

criteria for a recommended standard....

**OCCUPATIONAL EXPOSURE
TO
ALKANES
(C5—C8)**



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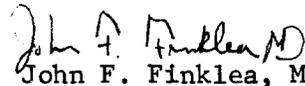
PREFACE

The Occupational Safety and Health Act of 1970 emphasizes the need for standards to protect the health and safety of workers exposed to an ever-increasing number of potential hazards at their workplace. The National Institute for Occupational Safety and Health has projected a formal system of research, with priorities determined on the basis of specified indices, to provide relevant data from which valid criteria for effective standards can be derived. Recommended standards for occupational exposure, which are the result of this work, are based on the health effects of exposure. The Secretary of Labor will weigh these recommendations along with other considerations such as feasibility and means of implementation in developing regulatory standards.

It is intended to present successive reports as research and epidemiologic studies are completed and as sampling and analytical methods are developed. Criteria and standards will be reviewed periodically to ensure continuing protection of the worker.

I am pleased to acknowledge the contributions to this report on alkanes (C5-C8) by members of the NIOSH staff and the valuable constructive comments by the Review Consultants on Alkanes (C5-C8), by the ad hoc committees of the American Industrial Hygiene Association and the American Occupational Medical Association and by Robert B. O'Connor, M.D., NIOSH

consultant in occupational medicine. The NIOSH recommendations for standards are not necessarily a consensus of all the consultants and professional societies that reviewed this criteria document on alkanes. A list of Review Consultants appears on page vi.


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The Division of Criteria Documentation and Standards Development, National Institute for Occupational Safety and Health, had primary responsibility for development of the criteria and recommended standard for alkanes (C5-C8). The division review staff for this document consisted of Richard A. Rhoden, Ph.D., Chairman, Keith H. Jacobson, Ph.D., and Victor E. Archer, M.D. (Division of Surveillance, Hazard Evaluations, and Field Studies), with Charles C. Hassett, Ph.D., and Seymour D. Silver, Ph.D. Stanford Research Institute (SRI) developed the basic information for consideration by NIOSH staff and consultants under contract No. CDC-99-74-31. Patricia G. Heitman served as criteria manager.

The views expressed and conclusions reached in this document, together with the recommendations for a standard, are those of NIOSH, after review of the evidence and considering the comments of reviewers; these views and conclusions are not necessarily those of the consultants, other federal agencies, and professional societies, or of the contractor.

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CRITERIA DOCUMENT:
RECOMMENDATIONS FOR AN OCCUPATIONAL
EXPOSURE STANDARD FOR ALKANES (C5-C8)

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I. RECOMMENDATIONS FOR AN ALKANES (C5-C8) STANDARD

The National Institute for Occupational Safety and Health (NIOSH) recommends that employee exposure to pentane, hexane, heptane, and octane in the workplace be controlled by adherence to the following sections. The standard is designed to protect the health and safety of employees for up to a 10-hour work shift in a 40-hour workweek over a working lifetime. Compliance with all sections of the standard should prevent adverse effects of pentane, hexane, heptane, and octane on the health and safety of employees. Sufficient technology exists to permit compliance with the recommended standard. Although the workplace environmental limits are considered to be safe levels based on current information, they should be regarded as the upper boundaries of permissible exposure and every effort should be made to maintain the exposure as low as is technically feasible. The criteria and standard will be subject to review and revision as necessary.

These criteria and the recommended standard apply to exposure of workers to alkanes which are aliphatic hydrocarbons with the empirical formula $C(n) H(2n+2)$ where $n = 5, 6, 7, \text{ or } 8$. These alkanes are hereinafter referred to as pentane, hexane, heptane, and octane, respectively. The prefix "n-" will be used to refer to the straight chain isomeric form of an alkane, eg, n-pentane. An alkane without the "n-" prefix is a mixture of isomeric forms, unless otherwise designated.

"Action level" is defined as an airborne time-weighted average (TWA) concentration of 200 milligrams per cubic meter of air (mg/cu m) of these alkanes for up to a 10-hour work shift in a 40-hour workweek.

"Occupational exposure" to alkanes is defined as exposure above the action level. Exposure at lower concentrations will not require adherence to the following sections of the standard except sections 3a, 4a, 4b, 5a, 6, and 7a.

Section 1 - Environmental (Workplace Air)

(a) Workplace Environmental Limits

Occupational exposure to airborne C5-C8 alkanes shall be controlled so that no employee is exposed at concentrations greater than 350 mg/cu m as a TWA concentration for up to a 10-hour work shift in a 40-hour workweek. This concentration is equivalent to about 120 parts of pentane per million parts of air (ppm), 100 ppm of hexane, 85 ppm of heptane, or 75 ppm of octane. If an employee is exposed to a mixture of C5-C8 alkanes, total alkane exposure shall not be greater than 350 mg/cu m. In addition, no employee shall be exposed to individual C5-C8 alkanes or mixtures of these alkanes at ceiling concentrations greater than 1,800 mg/cu m as determined over a sampling time of 15 minutes. This concentration is equivalent to about 610 ppm pentane, 510 ppm hexane, 440 ppm heptane, or 385 ppm octane.

(b) Sampling and Analysis

Procedures for the collection of workplace environmental samples shall be as provided in Appendix I, or by any method shown to be at least as efficient. Analysis of samples shall be performed as provided in Appendix II or by any methods shown to be at least equivalent in precision, sensitivity, and accuracy.

Section 2 - Medical

Medical surveillance shall be made available as outlined below to all workers subject to occupational exposure to alkanes (C5-C8).

(a) Preplacement examinations shall include at least:

(1) Comprehensive medical and work histories with special emphasis toward conditions affecting the peripheral and central nervous systems and skin.

(2) Physical examination giving particular attention to general tests of nervous system function and evidence of skin conditions.

(3) An evaluation of the worker's ability to use positive and negative pressure respirators.

(b) Periodic examinations shall be made available on at least an annual basis. These examinations shall include at least:

(1) Interim medical and work histories.

(2) Physical examination as outlined in (a)(2) and (3) above.

(c) During examinations, applicants or employees having medical conditions which would be directly or indirectly aggravated by exposure to alkanes shall be counseled on the increased risk of impairment of their health from working with these substances.

(d) Initial medical examinations shall be made available to all workers within 6 months after the promulgation of a standard based on these recommendations.

(e) Pertinent medical records shall be maintained for all employees exposed to alkanes in the workplace. Such records shall be kept for at least 30 years after termination of employment. These records shall

be made available to the designated medical representatives of the Secretary of Health, Education, and Welfare, of the Secretary of Labor, and of the employer, employee, or former employee.

Section 3 - Labeling and Posting

(a) Containers of substances which comprise 10% or more alkanes shall bear the following label in addition to, or in combination with, labels required by other statutes, regulations, or ordinances:

CONTAINS ALKANES

WARNING! HIGHLY FLAMMABLE

Keep away from sparks and open flame.
In case of fire, use foam, dry chemical, or carbon dioxide fire extinguisher.
In case of spill, flush area with water spray.
Use with adequate ventilation.
Avoid prolonged or repeated breathing of vapor.
Repeated exposure may produce nerve damage.
Avoid contact with eyes.
Do not take internally.

First Aid: In case of eye contact, flush with plenty of water. Call a physician.

(b) Areas where there is occupational exposure to pentane, hexane, heptane, octane, or mixtures of these, and areas where there is bulk storage of alkanes shall be posted with signs reading:

ALKANE NAME (eg, PENTANE)

WARNING! HIGHLY FLAMMABLE

Avoid heat, sparks, and open flames.
No smoking permitted.
In case of fire, use fire extinguishers located at (location).
Avoid breathing vapor.
Avoid contact with skin, eyes, and clothing.

These warning signs shall be printed both in English and in the predominant language of non-English-reading employees. All employees shall be trained and informed of the hazardous areas, with special instructions given to illiterate employees and to those reading only languages other than those used on labels and posted signs.

Section 4 - Personal Protective Equipment and Clothing

(a) Eye Protection

Full-facepiece respirators, safety glasses, or chemical safety goggles shall be provided and worn by workers during those operations in which pentane, hexane, heptane, or octane may splash into the eyes. Face shields may be used to augment chemical safety goggles and safety glasses where full facial protection is needed, but face shields are not adequate for eye protection when used alone. Eye protective equipment shall be selected and used in accordance with 29 CFR 1910.133.

(b) Respiratory Protection

Engineering controls shall be used wherever feasible to maintain alkane concentrations below the recommended environmental limits. Compliance with the permissible exposure limit by the use of respirators is allowed only while required engineering controls are being installed or tested, when nonroutine maintenance or repair is being accomplished, or during emergencies. When a respirator is thus permitted, it shall be selected and used in accordance with the following requirements:

(1) For the purpose of determining the type of respirator to be used, the employer shall measure, when possible, the concentration of the airborne alkane or mixture of alkanes in the workplace both initially

and thereafter whenever process, worksite, or control changes occur which are likely to result in increases in the alkane concentrations; this requirement does not apply when only atmosphere-supplying positive pressure respirators are used.

(2) The employer shall ensure that no worker is exposed to alkanes at concentrations in excess of the workplace environmental limits because of improper respirator selection, fit, use, or maintenance.

(3) A respiratory protection program meeting the requirements of 29 CFR 1910.134 shall be established and enforced by the employer.

(4) The employer shall provide respirators in accordance with Table I-1 and shall ensure that the employees use the respirators provided.

(5) Respiratory protective devices described in Table I-1 shall be those approved under the provisions of 30 CFR 11.

(6) Respirators specified for use in higher concentrations of alkanes may be used in atmospheres of lower concentrations.

(7) The employer shall ensure that respirators are cleaned, maintained, and stored in accordance with 29 CFR 1910.134.

(8) The employer shall ensure that employees are instructed on the use of respirators assigned to them and on how to test for leaks.

(9) Each area where posting is required in accordance with Section 3(b) shall have emergency respiratory protective devices readily available in nearby locations which do not require entry into a contaminated atmosphere for access. Respiratory protective devices provided shall consist of at least two self-contained breathing apparatus

TABLE I-1

RESPIRATOR SELECTION GUIDE FOR ALKANES (C5-C8)

Concentration of Alkanes	Respirator Type Approved Under Provisions of 30 CFR 11
Less than or equal to 3,500 mg/cu m	Chemical cartridge respirator with half-mask or full facepiece and organic vapor cartridge
Less than or equal to 12,500 mg/cu m	(1) Gas mask with chin-style or front- or back-mounted organic vapor canister and full facepiece (2) Supplied-air respirator with full facepiece, helmet, hood, or suit operated in continuous-flow, demand (negative pressure), or pressure-demand mode (positive pressure)
Less than or equal to 17,500 mg/cu m	Self-contained breathing apparatus operated in demand mode (negative pressure) with full facepiece
Greater than 17,500 mg/cu m	(1) Self-contained breathing apparatus with full facepiece operated in pressure-demand or other positive pressure mode (2) Combination Type C supplied-air respirator with full facepiece operated in the pressure-demand or other positive pressure mode and an auxiliary self-contained air supply operated in the pressure-demand or other positive pressure mode
Emergency (entry into an area of unknown concentration for emergency purposes)	(1) Self-contained breathing apparatus with full facepiece operated in the pressure-demand or other positive pressure mode (2) Combination Type C supplied-air respirator with full facepiece operated in the pressure-demand or other positive pressure mode and an auxiliary self-contained air supply operated in the pressure-demand or other positive pressure mode
Escape (from an area of unknown concentration)	(1) Any gas mask providing protection against organic vapors (2) Any self-contained breathing apparatus

as described in Table I-1. Well-ventilated outdoor locations where egress and escape are unhindered may be exempted from this requirement.

(c) Skin Protection

The employer shall provide protective apparel, including gloves, aprons, suits, boots, or face shields (8-inch minimum) with goggles, and ensure that they are worn where needed to prevent skin contact with liquid alkanes. Protective apparel shall be made of materials which most effectively prevent skin contact under the conditions for which it is deemed necessary. Rubber articles may be used provided care is taken to ensure that permeation does not occur during usage. Protective apparel should be discarded at the first sign of deterioration.

Section 5 - Informing Employees of Hazards from Alkanes

(a) At the beginning of employment, employees shall be informed of the presence of alkanes in the workplace, including the trade-name substances, if any, that contain alkanes, the hazards, signs and symptoms of overexposure, emergency procedures including first aid, and precautions to take to ensure safe use and to minimize exposure. This information shall also be posted in the workplace and kept on file, readily accessible to all employees.

(b) The employer shall institute a continuing education program, conducted by persons qualified by experience or special training, to ensure that all employees occupationally exposed to alkanes shall have current knowledge of job hazards, proper maintenance procedures, cleanup methods, and proper use of protective clothing and equipment, including respirators. In addition, employees and members of emergency teams who work adjacent to

alkane systems or containers where a potential for emergencies exists shall participate in periodic drills simulating emergencies appropriate to the work situation. Drills shall be held at intervals not greater than 6 months. Drills should cover, but should not be limited to:

- Evacuation procedures.
- Handling of spills and leaks, including decontamination.
- Location and use of emergency firefighting equipment, and handling of alkane systems and containers in case of fire.
- First-aid and rescue procedures, including prearranged procedures for obtaining emergency medical care.
- Location, use, and care of protective apparel and respiratory protective equipment.
- Location of shutoff valves or switches.
- Location, purpose, and use of safety showers, eyewash fountains, and other sources of water for emergency use.
- Operating procedures, including communication procedures.
- Entry procedures for confined spaces.

Deficiencies noted during drills shall be included in a continuing educational program, together with the required remedial actions. Records of drills and training conducted shall be kept for 1 year and made available for inspection by authorized personnel. Information as required shall be recorded on the "Material Safety Data Sheet" shown in Appendix III or on a similar form approved by the Occupational Safety and Health Administration, US Department of Labor, and shall be filed in a location readily accessible to employees.

Section 6 - Work Practices

Alkanes present significant fire hazards. Therefore, appropriate regulations for Class IA or Class IB flammable liquids as provided in 29 CFR 1910.106 shall be followed.

(a) Control of Airborne Alkanes

Engineering controls, such as process enclosure or local exhaust ventilation, shall be used to maintain airborne alkane concentrations at or below the recommended environmental limits. All such control equipment shall meet the requirements of subpart S of 29 CFR 1910 for hazardous locations. Ventilation systems, if used, shall be designed and operated to minimize the accumulation or recirculation of airborne alkanes in the workplace and to effectively decrease the concentrations of airborne alkanes to safe levels in the breathing zones of employees. Exhaust ventilation systems discharging into outside air must conform with applicable local, state, and federal air pollution regulations and must not constitute a hazard. Ventilation systems shall be subject to regular preventive maintenance and cleaning to ensure effectiveness, which shall be verified by airflow measurements taken at least quarterly.

(b) Sources of Ignition

(1) Precautions shall be taken to prevent the ignition of alkanes or, in the case of engines, torches, or other devices fueled by alkanes, to control their ignition.

(2) Workplaces in which explosive concentrations of alkane vapors may develop shall meet provisions for Class I, Division 2, of the National Electric Code as required by 29 CFR 1910.309.

(3) Where spark- and flame-generating operations are necessary, they shall be started only after an authorized representative of the employer signs a permit declaring the operation to be safe. This should be done only after a calibrated combustible-gas meter or other suitable instrument indicates that the concentration of alkane vapors is

less than 10% of the lower explosive limit.

(4) Alkanes in bulk quantities may not be dispensed into metal containers unless the nozzle and the container are electrically bonded. The container and the nozzle shall be grounded properly as required by 29 CFR 1910.106.

(5) Smoking shall be prohibited in alkane work and storage areas.

(c) Loading and Unloading

(1) Safety showers and eyewash fountains, as well as fire extinguishers containing chemicals approved for Class B fires, shall be installed in bulk loading and unloading areas. Safety showers, eyewash fountains, and fire extinguishers shall be checked to ensure that they are in working order before alkanes are loaded or unloaded.

(2) If a leak in an alkane container occurs during the loading or unloading process, the operation shall be stopped and resumed only after necessary repair or replacement has been completed.

(3) Bonding facilities for protection against sparks from discharge of static charge during the loading of tank vehicles shall be provided as required by 29 CFR 1910.106.

(d) Storage

Containers shall be stored in accordance with the applicable provisions of 29 CFR 1910.106 and shall be protected from heat, mechanical damage, and sources of ignition.

(e) Disposal

Spills shall be flushed with water. Where it is not possible to flush a spill with water, the area should be cordoned off and ventilated

until it is cleaned by other means, such as a venturi-type vacuum system.

(f) Vessel Entry

(1) Entry into confined spaces, such as tanks, pits, tank cars, and process vessels which have contained alkanes, shall be controlled by a permit system. Permits shall be signed by an authorized employer representative, certifying that preparation of the confined space, precautionary measures, and personal protective equipment are adequate, and that prescribed procedures will be followed.

(2) Confined spaces which have contained alkanes shall be thoroughly ventilated, cleaned, washed, inspected, and tested for oxygen deficiency and for the presence of alkanes and other contaminants prior to entry.

(3) All efforts shall be made to prevent inadvertent release of alkanes into the confined space while work is in progress. Alkane supply lines shall be disconnected and blocked off while such work is in progress.

(4) Confined spaces shall be ventilated while work is in progress to keep airborne alkane concentrations at or below the recommended environmental limits and to prevent oxygen deficiency.

(5) Individuals entering confined spaces where they may be exposed to alkanes shall wear respirators as outlined in Section 4(b) and lifelines tended by another worker outside the space who shall also be equipped with the necessary protective equipment.

(g) Emergency Procedures

For all work areas where a reasonable potential for emergencies exists, procedures as specified below, as well as any other procedures

appropriate for a specific operation or process, shall be formulated in advance and employees shall be instructed in their implementation:

(1) Procedures shall include prearranged plans for obtaining emergency medical care, for necessary transportation of injured employees, and for general evacuation.

(2) Firefighting procedures shall be established. These shall include procedures for emergencies involving release of alkane vapors. In case of fire, alkane sources shall be shut off or removed. Alkane containers shall be removed or cooled with water spray. Chemical foam, carbon dioxide, or dry chemicals shall be used for fighting alkane fires, and proper respiratory protective devices and protective attire shall be worn.

(3) Approved eye, skin, and respiratory protective devices, as specified in Section 4, shall be used by personnel involved in the emergency operations.

(4) Employees not essential for emergency operations shall be evacuated from exposure areas during emergencies. The perimeters of hazardous exposure areas shall be delineated, posted, and secured.

(5) Only personnel properly trained in the relevant procedures and adequately protected against the attendant hazards shall shut off sources of alkanes, clean up spills, and repair leaks.

(6) Eyewash fountains and emergency showers shall be provided in accordance with 29 CFR 1910.151.

(7) Warning or alarm systems shall be considered to warn workers of possible hazardous exposures to alkanes during emergencies involving release of alkane vapors.

Section 7 - Monitoring and Recordkeeping Requirements

(a) Survey Requirements

Workers are not considered to have occupational exposure to alkanes if environmental concentrations, as determined on the basis of an industrial hygiene survey, do not exceed the action level. Surveys shall be repeated at least once a year and within 30 days after any process change likely to result in increases of airborne alkane concentrations. Records of these surveys, including the basis for concluding that airborne concentrations of alkanes are at or below the action level, shall be maintained. If there is occupational exposure to alkanes, then the following requirements apply:

(b) Personal Monitoring

(1) A program of personal monitoring shall be instituted to identify and measure, or permit calculation of, the exposures of all employees who are occupationally exposed to alkanes. Monitoring of employee exposures to airborne alkanes shall be conducted at least every 6 months. If monitoring of an employee's exposure to an alkane or a mixture of alkanes reveals that he is exposed at concentrations in excess of either recommended environmental limit, control measures shall be initiated, the employee shall be notified of his exposure and the control measures being implemented to correct the situation, and the exposure of that employee shall be measured at least once every 30 days. Such monitoring shall continue until two consecutive samplings, at least a week apart, indicate that the employee's exposure no longer exceeds the environmental limit stated in Section 1(a). Semiannual monitoring may then be resumed.

(2) In all personal monitoring, samples of airborne alkanes shall be collected which, when analyzed, will provide an accurate representation of the concentration of an alkane or a mixture of alkanes in the air breathed by the worker. Procedures for sampling and analysis of alkanes shall be as provided in Appendices I and II, or by any method shown to be at least equivalent in precision, accuracy, and sensitivity to the methods specified.

(3) For each TWA determination, a sufficiently large number of samples shall be taken to characterize every employee's exposure during each work shift. Variations in work and production schedules shall be considered in deciding when and how many samples are to be collected. The number of representative TWA determinations for an operation or process shall be based on the variations in location and job functions of employees in relation to that operation or process.

(c) Recordkeeping

Records of environmental monitoring shall be kept by the employer for at least 30 years. These records shall include the dates of measurements, job function and location of the employees at the worksite, sampling and analytical methods used, number, duration, and results of the samples taken, TWA concentrations estimated from these samples, type of personal protective equipment used, and exposed employees' names. Each employee shall have access to information on his or her own environmental exposures. Environmental records shall be made available to designated representatives of the Secretary of Labor, and of the Secretary of Health, Education, and Welfare. Pertinent medical records shall be retained by the employer for 30 years after termination of employment. Records of environmental

exposures applicable to an employee should be included in that employee's medical records. These medical records shall be made available to the designated medical representatives of the Secretary of Labor, of the Secretary of Health, Education, and Welfare, of the employer, and of the employee or former employee.

II. INTRODUCTION

This report presents the criteria and the recommended standard based thereon which were prepared to meet the need for preventing occupational disease and injury arising from workplace exposure to pentane, hexane, heptane, or octane. The criteria document fulfills the responsibility of the Secretary of Health, Education, and Welfare under Section 20(a)(3) of the Occupational Safety and Health Act of 1970 to "...develop criteria dealing with toxic materials and harmful physical agents and substances which will describe...exposure levels at which no employee will suffer impaired health or functional capacities or diminished life expectancy as a result of his work experience."

The National Institute for Occupational Safety and Health (NIOSH), after a review of data and consultation with others, formalized a system for the development of criteria on which standards can be established to protect the health of employees from exposure to hazardous chemical and physical agents. Criteria and recommended standards should enable management and labor to develop better engineering controls resulting in more healthful work environments. Mere compliance with the recommended standard should not be used as a final goal.

These criteria for a standard for alkanes are part of a continuing series of criteria developed by NIOSH. The recommended standard applies to the processing, manufacture, and handling of these alkanes in products as applicable under the Occupational Safety and Health Act of 1970. The standard was not designed for the population-at-large, and any extrapolation beyond occupational exposures is not warranted. It is

intended to (1) protect against the development of acute and chronic alkane (C5-C8) poisoning, (2) be measurable by techniques that are available to industry and official agencies, and (3) be attainable with existing technology.

Although the neurologic effects of exposure to airborne hexane have been documented and some experimental and epidemiologic studies have been conducted to determine the effects of exposure to hexane at various concentrations, at the present time, limited data exist to present a definitive correlation between hexane exposure concentrations and acute and chronic effects observed in humans or animals. There are even fewer data concerning the relationships between concentrations of pentane, heptane, or octane and the observed effects. Further research is needed to determine (1) the nature of these relationships, (2) the mechanisms of toxic action of these alkanes, (3) if additive or synergistic effects occur when humans or animals are exposed to mixtures of these alkanes, (4) how the toxicities of the normal forms of the alkanes and the toxicities of their isomeric forms are related, and (5) whether or not any of these alkanes produce carcinogenic, mutagenic, or teratogenic effects.

The alkanes reviewed in this criteria document and included in the recommended standard are the straight- or branched-chain saturated aliphatic hydrocarbons containing from five to eight carbon atoms. In practice, alkanes are available as mixtures of two or more isomers; the data reviewed in this criteria document are based on human and animal exposures to such mixtures, often incompletely characterized as to their components. The recommended standard is based on the conclusion that acute intoxication by these alkanes involves a transient central nervous system

depression and that chronic intoxication may involve a more persistent effect, polyneuropathy. Polyneuropathy has usually been attributed to n-hexane, but exposures to n-hexane alone have not been described, and the recommended standard is based on the belief that this neuropathy can be caused by other alkanes and their isomers as well. It might be reasoned, by analogy with the metabolism of straight-chain fatty acids or with the biologic degradation of straight-chain versus branched-chain alkyl benzene sulfonates (detergents), that only straight-chain or straight-chain alkanes with even numbers of carbon atoms could cause polyneuropathy. It might also be interpreted, from the limited evidence on metabolism of n-hexane presented in Chapter III, that only n-hexane among the C5-C8 alkanes could cause polyneuropathy. Should sufficient evidence be developed that this is the case, the TWA limit of 350 mg/cu m of total alkanes recommended in this document might be considered for revision in the case of those substances not causing polyneuropathy.

III. BIOLOGIC EFFECTS OF EXPOSURE

Extent of Exposure

Pentane, hexane, heptane, and octane are members of a homologous series of aliphatic hydrocarbons with the empirical formula $C(n)H(2n+2)$. The molecular formula for each alkane in this series can be determined by setting $n = 5, 6, 7, \text{ or } 8$. A complete listing of the alkane isomers included in this series is presented in Table XII-1. At room temperature, these four classes of alkanes are colorless, neutral liquids with a light petroleum odor. Additional physical properties of n-pentane, n-hexane, n-heptane, and n-octane are presented in Table XII-2 [1]. Physical properties of alkane isomers are presented in Table XII-3 [2-4].

Pentane, hexane, heptane, and octane are produced almost exclusively from crude petroleum by catalytic cracking [5], thermal cracking [5], hydrocracking [6], and catalytic reforming [5-8]. In the processes of catalytic and thermal cracking, high molecular weight hydrocarbons are broken down at high temperatures either with or without a catalyst into lower molecular weight mixtures. During the process of hydrocracking, high molecular weight hydrocarbons are broken down with hydrogen at high pressures and temperatures without a catalyst. In catalytic reforming, high molecular weight hydrocarbons are passed over a platinum catalyst at elevated temperatures in the presence of high pressure hydrogen to produce lower molecular weight mixtures which are then separated by distillation into high-purity fractions that include pentane, hexane, heptane, and octane. One-third of the pentane produced in the United States comes from another source, fractional condensation of natural gas [9]. Natural gas in

the United States contains an average of 0.4% pentane by volume [10].

The estimated US production of n-pentane and methylbutane (isopentane) in 1967 was 310,000 and 449,000 barrels/day, respectively [11]. This is equivalent to approximately 13 million gallons/day of n-pentane and 19 million gallons/day of methylbutane [11]. In 1974, the US Tariff Commission reported an annual production of 358,341,000 pounds (approximately 66 million US gallons) of hexane [9]. No production estimates were found for heptane or octane.

Alkanes are used in a variety of industrial applications and processes. A major use of pentane is in the formulation of gasoline [12]. Hexane is used commercially as a solvent in glues, varnishes, cements, and other products such as inks [13-15]. It is also used in the seed oil industry to extract the natural oils from various seeds, including soybeans and cottonseed [16]. Heptane and octane are used principally as solvents and to some extent in the formulation of gasoline [14,15].

A number of occupations with potential exposure to pentane, hexane, heptane, and octane are listed in Table XII-5 [11-15,17-24,26-31,118]. NIOSH estimates that 10,000 workers in the United States are potentially exposed to pentane and heptane and 300,000 workers are potentially exposed to octane. It is not clear if these estimates take into account fuel handling operations. NIOSH estimates that 2.5 million workers are potentially exposed to hexane.

Historical Reports

Early reports of exposures to pentane, hexane, heptane, and octane dealt, in most instances, with mixtures of alkanes rather than with pure

substances. For example, in 1942, Drinker et al [32] exposed volunteers to petroleum distillate. Ninety percent of the distillate boiled between 42 and 127 C, a range that included hexane in addition to several other components. A group of eight women ranging in age from 17 to 32 years was exposed to distillate vapor at a concentration of 140 ppm. Another group of 10 women ranging in age from 17 to 22 years was exposed to distillate vapor at a concentration of 150 ppm. The exposures were for 8 hours in a static chamber. The volunteers exposed at both concentrations complained of nausea, headache, and throat and eye irritation.

In 1942, Nelson et al [33] exposed volunteer groups which contained an average of 10 men and women to hexane at various vapor concentrations for 3-5 minutes. The purity of the hexane used for the study was not described. The authors [33] stated that hexane at a concentration of 500 ppm was quite "innocuous" to the volunteers (on short exposures). This was the lowest concentration investigated.

Pentane, hexane, and heptane were at one time investigated for use as anesthetics [12], but they produced undesirable side effects such as respiratory irritation and central nervous system inhibition leading to respiratory arrest [12,32,34,35]. In 1936, Henderson and Smith [35] compared the lethal and anesthetic concentrations of hexane in rats. They [35] found that exposure to hexane at a concentration of approximately 7% (70,000 ppm) was necessary to produce anesthesia, but at this concentration some rats also experienced respiratory arrest.

Effects on Humans

(a) Nervous System

Yamada [17], in 1972, investigated the cases of 17 workers who had reported symptoms of polyneuropathy while exposed to hexane vapor from 1960 to 1962 in Japan. Six of the workers were employed in small polyethylene-laminating plants where hexane was vaporized into the workroom air; the concentration of hexane vapor released during the process was 1,000-2,500 ppm. Symptoms of intoxication began in one worker after 1.5 months of exposure. The methods used to determine these vapor concentrations were not described. The hexane solvent used in these plants contained 16% methyl pentane, 20% methyl cyclopentane, and 64% n-hexane.

Eleven of the 17 employees worked in a pharmaceutical plant where a mixture containing 95% n-hexane was used to remove oil from the surfaces of tablets. The tablets were placed on wire netting, immersed in the n-hexane, removed, and then air-dried. The concentrations of n-hexane around the immersion box and in the center of the workroom were 1,000 ppm and 500 ppm, respectively. The first complaints, noticed within 1 month of exposure, were fatigue and loss of appetite, followed within 1-9 months by paresthesia in distal parts of the extremities, exhaustion, and difficulty in walking so severe that the employees' work and manner of living were affected. Within 6-18 months, muscular atrophy was so severe that the employees were hospitalized. As the cause of the malady was not recognized, exposures had continued. Yamada [17] therefore concluded that all of the workers had developed polyneuropathy because of exposure to hexane. He reported that the progress of the disease was arrested about 3 months after the termination of exposure to hexane and that gradual

recovery took place over periods extending from 6 to 30 months, according to the reports of department physicians.

In 1971, Herskowitz et al [13] described the effects of hexane vapor on three female employees who worked in a furniture factory in New York. The three employees worked in a poorly ventilated room, 3.6 x 3.6 meters, that contained an open 189-liter drum of n-hexane solvent. Their jobs included dipping rags into the open drum and wiping excess glue from finished cabinets. Air sampling indicated that they were exposed to n-hexane at concentrations in the air which averaged 650 ppm and peaked at 1,300 ppm. They first noticed symptoms 2-4 months after beginning work and were hospitalized 6-10 months later, when they complained of one or more of the following symptoms: headache; burning sensation of the face; abdominal cramps; numbness, paresthesia, and weakness of the distal extremities. Physical examination revealed bilateral foot-drop gait, bilateral wrist drop, and absence of Achilles tendon reflexes. Electromyographic examination revealed fibrillation potentials in the small muscles of the hands and feet, and nerve conduction studies showed decreased conduction time in the motor and sensory nerves of the arms and legs, indicating peripheral nerve damage. Biopsies were made of the anterior tibial muscle and sural nerves of two of the patients. The muscles contained small angulated fibers and other fibers with clear central zones (denervation-type injury). Small bundles of axons from the muscle sections were studied by electron microscopy and found to contain dense bodies and fibrous formations, increased numbers of neurofilaments, and abnormal membranous structures with clumped and degenerated mitochondria. Motor-end plates were also damaged, having swollen terminal axoplasmic expansions, an

increased number of degenerated mitochondria, and an increased number of glycogen granules, dense bodies, large osmiophilic membranes, synaptic folds and vesicles. The sural nerve sections were normal under light microscopy, but electron microscopy revealed dense bodies and many mitochondria in some myelinated axons. No information was provided concerning the recoveries of the patients from the effects of hexane.

Gaultier et al [36], in 1973, reported polyneuropathy in five individuals employed in a belt-manufacturing shop in Paris. The solvent used in this shop contained only 5% hexane; however, it also contained 14% heptane and 80% pentane. The symptoms in the three patients treated by the authors were anorexia, asthenia, paresthesia, fatigue, and bilateral, symmetrical muscle failure found mostly in the legs. Electromyographic and nerve conduction studies revealed the presence of diffuse, symmetrical peripheral nerve changes, such as slowed motor nerve conduction rates and signs of denervation in the legs. The authors [36] reported that recuperation was slow and, in one case, was still incomplete after 20 months. No information was given about the two individuals not treated by the authors.

In 1974, Yoshida et al [24] reported the electrophysiologic evaluations of four patients with peripheral polyneuropathy resulting from exposure to hexane. Electromyography indicated that fibrillation, fasciculation, and positive sharp waves were seen in the muscle tests on all patients. Motor nerve conduction velocity in the median, ulnar, and tibial nerves was reduced. Conduction velocity in sensory fibers of the finger-to-wrist segment of the median nerve was slowed in all patients and was diminished in the wrist-to-elbow segment as well. The somatosensory

evoked potentials were prolonged in three of the four patients who were examined. The electroencephalogram was normal in all four patients. The knee-jerk and Achilles tendon reflexes were absent and muscular atrophy was present, especially in the finger, pelvic girdle, lower leg, and foot muscles. The sensations of touch and heat were diminished. Microscopic examination of nerve and muscle biopsy specimens revealed abnormalities in both. The authors [24] diagnosed acute polyneuropathy from these observations.

In 1969, Yamamura [37] reported an outbreak of polyneuropathy resulting from exposure to hexane that was used as a glue solvent in sandal production in Japan. In 1967, it had been discovered that two workers had quadriplegia. Following this discovery, a 6-month epidemiologic investigation was initiated. Of 1,662 workers checked by questionnaire, 296 whose answers indicated the possible existence of neuropathy received medical examinations. Of these 296 workers, 93 (31%) were found to have polyneuropathy. All the patients with polyneuropathy had been engaged in the gluing process of sandal production. Manufacturing the sandals was a household industry where all production took place in the workers' homes. The dwellings were poorly ventilated, and many workers labored for more than 8 hours/day. The organic solvent used in the rubber glue was analyzed by gas chromatography and found to contain at least 70% n-hexane with a small amount of toluene. The concentrations of hexane in the air of the pasting rooms of the dwellings ranged from 500 to 2,500 ppm. The age of those with polyneuropathy ranged from 10 to 75 years and averaged 40 years. Of the 93 persons affected, 21 were males and 72 were females. The initial symptoms of the disease included sensory impairment in the distal portion

of the extremities in 82 workers (88%) and muscular weakness in 13 (14%). Some of those with polyneuropathy also experienced cold sensations of the extremities, blurred vision, headache, easy fatigability, anorexia, and weight loss at the time of onset of the disease. The symptoms and signs at the time of medical examination are summarized in Table III-1 [37].

The 93 patients were divided into three groups on the basis of the severity of neuropathic involvement [37]. Group I contained those with sensory polyneuropathy (53 patients); clinical examinations were performed on 11 patients. Group II contained those with sensorimotor polyneuropathy (32 patients); clinical examinations were performed on 25 patients. Group III contained those with sensorimotor polyneuropathy with amyotrophy (8 patients); clinical examinations were performed on all 8 patients. The results of the clinical examinations are summarized in Table III-2 [37]. The author did not mention a control population.

Muscle biopsies were made on the anterior tibial muscles of three of the patients in group III [37]. Light-microscopic examination showed fatty degeneration of the muscle fibers, diminution of fiber size, and slight proliferation of the sarcolemmal nuclei. In a transverse section, all muscle fibers appeared atrophic, while diminution of size varied randomly. Biopsies were made of peripheral nerves of six other patients in groups II and III. The peripheral nerves of one patient showed demyelination with the appearance of fat granules. The axons were destroyed in part of the demyelinated areas but, in five of the six patients, the axonal degeneration was mild compared with the demyelination. Yamamura [37] suggested that the exposure to hexane had resulted in demyelination and axonal degeneration, with demyelination being generally more pronounced.

TABLE III-1

SIGNS AND SYMPTOMS IN 93 SANDAL-
PRODUCTION WORKERS EXPOSED TO HEXANE

Signs and Symptoms	No. of Cases	% of Total
Numbness	93	100.0
Coldness, redness, roughness of skin	55	59.2
Muscular weakness	40	43.0
Hypoactive reflexes	36	38.7
Dysesthesia	21	22.6
Emaciation	14	15.1
Blurred vision	13	14.0
Hyperactive reflexes	10	10.8
Muscular atrophy	8	8.6
Visual field constriction	7	7.5
Loss of sense of smell	5	5.4
Face numbness	5	5.4
Pain or tenderness	5	5.4
Anemia	3	3.3
Optic nerve atrophy	2	2.2
Facial muscle weakness	2	2.2
Optic nerve inflammation	1	1.1
Urination disturbance	1	1.1

Adapted from reference 37

TABLE III-2

CLINICAL FINDINGS IN SANDAL-
PRODUCTION WORKERS EXPOSED TO HEXANE

Laboratory Findings	Group*			Subtotal*
	I	II	III	
Urine:				
sugar content elevated	0/11	2/25	0/7	2/43
protein content elevated	1/11	0/25	0/7	1/43
urobilinogen content elevated	3/11	8/25	5/7	16/43
coproporphyrin content elevated	1/11	3/24	0/6	4/41
Blood:				
erythrocyte count <3,500,000/cu mm**	0/11	0/25	1/7	1/43
hemoglobin content <11 g/100 ml**	4/11	0/25	1/7	5/43
leukocyte count <4,000/cu mm**	0/11	0/25	1/7	1/43
>10,000/cu mm**	2/11	2/25	2/7	6/43
total protein content <6.5 g/100 ml**	0/11	0/25	1/8	1/44
albumin content <4.0 g/100 ml**	2/11	1/25	2/8	5/44
cholesterol content <150 mg/100 ml**	0/11	8/25	2/7	10/43
>250 mg/100 ml	1/11	0/25	0/7	1/43
thymol turbidity >4**	2/11	0/25	0/7	2/43
cephalin-cholesterol flocculation elevated	5/11	4/25	0/6	9/42
SGOT activity elevated	0/11	0/25	0/8	0/44
SGPT activity elevated	0/11	0/25	0/7	0/43
LDH activity elevated	3/11	10/25	4/6	17/42

TABLE III-2 (CONTINUED)

CLINICAL FINDINGS IN SANDAL-
PRODUCTION WORKERS EXPOSED TO HEXANE

Laboratory Findings	Group*			Subtotal*
	I	II	III	
creatine phosphokinase activity elevated	0/0	0/0	1/3	1/3
cholinesterase activity inhibited	6/11	18/25	2/6	26/42
serum test for syphilis (VDRL)	0/11	0/25	0/8	0/44
Cerebrospinal fluid:				
abnormal pressure	0/0	0/3	0/4	0/7
cell number >5/cu mm**	0/0	0/3	0/4	0/7
protein content >40 mg/100 ml**	0/0	0/3	1/4	1/7
globulin content elevated	0/0	0/3	0/4	0/7

*Number of people with abnormal findings/number of people examined

**Limits of normal values used by the authors for comparison

Adapted from reference 37

Although a positive urobilinogen reaction and positive cephalin-cholesterol flocculation tests were obtained in some cases, the normal values for serum transaminase activity were interpreted by the author as an indication that there was little likelihood of liver damage. He considered the depressed cholinesterase activity found in some of the patients as being possibly the result of factors extraneous to exposure to hexane, but it also could have been indicative of liver damage. No other data have been found which correlate hexane exposure with depressed cholinesterase activity or liver damage.

In 1973, Iida et al [38] published a followup investigation of the 93 Japanese sandal workers with polyneuropathic disturbances previously studied by Yamamura [37]. Iida et al [38] divided the patients into the same three groups defined in the earlier study. Yamamura [37] had reported that there were 8 patients in group III (sensorimotor polyneuropathy with amyotrophy), 32 in group II (sensorimotor polyneuropathy), and 53 in group I (sensory polyneuropathy). Iida et al [38] found that 2 years after the original study, there had been sufficient improvement so that no patients remained in group III, 5 were classified in group II, and 34 were classified in group I. A total of 51 patients had recovered. By 1972, there were 7 patients in group I, and 82 (92%) of the original 93 had recovered completely. Four patients were lost to the study; however, only one death (from stomach cancer) was reported.

Inoue et al [18], in 1970, published the results of an analysis of the hexane solvent in the glue used by the sandal makers who were studied by Yamamura [37]. Because of chronic benzene intoxication in vinyl-sandal manufacturing workers, benzene had been replaced approximately 10 years earlier by hexane as a glue solvent [18]. Gas-chromatographic analysis [18] indicated that the solvent contained 2-methylpentane, 3-methylpentane, methylcyclopentane, and n-hexane. The concentrations of individual constituents were not given. The authors [18] stated that most commercial hexane solvents contain these four compounds, with n-hexane constituting about 60% of the total. They [18] also reported that each dwelling where sandal workers had developed polyneuropathy was inspected, and single measurements of airborne hexane were made. The type of equipment used for

these measurements was not described. The reported results, although of limited value statistically, suggested that some workers classified as having group I or group II polyneuropathy may have developed polyneuropathy as a result of being exposed to n-hexane at concentrations below 500 ppm.

In 1976, Abbritti et al [39] reported an investigation of 122 Italian workers who developed polyneuropathy while working in shoe factories during the period of 1971-1974. All workers were interviewed and given electromyographic examinations in addition to other unspecified laboratory examinations to determine if other types of exposure were present that could cause polyneuropathy. Clinical and electromyographic details were not provided. In none of the observed cases was there evidence of contact with any other chemicals which might have caused polyneuropathy. The ages of the workers ranged from 15 to 59 years and averaged 35 years. Most of the symptoms of polyneuropathy were found in those who worked directly with solvents in gluing and cleaning processes. A high proportion of these were women. Polyneuropathy occurred most commonly in workers in small factories with fewer than 20 employees. Work was often done in small rooms at ground level or in basements with poor ventilation. The glue containers were left open during working hours. Even those not working directly with glues or solvents were exposed to solvent vapor at high concentrations; however, no exposure concentration data were reported for any of the factories. Analysis of the solvents and glues used in shoe factories in which 20 workers developed polyneuropathy indicated that they contained 79-95% alkanes including isopentane, n-pentane, 2-methylpentane, 3-methylpentane, n-hexane, iso-heptane, and n-heptane, although not all of these were present in each. These products also contained up to 18% cyclopentane,

methyl cyclopentane, or cyclohexane, and, in some cases, up to 3% toluene. The polyneuropathy reported by the authors was first thought to be caused by triorthocresyl phosphate [40], but numerous chemical analyses of glues and leathers taken from factories where the disease occurred showed that, in most instances, little or no triorthocresyl phosphate was present. They also stated that it was not clear whether one particular alkane was responsible for the development of neurotoxicity, or whether it was caused by the combined action of several alkanes.

In 1929, Patty and Yant [41] investigated the odor intensities and the symptoms produced by commercial pentane, hexane, and heptane. Analysis of the commercial materials showed that the pentane contained 1.3% butane, 20.8% isopentane, 76.5% n-pentane, and 1.4% hexane by volume. The commercial hexane sample contained nearly 100% hexanes, roughly one-third of which was believed to be composed of n-hexane. Although no analysis was performed for benzene, the authors [41] felt that the sample probably contained a trace of benzene because small quantities of aromatics had been found to distill over into hexane fractions during purification. The heptane sample was composed largely of isomers of n-heptane (about 75%). No further clarification of the composition of this isomeric fraction was given. The sulfur content of the samples was measured, since it would influence the odor intensity of the fraction. No analysis for sulfur was performed on the pentane sample; however, a later sample, prepared in a similar manner, did not show the presence of sulfur. A laboratory determination using the Kennedy lamp method, which is a turbidimetric method [42] of analysis, showed no sulfur in the hexane sample. Analysis of the heptane sample indicated a sulfur content of 0.004% by weight. The

authors [41] considered this high, since analysis of other heptane samples indicated the absence of sulfur. Groups of three to six volunteers were exposed to the vapor of each of the three alkanes at various concentrations in a 1,000-cubic foot static chamber. They were instructed to make independent notes on odor intensity and on symptoms at 2-minute intervals throughout the period of vapor introduction and for about 10 minutes afterward. These experiments were designed to simulate cases of continuous exposure. Tests were also conducted in which subjects were exposed to various concentrations and asked to note immediate effects. These experiments were designed to simulate the effect of entering existing contaminated atmospheres.

In the chamber, pentane, hexane, or heptane was allowed to drip from a buret onto a piece of cotton gauze suspended in front of a fan. The concentration of the vapor in the chamber was computed from the quantity of material introduced; it was also checked periodically by sampling and analysis. The method used for determining the vapor concentration in the chamber was not described.

In another series of tests, groups of volunteers were exposed to samples of pentane, hexane, and heptane that were purified by successive treatment with alkaline permanganate, water, concentrated sulfuric acid, and, finally, sodium hydroxide. The purified products were then distilled and a middle distillate with a temperature range of 3-4 C was collected to produce what was termed "purified grade." Purification of the commercial solvents markedly reduced the odor intensity. The physiologic responses, except for odor, produced by the commercial products were not found to differ from those of the purified samples.

No symptoms were noted after exposure to pentane at concentrations up to 5,000 ppm for 10 minutes. Exposure to hexane at 5,000 ppm caused marked vertigo after 10 minutes but heptane at a concentration of only 1,000 ppm caused slight vertigo after 6 minutes of exposure [41]. Exposure to heptane at 5,000 ppm resulted in marked vertigo, inability to walk straight, and hilarity after 4 minutes, and similar signs and symptoms, including incoordination, after 7 minutes. Although it was not clear from the study whether these effects resulted from exposure to the alkanes at concentrations which slowly increased to the reported levels, or from exposure at constant concentrations, these results indicated that the alkane concentration required to produce physiologic response decreased as the number of carbon atoms in the compound increased. The authors concluded that both odor intensity and physiologic response increased markedly in humans upon exposure to alkanes with increasing numbers of carbon atoms.

(b) Skin

In 1936, Oettel [43] studied the effects of liquid alkanes on the intact skin of five human volunteers. Circular glass dishes, 1 cm in diameter, were filled with undiluted hexane, heptane, or octane and were loosely attached to the anterior surface of each subject's forearm for 1 hour. Open glass rods were used to administer pentane; this allowed for the release of the vaporized sample. Blister-inducing properties were also investigated by attaching the dishes containing alkanes to the thighs of the volunteers for 5 hours. The alkanes used in all the experiments were purified by distillation; however, no analysis was reported. Dermal exposure to the liquid alkanes resulted in the immediate development of

irritation characterized by erythema, hyperemia, swelling, and pigmentation. After 5 hours, blisters formed on the alkane-exposed areas. When exposed to pentane, the subjects complained of constant painful burning sensations accompanied by itching. The intensity of these symptoms increased when the subjects were exposed to hexane and heptane. Exposure to octane resulted in diffuse and undefinable sensations. No anesthetic action was reported with any of the alkanes tested, even after 5 hours of skin contact.

The length of time necessary for the sensation of pain to disappear following the removal of these alkanes from the skin increased as the carbon number of the alkanes increased. When pentane was removed from the skin after 5 hours, the pain subsided in 15 minutes; it subsided in 90 minutes with hexane, in 120 minutes with heptane, and in 180 minutes with octane. After 1-hour exposures, Oettel [43] observed marked increases in erythema and skin pigmentation accompanied by pain for a period of up to 24 hours, followed by minor increases in erythema and pigmentation which culminated in a peak effect in 96 hours. According to the author, the exposed skin then gradually returned to normal; no scars were observed. He [43] concluded that the acute effects caused by dermal exposure to the alkanes were probably due to histamine release and the delayed effects were probably due to cellular damage and the accumulation of metabolic products.

In 1975, Nomiyama and Nomiyama [23] investigated the absorption rates of hexane and toluene through the skin of humans. An unspecified number of subjects immersed their hands up to the wrists in a dish containing analytically pure hexane (95% n-hexane) for 1 minute. At intervals following skin exposure, breath, blood, and urine samples were analyzed for

hexane by gas chromatography. The authors were unable to detect hexane in either the breath or the blood of any of the subjects following exposure to n-hexane. The detection limit for hexane was 1 ppm in the breath and 3.5 ppm in the blood. The authors did not describe any physiologic effects.

Animal Toxicity

In 1974, Swann et al [44] investigated the inhalation toxicity of various hydrocarbons including reagent grade n-pentane, n-hexane, n-heptane and iso-octane. Groups of four (sex unspecified) Swiss mice weighing approximately 25 g each were exposed for 5-minute periods to n-pentane and n-hexane at each of the following concentrations: 1,000, 2,000, 4,000, 8,000, 16,000, 32,000, 64,000, and 128,000 ppm. In addition, similar groups of mice were exposed for 5-minute periods to heptane and iso-octane at concentrations of 1,000, 2,000, 4,000, 8,000, 16,000, 32,000, and 48,000 ppm. Only the heads of the mice were exposed to the solvent vapor in a 1-liter chamber; the rest of their bodies were enclosed in plethysmographs as in the Alarie method [45]. Respiration patterns (rate, depth, configuration) were recorded before and during the exposure period and during a 5-minute postexposure recovery period. Alarie's system used an aerosol generator to produce particles with diameters smaller than 0.5 microns. The use of an aerosol generator could explain why some of concentrations reported by Swann et al [44] exceeded the air saturation concentrations reported in Table XII-2 [1].

Exposure [44] to pentane at 16,000 and 32,000 ppm produced no anesthesia; light anesthesia was noted during the recovery period after exposures at 32,000 ppm and 64,000 ppm. At 128,000 ppm, deep anesthesia

was produced during exposure to pentane. Respiratory arrest occurred in one mouse approximately 4.8 minutes after exposure to pentane at 128,000 ppm began. Respiratory irritation, indicated by sporadic body movements, was noted at 32,000, 64,000, and 128,000 ppm.

n-Hexane at a concentration of 8,000 ppm produced no anesthesia during exposure; this concentration produced respiratory patterns similar to those produced by pentane at 32,000 and 64,000 ppm. n-Hexane at 32,000 ppm produced deep anesthesia in the mice. At 64,000 ppm, all four mice had respiratory arrest within 4.5 minutes of exposure. The respiratory irregularities which the mice developed during exposure to n-heptane at 32,000 ppm and 48,000 ppm were similar to those resulting from exposure to n-hexane at 64,000 ppm. Exposure to n-heptane at 48,000 ppm produced respiratory arrest in three of the four mice in the group after 3.75 minutes of exposure. No anesthesia was noted in mice exposed to iso-octane at concentrations up to 8,000 ppm. At 16,000 ppm of iso-octane, there was no apparent anesthesia, but the respiratory pattern of the mice was similar to that resulting from exposure to heptane at 48,000 ppm. One mouse had "sudden" respiratory arrest during the recovery period after exposure to iso-octane at 16,000 ppm. All the mice in the iso-octane group stopped breathing within 4 minutes of exposure at 32,000 ppm, with no apparent anesthesia. The evidence indicates that the higher the carbon number of a hydrocarbon, the greater the anesthetic activity of its vapor, and the lower the concentration required to produce respiratory irritation and respiratory arrest in mice.

In 1967, Miyagaki [46] reported a study of the effects of hexane on the nerves and muscles in the hind legs of mice. The animals were exposed

to hexane at five different concentrations in static chambers for 24 hours/day, 6 days/week, for 1 year. Pure Swiss-strain male mice were separated into 6 groups of 10 mice each and exposed at the following concentrations: group 1, 100 ppm; group 2, 250 ppm; group 3, 500 ppm; group 4, 1,000 ppm; group 5, 2,000 ppm; and group 6, controls. The mice were approximately 8 weeks old at the beginning of the study, and the mean body weights in each of the six groups ranged from 32.3 to 34.6 g. The concentrations inside the static chambers were measured three times daily during the exposure with an n-hexane-calibrated interferometer.

The hexane used for the study was a commercial grade solvent. Gas-chromatographic analysis of the hexane showed that it contained 65-70% n-hexane. Although the author [46] stated that the remaining hydrocarbons were principally other hexane isomers, their individual concentrations and identities were not reported. The mean hexane concentrations in the chambers throughout the year were 99 ppm (100 ppm intended), 272 ppm (250 ppm intended), 552 ppm (500 ppm intended), 1,030 ppm (1,000 ppm intended), and 1,900 ppm (2,000 ppm intended).

The hind legs of the mice were examined after the 1-year exposure. Electromyographic responses, strength-duration curves, electrical reaction times, and flexor-extensor chronaxie ratios were recorded; examinations for gait posture, muscle atrophy, and distal muscle integrity were performed. Miyagaki [46] did not explain why only six mice/group in groups 1-3 were examined, although he indicated that only three mice in group 4 and four mice in group 5 were examined because they were the only survivors in those groups. Abnormal posture and muscle atrophy were slight in the animals exposed at 250 ppm, but were more pronounced in those exposed at 500 ppm

and at all higher concentrations. Light fibrillation was detected in the electromyograms of mice exposed at 250 ppm. No fibrillation was recorded for those exposed at 500 ppm, but definite fibrillation waves were recorded for mice exposed at 1,000 and 2,000 ppm. High spiking voltages were also observed in the electromyograms of those exposed at 1,000 and 2,000 ppm. Above 500 ppm, complex NMU (neuromotor unit) voltages appeared, along with weakening of the interference waves and a decrease in voltages. At concentrations of 250 ppm and greater, the height of the strength-duration curve increased with an increase in concentration.

This increase showed, according to the author [46], slight-to-serious damage to the peripheral nerve-motor branches at the neuromuscular junctions. The flexor-extensor mean chronaxie ratio was approximately 1.6 for the exposure at 100 ppm and for the control mice. It then decreased to 1.2 at 250 ppm and to 1.0 at 500 ppm. However, at 1,000 and 2,000 ppm, a reversal of the flexor and extensor means took place to produce chronaxie ratios of 0.5 and 0.6, respectively. Also, the electrical reaction time, ie, the time that elapsed between electrical stimulation of muscle tissue and the resulting electrical discharge, was longer in the muscles of mice exposed to hexane at 1,000 and 2,000 ppm than in normal muscle. Marked muscular atrophy also was observed in those exposed to hexane at 1,000 and 2,000 ppm.

Miyagaki [46] interpreted the fibrillation, the weakening of interference waves, and the tendency toward higher potential discharges and prolongation of discharge time observed in electromyograms as evidence of peripheral neurogenic damage and nerve degeneration. He also pointed out that the high spiking NMU voltages observed in the electromyograms and the

reversal of the flexor-extensor chronaxie ratios observed at 1,000 and 2,000 ppm might indicate central nervous system damage; however, he stated that further studies were needed to determine the effects of hexane on the central nervous system.

The histologic examinations of the hind leg muscles after exposure to hexane at 1,000 and 2,000 ppm showed atrophy and degeneration of the muscle fiber. The study indicated that a neurotoxicity threshold between 100 and 250 ppm existed in mice. Miyagaki [46] found neurotoxic effects in the animals exposed to hexane at 250 ppm and at all higher concentrations, whereas no definite abnormalities were observed in those exposed to hexane at 100 ppm or in the control mice. Furthermore, no abnormal changes were found in the electromyograms and in the intensity-duration curves in the control mice or in those exposed at 100 ppm, but were noted in 67% of the mice exposed at 250 ppm and in all of those exposed at 500 ppm and higher concentrations. However, the author [46] pointed out that, although hexane at 100 ppm seemed to be harmless to mice, it would be imprudent to consider 100 ppm harmless to humans. He reported no data on human susceptibility.

Truhaut et al [20], in 1973, exposed Wistar rats to airborne hexane at a concentration of 2,000 ppm and to heptane at a concentration of 1,500 ppm, 5 hours/day, 5 days/week, for 1-6 months. Technical grade hexane and heptane were used for the investigation. Analysis of the hexane gave the following results based on total volume: 0.3% n-pentane, 25.1% 2-methylpentane plus cyclopentane, 18.4% 3-methylpentane, 45.8% n-hexane, 8% methylcyclopentane, 1.2% methylhexane, and 1.2% benzene. The analysis of the heptane gave the following results based on total volume: 9.8% 2-methylhexane, 2,3-dimethylpentane, and cyclohexane; 16.2%

3-methylhexane; 52.4% n-heptane; 18.2% 2,4-dimethylhexane, methylcyclohexane, and toluene; 3.3% methylheptane; 0.1% benzene; and 2.8% toluene (assayed separately). The authors [20] did not state how the analyses were performed. The sciatic and saphenous nerves were removed from anesthetized rats at the end of the 1- to 6-month exposure period, mounted in a nerve chamber, and stimulated by square pulses of various voltages. The stimulations and responses were displayed on an oscilloscope. The studies showed a decrease in the threshold conduction rate (undefined), an increase in the refractory periods, and a decrease in the excitability of the nerves. Microscopic examination of the nerves after 5-6 months of exposure to hexane or heptane showed retraction of the myelin sheaths and, in some cases, a rupture of the Schwann cell membranes. The authors [20] noted that impurities, such as 3-methylpentane in the technical grade hexane and 3-methylhexane in the heptane used for the studies, might have been responsible for some of the results observed. The cycloalkanes, benzene, and toluene present in the technical hexane and heptane may also have contributed to the results observed.

In 1971, Kimura et al [47] studied the single-dose oral toxicity of 16 common solvents, including hexane, in different age groups of rats: newborn (1- to 2-days-old, 5-8 g), 14-day-old (16-50 g), young adult (80-160 g), and older adult (300-470 g). Groups of six male Sprague-Dawley rats were used for the young and older adult studies, and groups of 6-12 Sprague-Dawley rats of both sexes were used for the newborn and the 14-day-old studies. The hexane used was of analytical grade, meeting American Chemical Society specifications. The undiluted solvents were administered orally to nonfasted rats. A precise LD50 value for hexane could not be

determined for the newborn rats because of measurement limitations, but amounts equivalent to less than 1 ml/kg body weight were fatal. The acute oral LD50 was 24.0 ml/kg for 14-day-old rats, 49.0 ml/kg for young adults, and 43.5 ml/kg for older adult rats.

Fuhner [12], in 1921, reported the results of a study of the narcotic effects of gasoline and its components on white mice. Hydrocarbons of "highest purity" were obtained for the experiments; however, no analysis of chemical purity was reported, although the boiling range for each substance was given. The pentane had a boiling range of 30-35 C; hexane, 66-71 C; heptane, 96-100 C; and octane, 122-125 C. Mice were individually exposed to each of the alkanes in 11.2- to 11.3-liter glass-stoppered widemouthed flasks. Each hydrocarbon substance being investigated was introduced onto filter paper for evaporation inside a flask. Air samples were taken periodically from the flask for analytical determinations by unspecified methods. One mouse was exposed in each flask at each concentration. Mice lay on their sides when exposed to pentane at concentrations ranging from 0.27 to 0.38 g/liter for 28-116 minutes. Exposures to pentane at concentrations of 0.32, 0.37, and 0.38 g/liter resulted in loss of reflexes after 97, 50, and 21 minutes, respectively. Full recovery followed the termination of exposure. One mouse, exposed to pentane at 0.38 g/liter, suffered a complete loss of reflexes after 26 minutes and died after 37 minutes.

The animals also lay on their sides when exposed to hexane at concentrations ranging from 0.12 to 0.15 g/liter for durations of 29-123 minutes with no loss of reflexes. Death occurred in five of nine mice at concentrations ranging from 0.14 to 0.18 g/liter.

Exposure to heptane at concentrations ranging from 0.06 to 0.08 g/liter resulted in narcosis followed by respiratory arrest in four of eight mice. Exposure to octane at 0.025 g/liter produced no noticeable signs of narcosis after 180 minutes, but at 0.031 g/liter, the mice lay on their sides after 1 hour of exposure. Exposure to octane at 0.04 g/liter caused narcosis in the mice.

In addition to administration by inhalation, the gasoline components were injected into mice subcutaneously [12]. Because pentane has a boiling point below the body temperature of mice, pneumoderma occurred when 0.1 cc of pentane was injected. Hexane and heptane were lethal when administered in large subcutaneous injections; however, Fuhner [12] did not specify the size of the injections which caused death. When 1 cc of octane was injected, it was not distributed because of poor absorption and remained under the skin for an unspecified number of weeks until the skin became necrotic and sloughed off. Skin damage appeared to be the only effect resulting from subcutaneous exposure to octane. Pentane, hexane, and heptane also caused skin damage; however, the nature of the damage was not described.

In 1929, Lazarew [34] investigated the toxicity of various components of gasoline. An unspecified number of white mice were exposed to pentane, hexane, heptane, octane, and to two isomers of heptane and octane, 2-methylhexane and 2,5-dimethylhexane, respectively. The mice were exposed in 10-liter flasks for 2 hours to determine the minimal airborne concentrations at which (1) they lay on their sides, (2) loss of reflexes occurred, and (3) death resulted. The chemical purity of the alkanes was not reported. The methods used for exposure were the same as those

reported earlier in a study by Fuhner [12].

The airborne concentrations at which the mice lay on their sides were 200-300 mg/liter for pentane, 100 mg/liter for hexane, 40 mg/liter for heptane, 50 mg/liter for 2-methylhexane, 35 mg/liter for octane, and 70-80 mg/liter for 2,5-dimethylhexane. The minimum vapor concentration necessary to produce loss of reflexes was not determined for either pentane or 2,5-dimethylhexane, and it could not be determined for hexane, heptane, or 2-methylhexane since reflexes remained until death in some mice. A loss of reflexes was observed in mice exposed to octane at 50 mg/liter. The concentration of pentane producing death could not be determined, but mice exposed to hexane at 120-150 mg/liter, to heptane at 75 mg/liter, or to 2-methylhexane at 70-80 mg/liter died. A lethal concentration could not be obtained for either octane or 2,5-dimethylhexane because of their low vapor pressures. The lengths of exposure resulting in prostration, loss of reflexes, and death were not given. Lazarew [34] concluded that the acute toxic action of hydrocarbons in a homologous series increases with an increase in carbon number and that the branched isomers were less toxic than straight-chain alkanes. Ratios of alkane concentrations necessary to produce the first toxicity signs (mice lying on their sides) were calculated on the basis of the molar concentrations necessary to produce this effect. The ratio of heptane to octane was 1.3, pentane to hexane was 3.0, and hexane to heptane was 2.9. The author [34] concluded that octane was about nine times more toxic than pentane based on these molar ratios (1:3:3).

Tsobkallo [48], in 1947, reported the effects of heptane on respiration and blood pressure in decerebrated cats. The method used for

monitoring respiration and blood pressure was not described in this report. Cats weighing 2.1-3.3 kg were exposed for 5 minutes to heptane vapor at concentrations of 25, 50, and 100 mg/liter through a tracheal cannula connected through a spirometer. After the exposure to heptane, the cats were exposed to fresh air for 20 minutes. The authors stated that exposure to heptane at all of the concentrations investigated caused an initial increase in respiration rate and then a decrease to below normal. The blood pressure decreased during heptane exposure, then rapidly returned to normal during the recovery period. These effects rapidly dissipated after exposure ended.

Bohlen et al [49], in 1973, investigated the absorption and distribution of hexane in rat tissues. An unspecified number of female albino rats weighing 200-230 g were exposed to airborne hexane in a desiccator at a concentration of 170 g/cu m (5% by volume). The concentration was maintained by blowing compressed air over a reservoir of liquid hexane. Inhalation periods ranged from 2 to 10 hours. Gas-chromatographic analysis was used to determine the concentrations of hexane in the blood, brain, liver, adrenals, kidneys, and spleen after the animals were anesthetized and the organs removed. The hexane concentration in all tissues, with the exception of the liver, increased to a tissue saturation concentration within 4-5 hours. The concentration of hexane continued to increase in the liver throughout the longest exposure. The saturation concentrations for hexane were 0.14 mg/g in the spleen, 0.15 mg/g in the blood, 0.49 mg/g in the adrenals, 0.39 mg/g in the brain, and 0.20 mg/g in the kidneys. Exposure to hexane did not change the amounts of tissue lipids found in the rats, with the exception of that found in the liver.

The lipid content of the liver increased linearly with the duration of exposure. The continuous accumulation of lipids, exclusively triglycerides, increased the affinity of the liver for hexane and indicated to the authors why saturation in the liver was not reached during exposure. Exposure to organic solvents, anesthetics, and other substances, such as ethanol, can result in fatty liver from triglyceride accumulation [50].

Nomiyama and Nomiyama [23], in 1975, studied the absorption rates of hexane and toluene through the skin of the shaved backs of an unspecified number of rabbits. Gauze containing a measured quantity of hexane was applied to the shaved backs of the animals [23]. The gauze was then covered, taped, and allowed to remain in contact with the skin for 24 hours. The unabsorbed n-hexane was measured to determine the quantity that had been absorbed through the skin. After exposing the rabbits to toluene in a similar manner, the authors reported that after 3 hours, 10 times more n-hexane than toluene had been absorbed. Since the authors neither performed tissue analysis nor recorded observations concerning the effects of hexane on the rats, the results of this study are of limited application.

A proposed metabolic pathway for n-hexane and methyl n-butylketone is shown in Figure III-1.

DiVincenzo et al [51], in 1976, reported on the metabolism of n-hexane, methyl n-butyl ketone, and other aliphatic ketones in guinea pigs. All chemicals were dissolved in corn oil (25% solution) and injected intraperitoneally in a single dose of 450 mg/kg body weight in male guinea pigs weighing from 250-450 g. Blood samples were collected 1, 2, 4, 6, 8, 12, and 16 hours after the doses were administered. The serum was

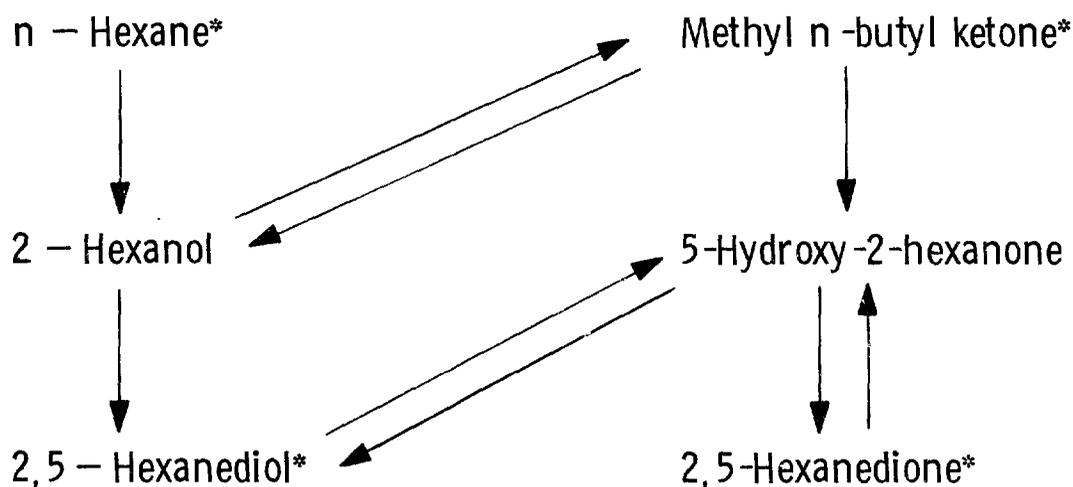


FIGURE III-1

PROPOSED METABOLIC PATHWAY FOR METHYL n-BUTYLKETONE AND n-HEXANE

*These compounds have been shown to be neurotoxic [51-54].

Adapted from Spencer (written communication, 1976)

separated and then analyzed within 48 hours by gas chromatography for n-hexane, aliphatic ketones, and their metabolites. Identification of metabolites was performed by gas chromatography coupled with mass spectrometry. The compounds used in the study were reagent grade. The authors [51] were most interested in the metabolism of aliphatic ketones, but they did report on the identification of two metabolites of n-hexane. The metabolites identified were 5-hydroxy-2-hexanone and 2,5-hexanedione; several other metabolites were detected but not identified. Because no quantitative determinations were made for n-hexane or its metabolites, recoveries could not be calculated. The authors [51] concluded from their

investigation that n-hexane and methyl n-butyl ketone are metabolized to the same compounds and thus have the same neurotoxicity.

Correlation of Exposure and Effect

For many years, alkanes were thought to be relatively nontoxic [29,41] although they were recognized as being fire hazards [55-59]. Patty and Yant [41] determined that exposures to airborne pentane at a concentration of 5,000 ppm for 10 minutes and to hexane at 2,000 ppm for 10 minutes caused no symptoms of intoxication, although exposure to hexane at 5,000 ppm for 10 minutes caused marked vertigo. Heptane caused slight vertigo after 6 minutes at 1,000 ppm, moderate vertigo after 4 minutes at 3,500 ppm, marked vertigo after 4 minutes at 5,000 ppm, and incoordination after 7 minutes of exposure at 5,000 ppm. These results indicated that the alkane concentrations required to produce a physiologic response decreased as the number of carbon atoms in the compound increased.

No data have been reported on health effects resulting from dermal exposure within the workplace. Oettel [43], however, studied the effects of certain alkanes on the skin of humans under controlled laboratory conditions. He found that dermal exposure to alkanes for up to 1 hour produced irritation characterized by erythema, hyperemia, swelling, and pigmentation. After 5 hours of exposure, the alkanes produced blisters on the skin.

No studies that correlate environmental concentrations of pentane, hexane, heptane, and octane with observed toxic effects have been found, except for those relating industrial exposures to hexane with the development of polyneuropathy [13,17,18,24,36-38]. Neither were any long-

term epidemiologic studies of low-level occupational exposures to alkanes found.

In 1960, the first cases of polyneuropathy resulting from hexane exposure were observed in Japan [17]. There has been no clear documentation demonstrating the neurotoxicity of pentane, heptane, or octane, although, in many cases, the solvent thought to cause polyneuropathy contained one or all of these alkanes as constituents in a hydrocarbon mixture [17,18,36]. For example, in a Paris belt-manufacturing shop [36] where five employees were found to have polyneuropathy, the solvent responsible for the neurotoxicity contained 5% hexane, 14% heptane, and 80% pentane.

Studies conducted on mice and rats [12,20,44] support the hypothesis that as the carbon number of the alkanes increases, the adverse effects produced by equivalent doses of the alkanes tend to increase. Lazarew [34] concluded from his study of the comparative inhalation toxicities of 2-methylhexane and 2,5-dimethylhexane versus n-heptane and n-octane in mice that straight-chain alkanes are more toxic than their branched isomers.

The uptake and distribution of hexane in rats were investigated by Bohlen et al [49]. The hexane was administered to the rats by inhalation. Analysis of blood, brain, liver, adrenals, kidneys, and spleen for hexane showed that all the tissues except the liver reached saturation concentrations within 4-5 hours. The concentration of hexane in the liver continued to increase throughout the exposure, probably because of continued triglyceride accumulation in the organ.

Carcinogenicity, Mutagenicity, Teratogenicity and Other

Effects on Reproduction

No studies have been found that are related to the carcinogenic, mutagenic, or teratogenic potential of pentane, hexane, heptane, or octane. Since these compounds are not related chemically to compounds known to have carcinogenic, mutagenic, or teratogenic activity, there is no present reason to suspect that they will be found to have such activity.

Summary Tables of Exposure and Effects

The effects of exposure to pentane, hexane, heptane, and octane on humans, which were presented in detail in Chapter III, are summarized in Tables III-3, III-4, III-5, and III-6, respectively; those of exposures to pentane, hexane, heptane, and octane on animals are shown in Tables III-7, III-8, III-9, and III-10, respectively.

TABLE III-3

EFFECTS OF PENTANE EXPOSURE ON HUMANS

Routes of Exposure	Subjects	Exposure Concentration and Duration	Effects	Reference
Respiratory	3 - 6 men and women	Up to 5,000 ppm 10 min	No symptoms	41
Dermal	5 men and women	Undiluted 5 hr	Blister formation, no anesthesia	43
"	"	Undiluted 1 hr	Irritation, itching, erythema, pigmentation, swelling, painful burning sensation, reduced pain 15 min after removal	43

TABLE III-4

EFFECTS OF HEXANE EXPOSURE ON HUMANS

Routes of Exposure	Subjects	Exposure Concentration and Duration	Effects	Reference
Respiratory	3 - 6 men and women	5,000 ppm 10 min	Marked vertigo	41
"	6 men and women	2,500 - 1,000 ppm 10 - 12 hr/d -	Drowsiness in 0.5 hr, fatigue, loss of appetite in some, paresthesia in distal extremities	17
"	93 men and women	2,500 - 500 ppm -	Sensory impairment in distal portion of extremities, muscle weakness in 13, cold sensation of extremities in some, blurred vision, headache, easy fatigability, anorexia, weight loss by onset of polyneuropathy	37
"	3 - 6 men and women	2,000 ppm 10 min	No symptoms	41
"	11 men and women	1,000 - 500 ppm 3 - 6 mon	Fatigue, loss of appetite in some, paresthesia in distal extremities	17
Dermal	5 men and women	Undiluted 5 hr	Blister formation, no anesthesia	43
"	"	Undiluted 1 hr	Irritation, itching, erythema, pigmentation, swelling, painful burning sensation, reduced pain 90 min after removal	43

TABLE III-4 (CONTINUED)

EFFECTS OF HEXANE EXPOSURE ON HUMANS

Routes of Exposure	Subjects	Exposure Concentration and Duration	Effects	Reference
Respiratory, dermal, and oral	1 woman 27 yr	1,300 - 650 ppm 2 mon	Frequent headaches, abdominal cramps, burning sensation of face, numbness of distal extremities, decreased left ulnar nerve conduction rate	13
"	1 woman 47 yr	"	Abdominal cramps, numbness of distal extremities, paresthesia, bilateral foot and wrist drop, sensory impairment of extremities, decreased left ulnar nerve conduction rate	13
"	1 woman 46 yr	1,300 - 650 ppm 4 mon	Weakness in extremities, moderate weakness and sensory impairment of distal extremities, decreased left ulnar nerve conduction time	

TABLE III-5

EFFECTS OF HEPTANE EXPOSURE ON HUMANS

Routes of Exposure	Subjects	Exposure Concentration and Duration	Effects	Reference
Respiratory	3 - 6 men and women	5,000 ppm 15 min	Marked vertigo, incoordination, hilarity for 30 min	41
"	"	5,000 ppm 7 min	Marked vertigo, incoordination of space, hilarity in some	41
"	"	5,000 ppm 4 min	Marked vertigo, inability to walk straight, hilarity	41
"	"	3,500 ppm 4 min	Moderate vertigo	41
"	"	2,000 ppm 4 min	Slight vertigo	41
"	"	1,000 ppm 6 min	"	41
Dermal	5 men and women	Undiluted 5 hr	Blister formation, no anesthesia	43
"	"	Undiluted 1 hr	Irritation, itching, erythema, pigmentation, swelling, painful burning sensation in skin, reduced pain 120 min after removal	43

TABLE III-6

EFFECTS OF OCTANE EXPOSURE ON HUMANS

Routes of Exposure	Subjects	Exposure Concentration and Duration	Effects	Reference
Dermal	5 men and women	Undiluted 5 hr	Blister formation, no anesthesia	43
"	"	Undiluted 1 hr	Diffuse and undefinable burning sensations, reduced pain 180 min after removal	43

TABLE III-7

EFFECTS OF PENTANE EXPOSURE ON ANIMALS

Routes of Exposure	Species	No.	Exposure Concentration and Duration	Effects	Reference
Respiratory	Mice	1	129,200 ppm 37 min	Decreased respiration rate, loss of reflexes, death by 37 min of exposure	12
"	"	4	128,000 ppm 5 min	Irritation, deep anesthesia, respiratory arrest in 1 by 4.75 min of exposure	44
"	"	1	108,800 ppm 26 min	Lying down by weakened reflexes	12
"	"	-	102,000 - 68,000 ppm 2 hr	Lying down	34
"	"	1	91,800 ppm 66 min	Temporary lying down	12
"	"	4	64,000 ppm 5 min	Irritation, anesthesia during recovery period	44
"	"	4	32,000 ppm 5 min	Anesthesia during recovery period	44

TABLE III-8

EFFECTS OF HEXANE EXPOSURE ON ANIMALS

Routes of Exposure	Species	No.	Exposure Concentration and Duration	Effects	Reference
Respiratory	Mice	4	64,000 ppm 5 min	Irregular respiratory pattern, respiratory arrest by 2.5-4.5 min	44
"	"	1	51,120 ppm 9 min	Death after spasms, no narcosis	12
"	"	1	42,600 ppm 127 min	Loss of reflexes, death	12
"	"	-	42,600 - 34,080 ppm 2 hr	Death	34
"	"	-	36,920 ppm 127 min	"	12
"	"	1	34,080 ppm 123 min	Light narcosis	12
"	"	-	32,000 ppm 5 min	Deep anesthesia	44
"	"	-	28,400 ppm 2 hr	Lying down	34
"	"	4	16,000 ppm 5 min	No anesthesia	44
"	"	4	8,000 ppm 5 min	"	44

TABLE III-8 (CONTINUED)

EFFECTS OF HEXANE EXPOSURE ON ANIMALS

Routes of Exposure	Species	No.	Exposure Concentration and Duration	Effects	Reference
Respiratory	Mice	7	1,000-2,000 ppm 6 d/wk 1 yr	Marked abnormal posture and muscular atrophy; in electromyographic tests, fibrillation at rest, complex NMU voltage and high amplitude NMU voltage during movement, and weakened interference waves during strong contractions; increased electrical reaction time; reversal of flexor-extensor chronaxy ratio	46
"	"	6	500 ppm 6 d/wk 1 yr	Abnormal posture and muscular atrophy	46
"	"	19	250 - 2,000 ppm 6 d/wk 1 yr	Higher strength-duration curve with increased concentrations	46
"	"	6	250 ppm 6 d/wk 1 yr	Slightly abnormal posture and muscular atrophy; in electromyographic tests, some fibrillation at rest	46
Oral	Rats	-	49.0 ml/kg*	LD50 (young adults, 80-160 g)	47
"	"	-	43.5 ml/kg*	LD50 (older adults, 300-470 g)	47
"	"	-	24.0 ml/kg*	LD50 (14 d of age, 16-50 g)	47
"	"	-	Less than 1.0 ml/kg*	LD50 (24-48 hr of age, 5-8 g)	47

*Analytical grade, meeting American Chemical Society specifications

TABLE III-9

EFFECTS OF HEPTANE EXPOSURE ON ANIMALS

Route of Exposure	Species	No.	Exposure Concentration and Duration	Effects	Reference
Respiratory	Mice	4	64,000 ppm 5 min	Respiratory arrest in 3 by 3.75 min of exposure	44
"	"	4	32,000 ppm 5 min	Irregular respiratory pattern	44
"	"	-	18,300 ppm 2 hr	Death in 2 hr	34
"	"	4	16,000 ppm 5 min	No anesthesia	44
"	"	-	9,760 ppm 2 hr	Lying down	34
"	Cats (Decerebrated)	-	24,400 - 6,100 ppm 5 min	Decreased blood pressure during exposure, rapid return to normal during recovery period; initial increased respiration, then decreased	48

TABLE III-10

EFFECTS OF OCTANE EXPOSURE ON ANIMALS

Routes of Exposure	Species	No.	Exposure Concentration and Duration	Effects	Reference
Respiratory	Mice	4	32,000 ppm 5 min	Respiratory arrest in 4 by 4 min of exposure	44
"	"	4	16,000 ppm 5 min	Respiratory arrest in 1 during recovery period	44
"	"	1	12,840 ppm 185 min	Decreased respiration rate, death by following day	12
"	"	-	10,700 ppm 2 hr	Loss of reflexes	34
"	"	-	8,560 ppm 55 min	Narcosis	12
"	"	-	7,490 ppm 2 hr	Lying down	34
"	"	-	6,634 ppm 1 hr	"	12
"	"	-	5,350 ppm 48 min	No narcosis	12

IV. ENVIRONMENTAL DATA AND ENGINEERING CONTROLS

Sampling and Analysis

There are many general methods of sampling and analysis for alkanes and for various hydrocarbon mixtures containing alkanes. Many of these methods were developed for specific purposes, such as analyses of ambient air [60,61], petroleum distillates [62-64], gasoline components [63-65], crude oil [66], automobile exhausts [67], polluted atmospheres [68-70], and polluted water samples [71].

Sampling with plastic bags [72-75] or with glass bottles [76] involves drawing a volume of environmental air at a known temperature and pressure into a container of known volume. This type of "grab" sample is collected from a few seconds to several hours depending on flowrate. Although plastic bags are lightweight and inexpensive, and no correction is necessary for dilution of the sample during analysis, the rate of sample decay within the bags may vary as a function of storage time [75], and sample transport may be inconvenient because of the bulkiness of the containers. The rate of loss of alkane vapors from plastic bags is also a function of the type of plastic used, adsorption and diffusion characteristics for the specific plastic, the concentration of alkanes present, temperatures, and pressure [73]. No reports were found on the specific use of plastic bags and glass bottles for sampling alkanes.

Another type of collection device involves the passage of a known volume of air through an absorbing or adsorbing medium to retain the alkanes [77-80]. With such devices, samples can be collected over recorded periods of time, and the resultant data can be analyzed to calculate the

TWA concentration of the alkanes present. Impingers and bubblers can be used to collect alkane vapors in carbon disulfide, although caution should be exercised with carbon disulfide because of its high toxicity [61]. Direct-feed sampling can also be done where air samples containing alkanes are flushed directly into a gas chromatograph with helium [68,70] or alkane samples are collected in freeze-traps at low temperatures [60,69]. No efficiency data have been determined, but, where adsorbing or absorbing media are used to collect samples, it might be necessary to use more than one impinger, bubbler, or freeze-trap in series.

Of the various techniques, adsorption offers the greatest ease of collection. Activated charcoal [61,79,80,81], silica gel [77,78], and bonded stationary phases [60] have been used to adsorb hydrocarbon vapors. The method of Otterson and Guy [79] provides a simple means of sample collection: alkane vapors are adsorbed on activated charcoal and then desorbed with carbon disulfide. Liquid desorption offers the advantage of permitting multiple analyses of each sample.

The efficiency of the adsorption on activated charcoal is not affected by small variations in mesh size or type of charcoal used [79,82]. In this charcoal sampling system, a pump capable of drawing a measured quantity of air through a charcoal tube is used. Once the sampling is completed, charcoal tubes are easy to seal, handle, transport, and store. One disadvantage of charcoal tubes is that the amount of sample that can be collected is limited by the weight of charcoal in a given tube. If too much sample is drawn through the charcoal, overloading occurs and the possibility of sample loss (breakthrough) exists. When the sample in the backup section of the charcoal trap exceeds 25% of that found in the front

section, either the charcoal section length in the front section should be increased to prevent loss of the sample or the size of the sample should be decreased. The precision of the charcoal tube method is limited by the reproducibility of the pressure drop across the charcoal tubes. Because the sampling pump is usually calibrated for one tube for each batch, variation in tubes may affect the flow rate and cause the volume calculation to be imprecise.

The charcoal tube method is nevertheless recommended as the method of choice. Details concerning its use are presented in Appendix I. Because the charcoal tube collects a large number of organic vapors, the use of a specific analytical method is necessary.

A number of analytical methods have been developed that, when coupled with gas chromatography, can be used for the detection of alkanes. These various methods use infrared spectrometry [67,83], nuclear magnetic resonance spectrometry [66], and mass spectrometry [66] as gas-chromatographic detectors instead of a flame ionization detector which is employed often in alkane analysis [61,65,68].

Indicator-type detector tubes are used frequently for a quick, direct detection of the concentrations of alkanes in air [84]. They have been shown to detect n-pentane at concentrations ranging from 290 to 4,400 mg/cu m and hexane, heptane, and octane at concentrations ranging from 2,000 to 25,000 mg/cu m [84]. Currently, no alkane detector tubes have been certified for use by NIOSH.

In addition to the previously described detection apparatus, there are various types of combustion detectors [85]. The most common types use a Wheatstone bridge and a balanced electrical circuit. When a combustible

gas is drawn over an arm of the Wheatstone bridge, there is an increase in resistance due to the effect of the gas in one section of the circuit and the imbalance over the total circuit is measured. The Wheatstone bridge is not very sensitive to the presence of low concentrations of various combustible vapors; it is also affected by environmental conditions and by the presence of other substances in the atmosphere. These detectors are useful for locating leaks in closed systems and testing for the presence of alkane vapor in confined spaces. They may also be used to make rough estimates of airborne alkane concentrations.

The method recommended for the analysis of alkanes was adapted from the NIOSH/OSHA Standards Completion Program [61] and is described in Appendix II. In the method, a charcoal tube is used to adsorb the alkanes from the air drawn through the tube, the alkanes are desorbed from the charcoal with carbon disulfide solution, and then the carbon disulfide solution is analyzed with a gas chromatograph. The gas-chromatographic separation is performed on a column packed with 10% FFAP on 80/100 mesh Chromosorb W-AW. This method provides for a quick, accurate means of analysis and for the analysis of two or more compounds suspected to be present in a mixture. In conjunction with this method, mass spectrometry can be used to determine the identities of compounds in complex mixtures.

Engineering Controls

Alkanes are used primarily as solvents in operations involving extraction, spraying, pouring, mixing, and oven-drying [86-88]. Some of these operations are not enclosed and alkane vapor may be released into the atmosphere. The principles set forth in Industrial Ventilation--A Manual

of Recommended Practices, published by the American Conference of Governmental Industrial Hygienists Committee on Industrial Ventilation [89], and Fundamentals Governing the Design and Operation of Local Exhaust Systems, Z9.2-1971 [90], published by the American National Standards Institute, should be applied to the control of atmospheric releases of alkanes. Seed-oil extraction with alkanes is normally performed in closed systems so that only small amounts of vapor are released to the atmosphere [87,88]. However, when closed systems are opened for maintenance, the possibility of concentrations existing which may exceed 10% of the lower explosive limit should be considered. Such operations should always be ventilated, preferably by blowers and correctly positioned ducts. Where possible, the release of alkane vapors should be controlled by local ventilation at the source of emission. Operations such as extraction, drying, and evaporation which involve the use of alkanes at elevated temperatures may require special placement of local ventilation controls. Such controls must be explosion-proof [87]. Special care must be taken to make sure that substances that form explosive mixtures are not vented into the same system. Frequent tests should be conducted to ensure that leaks do not occur in closed systems containing alkanes. The major alkane-manufacturing processes in use in the United States are currently closed processes [88].

V. DEVELOPMENT OF A STANDARD

Basis for Previous Standards

(a) ACGIH Threshold Limit Values

(1) Pentane

In 1929, Patty and Yant [41] reported that pentane at 5,000 ppm produced no sensory effects on human subjects after 10 minutes of exposure. Fuhner [12] found that mice exposed to pentane at air concentrations of approximately 270,000 mg/cu m in air showed no loss of reflexes after 116 minutes of exposure. In 1945, based on the Patty and Yant report [41], Cook [91] suggested a maximum allowable concentration (MAC) of 5,000 ppm (14,750 mg/cu m) for pentane. It was this 5,000-ppm MAC value that the Committee on Threshold Limits of the American Conference of Governmental Industrial Hygienists (ACGIH) adopted as the recommended environmental limit in 1946 [92].

In 1947, the ACGIH Committee [93] changed the MAC for pentane to 1,000 ppm (2,950 mg/cu m). The reason for this change was not specified, and whether this MAC was intended as a ceiling value or as a TWA concentration was not indicated.

In 1948, the ACGIH [94] still designated 1,000 ppm as the recommended limit for pentane but called the limit a Threshold Limit Value (TLV). The TLV for pentane remained at 1,000 ppm until 1970 when the ACGIH [95] lowered it to 500 ppm (1,500 mg/cu m). A notice of intended change, calling for a revision of the TLV for pentane from 500 to 600 ppm (1,800 mg/cu m), was published by the ACGIH [96] in 1974; 600 ppm was adopted as the TLV in 1976 [97]. The ACGIH [98] stated that a TLV for pentane of 600

ppm, as a TWA concentration, was at a level "where the odor and irritation did not constitute a nuisance during prolonged exposure" and that this was also consistent with the findings of Swann et al [44] and others [12,41] that the shorter the carbon chain in a homologous series, the less the toxic effect.

(2) Hexane

In 1943, Drinker et al [32] had two groups of volunteers inhale petroleum distillate for 8 hours. Ninety percent of the distillate boiled between 42 and 127 C, a range which would include hexane. The wide boiling range indicates that the distillate contained a number of aliphatic and possibly aromatic hydrocarbon components in addition to hexane. Volunteers in one group were exposed to the distillate vapor at 150 ppm, and those in the other group were exposed at 140 ppm. At both concentrations, nausea, headache, and throat and eye irritation were the common complaints, but the authors [32] stated that none of the volunteers considered the exposure sufficiently disagreeable to preclude working in the exposure area. Nelson et al [33], in 1942, exposed volunteers to n-hexane at 500 ppm for 3-5 minutes; the subjects described this exposure as being quite innocuous. Although the effects of higher concentrations were not evaluated, the volunteers felt that higher concentrations could be tolerated in the workplace.

In 1948, the ACGIH [94] designated 500 ppm as a TLV for hexane. The TLV remained at 500 ppm until 1974 when a notice [96] of intended change, calling for a revision of the TLV for n-hexane from 500 to 100 ppm (360 mg/cu m), was published. In 1976, the ACGIH [97] adopted a new TLV, 100 ppm for n-hexane. The decision [99] to lower the TLV of n-hexane from 500

to 100 ppm was based on reports [13,17,18] of polyneuropathy in workers who used hexane as a solvent in various industrial applications. Yamada [17] described the occurrence of polyneuropathy in 17 workers in Japan, 6 of whom were exposed to hexane vapor in a polyethylene-laminating plant and 11 to hexane in a pharmaceutical plant. Inoue et al [18] reported an outbreak of polyneuropathy from exposure to the vapor of hexane from glue used in sandal making in Japan. Herskowitz et al [13] described sensorimotor polyneuropathy in three employees in a furniture factory in the United States. Inoue et al [100] showed that inhalation of hexane at 250 ppm caused peripheral nerve disturbances in mice, but no disturbances were observed at 100 ppm. Based on these and another report [101] of polyneuropathy, the ACGIH lowered the TLV for n-hexane from 500 ppm to 100 ppm.

(3) Heptane

In 1929, Patty and Yant [41] reported that exposure of humans to heptane at a concentration of 1,000 ppm (4,000 mg/cu m) for 6 minutes resulted in only slight dizziness. Based on this report, Cook [91], in 1943, suggested an MAC for heptane of 500 ppm (2,000 mg/cu m), although he stated, "exposures somewhat in excess of this concentration are not considered toxic." In 1946, the ACGIH adopted an MAC for heptane of 500 ppm. In 1948, the ACGIH designated 500 ppm as the limit for heptane and changed the name to a TLV, specified as a TWA concentration. The TLV remained at 500 ppm until 1974 when a notice [96] of intended change, calling for a lowering of the TLV for n-heptane from 500 ppm to 400 ppm (1,600 mg/cu m), was published. In 1976, the ACGIH [97] adopted 400 ppm as the TLV for n-heptane. The ACGIH [102] based this revision on the

possibility that heptane could cause polyneuropathy since it probably had been in the mixtures of hydrocarbon solvents implicated in numerous cases of polyneuropathy [13,17,101], although no nervous system disturbances had been directly attributed to heptane.

(4) Octane

In 1945, Cook [91] suggested an MAC value of 500 ppm (2,350 mg/cu m) for octane, based on the investigation by Patty and Yant [41] whose report stated that heptane at 1,000 ppm caused slight dizziness in humans. The MAC value of 500 ppm was suggested by Cook [91] because he felt that octane was a more potent narcotic agent than heptane.

In 1946, the ACGIH [92] adopted an MAC for octane of 500 ppm. In 1948, the ACGIH [94] designated 500 ppm as the TLV for octane. The TLV for octane remained at 500 ppm until 1970 when the ACGIH [95] lowered it to 400 ppm (1,900 mg/cu m). A notice [96] of intended change, calling for a reduction of the TLV for octane from 400 to 300 ppm (1,450 mg/cu m), was published in 1974. The change was adopted [97] in 1976. The ACGIH [103] reasoned that since, according to several studies [12,44,104], octane was more toxic than heptane and had a greater molecular weight than heptane, octane should have a lower TLV than heptane to avoid narcosis or irritation. Since a TLV for heptane of 400 ppm had been chosen, the TLV for octane was lowered to 300 ppm.

(b) Other Workplace Limits

In 1971, the Pennsylvania Department of Environmental Resources [105] adopted 500-ppm TLV's for pentane (1,475 mg/cu m), n-hexane (1,770 mg/cu m), and n-heptane (2,050 mg/cu m), and a 400-ppm TLV for octane (1,870 mg/cu m). These values were specified as TWA concentrations. The

department also adopted Short-Term Limits (STL) of 500 ppm for a 30-minute exposure to hexane, heptane, and octane.

In 1976, the ACGIH [97] set tentative Threshold Limit Value-Short Term Exposure Limits (TLV-STEL) of 750 ppm (2,250 mg/cu m) for pentane, 125 ppm (450 mg/cu m) for n-hexane, 500 ppm (2,000 mg/cu m) for n-heptane, and 375 ppm (1,800 mg/cu m) for octane. These limits were described as maximal concentrations to which employees could be exposed for a period up to 15 minutes continuously without suffering from intolerable irritation, chronic or irreversible tissue change, or narcosis of sufficient degree to increase accident proneness, impair self-rescue, or reduce work efficiency. A provision that limited the number of excursions to no more than four each day, with at least 60 minutes between exposure periods, was also included.

The MAC values for pentane, hexane, heptane, and octane that have been established in various foreign countries are shown in Table V-1.

In 1971, the Japanese Subcommittee on Permissible Concentrations of Hazardous Substances [109] recommended the continued acceptance of the 1966 TWA concentration of 100 ppm (360 mg/cu m) for n-hexane. The recommendation was based on reports and data from human and animal experiments as well as from experience in industry. No documentation was provided.

The present federal workplace environmental limit (29 CFR 1910.1000) for pentane is an 8-hour TWA concentration of 1,000 ppm (2,950 mg/cu) for a 40-hour workweek. For n-hexane, n-heptane, and octane, the limits are 8-hour TWA concentrations of 500 ppm (1,800 mg/cu m, 2,000 mg/cu m, and 2,350 mg/cu m, respectively) for a 40-hour workweek. These limits are based on the ACGIH TLV concentrations for 1968 [110].

TABLE V-1

MAXIMUM ALLOWABLE ALKANE CONCENTRATION VALUES
FOR VARIOUS FOREIGN COUNTRIES

Country	Pentane		Hexane		Heptane		Octane	
	ppm	mg/cu m	ppm	mg/cu m	ppm	mg/cu m	ppm	mg/cu m
Japan	-	-	100*	360	-	-	-	-
Finland	1,000	2,950	500*	1,800	500*	2,000	500	2,350
Germany (Federal Republic)	1,000	2,950	100*	360	500*	2,000	500	2,350
Poland	-	1,000	-	400	-	200	-	200
Rumania	-	2,400	-	1,500*	-	1,500*	-	1,500
Yugoslavia	1,000	2,950	500*	1,800	500*	2,000	-	2,350
Sweden	-	-	-	-	-	-	300	1,400

*Values for straight chain isomers

Adapted from references 106-108

Basis for the Recommended Standard

(a) Workplace Environmental Limits

Toxicologic data suitable for establishing a standard for the alkanes in the occupational environment are limited. Data have been reported that indicate that exposure to hexane can result in the development of polyneuropathy [13,17,18,36-39]. Yamamura [37] reported that workers exposed to hexane used in glue for sandal production in Japan had developed polyneuropathy. Of 296 sandal workers examined, 93 were classified as

having polyneuropathy. All 93 had been engaged in the gluing operation that took place in the workers' poorly ventilated dwellings. The airborne hexane concentration in the pasting rooms of the dwellings ranged from 500 to 2,500 ppm with exposure durations exceeding 8 hours/day for 6-7 days/week. Inoue and his coworkers [18], reporting on the same study, indicated that some workers who developed polyneuropathy had been exposed to concentrations of n-hexane below 500 ppm.

Yamada [17] described the conditions under which 17 workers who developed polyneuropathy were exposed to hexane vapor in Japan. Six of the patients worked in small laminating plants for an average of 10 hours/day, 6 days/week. During the laminating process, airborne concentrations of hexane vapor ranged from 1,000 to 2,500 ppm. The hexane solvent used in these plants contained 16% methyl pentane, 20% methyl cyclopentane, and 64% n-hexane. Eleven of the 17 cases of polyneuropathy occurred in a pharmaceutical plant where a 95% n-hexane solution was used to remove oil from the surfaces of tablets. The workers lived and worked in the factory, where the concentration of airborne hexane was 500-1,000 ppm. Herskowitz et al [13] described three cases of sensorimotor polyneuropathy in employees of a furniture factory in New York. Air sampling indicated that the employees were exposed to n-hexane at concentrations which averaged 650 ppm.

Miyagaki [46] exposed mice to n-hexane at various concentrations for 24 hours/day, 6 days/week, for 1 year. After the 1-year exposure, examinations of the lower extremities of the mice for neurotoxic effects were performed. The author [46] determined that the toxic concentration of hexane in mice was 250 ppm. At a concentration of 100 ppm, he found no

clear neurotoxic effects.

In view of the evidence that exposure to hexane at concentrations below 500 ppm [18,46] has been associated with the development of polyneuropathy, an environmental limit well below 1,800 mg/cu m (500 ppm) of hexane is needed. The absence of definitive epidemiologic or toxicologic evidence makes it difficult to determine how much lower the environmental limit should be. Professional judgment suggests that a TWA concentration of 350 mg/cu m (100 ppm) offers a sufficient margin of safety to protect against the development of chronic nerve disorders in workers. Further research should be conducted to better define this limit. It is noted that the German Research Association and the Japanese Association of Occupational Health have come to a similar conclusion regarding hexane.

Although polyneuropathy in humans has not been attributed to exposure to pentane, heptane, or octane, evidence exists which suggests that these alkanes are similar in toxicity to hexane. Five workers in a belt-manufacturing shop in Paris developed polyneuropathy as a result of exposure to a solvent which contained 80% pentane, 14% heptane, and only 5% hexane [36]. Although neither the duration of exposure to the solvent nor the concentration of the solvent in the environment was described, the authors [36] concluded that pentane and heptane might also cause polyneuropathy. It was experimentally shown [41,44] that the concentration of an alkane required to cause the development of acute toxic effects decreases as the carbon number of an alkane increases. It is reasonable to conclude that this trend applies to the effects of long-term exposures to these compounds.

Truhaut et al [20] exposed rats to technical grade hexane, which contained pentane, hexane, heptane, cycloalkanes, and benzene, and to technical grade heptane, which contained heptane, octane, cycloalkanes, toluene, and benzene. Exposure to the two grades of alkanes resulted in the development of similar signs of neurologic disorder in two groups of rats. The authors noted that components other than straight-chain alkanes might have been responsible for some of the results observed.

On the basis of these studies [20,36,41,44], TWA concentrations of 350 mg/cu m are also recommended as the environmental limits for pentane, heptane, and octane. On a volume/volume basis, these concentrations are equal to about 120 ppm pentane, 100 ppm hexane, 85 ppm heptane, and 75 ppm octane. The recommended limits decrease slightly with increasing carbon number. In addition, ceiling concentration limits of 1,800 mg/cu m (about 610 ppm pentane, 510 ppm hexane, 440 ppm heptane, and 385 ppm octane), based on a sample collection period of 15 minutes, are recommended to protect workers from acute exposures which might cause effects such as vertigo or other adverse reactions which could result in accident-proneness.

In most workplace situations, workers will be exposed to a mixture of alkanes rather than to a single alkane isomer. Because similar effects result from acute exposures to hexane and to heptane [41], and adverse effects produced by the alkanes tend to increase as the carbon number of the alkane increases [12,41], it seems likely that components of an alkane mixture may exert additive toxic effects.

In the absence of more substantial data on mixtures and on the metabolism of individual alkanes, environmental limits of 350 mg/cu m of

total alkanes as a TWA concentration and 1,800 mg/cu m of total alkanes as a 15-minute ceiling concentration are recommended.

(b) Sampling and Analysis

Sampling and analytical methods were reviewed in Chapter IV. According to the recommended sampling method, airborne alkane vapors are collected in charcoal-filled tubes and then desorbed from the charcoal with carbon disulfide. An aliquot of the solution of desorbed alkanes and carbon disulfide is analyzed with a gas chromatograph. The areas of the resulting peaks are determined and compared with those of injected standards. The sampling method was chosen because it is thought to be the best available at the present time and is expected to provide adequate collection efficiency for airborne alkanes. The gas-chromatographic method of analysis was selected because it is sensitive and relatively simple to perform. The method is not entirely specific for alkanes. Other compounds having the same retention times as the alkanes being analyzed will interfere with the analysis; however, mass spectrometry can be used to identify some of the eluted compounds (see Appendix II). To ensure that sampling and analysis information is available for later reference, the employer should keep records of environmental monitoring for at least 30 years.

(c) Medical Surveillance

The neurotoxicity of hexane and the possible neurotoxicity of pentane, heptane, and octane have been discussed in Chapter III. The possibility of the development of polyneuropathy from exposure to alkanes warrants a requirement for preplacement physical examinations directed towards the nervous system. In addition, similar physical examinations

giving particular attention to the skin and to the nervous system should be made on an annual basis. Preplacement examinations can serve as a useful basis for comparison in the event that overexposure to alkanes occurs. To ensure that these records are available if needed, the employer should keep them for 30 years after termination of a worker's employment.

(d) Labeling and Posting

Containers holding 10% or more alkanes should bear labels which provide a brief description of the hazards associated with the alkanes and the precautions necessary for safe use and minimal exposure. Signs containing similar information should be posted in areas where alkanes are stored in bulk quantities or where there is occupational exposure to alkanes.

(e) Personal Protective Equipment

Alkanes are moderate eye irritants; the use of safety glasses or goggles is recommended when contact of alkanes with the eyes is likely. Other personal protective equipment should include respirators, gloves, and other protective clothing when necessary. The types of respiratory protective devices described in Table I-1 are those approved under the provisions of 30 CFR 11 for the concentrations specified. In conjunction with this approval, other factors have been considered for each class of alkanes [111].

(f) Information and Education

The employer should institute a continuing education program to ensure that all employees occupationally exposed to alkanes have current knowledge of job hazards, signs and symptoms of overexposure, proper maintenance and emergency procedures, proper use of protective clothing and

equipment, and precautions to take to ensure safe use of, and minimal exposure to, alkanes. Where a potential for emergencies exists, periodic drills should be held to provide employees with an opportunity to develop skill in dealing with emergency situations.

(g) Work Practices

Work practices are discussed in Chapter VI. Precautions against fire and explosion hazards are emphasized to ensure that flammable substances are handled properly and that their vapors do not build up to explosive levels in the work environment.

(h) Action Level

It is recognized that many workers handle small amounts of either pentane, hexane, heptane, or octane or work in situations where, regardless of the amount used, there is only negligible contact with these substances. Under these conditions, compliance with only a limited number of the provisions of this recommended standard, which has been prepared primarily to protect the workers' health under more hazardous circumstances, should be necessary. Concern for the workers' health requires that protective measures be instituted below the enforceable limits to ensure that exposures stay below those limits. A TWA concentration of 200 mg/cu m has been chosen as an action level on the basis of professional judgment rather than on quantitative data that delineate nonhazardous areas from areas in which a hazard may exist. Occupational exposure to alkanes has been defined as worker exposure above the action level, thereby delineating those work situations which do not require the expenditure of health resources for environmental and medical monitoring and associated recordkeeping. However, because of nonrespiratory hazards such as those

resulting from skin or eye contact or from ingestion, it is recommended that appropriate work practices and protective measures to prevent topical contact or ingestion be required regardless of the air concentration.

VI. WORK PRACTICES

Work practices and safety precautions for handling alkanes have been the subject of reports dealing mainly with the flammability and explosiveness of the alkanes [16,87]. No specific work practice guidelines designed for the prevention of alkane exposure are available. In general, engineering controls should be used to ensure that exposures remain below the recommended environmental limits, to minimize excursions and eye and skin contact, and to prevent fires.

Tables XII-2, XII-3, XII-4 [1-4] give the physical properties for pentane, hexane, heptane and octane. These alkanes are designated as flammable liquids of Class IA or IB based on the criteria in 29 CFR 1910.106 (19)(ii). The National Fire Protection Association's NFPA No. 30 Flammable and Combustible Liquids Code [55] and NFPA No. 70 Electrical Code [112] should be strictly adhered to; NFPA No. 36 Solvent Extraction Plants Code [16] should be complied with where applicable.

Special precautions are necessary when entering tanks, extractors, or vessels which may contain alkanes, when performing flame- or spark-generating operations such as welding and cutting, and when transferring alkanes. Before any employee enters a vessel, all pipelines leading into or out of the vessel must be blanked to prevent the entry of alkane liquids or vapors [87]. Vessels should be drained of all alkanes, cooled to a temperature below 110 F, and purged of all alkanes with steam or an inert gas [87]. A person should be designated to test the vessel atmosphere following purging by using a combustible gas meter or other suitable instrument [87]. No one should enter a tank, vessel, or extractor without

first being equipped with a lifebelt to which at least one lifeline, manned by a worker stationed outside the entrance, has been attached [87]. If hazards are such that a second coworker is needed outside the entrance, a second lifeline should be attached to the worker entering the enclosure. The use of portable lights to illuminate the interior of tanks, vessels, or extractors when they are undergoing cleaning or repairs should be prohibited. Such interiors should be illuminated by reflected light [87]. Only nonferrous tools should be used for scraping or chipping away clinging residues or accumulated deposits. Rags and other materials used to wipe up and absorb alkanes should be placed in standard safety containers. Cutting or welding must be performed only when an authorized representative of the employer signs a permit indicating that all necessary safety precautions have been taken [87].

The transfer of alkanes by means of gravity flow or compressed gas should be avoided [87]. When the use of these methods of transfer is unavoidable, positive automatic shutoffs are necessary. Transfer by compressed air is prohibited. Transfer from tank to process use should, where feasible, be through rigid pipe systems which are operated by remote control. When performed indoors, the transfer of liquids from portable containers should be by means of readily attached approved pumps and through continuous armored hose lines [87]. If safety cans are used, they should be of the approved kind, with a spring-closing lid and spout cover, and designed so that internal pressure is relieved when they are subjected to heat [113]. Alkanes must not be dispensed into metal containers unless the dispensing nozzle and containers are electrically interconnected.

Alkanes may generate high pressures in their storage containers if they are exposed to direct sunlight. Storage areas for alkanes should therefore be protected against the effects of direct sunlight. If tarpaulins and similar coverings are used, they should be positioned over containers to allow for air space [56]. Heating of an area, if required, should be by indirect means. Open-flame devices must be prohibited in any area where alkanes are used, stored, or handled [87].

Engineering controls should be designed and maintained to keep the levels of airborne alkanes below the recommended environmental limits. This will ensure that these levels remain well below their lower explosive limits. When a fan is located in duct work where the concentrations of alkanes may exceed 10% of a lower flammable limit, the rotating element should be of nonsparking material or the casting should be coated with, or consist of, nonsparking material. The ventilation system should contain devices along its length intended to prevent the propagation of flashbacks [87]. Additional information regarding ventilation systems can be found in Industrial Ventilation--A Manual of Recommended Practice [89], Fundamentals Governing the Design and Operation of Local Exhaust Systems Z9.2-1971 [90], and Recommended Industrial Ventilation Guidelines [114].

Evidence of skin irritation indicates that contact with liquid alkanes will probably cause eye injury. Therefore, the use of personal protective equipment, such as safety glasses or goggles, is required when contact of alkanes with the eyes is likely [115-117]. If eye contact or irritation occurs, the affected eye must be flushed immediately with gently flowing water for at least 10 minutes. A physician should be consulted to determine if additional treatment is necessary.

In alkane-manufacturing areas, routine checks should be made to ensure that leaks occurring in closed processes are detected. When leaks occur, they must be promptly repaired by trained maintenance workers wearing the appropriate protective clothing and respiratory protection as described in Section 4 of Chapter I; the repair operations should be properly supervised. If employees must withdraw samples from the process, and there is a possibility of significant exposure to the alkanes in liquid or vapor form, then a fire-resistant suit, which is impervious to alkanes and includes gloves, conductive boots, and a positive pressure supplied-air hood, should be worn. Protective clothing is normally not required for other operations involving the manufacture and use of alkanes; however, if it is worn, it should be fire-resistant. Fabrics that generate static electricity should be avoided. A change of clothing shall be made available to an employee whose regular work clothes become contaminated with alkanes. If the clothing becomes wet with liquid alkanes, the affected employee should avoid sources of ignition, quickly remove the clothing, and shower with soap and water. The clothing should then be air-dried and laundered before it is reworn. This procedure is recommended because liquid alkanes in contact with the skin have caused dermatitis and blistering [23,43]. The degree of irritation varies with the extent of exposure. Skin that has become chapped or cracked because of contact with alkanes may become infected; therefore, appropriate precautions should be taken.

Protective clothing and equipment, including respirators, should be kept clean and maintained in good condition. This can be ensured by regular cleaning after use and periodic inspection by trained personnel.

Worn equipment should be replaced when necessary. The employer must ensure that all equipment is in working order and that it is stored properly when not in use.

In emergency operations, fire and explosion may be the primary hazards. A program must be instituted for the quick evacuation of the work area. All personnel should be provided with respirators as designated for emergencies in Table I-1. All potentially exposed employees must be familiarized with escape procedures, and procedures for obtaining emergency medical care, for transporting injured employees, and for firefighting. Only personnel properly trained in emergency operations and properly equipped should be allowed into the work area for repair operations.

Safety showers, eyewash fountains, and fire extinguishers must be located in or near areas where alkane splashes are likely to occur and must be properly maintained. Washing facilities, soap, and water must be available to employees. As a good hygiene practice, it is recommended that employees wash their hands before eating, smoking, or using toilet facilities.

In summary, precautions must be taken to guard against exposure of personnel to toxic concentrations of alkanes and to the fire hazards associated with them. It is also important that employees be informed before job placement of the hazards associated with the use of alkanes, and whenever any changes are made in any process that may alter their exposure to alkanes. Appropriate emergency procedures should be stressed. Recommended labels and posters must be displayed. The US Department of Labor "Material Safety Data Sheet" shown in Appendix III or a similar approved form must be filled out and filed in a location readily accessible

to all workers who may be exposed to alkanes. If the recommended work practices are observed and good engineering controls are installed, employees working with alkanes should be adequately protected from the various hazards associated with alkanes, including overexposure, fire, and explosion.

VII. RESEARCH NEEDS

One of the most pressing research needs for pentane, hexane, heptane, and octane is the acquisition of additional information concerning worker exposures and any corresponding health effects in the contemporary workplace environment. The present available information pertaining to these exposures is seriously inadequate. Most of the data deal with exposures to either hexane or mixtures of alkanes. The reports of exposures to mixtures of alkanes normally lack analyses of the mixtures and give insufficient information on the data necessary for the determination of dose-response relationships.

There is a need for additional information in the following areas to set better standards for pentane, hexane, heptane, and octane:

(a) Mechanism of Toxicity and Metabolism

The mechanism of toxicity and the metabolism of hexane have not yet been identified. Hexane seems to be metabolized in a manner similar to that of methyl n-butyl ketone. Research should be conducted to confirm or refute this theory. Although there is some evidence that pentane and heptane are neurotoxic, animal studies are needed to determine the relative neurotoxicity of pentane, heptane, and octane. Studies on animals other than rodents, especially primates, should be done to ascertain the systemic effects, if any, of long-term low-level exposures to hexane or other alkanes.

(b) Relationship Between the Toxicities of the Alkanes

Animal studies of the effects of exposures to mixtures containing alkanes and other carbon compounds, such as ketones, aldehydes, and

aromatics, are needed to determine if additive, potentiating, or synergistic effects result.

(c) Carcinogenicity, Mutagenicity, and Teratogenicity Studies

Studies are needed to determine if alkanes produce carcinogenic, mutagenic, or teratogenic effects in humans or animals.

(d) Sampling and Analytical Methods

Additional work is needed both to validate the recommended sampling and analytical methods and to develop improved procedures and equipment that will minimize interferences with the qualitative and quantitative analyses of the alkanes present in collected samples.

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IX. APPENDIX I

METHOD FOR SAMPLING ALKANES (C5-C8) IN AIR

General Requirements

To evaluate conformance with the recommended environmental limits, airborne concentrations of pentane, hexane, heptane, and octane must be measured within the individual worker's breathing zone. Sampling procedures must conform with the following criteria:

(a) Samples collected must be representative of the individual worker's exposure.

(b) Sampling data sheets must include:

- (1) The date and time of sample collection.
- (2) Sampling duration.
- (3) Volumetric flow rate of sampling.
- (4) A description of the sampling location.
- (5) Ambient temperature and pressure.
- (6) Other pertinent information (eg, worker's name, shift, work process).

Recommended Method

(a) Personal samples must be collected in the breathing zone of the employee without interfering with his freedom of movement and must characterize the exposure from each job or specific operation in each production area.

(b) A portable, battery-operated personal sampling pump whose flow can be accurately controlled to within 5% at 50 ml/minute and 250 ml/minute should be used in conjunction with activated charcoal tubes to collect the samples.

(c) The tube of activated charcoal should be attached to the employee. The shirt collar is convenient for this purpose.

(d) The sampling rate for TWA concentration determinations should be maintained at a value of 50 ml/minute; each sample taken to determine a TWA concentration should be collected for 80 minutes. Samples, taken to determine if airborne alkane concentrations greater than the ceiling concentration exist, should be collected at a rate of 250 ml/minute for 15 minutes.

(e) At least one unused tube of activated charcoal from the same batch as that of the tube or tubes used for sampling shall be sent to the analytical laboratory to determine the blank correction value.

Equipment for Air Sampling

(a) Battery-operated personal sampling pump: The pump should have a clip for attachment to the employee. All pumps and flowmeters must be calibrated using a calibrated test meter or other reference, as described in the section of this appendix entitled Calibration of Equipment.

(b) Charcoal tubes: Glass tubes with both ends flame-sealed, 7 cm long with a 6-mm outer diameter and a 4-mm internal diameter, containing two sections of 20/40 mesh activated coconut-shell charcoal separated by a 2-mm portion of polyurethane foam. The adsorbing section should contain 100 mg of charcoal, the backup section 50 mg. A 3-mm portion of the

polyurethane foam should be placed between the outlet end of the tube and the backup section. A plug of silyated glass wool should be placed in front of the adsorbing section.

Calibration of Equipment

Accurate calibration of the sampling pump is essential to the correct interpretation of the volume indicated. The necessary frequency of calibration is dependent upon the use, care, and handling to which the pump is subjected. Pumps should be recalibrated if they have been misused or if they have just been repaired or received from a manufacturer. If the pump receives hard use, it should be calibrated more frequently. Regardless of use, maintenance and calibration should be performed on a regular schedule and records of these should be kept.

Ordinarily, pumps should be calibrated in the laboratory both before they are used in the field and after they have been used to collect a large number of field samples. The accuracy of calibration is dependent on the type of instrument used as a reference. The choice of calibration instrument will depend largely upon where the calibration is to be performed. For laboratory testing, primary standards such as a spirometer or soapbubble meter are recommended, although other standard calibration instruments such as a wet test meter or dry gas meter can be used. The actual setups will be similar for all instruments.

The proper calibration setup for personal sampling pumps with charcoal-tubes is as shown in Figure XII-1. If some other calibration device is selected, an equivalent procedure should be used. Since the flow rate produced by a pump is dependent on the pressure drop across the

sampling device, in this case a charcoal tube, the pump must be calibrated while operating with a representative charcoal tube in line. Instructions for calibration with the soapbubble meter are as follows:

(a) The voltage of the pump battery is checked with a voltmeter to ensure adequate voltage for calibration. The battery is charged if necessary.

(b) Both tips of a charcoal tube are broken off to produce openings of at least 2 mm in diameter.

(c) The sampling train is assembled as shown in Figure XII-1.

(d) The pump is turned on, and the inside of the soapbubble meter is moistened by immersing the buret into the soap solution and drawing bubbles up the inside until they are able to travel the entire length of the buret without bursting.

(e) The pump flow controller is adjusted to provide the desired flow rate.

(f) The water manometer is checked to ensure that the pressure drop across the sampling train does not exceed 15.2 mm of water at 50 ml/minute or 76.2 mm of water at 250 ml/minute.

(g) A soapbubble is started up the buret, and the time it takes the bubble to move from one calibration mark to another is measured with a stopwatch.

(h) The procedure described in (g) is repeated at least twice, the results averaged, and the flow rate calculated by dividing the volume between the preselected marks by the time required for the soapbubble to traverse the distance. If, for the pump being calibrated, the volume of air sampled is the product of the number of strokes times a stroke factor

(given in units of volume/stroke), the stroke factor is the quotient of the volume between the two preselected marks divided by the number of strokes.

(i) The volume measured, the elapsed time or number of strokes, the pressure drop, the air temperature, the atmospheric pressure, the serial number of the pump, and the name of the person performing the calibration should be recorded.

Collection of Samples

(a) Both ends of a charcoal tube are broken to provide openings of at least 2 mm, which is 1/2 of the internal diameter of the tube. A smaller opening causes a limiting orifice effect which reduces the flow through the tube. The main adsorbing section of the charcoal tube should contain 100 mg of charcoal.

(b) The smaller section of charcoal (50 mg) in the tube is used as a backup adsorbing section and should therefore be placed nearest the sampling pump. Noncollapsible tubing may be used to connect the back of the tube to the pump, but no tubing should ever be put in front of the charcoal tube. During sampling, the tube should be supported in a vertical position to prevent channeling. After the sample is collected, the tube must be capped; caps are provided with commercially available tubes. Masking tape can be substituted for caps when sealing the tube. Rubber caps must never be used.

(c) The recommended sampling flow rate is 50 ml/minute for TWA concentration determinations and 250 ml/minute for ceiling concentration determinations. A 4-liter sample is normally adequate. The flow rate

should be set as accurately as possible according to the manufacturer's directions.

(d) The initial and final counter readings of the pump must be recorded. The sample volume can be obtained by multiplying the number of strokes by the volume/stroke factor.

(e) One charcoal tube should be treated in the same manner as the sample tubes (break, seal, ship), except that no air is drawn through it. This tube will serve as a blank.

Special Consideration

(a) Where two or more alkanes or other compounds are known or suspected to be present in the air, such information, including their suspected identities, should be conveyed with the sample.

(b) The pump must not be operated for more than 8 hours without recharging the battery.

(c) If high humidity or water mist is present, breakthrough volume can be severely reduced. If condensation of water occurs in the tube, alkanes will not be trapped quantitatively. Therefore, in high humidity, the volume sampled should be reduced.

(d) The desorption efficiency of charcoal varies from batch to batch. Therefore, all the tubes used to collect a set of samples must contain charcoal from the same batch. Unused charcoal tubes should accompany the samples. Information on the batch number of the charcoal must be supplied.

Shipping of Samples

Capped charcoal tubes should be packed tightly and padded before they are shipped to prevent tube breakage during shipping. Bulk samples of materials which may have been introduced into the workplace air and which may be collected by charcoal tubes must be submitted in addition to charcoal tubes. These bulk samples should be at least 20 ml each and should be refrigerated when practical. Bulk samples and charcoal tubes must be shipped in separate containers.

X. APPENDIX II

ANALYTICAL METHOD FOR ALKANES (C5-C8)

The following analytical method is adapted from the NIOSH/OSHA Standards Completion Program [61].

Principle of the Method

A known volume of air is drawn through a charcoal tube to collect alkane vapors.

Alkane vapors trapped on charcoal from a known volume of air are desorbed with carbon disulfide. An aliquot of the desorbed sample is injected into a gas chromatograph. The total area of the resulting peaks is determined and compared with those obtained from injection of alkane standards.

Range and Sensitivity

(a) The Standards Completion Program methods are valid over the concentration range of 800-7,000 mg/cu m at an atmospheric temperature of 25 C and a pressure of 760 mmHg for a 3-liter sample of the individual alkanes. Although not demonstrated, it is anticipated that this method will be valid for the concentration ranges specified in this document. The method is capable of measuring much smaller amounts if the desorption efficiency is adequate. Desorption efficiency must be determined over the

range of concentrations for each alkane analyzed.

(b) The upper limit of the range of the method is dependent on the adsorptive capacity of the charcoal tube. This capacity varies with the concentrations of the alkanes in the air.

Interference

Any compound which has about the same retention time as the alkanes under the gas-chromatographic conditions described in this method will interfere with the analysis. This type of interference might be overcome by changing the operating conditions of the instrument, the column, the column temperature, or all three. The interfering compounds can be identified by a combination of gas chromatography and mass spectrometry if interference is suspected. If the carbon disulfide interferes with components of a complex mixture, each sample may be analyzed on separate gas-chromatographic columns of widely different polarity. This will ensure that each component of the complex mixture can be analyzed in a region free of interference from carbon disulfide.

Advantages and Disadvantages of the Sampling and Analytical Methods

(a) The sampling device is small, portable, and involves no liquids. Samples are analyzed by means of a rapid instrumental method. The method provides for the simultaneous analysis of two or more compounds suspected to be present in a mixture by changing gas-chromatographic conditions from isothermal to a temperature-programmed mode of operation. Interferences may affect the qualitative and quantitative analysis of the

compounds present in the sample. Mass spectrometry may be necessary to determine the identity of each compound present, if the alkane mixture being analyzed is complex. It may, however, not be able to provide an accurate quantitative analysis of the alkanes present in a complex mixture.

(b) The amount of sample which can be taken is limited by the amount that the charcoal tube will hold before it is overloaded. When the sample value obtained for the backup section of the charcoal tube exceeds 25% of that found on the front section, the possibility of sample loss exists.

Apparatus

(a) Gas chromatograph equipped with flame ionization detector and mass spectrometer.

(b) Column (20-ft x 1/8-in stainless steel) packed with 10% FFAP on 80/100 Chromosorb W-AW for operation above 50 C; column (10-ft x 1/8-in stainless steel) packed with 10% TCEP (triscyanoethoxy propane) on Chromosorb P-AW for operation below 50 C.

(c) Electronic integrator or some other suitable method of determining peak areas.

(d) Sample containers: 2 ml, with glass stoppers or Teflon-lined caps. If an automatic sample injector is used, the sample injector vials can be used.

(e) Microliter syringes: 10- μ l, and other convenient sizes for making standards.

(f) Pipets: 1.0 ml, graduated in 0.1-ml increments.

(g) Volumetric flasks: 10 ml or other convenient sizes for making standard solutions.

Reagents

- (a) Chromatographic quality carbon disulfide.
- (b) Samples of specific alkanes under study, preferably chromatography grade.
- (c) Nonane or other suitable alkane for use as an internal standard.
- (d) Purified compressed helium.
- (e) Purified compressed hydrogen.
- (f) Filtered compressed air.

Procedure

- (a) Cleaning of Equipment

Wash all glassware used for the laboratory analysis with detergent in water, and thoroughly rinse with tapwater and distilled water.
- (b) Analysis of Samples
 - (1) Preparation of samples: Score each charcoal tube with a file in front of the first section of charcoal, and break it open. Remove the glass wool and discard. Transfer the charcoal in the first (larger) section to a 2-ml stoppered sample container or to an automatic sample injector vial. Remove the separating section of foam and discard; transfer the second section to another sample container or vial. Analyze these two sections separately.

(2) Desorption of samples: Prior to analysis, pipet 1.0 ml of carbon disulfide into each sample container. For the internal standard method, use a 0.2% solution of internal standard in carbon disulfide. (Perform all work with carbon disulfide under a fume hood because of its high toxicity.) Desorb for 30 minutes. Tests indicate that this is adequate if the sample is agitated occasionally during this period. If an automatic sample injector is used, cap the sample vials as soon as the solvent is added to minimize volatilization.

(3) Gas-chromatographic conditions: The typical operating conditions for the gas chromatograph are:

- (A) 30 ml/minute (60 psig) helium carrier gas flow.
- (B) 35 ml/minute (25 psig) hydrogen gas flow to detector.
- (C) 400 ml/minute (60 psig) airflow to detector.
- (D) 225 C injection port temperature.
- (E) 250 C manifold temperature (detector).
- (F) 52 C column (FFAP) temperature.

(4) Injection: The first step in the analysis is the injection of the sample into the gas chromatograph. To eliminate difficulties arising from blowback or distillation within the syringe needle, employ the solvent-flush injection technique. First, flush a 10- μ l syringe with solvent several times to wet the barrel and plunger. Draw 3 μ l of solvent into the syringe to increase the accuracy and reproducibility of the injected sample volume. Remove the needle from the solvent, and pull back the plunger about 0.2 μ l to separate the solvent flush from the sample with a pocket of air to be used as a marker. Immerse the needle in

the sample, and withdraw a 5- μ l aliquot, taking into consideration the volume of the needle, since the sample in the needle will be completely injected. After the needle is removed from the sample and prior to injection, pull back the plunger 1.2 μ l to minimize evaporation of the sample from the tip of the needle. Make certain that the sample occupies 4.9-5.0 μ l in the barrel of the syringe. Make duplicate injections of each sample and standard. No more than a 3% difference in peak area is to be expected. An automatic sample injector can be used if it is shown to give reproducibility at least as good as the solvent flush technique. In this case, 2- μ l injection volumes are satisfactory.

(5) Measurement of the peak area: Measure the area of the sample peak with an electronic integrator or by some other suitable means of area measurement, and read preliminary results from standard curves prepared as discussed below.

(c) Determination of Desorption Efficiency

(1) Importance of determination: The determined desorption efficiency of a particular compound can vary from one laboratory to another and also from one batch of charcoal to another. Thus, it is necessary to determine at least once the percentage of the specific compound that is removed in the desorption process, provided that the same batch of charcoal is used.

(2) Procedure for determining desorption efficiency: Measure activated charcoal equivalent to the amount in the first section of the sampling tube (100 mg) into a 63.5 mm, 4-mm ID glass tube, flame-sealed at one end. This charcoal must be from the same batch as that used in obtaining the samples and can be obtained from unused charcoal tubes.

Inject a known amount of each alkane directly into the activated charcoal with a microliter syringe, and cap the tube. When using an automatic sample injector, sample injector vials, capped with inert polymer-faced septa, may be used instead of the glass tubes.

Prepare six tubes at each of three concentration levels (one-half, one, and two times the recommended limit) by adding an amount of each alkane equivalent to that which would be present in a 4-liter sample at the selected level. Allow the tubes to stand overnight to ensure complete adsorption of the alkanes onto the charcoal. These tubes are referred to as the samples. Treat a parallel blank tube in the same manner, except add no sample to it. Desorb and analyze the blank tubes in exactly the same manner as the sampling tube.

Prepare two or three standards by injecting the same volume of compound into 1.0 ml of carbon disulfide with the same syringe used in the preparation of the samples. These are analyzed with the samples.

If the internal standard method is used, prepare calibration standards with 1.0 ml of carbon disulfide containing a known amount of the internal standard.

The desorption efficiency equals the average weight in mg recovered from the tube divided by the weight in mg added to the tube, or

$$\text{desorption efficiency} = \frac{\text{average weight recovered (mg)}}{\text{weight added (mg)}}$$

Plot the desorption efficiency versus the weight of each alkane added. This curve is used in calculations to correct for adsorption losses.

(d) Curves

It is convenient to express concentration of standards in terms of mg/1.0 ml of carbon disulfide because samples are desorbed in this amount of carbon disulfide. The density of each alkane is used to convert mg into microliters for easy measurement with a microliter syringe. A series of n-alkane standards, varying in concentration over the range of interest, is prepared and analyzed under the same gas-chromatographic conditions and during the same time period as the unknown samples. When standards containing more than one n-alkane are blended, each component should be present in different relative amounts. Curves are established by plotting concentrations in mg/1.0 ml versus peak area.

For the internal standard method, use carbon disulfide containing a predetermined amount of the internal standard. The internal standard concentration used should be approximately 70% of the concentration at twice the environmental limit. The alkane concentration in mg/ml is plotted versus the area ratio of each alkane to that of the internal standard. Note: Whether the absolute area or the internal standard method is used, standard solutions should be analyzed at the same time that the sample analysis is done. This will minimize the effect of variations of flame ionization detector response.

Calculations

(a) The areas of peaks with retention times less than or equal to n-pentane are summed and converted to milligrams of pentane according to the n-pentane standard curve. The area of peaks with retention times greater than n-pentane but less than or equal to n-hexane are summed and

converted to milligrams of hexane with the n-hexane standard curve. Heptanes and octanes are treated in a similar manner. For a homologous series of isomers, the flame ionization detector response factors are nearly the same as the parent alkane [119]. If a component can be demonstrated to be something other than an alkane, its area is not included. No volume corrections are needed, because the standard curves are based on mg/1.0 ml carbon disulfide and the volume of sample injected is identical to the volume of the standards injected.

(b) Corrections for the blank must be made for each sample.

$$\text{mg} = \text{mg sample} - \text{mg blank}$$

where:

$$\text{mg sample} = \text{mg found in front section of sample tube}$$

$$\text{mg blank} = \text{mg found in front section of blank tube}$$

A similar procedure is followed for the backup sections.

(c) Read the desorption efficiency from the appropriate n-alkane curve for the amounts found in either the front or backup sections. Divide the total weight of the alkane by the desorption efficiency to obtain the corrected mg/sample.

$$\text{corrected mg/sample} = \frac{\text{total weight}}{\text{desorption efficiency}}$$

(d) Add the corrected weights of the pentanes, hexanes, heptanes, and octanes present in the front and backup sections of the same sample tube to determine the total weight of the alkanes in the sample.

(e) The concentrations of alkanes in the air sampled can be expressed in mg/cu m.

$$\text{mg/cu m} = \frac{\text{corrected mg} \times 1,000 \text{ (liter/cu m)}}{\text{air volume sampled (liters)}}$$

XI. APPENDIX III
MATERIAL SAFETY DATA SHEET

The following items of information which are applicable to a specific product or material shall be provided in the appropriate block of the Material Safety Data Sheet (MSDS).

The product designation is inserted in the block in the upper left corner of the first page to facilitate filing and retrieval. Print in upper case letters as large as possible. It should be printed to read upright with the sheet turned sideways. The product designation is that name or code designation which appears on the label, or by which the product is sold or known by employees. The relative numerical hazard ratings and key statements are those determined by the rules in Chapter V, Part B, of the NIOSH publication, An Identification System for Occupationally Hazardous Materials. The company identification may be printed in the upper right corner if desired.

(a) Section I. Product Identification

The manufacturer's name, address, and regular and emergency telephone numbers (including area code) are inserted in the appropriate blocks of Section I. The company listed should be a source of detailed backup information on the hazards of the material(s) covered by the MSDS. The listing of suppliers or wholesale distributors is discouraged. The trade name should be the product designation or common name associated with the material. The synonyms are those commonly used for the product, especially formal chemical nomenclature. Every known chemical designation or

competitor's trade name need not be listed.

(b) Section II. Hazardous Ingredients

The "materials" listed in Section II shall be those substances which are part of the hazardous product covered by the MSDS and individually meet any of the criteria defining a hazardous material. Thus, one component of a multicomponent product might be listed because of its toxicity, another component because of its flammability, while a third component could be included both for its toxicity and its reactivity. Note that a MSDS for a single component product must have the name of the material repeated in this section to avoid giving the impression that there are no hazardous ingredients.

Chemical substances should be listed according to their complete name derived from a recognized system of nomenclature. Where possible, avoid using common names and general class names such as "aromatic amine," "safety solvent," or "aliphatic hydrocarbon" when the specific name is known.

The "%" may be the approximate percentage by weight or volume (indicate basis) which each hazardous ingredient of the mixture bears to the whole mixture. This may be indicated as a range or maximum amount, ie, "10-40% vol" or "10% max wt" to avoid disclosure of trade secrets.

Toxic hazard data shall be stated in terms of concentration, mode of exposure or test, and animal used, eg, "100 ppm LC50-rat," "25 mg/kg LD50-skin-rabbit," "75 ppm LC man," or "permissible exposure from 29 CFR 1910.1000," or, if not available, from other sources of publications such as the American Conference of Governmental Industrial Hygienists or the American National Standards Institute Inc. Flashpoint, shock sensitivity

or similar descriptive data may be used to indicate flammability, reactivity, or similar hazardous properties of the material.

(c) Section III. Physical Data

The data in Section III should be for the total mixture and should include the boiling point and melting point in degrees Fahrenheit (Celsius in parentheses); vapor pressure, in conventional millimeters of mercury (mmHg); vapor density of gas or vapor (air = 1); solubility in water, in parts/hundred parts of water by weight; specific gravity (water = 1); percent volatiles (indicated if by weight or volume) at 70 degrees Fahrenheit (21.1 degrees Celsius); evaporation rate for liquids or sublimable solids, relative to butyl acetate; and appearance and odor. These data are useful for the control of toxic substances. Boiling point, vapor density, percent volatiles, vapor pressure, and evaporation are useful for designing proper ventilation equipment. This information is also useful for design and deployment of adequate fire and spill containment equipment. The appearance and odor may facilitate identification of substances stored in improperly marked containers, or when spilled.

(d) Section IV. Fire and Explosion Data

Section IV should contain complete fire and explosion data for the product, including flashpoint and autoignition temperature in degrees Fahrenheit (Celsius in parentheses); flammable limits, in percent by volume in air; suitable extinguishing media or materials; special firefighting procedures; and unusual fire and explosion hazard information. If the product presents no fire hazard, insert "NO FIRE HAZARD" on the line labeled "Extinguishing Media."

(e) Section V. Health Hazard Information

The "Health Hazard Data" should be a combined estimate of the hazard of the total product. This can be expressed as a TWA concentration, as a permissible exposure, or by some other indication of an acceptable standard. Other data are acceptable, such as lowest LD50 if multiple components are involved.

Under "Routes of Exposure," comments in each category should reflect the potential hazard from absorption by the route in question. Comments should indicate the severity of the effect and the basis for the statement if possible. The basis might be animal studies, analogy with similar products, or human experiences. Comments such as "yes" or "possible" are not helpful. Typical comments might be:

Skin Contact--single short contact, no adverse effects likely; prolonged or repeated contact, possibly mild irritation.

Eye Contact--some pain and mild transient irritation; no corneal scarring.

"Emergency and First Aid Procedures" should be written in lay language and should primarily represent first-aid treatment that could be provided by paramedical personnel or individuals trained in first aid.

Information in the "Notes to Physician" section should include any special medical information which would be of assistance to an attending physician including required or recommended preplacement and periodic medical examinations, diagnostic procedures, and medical management of overexposed employees.

(f) Section VI. Reactivity Data

The comments in Section VI relate to safe storage and handling of hazardous, unstable substances. It is particularly important to highlight instability or incompatibility to common substances or circumstances, such as water, direct sunlight, steel or copper piping, acids, alkalies, etc. "Hazardous Decomposition Products" shall include those products released under fire conditions. It must also include dangerous products produced by aging, such as peroxides in the case of some ethers. Where applicable, shelf life should also be indicated.

(g) Section VII. Spill or Leak Procedures

Detailed procedures for cleanup and disposal should be listed with emphasis on precautions to be taken to protect employees assigned to cleanup detail. Specific neutralizing chemicals or procedures should be described in detail. Disposal methods should be explicit including proper labeling of containers holding residues and ultimate disposal methods such as "sanitary landfill," or "incineration." Warnings such as "comply with local, state, and federal antipollution ordinances" are proper but not sufficient. Specific procedures shall be identified.

(h) Section VIII. Special Protection Information

Section VIII requires specific information. Statements such as "Yes," "No," or "If necessary" are not informative. Ventilation requirements should be specific as to type and preferred methods. Respirators shall be specified as to type and NIOSH or US Bureau of Mines approval class, ie, "Supplied air," "Organic vapor canister," etc. Protective equipment must be specified as to type and materials of construction.

(i) Section IX. Special Precautions

"Precautionary Statements" shall consist of the label statements selected for use on the container or placard. Additional information on any aspect of safety or health not covered in other sections should be inserted in Section IX. The lower block can contain references to published guides or in-house procedures for handling and storage. Department of Transportation markings and classifications and other freight, handling, or storage requirements and environmental controls can be noted.

(j) Signature and Filing

Finally, the name and address of the responsible person who completed the MSDS and the date of completion are entered. This will facilitate correction of errors and identify a source of additional information.

The MSDS shall be filed in a location readily accessible to employees exposed to the hazardous substance. The MSDS can be used as a training aid and basis for discussion during safety meetings and training of new employees. It should assist management by directing attention to the need for specific control engineering, work practices, and protective measures to ensure safe handling and use of the material. It will aid the safety and health staff in planning a safe and healthful work environment and in suggesting appropriate emergency procedures and sources of help in the event of harmful exposure of employees.

--

MATERIAL SAFETY DATA SHEET

I PRODUCT IDENTIFICATION		
MANUFACTURER'S NAME	REGULAR TELEPHONE NO. EMERGENCY TELEPHONE NO.	
ADDRESS		
TRADE NAME		
SYNONYMS		
II HAZARDOUS INGREDIENTS		
MATERIAL OR COMPONENT	%	HAZARD DATA
III PHYSICAL DATA		
BOILING POINT, 760 MM HG		MELTING POINT
SPECIFIC GRAVITY (H ₂ O=1)		VAPOR PRESSURE
VAPOR DENSITY (AIR=1)		SOLUBILITY IN H ₂ O, % BY WT
% VOLATILES BY VOL		EVAPORATION RATE (BUTYL ACETATE=1)
APPEARANCE AND ODOR		

IV FIRE AND EXPLOSION DATA			
FLASH POINT (TEST METHOD)		AUTOIGNITION TEMPERATURE	
FLAMMABLE LIMITS IN AIR, % BY VOL.	LOWER	UPPER	
EXTINGUISHING MEDIA			
SPECIAL FIRE FIGHTING PROCEDURES			
UNUSUAL FIRE AND EXPLOSION HAZARD			
V HEALTH HAZARD INFORMATION			
HEALTH HAZARD DATA			
ROUTES OF EXPOSURE			
INHALATION			
SKIN CONTACT			
SKIN ABSORPTION			
EYE CONTACT			
INGESTION			
EFFECTS OF OVEREXPOSURE			
ACUTE OVEREXPOSURE			
CHRONIC OVEREXPOSURE			
EMERGENCY AND FIRST AID PROCEDURES			
EYES			
SKIN:			
INHALATION:			
INGESTION			
NOTES TO PHYSICIAN			

VI REACTIVITY DATA
CONDITIONS CONTRIBUTING TO INSTABILITY
INCOMPATIBILITY
HAZARDOUS DECOMPOSITION PRODUCTS
CONDITIONS CONTRIBUTING TO HAZARDOUS POLYMERIZATION
VII SPILL OR LEAK PROCEDURES
STEPS TO BE TAKEN IF MATERIAL IS RELEASED OR SPILLED
NEUTRALIZING CHEMICALS
WASTE DISPOSAL METHOD
VIII SPECIAL PROTECTION INFORMATION
VENTILATION REQUIREMENTS
SPECIFIC PERSONAL PROTECTIVE EQUIPMENT RESPIRATORY (SPECIFY IN DETAIL)
EYE
GLOVES
OTHER CLOTHING AND EQUIPMENT

IX SPECIAL PRECAUTIONS

PRECAUTIONARY
STATEMENTS

OTHER HANDLING AND
STORAGE REQUIREMENTS

PREPARED BY _____

ADDRESS _____

DATE _____

XII. TABLES AND FIGURE

TABLE XII-1

ALKANE ISOMERS

Alkane	Formula	Isomer Name
Pentane	C ₅ H ₁₂	n-pentane 2-methylbutane 2,2-dimethylpropane
Hexane	C ₆ H ₁₄	n-hexane 2-methylpentane 3-methylpentane 2,2-dimethylbutane 2,3-dimethylbutane
Heptane	C ₇ H ₁₆	n-heptane 2-methylhexane 3-methylhexane 3-ethylpentane 2,2-dimethylpentane 2,3-dimethylpentane 2,4-dimethylpentane 3,3-dimethylpentane 2,3,3-trimethylbutane
Octane	C ₈ H ₁₈	n-octane 2-methylheptane 3-methylheptane 4-methylheptane 2,3-dimethylhexane 2,4-dimethylhexane 2,5-dimethylhexane 2,2-dimethylhexane 3,4-dimethylhexane 3,3-dimethylhexane 3-ethylhexane 2-methyl,3-ethylpentane 3-methyl,3-ethylpentane 2,2,3-trimethylpentane 2,3,3-trimethylpentane 2,3,4-trimethylpentane 2,2,4-trimethylpentane 2,2,3,3-tetramethylbutane

TABLE XII-2

PHYSICAL PROPERTIES OF NORMAL ALKANE ISOMERS

Alkane	Vapor Density (air=1)	Vapor Pressure (mmHg)	% in Saturated Air (25 C at 760 mmHg)	Vapor Saturated Air Density (25 C at 760 mmHg; air=1)	Flammable Limits (% v/v)	Conversion Factors
n-Pentane	2.49	500 (at 24.34 C)	66.0	1.98	1.42-7.80	340 ppm=1 mg/liter 1 ppm=2.94 mg/cu m
n-Hexane	2.97	150 (at 24.81 C)	19.7	1.39	1.18-7.43	284 ppm=1 mg/liter 1 ppm=3.52 mg/cu m
n-Heptane	3.52	47.70 (at 25 C)	6.3	1.18	1.10-6.70	244 ppm=1 mg/liter 1 ppm=4.10 mg/cu m
n-Octane	3.94	10.45 (at 20 C)	1.4	1.04	0.96-4.66	214 ppm=1 mg/liter 1 ppm=4.67 mg/cu m

From reference 1

TABLE XII-3

PHYSICAL PROPERTIES OF ALKANE ISOMERS

Alkane	Formula	Formula Weight	Density of Liquid (20/4 C)	Melting Point (C)	Boiling Point at 760 mmHg (C)	Refractive Index (at 20 C)	Flash-point (C)
n-pentane (amyl hydride)	CH ₃ (CH ₂) ₃ CH ₃	72.15	0.6262	-129.72	36.07	1.3575	-49
2-methylbutane (isopentane; ethyldimethylmethane)	(CH ₃) ₂ CHCH ₂ CH ₃	72.15	0.6201	-159.890	27.85	1.3537	-57
2,2-dimethylpropane (neopentane; tetramethylmethane)	C(CH ₃) ₄	72.15	0.61350	-16.55	9.50	1.3476*	-65
n-hexane	CH ₃ (CH ₂) ₄ CH ₃	86.18	0.6603	-95.00	68.95	1.37506	-26
2-methylpentane (isohexane)	CH ₃ (CH ₂) ₂ CH(CH ₃) ₂	86.18	0.6532	-153.67	60.271	1.3715	-23
3-methylpentane (diethylmethylmethane)	CH ₃ CH ₂ CH(CH ₃)CH ₂ CH ₃	86.18	0.6645	-118	63.282	1.3765	<-7
2,2-dimethylbutane (neohexane)	C ₂ H ₅ C(CH ₃) ₃	86.18	0.6485	-99.87	49.74	1.3688	-48
2,3-dimethylbutane (diisopropyl)	(CH ₃) ₂ CHCH(CH ₃) ₂	86.18	0.6616	-128.53	58	1.3750	-29
n-heptane	CH ₃ (CH ₂) ₅ CH ₃	100.21	0.68376	-90.61	98.42	1.38777	-4
2-methylhexane (isoheptane; ethylisobutylmethane)	CH ₃ (CH ₂) ₃ CH(CH ₃) ₂	100.21	0.67869	-118.27	90	1.38485	<-18
3-methylhexane	CH ₃ CH ₂ CH ₂ CH(CH ₃)CH ₂ CH ₃	100.21	0.6872**	-173**	92**	1.3885**	-4
2,2-dimethylpentane	CH ₃ CH ₂ CH ₂ C(CH ₃) ₃	100.21	0.6739	-123.82	79.197	1.3822	-
2,3-dimethylpentane	CH ₃ CH ₂ CH(CH ₃)CH(CH ₃) ₂	100.21	0.6951	-	89.8	1.3919	-
3,3-dimethylpentane	CH ₃ CH ₂ C(CH ₃) ₂ CH ₂ CH ₃	100.21	0.6936	-134.46	86.064	1.3909	-
2,4-dimethylpentane	(CH ₃) ₂ CHCH ₂ CH(CH ₃) ₂	100.21	0.6727	-119.24	80.5	1.3815	-12
3-ethylpentane (triethylmethane)	(C ₂ H ₅) ₃ CH	100.21	0.6982	-118.604	93.5	1.3934	-
2,2,3-trimethylbutane (isopropyltrimethylmethane; triptane)	(CH ₃) ₂ CHC(CH ₃) ₃	100.21	0.6901	-24.19	80.88	1.3894	-
n-octane	CH ₃ (CH ₂) ₆ CH ₃	114.23	0.7025	-56.79	125.66	1.3974	13
2-methylheptane	(CH ₃) ₂ CH(CH ₂) ₄ CH ₃	114.23	0.6980	-109.0	117.7	1.39494	-
3-methylheptane	C ₂ H ₅ CH(CH ₃)(CH ₂) ₃ CH ₃	114.23	0.70583**	-120.5**	118.9**	1.3985**	-
4-methylheptane (methyl dipropylmethane)	(C ₂ H ₅ CH ₂) ₂ CHCH ₃	114.23	0.70463	-121.0	117.7	1.39792	-
3-ethylhexane	(C ₂ H ₅) ₂ CHCH ₂ C ₂ H ₅	114.23	0.7136	-	118.5	1.4018	-
2,2-dimethylhexane	CH ₃ (CH ₂) ₃ C(CH ₃) ₃	114.23	0.69528	-121.18	106.84	1.39349	-
2,3-dimethylhexane	(CH ₃) ₂ CHCH(CH ₃)CH ₂ C ₂ H ₅	114.23	0.71214**	-	115.6**	1.40113**	-
2,4-dimethylhexane	C ₂ H ₅ CH(CH ₃)CH ₂ CH(CH ₃) ₂	114.23	0.70036**	-	109.4**	1.39534**	-
2,5-dimethylhexane	(CH ₃) ₂ CHCH ₂ CH ₂ CH(CH ₃) ₂	114.23	0.69354	-91.2	109.1	1.39246	-
3,4-dimethylhexane	CH ₃ CH ₂ CH(CH ₃)CH(CH ₃)CH ₂ CH ₃	114.23	0.7200	-	117.7	1.4046	-
3,3-dimethylhexane	CH ₃ (CH ₂) ₂ C(CH ₃) ₂ CH ₂ CH ₃	114.23	0.7100	-126.1	112.0	1.40009	-
2-methyl,3-ethylpentane	(CH ₃) ₂ CHCH(C ₂ H ₅) ₂	114.23	0.7193	-115.0	115.7	1.4040	-
3-methyl,3-ethylpentane	(C ₂ H ₅) ₃ CCCH ₃	114.23	0.7274	-90.87	118.26	1.4078	-
2,2,3-trimethylpentane	(CH ₃) ₃ CCCH(CH ₃)C ₂ H ₅	114.23	0.7161	-112.3	109.8	1.4030	-
2,2,4-trimethylpentane (isooctane)	(CH ₃) ₃ CCCH ₂ CH(CH ₃) ₂	114.23	0.6919	-107.4	99.2	1.3915	-12
2,3,3-trimethylpentane	C ₂ H ₅ C(CH ₃) ₂ CH(CH ₃) ₂	114.23	0.7262	-100.7	114.8	1.4075	-
2,3,4-trimethylpentane	(CH ₃) ₂ CHCH(CH ₃)CH(CH ₃) ₂	114.23	0.7191	-109.2	113.5	1.4042	5
2,2,3,3-tetramethylbutane	CH ₃ C(CH ₃) ₂ C(CH ₃) ₂ CH ₃	114.23	0.8242	-100.7	106.3	1.4695	-

*at 6 C

**For mixture of d and l isomers
From references 2-4

TABLE XII-4

SOLUBILITY OF ALKANE ISOMERS

Alkane	In Water	In Ethyl Alcohol	In Diethyl Ether	In Acetone	In Benzene
n-pentane	Slight	Soluble*	Soluble*	Soluble*	Soluble*
2-methylbutane	Insoluble	"	"	-	-
2,2-dimethylpropane	"	Soluble	Soluble	-	-
n-hexane	"	Very soluble	"	-	-
2-methylpentane	"	Soluble	"	Soluble*	Soluble*
3-methylpentane	"	"	Soluble*	"	"
2,2-dimethylbutane	"	"	Soluble	Very soluble	Very soluble
2,3-dimethylbutane	"	"	"	"	"
n-heptane	"	Very Soluble	Soluble*	Soluble*	Soluble
2-methylhexane	"	Soluble	"	"	Soluble*
3-methylhexane	"	"	"	"	"
2,2-dimethylpentane	"	"	Soluble	"	"
2,3-dimethylpentane	"	"	"	"	"
3,3-dimethylpentane	"	"	"	"	"
2,4-dimethylpentane	"	"	"	"	"
3-ethylpentane	"	"	"	"	"
2,2,3-trimethylbutane	"	"	"	Very soluble	Very soluble
n-octane	"	Soluble*	"	Soluble*	Soluble*
2-methylheptane	"	"	"	"	"
3-methylheptane	"	"	"	"	"
4-methylheptane	"	"	"	"	"
3-ethylhexane	"	"	Soluble*	"	"
2,2-dimethylhexane	"	Very soluble	"	"	"
2,3-dimethylhexane	"	Soluble*	Soluble	"	"
2,4-dimethylhexane	"	"	"	"	"
2,5-dimethylhexane	"	"	"	"	"
3,4-dimethylhexane	"	"	"	"	"
3,3-dimethylhexane	"	"	Very soluble	Very soluble	Very soluble
2-methyl,3-ethylpentane	"	"	Soluble	Soluble*	Soluble*
3-methyl,3-ethylpentane	"	"	"	"	"
2,2,3-trimethylpentane	"	"	Soluble*	"	Soluble
2,2,4-trimethylpentane	"	"	Soluble	"	Soluble*
2,3,3-trimethylpentane	"	Very soluble	Soluble*	"	"
2,3,4-trimethylpentane	"	"	"	"	"
2,2,3,3-tetramethylbutane	"	-	Soluble	-	-

*In all proportions

From reference 2

TABLE XII-5

POTENTIAL OCCUPATIONAL EXPOSURES
TO PENTANE, HEXANE, HEPTANE, AND OCTANE

Adhesive workers	Petroleum refinery workers
Automobile fuel handlers	Plastics manufacturing workers
Aviation fuel handlers	Polyethylene laminating workers
Cabinet finishers	Printers
Degreasing workers	Printing ink production workers
Farm fuel handlers	Resin makers
Furniture makers	Rubber cement workers
Glue fabrication workers	Shoe factory workers
Gluing machine operators	Solvent workers
Laboratory workers, chemical	Spray painters
Lacquerers	Stainers
Lacquer makers	Stain makers
Laminators	Synthetic chemical production workers
Leather cementers	Synthetic rubber workers
Metal degreasers	Thermometer makers, low temperature
Petrochemical process workers	Varnish makers
Petroleum distillation workers	Vegetable oil extraction workers
Petroleum extraction workers	Vinyl production workers

From references 11-15, 17-24, 26-31, 118

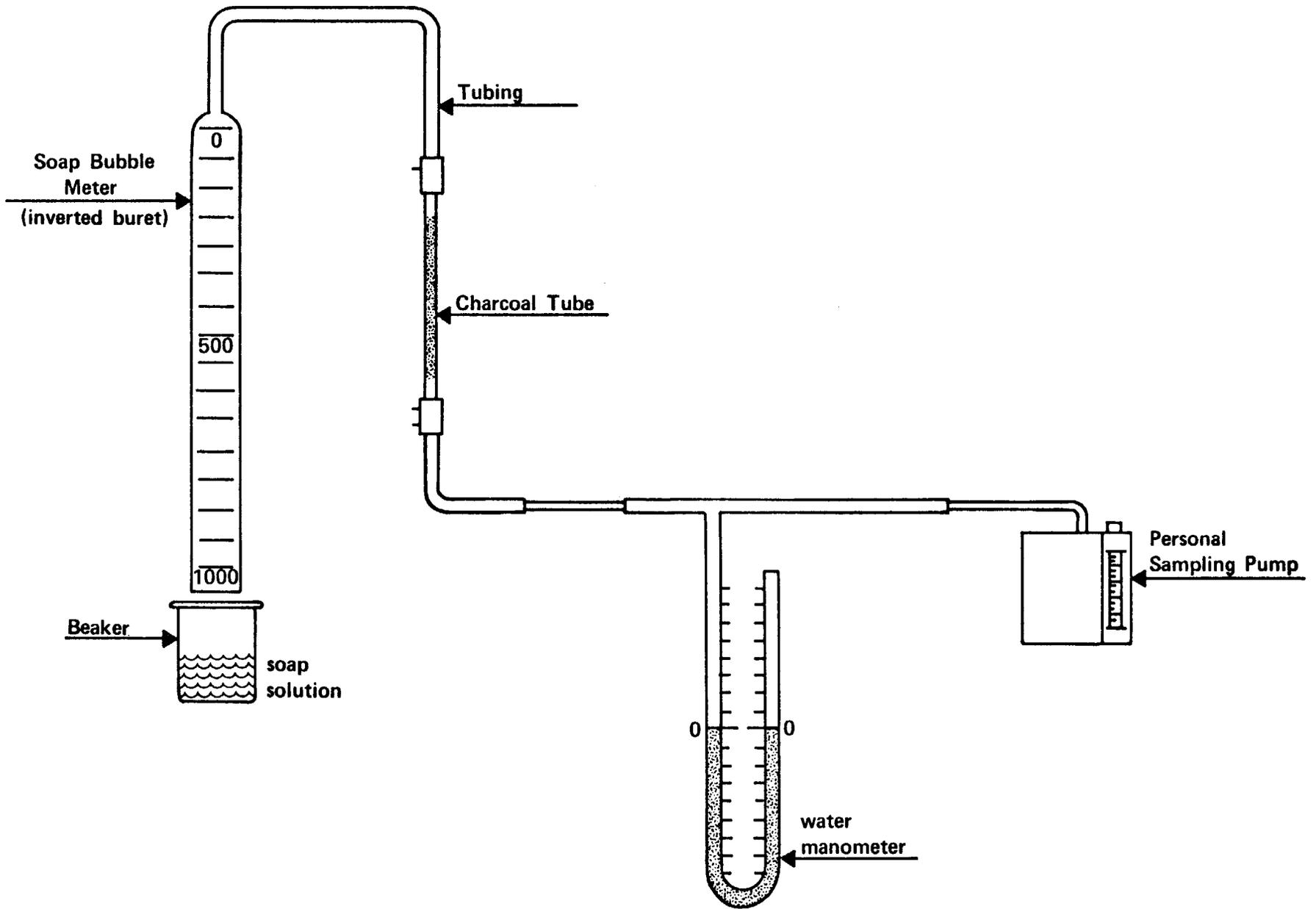


FIGURE XII-1

CALIBRATION SETUP FOR PERSONAL SAMPLING PUMP WITH CHARCOAL TUBE

DEPARTMENT OF
HEALTH, EDUCATION, AND WELFARE
PUBLIC HEALTH SERVICE
CENTER FOR DISEASE CONTROL
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