ molecule-set (Atkinson et al. 1985). Using an average concentration of tropospheric hydroxyl radicals of 6×10^5 molecules/cm^3 (Atkinson et al. 1985), the calculated atmospheric halflife of 2-hexanone is about 36 hours. However, the half-life may be shorter in polluted atmospheres with higher OH radical concentrations (MacLeod et al. 1984). Consequently, it appears that vapor-phase 2-hexanone is labile in the atmosphere.

5.3.2.2 Water

2-Hexanone is a ketone, and ketones are generally not degraded by hydrolysis (Lande et al. 1976; Morrison and Boyd 1974). Based on its reactions in air, it seems likely that 2-hexanone will undergo photolysis in water, however no information was located. Based on studies with microorganisms (see Section 5.3.2.3), it is probable that 2-hexanone will be biodegraded in water.

5.3.2.3 Soil

2-Hexanone may be biodegraded in soil. 2-Hexanone has been shown to be degraded by hydrocarbon-utilizing mycobacteria (Lukins and Foster 1963; Perry -1968). Similarly, certain yeasts have been isolated that can use 2-hexanone

as a carbon source (Lowery et al. 1968). In a study using acclimated microbial cultures, 2-hexanone was significantly biodegraded (Babeu and Vaishnav 1987). An experimental 5-day biological oxygen demand (BOD) determination was about 61% of the theoretical BOD value. Although these studies have demonstrated that 2-hexanone may be biodegraded under ideal conditions, no information was located on its biological half-life in soils.

5.4 LEVELS MONITORED OR ESTIMATED IN THE ENVIRONMENT

5.4.1 Air

No studies were located which measured or estimated the concentration of 2-hexanone in ambient air.

In the past, workplace air concentrations in facilities where 2-hexanone was manufactured or used as a solvent ranged from 1 to 156 ppm (4.1 to 640 mg/m^3) (ACGIH 1986), and air concentrations up to 1,636 mg/m^3 were measured in the operations areas of some facilities (Bierbaum and Marceleno 1973; Marceleno et al. 1974). However, because 2-hexanone is no longer produced or used commercially in the United States, and because OSHA has reduced the Permissible Exposure Limit (PEL) to 5 ppm (20 mg/m^3) (OSHA 1989), it is unlikely that current workplace air concentrations are as high as they were in the past.

5.4.2 Water

Data estimating 2-hexanone concentrations in water are sparse. 2-Hexanone was identified in one of three groundwater samples at a concentration of 87 µg/L (ppb) near a hazardous waste site in Florida (Myers 1983). This compound was also identified in a study of drinking water concentrates and advanced waste treatment concentrates (Lucas 1984).

2-Hexanone has been detected in both surface water and groundwater at hazardous waste sites. Data from the Contract Laboratory Program (CLP) Statistical Database indicate that 2-hexanone was found at 2% of the sites at a geometric mean concentration of 7.5 µg/L (ppb) in positive surface water samples and 12 µg/L (ppb) in positive groundwater samples (CLPSD 1989). This database provides data from both NPL and non-NPL waste sites.

5.4.3 Soil

2-Hexanone was detected in soil samples at 3% of hazardous waste sites (both NPL and non-NPL) at a geometric mean concentration of 40 µg/kg (ppb) in positive samples (CLPSD 1989). No other data were located regarding estimation of 2-hexanone in soils or sediments.

5.4.4 Other Environmental Media

2-Hexanone has been identified among the natural volatile components of several foods including blue and Beaufort cheeses, nectarines, roasted filberts, and chicken muscle (Day and Anderson 1965; Dumont and Adda 1978; Grey and Shrimpton 1967; Kinlin et al. 1972; Takeoka et al. 1988); levels were not stated in these reports. It has also been detected in milk and cream at concentrations ranging from 0.007 to 0.018 ppm (7-18 ppb) and in bread (Lande et al. 1976). Because few quantitative data are available, it is not known if food is an important source of human exposure to 2-hexanone.

No studies were located regarding the occurrence of 2-hexanone in any other media.

5.5 GENERAL POPULATION AND OCCUPATIONAL EXPOSURE

Human exposure to 2-hexanone may occur by inhalation, ingestion, or dermal exposure. Exposure to small amounts of 2-hexanone may occur by ingestion of foods in which it has been detected. However, since this compound is no longer manufactured or used commercially in the United States, widespread or high-level exposure of the general population to 2-hexanone is not likely.

According to surveys conducted by NIOSH, the number of employees potentially exposed to 2-hexanone dropped from 41,600 in the early 1970s (NOHS 1989) to 1,100 in the early 1980s (NIOSH 1989). Neither the NOHS nor the NOES databases contain information on the frequency, concentration, or duration of exposures of workers to any of the chemicals listed therein. These surveys provide only estimates of the number of workers potentially exposed to chemicals in the workplace. This dramatic reduction in the extent of occupational exposure parallels the halt of production and the reduction in use of this chemical (EPA 1987b). It is unlikely that many persons are currently occupationally exposed to 2-hexanone, other than as a degradation product resulting from wood pulping, oil shale processing, or coal gasification operations. The NIOSH does not list 2-hexanone among the chemicals considered in an occupational exposure evaluation of coal gasification plants (NIOSH 1978b).

5.6 POPULATIONS WITH POTENTIALLY HIGH EXPOSURES

Populations with potentially high exposure to 2-hexanone include people living near or working in coal gasification, oil shale processing or wood pulping operations, or living near the hazardous waste sites at which 2-hexanone is likely to occur. The most likely exposure routes are ingestion of or dermal contact with water contaminated from these sources or inhalation of 2-hexanone which has volatilized from contaminated water or soil.

Individuals may still be exposed by inhalation or skin absorption from consumer products manufactured prior to 1982 such as lacquers, primers, sealers, and thinners that contain 2-hexanone.

5.7 ADEQUACY OF THE DATABASE

Section 104(i)(5) of CERCLA, as amended, directs the Administrator of ATSDR (in consultation with the Administrator of EPA and agencies and programs of the Public Health Service) to assess whether adequate information on the health effects of 2-hexanone is available. Where adequate information is not available, ATSDR, in conjunction with the NTP, is required to assure the initiation of a program of research designed to determine the health effects (and techniques for developing methods to determine such health effects) of 2-hexanone.

The following categories of possible data needs have been identified by a joint team of scientists from ATSDR, NTP, and EPA. They are defined as substance-specific informational needs that, if met, would reduce or eliminate the uncertainties of human health assessment. In the future, the identified data needs will be evaluated and prioritized, and a substance-specific research agenda will be proposed.

5.7.1 Data Needs

Physical and Chemical Properties. The physical and chemical property data available for 2-hexanone are sufficient to allow a limited estimation of the potential environmental fate of this chemical. The estimated Henry's law constant (Mabey et al, 1982) and K_{oc} (Hassett et al. 1983) need to be verified experimentally to help confirm the estimates of partitioning in environmental media. Since there does not seem to be a consensus on the solubility of 2-hexanone in water (reported values range from about 20-35 g/L) (Morrison and Boyd 1974; Verschueren 1983), additional measurements would be useful to more accurately predict the environmental fate of this compound.

Production, Import/Export, Use, and Disposal. 2-Hexanone is no longer produced, imported, or used commercially in the United States (EPA 1987b). Any future manufacture or use is required to be reported to EPA (EPA 1987b). Data from these reports would be helpful in estimating the potential for human exposure to this compound. No data on disposal of 2-hexanone were located. Information on disposal practices for wastes containing 2-hexanone is necessary for estimations of human exposure from this source. No regulations govern the disposal of 2-hexanone.

Environmental Fate. The probable transport and partitioning of 2-hexanone in environmental media have been predicted based on estimated partition coefficients. Experimental confirmation of these values would help to increase the accuracy of transport and partitioning assessments. The loss mechanisms of 2-hexanone transformations in the atmosphere are fairly-well

understood (Atkinson et al. 1985; Calvert and Pitts 1966; Laity et al. 1973; MacLeod et al. 1984), but the reaction pathways and environmental fates of the transformation products are not known. Very little is known about the fate of 2-hexanone in water or soil (Babeu and Vaishnav 1987; Lande et al. 1976; Lowery et al. 1968; Lukins and Foster 1963; Perry 1968). Data on photodegradation and biodegradation of 2-hexanone in surface water and biodegradation of 2-hexanone in groundwater and soil may be helpful in assessing the persistence of 2-hexanone in these media.

Bioavailability from Environmental Media. Information on absorption by humans and other animal species indicates that it is well absorbed via the oral and dermal routes (DiVincenzo et al. 1977, 1978). 2-Hexanone has also been demonstrated to be well absorbed by humans and animals following inhalation exposure (DiVincenzo et al. 1978). Information on its bioavailability from contaminated soils would be useful in assessing the risk from exposure to this medium by populations in the vicinity of hazardous waste sites.

Food Chain Bioaccumulation. There are no data on the bioaccumulation of 2-hexanone in food chains. This lack of data may not be a major limitation in the database because it is unlikely that 2-hexanone is bioconcentrated by plants, aquatic organisms, or animals at lower trophic levels based on its high water solubility (Lande et al. 1976). However, data confirming that bioconcentration does not occur would help to more accurately assess the probability of bioaccumulation of 2-hexanone.

Exposure Levels in Environmental Media. Very few data are available regarding the presence of 2-hexanone in any environmental media (CLPSD 1989; Lucas 1984; Myers 1983). Although high levels of this compound are not expected to occur in ambient air, water, or soil, concentrations of 2-hexanone in these media near effluent sources or hazardous waste sites would be helpful in assessing the potential extent and magnitude of human exposures. Exposure Levels in Humans. No information has been located on exposure levels of humans to 2-hexanone in the workplace or in the vicinity of hazardous waste sites. It would be useful to collect information on levels of exposure to 2-hexanone in the environment and associated blood, urine or tissue levels of 2-hexanone and/or its metabolites in the exposed populations. Additional information relating those levels to the subsequent development of health effects would also be extremely useful.

Exposure Registries. No exposure registries for 2-hexanone were located. This compound is not currently one of the compounds for which a subregistry has been established in the National Exposure Registry. The compound will be considered in the future when chemical selection is made for subregistries to be established. The information that is amassed in the

National Exposure Registry facilitates the epidemiological research needed to assess adverse health outcomes that may be related to the exposure to this compound.

5.7.2 On-going Studies

Remedial investigations and feasibility studies conducted at the 15 NPL sites known to be contaminated with 2-hexanone will add to the available database in the categories of exposure levels in humans, exposure levels in the environmental media, and exposure registries.

No other on-going studies were located on the fate, transport, or potential for human exposure for 2-hexanone.

6. ANALYTICAL METHODS

The purpose of this chapter is to describe the analytical methods that are available for detecting and/or measuring and monitoring 2-hexanone in environmental media and in biological samples. The intent is not to provide an exhaustive list of analytical methods that could be used to detect and quantify 2-hexanone. Rather, the intention is to identify well-established methods that are used as the standard methods of analysis. Many of the analytical methods used to detect 2-hexanone in environmental samples are the methods approved by federal agencies such as EPA and the National Institute for Occupational Safety and Health (NIOSH). Other methods presented in this chapter are those that are approved by groups such as the Association of Official Analytical Chemists (AOAC) and the American Public Health Association (APHA). Additionally, analytical methods are included that refine previously used methods to obtain lower detection limits, and/or to improve accuracy and precision.

6.1 BIOLOGICAL MATERIALS

In biological systems in which 2-hexanone may have been metabolized, or may itself be a metabolite, consideration must be given to possible binding of the analyte as a conjugate. In such cases, 2-hexanone may be released by hydrolysis with acid (Fedtke and Bolt 1986). Following pre-treatment, which varies with the sample and may include homogenization, centrifugation, and acidification, 2-hexanone can be released from biological samples by purging or perfusion and trapped on a sorbent, extracted with a solvent such as acetone, or extracted directly onto sorbent solids.

Sensitive and selective methods are available for the qualitative and quantitative measurement of 2-hexanone, after it is separated from its sample matrix. Gas chromatography using sensitive and highly specific mass spectrometry (MS) or highly sensitive flame ionization detection (FID) is the analytical method most commonly used. Capillary gas chromatography, also known broadly as high resolution gas chromatography (HRGC), has greatly facilitated the analysis of compounds such as 2-hexanone that can be measured by gas chromatography and has resulted in vast improvements in resolution and sensitivity. It has made the choice of a stationary phase much less crucial than is the case with the older method using packed columns. The instrumental capability to separate volatile analytes by HRGC is, for the most part, no longer the limiting factor in their analysis. High performance liquid chromatography (HPLC) may also be used and has the advantage of compatibility with the liquid matrix of biological samples.

Methods for detection of 2-hexanone in biological materials are summarized in Table 6-1.

TABLE 6-1. Analytical Methods for Determining 2-Hexanone in Biological Materials

Sample matrix	Preparation method	Analytical method	Sample detection limit	Percent recovery	Reference
Urine	Hydrolysis of metabolic conjugates with HCl, extraction on C18 cartridges, desorption	HRGC/MS	0.05-0.08 µg/mL	81±3.2%[a]	Fedtke and Bolt 1986
Biological samples (chicken plasma)[b]	Extraction with ether after addition of HCl and Na_2SO_4, concentrated under N_2	HRGC/FID	No data	78±4%[c]	Nomeir and Abou-Donia 1985
Biological samples (chicken plasma)[b]	Extraction with ether after addition of HCl and Na_2SO_4, concentrated under N_2	HPLC/UV	No data	No data	Nomeir and Abou-Donia 1985
Biological tissues, (blood, brain, kidney, liver)[b]	Homogenization with acetone, centrifugation, injection of acetone extract	GC/MS	No data	98±12%-110±16%[d]	White et al. 1979
Blood (human)[e]	Perfusion at 95°C, collection on Tenax®, release by heating	GC/MS	No data	No data	Anderson and Harland 1980

[a]Percent recovery for 2,5-hexanedione was 83±3.6%.
[b]This method was also used in the determination of 2,5-hexanedione, a metabolic product of 2-hexanone.
[c]Percent recovery for 2,5-hexanedione was 62±3%
[d]Percent recovery for 2,5-hexanedione was 96±13% to 110±16%
[e]$C_6H_{12}O$ ketone detected in blood of fire victims at necropsy

GC = gas chromatography; FID = flame ionization detector; HPLC = high performance liquid chromatography; HRGC = high resolution gas chromatography; MS = mass spectrometry; RSD = relative standard deviation; UV = ultraviolet light

6. ANALYTICAL METHODS

6.2 ENVIRONMENTAL SAMPLES

For the determination of 2-hexanone in air, the analyte is usually trapped and concentrated from a large volume of air on a solid sorbent such as Tenax® or activated carbon from which it can be released thermally or eluted with a solvent such as carbon disulfide for subsequent measurement. For aqueous samples, 2-hexanone is purged with an inert gas and collected on a solid such as Tenax®, followed by thermal desorption and measurement. Cryogenic trapping has also been used for removal of 2-hexanone from water samples (Badings et al. 1985). Gas chromatography using sensitive and highly specific MS or highly sensitive FID is the analytical method of choice for the determination of 2-hexanone in environmental samples.

Methods for the determination of 2-hexanone in environmental samples are summarized in Table 6-2.

6.3 ADEQUACY OF THE DATABASE

Section 104(i)(5) of CERCLA, as amended, directs the Administrator of ATSDR (in consultation with the Administrator of EPA and agencies and programs of the Public Health Service) to assess whether adequate information on the health effects of 2-hexanone is available. Where adequate information is not available, ATSDR, in conjunction with the NTP, is required to assure the initiation of a program of research designed to determine the health effects (and techniques for developing methods to determine such health effects) of 2-hexanone.

The following categories of possible data needs have been identified by a joint team of scientists from ATSDR, NTP, and EPA. They are defined as substance-specific informational needs that, if met, would reduce or eliminate the uncertainties of human health assessment. In the future, the identified data needs will be evaluated and prioritized, and a substance-specific research agenda will be proposed.

6.3.1 Data Needs

Methods for Determining Biomarkers of Exposure and Effect. As noted in Section 6.1, methods are available for the qualitative and quantitative measurement of 2-hexanone after it is separated from its sample matrix (Anderson and Harland 1980; Fedtke and Bolt 1986; Nomeir and Abdou-Donia 1985; White et al. 1979). High-resolution gas chromatography for 2-hexanone analysis has been developed to the point that the instrumental capability to separate volatile analytes by HRGC is, for the most part, no longer the limiting factor in their analysis. Flame ionization detection has enabled detection at very low levels and MS has assured specificity in measurement.

TABLE 6-2. Analytical Methods for Determining 2-Hexanone in Environmental Samples

Sample matrix	Preparation method	Analytical method	Sample detection limit	Percent recovery	Reference
Wastewater and spent oil shale	Collection on Tenax®, thermal desorption	HRGC/FID; GC/MS	No data	No data	Hawthorne et al. 1985
Air	Retention by activated carbon, elution with carbon disulfide	GC/FID	20 µg	No data	NIOSH 1984
Water, environmental samples	Purge, cryogenic trap	HRGC	<10 µg/kg	No data	Badings et al. 1985
Groundwater	Purge by helium, collection on solid, thermal desorption	GC/MS	50 µg/L	No data	EPA 1986
Solid waste	Purge by helium, collection on solid, thermal desorption	GC/MS	50 µg/kg	No data	EPA 1986

FID = flame ionization detector; GC = gas chromatography; HRGC = high-resolution gas chromatography; MS = mass spectrometry

6. ANALYTICAL METHODS

More specific methods to determine biomarkers of exposure to 2-hexanone would be helpful in detecting exposure to this compound before adverse morphological or clinical effects occur. Finding biological markers of exposure to 2-hexanone is complicated by the fact that this compound is itself a biological indicator of exposure to n-hexane (Fedtke and Bolt 1986). In addition, the presence of the metabolite, 2,5-hexanedione, may indicate exposure to 2-hexanone, but it is also a biological indicator of exposure to n-hexane (Fedtke and Bolt 1986). There is insufficient information in the literature to determine if methods for determining biomarkers of exposure and effect of 2-hexanone are sensitive enough to measure background levels in the population and levels at which biological effects occur. The precision, accuracy, reliability, and specificity of these methods are not sufficiently documented. This information would be valuable for interpreting monitoring data.

Refinement of existing purge-and-trap extraction techniques and investigation of alternative concentration methods such as cryotrapping (Pankow and Rosen 1988) and supercritical fluid extraction (King 1989) would be useful. In addition, several major challenges remain. One of these is to transfer analytes that have been isolated from a biological or environmental matrix quantitatively and in a narrow band to the HRGC. Another major challenge is to identify and accurately measure the quantity of compounds in the HRGC peaks. Mass spectrometric detection has been outstanding for identification, but other techniques, particularly Fourier transform infrared spectroscopy (FTIR), may offer some advantages (Wieboldt et al. 1988).

Metabolites of 2-hexanone in biological materials are difficult to determine in routine practice because of the lack of standardized methods for their measurement. As shown in Table 6-1, there are very few well characterized methods for the determination of metabolites of 2-hexanone in biological materials (Nomeir and Abou-Donia 1985; White et al. 1979). The precision, accuracy, reliability, and specificity of existing methods need to be evaluated, and the methods refined and adapted to routine practice.

Methods for Determining Parent Compounds and Degradation Products in Environmental Media. The media of most concern for human exposure to 2-hexanone are drinking water (primarily from groundwater sources) and air. From the data presented in Table 6-2 (Badings et al. 1985; EPA 1986; Hawthorne et al. 1985; NIOSH 1984), it may be concluded that the methods available for the determination of 2-hexanone in water and air are not sensitive enough to determine background levels of this compound. Existing methods are satisfactory for measuring levels at which health effects occur.

The precision, accuracy, reliability, and specificity of methods to determine 2-hexanone in water and air are not well documented, and additional work is needed in this area.

6. ANALYTICAL METHODS

Methods for determining the parent compound, 2-hexanone, in water, air, and waste samples are available (Badings et al. 1985; EPA 1986; Hawthorne et al. 1985; NIOSH 1984). Sampling methodologies for compounds such as 2-hexanone continue to pose problems such as nonrepresentative samples, insufficient sample volumes, contamination, and labor-intensive, tedious extraction and purification procedures (Green and Le Pape 1987). It would be helpful to have means to measure organic compounds such as 2-hexanone in situ in water and other environmental media without the need for sampling and extraction procedures to isolate the analyte prior to analysis.

6.3.2 On-going Studies

There are no known on-going studies to improve methods of analysis for 2-hexanone or its metabolites in biological or environmental samples.

7. REGULATIONS AND ADVISORIES

Because of the potential of 2-hexanone to cause adverse health effects in exposed people, a number of regulations and guidelines have been established by various national and state agencies. These values are summarized in Table 7-1.

7. REGULATIONS AND ADVISORIES

TABLE 7-1. Regulations and Guidelines Applicable to 2-Hexanone

Agency	Description	Information	References
NATIONAL			
Regulations:			
a. Air:			
OSHA	PEL TWA	5 ppm (20 mg/m^3)	OSHA 1989 (29 CFR 1910.1000) Table Z-1-A
b. Nonspecific media:			
EPA OSW	Groundwater monitoring list (Appendix IX)	Yes	EPA 1987a (40 CFR 264)
EPA OTS	Significant new use rule	Yes	EPA 1987b (40 CFR 721.385)
Guidelines:			
a. Air:			
ACGIH	TLV TWA	5 ppm (20 mg/m^3)	ACGIH 1986
NIOSH	IDLH	5,000 ppm	NIOSH 1985
	TWA (10 hr)	1 ppm (4 mg/m^3)	
STATE			
Regulations and Guidelines:			
a. Air:	Acceptable ambient air concentrations		NATICH 1989
Connecticut		80.0 μg/m^3 (8 hr)	
Nevada		0.476 mg (476 μg)/m^3 (8 hr)	
North Dakota		0.20 mg (200 μg)/m^3 (8 hr)	
Virginia		350 μg/m^3 (24 hr)	
Massachusetts		10.88 μg/m^3 (24 hr)	West 1990

ACGIH = American Conference of Governmental Industrial Hygienists; EPA = Environmental Protection Agency; IDLH = Immediately Dangerous to Life or Health Level; NIOSH = National Institute for Occupational Safety and Health; OSHA = Occupational Safety and Health Administration; OSW = Office of Solid Wastes; OTS = Office of Toxic Substances; PEL = Permissible Exposure Limit; TLV = Threshold Limit Value; TWA = Time-Weighted Average

8. REFERENCES

Abdel-Rahman MS, Hetland LB, Couri D. 1976. Toxicity and metabolism of methyl n-butyl ketone. Am Ind Hyg Assoc J 37:95-102.

*Abdel-Rahman MS, Saladin JJ, Bohman CE, et al. 1978. The effect of 2-hexanone and 2-hexanone metabolites on pupillomotor activity and growth. Am Ind Hyg Assoc J 39:94-99.

*Abdo KM, Graham DG, Timmons PR, et al. 1982. Neurotoxicity of continuous (90 days) inhalation of technical grade methyl butyl ketone in hens. J Toxicol Environ Health 9:199-215.

Abe K, Misumi J, Kawakami M, et al. 1980. Effects of n-hexane, methyl n-butyl ketone, and 2,5-hexanedione on the excitability of sweat glands in rats to mecholyl. Jap J Ind Health 22:380-381.

Abou-Donia MB. 1983. Interaction between neurotoxicities induced by organophosphorus and long-chain hexacarbon compounds. Neurotoxicity 4:117-135.

Abou-Donia MB, Nomeir AA. 1986. The role of pharmacokinetic and metabolism in species sensitivity to neurotoxic agents. Fundam Appl Toxicol 6:190-207.

*Abou-Donia MB, Makkawy H-AM, Graham DB. 1982. The relative neurotoxicities of n-hexane, methyl n-butyl ketone, 2,5-hexanediol, and 2,5-hexanedione following oral or intraperitoneal administration in hens. Toxicol Appl Pharmacol 62:369-389.

*Abou-Donia MB, Lapadula DM, Campbell G, et al. 1985a. The joint neurotoxic action of inhaled methyl butyl ketone vapor and dermally applied 0-ethyl 0-4-nitrophenyl phenylphosphonothioate in hens: Potentiating effect. Toxicol Appl Pharmacol 79:69-82.

*Abou-Donia MB, Makkawy H-AM, Campbell GM. 1985b. Pattern of neurotoxicity of n-hexane, methyl n-butyl ketone, 2,5-hexanediol, and 2,5-hexanedione alone and in combination with 0-ethyl 0-4-nitrophenyl phenylphosphonothioate in hens. J Toxicol Environ Health 16:85-100.

*Abou-Donia MB, Lapadula DM, Campbell G, et al. 1985c. The synergism of n-hexane-induced neurotoxicity by methyl isobutyl ketone following subchronic (90 days) inhalation in hens: Induction of hepatic microsomal cytochrome P-450. Toxicol Appl Pharmacol 81:1-16.

* Cited in text

8. REFERENCES

*ACGIH. 1986. Documentation of the threshold limit values and biological exposure indices. 5th ed. American Conference of Governmental Industrial Hygienists. Cincinnati, OH.

Allen N, Mendell JR, Billmaier D, et al. 1974. An outbreak of a previously undescribed toxic polyneuropathy due to industrial solvent. Transactions of the American Neurological Association 99:74-79.

*Allen N, Mendell JR, Billmaier DJ, et al. 1975. Toxic polyneuropathy due to methyl n-butyl ketone: An industrial outbreak. Arch Neurol 32:209-218.

Altenkirch H, Mager J, Stoltenburg G, et al. 1977. Toxic polyneuropathies after sniffing a glue thinner. J Neurol 214:137-152.

*Ambrose D, Ellender JH, Lees EB, et al. 1975. Thermodynamic properties of organic oxygen compounds. XXXVIII. Vapour pressures of some aliphatic ketones. J Chem Thermodynamics 7:453-472.

*Amoore JE, Hautala E. 1983. Odor as an aid to chemical safety: Odor thresholds compared with threshold limit values and volatilities for 214 industrial chemicals in air and water dilution. J Appl Toxicol 3:272-290.

*Anderson RA, Harland WA. 1980. The analysis of volatiles in blood from fire fatalities. In: Proceedings of the Forensic Toxicology European Meeting, Int Assoc Toxicol, 279-292.

Anger WK, Lynch DW. 1977. The effect of methyl n-butyl ketone on response rates of rats performing on a multiple schedule of reinforcement. Environ Res 14:204-211.

Anonymous. 1974. Solvent causes motor neuropathy in workers at clothing factory. J Am Med Assoc 229:247-248.

Anonymous. 1979. Hexacarbon neuropathy. The Lancet 2(November 3):942-943.
Anthony DC, Boekelheide K, Anderson CW, et al. 1983. The effect of 3,4-dimethyl substitution on the neurotoxicity of 2,5-hexanedione. II. Dimethyl substitution acccelerates pyrrole formation and protein crosslinking. [Abstract] Toxicol Appl Pharmacol 71:372-382.

Asbury AK. 1979. Pathology of industrial toxic neuropathies. Acta Neurol Stand Suppl 60:52-53.

ASTM. 1987a. Standard practice for sampling atmospheres to collect organic compound vapors (activated charcoal tube adsorption method) - method D 3686-84. In: 1987 annual book of ASTM standards. Vol. 11.03. Atmospheric analysis; occupational health and safety. Philadelphia, PA: American Society for Testing and Materials, 326-336.

8. REFERENCES

ASTM. 1987b. Standard practice for analysis of organic compound vapors collected by the activated charcoal tube adsorption method - method D 3687-84. In: 1987 annual book of ASTM standards. Vol. 11.03. Atmospheric analysis; occupational health and safety. Philadelphia, PA: American Society for Testing and Materials, 337-344.

ASTM. 1988. Standard practice for measuring volatile organic matter in water by aqueous-injection gas chromatography - method D 2908-87. In: 1988 annual book of ASTM standards. Vol. 11.02. Water II. Philadelphia, PA: American Society for Testing and Materials, 46-51.

*Atkinson R, Carter WP, Aschmann SM, et al. 1985. Atmospheric fates of organic chemicals: Prediction of ozone and hydroxyl radical reaction rates and mechanisms. Report to U.S. Environmental Protection Agency, Office of Research and Development, Research Triangle Park, NC, by Statewide Air Pollution Research Center, University of California, Riverside, CA. EPA/600/3-85/063. NTIS Publication No. PB85-241529.

*Babeu L, Vaishnav DD. 1987. Prediction of biodegradability for selected organic chemicals. J Ind Microbial 2:107-115.

*Badings HT, De Jong C, Dooper RP. 1985. Automatic system for rapid analysis of volatile compounds by purge-and-cold trapping/capillary gas chromatography. J High Resolut Chromatogr Commun 8:755-763.

Baker EL Jr. 1983. Neurological disorders. In: Rom WN et al., eds. Environmental and Occupational Medicine. Boston, MA: Little, Brown and Company, 313-327.

Baker EL, Fine LJ. 1986. Solvent neurotoxicity: The current evidence. J Occup Med 28:126-129.

*Barnes D, Bellin J, DeRosa C, et al. 1988. Reference dose (RfD): Description and use in health risk assessments. Vol. I. Appendix A: Integrated risk information system supportive documentation. Washington, DC: U.S. Environmental Protection Agency, Office of Health and Environmental Assessment. EPA/600/8-88/032a.

Bierbaum PJ. 1973. Survey of Columbus Coated Fabrics, Newark, California. Cincinnati, OH: National Institute for Occupational Safety and Health, Division of Field Studies and Clinical Investigations. NTIS No. PB81-229601.

*Bierbaum PJ, Marceleno T. 1973. Survey of Brammer Manufacturing Company, Davenport, Iowa. Cincinnati, OH: National Institute for Occupational Safety and Health, Division of Field Studies and Clinical Investigations. NTIS No. PB81-231318.

8. REFERENCES

Bierbaum PJ, Parnes WD. 1974. Survey of Electrical Division of Bristol Brass Corporation, South Windsor, Connecticut. Cincinnati, OH: National Institute for Occupational Safety and Health, Division of Field Studies and Clinical Investigations. NTIS No. PB-82-110073.

*Billmaier D, Yee HT, Allen N, et al. 1974. Peripheral neuropathy in a coated fabrics plant. J Occup Med 16:665-671.

*Boekelheide K. 1987. 2,5-Hexanedione alters microtubule assembly. I. Testicular atrophy, not nervous system toxicity, correlates with enhanced tubulin polymerization. Toxicol Appl Pharmacol 88:370-382.

*Branchflower RV, Pohl IX. 1981. Investigation of the mechanism of the potentiation of chloroform-induced hepatotoxicity and nephrotoxicity by methyl a-butyl ketone. Toxicol Appl Pharmacol 61:407-413.

Branchflower RV, Schulick RD, George JW, et al. 1983. Comparison of the effects of methyl-n-butyl ketone and phenobarbital on rat liver cytochromes P-450 and the metabolism of chloroform to phosgene. Toxicol Appl Pharmacol 71:414-421.

*Bronstein AC, Currance PL. 1988, Emergency care for hazardous materials exposure. St, Louis, MO: The C.V. Mosby Company, 65, 215-216.

*Brown EM, Hewitt WR. 1984. Dose-response relationships in ketone-induced potentiation of chloroform hepato- and nephrotoxicity. Toxicol Appl Pharmacol 76:437-453.

*Brown KW, Donnelly KC. 1988. An estimation of the risk associated with the organic constituents of hazardous and municipal waste landfill leachates. Hazardous Wastes and Hazardous Materials 5:1-30.

Browning E. 1965. Toxicity and metabolism of industrial solvents. London, England: Elsevier Publishing Company, 428-429.

*Calvert JG, Pitts JN. 1966. Photochemistry of the polyatomic molecules. In: Photochemistry. New York, NY: John Wiley & Sons, Inc.

*CLPSD. 1989, Contract Laboratory Program Statistical Database. Viar and Company, Management Services Division, Alexandria, VA. June 1986.

Couri D, Milks M. 1982. Toxicity and metabolism of the neurotoxic hexacarbons n-hexane, 2-hexanone, and 2,5-hexanedione. Ann Rev Pharmacol Toxicol 22:145-166.

8. REFERENCES

Couri D, Hetland LB, O'Neill JJ, et al. 1974. Comments on a plastics industry neurotoxicity in relationship to methylbutyl ketone. Wright-Patterson Air Force Base, OH: Aerospace Medical Research Laboratory. NTIS No. ADA-011857.

*Couri D, Hetland LB, Abdel-Rahman MS, et al. 1977. The influence of inhaled ketone solvent vapors on hepatic microsomal biotransformation activities. Toxicol Appl Pharmacol 41:285-289.

Couri D, Abdel-Rahman MS, Hetland LB. 1978. Biotransformation of n-hexane and methyl n-butyl ketone in guinea pigs and mice. Am Ind Hyg Assoc J 39:295-300.

*Cowlen MS, Hewitt WR, Schroeder F. 1984a. 2-Hexanone potentiation of [^{14}C]chloroform hepatotoxicity: Covalent interaction of a reactive intermediate with rat liver phospholipid. Toxicol Appl Pharmacol 73:478-491.

*Cowlen MS, Hewitt WR, Schroeder F. 1984b. Mechanisms in 2-hexanone potentiation of chloroform hepatotoxicity. Toxicol Lett 22:293-299.

Craft BF. 1973. Summary status report of an investigation of an incident of toxic polyneuropathy at the Borden Chemical Company's Columbus Coated Fabrics Division, Columbus, Ohio. Cincinnati, OH: National Institute for Occupational Safety and Health. NTIS No. PB89-122915.

Davenport JG, Farrell DF, Sumi SM. 1976. Giant axonal neuropathy caused by industrial chemicals: Neurofilamentous axonal masses in man. Neurology 26:919-923.

*Day EA, Anderson DF. 1965. Gas chromatographic and mass spectral identification of natural components of the aroma fraction of blue cheese. J Agric Food Chem 13:2-4.

*DeCaprio AP, Olajos EJ, Weber P. 1982. Covalent binding of a neurotoxic n-hexane metabolite: Conversion of primary amines to substituted pyrrole adducts by 2,5-hexanedione. Toxicol Appl Pharmacol 65:440-450.

*DeCaprio AP, Briggs RG, Jackowski SJ, et al. 1988. Comparative neurotoxicity and pyrrole-forming potential of 2,5-hexanedione and perdeuterio-2,5-hexanedione in the rat. Toxicol Appl Pharmacol 92:75-85.

DeJesus C, Pleasure DF, Asbury AK, et al. 1977. Effects of methyl butyl ketone on peripheral nerves and its mechanism of action. Report to National Institute of Occupational Safety and Health, Cincinnati, OH, by Yale University of Medicine, New Haven, CT and Veterans Administration Hospital, West Haven, CT. NTIS No. PB83-105148.

8. REFERENCES

*DiVincenzo GD, Kaplan CJ, Dedinas J. 1976. Characterization of the metabolites of methyl n-butyl ketone, methyl iso-butyl ketone, and methyl ethyl ketone in guinea pig serum and their clearance. Toxicol Appl Pharmacol 36:511-522.

*DiVincenzo GD, Hamilton ML, Kaplan CJ, et al. 1977. Metabolic fate and disposition of ^{14}C-labeled methyl n-butyl ketone in the rat. Toxicol Appl Pharmacol 41:547-560.

*DiVincenzo GD, Hamilton ML, Kaplan CJ, et al. 1978. Studies on the respiratory uptake and excretion and the skin absorption of methyl n-butyl ketone in humans and dogs. Toxicol Appl Pharmacol 44:593-604.

DiVincenzo GD, Hamilton ML, Kaplan CJ, et al. 1980. Characterization of the metabolites of methyl n-butyl ketone. In: Spencer PS, Schaumburg HH, eds. Experimental and clinical neurotoxicology. Baltimore, MD: Williams and Wilkins Company, 846-855.

Duckett S, Williams N, Francis S. 1974. Peripheral neuropathy associated with inhalation of methyl-n-butyl ketone. Experientia 30:1283-1284.

*Duckett S, Streletz IJ, Chambers RA, et al. 1979. 50 ppm MnBK subclinical neuropathy in rats. Experientia 35:1365-1367.

Dumdei BE, Henderson R. 1988. Air toxics monitoring program during bioremediation of a Superfund site. Proceedings of the 81st Annual Meeting of Air Pollution Control Association, Dallas, TX. June, 1988.

*Dumont JP, Adda J. 1978. Occurrence of sesquiterpenes in mountain cheese volatiles. J Agric Food Chem 26:364-367.

Durham HD, Pena SD J, Ecobichon DJ. 1988. Hexahydrocarbon effects on intermediate filament organization in human fibroblasts. Muscle Nerve 11:160-165.

*Eben A, Flucke W, Mihail F, et al. 1979. Toxicological and metabolic studies of methyl n-butylketone, 2,5-hexanedione, and 2,5-hexanediol in male rats. Ecotoxicol Environ Safety 3:204-217.

*Egan G, Spencer P, Schaumburg H, et al. 1980. n-Hexane-"free" hexane mixture fails to produce nervous system damage. Neurotoxicology 1:515-524.

*Ellenhorn MJ, Barceloux DG. 1988. Medical toxicology: Diagnosis and treatment of human poisoning. New York, NY: Elsevier, 999-1000.

*EPA. 1981. Chemical hazard information profile: Draft report methyl n-butyl ketone. Washington, DC: U.S. Environmental Protection Agency, Office of Pesticides and Toxic Substances.

8. REFERENCES

*EPA. 1986. Gas chromatography/mass spectrometry for volatile organics - method 8240. In: Test methods for evaluating solid waste. 3rd ed. SW-846. Washington, DC: U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response.

*EPA. 1987a. U.S. Environmental Protection Agency: Part II. Federal Register 52:25942-25953.

*EPA. 1987b. U.S. Environmental Protection Agency. Federal Register 52:11823-11826.

*EPA. 1989. Interim methods for development of inhalation reference doses. Washington, DC: U.S. Environmental Protection Agency, Office of Health and Environmental Assessment. EPA 600/8-88/066F.

*Fedtke N, Bolt HM. 1986. Methodological investigations on the determination of E-hexane metabolites in urine. Int Arch Occup Environ Health 57:149-158.

Garman JR, Freund T, Lawless EW. 1987. Testing for groundwater contamination at hazardous waste sites. J Chromatogr Sci 25:328-337.

Genter MB, Szakal-Quin G, Anderson W, et al. 1986. Evidence that pyrrole formation is a pathogenetic step in gamma-diketone neuropathy. [Abstract] Toxicol Appl Pharmacol 87:351-362.

Goldberg AM. 1980. Mechanisms of neurotoxicity as studied in tissue culture systems. Toxicology 17:201-208.

Goldstein MN. 1981. Effect of methyl-n-butyl ketone and other ketone homologues on mammalian cells in culture. Report to National Institute of Occupational Health and Safety, Cincinnati, OH, by Washington University, St. Louis, MO. NTIS No. PB81-225997.

Gosselin RE, Smith RP, Hodge HC, et al. 1984. Clinical toxicology of commercial products. 5th ed. Baltimore, MD: Williams and Wilkins, 11-185-11-186.

Graedel TE. 1978. Aliphatic ketones. In: Chemical compounds in the atmosphere. New York, NY: Academic Press, 181, 184-185.

*Green DR, Le Pape D. 1987. Stability of hydrocarbon samples on solid-phase extraction columns. Anal Chem 59:699-703.

*Grey TC, Shrimpton DH. 1967. Volatile components of raw chicken breast muscle. Br Poult Sci 8:23-33.

8. REFERENCES

*Hassett JJ, Banwart WL, Griffin RA. 1983. Correlation of compound properties with sorption characteristics of nonpolar compounds by soils and sediments: Concepts and limitations. In: Francis CW, Auerbach SI, Jacobs VA, eds. Environment and solid wastes: Characterization, treatment, and disposal. Boston, MA: Butterworths, 161-176.

*Hawthorne SB, Sievers RE, Barkley RM. 1985. Organic emissions from shale oil wastewaters and their implications for air quality. Environ Sci Technol 19:992-997.

*Hewitt WR, Miyajima H, Cote MG, et al. 1980a. Acute alteration of chloroform-induced hepato- and nephrotoxicity by n-hexane, methyl n-butyl ketone and 2,5-hexanedione. Toxicol Appl Pharmacol 53:230-248.

*Hewitt WR, Miyajima H, Cote MG, et al. 1980b. Modification of haloalkane-induced hepatotoxicity by exogenous ketones and metabolic ketosis. Fed Proc 39:3118-3123.

*Hewitt WR, Brown EM, Plaa GL. 1983. Relationship between the carbon skeleton length of ketonic solvents and potentiation of chloroform-induced hepatotoxicity in rats. Toxicol Lett 16:297-304.

*Hewitt LA, Ayotte P, Plaa GL. 1986. Modifications in rat hepatobiliary function following treatment with acetone, 2-butanone, 2-hexanone, mirex, or chlordecone and subsequently exposed to chloroform. Toxicol Appl Pharmacol 83:465-473.

*HSDB. 1989. Hazardous Substances Data Bank. National Library of Medicine, National Toxicology Information Program, Bethesda, MD. September 5, 1989.

IRPTC. 1989. International Register of Potentially Toxic Chemicals. United Nations Environment Programme, Geneva, Switzerland. September 1989.

*Johnson BL, Setzer JV, Lewis TR, et al. 1977. Effects of methyl n-butyl ketone on behavior and the nervous system. Am Ind Hyg Assoc J 38:567-579.

Johnson BL, Setzer JV, Lewis TR, et al. 1978. An electrodiagnostic study of the neurotoxicity of methyl n-amyl ketone. Am Ind Hyg Assoc J 39:866-872.

Johnson BL, Anger WK, Setzer JV, et al. 1979. Neurobehavioral effects of methyl n-butyl ketone and methyl n-amyl ketone in rats and monkeys: A summary of NIOSH investigations. J Environ Pathol Toxicol 2:113-133.

*Katz GV, O'Donoghue JL, DiVincenzo GD, et al. 1980. Comparative neurotoxicity and metabolism of ethyl n-butyl ketone and methyl n-butyl ketone in rats. Toxicol Appl Pharmacol 52:153-158.

8. REFERENCES

*King JW. 1989. Fundamentals and applications of supercritical fluid extraction in chromatographic science. J Chromatogr Sci 27:355-364.

*Kinlin TE, Muralidhara R, Pittet AO, et al. 1972. Volatile components of roasted filberts. J Agr Food Chem 20:1021-1028.

Konasewich D, Traversy W, Zar H. 1978. Status report on organic and heavy metal contaminants in the Lakes Erie, Michigan, Huron and Superior basins. Great Lakes Water Quality Board.

*Krasavage WJ, O'Donoghue JL, DiVincenzo GD, et al. 1980. The relative neurotoxicity of methyl-n-butyl ketone, n-hexane and their metabolites. Toxicol Appl Pharmacol 52:433-441.

*Laity JL, Burstain IG, Appel BR. 1973. Photochemical smog and the atmospheric reactions of solvents. In: Tess RW, ed. Solvents theory and practice. Advances in Chemistry Series 124, Washington, DC: American Chemical Society, 95-112.

*Lande SS, Durkin PR, Christopher DE, et al. 1976. Investigation of selected potential environmental contaminants: Ketonic solvents. Washington, DC: U.S. Environmental Protection Agency, Office of Toxic Substances. EPA-560/2-76-003. NTIS No. TR 76-500.

*Lapin EP, Weissbarth S, Maker HS, et al. 1982. The sensitivities of creatine and adenylate kinases to the neurotoxins acrylamide and methyl n-butyl ketone. Environ Res 28:21-31.

Leo A, Hansch C, Elkins D. 1971. Partition coefficients and their uses. Chem Rev 71:525,563.

Lloyd AC. 1979. Tropospheric chemistry of aldehydes. Washington, DC: National Bureau of Standards. Special Publication No. 557.

*Lowery CE Jr., Foster JW, Jurtshuk P. 1968. The growth of various filamentous fungi and yeasts on n-alkanes and ketones: I. Studies on substrate specificity. Arch Mikrobiol 60:246-254.

*Lucas SV. 1984, GC/MS analysis of organics in drinking water concentrates and advanced waste treatment concentrates. Vol. 1. Analysis results for 17 drinking water, 16 advanced waste treatment and 3 process blank concentrates. Report to U.S. Environmental Protection Agency, Office of Research and Development, Research Triangle Park, NC, Battelle Columbus Laboratories, Columbus, OH. EPA-600/l-84-020a. NTIS No. PB85-128221.

*Lukins HB, Foster JW. 1963. Methyl ketone metabolism in hydrocarbonutilizing mycobacteria. J Bacterial 85:1074-1087.

8. REFERENCES

*Mabey WR, Smith JH, Pod011 RT, et al. 1982. Aquatic fate process data for organic priority pollutants. Report to U.S. Environmental Protection Agency, Office of Water Regulations and Standards, Washington, DC, by SRI International, Menlo Park, CA. EPA 440/4-81-014. NTIS No. PB87-169090.

*MacLeod H, Jourdain JL, Poulet G, et al. 1984. Kinetic study of reactions of some organic sulfur compounds with OH radicals. Atmos Environ 18:2621-2626.

Makkawy HM, Graham DG, Abou-Donia MB. 1981. Differential neuro toxicity of n - hexane methyl-E-butyl ketone, 2,5-hexanediol and 2,5-hexanedione following subchronic 90 days oral administration in hens. Fed Proc 40:678.

Mallov JS. 1976. MBK neuropathy among spray painters. J Am Med Assoc 235:1455-1457.

Mallov JS, Marceleno T, Fontaine R. 1975. Methyl n-butyl ketone and peripheral neuropathy: A summary report. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Division of Field Studies and Clinical Investigations. NTIS No. PB81-229981.

*Marceleno T, Bierbaum PJ, Mallov JS. 1974. Survey of Premium Finishes, Incorporated, Cincinnati, OH. Cincinnati, OH: National Institute for Occupational Safety and Health, Division of Field Studies and Clinical Investigations. NTIS No. PB81-242729.

McDonough JR. 1974. Possible neuropathy from methyl butyl ketone. N Engl J Med 290:695.

Mendell JR, Duckett S, Williams N, et al. 1974a. Neuropathy and methyl n-butyl ketone. N Engl J Med 290:1263-1264.

*Mendell JR, Saida K, Ganansia MF, et al. 1974b. Toxic polyneuropathy produced by methyl n-butyl ketone. Science 185:787-789.

Mendell JR, Sahenk Z, Saida K, et al. 1977. Alterations of fast axoplasmic transport in experimental methyl n-butyl ketone neuropathy. Brain Res 133:107-118.

Michael LC, Pellizzari ED, Wiseman RW. 1988. Development and evaluation of a procedure for determining volatile organics in water. Environ Sci Technol 22:565-570.

Misumi J, Nagano M. 1984. Neurophysiological studies on the relation between the structural properties and neurotoxicity of aliphatic hydrocarbon compounds in rats. Br J Ind Med 41:526-532.

8. REFERENCES

Misumi J, Nagano M. 1985. Experimental study on the enhancement of the neurotoxicity of methyl n-butyl ketone by non-neurotoxic aliphatic monoketones. Br J Ind Med 42:155-161.

*Morrison RT, Boyd RN. 1974. Organic chemistry. 3rd ed. Boston, MA: Allyn and Bacon, Inc., 620.

*Myers VB. 1983. Remedial activities at the Miami Drum site, Florida. In: National conference on management of uncontrolled hazardous waste sites. Silver Springs, MD: Hazardous Materials Control Research Institute, 354-357.

Nachtman JP, Couri D. 1984. An electrophysiological study of 2-hexanone and 2,5-hexanedione neurotoxicity in rats. Toxicol Lett 23:141-145.

*NAS/NRC. 1989. Biologic markers in reproductive toxicology. Washington, DC: National Academy of Sciences, National Research Council, National Academy Press.

*NATICH. 1989. National Air Toxics Information Clearinghouse: NATICH database report on state, local and EPA air toxics activities. Report to U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC, by Radian Corporation, Austin, TX. EPA-450/3-89-29.

*Neely WB, Branson DR, Blau GE. 1974. Partition coefficient to measure bioconcentration potential of organic chemicals in fish. Environ Sci Technol 8:1113-1115.

Nelson BK. 1986. Developmental neurotoxicology of in utero exposure to industrial solvents in experimental animals. Neurotoxicology 7:441-448.

NIOSH. 1978a. Criteria for a recommended standard: Occupational exposure to ketones. Cincinnati, OH: U.S. Department of Health, Education and Welfare, National Institute for Occupational Safety and Health. DHEW (NIOSH) Publication No. 78-173.

*NIOSH. 1978b. Criteria for a recommended standard: Occupational exposure in coal gasification plants. Cincinnati, OH: National Institute for Occupational Safety and Health. DHEW (NIOSH) Pub No. 78-191.

*NIOSH. 1984. Ketones I - method 1300. In: NIOSH manual of analytical methods. 3rd ed. Vol. 2. Cincinnati, OH: U.S. Department of Health and Human Services, National Institute for Occupational Safety and Health.

*NIOSH. 1985. Pocket guide to chemical hazards. Washington, DC: U.S. Department of Health and Human Services, National Institute for Occupational Safety and Health. DHHS (NIOSH) Publication No. 85-114.

8. REFERENCES

NIOSH. 1987. Organic solvent neurotoxicity. Cincinnati, OH: U.S. Department of Health and Human Services, National Institute for Occupational Safety and Health. Current Intelligence Bulletin 48. DHHS (NIOSH) Publication No. 87-104.

*NIOSH. 1989. National Occupational Exposure Survey. National Institute of Occupational Safety and Health, Cincinnati, OH. October 18, 1989.

*NLM , 1989. Chemline. National Library of Medicine, Bethesda, MD. September 1989.

*NOHS. 1989. National Occupational Hazard Survey. National Institute of Occupational Safety and Health, Cincinnati, OH. October 18, 1989.

*Nomeir AA, Abou-Donia MB. 1985. Analysis of D-hexane, 2-hexanone, 2,5-hexanedione, and related chemicals by capillary gas chromatography and high performance liquid chromatography. Anal Biochem 151:381-388.

*O'Donoghue, JL. 1985. Alkanes, alcohols, ketones, and ethylene oxide. In: O'Donoghue JL, ed. Neurotoxicity of industrial and commercial chemicals. Vol. II. Boca Raton, FL: CRC Press, Inc. 61-97.

O'Donoghue JL, Krasavage WJ, DiVincenzo GD, et al. 1984. Further studies on ketone neurotoxicity and interactions. Toxicol Appl Pharmacol 72:201-209.

O'Donoghue JL, Haworth SR, Curren RD, et al. 1988. Mutagenicity studies on ketone solvents: Methyl ethyl ketone, methyl isobutyl ketone, and isophorone. Mutat Res 206:149-161.

*OSHA. 1989. Occupational Safety and Health Administration: Part III. Federal Register 54:2940.

*Pankow JF, Rosen ME. 1988. Determination of volatile compounds in water by purging directly to a capillary column with whole column cryotrapping. Environ Sci Technol 22:398-405.

*Pellizzari ED, Castillo NP, Willis S, et al. 1979. Identification of organic components in aqueous effluents from energy-related processes. In: Van Hall CE, ed. Measurement of organic pollutants in water and wastewater. Philadelphia, PA: American Society for Testing and Materials, 256-274. ASTM Special Technical Publication No. 686.

*Perry JJ. 1968. Substrate specificity in hydrocarbon utilizing microorganisms. Antonie Van Leeuwenhoek 34:27-36.

8. REFERENCES

*Perry DL, Chuang CC, Jungclaus GA, et al. 1979. Identification of organic compounds in industrial effluent discharges. Athens, GA: U.S. Environmental Protection Agency, Office of Research and Development, Environmental Research Laboratory. EPA-600/4-79-016. PB-294794.

*Peters MA, Hudson PM, Dixon RL. 1981. The effect totigestational exposure to methyl n-butyl ketone has on postnatal development and behavior. Ecotoxicol Environ Safety 5:291-306.

Pilon D, Charbonneau M, Brodeur J, et al. 1986. Metabolites and ketone body production following methyl n-butyl ketone exposure as possible indices of MnBK potentiation of carbon tetrachloride hepatotoxicity. Toxicol Appl Pharmacol 85:49-59.

Politis MJ, Pellegrino RG, Spencer PS. 1980. Ultrastructural studies of the dying-back process. 5. Axonal neurofilaments accumulate at sites of 2,5-hexanedione application: Evidence for nerve fibre dysfunction in experimental hexacarbon neuropathy. [Abstract] J Neurocytol 9:505-516.

Prockop L, Couri D. 1977. Nervous system damage from mixed organic solvents. In: Sharp CW, ed. Review of inhalants: Euphoria to dysfunction. Washington, DC: U.S. Government Printing Office, 185-198.

Proctor NH, Hughes JP, Fischman ML. 1988. Chemical hazards of the workplace. 2nd edition. Philadelphia, PA: J. B. Lippincott Company, 324-325.

Puskar MA, Levine SP, Lowry SR. 1987. Qualitative screening of hazardous waste mixtures. Environ Sci Technol 21:90-96.

Raisbeck MF. 1984. Effects of 2-hexanone upon hepato- and nephrotoxicity of several haloalkanes and cephaloridine. Diss Abstr Int B 46:1083.

Raisbeck MF, Brown EM, Hewitt WR. 1986. Renal and hepatic interactions between 2-hexanone and carbon tetrachloride in F-344 rats. Toxicol Lett 31:15-21.

Raleigh RL, Spencer PS, Schaumburg HH. 1975. Toxicity of methyl- n-butyl ketone. Arch Environ Health 30:317-318.

Roy WR, Griffin RA. 1985. Mobility of organic solvents in water-saturated soil materials. Environ Geol Water Sci 7:241-247.

*Sabri MI. 1984. In vitro effect of n-hexane and its metabolites on selected enzymes in glycolysis, pentose phosphate pathway and citric acid cycle. Brain Res 297:145-150.

8. REFERENCES

Sabri MI, Moore CL, Spencer PS. 1979a. Studies on the biochemical basis of distal axonopathies-I. Inhibition of glycolysis by neurotoxic hexacarbon compounds. J Neurochem 32:683-689.

*Sabri MI, Ederle K, Holdsworth CE, et al. 1979b. Studies on the biochemical basis of distal axonipathies. II. Specific inhibition of fructose-6-phosphate kinase by 2,5-hexanedione and methyl-butyl ketone. Neurotoxicologly 1:285-297.

*Saida K, Mendell JR, Weiss HS. 1976. Peripheral nerve changes induced by methyl E-butyl ketone and potentiation by methyl ethyl ketone. Neuropathol Exp Neurol 35:207-225.

*Sate A, Nakaj ima T. 1979. Partition coefficients of some aromatic hydrocarbons and ketones in water, blood and oil. Br J Ind Med 36:231-234.

*Sax NI. 1984. Dangerous properties of industrial materials. 6th ed. New York: Van Nostrand Reinhold Company, 1526-1527.

*Sax NI, Lewis RJ Sr. 1987. Hawley's condensed chemical dictionary. 11th ed. New York: Van Nostrand Reinhold Company, 762.

Sayre LM, Shearson CM, Wongmongkolrit T, et al. 1986. Structural basis of gamma-diketone neurotoxicity: Non-neurotoxicity of 3,3-dimethyl-2,5-hexanedione, a gamma-diketone incapable of pyrrole formation. [Abstract] Toxicol Appl Pharmacol 84:36-44.

Schrenk HH, Yant WP, Patty FA. 1936. Acute response of guinea pigs to vapors of some new commercial organic compounds. Public Health Rep 51:624-631.

Selkoe DJ, Luckenbill-Edds L, Shelanski ML. 1978. Effects of neurotoxic industrial solvents on cultured neuroblastoma cells: Methyl n-butyl ketone, n-hexane and derivatives. J Neuropathol Exp Neurol 37:768-789.

*Shackelford WM, Keith LH. 1976. Frequency of organic compounds identified in water. Athens, GA: U.S. Environmental Protection Agency, Office of Research and Development. EPA-600/4-76-062. NTIS No. PB-165470.

Sharkawi M, Elfassy B. 1985. Inhibition of mouse liver alcohol dehydrogenase by methyl n-butyl ketone. Toxicol Lett 25:185-189.

*Smyth HF, Carpenter CP, Weil CS, et al. 1954. Range-finding toxicity data: List V. Arch Ind Hyg Occup Med 10:61-68.

Spector WS, ed. 1956. Lethal doses of solid and liquid compounds: Laboratory animals. In: Spector WS, ed. Handbook of Toxicology. Vol. I. Philadelphia, PA: W.B. Saunders and Company 5, 156-157, 321, 338-339.

8. REFERENCES

Spencer PS, Schaumburg HH. 1976. Feline nervous system response to chronic intoxication with commercial grades of methyl n-butyl ketone, methyl isobutyl ketone, and methyl ethyl ketone. Toxicol Appl Pharmacol 37:301-311.

Spencer PS, Schaumburg HH. 1977a. Ultrastructural studies of the dying-back process. III. The evolution of experimental peripheral giant axonal degeneration. J Neuropathol Exp Neurol 36:276-299.

*Spencer PS, Schaumburg HH. 1977b. Ultrastructural studies of the dying-back process. IV. Differential vulnerability of PNS and CNS fibers in experimental central-peripheral distal axonopathies. J Neuropathol Exp Neurol 36:300-320.

*Spencer PS, Schaumburg HH, Raleigh RL, et al. 1975. Nervous system degeneration produced by the industrial solvent methyl n-butyl ketone. Arch Neurol 32:219-222.

*Stutz DR, Janusz SJ. 1988. Hazardous materials injuries: A handbook for pre-hospital care. 2nd ed. Beltsville, MD: Bradford Communications Corporation, 312-313.

*Takeoka GR, Flath RA, Guntert M, et al. 1988. Nectarine volatiles: Vacuum steam distillation versus headspace sampling. J Agric Food Chem 36:553-560.

Thomas RD, ed. 1986. Drinking water and health. Vol. 6. Washington, DC: National Academy Press, 130.

Thorn P, Gardener H, Hrutfiord B. 1977. Odorous compounds from magnefite pulping. Pulp and Paper Canada 78:93-95.

TRI. 1989. Toxic Chemical Release Inventory. National Library of Medicine, National Toxicology Information Program, Bethesda, MD.

*Upreti RK, Shanker S. 1987. 2,5-Hexanedione-induced immunomodulatory effect in mice. Environ Res 43:48-59.

*Upreti RK, Singh KP, Saxena AK, et al. 1986. Effect of 2,5-hexanedione on lymphoid organs of rats: A preliminary report. Environ Res 39:188-198.

Vaishnav DD, Boethling RS, Babeu L. 1987. Quantitative structurebiodegradability relationships for alcohols, ketones and alicyclic compounds. Chemosphere 16:695-703.

Veronesi B, Peterson ER, Bornstein MB, et al. 1983. Ultrastructural studies of the dying-back process. VI. Examination of nerve fibers undergoing giant axonal degeneration in organotypic culture. J Neuropathol Exp Neurol 42:153-165. [Abstract]

8. REFERENCES

*Verschueren K. 1983. Handbook of environmental data on organic chemicals. 2nd ed. New York: Van Nostrand Reinhold Company, 320.

*View Database. 1989. Agency for Toxic Substances and Disease Registry (ATSDR), Office of External Affairs, Exposure and Disease Registry Branch, Atlanta GA. September 25, 1989.

*Weast RC, ed. 1985. CRC Handbook of chemistry and physics. Boca Raton, FL: CRC Press, Inc., C-307.

*West C. 1990. Written communication (March 5) to Barry L. Johnson, Agency for Toxic Substances and Disease Registry, regarding regulatory information of hazardous substances. Department of Environmental Quality Engineering, The Commonwealth of Massachusetts, Boston, MA.

*White EL, Bus JS, Heck HD. 1979. Simultaneous determination of n-hexane, 2-hexanone and 2,5-hexanedione in biological tissues by gas chromatography mass spectrometry. Biomed Mass Spectrum 6:169-172.

*Wieboldt RC, Adams GE, Later DW. 1988. Sensitivity improvement in infrared detection for supercritical fluid chromatography. Anal Chem 60:2422-2427.

*Windholz M, ed. 1983. The Merck index: An encyclopedia of chemicals, drugs, and biologicals. 10th ed. Rahway, NJ: Merck and Company, Inc., 5909.

9. GLOSSARY

Acute Exposure -- Exposure to a chemical for a duration of 14 days or less, as specified in the Toxicological Profiles.

Adsorption Coefficient (K_{oc}) -- The ratio of the amount of a chemical adsorbed per unit weight of organic carbon in the soil or sediment to the concentration of the chemical in solution at equilibrium.

Adsorption Ratio (K_d) -- The amount of a chemical adsorbed by a sediment or soil (i.e., the solid phase) divided by the amount of chemical in the solution phase, which is in equilibrium with the solid phase, at a fixed solid/solution ratio. It is generally expressed in micrograms of chemical sorbed per gram of soil or sediment.

Bioconcentration Factor (BCF) -- The quotient of the concentration of a chemical in aquatic organisms at a specific time or during a discrete time period of exposure divided by the concentration in the surrounding water at the same time or during the same period.

Cancer Effect Level (CEL) -- The lowest dose of chemical in a study, or group of studies, that produces significant increases in the incidence of cancer (or tumors) between the exposed population and its appropriate control.

Carcinogen -- A chemical capable of inducing cancer.

Ceiling Value -- A concentration of a substance that should not be exceeded, even instantaneously.

Chronic Exposure -- Exposure to a chemical for 365 days or more, as specified in the Toxicological Profiles.

Developmental Toxicity -- The occurrence of adverse effects on the developing organism that may result from exposure to a chemical prior to conception (either parent), during prenatal development, or postnatally to the time of sexual maturation. Adverse developmental effects may be detected at any point in the life span of the organism.

Embryotoxicity and Fetotoxicity -- Any toxic effect on the conceptus as a result of prenatal exposure to a chemical; the distinguishing feature between the two terms is the stage of development during which the insult occurred. The terms, as used here, include malformations and variations, altered growth, and in utero death.

EPA Health Advisory -- An estimate of acceptable drinking water levels for a chemical substance based on health effects information. A health advisory is not a legally enforceable federal standard, but serves as technical guidance to assist federal, state, and local officials.

9. GLOSSARY

Immediately Dangerous to Life or Health (IDLH) -- The maximum environmental concentration of a contaminant from which one could escape within 30 min without any escape-impairing symptoms or irreversible health effects.

Intermediate Exposure -- Exposure to a chemical for a duration of 15-364 days as specified in the Toxicological Profiles.

Immunologic Toxicity -- The occurrence of adverse effects on the immune system that may result from exposure to environmental agents such as chemicals.

In Vitro -- Isolated from the living organism and artificially maintained, as in a test tube.

In Viva -- Occurring within the living organism.

Lethal Concentration$_{(LO)}$ (LC$_{LO}$) -- The lowest concentration of a chemical in air which has been reported to have caused death in humans or animals.

Lethal Concentration$_{(50)}$ (LC$_{50}$) -- A calculated concentration of a chemical in air to which exposure for a specific length of time is expected to cause death in 50% of a defined experimental animal population.

Lethal Dose$_{(LO)}$ (LD$_{LO}$) -- The lowest dose of a chemical introduced by a route other than inhalation that is expected to have caused death in humans or animals.

Lethal Dose$_{(50)}$ (LD$_{50}$) -- The dose of a chemical which has been calculated to cause death in 50% of a defined experimental animal population.

Lethal Time$_{(50)}$(LT$_{50}$) -- A calculated period of time within which a specific concentration of a chemical is expected to cause death in 50% of a defined experimental animal population.

Lowest-Observed-Adverse-Effect Level (LOAEL) -- The lowest dose of chemical in a study or group of studies, that produces statistically or biologically significant increases in frequency or severity of adverse effects between the exposed population and its appropriate control.

Malformations -- Permanent structural changes that may adversely affect survival, development, or function.

Minimal Risk Level -- An estimate of daily human exposure to a chemical that is likely to be without an appreciable risk of deleterious effects (noncancerous) over a specified duration of exposure.

Mutagen -- A substance that causes mutations. A mutation is a change in the genetic material in a body cell. Mutations can lead to birth defects, miscarriages, or cancer.

9. GLOSSARY

Neurotoxicity -- The occurrence of adverse effects on the nervous system following exposure to chemical.

No-Observed-Adverse-Effect Level (NOAEL) -- The dose of chemical at which there were no statistically or biologically significant increases in frequency or severity of adverse effects seen between the exposed population and its appropriate control. Effects may be produced at this dose, but they are not considered to be adverse.

Octanol-Water Partition Coefficient (K_{ow}) -- The equilibrium ratio of the concentrations of a chemical in n-octanol and water, in dilute solution.

Permissible Exposure Limit (PEL) -- An allowable exposure level in workplace air averaged over an 8-hour shift.

q_{1^*} -- The upper-bound estimate of the low-dose slope of the dose-response curve as determined by the multistage procedure. The q_I^* can be used to calculate an estimate of carcinogenic potency, the incremental excess cancer risk per unit of exposure (usually pg/L for water, mg/kg/day for food, and pg/m3 for air).

Reference Dose (RfD) -- An estimate (with uncertainty spanning perhaps an order of magnitude) of the daily exposure of the human population to a potential hazard that is likely to be without risk of deleterious effects during a lifetime. The RfD is operationally derived from the NOAEL (from 'animal and human studies) by a consistent application of uncertainty factors that reflect various types of data used to estimate RfDs and an additional modifying factor, which is based on a professional judgment of the entire database on the chemical. The RfDs are not applicable to nonthreshold effects such as cancer.

Reportable Quantity (RQ) -- The quantity of a hazardous substance that is considered reportable under CERCLA. Reportable quantities are: (1) 1 lb or greater or (2) for selected substances, an amount established by regulation either under CERCIA or under Sect. 311 of the Clean Water Act. Quantities are measured over a 24-hour period.

Reproductive Toxicity -- The occurrence of adverse effects on the reproductive system that may result from exposure to a chemical. The toxicity may be directed to the reproductive organs and/or the related endocrine system. The manifestation of such toxicity may be noted as alterations in sexual behavior, fertility, pregnancy outcomes, or modifications in other functions that are dependent on the integrity of this system.

Short-Term Exposure Limit (STEL) -- The maximum concentration to which workers can be exposed for up to 15 min continually. No more than four excursions are allowed per day, and there must be at least 60 min between exposure periods. The daily TLV-TWA may not be exceeded.

9. GLOSSARY

Target Organ Toxicity -- This term covers a broad range of adverse effects on target organs or physiological systems (e.g., renal, cardiovascular) extending from those arising through a single limited exposure to those assumed over a lifetime of exposure to a chemical.

Teratogen -- A chemical that causes structural defects that affect the development of an organism.

Threshold Limit Value (TLV) -- A concentration of a substance to which most workers can be exposed without adverse effect. The TLV may be expressed as a TWA, as a STEL, or as a CL.

Time-weighted Average (TWA) -- An allowable exposure concentration averaged over a normal 8-hour workday or-40-hour workweek.

Toxic Dose (TD_{50}) -- A calculated dose of a chemical, introduced by a route other than inhalation, which is expected to cause a specific toxic effect in 50% of a defined experimental animal population.

Uncertainty Factor (UF) -- A factor used in operationally deriving the RfD from experimental data. UFs are intended to account for (1) the variation in sensitivity among the members of the human population, (2) the uncertainty in extrapolating animal data to the case of human, (3) the uncertainty in extrapolating from data obtained in a study that is of less than lifetime exposure, and (4) the uncertainty in using LOAEL data rather than NOAEL data. Usually each of these factors is set equal to 10.

APPENDIX A

USER'S GUIDE

Chapter 1

Public Health Statement

This chapter of the profile is a health effects summary written in nontechnical language. Its intended audience is the general public especially people living in the vicinity of a hazardous waste site or substance release. If the Public Health Statement were removed from the rest of the document, it would still communicate to the lay public essential information about the substance. The major headings in the Public Health Statement are useful to find specific topics of concern. The topics are written in a question and answer format. The answer to each question includes a sentence that will direct the reader to chapters in the profile that will provide more information on the given topic.

Chapter 2

Tables and Figures for Levels of Significant Exposure (LSE)

Tables (2-1, 2-2, and 2-3) and figures (2-l and 2-2) are used to summarize health effects by duration of exposure and endpoint and to illustrate graphically levels of exposure associated with those effects. All entries in these tables and figures represent studies that provide reliable, quantitative estimates of No-Observed-Adverse-Effect Levels (NOAELs), Lowest-Observed-Adverse-Effect Levels (LOAELs) for Less Serious and Serious health effects, or Cancer Effect Levels (CELs). In addition, these tables and figures illustrate differences in response by species, Minimal Risk Levels (MRLs) to humans for noncancer end points, and EPA's estimated range associated with an upper-bound individual lifetime cancer risk of 1 in 10,000 to 1 in 10,000,000. The LSE tables and figures can be used for a quick review of the health effects and to locate data for a specific exposure scenario. The LSE tables and figures should always be used in conjunction with the text.

The legends presented below demonstrate the application of these tables and figures. A representative example of LSE Table 2-l and Figure 2-l are shown. The numbers in the left column of the legends correspond to the numbers in the example table and figure.

LEGEND

See LSE Table 2-l

(1) Route of Exposure One of the first considerations when reviewing the toxicity of a substance using these tables and figures should be the relevant and appropriate route of exposure. When sufficient data exist,

three LSE tables and two LSE figures are presented in the document. The three LSE tables present data on the three principal routes of exposure, i.e., inhalation, oral, and dermal (LSE Table 2-1, 2-2, and 2-3, respectively). LSE figures are limited to the inhalation (LSE Figure 2-l) and oral (LSE Figure 2-2) routes.

(2). Exoosure Duration Three exposure periods: acute (14 days or less); intermediate (15 to 364 days); and chronic (365 days or more) are presented within each route of exposure. In this example, an inhalation study of intermediate duration exposure is reported.

(3). Health Effect The major categories of health effects included in LSE tables and figures are death, systemic, immunological, neurological, developmental, reproductive, and cancer. NOAELs and LOAELs can be reported in the tables and figures for all effects but cancer. Systemic effects are further defined in the "System" column of the LSE table.

(4). Key to Figure Each key number in the LSE table links study information to one or more data points using the same key number in the corresponding LSE figure. In this example, the study represented by key number 18 has been used to define a NOAEL and a Less Serious LOAEL (also see the two "18r" data points in Figure 2-l).

(5). Species The test species, whether animal or human, are identified in this column.

(6). Exposure Frequency/Duration The duration of the study and the weekly and daily exposure regimen are provided in this column. This permits comparison of NOAELs and LOAELs from different studies. In this case (key number la), rats were exposed to [substance x] via inhalation for 13 weeks, 5 days per week, for 6 hours per day.

(7). System This column further defines the systemic effects. These systems include: respiratory, cardiovascular, gastrointestinal, hematological, musculoskeletal, hepatic, renal, and dermal/ocular. "Other" refers to any systemic effect (e.g., a decrease in body weight) not covered in these systems. In the example of key number 18, one systemic effect (respiratory) was investigated in this study.

(8). NOAEL A No-Observed-Adverse-Effect Level (NOAEL) is the highest exposure level at which no harmful effects were seen in the organ system studied. Key number 18 reports a NOAEL of 3 ppm for the respiratory system which was used to derive an intermediate exposure, inhalation MRL of 0.005 ppm (see footnote "c").

(9) LOAEL A Lowest-Observed-Adverse-Effect Level (LOAEL) is the lowest exposure level used in the study that caused a harmful health effect. LOAELs have been classified into "Less Serious" and "Serious" effects. These,,distinctions help readers identify the levels of exposure at which adverse health effects first appear and the gradation of effects with increasing dose. A brief description of the specific end point used to

quantify the adverse effect accompanies the LOAEL. The "Less Serious" respiratory effect reported in key number 18 (hyperplasia) occurred at a LOAEL of 10 ppm.

(10) Reference The complete reference citation is given in Chapter 8 of the profile.

(11) CEL A Cancer Effect Level (CEL) is the lowest exposure level associated with the onset of carcinogenesis in experimental or epidemiological studies. CELs are always considered serious effects. The LSE tables and figures do not contain NOAELs for cancer, but the text may report doses which did not cause a measurable increase in cancer.

(12) Footnotes . Explanations of abbreviations or reference notes for data in the LSE tables are found in the footnotes. Footnote "c" indicates the NOAEL of 3 ppm in key number 18 was used to derive an MRL of 0.005 ppm.

LEGEND

See LSE Figure 2-l

LSE figures graphically illustrate the data presented in the corresponding LSE tables. Figures help the reader quickly compare health effects according to exposure levels for particular exposure duration.

(13) Exposure Duration The same exposure periods appear as in the LSE table. In this example, health effects observed within the intermediate and chronic exposure periods are illustrated.

(14) Health Effect These are the categories of health effects for which reliable quantitative data exist. The same health effects appear in the LSE table.

(15) Levels of Exposure Exposure levels for each health effect in the LSE tables are graphically displayed in the LSE figures. Exposure levels are reported on the log scale "y" axis. Inhalation exposure is reported in mg]m3 or ppm and oral exposure is reported in mg/kg/day.

(16) NOAEL In this example, 18r NOAEL is the critical end point for which an intermediate inhalation exposure MRL is based. As you can see from the LSE figure key, the open-circle symbol indicates a NOAEL for the test species (rat). The key number 18 corresponds to the entry in the LSE table. The dashed descending arrow indicates the extrapolation from the exposure level of 3 ppm (see entry 18 in the Table) to the MRL of 0.005 ppm (see footnote "b" in the LSE table).

(17) CEL Key number 38r is one of three studies for which Cancer Effect Levels (CELs) were derived. The diamond symbol refers to a CEL for the test species (rat). The number 38 corresponds to the entry in the LSE table.

APPENDIX A

(18). Estimated Upper-Bound Human Cancer Risk Levels This is the range associated with the upper-bound for lifetime cancer risk of 1 in 10,000 to 1 in 10,000,000. These risk levels are derived from EPA's Human Health Assessment Group's upper-bound estimates of the slope of the cancer dose response curve at low dose levels (q_1*).

(19). Key to LSE Figure The Key explains the abbreviations and symbols used in the figure.

SAMPLE

1 → TABLE 2-1. Levels of Significant Exposure to [Chemical x] - Inhalation

Key to figure[a]	Species	Exposure frequency/ duration	System	NOAEL (ppm)	LOAEL (effect) Less serious (ppm)	LOAEL (effect) Serious (ppm)	Reference
2 → INTERMEDIATE EXPOSURE							
3 → Systemic	5 ↓	6 ↓	7 ↓	8 ↓	9 ↓		10 ↓
4 → 18	Rat	13 wk 5d/wk 6hr/d	Resp	3[b]	10 (hyperplasia)		Nitschke et al. 1981
CHRONIC EXPOSURE							
Cancer					11 ↓		
38	Rat	18 mo 5d/wk 7hr/d			20 (CEL, multiple organs)		Wong et al. 1982
39	Rat	89-104 wk 5d/wk 6hr/d			10 (CEL, lung tumors, nasal tumors)		NTP 1982
40	Mouse	79-103 wk 5d/wk 6hr/d			10 (CEL, lung tumors, hemangiosarcomas)		NTP 1982

[a] The number corresponds to entries in Figure 2-1.

12 → [b] Used to derive an intermediate inhalation Minimal Risk Level (MRL) of 5×10^{-3} ppm; dose adjusted for intermittent exposure and divided by an uncertainty factor of 100 (10 for extrapolation from animal to humans, 10 for human variability).

CEL = cancer effect level; d = day(s); hr = hour(s); LOAEL = lowest-observed-adverse-effect level; mo = month(s); NOAEL = no-observed-adverse-effect level; Resp = respiratory; wk = week(s)

SAMPLE

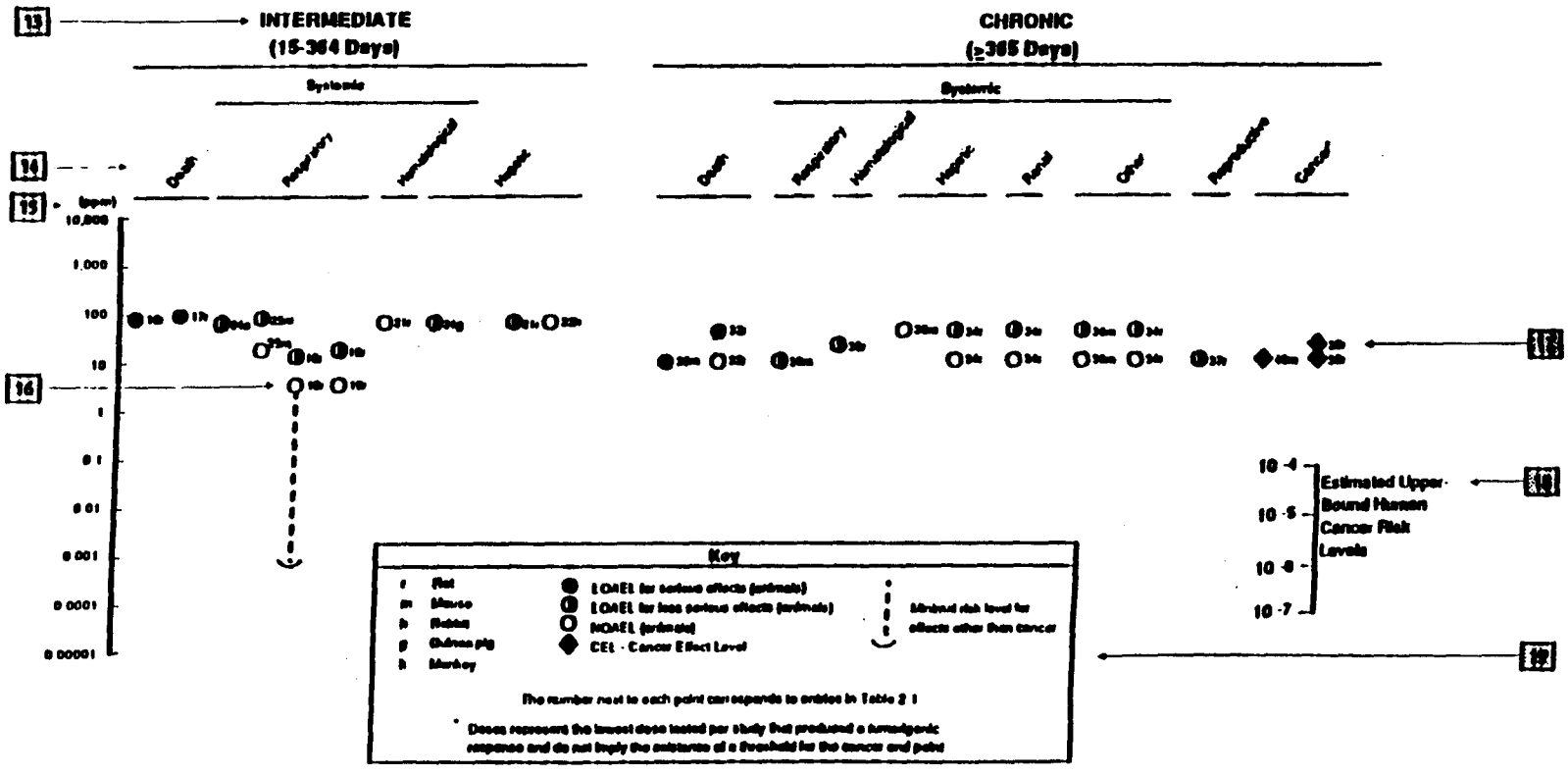


FIGURE 2-1. Levels of Significant Exposure to [Chemical X]-Inhalation

APPENDIX A

Chapter 2 (Section 2.4)

Relevance to Public Health

The Relevance to Public Health section provides a health effects summary based on evaluations of existing toxicological, epidemiological, and toxicokinetic information. This summary is designed to present interpretive, weight-of-evidence discussions for human health end points by addressing the following questions.

1. What effects are known to occur in humans?

2. What effects observed in animals are likely to be of concern to humans?
3. What exposure conditions are likely to be of concern to humans, especially around hazardous waste sites?

The section discusses health effects by end point. Human data are presented first, then animal data. Both are organized by route of exposure (inhalation, oral, and dermal) and by duration (acute, intermediate, and chronic). In vitro data and data from parenteral routes (intramuscular, intravenous, subcutaneous, etc.) are also considered in this section. If data are located in the scientific literature, a table of genotoxicity information is included.

The carcinogenic potential of the profiled substance is qualitatively evaluated, when appropriate, using existing toxicokinetic, genotoxic, and carcinogenic data. ATSDR does not currently assess cancer potency or perform cancer risk assessments. MRLs for noncancer end points if derived, and the end points from which they were derived are indicated and discussed in the appropriate
section(s).

Limitations to existing scientific literature that prevent a satisfactory evaluation of the relevance to public health are identified in the Identification of Data Needs section.

Interpretation of Minimal Risk Levels

Where sufficient toxicologic information was available, MRLs were derived. MRLs are specific for route (inhalation or oral) and duration (acute, intermediate, or chronic) of exposure. Ideally, MRLs can be derived from all six exposure scenarios (e.g., Inhalation - acute, -intermediate, -chronic; Oral - acute, - intermediate, - chronic). These MRLs are not meant to support regulatory action, but to aquaint health professionals with exposure levels at which adverse health effects are not expected to occur in humans. They should help physicians and public health officials determine the safety of a community living near a substance emission, given the concentration of a contaminant in air or the estimated daily dose received via food or water. MRLs are based largely on toxicological studies in animals and on reports of human occupational exposure.

APPENDIX A

MRL users should be familiar with the toxicological information on which the number is based. Section 2.4, "Relevance to Public Health," contains basic information known about the substance. Other sections such as 2.6, "Interactions with Other Chemicals" and 2.7, "Populations that are Unusually Susceptible" provide important supplemental information.

MRL users should also understand the MRL derivation methodology. MRLs are derived using a modified version of the risk assessment methodology used by the Environmental Protection Agency (EPA) (Barnes and Dourson, 1988; EPA 1989a) to derive reference doses (RfDs) for lifetime exposure.

To derive an MRL, ATSDR generally selects the end point which, in its best judgement, represents the most sensitive humanhealth effect for a given exposure route and duration. ATSDR cannot make this judgement or derive an MRL unless information (quantitative or qualitative) is available for all potential effects (e.g., systemic, neurological, and developmental). In order to compare NOAELs and LOAELs for specific end points, all inhalation exposure levels are adjusted for 24hr exposures and all intermittent exposures for inhalation and oral routes of intermediate and chronic duration are adjusted for continous exposure (i.e., 7 days/week). If the information and reliable quantitative data on the chosen end point are available, ATSDR derives an MRL using the most sensitive species (when information from multiple species is available) with the highest NOAEL that does not exceed any adverse effect levels. The NOAEL is the most suitable end point for deriving an MRL. When a NOAEL is not available, a Less Serious LOAEL can be used to derive an MRL, and an uncertainty factor (UF) of 10 is employed. MRLs are not derived from Serious LOAELs. Additional uncertainty factors of 10 each are used for human variability to protect sensitive subpopulations (people who are most susceptible to the health effects caused by the substance) and for interspecies variability (extrapolation from animals to humans). In deriving an MRL, these individual uncertainty factors are multiplied together. The product is then divided into the adjusted inhalation concentration or oral dosage selected from the study. Uncertainty factors used in developing a substance-specific MRL are provided in the footnotes of the LSE Tables.

APPENDIX B

ACRONYMS, ABBREVIATIONS, AND SYMBOLS

ACGIH	American Conference of Governmental Industrial Hygienists
ADME	Absorption, Distribution, Metabolism, and Excretion
ATSDR	Agency for Toxic Substances and Disease Registry
BCF	bioconcentration factor
BSC	Board of Scientific Counselors
CDC	Centers for Disease Control
CEL	Cancer Effect Level
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CLP	Contract Laboratory Program
cm	centimeter
CNS	central nervous system
DHEW	Department of Health, Education, and Welfare
DHHS	Department of Health and Human Services
DOL	Department of Labor
ECG	electrocardiogram
EEG	electroencephalogram
EPA	Environmental Protection Agency
EKG	see ECG
FAO	Food and Agricultural Organization of the United Nations
FEMA	Federal Emergency Management Agency
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
f_1	first generation
fpm	feet per minute
ft	foot
FR	Federal Register
g	gram
GC	gas chromatography
HPLC	high performance liquid chromatography
hr	hour
IDLH	Immediately Dangerous to Life and Health
IARC	International Agency for Research on Cancer
ILO	International Labor Organization
in	inch
Kd	adsorption ratio
kg	kilogram
Koc	octanol-soil partition coefficient
Kow	octanol-water partition coefficient
L	liter
LC	liquid chromatography
LC_{Lo}	lethal concentration low
LC_{50}	lethal concentration 50 percent kill
LD_{Lo}	lethal dose low
LD_{50}	lethal dose 50 percent kill
LOAEL	lowest-observed-adverse-effect level

APPENDIX B

LSE	Levels of Significant Exposure
m	meter
mg	milligram
min	minute
mL	milliliter
mm	millimeters
mmol	millimole
mppcf	millions of particles per cubic foot
MRL	Minimal Risk Level
MS	mass spectroscopy
NIEHS	National Institute of Environmental Health Sciences
NIOSH	National Institute for Occupational Safety and Health
NIOSHTIC	NIOSH's Computerized Information Retrieval System
nm	nanometer
ng	nanogram
NHANES	National Health and Nutrition Examination Survey
nmol	nanomole
NOAEL	no-observed-adverse-effect level
NOES	National Occupational Exposure Survey
NOHS	National Occupational Hazard Survey
NPL	National Priorities List
NRC	National Research Council
NTIS	National Technical Information Service
NTP	National Toxicology Program
OSHA	Occupational Safety and Health Administration
PEL	permissible exposure limit
pg	picogram
pmol	picomole
PHS	Public Health Service
PMR	proportional mortality ratio
ppb	parts per billion
ppm	parts per million
ppt	parts per trillion
REL	recommended exposure limit
RfD	Reference Dose
RTECS	Registry of Toxic Effects of Chemical Substances
sec	second
SCE	sister chromatid exchange
SIC	Standard Industrial Classification
SMR	standard mortality ratio
STEL	short-term exposure limit
STORET	STORAGE and RETRIEVAL
TLV	threshold limit value
TSCA	Toxic Substances Control Act
TRI	Toxic Release Inventory
TWA	time-weighted average
U.S.	United States
UF	uncertainty factor

APPENDIX B

WHO	World Health Organization
>	greater than
≥	greater than or equal to
=	equal to
<	less than
≤	less than or equal to
%	percent
α	alpha
β	beta
δ	delta
γ	gamma
μm	micron
μg	microgram

APPENDIX C

PEER REVIEW

A peer review panel was assembled for 2-hexanone. The panel consisted of the following members: Dr. Richard J. Bull, Associate Professor, Department of Pharmacology and oxicology, Washington State University, Pullman, Washington; Dr. Anthony DeCaprio, Private Consultant, Albany, New York; Dr. Theodore Mill, Director, Physical Organic Chemistry Department, SRI International, Menlo Park, California. A second panel of reviewers was assembled to review the sections on mitigation of effects. This panel consisted of: Dr. Brent Burton, Medical Director, Oregon Poison Center, Oregon Health Sciences University, Portland, Oregon; Dr. Alan Hall, Private Consultant, Evergreen, Colorado; and Dr. Alan Woolf, Director of Clinical Pharmacology and Toxicology, Massachusetts Poison Control System, The Children's Hospital, Boston, Massachusetts. These experts collectively have knowledge of 2-hexanone's physical and chemical properties, toxicokinetics, key health end points, mechanisms of action, human and animal exposure, and quantification of risk to humans. All reviewers were selected in conformity with the conditions for peer review specified in Section 104(i)(13) of the Comprehensive Environmental Response, Compensation, and Liability Act, as amended.

Scientists from the Agency for Toxic Substances and Disease Registry (ATSDR) have reviewed the peer reviewers' comments and determined which comments will be included in the profile. A listing of the peer reviewers' comments not incorporated in the profile, with a brief explanation of the rationale for their exclusion, exists as part of the administrative record for this compound. A list of databases reviewed and a list of unpublished documents cited are also included in the administrative record.

The citation of the peer review panel should not be understood to imply its approval of the profile's final content. The responsibility for the content of this profile lies with the ATSDR.