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TOXICITY DATA TO DETERMINE REFRIGERANT CONCENTRATION LIMITS

September 2000

prepared by

James M. Calm, P.E.
Engineering Consultant
10887 Woodleaf Lane
Great Falls, VA 22066-3003 USA

for the

Air-Conditioning and Refrigeration Technology Institute
4301 North Fairfax Drive, Suite 425
Arlington, VA 22203-1627 USA

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Please refer questions or comments on this document to:

James M. Calm, P.E.
Engineering Consultant
10887 Woodleaf Lane
Great Falls, VA 22066-3003 USA

phone: 703/450-4313
fax: 707/516-0552
e-mail: jmc@spectrum-internet.com

Glenn C. Hourahan, P.E.
Vice President
Air-Conditioning and Refrigeration Technology Institute
4301 North Fairfax Drive, Suite 425
Arlington, VA 22203-1627 USA

phone: 703/524-8800
fax: 703/522-2349
e-mail: hourahan@ari.org

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ABSTRACT: This report reviews toxicity data, identifies sources for them, and presents resulting exposure limits for refrigerants for consideration by qualified parties in developing safety guides, standards, codes, and regulations. It outlines a method to calculate an *acute toxicity exposure limit* (ATEL) and from it a recommended *refrigerant concentration limit* (RCL) for emergency exposures. The report focuses on acute toxicity with particular attention to lethality, cardiac sensitization, anesthetic and central nervous system (CNS) effects, and other escape-impairing effects. It addresses R-11, R-12, R-22, R-23, R-32, R-113, R-114, R-116, R-123, R-124, R-125, R-134, R-134a, R-E134, R-141b, R-142b, R-143a, R-152a, R-218, R-227ea, R-236fa, R-245ca, R-245fa, R-290, R-500, R-502, R-600a, R-717, and R-744. It summarizes additional data for R-14, R-115, R-170 (ethane), R-C318, R-600 (n-butane), and R-1270 (propylene) to enable calculation of limits for blends incorporating them. The report summarizes the data and related safety information, including classifications and flammability data. It also presents a series of tables with proposed ATEL and RCL concentrations — in dimensionless form and the latter also in both metric (SI) and inch-pound (IP) units of measure — for both the cited refrigerants and 66 zeotropic and azeotropic blends. They include common refrigerants, such as R-404A, R-407C, R-410A, and R-507A, as well as others in commercial or developmental status. Appendices provide profiles for the cited single-compound refrigerants and for R-500 and R-502 as well as narrative toxicity summaries for common refrigerants. The report includes an extensive set of references.

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TOXICITY DATA TO DETERMINE REFRIGERANT CONCENTRATION LIMITS

INTRODUCTION

This report reviews toxicity data, identifies sources for them, and presents resulting exposure limits for refrigerants. The data primarily address those pertinent to *acute* inhalation exposures from *emergency* releases rather than *chronic* exposures. *Acute* toxicity refers to the adverse health effects of a short-term, single exposure. *Chronic* toxicity refers to those from long-term or repeated exposures. *Emergency* signifies unplanned and unintended releases with a view toward mitigating risks for the general public. In contrast, *occupational* exposure limits assume that potentially affected personnel should be cognizant of the potential for exposures, have special awareness or training, and may employ protective measures or devices.

The specific data addressed are those pertinent to a proposed method to set recommended concentration limits, in turn to improve refrigeration safety. This report does not address how those limits should be applied, for example adjustments for specific building occupancies or circumstances. It also does not address measures to assure that the recommended limits are not exceeded, the combinatorial influences of other chemicals that may be present or released in an emergency, or the decomposition products from refrigerant breakdown in fires or other chemical reactions. Based on differences in individual sensitivities to chemical hazards, some people may experience adverse or even life-threatening affects from exposures below the recommended concentration limits.

The scope of this compilation is data gathering and analysis. This report does not present new test results, verify prior findings, or imply endorsement of the identified data. The compilation is intended to assist qualified safety professionals; it is not meant for use by individuals lacking training and experience in control of chemical hazards and refrigeration safety.

The refrigerants covered include those in common use for the last decade, those used as components in common blends, and selected candidates for future replacements.

The data and recommendations are not the result of a consensus determination. Rather this report documents input for consideration by qualified parties in developing guides, standards, codes, and regulations. The primary intended use of the data is to assist the project committees for ASHRAE Standard 34, *Designation and Safety Classification of Refrigerants*,[1] and in turn ASHRAE Standard 15, *Safety Code for Mechanical Refrigeration* (soon to be *Safety Code for Refrigeration*).[2] Indeed, some of the recommended data differ from working and review drafts, prepared by those committees, based on preliminary data from this effort and other sources.

PERSPECTIVE

Most of the dominant refrigerants for the past fifty years have been or are being replaced, to protect the stratospheric ozone layer and to reduce contributions to global warming. Much to

the credit of the air-conditioning and refrigeration industry, both chemical and equipment manufacturers have resisted compromise to either safety or performance in developing replacements. None of the alternative refrigerants commercialized are *highly toxic* or even *toxic* as classified by federal regulations.[3] Scrutiny of the new refrigerants shows them to be as safe or safer than those they replace.[4] Most safety concerns with the new refrigerants stem from lack of familiarity and necessary information rather than increased hazard levels.

The majority of early refrigerants — those applied before 1930 — were flammable, toxic, or both. The advent of fluorochemicals* ushered in a new era of safety, as illustrated by the dramatic demonstration by Thomas Midgley in April 1930. In announcing the development of fluorochemicals to the American Chemical Society, he inhaled R-12 and blew out a candle with it.[5] Although this dramatic stunt suggested that the new refrigerant was deemed safe for toxicity and flammability, it would clearly violate current safety practices.

As subsequent testing established the low toxicity of the new refrigerants, recognition emerged that the primary safety risks were the pressure hazards inherent to any compressed gas, asphyxiation from possible displacement of air, and frostbite with skin contact at low temperatures. These concerns were, however, common to the volatile compounds used before fluorochemicals. As the level of safety improved, so did expectations. Rules evolved to also address acute exposure hazards under emergency conditions, for example potential decomposition in fires into carbonyl halides as well as hydrochloric and hydrofluoric acids. New safety provisions also address the potential for cardiac sensitization and the effects of chronic exposures for both technicians and building occupants. These standards and regulations restrict the use of refrigerants, set quantity limits in occupied areas, impose isolation requirements for refrigerant-containing components and machinery rooms, and prescribe a range of detection, ventilation, pressure relief, emergency discharge, and other safety provisions.

Recent focus on the effects of refrigerants on the environment spawned three significant safety measures, namely system tightening, modification of service practices to reduce venting, and use of electronic refrigerant detectors. Although motivated by environmental protection, to curtail avoidable emissions, the results also lower both the likelihood and the concentrations of refrigerant exposures. The advent of reliable leak detectors affords a mechanism to warn of leaks before harmful concentrations are reached.

The combination of safer chemicals, system tightening, improved service practices, and use of leak detection has greatly reduced the hazard of refrigerant use. In contrast to safety risks that obstructed wide use of refrigerators 70 years ago, consumers presume such appliances and even much larger systems to pose negligible or at least acceptable safety risks. While very infrequent accidents and deaths from refrigerants still occur, most now result from failure to comply with safety requirements and recommended practices. The most dangerous part of working on refrigeration systems today is getting to and from the job site. The chance of death from a refrigerant exposure, excluding intentional abuse, now is more than twenty times less than of being killed by lightning.† Unlike lightning, refrigeration saves far more — perhaps several magnitudes more — lives each year than are lost in refrigerant-related accidents. The lives saved

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* compounds consisting of carbon, fluorine, and possibly hydrogen, other halogens such as chlorine, or other elements

† based on known incidents and published statistics for the United States from 1985-1999

and enhanced result from preservation of foods and pharmaceuticals, conditioning of indoor climates to counter severe heat, and enabling of essential technologies.

While the safety record should improve with new products and compliance with updated safety standards and codes, there still is room for further progress. This report addresses one facet of the problem, to recommend concentration limits as the basis for safety standards and codes to protect the public from unplanned exposures.

A brief review of the fundamental toxicity basis precedes that topic.

FUNDAMENTAL TOXICITY

*Dosis solo facit venenum.**

* ***The dose alone makes the poison***, a fundamental tenet of toxicology attributed to Paracelsus in the 16th century[6]

Toxicity Data to Determine Refrigerant Concentration Limits
James M. Calm, Engineering Consultant

EXPOSURE CONCENTRATION LIMITS

The principle from Paracelsus, *dosis solo facit venenum* (the dose alone makes the poison), is axiomatic to the objectives of this report. It suggests that exposures to refrigerants, or other chemicals, will not cause harm if kept to a safe level. The goal here is to determine that level — as a concentration — for a specified period of time, for common refrigerants, for the majority of people. It does not address exposure limits for people with rare conditions or taking special medications that may make them more sensitive or vulnerable.

Many steps can be taken to isolate refrigerants, to minimize the risks of human (and animal) exposures; they are a separate subject. The issue here is to quantify the concentration to which nearly all people can be exposed without harm. More specifically, the focus is on emergency exposures — those that may occur in unanticipated circumstances such as piping ruptures in occupied spaces. The goal is to determine objectively the highest concentration that will not harm people while they escape or until the refrigerant is removed (for example by ventilation or dissipation of the refrigerant to outside the space).

Such limits differ from occupational exposure limits, in which repeated exposures or potential exposures of worker are anticipated. Beyond using refrigerants with low toxicity, measures such as training, confinement, ventilation, special garments, or even self-contained-breathing apparatus may offer protection as appropriate to the refrigerants, tasks, and locations involved for occupational needs.

Emergency limits for public exposures are different. Most people are not trained or equipped for exposures and do not expect them. Indeed, exposures are infrequent and unlikely for most people.

The objective of this report is to propose data for and to calculate recommended concentration limits for unplanned releases. No practical limit assures complete safety. Differences in individual sensitivities, nonuniform mixing of releases, direct contact, abuse, occurrence of multiple catastrophic events, and similar additional factors may lead to injuries or death despite the best precautions. The method addressed herein builds on that embodied in ASHRAE 15, *Safety Code for Mechanical Refrigeration*,[2] which has provided a very high degree of protection.

EMERGENCY EXPOSURE DURATION

Consistent with ASHRAE 15 and underlying measures to calculate its refrigerant limits in unprotected spaces, the basis in the present work is a maximum exposure duration of 30 minutes. This length is admittedly somewhat arbitrary, but experience suggests that it is ample or even conservative in nearly all cases. Most buildings can be evacuated in less time; institutional oc-

cupancies* may warrant adjustments to the resulting limits, to compensate for longer evacuation times.

It is difficult to sustain high concentrations of refrigerants. Low-pressure refrigerants (typically those with atmospheric boiling points near or exceeding room temperature) are of low volatility and do not reach high concentrations under the conditions normally maintained in buildings. Indeed, with operation at subatmospheric pressures, air typically is sucked in rather than refrigerant escaping in the event of a leak. Even a catastrophic spill remains a liquid and yields comparatively low airborne concentrations. High-pressure refrigerants (typically those with atmospheric boiling points below or well below room temperature) quickly diffuse into the surrounding space, but then escape out of building openings — also quickly. As a result, they reach high concentrations, but generally only for short periods. The controlling "magic" in both cases is refrigerant volatility, an essential selection criterion for common refrigeration cycles.

Building ventilation helps, but cannot be assumed to function under all emergency conditions. Conversely, catastrophic emergencies — such as earthquakes and explosions — often create new openings by shattering windows, skylights, or even structural holes, thereby increasing ventilation.

Neither low nor high volatility assures safety. Elevated temperatures may increase concentrations or concentration spikes. Sealed areas may sustain them. The 30-min criterion is no more than a planning measure, not a guarantee. Other safety measures as specified in ASHRAE 15; similar safety standards; in building, fire, and mechanical codes and regulations; and incorporated into refrigeration equipment and systems provide further — but not absolute — protection.

As discussed below (see pages 9 and 19), some of the toxicity measures are based on exposure tests for shorter intervals. Some toxic effects develop quickly and then stay level or even decrease with time. Others can be extrapolated for selected intervals as reflected in the methodology proposed. Still others are intentionally longer to be conservative, based on the severity of consequences or inadequacy of samples.

EFFECTS

The method proposed concentrates on toxicity, oxygen deprivation (asphyxiation), and flammability. Within toxicity, it focuses on lethality, cardiac sensitization, anesthetic effects, and a catch-all category of other escape-impairing and or permanently injuring effects. The first three types of toxicity are deemed those most pertinent for protection against acute, emergency exposures and the fourth category allows latitude for special cases, as follows:

- *Lethality* (or mortality) indicates the likelihood of toxic fatalities from exposure, without regard to the mechanism except to exclude those from dismemberment, crushing, burning, or similar physical harm. Review of the toxicity studies cited below shows that the causes of death found in animal exposures varied in the affected organs or biological systems. The pertinent path is by inhalation, based on the premise that neither normal use nor emergency release of refrigerants is likely to result in sufficient dermal (skin) contact or ingestion (oral) to be issues. Some of the refriger-

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* Examples of *institutional* occupancies include those for care of disabled people such as hospitals and convalescent homes, care or education of infants such as nurseries, and housing of confined people such as prisons.

ants addressed herein (see page 35) either are or previously have been used for direct-contact food freezing, food propellants, or foam blowing agents for food packaging. Likewise, some either are or previously have been used as propellants in cosmetic, pharmaceutical, or other aerosol products. Some either are or previously have been used as topical, dental, or surgical anesthetic agents or as solvents in consumer and industrial products. Some either are or previously have been used as fire suppressants or in a range of specialty applications such as expansion gases for retinal eye surgery. The relevant toxicities for those applications, including both acute and chronic effects, go beyond the present scope.

- *Cardiac sensitization* refers to an acute effect in which the heart is rendered more sensitive to the body's own catecholamine compounds* or administered drugs, such as epinephrine, possibly resulting in irregular heart beat (cardiac arrhythmia) that could be fatal.
- *Anesthetic effect* refers to dulling of the senses, as manifested in loss of the ability to perceive pain and other sensory stimulation. Some toxicologists include impairment of judgement or mental ability to respond while others deem it to include only analgesia (insensibility to pain without loss of consciousness) or induced loss of consciousness. *Central nervous system (CNS) effects* include depression, distraction, stimulation, or other behavioral modification suggesting temporary or permanent changes to control by the brain. As addressed herein, anesthetic and central nervous system effects exclude those from intentional abuse (deliberate refrigerant inhalation seeking either a narcotic effect from either chemical induction or oxygen deprivation), sometimes referred to as "sniffing," for which the only safe limit is zero.
- *Other escape impairing effects or permanent injuries* include any effect that is likely to impede the ability to escape (such as distraction, blinding, tearing of the eyes sufficiently to reduce vision, or severe sensory irritation) or to cause other irreversible health effects (such as damage to or lesions in skin or other tissues that is not self-healing).

There are many other forms of toxicity, such as carcinogenicity and reproductive effects. They warrant consideration in selection or regulation to protect exposed technicians. The effects addressed herein are those deemed pertinent to acute inhalation exposures from emergency releases rather than chronic exposures.

QUANTIFICATION

Toxicologists refer to the concentrations, determined by toxicity studies, that bracket the threshold (or trigger) effect level for specified exposure periods based on the number of subjects of the sample tested that show no or some treatment-related response. These concentration levels are the *dose* that makes the *poison* for specified exposure durations, biological species, and

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* Catecholamines include adrenaline or adrenaline like chemicals that consist of benzene rings with attached groups of nitrogen and halogen atoms or nitrogen and halocarbon or hydrocarbon radicals. They function in the body as hormones, neurotransmitters, or both: The body's adrenal glands release them under conditions of stress or strong emotion such as fear or anger. Medical injections of epinephrine as a stimulant in cardiac arrest, as a vasoconstrictor in shock, and as a bronchodilator and antispasmodic in bronchial asthma have similar effects.

conditions. The species tested, typically laboratory animals such as mice, rats, dogs, or monkeys but sometimes bacteria or plants, are selected for their suitability as models of specific toxic effects in humans or the environment.

The three effect levels used in the method described herein are the:

- *no observed effect level (NOEL)* — the highest concentration of a material, a refrigerant in the present context, at which no effect has been observed in even one tested animal.
- *lowest observed effect level (LOEL)* — the concentration of a material, a refrigerant in the present context, that has caused an observed effect to even one tested animal.
- *median effective concentration (EC_{50})* — the concentration of a material, a refrigerant in the present context, that has caused a biological effect to half the animals tested. EC_{50}s generally are calculated estimates from regression of the test data based on accepted methods.

Some toxicologists prefer to cite *no observed adverse effect level (NOAEL)* or the *lowest observed adverse effect level (LOAEL)* to exclude effects deemed of no toxicological import. Similarly, some toxicologist prefer no or lowest *observable* rather than no *observed*. Except as specifically noted, subsequent references in this report to NOEL and LOEL concentrations make no distinction between *NOEL* and *NOAEL*, between *LOEL* and *LOAEL*, or *observed* and *observable*.

Toxicologists sometimes refer to specific forms of the NOEL, LOEL, and EC_{50} concentrations, namely the:

lethality

- *median lethal concentration (LC_{50})* — an EC_{50} for lethality. It is the concentration that is fatal to half of exposed animals for an identified species and exposure duration either during the exposure or during a subsequent recovery and observation period. The LC_{50} is a primary measure of acute toxicity by inhalation of gases. It most commonly is measured with rats for exposures of four hours. A number of federal regulations in the USA (for example reference 1) and most building, fire, and mechanical codes deem substances to be *toxic* for a one-hour LC_{50} of 200–2,000 ppm v/v and *highly toxic* for less than 200 ppm v/v. Based on adjustments discussed on page 11, typical LC_{50} concentrations for four hours are approximately equivalent in effect to half of those for one hour. This extrapolation suggests corresponding criteria for *toxic* substances of a 4-hr LC_{50} of 100–1,000 ppm v/v and *highly toxic* substances for less than 100 ppm v/v.
- *median lethal dose (LD_{50})* — an EC_{50} for lethality. The LD_{50} generally is used to quantify exposures in dermal (skin) and ingestion (oral) toxicity studies, but some old papers also use LD_{50} in place of LC_{50} for inhalation studies.
- *approximate lethal concentration (ALC)* — a LOEL for lethality. It is the lowest concentration that is fatal to one or more exposed animals for an identified species and exposure duration. It most commonly is measured with rats for inhalation exposures of four hours. The ALC is now more widely used to minimize the number of animals killed in testing, since further tests at higher concentrations and the larger sample sizes needed to determine an LC_{50} can be avoided. The ALC is a conservative ap-

proximation to the LC_{50} as long as the ALC was fatal to less than half the animals exposed. It is a close approximation, but not necessarily conservative, when fatal to exactly half the animals tested.

- *approximate lethal dose (ALD)* — a LOEL for lethality. The ALD generally is used to quantify exposures in dermal and ingestion toxicity studies, but some old papers also use ALD in place of ALC for inhalation studies.
- *minimal lethal concentration* or *minimum lethal concentration (MLC)* — alternative descriptors for ALC.

cardiac sensitization

- *median cardiac sensitization concentration (CS_{50})* — an EC_{50} for cardiac sensitization. It is the concentration that sensitizes the hearts of half of animals exposed by inhalation and given an epinephrine (or similar) challenge by injection for an identified species and exposure duration. It most commonly is measured with beagle dogs based on their aptitude for training for this test and their suitability as a model for human cardiovascular responses. Most studies simply refer to an EC_{50} for cardiac sensitization rather than a CS_{50}.

anesthetic or central nervous system (CNS) effects

- *anesthetic concentration (AC_{50})* — an EC_{50} for anesthetic or CNS effects. It is the concentration that caused an anesthetic or CNS effect in half of test animals, normally measured for 10 minute exposures of mice or rodents. Most studies simply refer to an EC_{50} for anesthetic effect rather than an AC_{50}.
- *approximate anesthetic concentration (AAC)* or *approximate anesthetic dose (AAD)* — a LOEL for anesthetic or CNS effects. It is the concentration that caused an anesthetic or CNS effect in one or more test animals. Most studies simply refer to a LOEL for anesthetic effect rather than an AAC or AAD.

other

- *median rate decrease (RD_{50}) for respiration* — the concentration that resulted in 50% decrease in respiratory rate, normally measured in mice. A maximal effect generally occurs in less than 30 minutes; the response to R-717 (ammonia), as an example, takes approximately two minutes (see page 80).

TEN BERGE ADJUSTMENT

The exposure time used to test the lethality of chemicals differs between studies. The norm is 30 min or less for most old studies and in those explicitly gauging the effects of brief exposures. Most recent tests, particularly those of chemicals with low acute inhalation toxicity, are for intervals of 4 hours or longer to increase reliability. The Programme for Alternative Fluorocarbon Toxicity Testing (PAFT) studies, drawn on herein for some data for new refrigerants, used four-hour tests.[7,8]

There are several ways to estimate consistent LC_{50}s or ALCs determined for different time periods. Haber's law, a tenet of toxicology, states that different concentrations have the same lethal effect when the product of the exposure concentration and duration — $c \cdot t$ (where c is concentration and t is time) — is constant for small differences in time,[6,9] hence:

$LC_{50\ for\ T} = LC_{50\ for\ t} \cdot (t/T)$
or
$ALC_T = ALC_t \cdot (t/T)$

where:

T is the desired lethality indication time, and
t is the exposure time from the study being adjusted.

A widely cited study by ten Berge et al. found that treating $c^n \cdot t$ as constant — with the added exponent n — affords better prediction.[10] They found that n ranged from 0.8 to 3.5, with an average of 1.86, for 20 different chemicals. That finding suggests that:

$LC_{50\ for\ T} = LC_{50\ for\ t} \cdot (t/T)^{1/n}$
or
$ALC_T = ALC_t \cdot (t/T)^{1/n}$

where:

n is the ten Berge et al. exponent.

Inspection shows that Haber's law and the ten Berge adjustment are the same for n=1. In determining the NIOSH IDLH concentrations (discussed below), Ludwig et al. use the coefficients for the chemicals studied by ten Berge et al. and a coefficient of n=3.0 for other substances.[11] The *International Fire Code*,[12] *International Maritime Dangerous Goods Code*,[13] and *Uniform Fire Code*[14] use n=2.0, which is the coefficient that ten Berge et al. report for five chemicals including HF (hydrofluoric acid) and R-717 (ammonia).[10] The indication by Ludwig et al. that n=3.0 is "a conservative estimate" usually holds true as they used it, namely to estimate 30-minute lethal concentrations most often from studies for longer periods.[11] Whereas n=2.0 is more conservative than n=3.0 to estimate four-hour lethality from studies for shorter periods, and since n=2.0 is widely accepted in codes as noted, the exponent n=2.0 is used for the remainder for this report except where indicated.

EXPOSURE LIMITS AND TOXICITY INDICATORS

The following paragraphs explain several related terms that are cited in the discussion of toxicity data to arrive at the concentration limits or of those limits:

immediately dangerous to life and health (IDLH) concentration — a measure developed as a criterion for respirator selection. Some safety standards as well as building, fire, and mechanical codes subsequently applied IDLH concentrations to approximate the threshold level for unacceptable toxicity or flammability risk.* The U.S. National Institute for Occu-

* Although widespread, these uses beg controversy as inconsistent with the IDLH definition and for clouding of occupational and emergency risk criteria. Nevertheless, most fire codes in the USA use the IDLH, typically reduced by a safety factor, as a criterion for ventilation rates and emergency discharge treatment for refrigerants and other hazardous materials. ASHRAE 15 also uses the SCP IDLH as one of several criteria to determine allowed refrigerant quantities for occupied areas.

pational Safety and Health (NIOSH) and U.S. Occupational Safety and Health Administration (OSHA) jointly promulgated the original IDLH values in the mid-1970s as part of the Standards Completion Program (SCP). The SCP definition for IDLH was "the maximum concentration from which, in the event of a respirator failure, one could escape within 30 minutes without a respirator and without experiencing any escape-impairing (e.g., severe eye irritation) or irreversible health effects." A NIOSH revision in 1994 defines the IDLH concentration as one "that poses a threat of exposure to airborne contaminants when that exposure is likely to cause death or immediate or delayed permanent adverse health effects or prevent escape from such an environment." The new IDLHs reflect additional toxicity criteria and data as well as a more restrictive multiplier for flammability, reduced from 100% to 10% of the lower-flammability limit (LFL). Of the 387 IDLH concentrations, the revision lowered all but 56 and raised none.

permissible exposure limit (PEL) — the occupational concentration limit established by OSHA. Without qualification, the PEL implies a time-weighted average (TWA) for an eight-hour work shift in a 40-hour work week. Consistent data include similarly-defined limits set by manufacturers, the Recommended Exposure Limit (REL) set by NIOSH,[15] the Threshold Limit Value (TLV) adopted by the American Conference of Governmental Industrial Hygienists (ACGIH),[16] and the Workplace Environmental Exposure Level (WEEL) guides developed by the American Industrial Hygiene Association (AIHA).[9] Several countries also publish similar measures, of which the German *Maximale Arbeitsplatz Konzentration* (MAK, maximum workplace concentration) is the most commonly cited.[17,18] Where designated as a PEL-C (for example for R-11), the PEL is a *ceiling* concentration that shall not be exceeded. Most codes specify either the PEL or TLV-TWA values and consistent measures as the maximum activation levels for refrigerant leak-detector alarms. While the PEL and TLV-TWA are similarly defined, and the original PELs were based on TLVs, the PEL values have not been revised since 1971. More protective limits published in 1989 were vacated by a court order in 1992. ACGIH publishes annual TLV updates. Still, neither PELs nor TLVs have been set for most alternative refrigerants, for which the primary recourse is use of WEELs or other consistent measures. Some manufacturers identify their consistent or modified limits for refrigerants and other chemicals as a PEL while others use the terms allowable exposure limit (AEL), industrial exposure limit (IEL), or occupational exposure limit (OEL).

ASHRAE 34 safety group — This classification consists of a letter (A or B), which indicates the toxicity class, followed by a number (1, 2, or 3), which indicates the flammability class.[1] Toxicity classes A and B signify refrigerants with *lower toxicity* and *higher toxicity*, respectively, based on prescribed measures of chronic (long-term, repeated exposures) toxicity.* Flammability class 1 indicates refrigerants that do not show flame propagation in air when tested by prescribed methods at specified conditions. Classes 2 and 3 signify refrigerants with *lower flammability* and *higher flammability*, respectively; the distinction depends on both the LFL and heat of combustion (HOC). Some of the mechanical codes written before 1993 used an older safety classification system from earlier editions of ASHRAE 34.[19] They included groups 1 (no flame propagation and low degree of toxicity), 2 (TLV-TWA less than 400 ppm), 3a (flammable with low LFL or high HOC), 3b (flammable with high LFL and low HOC), 4a (mixtures of groups 1 and 3a that are nonflammable

* The distinction is based on the data used to determine the TLV-TWA or consistent measures. Those with no identified toxicity at 400 ppm v/v or less are assigned to Class A, and those with identified toxicity at 400 ppm v/v or less are assigned to Class B.

as formulated, but could become flammable upon fractionation), and 4b (mixtures of groups 1 and 3b that are nonflammable as formulated, but could become flammable upon fractionation). Excluding the group 2 refrigerants, the ranked order from the lowest to highest flammability hazard was 1, 4b, 4a, 3b, and 3a. One motive for the current classification system, introduced in 1992, was to provide a more rational system.

quantity limits for occupied areas — the primary criterion to determine whether refrigeration systems, or refrigerant-containing components, are allowed in occupied areas of buildings. The limits are set by ASHRAE 15 and by building, fire, and mechanical codes.[2] Nearly all limits set in the codes are transcribed from ASHRAE 15 (or earlier versions of this standard), though a few intended and unintended revisions are included.

UL group — the Underwriters Laboratories classification reflects the comparative life hazard of refrigerants in the absence of flames or surfaces at high temperatures. Group 1 is the most toxic (for example R-764, sulfur dioxide) and group 6 the least.[20] This measure is used to classify refrigerants in older codes, still in effect in some jurisdictions.

PROPOSED METHOD

The method developed to determine a recommended *refrigerant concentration limit* (RCL) for each refrigerant, on a consistent basis, is rooted in the "quantity of refrigerant per occupied space" from ASHRAE Standard 15, *Safety Code for Mechanical Refrigeration*.[2] The standard provides that it shall be "the maximum amount of refrigerant that will leak into the occupied space at any one time, based on a leak from any single independent refrigerant circuit." Although referred to as a "quantity" in ASHRAE 15 and most safety code provisions derived from that standard, the limit actually is a concentration. The *quantity limit* is the product of this concentration and the calculated volume of the space. The concentration limit (or quantity limit) may be exceeded in certain circumstances with adherence to identified provisions, most commonly isolation of the portions of the system containing refrigerant in a *refrigeration machinery room* that meets prescribed safety requirements. Use of refrigeration machinery rooms is standard practice for large systems and sometimes opted even when not required. Neither ASHRAE nor most codes place a limit on the amount of refrigerant allowed in a refrigeration machinery room except in the case of flammable refrigerants.

Many of the specific requirements in ASHRAE 15 are based on safety classifications* from ASHRAE 34.[1] The latter standard is the definitive source for assignment of refrigerant number designations. It also provides a safety classification system and assigned classifications.

The RCL determination method† was first proposed to the separate project committees developing ASHRAE 15 and 34 on 1995.09.04 for incorporation into these consensus standards, which are the basis for most refrigerant safety regulations both in the USA and internationally. By agreement of the two standards committees, the one for ASHRAE 34 and initially its Designations and Nomenclature Subcommittee and now its Toxicity Subcommittee are taking the lead to incorporate the method into a consensus standard. The subcommittee addressing *Safety of Refrigeration Systems* of the International Standards Organization (ISO) Technical Committee

* The key distinctions in ASHRAE 15 and code requirements relate to the flammability component of the safety group. As discussed on page 105, the toxicity component of the classification is of minor consequence.

† The initial draft identified the RCL as the *Recommended Quantity Limit* (RQL) in keeping with ASHRAE 15, but SSPC 34 recommended revision to reflect its quantification as a *concentration* rather than an absolute amount. The text shown starting on page 19 reflects minor revisions subsequently proposed to and/or recommended by SSPC 34.

The draft method was placed in the public domain to avoid copyright complications and to facilitate its adoption in standards and codes. The following note was included in the original proposal and subsequent revisions: "As the author of part or all of [the Proposed Revision to ANSI/ASHRAE Standard 34-1992], James M. Calm, Engineering Consultant, is placing the original portion in the public domain. The author grants to ASHRAE and to all other parties nonexclusive and royalty-free permission to publish, reproduce, sell, or reprint it, in whole or in part and in its present form or with modifications. No warranty is implied that portions of this document have not been copyrighted previously by other parties."

on *Refrigeration and Air Conditioning* — "ISO TC86/SC1/WG1" and "ISO TC86/SC1/WG5" — are drafting amendments to the pertinent international standards to incorporate the method, possibly with changes still being debated.

PROPOSED REVISIONS TO ASHRAE 34

The RCL is the lowest of three independently calculated limits for toxicity, oxygen deprivation, and flammability. The toxicity component is identified as the *acute toxicity exposure limit* (ATEL), based on the most restrictive of four effects addressed above (see page 8). The method is currently pending a third public review, previously identified as proposed addendum 34aa to 34-1992 and now as proposed addendum 34u to 34-1997, for revision of ASHRAE 34.

For context, the following terms already are defined in ASHRAE 34:[1]

> *acute toxicity*: the adverse health effect(s) from a single, short-term exposure, as might occur during an accidental release of refrigerants.
>
> *cardiac sensitization*: an acute effect in which the heart is rendered more sensitive to the body's own catecholamine compounds or administered drugs, such as epinephrine, possibly resulting in irregular heartbeat (cardiac arrhythmia), which could be fatal.
>
> *ceiling*: an exposure level, permissible exposure level-ceiling (PEL-C) or threshold limit value-ceiling (TLV-C), that should not be exceeded during any part of the day.
>
> *chronic toxicity*: adverse health effect(s) from long-term, repeated exposures. This information is used, in part, to establish a TLV-TWA, PEL, or consistent indices.
>
> LC_{50}: a measure of acute, inhalation toxicity representing a lethal concentration for 50% of exposed test animals for a specified time interval and species of animal.
>
> *ppm*: parts per million
>
> *permissible exposure limit (PEL)*: the time-weighted average concentration (set by OSHA, the U.S. Occupational Safety and Health Administration) for a normal 8-hour work day and a 40-hour work week to which nearly all workers can be repeatedly exposed without adverse effect. Chemical manufacturers publish similar recommendations (e.g., acceptable exposure level, AEL; industrial exposure limit, IEL; or occupational exposure limit, OEL; depending on the company), generally for substances for which PEL has not been established.
>
> *refrigerant*: the fluid used for heat transfer in a refrigerating system; the refrigerant absorbs heat and transfers it at a higher temperature and a higher pressure, usually with a phase change
>
> *short-term exposure limit (STEL)*: typically a 15-minute time-weighted average (TWA) exposure that should not be exceeded any time during a work day.
>
> *threshold limit values (TLVs)*: refer to airborne concentrations of substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse health effects. Because of wide variation in individual susceptibility, however, a small percentage of workers may experience discomfort

from some substances at concentrations at or below the threshold limit; a smaller percentage may be affected more seriously by aggravation of a pre-existing condition or by development of an occupational illness. Smoking of tobacco is harmful for several reasons. Smoking may act to enhance the biological effects of chemicals encountered in the workplace and may reduce the body's defense mechanisms against toxic substances.

Individuals may also be hypersusceptible or otherwise unusually responsive to some industrial chemicals because of genetic factors, age, personal habits (smoking, use of alcohol or other drugs), medication, or previous exposure. Such workers may not be adequately protected from adverse health effects from certain chemicals at or below the threshold limits. An occupational physician should evaluate the extent to which such workers require additional protection.

TLVs are based on the best available information from industrial experience, from experimental human and animal studies, and, when possible, from a combination of the three. The basis on which the values are established may differ from substance to substance; protection against impairment of health may be a guiding factor for some, whereas reasonable freedom from irritation, narcosis, nuisance, or other forms of stress may form the basis for others.*

threshold limit value–time-weighted average (TLV-TWA): the time-weighted average concentration for a normal 8-hour workday and a 40-hour workweek, to which nearly all workers may be repeatedly exposed, day after day, without adverse effect.*

toxicity: the ability of a refrigerant to be harmful or lethal due to acute or chronic exposure by contact, inhalation, or ingestion: The effects of concern include, but are not limited to, those of carcinogens, poisons, reproductive toxins, irritants, corrosives, sensitizers, hepatoxins [hepatotoxins], nephrotoxins, neurotoxins, agents that act on the hematopoietic system, and agents that damage the lungs, skin, eyes, or mucous membranes. For this Standard, temporary discomfort at a level that is not impairing is excluded.

WEEL: workplace environmental exposure limit (set by the American Industrial Hygiene Association, AIHA)

* The definition in ASHRAE 34 is reprinted from ACGIH.[21] An ACGIH update adds:[16]

"The amount and nature of the information available for establishing a TLV varies from substance to substance; consequently, the precision of the estimated TLV is also subject to variation and the latest TLV *Documentation* should be consulted in order to assess the extent of the data available for a given substance.

"These limits are intended for use in the practice of industrial hygiene as guidelines or recommendations in the control of potential workplace health hazards and for no other use, e.g., in the evaluation or control of community air pollution nuisances; in estimating the toxic potential of continuous, uninterrupted exposures or other extended working periods; as proof or disproof of an exiting disease or physical condition; or adoption or use by countries whose working conditions or cultures differ from those in the United States of America and where substances and processes differ. These limits are *not* fine lines between safe and dangerous concentrations, nor are they a relative index of toxicity. They *should not* be used by anyone untrained in the discipline of industrial hygiene.

"The TLVs, as issued by ACGIH, are recommendations and should be used as guidelines for good practices. In spite of the fact that serious adverse health effects are not believed likely as a result of exposures to the threshold limit concentrations, the best practice is to maintain concentrations of all atmospheric concentrations as low as is practical."

The section numbers in the text that follows refer to sections of ASHRAE 34:[1]

New Definitions

Add new definitions to ASHRAE 34 section 3 as follows:

acute-toxicity exposure limit (ATEL): the refrigerant concentration limit determined in accordance with this Standard and intended to reduce the risks of acute toxicity hazards in normally occupied, enclosed spaces. ATEL values are similar to the Immediately Dangerous to Life or Health (IDLH) concentrations, set by the National Institute of Occupational Safety and Health (NIOSH). ATELs include explicit, additional components for cardiac sensitization and anesthetic effects, but do not address flammability. The lowest of the ATEL, 50,000 ppm v/v, or 10% of the LFL, therefore, provides a conservative approximation to IDLH concentrations, when needed for refrigerants without adopted IDLH values.

approximate lethal concentration (ALC): the concentration of a substance, a refrigerant in this Standard, that was lethal to even a single test animal when tested by the same conditions as for an LC_{50} test.

anesthetic effect or *anesthesia*: loss of the ability to perceive pain and other sensory stimulation.

EC_{50}: effective concentration 50%, the concentration of a material, a refrigerant in this Standard, that has caused a biological effect to 50% of test animals.

flammable concentration limit (FCL): the refrigerant concentration limit, in air, determined in accordance with this Standard and intended to reduce the risk of fire or explosion in normally occupied, enclosed spaces.

lowest observed effect level (LOEL): the concentration of a material, a refrigerant in this Standard, that has caused any observed effect to even one test animal.

no-observed effect level (NOEL): the highest concentration of a material, a refrigerant in this Standard, at which no effect has been observed in even one test animal.

oxygen deprivation limit (ODL): the concentration of a refrigerant or other gas that results in insufficient oxygen for normal breathing. For this Standard, the ODL is the concentration that reduces the oxygen content in normal air to below 19.5%, assuming uniform mixing.

refrigerant concentration limit (RCL): the refrigerant concentration limit, in air, determined in accordance with this Standard and intended to reduce the risks of acute toxicity, asphyxiation, and flammability hazards in normally occupied, enclosed spaces.

RCL Determination

Also, add a new section to ASHRAE 34 as follows:

7. REFRIGERANT CONCENTRATION LIMIT (RCL)

7.1 Single-Compound Refrigerants. The RCL for each refrigerant shall be the lowest of the quantities calculated in accordance with 7.1.1, 7.1.2, and 7.1.3, using data as indicated in 7.3, and adjusted in accordance with 7.4. Determination shall assume full vaporization; no removal by ventilation, dissolution, reaction, or decomposition; and complete mixing of the refrigerant in the space to which it is released.

7.1.1 Acute-Toxicity Exposure Limit (ATEL). The ATEL shall be the lowest of items (a)-(d) as follows:

(a) Mortality: 28.3% of the 4-hour LC_{50} for rats. If not determined, 28.3% of the 4-hour ALC for rats provided that it did not result in mortality for more than half the exposed animals. If neither has been determined, 0 ppm. The following equations shall be used to adjust LC_{50} or ALC values that were determined with 15-minute to 8-hour tests, for refrigerants for which 4-hour test data are not available:

$$LC_{50\ for\ T} = LC_{50\ for\ t} \cdot (t/T)^{1/2}$$
or
$$ALC_T = ALC_t \cdot (t/T)^{1/2}$$

where:

T is 4 hours, and
t is the test duration expressed in hours, 0.25-8

(b) Cardiac Sensitization: 100% of the NOEL for cardiac sensitization in unanesthetized dogs. If not determined, 80% of the LOEL for cardiac sensitization in dogs provided that the LOEL did not induce sensitization in more than half the exposed animals. If neither has been determined, 0 ppm. The cardiac sensitization term is omitted from ATEL determination if the LC_{50} or ALC in (a) is less than 10,000 ppm v/v or if the refrigerant is found, by toxicological review, to not cause cardiac sensitization.

(c) Anesthetic Effect: 50% of the 10-minute EC_{50} for anesthesia in mice or rats. If not determined, 50% of the LOEL for signs of anesthesia in rats during acute toxicity studies, provided that the LOEL did not induce an anesthetic effect for more than half the exposed animals. If neither has been determined, 80% of the NOEL for signs of anesthesia in rats during an acute, subchronic, or chronic toxicity study in which clinical signs were documented.

(d) Other Escape-Impairing Effects and Permanent Injury: The lowest concentration, for human exposures of 30 minutes, that is likely to impair ability to escape or to cause either irreversible health effects or severe sensory irritation.

7.1.2 Oxygen Deprivation Limit (ODL). The ODL shall be 69,100 ppm v/v.

7.1.3 Flammable Concentration Limit (FCL). The FCL shall be calculated as 25% of the LFL determined in accordance with 6.1.3.

7.2 Blends. The RCL for refrigerants comprising multiple compounds shall be determined by the method in 7.1 except that individual parameter values in 7.1.1 (a) though (d) shall be calculated as the mole-weighted average, by composition of the nominal formulation, of the values for the components.

7.3 Data for Calculations. The data used to calculate the RCL shall be taken from scientific and engineering studies or published safety assessments by governmental agencies or expert panels. Source studies for toxicity data must comply with Good Laboratory Practices (GLP) in accordance with reference 6, 7, 8, or 9. Data from peer-reviewed publications, including journal articles and reports, also are allowed.

7.3.1 Alternative Data. Data from studies that have not been published, from studies that have not been peer reviewed, or from studies involving species other than indicated in 7.1.1 (a)-(d), shall be submitted to the authority having jurisdiction (AHJ) for approval. For RCL values to be published in addenda or revisions to this Standard, the AHJ shall be the Committee. Submissions shall include an evaluation of the experimental and analytical methods used, data from alternative sources, and the extent of the data search. The submissions shall summarize the qualifications of the person or persons providing the evaluation.

7.3.2 Consistent Measures. Use of data that are determined in a consistent manner, or by methods that consistently yield a lower RCL for the same effects, is allowed for the parameters identified in 7.1.

7.3.3 No-Effect Data. Where no treatment-related effect was observed in animal tests for items 7.1.1 (a)-(d), the ATEL calculation required by 7.1.1 shall use the highest concentration tested in lieu of the specified effect or no-effect level.

7.3.4 Conservative Data. Where multiple data values have been published, the values used shall be those resulting in the lowest RCL.

EXCEPTIONS:

1. Where subsequent, peer-reviewed studies explicitly document flaws in or refinements to previously published data, the newer values shall be used.

2. For the cardiac sensitization and anesthetic effect NOEL in 7.1.1 (b) and (c), respectively, the highest-published NOEL not exceeding a published LOEL, for any fraction of tested animals, shall be used. Both the NOEL and LOEL must conform to 7.3 or 7.3.1 for this exception.

7.4 Units Conversion

7.4.1 Mass per Unit Volume. The following equation shall be used to convert the RCL from a volumetric ratio, ppm v/v, to mass per unit volume, kg/m^3 (lb/Mcf):

$rcl = RCL \cdot a \cdot M$

where:

rcl = the RCL expressed as kg/m^3 (lb/Mcf)
RCL = the RCL expressed as ppm v/v
a = $4.096 \cdot 10^{-8}$ for kg/m^3 ($2.557 \cdot 10^{-6}$ for lb/Mcf)*
M = the molecular mass of the refrigerant

7.4.2 Adjustment for Altitude. The RCL shall be adjusted for altitude, when expressed as mass per unit volume, kg/m^3 (lb/Mcf), for locations above sea level. The RCL shall not be adjusted when expressed as a volumetric ratio in ppm.

$rcl_a = rcl \cdot (1-(b \cdot h))$

where:

rcl_a = the adjusted rcl
b = $7.94 \cdot 10^{-5}$ for m ($2.42 \cdot 10^{-5}$ for ft)
h = altitude above sea level in m (ft)

7.5 RCL Values. Refrigerants are assigned the RCLs indicated in Tables 1 and 2.† RCLs for other refrigerants shall be determined in accordance with this Standard and submitted to the authority having jurisdiction (AHJ) for approval. Submissions shall include an evaluation of the experimental and analytical methods used, data from alternative sources, and an indication of the extent of the data search. The submission shall summarize the qualifications of the person or persons that determined the recommended RCLs.

New References

Also, add references in ASHRAE 34 section 10 as follows:

[6] *OECD Principles of Good Laboratory Practice*, Annex 2 of Decision C(81)30(Final), Organization for Economic Cooperation and Development (OECD), Paris, France, 13 May 1981

[7] *Good Laboratory Practice for Nonclinical Laboratory Studies*, Food and Drug Administration (FDA), 21 CFR Chapter 1 Part 58, Subparts A-K, Government Printing Office, Washington, DC, 1996

* The factor shown to convert the RCL from a volumetric ratio in ppm v/v to mass per unit volume in lb/Mcf, $2.557 \cdot 10^{-6}$ for lb/Mcf, actually is incorrect and should be $1.160 \cdot 10^{-3}$ for lb/Mcf. The conversion is shown in its present form for calculation with mixed units, namely with the molecular mass in g/mol, rather than lb/mol, even for inch-pound (lb/Mcf) calculations.

† These tables are not included in this report. The language citing them is a recommendation for incorporation into ASHRAE 34, with expectation that the RCL values recommended later in this report (see pages 97-100), as modified through the consensus standard development process, will be added to existing Tables 1 and 2 of ASHRAE 34.

[8] *Good Laboratory Practice Standards*, Environmental Protection Agency, 40 CFR Part 792, Subparts A-J, Government Printing Office, Washington, DC, 1996

[9] *GLP for Industrial Chemicals*, Kikyoku [Basic Industries Bureau] Dispatch 85, Ministry of International Trade and Industry (MITI), and Kanpogyo [Planning and Coordination Bureau] Dispatch 39, Environmental Agency, Tokyo, Japan, 31 March 1984

SUGGESTED FURTHER CHANGES

Several suggested revisions to improve the RCL method follow. The conventions used to highlight changes are strikethroughs (e.g., ~~delete~~) to show deletions, underscores (e.g., add) to show additions, and double strikethroughs or underscores (e.g., ~~deleted~~ or added) to show deletions or additions from a companion change already addressed.

Qualifying LOELs

§7.1.1(a), (b), and (c) provide for use of an ALC when an LC_{50} was not determined, for use of a LOEL if a NOEL was not determined for cardiac sensitization, and for use of a LOEL when a 10-minute EC_{50} was not determined for anesthetic effects, respectively. These sections stipulate that the ALC and LOELs must not have caused death or affected more than half the exposed animals. The intent was to require data that is approximately equal to or more conservative than a median effective concentration. However, in disqualifying some data, the provision as currently written may allow use of less conservative data.

To illustrate this point, consider the hypothetical case in which:

- One study reports 20,000 ppm v/v was fatal to four of six rats.
- A second indicates that 30,000 ppm v/v was fatal to three of six rats for the same exposure duration.*
- Both studies found increasing mortality fractions at higher concentrations, but neither determined an LC_{50}.

The 20,000 ppm v/v ALC would be disqualified on the basis of 67% mortality (more than half the animals). The ALC of 30,000 ppm v/v from the second study would then qualify even though the first study indicates that the lethality threshold is less than 20,000 ppm v/v. The 50% mortality criterion, therefore, forces use of less conservative data in this hypothetical but plausible case.

The following changes address this problem. The key changes insert a new provision, as §7.3.4, and delete the qualification criteria from §7.1.1 (a)-(c). The revision also modifies the sequence of §7.3.2-7.3.5 to make the expanded text more cohesive.

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* 30,000 ppm v/v should yield more deaths than 20,000 ppm v/v for treatment-related lethality, but incongruities such as the one postulated here are common for separate studies and sometimes within a single study.

7.1.1 Acute-Toxicity Exposure Limit (ATEL). The ATEL shall be the lowest of items (a)-(d) as follows:

(a) Mortality: 28.3% of the 4-hour LC_{50} for rats. If not determined, 28.3% of the 4-hour ALC for rats ~~provided that it did not result in mortality for more than half the exposed animals~~. If neither has been determined, 0 ppm. The following equations shall be used to adjust LC_{50} or ALC values that were determined with 15-minute to 8-hour tests, for refrigerants for which 4-hour test data are not available:

$$LC_{50\ for\ T} = LC_{50\ for\ t} \cdot (t/T)^{1/2}$$
or
$$ALC_T = ALC_t \cdot (t/T)^{1/2}$$

where:

T is 4 hours, and
t is the test duration expressed in hours, 0.25-8

(b) Cardiac Sensitization: 100% of the NOEL for cardiac sensitization in unanesthetized dogs. If not determined, 80% of the LOEL for cardiac sensitization in dogs ~~provided that the LOEL did not induce sensitization in more than half the exposed animals~~. If neither has been determined, 0 ppm. The cardiac sensitization term is omitted from ATEL determination if the LC_{50} or ALC in (a) is less than 10,000 ppm v/v or if the refrigerant is found, by toxicological review, to not cause cardiac sensitization.

(c) Anesthetic Effect: 50% of the 10-minute EC_{50} for anesthesia in mice or rats. If not determined, 50% of the LOEL for signs of anesthesia in rats during acute toxicity studies~~, provided that the LOEL did not induce an anesthetic effect for more than half the exposed animals~~. If neither has been determined, 80% of the NOEL for signs of anesthesia in rats during an acute, subchronic, or chronic toxicity study in which clinical signs were documented.

⋮

7.3 Data for Calculations. The data used to calculate the RCL shall be taken from scientific and engineering studies or published safety assessments by governmental agencies or expert panels. Source studies for toxicity data must comply with Good Laboratory Practices (GLP) in accordance with reference 6, 7, 8, or 9. Data from peer-reviewed publications, including journal articles and reports, also are allowed.

7.3.1 Alternative Data. Data from studies that have not been published, from studies that have not been peer reviewed, or from studies involving species other than indicated in 7.1.1 (a)-(d), shall be submitted to the authority having jurisdiction (AHJ) for approval. For RCL values to be published in addenda or revisions to this Standard, the AHJ shall be the Committee. Submissions shall include an evaluation of the experimental and analytical methods used, data from alternative sources, and the extent of the data search. The submissions shall summarize the qualifications of the person or persons providing the evaluation.

7.3.2 ~~7.3.4~~ **Conservative Data.** Where multiple data values have been published, the values used shall be those resulting in the lowest RCL.

EXCEPTIONS:

1. Where subsequent, peer-reviewed studies explicitly document flaws in or refinements to previously published data, the newer values shall be used.

2. For the cardiac sensitization and anesthetic effect NOEL in 7.1.1 (b) and (c), respectively, the highest-published NOEL not exceeding a published LOEL, for any fraction of tested animals, shall be used. Both the NOEL and LOEL must conform to 7.3 or 7.3.1 for this exception.

7.3.3 No-Effect Data. Where no treatment-related effect was observed in animal tests for items 7.1.1 (a)-(d), the ATEL calculation required by 7.1.1 shall use the highest concentration tested in lieu of the specified effect or no-effect level.

7.3.4 ALC and LOEL Qualification. No ALC or LOEL shall be used for items 7.1.1 (a)-(c) if it resulted in the effect measured (mortality, cardiac sensitization, or anesthetic effect) in more than half the animals exposed at that concentration or if there is a lower ALC or LOEL for any fraction of tested animals.

7.3.5 ~~7.3.2~~ **Consistent Measures.** Use of data that are determined in a consistent manner, or by methods that consistently yield a lower RCL for the same effects, is allowed for the parameters identified in 7.1.

Note that the change could result in no qualifying data for the hypothetical case, the same result if both studies had found lethality in more than half the animals tested at the lowest concentration each tested. As implied, the testing was insufficient.

Ambiguity in Anesthetic Effect

The language in §7.1.1(c) is inconsistent and, therefore, invites interpretation. The intent was to include all signs of anesthetic or central nervous system (CNS) effect on the premise that they suggest impairment in perception, judgement, or ability to respond to the circumstances for which the RCL pertains, namely a potential refrigerant release or an emergency causing it. Use of the words "for anesthesia" suggests a more severe impact. Moreover, the current §7.1.1(c) language is vague. The following changes to the definitions and to §7.1.1(c) address these concerns:

anesthetic effect ~~*or anesthesia*~~: Loss of the ability to perceive pain and other sensory stimulation.

central nervous system (CNS) effect: Treatment-related depression, distraction, stimulation, or other behavioral modification suggesting temporary or permanent changes to control by the brain.

(c) Anesthetic or Central Nervous System Effects: 50% of the 10-minute EC_{50} ~~for anesthesia~~ in mice or rats for loss of righting ability in a rotating apparatus. If not determined, 50% of the LOEL for signs of ~~anesthesia~~ any anesthetic or CNS effect

in rats during acute toxicity studies~~, provided that the LOEL did not induce an anesthetic effect for more than half the exposed animals~~. If neither has been determined, 80% of the NOEL for signs of ~~anesthesia~~ any anesthetic or CNS effect in rats during an acute, subchronic, or chronic toxicity study in which clinical signs were documented.

Safety Margin for Other Escape Impairing Effects or Permanent Injury

Of the four toxic effects used to calculate the ATEL, the first three are guidance levels — effect levels reduced by multipliers to provide a margin of safety for differences in both inter- and intra-species sensitivities. The fourth term, *other escape impairing effects or permanent injury*, is the "lowest concentration, for human exposures of 30 minutes, that is likely to impair ability to escape or to cause either irreversible health effects or severe sensory irritation." The result is that the ATEL and RCL will be at a concentration likely to cause harm when this term governs.

The following revision to §7.1.1(d) changes the term to a guidance level using the same multiplier as for the cardiac sensitization LOEL:

> **(d) Other Escape-Impairing Effects and Permanent Injury:** ~~The~~ 80% of the lowest concentration, for human exposures of 30 minutes, that is likely to impair ability to escape or to cause either irreversible health effects or severe sensory irritation.

As indicated on pages 92 and 94, this change would make the ATEL for R-744 (carbon dioxide) match the revised 1994 IDLH for it and reduce the difference between the ATEL and the 1994 IDLH for R-12 and R-717 (ammonia).

RCL Conversion to Mass per Unit Volume

The factor shown to convert the RCL from a volumetric ratio in ppm v/v to mass per unit volume in lb/Mcf, $2.557 \cdot 10^{-6}$ for lb/Mcf, is incorrect for consistent use of inch-pound units. The conversion shown assumes mercurial calculation with mixed units, namely with the molecular mass in g/mol rather than lb/mol. The following changes make the units consistent and reduce the likelihood of someone incorrectly applying the conversion now shown with molecular mass in lb/mol.

> **7.4.1 Mass per Unit Volume.** The following equation shall be used to convert the RCL from a volumetric ratio, ppm v/v, to mass per unit volume, kg/m^3 (lb/Mcf):
>
> $$rcl = RCL \cdot a \cdot M$$
>
> where:
>
> rcl = the RCL expressed as kg/m^3 (lb/Mcf)
> RCL = the RCL expressed as ppm v/v
> a = $4.096 \cdot 10^{-8}$ for kg/m^3 (~~$2.557 \cdot 10^{-6}$~~ $1.160 \cdot 10^{-3}$ for lb/Mcf)
> M = the molecular mass of the refrigerant in g/mol (lb/mol)

Historical Studies

The ASHRAE 34u draft (see page 16) calls for toxicity data from studies that indicate compliance with *Good Laboratory Practices* (GLP). The referenced regulations changed with time, and investigators could not have foreseen future regulatory changes reliably. The following modification provides a recourse for studies performed under earlier GLP formulations:

> **7.3 Data for Calculations.** The data used to calculate the RCL shall be taken from scientific and engineering studies or published safety assessments by governmental agencies or expert panels. Source studies for toxicity data must indicate compliance with Good Laboratory Practices (GLP) in accordance with reference 7, 8, 9, or 10 or earlier editions of these references in effect when the studies were performed. Data from peer-reviewed publications, including journal articles and reports, also are allowed.

Updated References

Some of the references cited in the ASHRAE 34u draft (see page 16) are no longer current. The following changes cite updates:

> [6] *OECD Principles of Good Laboratory Practice*, Annex 2 of Decision C(81)30(Final), Organization for Economic Cooperation and Development (OECD), Paris, France, 13 May 1981 as revised through 1999
>
> [7] *Good Laboratory Practice for Nonclinical Laboratory Studies*, Food and Drug Administration (FDA), Department of Health and Human Services, 21 CFR Chapter 1 Part 58, Subparts A-K, Government Printing Office, Washington, DC, ~~1966~~ 1 April 2000
>
> [8] *Good Laboratory Practice Standards*, Environmental Protection Agency, 40 CFR Part 792, Subparts A-J, Government Printing Office, Washington, DC, ~~1966~~ 1 July 2000
>
> [9] *GLP for Industrial Chemicals*, Kikyoku [Basic Industries Bureau] Dispatch 85, Ministry of International Trade and Industry (MITI), and Kanpogyo [Planning and Coordination Bureau] Dispatch 39, Environmental Agency, Tokyo, Japan, 31 March 1984

REVISED TEXT OF METHOD WITH PROPOSED CHANGES

The following version of the method incorporates all of the suggested changes, to facilitate reading without interspersed explanations and highlighting:

New Definitions

Add new definitions in ASHRAE 34 section 3 as follows:

> *acute-toxicity exposure limit (ATEL)*: the refrigerant concentration limit determined in accordance with this Standard and intended to reduce the risks of acute toxicity hazards in normally occupied, enclosed spaces. ATEL values are similar to the Immediately Dangerous to Life or Health (IDLH) concentrations, set by the National Institute of Occupational Safety and Health (NIOSH). ATELs include explicit, additional components for car-

diac sensitization and anesthetic effects, but do not address flammability. The lowest of the ATEL, 50,000 ppm v/v, or 10% of the LFL, therefore, provides a conservative approximation to IDLH concentrations, when needed for refrigerants without adopted IDLH values.

approximate lethal concentration (ALC): the concentration of a substance, a refrigerant in this Standard, that was lethal to even a single test animal when tested by the same conditions as for an LC_{50} test.

anesthetic effect: loss of the ability to perceive pain and other sensory stimulation.

central nervous system (CNS) effect: treatment-related depression, distraction, stimulation, or other behavioral modification suggesting temporary or permanent changes to control by the brain.

EC_{50}: effective concentration 50%, the concentration of a material, a refrigerant in this Standard, that has caused a biological effect to 50% of test animals.

flammable concentration limit (FCL): the refrigerant concentration limit, in air, determined in accordance with this Standard and intended to reduce the risk of fire or explosion in normally occupied, enclosed spaces.

lowest observed effect level (LOEL): the concentration of a material, a refrigerant in this Standard, that has caused any observed effect to even one test animal.

no-observed effect level (NOEL): the highest concentration of a material, a refrigerant in this Standard, at which no effect has been observed in even one test animal.

oxygen deprivation limit (ODL): the concentration of a refrigerant or other gas that results in insufficient oxygen for normal breathing. For this Standard, the ODL is the concentration that reduces the oxygen content in normal air to below 19.5%, assuming uniform mixing.

refrigerant concentration limit (RCL): the refrigerant concentration limit, in air, determined in accordance with this Standard and intended to reduce the risks of acute toxicity, asphyxiation, and flammability hazards in normally occupied, enclosed spaces.

RCL Determination

Also, add a new section to ASHRAE 34 as follows:

7. REFRIGERANT CONCENTRATION LIMIT (RCL)

7.1 Single-Compound Refrigerants. The RCL for each refrigerant shall be the lowest of the quantities calculated in accordance with 7.1.1, 7.1.2, and 7.1.3, using data as indicated in 7.3, and adjusted in accordance with 7.4. Determination shall assume full vaporization; no removal by ventilation, dissolution, reaction, or decomposition; and complete mixing of the refrigerant in the space to which it is released.

7.1.1 Acute-Toxicity Exposure Limit (ATEL). The ATEL shall be the lowest of items (a)-(d) as follows:

(a) Mortality: 28.3% of the 4-hour LC_{50} for rats. If not determined, 28.3% of the 4-hour ALC for rats. If neither has been determined, 0 ppm. The following equations shall be used to adjust LC_{50} or ALC values that were determined with 15-minute to 8-hour tests, for refrigerants for which 4-hour test data are not available:

$$LC_{50\ for\ T} = LC_{50\ for\ t} \cdot (t/T)^{1/2}$$
or
$$ALC_T = ALC_t \cdot (t/T)^{1/2}$$

where:

T is 4 hours, and
t is the test duration expressed in hours, 0.25-8

(b) Cardiac Sensitization: 100% of the NOEL for cardiac sensitization in unanesthetized dogs. If not determined, 80% of the LOEL for cardiac sensitization in dogs. If neither has been determined, 0 ppm. The cardiac sensitization term is omitted from ATEL determination if the LC_{50} or ALC in (a) is less than 10,000 ppm v/v or if the refrigerant is found, by toxicological review, to not cause cardiac sensitization.

(c) Anesthetic or Central Nervous System Effects: 50% of the 10-minute EC_{50} in mice or rats for loss of righting ability in a rotating apparatus. If not determined, 50% of the LOEL for signs of any anesthetic or CNS effect in rats during acute toxicity studies. If neither has been determined, 80% of the NOEL for signs of any anesthetic or CNS effect in rats during an acute, subchronic, or chronic toxicity study in which clinical signs were documented.

(d) Other Escape-Impairing Effects and Permanent Injury: 80% of the lowest concentration, for human exposures of 30 minutes, that is likely to impair ability to escape or to cause either irreversible health effects or severe sensory irritation.

7.1.2 Oxygen Deprivation Limit (ODL). The ODL shall be 69,100 ppm v/v.

7.1.3 Flammable Concentration Limit (FCL). The FCL shall be calculated as 25% of the LFL determined in accordance with 6.1.3.

7.2 Blends. The RCL for refrigerants comprising multiple compounds shall be determined by the method in 7.1 except that individual parameter values in 7.1.1 (a) though (d) shall be calculated as the mole-weighted average, by composition of the nominal formulation, of the values for the components.

7.3 Data for Calculations. The data used to calculate the RCL shall be taken from scientific and engineering studies or published safety assessments by governmental agencies or expert panels. Source studies for toxicity data must comply with Good Laboratory Practices (GLP) in accordance with reference 6, 7, 8, or 9. Data from peer-reviewed publications, including journal articles and reports, also are allowed.

7.3.1 Alternative Data. Data from studies that have not been published, from studies that have not been peer reviewed, or from studies involving species other than indicated in 7.1.1 (a)-(d), shall be submitted to the authority having jurisdiction (AHJ) for approval. For RCL values to be published in addenda or revisions to this Standard, the AHJ shall be

the Committee. Submissions shall include an evaluation of the experimental and analytical methods used, data from alternative sources, and the extent of the data search. The submissions shall summarize the qualifications of the person or persons providing the evaluation.

7.3.2 Conservative Data. Where multiple data values have been published, the values used shall be those resulting in the lowest RCL.

EXCEPTIONS:

1. Where subsequent, peer-reviewed studies explicitly document flaws in or refinements to previously published data, the newer values shall be used.

2. For the cardiac sensitization and anesthetic effect NOEL in 7.1.1 (b) and (c), respectively, the highest-published NOEL not exceeding a published LOEL, for any fraction of tested animals, shall be used. Both the NOEL and LOEL must conform to 7.3 or 7.3.1 for this exception.

7.3.3 No-Effect Data. Where no treatment-related effect was observed in animal tests for items 7.1.1 (a)-(d), the ATEL calculation required by 7.1.1 shall use the highest concentration tested in lieu of the specified effect or no-effect level.

7.3.4 ALC and LOEL Qualification. No ALC or LOEL shall be used for items 7.1.1 (a)-(c) if it resulted in the effect measured (mortality, cardiac sensitization, or anesthetic effect) in more than half the animals exposed at that concentration or if there is a lower ALC or LOEL for any fraction of tested animals.

7.3.5 Consistent Measures. Use of data that are determined in a consistent manner, or by methods that consistently yield a lower RCL for the same effects, is allowed for the parameters identified in 7.1.

7.4 Units Conversion

7.4.1 Mass per Unit Volume. The following equation shall be used to convert the RCL from a volumetric ratio, ppm v/v, to mass per unit volume, kg/m^3 (lb/Mcf):

$$rcl = RCL \cdot a \cdot M$$

where:

rcl = the RCL expressed as kg/m^3 (lb/Mcf)
RCL = the RCL expressed as ppm v/v
a = $4.096 \cdot 10^{-8}$ for kg/m^3 ($1.160 \cdot 10^{-3}$ for lb/Mcf)
M = the molecular mass of the refrigerant in g/mol (lb/mol)

7.4.2 Adjustment for Altitude. The RCL shall be adjusted for altitude, when expressed as mass per unit volume, kg/m^3 (lb/Mcf), for locations above sea level. The RCL shall not be adjusted when expressed as a volumetric ratio in ppm.

$rcl_a = rcl \cdot (1-(b \cdot h))$

where:

rcl_a = the adjusted rcl
b = $7.94 \cdot 10^{-5}$ for m ($2.42 \cdot 10^{-5}$ for ft)
h = altitude above sea level in m (ft)

7.5 RCL Values. Refrigerants are assigned the RCLs indicated in Tables 1 and 2. RCLs for other refrigerants shall be determined in accordance with this Standard and submitted to the authority having jurisdiction (AHJ) for approval. Submissions shall include an evaluation of the experimental and analytical methods used, data from alternative sources, and an indication of the extent of the data search. The submission shall summarize the qualifications of the person or persons that determined the recommended RCLs.

New References

Also, add references in ASHRAE 34 section 10 as follows:

[6] *OECD Principles of Good Laboratory Practice*, Annex 2 of Decision C(81)30(Final), Organization for Economic Cooperation and Development (OECD), Paris, France, 13 May 1981 as revised through 1999

[7] *Good Laboratory Practice for Nonclinical Laboratory Studies*, Food and Drug Administration (FDA), Department of Health and Human Services, 21 CFR Chapter 1 Part 58, Subparts A-K, Government Printing Office, Washington, DC, 1 April 2000

[8] *Good Laboratory Practice Standards*, Environmental Protection Agency, 40 CFR Part 792, Subparts A-J, Government Printing Office, Washington, DC, 1 July 2000

[9] *GLP for Industrial Chemicals*, Kikyoku [Basic Industries Bureau] Dispatch 85, Ministry of International Trade and Industry (MITI), and Kanpogyo [Planning and Coordination Bureau] Dispatch 39, Environmental Agency, Tokyo, Japan, 31 March 1984

DATA LOCATION

The preceding sections of this report explain the objectives, focal toxicological effects, relevant measures for them, and the proposed method to calculate recommended concentration limits. This section identifies the resources used to locate the data presented in the following section, with emphasis on the toxicity data.

LITERATURE SEARCH

Data were located through systematic searches of several databases including:

- ARTI *Refrigerant Database*[22]
- National Library of Medicine (NLM) *Medline*
- National Library of Medicine (NLM) *Toxline*
- NIOSH *Occupational Safety and Health Database* (NIOSHTIC)
- NIOSH *Registry of Toxic Effects of Chemical Substances* (RTECS)[23]
- National Toxicology Program (NTP) *Chemical Hazard Information System (CHEM-HAZIS)*
- NTP *Health and Safety Database*
- U.K. Royal Society of Chemistry *Chemical Safety Newsbase*

Selective searches also were made in:

- Chemical Abstracts Service (CAS) *Chemical Abstracts*
- several major library catalogs including that of the U.S. Library of Congress and the National Technical Information Service

The following summaries and assessments were examined for references to relevant studies:

- published and to the extent obtainable unpublished assessments, summaries, and exposure limit or hygiene standard documentation from chemical manufacturers
- ACGIH documentation of Threshold Limit Values (TLVs)[24]
- AIHA Workplace Environmental Exposure Limit (WEEL) Guides for R-32, R-123, R-124, R-125, R-134a, R-141b, R-142b, R-143a, R-152a, and R-236fa
- Air-Conditioning and Refrigeration Institute (ARI) *Refrigerant Safety Data — Recommendations of the Air-Conditioning and Refrigeration Industry*[25]
- Department of Health and Human Services and Department of Labor occupational safety and health guidelines[26]
- Environmental Protection Agency published toxicity assessments[27-30]

- European Chemical Industry Ecotoxicology and Toxicology Centre (ECETOC) Joint Assessment of Commodity Chemicals (JACC) reports for R-22, R-32, R-123, R-124, R-125, R-134a, R-141b, and R-142b
- International Institute of Ammonia Refrigeration (IIAR) reference book on R-717 (ammonia)[31] as well as assessments of ammonia toxicity
- National Fire Protection Association (NFPA) references on hazardous materials[32]
- National Research Council (NRC) exposure limit assessments[33-43]
- NIOSH criteria documents for recommended exposure standards[44-46]
- NIOSH documentation for Immediately Dangerous to Life or Health (IDLH) concentrations[11]
- applications submitted for ASHRAE 34 designations and safety classifications
- chemical and hazardous materials handbooks, the most pertinent of which are cited in the discussion of the data

The following sources — usually lacking study citations for included data — were examined for relevant data. Their preparers were contacted to determine the data sources when not apparent from the prior steps:

- chemical manufacturer material safety data sheets (MSDSs), safety data sheets (SDSs), and hygiene standard recommendations
- Program for Alternative Fluorocarbon Toxicity Testing (PAFT) summaries[7]

Most of the data searches were conducted in 1995 and 1996 and summarized, together with background information on the approach, in a paper (see appendix 5 beginning on page 507).[47]

DATA ISSUES

Source Data

Wherever possible, the data shown in the following sections reflect "source data," that is data as presented or as converted from the original source, or as close to the original reports as could be located. While reliance on assessments, handbooks, and similar compilations is simpler, these "secondary" sources typically omit pertinent qualifiers and details. Moreover, the data integrity degrade with multiple quotations if rounded or converted. Toxicologists differ in their preferences for units. One study reported an effect at 204,000 ppm v/v. It was quoted first as 20% in a paper, then converted to 474 mg/L in a compilation. That value was cited later as 195,000 ppm v/v, which might be mistaken as a corroborating rather than the same study. Such differences grow with successive conversions.

Nominal and Actual Concentrations

Summaries and compilations often do not distinguish between nominal (or target) concentrations for toxicity studies and those actually determined by measurement and analysis. Such differences may exceed 20%. The data cited herein are measured rather than target data, since they are more indicative of the levels at which effects or absence of effects were found in tests.

RECOMMENDED DATA TO DETERMINE ATELS

This section addresses the data needed to calculate ATEL concentrations. It identifies pertinent findings from referenced toxicity studies for 29 refrigerants. The refrigerants were selected by the project sponsor, ARTI, based on those in use as single compounds and blend components at inception of the project as well as two added in the course of the work. They include:

R-11: trichlorotrifluoromethane
R-12: dichlorodifluoromethane
R-22: chlorodifluoromethane
R-23: trifluoromethane
R-32: difluoromethane
R-113: 1,1,2-trichloro-1,2,2-trifluoroethane
R-114: 1,2-dichloro-1,1,2,2-tetrafluoroethane
R-116: hexafluoroethane
R-123: 2,2-dichloro-1,1,1-trifluoroethane
R-124: 2-chloro-1,1,1,2-tetrafluoroethane
R-125: 1,1,1,1,2-pentafluoroethane
R-134: 1,1,2,2-tetrafluoroethane
R-134a: 1,1,1,2-tetrafluoroethane
R-E134: difluoromethoxy-difluoromethane [also identified as bis(difluoromethyl)ether]
R-141b: 1,1-dichloro-1-fluoroethane
R-142b: 1-chloro-1,1-difluoroethane
R-143a: 1,1,1-trifluoroethane
R-152a: 1,1-difluoroethane
R-218: octafluoropropane
R-227ea: 1,1,1,2,3,3,3-heptafluoropropane
R-236fa: 1,1,1,3,3,3-hexafluoropropane
R-245ca: 1,1,2,2,3-pentafluoropropane
R-245fa: 1,1,1,3,3-pentafluoropropane
R-290: propane
R-500: R-22/152a (73.8/26.2)
R-502: R-22/115 (48.8/51.2)
R-600a: isobutane
R-717: ammonia
R-744: carbon dioxide

Their selection does not imply a preference or recommendation, and data also are available for other refrigerants. Indeed, several refrigerants introduced since inception of the work are included in tables in subsequent sections of this report even though not addressed here.

The data for each of the 29 refrigerants addresses four toxicity concerns, namely:

- lethality,
- cardiac sensitization,
- anesthetic effect, and

- other escape-impairing effects and permanent injury

The data presented are not exhaustive either in terms of the toxicity endpoints (measures) addressed or in terms of all known data for each endpoint. Rather, the presentation covers the data needed to calculate ATEL values and examples of additional data that corroborate or disqualify cited data. The specific *data selection criteria* used, and referred to in the following discussion, are those defined by the proposed procedure for *ATEL* determination as qualified by the provisions on *Data for Calculations* (see text beginning on pages 19 and 20, respectively).

In the absence of corroborating data, the presentation cites representative toxicity assessments, manufacturer material safety data sheets (MSDSs), and similar documentation to show acceptance of specific data by others. Each subsection concludes with the author's recommendation based on the data selection criteria.

R-11: TRICHLOROTRIFLUOROMETHANE

Lethality

A number of studies report 4-hr ALCs and LC_{50}s in rats with a range of 26,000-66,000 ppm v/v. Morrison reports no deaths at 35,600 ppm v/v and death of one of four rats (25%) at 66,000 ppm v/v as found in a 4-hr study.[48] In a later study, Barras indicates a 4-hr LC_{50} in rats of 26,200 ppm v/v.[49] DuPont cites an LC_{50} of 26,000 ppm v/v in a bulletin summarizing PAFT findings.[50] This value appears to have been rounded from 26,200 ppm v/v since no source study was found to support it and DuPont cites 26,200 ppm v/v in its MSDS for R-11.[51] These data are reasonably consistent with LC_{50} findings of 120,000-130,000 ppm v/v for 10-30 minutes.[52-54] Applying the ten Berge (see page 11) extrapolation to them suggests 4-hr LC_{50}s of approximately 24,500-50,000 ppm v/v.

recommendation: 4-hr LC_{50} rat = 26,200 ppm v/v

Cardiac Sensitization

Hardy et al. report NOELs of 9,000 and 15,000 ppm v/v in two separate studies,[55,56] but an earlier and widely cited study by Reinhardt et al. indicates the measured range of 900-1,300 ppm v/v, with a midpoint of 1,100 ppm v/v, as a NOEL.[57] The same study indicates a LOEL for one of twelve dogs in a measured range of 3,500-6,100 ppm v/v, with a midpoint of 4,800 ppm v/v.

Two later studies, also by Hardy and colleagues, indicate LOELs for one of two dogs at 20,000 ppm v/v,[58,59] and other investigators report EC_{50}s of 12,400-12,500 ppm v/v.[53,60,61]

While it appears that the early Reinhardt et al. finding is lower than more recent data and that the NOEL would have been more than four times higher except for the response of one dog of twelve, it is the most conservative NOEL found and there is no basis to reject it.

recommendation: NOEL dog = 1,100 ppm v/v

Anesthetic Effect

Wada reports a 10-min EC_{50} in rats of 54,000 ppm v/v.[52] Weigand reports a 2-hr EC_{50} in rats of 60,000 ppm v/v,[62] which gives credence to the Wada finding, but Clark and Tinston report a more conservative 10-min EC_{50} in rats of 35,000 ppm v/v.[53] That study appears to be the source for similar indications by others.[63,64] Weigand also reports a 2-hr LOEL of 35,000 ppm v/v based on tests of four rats, but does not indicate the fraction of animals showing effects.[62] The same study reports a NOEL for 2-hr exposures of four rats at 12,500 ppm v/v.[62] Lester and Greenberg report a 30-min NOEL and LOEL for 30-min exposures of individual rats to 50,000 and 60,000 ppm v/v respectively.[65]

recommendation: 10-min EC_{50} rat = 35,000 ppm v/v

Other Escape-Impairing Effects and Permanent Injury

Stewart et al. report that eight male volunteers repetitively exposed to 1,000 ppm v/v for 1-10 hr/d, 5 d/wk, for 2-4 wk showed minor decrements in several cognitive tests, but no change in pulmonary function or alteration of in cardiac rhythm.[66,67] They note, however, that acute exposures of groups of eight male volunteers to 250, 500, or 1000 ppm v/v for 1 min to 8 hr "did not produce any untoward physiological effects."[66,67]

recommendation: none

R-12: DICHLORODIFLUOROMETHANE

Lethality

Lester and Greenberg report no deaths in 4-hr and 6-hr exposures of "a few" rats to 800,000 ppm v/v, suggesting an LC_{50} of >800,000 ppm v/v.[65] The 4-hr finding was corroborated by Clark and Tinston.[53] Several secondary sources cite an LC_{50} of 760,000 or >760,000 ppm v/v,[50,68] but no basis was found for them.

Shugaev indicates a 3-hr LC_{50} rat of 620,000.[69] This indication is echoed in an NRC examination of data.[38] Applying the ten Berge extrapolation (see page 11) suggests a 4-hr LC_{50} of approximately 540,000 ppm v/v. Even without time adjustment, the Shugaev finding challenges an LC_{50} of >800,000 ppm v/v.

Absent the ability to examine the Shugaev data carefully, recognizing the possibility that the test sample used may have been contaminated, recognizing that Lester and Greenberg repeated their finding in separate 4- and 6-hr tests, recognizing corroboration by Clark and Tinston, and absent a strict criterion to use the 3-hr or time-adjusted 3-hr data with available 4-hr data, the 4-hr LC_{50} of >800,000 ppm v/v seems to meet the data selection criteria (see page 19). In any case, the lethality term is not the most restrictive one for the R-12 exposure limits.

recommendation: 4-hr LC_{50} rat > 800,000 ppm v/v

Cardiac Sensitization

Reinhardt et al. indicate a NOEL from tests of twelve dogs exposed to 25,000 ppm v/v as well as a LOEL for five of twelve dogs at 50,000 ppm v/v.[57,70]

Hardy et al. report no marked responses in groups of five dogs at both 40,000 and 80,000 ppm v/v,[56] the latter of which is disqualified by the data selection criteria (see page 19) based on the 50,000 ppm v/v LOEL.

These data appear consistent with reported EC_{50}s of 77,000-120,000 ppm v/v.[53,60,71]

The Hardy et al. NOEL of 40,000 ppm v/v is the highest NOEL found that does not exceed a LOEL.

recommendation: NOEL dog = 40,000 ppm v/v

Anesthetic Effect

Clark and Tinston report a 10-min EC_{50} in rats of 250,000 ppm v/v.[53] Weigand reports a 2-hr EC_{50} in rats of 400,000 ppm v/v.[62] He also indicates no effect in four rats exposed to 100,000 ppm v/v for 2 hr. Scholz reports a higher 2-hr NOEL for rats of 200,000 ppm v/v.[72]

recommendation: 10-min EC_{50} rat = 250,000 ppm v/v

Other Escape-Impairing Effects and Permanent Injury

Stewart et al. summarize acute and subchronic toxicity tests in healthy human volunteers by whole-body exposures.[67,73] They indicate that acute exposures to 250, 500, or 1000 ppm v/v for 1 min to 8 hr "did not produce any untoward physiological effects" as determined by observation, routine hematology, clinical chemistry, EKG, and pulmonary function as well as by cognitive skill and other neurological measurements.[67,73] They further note that repetitive exposures to 1,000 ppm v/v for 1-10 hr/d, 5 d/wk, for 2-4 wk also showed no adverse effects.[67,73] Reinhold and Rusch report the same conclusion in a review of the findings.[74]

Azar et al. report acute inhalation tests in two human volunteers. The study found that exposures to 10,000 ppm v/v nominal (10,173 ppm v/v average) for 2½ hr evoked a 7% reduction in standardized psychomotor test scores. It notes that this finding is not indicative of a serious health threat and that breath samples showed that R-12 is quickly eliminated from the lungs.[75] Adjusting the concentration of 10,173 ppm v/v from 2½ hr to 30 min using the ten Berge approach yields a concentration of 22,700 ppm v/v.*

recommendation: LOEL = 22,700 ppm v/v

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* The ten Berge approach (see page 11) is not generally applicable to anesthetic effects. The present use was carefully considered following examination of the Azar data and conclusions, recognition that there may have been no relevant effect for a shorter exposure, and examination of the data for anesthetic effect cited herein, in a detailed survey by Lee and Graham,[76] and in the ARTI Refrigerant Database.[22]

R-22: CHLORODIFLUOROMETHANE

Lethality

Tinston found the 4-hr LC_{50} rat to be 220,000 ppm v/v,[77] as reported by Litchfield and Longstaff and by an ECETOC JACC assessment.[78,79] Weigand reports a 2-hr ALC in rats of 300,000 ppm v/v, based on death of one of four animals.[62] This finding suggests a 4-hr ALC of approximately 210,000 ppm v/v, with the ten Berge adjustment (see page 11), and therefore corroborates the Tinston finding.

recommendation: 4-hr LC_{50} rat = 220,000 ppm v/v

Cardiac Sensitization

Reinhardt et al. indicate a NOEL from tests of twelve dogs exposed to 50,000 ppm v/v as well as a LOEL for marked responses in two of twelve dogs at 25,000 ppm v/v.[57,70] Clark and Tinston report a consistent EC_{50} in dogs of 140,000 ppm v/v.[53]

recommendation: NOEL dog = 25,000 ppm v/v

Anesthetic Effect

Clark and Tinston report a 10-min EC_{50} in rats of 140,000 ppm v/v based on action as a central nervous system (CNS) depressant.[53] Weigand reports a LOEL of 50,000 ppm v/v in rats for 2-hr exposures in a subchronic inhalation toxicity study, but he does not indicate the number of animals affected of the four tested.[62]

recommendation: 10-min EC_{50} rat = 140,000 ppm v/v

Other Escape-Impairing Effects and Permanent Injury

None identified.

recommendation: none

R-23: TRIFLUOROMETHANE

Lethality

Nash indicates that the 4-hr ALC rat (and therefore the LC_{50}) for R-23 exceeds 663,000 ppm v/v, which was the highest concentration tested, since there were no fatalities.[80] The refrigerant-air mixture was enriched with oxygen to maintain 19.7-21% levels. Skaggs and Moore cite this finding.[81]

recommendation: 4-hr LC_{50} rat >663,000 ppm v/v

Cardiac Sensitization

Hopkins and Krantz found no sensitization in dogs tested at 800,000 ppm v/v R-23 with oxygen.[82] Hardy et al. indicate that the sensitization EC_{50} exceeds 500,000 ppm v/v, but give no indication of specific test findings.[71] The 800,000 ppm v/v NOEL is cited in manufacturer MSDSs.[83,84]

recommendation: NOEL dog = 800,000 ppm v/v

Anesthetic Effect

No EC_{50} was found. Van Poznak and Artusio report an anesthetic effect at 800,000 ppm v/v in two of two dogs in 10-90 min, but neither the species nor the fraction affected satisfy the data selection criteria (see page 19).[85] Nash reports that rats showed reduced response to sound during 4-hr exposures at 186,000 ppm v/v, but does not indicate how many of the six animals tested did so.[80] Leuschner et al. indicate no adverse effects in rats exposed to 10,000 ppm v/v in a subchronic inhalation toxicity study,[86] as summarized by Krentz et al. and by Skaggs and Moore.[81,87,88] Nash indicates that no behavioral changes were observed during exposures of six rats at 18,900 ppm v/v, so this concentration could be taken as a NOEL for anesthetic/CNS effect.[80]

Munley reports that no compound-related effects were observed for clinical signs at 51,000 ppm v/v in an inhalation developmental toxicity study in rats exposed for 6 hr/d on days 7-21 of gestation.[89] While interference might give false indications of an anesthetic/CNS effect during gestational studies, it is unlikely that gestation would suppress such an effect.

recommendation: NOEL rat = 51,000 ppm v/v

Other Escape-Impairing Effects and Permanent Injury

Fagan et al. indicate that four human volunteers experienced slight anesthetic effects, light headedness, tingling and numbness of the extremities, and hyperacusis* at 300,000 ppm v/v, discomfort by one subject at 400,000 ppm v/v, and significant anesthetic effect ("becoming lethargic") by one subject at 600,000 ppm v/v.[90] They adopted 300,000 ppm v/v as the "maximum

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* increased hearing

tolerated concentration." Van Poznak and Artusio report that self-testing by one of the authors resulted in "definite analgesia and impairment of consciousness" at 800,000 ppm v/v.[85]

recommendation: anesthetic effect in humans at 300,000 ppm v/v

R-32: DIFLUOROMETHANE

Lethality

Parr-Dobrzanski indicates that there were no fatalities in 4-hr, nose-only, inhalation tests of rats exposed to 520,000 ppm v/v R-32 in air with oxygen-enrichment to avoid asphyxiation.[91] Moore found no mortality in rats exposed for 4-hr to 760,000 ppm v/v.[92] This finding is cited by both Krentz et al. and a PAFT summary.[93,94]

recommendation: 4-hr LC_{50} rat >760,000 ppm v/v

Cardiac Sensitization

Mullin and Trochimowicz report a marked response in one of twelve dogs at 250,000 ppm v/v, but no sensitization in the affected dog when tested several days later at 200,000 ppm v/v.[95] They note that two dogs tested at 400,000 ppm v/v showed no response.[95] Hardy et al. report an EC_{50} in dogs of >350,000 ppm v/v.[71] This finding is cited in a PAFT summary.[7]

recommendation: NOEL dog = 200,000 ppm v/v

Anesthetic Effect

Parr-Dobrzanski indicates no effect in rats in 4-hr exposures at 7,510 ppm v/v, but notes an anesthetic effect in ten of ten rats at 85,900 ppm v/v.[91] In a separate study, Parr-Dobrzanski found no behavioral changes in rats at 49,500 ppm v/v, the highest concentration tested, by whole body exposures for 6 hr/d, 5 d/wk, for 4 wk.[96] Moore found an anesthetic effect in six of six rats exposed at 111,000 ppm v/v for 4-hr.[92,93]

recommendation: NOEL rat = 49,500 ppm v/v

Other Escape-Impairing Effects and Permanent Injury

None identified.

recommendation: none

R-113: 1,1,2-TRICHLORO-1,2,2-TRIFLUOROETHANE

Lethality

ACGIH indicates a range of 4-hr LC_{50} rat values of 52,000-56,000 ppm v/v.[24] Of them, Sarver's indication of 52,500 ppm v/v appears to be the most conservative (the difference between it and the concentration identified in the ACGIH range is due to rounding).[97] Sarver also indicates the lowest ALC identified, namely 45,000 ppm v/v for one of six tested rats. Clayton shows higher 4- and 6-hr ALCs, but does not give sufficient information to determine data qualification.[98,99]

recommendation: 4-hr LC_{50} rat = 52,500 ppm v/v

Cardiac Sensitization

Reinhardt et al. indicate no marked responses in twelve dogs at 2,600 ppm v/v and marked responses in ten of 29 tested dogs at 4,850 ppm v/v based on the midpoints of the measured concentrations.[100,101] These data are not inconsistent with EC_{50}s of 7,000 and 10,000 ppm v/v, both reported by Clark and Tinston.[53,60]

recommendation: NOEL dog = 2,600 ppm v/v

Anesthetic Effect

Raventós and Lemon indicate a 30-min EC_{50} mouse of 57,000 ppm v/v.[102] Clark and Tinston report a more conservative 10-min EC_{50} rat of 28,000 ppm v/v, based on action as a CNS stimulant.[53] Weigand reports a NOEL and LOEL of 25,000 and 80,000 ppm v/v, respectively, in rats for 2-hr exposures in a subchronic inhalation toxicity study, but he does not indicate the number of animals affected.[62]

Burn (with compound identification in a later paper by Burn et al.) indicates that one of ten, nine of ten, and fifteen of fifteen mice were anesthetized in 15 min at 50,000, 60,000, and 80,000 ppm v/v, respectively.[103,104]

recommendation: 10-min EC_{50} rat = 28,000 ppm v/v

Other Escape-Impairing Effects and Permanent Injury

None identified.

recommendation: none

R-114: 1,2-DICHLORO-1,1,2,2-TETRAFLUOROETHANE

Lethality

No lethality data were found for 4-hr exposures. Paulet reports a 30-min LC_{50} rat of 720,000 ppm v/v,[105] as cited by Ludwig et al.[11] Scholz indicates that the 2-hr LC_{50} rat exceeds 600,000 ppm v/v.[72] Waritz cites the Scholz finding in a data compilation.[106] DuPont indicates the former value in its MSDS while Honeywell cites the latter.[107,108] Based on the ten Berge adjustment (see page 11), the 30-min and 2-hr LC_{50}s suggest 4-hr LC_{50}s of 255,000 and >424,000 ppm v/v, respectively, of which the former is more conservative.

recommendation: 4-hr LC_{50} rat = 255,000 ppm v/v

Cardiac Sensitization

No NOELs were found. Reinhardt et al. indicate a LOEL based on a marked response in one of twelve dogs for an exposure of 25,000 ppm v/v.[57,70] Hardy et al. report an EC_{50} in dogs of 46,000-100,000 ppm v/v.[71]

recommendation: LOEL dog = 25,000 ppm v/v

Anesthetic Effect

Montgomery et al. cite an unpublished 10-min EC_{50} rat of 250,000 ppm v/v from D. G. Clark (ICI).[109] Weigand reports a 2-hr LOEL rat of 300,000 ppm v/v, but does not indicate the fraction of animals showing effects, as well as a NOEL of 100,000 ppm v/v.[62] The Weigand data corroborate the unpublished Clark data, even though efforts to obtain the source-study were unsuccessful.

recommendation: 10-min EC_{50} rat = 250,000 ppm v/v

Other Escape-Impairing Effects and Permanent Injury

The IPCS reports significant reduction in ventilatory lung capacity, bradycardia,* and increased variability in heart rate following exposures to 2,300-21,400 ppm v/v R-114 for 15, 45, or 60 seconds.[110] Ludwig et al. review these data in documenting the NIOSH IDLH, but based the IDLH of 15000 ppm v/v on cardiac sensitization data.[11] That determination indicates that the effects cited by the IPCS were not considered to be either escape impairing or permanent injury. No case histories corroborating the IPCS indication were found despite wide historic use of R-114 an aerosol propellant for cosmetics and pharmaceutical propellant in metered-dose inhalers (MDIs), both of which resulted in frequent human exposures.

recommendation: none

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* slow heart rate

R-116: HEXAFLUOROETHANE

Lethality

Morrison indicates that there were no deaths among four rats exposed to 800,000 ppm v/v R-116 in oxygen for 4 hr.[111] Clayton and Waritz both present the Morrison finding.[99,106] Hiddemen, contributing to a broader study by McHale, corroborates this finding with no deaths in a 1-hr ALC rat study at 800,000 ppm v/v.[112,113]

recommendation: 4-hr LC_{50} rat >800,000 ppm v/v

Cardiac Sensitization

Mullin and Trochimowicz indicate a NOEL at 200,000 ppm v/v from tests of twelve dogs.[114] Wills et al. report a similar finding, but their data do not qualify since the tests were conducted on anesthetized dogs.[115] Hughes suggests a NOEL in dogs of 600,000 ppm v/v,[116] but the summary of it by Lee and Graham does not indicate whether an epinephrine challenge was administered.[117] Brock examined the Hughes data, but also could not determine the basis.[118]

recommendation: NOEL dog = 200,000 ppm v/v

Anesthetic Effect

No EC_{50} was found. Morrison notes that rats exposed to 200,000 ppm v/v showed marginal signs of intoxication, but does not indicate how many of four rats were affected.[111] Hiddemen notes an anesthetic effect for all ten rats exposed to 780,000 ppm v/v for 1 hr, but indicates normal behavior for 20 rats in a 10-day, continuous exposure study at 121,000 ppm v/v.[112]

recommendation: 10-day NOEL rat = 121,000 ppm v/v

Other Escape-Impairing Effects and Permanent Injury

None identified.

recommendation: none

R-123: 2,2-DICHLORO-1,1,1-TRIFLUOROETHANE

Lethality

Waritz and Clayton indicate a 4-hr LC_{50} rat of 35,000 ppm v/v.[119,120] Hall and Moore obtained a similar finding, but slightly lower finding.[121] They report that 4-hr exposures of 20,700, 32,000, 33,700, 42,100, 52,500, and 55,000 ppm v/v were fatal to zero, three, three, four, six, and six rats, respectively, in groups of six,[121] indicating an ALC of 32,000 ppm v/v. They conclude that R-123 has a 4-hr LC_{50} rat of approximately 32,000 ppm v/v,[121] which a PAFT summary cites.[94] Coate reports a third, still later study with a somewhat higher 6-hr LC_{50} rat of 52,540 ppm v/v,[122] which is cited by both an ECETOC JACC assessment and IPCS survey.[123,124] The Hall and Moore finding is the most conservative.

recommendation: 4-hr LC_{50} rat = 32,000 ppm v/v

Cardiac Sensitization

Trochimowicz and Mullin report a NOEL for three dogs tested at 10,300 ppm v/v, a LOEL for four of six dogs (exceeds 50%) at 20,900 ppm v/v, and a calculated EC_{50} of 19,000 ppm.[61,125]

recommendation: NOEL dog = 10,300 ppm v/v

Anesthetic Effect

Tests by Robbins indicate a 10-min EC_{50} of 27,000 ppm v/v for mice by a standard *rotadrum* (rotating bottle) method.[126]

Raventós and Lemon measured a 30-min EC_{50} mouse of 24,000 ppm v/v.[102] This finding is cited in the NRC assessment to determine exposure guidance levels (CEGL, EGL, and EEGL) for special military applications on ships and aircraft.[39] Mullin reports behavioral test data for R-123 by show that the effective concentration decreases with increasing exposure duration (the effective concentration levels are lower at 30 min than at 15 min, and lower still at 60 min than at 30 min).[127] The slightly lower 30-min EC_{50} from Raventós and Lemon therefore corroborates the 10-min EC_{50} finding by Robbins.

Wada indicates the 10-min *approximate anesthetic concentration* (AAC) to be 130,000 ppm v/v.[128] The AAC appears to be an EC_{50}, but it is more conservative if it refers to a threshold concentration level.

The Mullin study also found "occasional failures in pinna reflex"* after 60 min in one of six rats at 0 ppm v/v (untreated control group) and in unspecified numbers of rats among six tested at 975 and 2,697 ppm v/v.[127] That indicates a possible effect as low as 975 ppm v/v, but it is not clear if it was exposure related, since a control animal (0 ppm v/v) also failed the same criterion. Mullin indicates a 15-min EC_{50} of 7,080 ppm v/v as the lowest in a range (7,080-9,710 ppm v/v) for a suite of behavioral measures including unconditioned reflexes, simple behavioral patterns,

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* characteristic response of flattening an ear touched lightly with a small brush or probe

modified locomotor activity (grip,* lift,† vertical bar,‡ ataxia,§ and pinna tactile**), and observation of unusual signs or symptoms.[127,129] The resulting EC_{50} is far more stringent than by the standard *rotadrum* test and is for 15-min rather than 10-minute tests.

Burns et al. report a LOEL of 40,000 ppm v/v.[130] Hall and Moore noted central nervous system (CNS) effects in rats at 20,700 ppm v/v for 4 hr exposures.[121] Trochimowicz reports a NOEL of 2,500 ppm v/v.[131] Magda indicates a NOEL of 5,000 ppm v/v in acute and subchronic inhalation studies.[132] The PAFT toxicity summary for R-123 notes that anesthetic-like effects are observed at concentrations exceeding 5,000 ppm v/v.[7]

The 10-min EC_{50} of 27,000 ppm v/v from Robbins meets the data selection criteria (see page 19) and is the most conservative of similar test findings.

recommendation: 10-min EC_{50} rat = 27,000 ppm v/v

Other Escape-Impairing Effects and Permanent Injury

There is anecdotal evidence of hepatotoxicty (liver toxicity) from chronic exposures well above the Workplace Environmental Exposure Level (WEEL) guide developed by the American Industrial Hygiene Association (AIHA) for R-123, but these accounts do not suggest any escape-impairing effects. Moreover, they indicate that the effects were reversible (not permanent).[133-136]

recommendation: none

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* ability to grasp a horizontal rod for support when swung gently by the tail toward the rod

† ability to raise the hind legs onto a horizontal rod, and remain there, while hanging from the rod by the forepaws

‡ ability to grasp a vertical rod with both front and hind feet when swung gently by tail toward the rod

§ inability to coordinate voluntary muscular movements determined by observation of gait on a non-slip surface

** characteristic response of flattening an ear touched lightly with a small brush or probe

R-124: 2-CHLORO-1,1,1,2-TETRAFLUOROETHANE

Lethality

Gleason and Coate indicate no mortality from 6-hr rat exposures to 360,000 ppm v/v.[137] In a PAFT data summary, Finegan and Rusch indicate that the 4-hr LC_{50} rat equals 360,000 ppm v/v.[138] In a separate summary of the PAFT data, Magda indicates that the LC_{50} rat exceeds 360,000 ppm v/v.[132] While he does not explicitly identify the duration of the tests, other data in the same table reflect 4-hr values. Honeywell's MSDS indicates that the 4-hr LC_{50} rat equals or exceeds 360,000 ppm v/v.[139]

Trochimowicz reports a 4-hr LC_{50} rat of 262,500 ppm v/v determined from tests by Kelly.[125,140] Kelly indicates 4-hr exposures to 230,000 ppm v/v yielded no deaths, but six of six rats died at 300,000 ppm v/v.[140] DuPont's MSDS reflects the Kelly finding with indication that the 4-hr ALC is 230,000-300,000 ppm v/v.[141]

The ECETOC JACC report for R-124 summarizes both the Gleason and Coate and the Kelly studies, but indicates that the 4-hr LC_{50} rat is 230,000-300,000 ppm v/v in the summary and conclusions.[142]

recommendation: 4-hr LC_{50} rat = 262,500 ppm v/v, 4-hr ALC rat >230,000 ppm v/v

Cardiac Sensitization

Mullin indicates a NOEL for zero of ten dogs at 10,100 ppm v/v and a LOEL for four of ten dogs at 25,000 ppm v/v. Kenny and Hardy cite an EC_{50} of 40,000 ppm v/v from an EPA draft with an incomplete reference.[143] An earlier external review draft obtained from EPA does not mention this EC_{50}.[144]

recommendation: NOEL dog = 10,100 ppm v/v

Anesthetic Effect

The PAFT summary for R-124 indicates a 10-min EC_{50} in animals of 140,000 ppm v/v for nervous system effects, but it neither identifies the species tested nor references the specific study.[7] Honeywell's MSDS also cites this EC_{50}.[139] Wada indicates a calculated "approximate anesthetic concentration (AAC)" that appears to be an EC_{50} of 150,000 ppm v/v from a 10-min test of rats.[52] Van Poznak and Artusio report an effect in dogs exposed to R-124 at 400,000 ppm v/v, but do not indicated the fraction of responses among six subjects.[85] Gleason and Coate indicate an effect for an unspecified quantity of the six rats at 100,000 ppm v/v in the first 30 min of a 4 hr, acute inhalation study.[137] Kelly indicates a NOEL from a 4-hr test of six rats at 48,000 ppm v/v.[140] Barring discovery of a source for and verification of the PAFT indication, the Wada data appears to best fit the data selection criteria (see page 19).

recommendation: 10-min EC_{50} rat = 150,000 ppm v/v

Other Escape-Impairing Effects and Permanent Injury

None identified.

recommendation: none

R-125: 1,1,1,1,2-PENTAFLUOROETHANE

Lethality

Nakayama et al. concluded that the 4-hr ALC rat, and therefore also the LC_{50}, exceeds 769,000 ppm v/v.[145] This result is cited in many MSDSs but often as 800,000 ppm v/v based on the target concentration. An earlier study by Panepinto found that the 4-hr ALC exceeds 709,000 ppm v/v based on no deaths in six tested rats.[146] Given that zero deaths is akin to a "NOEL" for scoring mortality and that Panepinto's open-ended finding does not contradict Nakayama's, the latter finding meets the selection criteria (see page 19).

recommendation: 4-hr LC_{50} rat >769,000 ppm v/v

Cardiac Sensitization

Hardy et al. report no and one marked responses among six dogs tested at 75,000 and 100,000 ppm v/v, respectively.[147] The same study reported an EC_{50} of 139,000 ppm v/v while a later compilation by the same authors indicates an EC_{50} of 170,000 ppm v/v.[71,147] While the EC_{50} selection is unclear in this case, the NOEL is not.

recommendation: NOEL dog = 75,000 ppm v/v

Anesthetic Effect

No 10-min EC_{50} in mice or rats were found. But several 4-hr acute inhalation studies provide NOEL and LOEL data. Nakayama et al. indicate an effect in more than half the rats exposed to 769,000 ppm v/v.[145] Burns et al. report no anesthetic effect in mice at 930,000 ppm v/v,[130] but this indication warrants verification since the animals should have experienced oxygen deprivation at that concentration even with a mixture of R-125 and pure oxygen. Moreover, this finding fails the data selection criteria (see page 19) for a NOEL since it exceeds the LOEL reported by Nakayama et al.[145] Panepinto indicates no effect for five rats at 709,000 ppm v/v.[146] Nakayama et al., in a separate study, report no effect at 50,113 ppm v/v among 40 rats in a subchronic study.[148] The Panepinto NOEL meets the selection criteria.

recommendation: 10-min EC_{50} rat = 709,000 ppm v/v

Other Escape-Impairing Effects and Permanent Injury

None identified.

recommendation: none

R-134: 1,1,2,2-TETRAFLUOROETHANE

Lethality

Warheit found no mortality in 4-hr exposures of rats at concentrations as high as 460,000 ppm v/v in air (with oxygen enrichment to maintain 20-22% levels), which indicates that the 4-hr ALC and EC_{50} rat exceed 460,000 ppm v/v.[149] No other acute inhalation lethality data were located, but the DuPont MSDS shows the Warheit finding.[150]

recommendation: 4-hr LC_{50} rat >460,000 ppm v/v

Cardiac Sensitization

A Huntingdon Research Centre (HRC) study found a NOEL at 75,000 ppm v/v and a LOEL for marked responses in 33% of tested dogs at 100,000 ppm v/v.[151]

recommendation: NOEL dog = 75,000 ppm v/v

Anesthetic Effect

The Warheit ALC study states that no clinical signs were observed at 120,000 ppm v/v, but that an unspecified number of rats exposed to 200,000 ppm v/v showed no response to tapping on the chamber.[149]

recommendation: 4-hr NOEL rat = 120,000 ppm v/v

Other Escape-Impairing Effects and Permanent Injury

None identified.

recommendation: none

R-134a: 1,1,1,2-TETRAFLUOROETHANE

The International Pharmaceutical Aerosol Consortium for Toxicology Testing (IPACT) and independent pharmaceutical companies have conducted extensive studies on the toxicity and tolerance of R-134a, to qualify its use as a pharmaceutical aerosol propellant for metered dose inhalers (MDIs), but declined to release those studies.

Lethality

Several sources cite a 4-hr ALC of 566,700 ppm v/v.[152,153] This ALC derives from a study by Silber, but it does not meet the data selection criteria (see page 19) since this concentration was fatal to more than half of the animals tested, namely five of six rats.[154] Silber also indicates no mortality in six rats exposed to 359,300 ppm v/v for 4 hr.[154]

Other sources cite a 4-hr LC_{50} rat of >500,000 ppm v/v.[153,155-157] Several PAFT summaries also cite it.[7,125,132,138] An ECETOC JACC report attributes it to unpublished ICI data.[158,159] Efforts to locate it through the identified source found only a citation by Ferguson-Smith that attributes the LC_{50} to an internal ICI communication that could not be retrieved.[160,161]

Rissolo found a 30-min ALC rat of 750,000 ppm v/v based on two deaths among four exposed rats.[162]

The 4-hr ALC of >359,300 ppm v/v from Silber, which implies a 4-hr LC_{50} of >359,300 ppm v/v, meets the data selection criteria. The cited 4-hr LC_{50} rat of >500,000 ppm v/v might meet the criteria if adequate documentation can be obtained. The LC_{50} will not impact the ATEL for R-134a or common blends that include it, but might influence the ATEL for some other blends.

recommendation: 4-hr LC_{50} rat >359,300 ppm v/v

Cardiac Sensitization

Mullin reports no sensitization in ten dogs at 49,800 ppm v/v, marked response in two of ten dogs at 75,200 ppm v/v, and in two of four dogs with one death at 101,900 ppm v/v.[163] Hardy et al. report later tests with no sensitization at 40,000 ppm v/v as well as marked responses in two of six dogs at 80,000 ppm v/v.[56] Kenny and Hardy as well as Hardy et al. indicate an EC_{50} of 205,000 ppm v/v.[71,114]

recommendation: NOEL dog = 49,800 ppm v/v

Anesthetic Effect

Shulman and Sadove report an EC_{50} level in mice of 270,000 ppm v/v based on loss of righting reflex.[164] They do not indicate the test duration except to note the anesthetic "action is rapid," but they note that induction times with concentrations of 500,000 ppm v/v or greater is under 30 seconds.[164] Ferguson-Smith attributes a 10-min EC_{50} rat of 280,000 ppm v/v to an internal ICI communication.[160,161]

Silber reports a LOEL of 205,200 ppm v/v from a 4-hr rat study, but does not indicate the number of affected rats, and a NOEL at 81,000 ppm v/v.[154] In a later study, Alexander found no evidence of acute toxicity or clinical reactions in rats or mice exposed for 1 hr to 810,000 ppm v/v with oxygen supplementation.[165]

Neither of the two EC_{50} values meet the letter of the data selection criteria, but they reinforce each other and appear consistent with the NOEL and LOEL data. The effect described by Shulman and Sadove as "rapid" probably was less than 10 min, especially considering the very short induction time indicated for higher concentrations. If in error, use of a 10-min EC_{50} rat of 270,000 ppm v/v is still slightly more conservative than the 10-min EC_{50} rat of 280,000 ppm v/v indicated by Ferguson-Smith.

recommendation: 10-min EC_{50} rat = 270,000 ppm v/v

Other Escape-Impairing Effects and Permanent Injury

Vinegar et al. describe tests in human volunteers, to validate a physiologically-based pharmacokinetic (PBPK) model, in which tests with R-134a had to be terminated when the subject lost consciousness and experienced reduced pulse and blood pressure at 4,000 ppm v/v.[166] The report notes that a second subject experienced a rapid rise in blood pressure and pulse in sequential exposures at 4,000 and 2,000 ppm v/v exposure as well as anomalous results with R-227ea (see page 65).[166] Subsequent investigation indicates that the reported responses probably were not due to the chemical exposures, and that no adverse effects were seen in other human exposures at lower or higher concentrations.[167,168]

recommendation: none

R-E134: DIFLUOROMETHOXY-DIFLUOROMETHANE

Lethality

Keller et al. with elaboration by Graham and Lardear indicate no fatalities among three rats exposed to 95,000 ppm v/v for 4 hr.[169,170]

Simons et al. summarize toxicity findings in a patent on dimethyl ethers.[171] They indicate no deaths in ten mice exposed to slightly more than 200,000 ppm v/v for 2 hr and in an unspecified quantity of rats exposed to 50,000 ppm v/v for 3 hr/d for 5 days.[171] These findings suggest 4-hr ALCs and LC_{50}s of >141,000 and >43,300 ppm v/v with the ten Berge adjustment (see page 11).

In an unpublished presentation, O'Neill (one of the inventors in the Simons patent) indicates no deaths in inhalation exposures of unspecified numbers of rats to 50,000 ppm v/v for 3 hr, 200,000 ppm v/v for 2 hr, and 300,000 ppm v/v for 30 min.[172] These data suggest 4-hr ALCs and LC_{50}s of >43,300, >141,000, and >106,000 ppm v/v with the ten Berge adjustment. While these unpublished and incomplete findings do not meet the data selection criteria (see page 19), they expand on the indications and corroborate the Simons et al. data.

recommendation: 4-hr LC_{50} rat >141,000 ppm v/v

Cardiac Sensitization

O'Neill summarizes a comparative study of R-11, R-12, R-21, R-22, and R-E134a in monkeys for 30-min exposures to 50,000 ppm v/v mixed with oxygen.[172] He reports that all of these chemicals predisposed the monkeys to cardiac arrhythmia and sensitized them to epinephrine challenges, but with only a limited sensitization for R-12. He notes that R-E134 behaved more like R-11 than the other compounds tested. O'Neill does not indicate either a NOEL or the fraction of monkeys with marked responses at 50,000 ppm v/v, but he makes clear that R-E134 is a cardiac sensitizer.[172] Moreover, the data are for monkeys rather than dogs, though monkeys usually are a good animal model for human toxicity.

recommendation: not determined

Anesthetic Effect

No EC_{50} was found.

O'Neill indicates that mice exposed to 100,000, 130,000, 182,500, or 307,500 ppm v/v showed anesthetic effects in 60, 30, 5, and 2 min respectively.[172] Simons et al. (including O'Neill) indicate anesthetic effects in ten mice exposed to slightly more than 200,000 ppm v/v for 2 hr.[171] These data do not enable determination of a qualifying LOEL or NOEL.

Keller et al. indicate that rats exposed to 45,000 ppm v/v for 4 hr appeared uncoordinated and responded sluggishly to sound.[169,170] They further indicate that rats exposed to 18,000 ppm v/v showed no signs of clinical toxicity.[169,170]

recommendation: 4-hr NOEL rat = 18,000 ppm v/v

Other Escape-Impairing Effects and Permanent Injury

None identified.

recommendation: none

R-141b: 1,1-DICHLORO-1-FLUOROETHANE

Lethality

Hardy et al. indicate 4-hr LC_{50}s of 58,931 ppm v/v from tests of five male rats, 64,991 ppm v/v for five females, and 61,647 ppm v/v overall.[173] These results also are summarized in an article by Seckar, who rounds the LC_{50} to 62,000 ppm v/v.[174] The LC_{50} finding is supported by an earlier 6-hr acute inhalation study in rats for which Doleba-Crowe reports an ALC of 50,200 ppm v/v,[175] cited by the IPCS and by Lee et al.[124,176] Janssen reports a separate 6-hr acute inhalation study that found the 6-hr ALC rat to exceed 11,096 ppm v/v.[177]

recommendation: 4-hr LC_{50} rat = 61,647 ppm v/v

Cardiac Sensitization

Mullin reports a NOEL and LOEL based on marked responses in zero and one of ten dogs at 2,600 and 5,200 ppm v/v, respectively.[178] These data suggest that R-141b is a strong cardiac sensitizer.

In a later study, Hardy et al. document a marked response in one of two dogs tested at 9,000 ppm v/v (the lowest concentration tested), a mild response at 3,000 ppm v/v in monkeys, and both a marked response in the same animal and a questionable response in a second monkey at 5,000 ppm v/v.[55]

In a third still later study, Kenny found neither marked responses nor abnormal clinical signs at 10,000 ppm v/v, but a marked response in one of six dogs tested at 20,000 ppm v/v.[179]

Brock et al. note the sensitization level as 9,000-19,000 ppm v/v in dogs as well as at 5,000 and 10,000 ppm v/v in monkeys.[180] They conclude that "HCFC-141b is able to induce a cardiac sensitization response at 5000 ppm and above, a similar response to that observed with CFC-11."[180]

The Mullin data appears to be the most conservative, though the data dispersion suggests some uncertainty.

recommendation: NOEL dog = 2,600 ppm v/v

Anesthetic Effect

Robbins indicates a 10-min EC_{50} rat of 25,000 ppm v/v.[126]

Hardy et al. indicate that the rats in all exposure groups, of which the lowest was 29,674 ppm v/v, showed "reduced motor activity, restless behavior, and abnormal body carriage" among other symptoms.[173] Summarizing that study, Brock et al. indicate that anesthesia was noted above 29,000 ppm v/v.[180] Seckar indicates behavior typical of CNS depression above 30,000 ppm v/v in an unspecified number of rats.[174] Janssen and Millischer et al. note NOELs at 11,096 in ten rats and 19,959 ppm v/v in 160 rats, respectively, in 6-hr exposures in acute and

chronic inhalation toxicity studies, again respectively.[177,181] Doleba-Crowe reports mild anesthesia within the first hour of 6-hr exposures of six rats at 31,730 ppm v/v.[175]

These data are reasonably consistent and support the Robbins EC_{50}.

recommendation: 10-min EC_{50} rat = 25,000 ppm v/v

Other Escape-Impairing Effects and Permanent Injury

None identified.

recommendation: none

R-142b: 1-CHLORO-1,1-DIFLUOROETHANE

Lethality

Davies et al. indicate a 30-min LC_{50} mouse of 300,000 ppm v/v,[182] as reported in an ECETOC JACC report.[183] Applying the ten Berge extrapolation (see page 11) suggests a 4-hr LC_{50} of approximately 106,000 ppm v/v.

Carpenter et al. indicate that 128,000 ppm v/v for 4 hr kills two to four of six rats.[184] Four of six would exceed the 50% criterion for an ALC.

Mecler and Knapinsky indicate a 6-hr ALC rat of 400,000 ppm with 20% mortality,[185] but this finding conflicts with those of Davies et al. (with or without the ten Berge adjustment) and Carpenter et al.

Lester and Greenberg report that "all animals died within 9 exposures; 6 died in 7 days, 2 in 8 days, and 2 in 9 days" for exposures at 100,000 ppm v/v for 16 hr/d.[65] This wording implies that no deaths occurred in the first day of the 9-day rat study, which suggests a 16-hr ALC of >100,000 ppm v/v. Applying the ten Berge adjustment suggests a 4-hr ALC of approximately 200,000 ppm v/v, but the full adjustment may not be appropriate for a *no-effect* rather than an *effect* level.

Further testing of R-142b is unlikely with its scheduled phaseout pursuant to the Montreal Protocol.

While no 4-hr LC_{50} or ALC was found there is reasonable agreement between the findings of Davies et al. (though in a mouse rather than a rat), Carpenter et al., and Lester and Greenberg. Use of the most conservative of them, namely the adjusted data from Davies et al., should be appropriate.

recommendation: 4-hr LC_{50} mouse = 106,000 ppm v/v

Cardiac Sensitization

Mullin indicates marked responses in zero of six, five of twelve, and twelve of twelve dogs tested at 25,000, 50,000, and 100,000 ppm v/v, respectively.[178,186] Reinhardt et al. (including Mullin) explain the test procedure and findings.[57]

recommendation: NOEL dog = 25,000 ppm v/v

Anesthetic Effect

Robbins reports a 10-min EC_{50} mouse of 250,000 ppm v/v.[126]

Lester and Greenberg state that a rat exhibited "slight intoxication" at 150,000 ppm v/v (the lowest concentration tested), lost postural reflex at 200,000 ppm v/v, and lost consciousness at 300,000 ppm v/v.[65] The goal of their study was to screen fluorocarbons as anesthetic agents, so the authors were seeking levels inducing deep anesthesia. While "slight intoxication" fits the

criterion of "any observed effect to even one test animal" in the definition of a LOEL, the tests involved only a single animal and therefore an effect in more than 50% of tested animals.

recommendation: 10-min EC_{50} rat = 250,000 ppm v/v

Other Escape-Impairing Effects and Permanent Injury

None identified.

recommendation: none

R-143a: 1,1,1-TRIFLUOROETHANE

Lethality

Kelly indicates no mortality in six rats exposed to 540,000 ppm v/v for 4 hr.[187] In a later study, Cracknell indicates a similar result for ten rats at 591,000 ppm v/v.[188] These results are reinforced by Nikijenko and Tolgskaya with no deaths in an acute inhalation test of mice at 540,000 ppm v/v.[189]

recommendation: 4-hr LC_{50} rat >591,000 ppm v/v

Cardiac Sensitization

Hardy and Sharman report no marked responses in six dogs at concentrations as high as 250,000 ppm v/v in air, but marked response in two of five dogs at 300,000 ppm v/v.[190] Brock et al. summarize the Hardy and Sharman study.[191] Hardy et al. indicate the EC_{50} to be 310,000 ppm v/v.[71]

recommendation: NOEL dog = 250,000 ppm v/v

Anesthetic Effect

Robbins indicates a 10-min EC_{50} range of 500,000-600,000 ppm v/v in mice.[126] The absence of any clinical signs of anesthetic effects in two acute inhalation toxicity studies, by Kelly at 540,000 ppm v/v and by Cracknell at 591,000 ppm v/v, support the Robbins finding.[187,188] A review of acute, subchronic, and chronic exposure studies by Brock et al. repeatedly notes the absence of adverse clinical signs.[191] Based on the conservative end of the Robbins range, the EC_{50} is at least 500,000 ppm v/v.

recommendation: 10-min EC_{50} rat = 500,000 ppm v/v

Other Escape-Impairing Effects and Permanent Injury

None identified.

recommendation: none

R-152a: 1,1-DIFLUOROETHANE

Lethality

Moore reports zero, one, and two deaths among groups of six rats exposed to 319,000, 383,000, or 437,500 ppm v/v, respectively, for 4 hr.[192] While Moore concludes that the ALC is 383,000 ppm v/v,[192] the data suggest that the 4-hr LC_{50} might exceed 437,500 ppm v/v.

An early study by Carpenter et al. suggest a contrary conclusion. A second by Lester and Greenberg does likewise, but also presents conflicting findings that are more consistent with the Moore data. A third early study by Limperos also offers consistent data, though insufficient to corroborate the Moore and Keller findings.

The study by Carpenter et al., published in 1949, indicates an ALC based on deaths of two to four of six rats at 64,000 ppm v/v in 4 hr.[184] Based on the uncertain number of deaths, this result might not meet the data selection criteria (see page 19).

A study by Lester and Greenberg, published in 1950, indicates that a 30-min exposure to 500,000 ppm v/v was fatal to the single rat tested.[65] Applying the ten Berge extrapolation (see page 11) suggests that a 4-hr exposure to 177,000 ppm v/v or a 16-hr exposure to 88,400 ppm v/v should be lethal. However, the same paper by Lester and Greenberg also reports a chronic exposure study of eight rats exposed to a concentration of 100,000 ppm for 16 hr/day for two months with no adverse clinical signs and only mild, microscopic effects in pathology at necropsy.[65] Applying the ten Berge extrapolation suggests comparability to a 4-hr ALC that exceeds 200,000 ppm v/v.

A 1951 study by Limperos reports occasional trembling and loss of coordination, but no deaths in pairs of rats at 100,000 and 200,000 ppm v/v for 2 hr.[193] Applying the ten Berge extrapolation suggests comparability to a 4-hr ALC that exceeds 141,000 ppm v/v.

Keller et al. interpret the Lester and Greenberg, Limperos, and Moore studies — the last two of which are Haskell studies as was the one by Keller et al. — as indicating a 4-hr LC_{50} rat exceeding 400,000 ppm v/v.[194]

The documentation for the R-152a WEEL cites a 4-hr ALC of 383,000 ppm v/v based on the Moore finding, a 3-min ALC exceeding 500,000 ppm v/v based on Lester and Greenberg,* and a 2-hr LC_{50} mouse of 369,000 ppm v/v based on Izmerov et al.[195,196] Applying the ten Berge extrapolation to the Izmerov finding suggests a 4-hr LC_{50} mouse of 261,000 ppm v/v.

Several toxicity assessments document additional testing, including for use as an aerosol propellant in consumer products.[23,195,197-201] Manufacturer MSDSs show no consensus, variously citing the 4-hr ALC rat of 64,000 ppm v/v from Carpenter et al.,[202] the 4-hr ALC of 383,000 ppm v/v from Moore,[203] the same concentration as a 4-hr LC_{50},[204] and the same concentration as a 2-hr LC_{50} rat.[205] Based on the present data selection criteria (see page 19), the ALC and values

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* The "3-min" indication appears to be an error. The intent may have been "30-min" based on the protocol description by Lester and Greenberg, but they state that "exposures to 50 and 55 per cent were lethal in from 10 to 25 minutes" for the R-152a tests.[65]

other than for 4-hr rat studies come into play only if there is no 4-hr LC_{50} rat. On that basis, the Keller et al. 4-hr LC_{50} rat of >400,000 ppm v/v qualifies. But the cited data conflicts and preference for conservative data beg further study of this item.

recommendation: 4-hr LC_{50} rat >400,000 ppm v/v subject to further review

Cardiac

Mullin indicates marked responses in zero of twelve and three of twelve dogs tested at 50,000 and 150,000 ppm v/v, respectively.[186] Although the results indicate a NOEL of 50,000 ppm v/v for cardiac sensitization, she notes that the compound was not well tolerated. Reinhardt et al. (including Mullin) explain the test procedure and findings.[57] Aviado examines the cardiotoxicity of R-152a in several papers, but draws on the Reinhardt et al. data for cardiac sensitization.[206,207]

recommendation: NOEL dog = 50,000 ppm v/v

Anesthetic Effect

No EC_{50} data were found. Lester and Greenberg indicate an effect in the single rat tested at 200,000 ppm for 30 min, but no effect in a single rat tested at 100,000 ppm v/v.[65] Limperos reports occasional trembling and loss of coordination in two rats (probably in both, but not clearly indicated) exposed at 100,000 ppm v/v for 2 hr, but no toxic effects at 74,000 ppm v/v for 105 min. Neither of the LOELs meet the data selection criteria (see page 19) since both were for 100% of the tested animals.

recommendation: 30-min NOEL rat = 100,000 ppm v/v

Other Escape-Impairing Effects and Permanent Injury

Van Poznak and Artusio report that several volunteers who inhaled 500,000 ppm v/v "briefly" noted "good analgesia and impending loss of consciousness".[85]

recommendation: anesthetic effect in humans at 500,00 ppm v/v

R-218: OCTAFLUOROPROPANE

Lethality

Hiddeman reports no mortality either in ten rats exposed to 800,000 ppm v/v with oxygen for 1-hr or in twenty rats exposed to 113,000 ppm v/v continuously for 10 days.[208] Two of twenty guinea pigs also exposed in the extended study became ill as did one control animal, but the cause was not attributed to exposures.[208] A Huntingdon Research Centre (HRC) study found no deaths in ten rats exposed to 110,000 ppm v/v for 4 hr,[209] as summarized by 3M.[210] Applying the ten Berge extrapolation to the acute exposure data from Hiddeman suggests that the 4-hr LC_{50} rat should exceed 400,000 ppm v/v.

recommendation: 4-hr LC_{50} rat >400,000 ppm v/v

Cardiac Sensitization

As summarized by 3M,[210] an HRC study found no responses in six dogs tested at 300,000 ppm v/v, but a marked response in one dog and a questionable response in a second among eight dogs tested at 400,000 ppm v/v.[211] Hardy et al. support the summary with an indication that the EC_{50} for dogs exceeds 400,000 ppm v/v.[71]

recommendation: NOEL dog = 300,000 ppm v/v

Anesthetic Effect

No EC_{50} data were found. Hiddeman reports that all ten rats exposed to 800,000 ppm v/v for 1 hr showed anesthetic effects, but that 20 rats and 20 guinea pigs exposed to 113,000 ppm v/v continuously for 10 days showed normal behavior (except as noted above for two of the guinea pigs).[208] 800,000 ppm v/v does not meet the data selection criteria (see page 19) for a LOEL since more than half of the animals showed an effect.

recommendation: subchronic NOEL rat = 113,000 ppm v/v

Other Escape-Impairing Effects and Permanent Injury

None identified.

recommendation: none

R-227ea: 1,1,1,2,3,3,3-HEPTAFLUOROPROPANE

Both the International Pharmaceutical Aerosol Consortium for Toxicology Testing (IPACT) and independent pharmaceutical companies have conducted extensive studies of the toxicity and tolerance of R-227ea, to qualify its use as a pharmaceutical aerosol propellant for metered dose inhalers (MDIs). However, they declined to release those studies.

Lethality

Bury notes that no deaths occurred at 110,000 ppm v/v, but does not give details.[212] Hoechst's safety data sheet cites the same concentration as a 4-hr LC_{50} rat.[213] Bury notes that higher concentrations were not tested because the animals breathed irregularly and became uncoordinated at 110,000 ppm v/v.[212]

WIL Research Laboratories reports no deaths in groups of six rats exposed to 121,267 ppm v/v for 4 hr or 241,188 ppm v/v for 4½ hr, the latter with a 19 min break during the exposure period,[214] as summarized Great Lakes Chemical (GLC) and by the National Industrial Chemicals Notification and Assessment Scheme (NICNAS) of Worksafe Australia.[215,216] WIL also reports no deaths in ten rats exposed to 788,696 ppm v/v in oxygen and concludes that the 4-hr LC_{50} rat exceeds this concentration,[217] again as summarized by GLC and NICNAS.[215,216]

Skaggs and Moore indicate that the 4-hr LC_{50} rat exceeds 800,000 ppm v/v, but it is based on the WIL data with rounding.[218] The UK Halon Alternatives Group (HAG) also shows the 4-hr LC_{50} rat as exceeding 800,000 ppm v/v, but gives no source for it.[219]

The WIL 4-hr LC_{50} rat appears to meet the data selection criteria (see page 19) except that the studies were not published or provided for examination. The recommendation relies on the NICNAS assessment of the WIL finding.

recommendation: 4-hr LC_{50} rat = 788,696 ppm v/v

Cardiac Sensitization

Bury indicates no effect at 50,000 ppm v/v in dogs, but does not give details.[212] WIL indicates no responses in dogs at 70,000 ppm v/v,[220] as summarized by NICNAS.[216] WIL further indicates marked responses in one of ten, five of ten, and six of ten dogs at 90,000, 105,000, and 140,000 ppm v/v, respectively, as summarized by NICNAS.[216,220] However, the GLC summary for the same study reports the NOEL and LOEL to be 90,000 and 105,000 ppm v/v, respectively,[215] which implies a different interpretation of the results at 90,000 ppm v/v.

The more conservative WIL NOEL appears to meet the data selection criteria (see page 19) except that the study was not published or provided for examination. The recommendation relies again on the NICNAS assessment of it, but is qualified based on the uncertainty raised by the GLC summary.

recommendation: NOEL dog = 70,000 ppm v/v subject to further review

Anesthetic Effect

No EC_{50} data were found. Bury indicates that animals became uncoordinated at 110,000 ppm v/v.[212] Hoechst's safety data sheet indicates the animals as rats and exposure duration as 4 hr, but does not indicate the number of rats tested or showing effects.[213] Bury also notes lethargy, sedation, and listlessness in mice and rats exposed to 150,000 ppm v/v for 1 hr, from a test to determine the maximum tolerable concentration.[212] Bury reports a third study in which four dogs showed no clinical signs at 50,000 ppm v/v, but exhibited lethargy, sedation, and listlessness at higher concentrations.[212]

WIL indicates that all six rats exposed to 121,267 ppm v/v exhibited temporary anesthesia, hypoactivity,* bradypnea,† and/or ataxia‡ during treatment,[214] as summarized by NICNAS.[216] The summaries of other WIL studies do not provide sufficient information to determine a NOEL for anesthetic effects, though the full reports might provide such information.[216,217]

The GLC summary of toxicity studies describes a 14-day inhalation toxicity screening study not cited in the NICNAS assesment.[215,216] It indicates that "there were no test-material related clinical findings" and that the exposures "did not cause any noticeable adverse effects" for tests at concentrations as high as 100,000 ppm v/v for 6 hr/d.[215] It similarly indicates "no treatment-related chemical signs" and "no test article related clinical signs" at concentrations as high as 105,000 ppm v/v in 24 rats for 6 hr/d in 14- and 90-day inhalation studies, respectively.[215] This summary does not meet the criteria for data sources, and attempts to obtain the study were unsuccessful.

The UK Halon Alternatives Group (HAG) indicates a NOEL and LOEL of 150,000 and 300,000 ppm v/v in dogs, respectively.[219] No source is given, but the data appear to be from Bury.[212] In any case, the Bury finding at 110,000 ppm v/v[212,213] and WIL finding at 121,267 ppm v/v disqualify them.[214,216]

recommendation: 6 hr NOEL rat = 105,000 ppm v/v subject to further review

Other Escape-Impairing Effects and Permanent Injury

Vinegar et al. describe a study with human exposures to R-134a and R-227ea to validate a physiologically-based pharmacokinetic (PBPK) model).[166] Tests with R-227ea were terminated when a subject suffered rapid rise in pulse 3 min into an exposure to 6,400 ppm v/v, following anomalous results in another volunteer with R-134a (see page 53).[166] Subsequent investigation indicates that the responses probably were not due to the chemical exposures, and that no adverse effects were seen in other human exposures at lower or higher concentrations.[167,168]

recommendation: none

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* less than normal activity

† slow breathing

‡ inability to coordinate voluntary muscular movements

R-236fa: 1,1,1,3,3,3-HEXAFLUOROPROPANE

Lethality

WIL reports the 4-hr LC_{50} rat as >457,000 ppm based on a single, whole-body exposure of ten rats.[221]

An earlier study by Robbins indicates an inconsistent 10-min LC_{50} mouse of 440,000 ppm v/v.[126] Applying the ten Berge extrapolation (see page 11) suggests an equivalent 4-hr LC_{50} of approximately 90,000 ppm v/v.

Findings by Keller refute the Robbins LC_{50} and lend support to the WIL finding. Keller indicates a 4-hr ALC rat exceeding 189,275 ppm v/v from tests in groups of four rats.[222] He also found no deaths in 4 rats exposed to 133,939 ppm v/v for 4 hr.[222]

Hilarski found no mortality in ten rats exposed to 148,600 ppm for 4 hr.[223]

The documentation for the R-236fa WEEL notes that R-236fa is low in acute toxicity with a 4-hr LC_{50} rat of >450,000 ppm v/v.[224]

recommendation: 4-hr LC_{50} rat >457,000 ppm v/v

Cardiac Sensitization

Hardy et al. report a NOEL at 100,000 ppm v/v for six dogs and a LOEL for positive responses in two of six dogs at 150,000 ppm v/v.[225] The WEEL documentation and an article by Valentine et al. both cite the Hardy et al. finding.[224,226]

recommendation: NOEL dog = 100,000 ppm v/v

Anesthetic Effect

Robbins indicates a 10-min EC_{50} rat of 110,000 ppm v/v.[126]

A Haskell Lab study by Keller reports symptoms of narcosis in an unspecified number of the four rats tested at 189,275 ppm v/v, but not in four rats exposed at 133,939 ppm v/v.[222] The symptoms are identified as lack of response to sound in a 4-hr acute inhalation toxicity.[222]

A later Haskell study indicates that exposed rats seem to develop a tolerance for R-236fa.[227] It notes that nearly all (six to eight of ten) rats exposed to 50,300 ppm v/v had a diminished response to an alerting stimulus on the first day of exposures, but that the number of rats so affected dropped to one to three during the first two weeks of the study.[227] All of the rats exhibited normal responses to the sudden auditory alerting stimulus by day 18 as did other rats exposed to 4,980 and 20,000 ppm v/v.[227]

In a third Haskell study, Valentine also suggests that rats develop a tolerance for R-236fa. He notes that all rats either did not respond or exhibited a diminished alerting response for the first two days of 50,000 ppm v/v exposures.[228] He further notes that four to five of ten rats had no

alerting response at some point during the 6-hr exposures, that the majority of rats showed normal responses on day three, and all did on day four, but some showed transient diminished responses on days five and nine.[228] Valentine notes that all ten rats exposed to 5,020 and 20,000 ppm v/v exhibited normal alerting response except for a transient, diminished response on test days two and three at 20,000 ppm v/v.[228]

WIL reports hyperactivity and then prostration in ten of ten rats exposed to 457,000 ppm v/v for 4 hr.[220]

The metric used by Robbins (loss of righting reflex in a *rotadrum* test) differs from that used in the cited Haskell studies (diminished alerting response) and WIL study (hyperactivity and then prostration). Based solely on the finding during the initial exposure at each concentration of the cited studies, Robbins offers a qualifying 10-min EC_{50} of 110,000 ppm v/v, none of the studies offer a qualifying LOEL, and two of the Haskell studies suggest a NOEL at 20,000 ppm v/v.

recommendation: 10-min EC_{50} rat = 110,000 ppm v/v

Other Escape-Impairing Effects and Permanent Injury

None identified.

recommendation: none

R-245ca: 1,1,2,2,3-PENTAFLUOROPROPANE

Only limited toxicity data were found for R-245ca. The **extent of testing is inadequate**.

Lethality

Bagnall indicates a 30-min ALC mouse of 240,000 ppm v/v in oxygen, found by successively testing individual mice to find the minimal lethal concentration.[229] Applying the ten Berge extrapolation (see page 11) suggests a 4-hr ALC mouse of approximately 84,900 ppm v/v. Grube references this study.[230] The data selection criteria (see page 19) call for tests in rats, but the Bagnall finding is indicative of the magnitude of the lethal concentration.

Smith et al. report a 4-hr acute inhalation study in rats at 993 ppm v/v that found no adverse effects, but note that more extensive tests will require larger quantities of the chemical than available then.[231,232]

recommendation: 4-hr ALC mouse = 84,900 ppm v/v subject to further review

Cardiac Sensitization

No data found.

recommendation: not determined

Anesthetic Effect

No EC_{50} data were found.

A Haskell Lab study found an anesthetic effect in mice exposed to 100,000 ppm v/v for 5 or 10 min in a *rotadrum* (rotating apparatus) test, but no effect at 50,000 ppm v/v,[233] as reported by Grube.[230]

Bagnall indicates a 30-min LOEL mouse of 100,000 ppm v/v in oxygen, found by successively testing individual mice to find the minimum anesthetic concentration.[229] The data selection criteria call for tests in rats (rats or mice for the 10-min EC_{50}), but the Bagnall finding is indicative of the magnitude of the lethal concentration.

Smith et al. found no adverse effects in rats at 993 ppm v/v in a 4-hr acute inhalation study.[231,232]

recommendation: 30-min LOEL mouse = 100,000 ppm v/v subject to further review

Other Escape-Impairing Effects and Permanent Injury

The cited Haskell Lab study found severe, but transient effects on respiration in mice exposed to 120,000 and 150,000 ppm v/v for 30 min,[233] as reported by Grube.[230] The finding suggests further testing to determine if humans would incur a similar effect.

recommendation: respiratory effect in mice at 120,000 ppm v/v subject to further review

R-245fa: 1,1,1,3,3-PENTAFLUOROPROPANE

Lethality

Jackson reports no deaths in groups of ten rats exposed to 116,000, 143,000, and 203,000 ppm v/v.[234,235] He concludes that 4-hr LC_{50} rat exceeds 203,000 ppm v/v, but notes that occasional clonic* convulsions were seen in three of ten rats during exposures at 143,000 ppm v/v.[234] Rusch et al. also cite and summarize these findings.[236]

recommendation: 4-hr LC_{50} rat >203,000 ppm v/v

Cardiac Sensitization

Kenny indicates that six dogs showed no signs of cardiac sensitization in tests at 10,000 and 20,000 ppm v/v.[237]

Rusch et al. summarize further tests in dogs with a fatal ventricular fibrillation† in the only dog tested at 73,000 ppm v/v, positive responses in one of four dogs at 44,000 ppm v/v, and no positive responses either in three dogs at 54,100 ppm v/v (the dog that showed a response at 44,000 ppm v/v was excluded) or in four dogs at 34,100 ppm v/v.[236]

The 54,100 ppm v/v level does not qualify as a NOEL since there was a lower qualifying LOEL. Likewise, the dog excluded based on its positive response at 44,000 ppm v/v presumably would have shown a similar or more severe response if tested at 54,100 ppm v/v. The recommended NOEL therefore is 34,100 ppm v/v.

recommendation: NOEL dog = 34,100 ppm v/v

Anesthetic Effect

No EC_{50} data were found.

Jackson indicates that all ten rats exposed to 143,000 and 203,000 ppm v/v adopted an abnormal posture and exhibited reduced response to external stimuli during exposures.[234] He concludes that there was evidence of an anesthetic effect.[234] Jackson also indicates that all ten rats exposed to 116,000 ppm v/v exhibited irregular respiration, restless behavior and intermittent muscular contractions.[235] Rusch et al. characterize these symptoms as "central nervous system depression" and note that they "were more pronounced at the highest exposure level group but were seen to some degree at all levels."[236]

Rusch et al. also summarize an inhalation toxicity study in mice. They note that ten mice given a single, snout-only exposure to 101,300 ppm v/v for 4 hr "all showed signs of reduced activity" that "abated almost immediately upon cessation of the exposure."[236] The Honeywell (formerly

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* spasms of alternating contractions and partial relaxations

† very rapid and irregular contractions of the ventricles of the heart resulting in loss of synchronization between the heartbeat and pulse beat

AlliedSignal) MSDS for R-245fa describes the observation as "evidence of transient underactivity during exposure."[238] The data selection criteria (see page 19) allow mice data only for the 10-min EC_{50}, but specify data from rats for the LOEL and NOEL.

Rusch et al. describe extended inhalation studies in rats exposed for 6 hr/d to concentrations as high as 50,400 ppm v/v for 2 wk, 49,600 ppm v/v for 4 wk, and 50,600 ppm v/v for 13 wk.[236] They indicate "absence of noticeable adverse effects of any kind" and further note that "no clinical signs were observed that appeared related to the treatment."[236]

The observed "signs of reduced activity" or "transient underactivity" at 101,300 ppm v/v and of "central nervous system depression" at 116,000 ppm v/v described by Rusch et al. constitute an *observed effect* — even if mild and/or quickly reversible — rather than *no effect*, as used to define LOEL and NOEL, respectively. The 116,000 ppm v/v finding does not satisfy the data selection criteria (see page 19) as a LOEL since Jackson notes that all ten exposed rats were affected. The NOEL from the 13-wk study fits the data selection criteria.

recommendation: 6-hr NOEL rat = 50,600 ppm v/v

Other Escape-Impairing Effects and Permanent Injury

Rusch et al. note that myocarditis* was seen in pathological studies of rats exposed to 10,000 and 50,000 ppm v/v and in one animal exposed to 2,000 ppm v/v.[236] They indicate that this effect did not compromise the overall health of the rats, but "could have progressed if the exposure had continued past three months."[236] The Honeywell (AlliedSignal) MSDS notes the severity as "trace to moderate."[238] The description and absence of related observations in acute studies suggest that this effect is not a concern for acute exposures.

recommendation: none

* inflammation of the heart muscle

R-290: PROPANE

As is typical of hydrocarbons, toxicity data are sparse for exposures above the lower flammability limit (LFL). The risks inherent to testing flammable mixtures and historical presumption that application exposures will be kept below the LFL both mitigate against testing higher concentrations. Kirwin notes that the toxic properties of paraffinic hydrocarbons such as propane are not manifest until levels exceed fire hazard concentrations.[239]

Lethality

Phillips Petroleum indicates that no deaths occurred in ten rats exposed to 12,190 ppm v/v for 4 hr.[240]

Clark and Tinston report that the 15-min LC_{50} rat exceeds 800,000 ppm v/v.[53] Applying the ten Berge extrapolation (see page 11) suggests that the 4-hr LC_{50} may exceed 200,000 ppm v/v.

recommendation: 4-hr LC_{50} rat >200,000 ppm v/v

Cardiac Sensitization

Mullin indicates marked responses in zero of six, two of twelve, and seven of twelve dogs tested at 50,000, 100,000, and 200,000 ppm v/v, respectively.[186] The results indicate a NOEL of 50,000 ppm v/v for cardiac sensitization. Reinhardt et al. (including Mullin) explain the test procedure and findings.[57]

Krantz et al. report that three of three dogs were sensitized at concentrations of 100,000-250,000 ppm.[241] Based on the wide range of uncertainty in the actual concentration tested, this finding could be consistent with, and does not necessarily challenge, that of Reinhardt et al. Aviado and Belej indicate sensitization in mice at 100,000 ppm v/v.[206,242] Clark and Tinston report the EC_{50} dog as 180,000 and 200,000 ppm v/v.[53,60]

The data from these sources are relatively consistent.

recommendation: NOEL dog = 50,000 ppm v/v

Anesthetic Effect

Clark and Tinston note that R-290 causes central nervous system (CNS) depression and report the 10-min EC_{50} rat as 280,000 ppm v/v.[53]

Kirwin, echoed by Sanders, notes that R-290 produces dizziness in a few minutes at 100,000 ppm v/v, but not in ten minutes at 10,000 ppm v/v.[239,243] He does not specify the species — possibly humans — for these findings.[239,243] He cites data from Brown and Henderson that show that R-290 produces analgesia and deep anesthesia in cats at 600,000 and 930,000 ppm v/v, respectively, in oxygen.[244]

recommendation: 10-min EC_{50} rat = 280,000 ppm v/v

Other Escape-Impairing Effects and Permanent Injury

Stewart et al. summarize acute and subchronic toxicity tests in healthy human volunteers by whole-body exposures.[67,245] They indicate that acute exposures to 250, 500, or 1000 ppm v/v for 1 min to 8 hr "did not produce any untoward physiological effects" as determined by observation, routine hematology, clinical chemistry, EKG, and pulmonary function as well as by cognitive skill and other neurological measurements. They further note that repetitive exposures to 1,000 ppm v/v for 1-10 hr/d, 5 d/wk, for 2-4 wk also showed no adverse effects.

recommendation: none

R-500: R-22/152A (73.8/26.2)

No toxicity findings were found for tests of R-500. Manufacturers base their safety recommendations on the components.[246-248]

Lethality

None identified.

recommendation: base on data for R-22 and R-152a

Cardiac Sensitization

None identified.

recommendation: base on data for R-22 and R-152a

Anesthetic Effect

None identified.

recommendation: base on data for R-22 and R-152a

Other Escape-Impairing Effects and Permanent Injury

None identified.

recommendation: base on data for R-22 and R-152a

R-502: R-22/115 (48.8/51.2)

Lethality

Clayton concludes that the 2-hr ALC rat exceeds 200,000 ppm v/v based on no deaths in a 2-hr exposure of four rats.[249,250] Applying the ten Berge extrapolation (see page 11) suggests that the 4-hr ALC may exceed 141,000 ppm v/v. This finding is consistent with and understates expectations based on the 4-hr LC_{50} of R-22 and the 4-hr ALC of R-115. The lower of them is a 4-hr LC_{50} of 220,000 ppm v/v for R-22 (see page 39), which suggests that the 4-hr LC_{50} blend should be higher in the absence of synergistic effects. Such effects are not evident in Clayton's reports.[249,250]

Honeywell indicates that the 4-hr LC_{50} rat exceeds 300,000 ppm v/v, but does not indicate the basis for it.[251] Once again, it is consistent with expectations based on data for R-22 and R-115.

While the Honeywell MSDS does not qualify as a source based on a rigid reading of the eligible data, the 4-hr LC_{50} cited is conservative relative to a mole-weighted average of the component data.

recommendation: 4-hr LC_{50} rat >300,000 ppm v/v subject to further review

Cardiac Sensitization

Mullin indicates marked responses in zero of six, five of twelve, and twelve of twelve dogs tested at 50,000, 100,000, and 200,000 ppm v/v, respectively.[186] Reinhardt et al. (including Mullin) explain the test procedure and findings.[57]

recommendation: NOEL dog = 50,000 ppm v/v

Anesthetic Effect

Clayton reports that the rats showed discomfort, tremors, and rapid respiration in an acute inhalation toxicity study at 200,000 ppm v/v, but does not note signs of anesthesia during the 2-hr exposures.[249,250]

Underwriters Laboratories (UL) indicates similar effects in all three guinea pigs exposed to 100,000 ppm v/v,[252] as summarized by Lee.[253] UL also reports signs of anesthesia including reduced activity, difficulty standing, loss of equilibrium, and difficulty walking in all three guinea pigs at 200,000 ppm v/v. While the data selection criteria (see page 19) call for data from rats (mice or rats for the 10-min EC_{50}), the UL finding is consistent with the Weigand report of a LOEL of 50,000 ppm v/v in rats for 2-hr exposures to R-22 (see page 39).[62] The Weigand finding is from a subchronic inhalation toxicity study, but he does not indicate the number of animals affected of the four tested.[62]

The UL findings suggest a more conservative limit than those of Clayton, but the 200,000 ppm v/v effects found by UL do not qualify as a LOEL since all three (100%) animals were affected and do not qualify here based on the species tested.

recommendation: 2-hr NOEL rat = 200,000 ppm v/v, but base on data for R-22 and R-115

Other Escape-Impairing Effects and Permanent Injury

Valic et al. conducted experimental exposures to R-502; neither a summary nor the document was obtained.[254]

recommendation: none subject to further review

R-600a: ISOBUTANE

As is typical of hydrocarbons, toxicity data are sparse for exposures above the lower flammability limit (LFL). The risks inherent to testing flammable mixtures and historical presumption that application exposures will be kept below the LFL both mitigate against testing higher concentrations. Kirwin notes that the toxic properties of paraffinic hydrocarbons such as isobutane are not manifest until levels exceed fire hazard concentrations.[239]

LETHALITY

Phillips Petroleum indicates no deaths in 10 rats exposed to 13,023 ppm v/v for 4 hr and a resulting conclusion that the 4-hr LC_{50} rat exceeds 13,023 ppm v/v.[255]

Clark and Tinston report a 15-min LC_{50} rat of 570,000 ppm v/v.[53] Applying the ten Berge extrapolation (see page 11) suggests a 4-hr LC_{50} of approximately 142,500 ppm v/v.

Stoughton and Lamson provide supporting data from tests in mice.[256] They found zero, six, and ten deaths in groups of ten mice for 2-hr exposures to 350,000, 410,000, and 520,000 ppm v/v, respectively.[256] Applying the ten Berge extrapolation suggests that the 4-hr ALC should exceed 247,000 ppm v/v, but that 290,000 ppm v/v for 4 hr should be fatal to more than half the mice.

Aviado et al. indicate a 2-hr LC_{50} mouse of 520,000 ppm v/v,[257] as identified by Bingham.[258] Applying the ten Berge extrapolation suggests a 4-hr LC_{50} mouse of 368,000 ppm v/v. ACGIH and Sandmeyer indicate the Aviado finding to be a 1-hr LC_{50} mouse.[24,259] On that basis, the ten Berge extrapolation suggests a 4-hr LC_{50} mouse of 260,000 ppm v/v, which is consistent with Stoughton and Lamson finding. These data suggest lower lethality than that found by Clark and Tinston, but they do not meet the data selection criteria (see page 19) based on the species tested.

RTECS cites the Clark and Tinston finding as does the only MSDS found for R-600a that cites an LC_{50}, from Rhône-Poulenc Chemicals.[23,260] Based on the data noted above, the 4-hr LC_{50} of approximately 142,500 ppm v/v derived from the Clark and Tinston 15-min LC_{50} rat meets the data selection criteria (see page 19).

recommendation: 4-hr LC_{50} rat = 142,500 ppm v/v

Cardiac Sensitization

Reinhardt, as confirmed in Reinhardt et al.,[57] indicate marked responses in zero of twelve dogs at 25,000 ppm v/v, four of twelve dogs at 50,000 ppm v/v, and six of six dogs at 100,000-200,000 ppm v/v.[261] Krantz et al. report that two of two dogs were sensitized at concentrations of 100,000-250,000 ppm v/v.[241] Clark and Tinston report the EC_{50} dog as 70,000 ppm v/v.[53]

The data from Krantz et al. and from Clark and Tinston are consistent with the Reinhardt findings, leading to confidence in the NOEL and LOEL of 25,000 and 50,000 ppm v/v, respectively.

recommendation: NOEL dog = 25,000 ppm v/v

Anesthetic Effect

Clark and Tinston note that R-600a causes central nervous system (CNS) stimulation and report the 10-min EC_{50} rat as 200,000 ppm v/v.[53]

Stoughton and Lamson report that light anesthesia (taken as loss of ability to maintain an upright position in a rotating bottle) was evident in groups of six mice in an average of 60 min at 150,000 ppm v/v, 17 min at 200,000 ppm v/v, and 26 min at 230,000 ppm v/v,[256] but these data do not suggest dose-dependence. Stoughton and Lamson also indicate that groups of ten mice showed loss of posture in a shaken and then stationary bottle in 25 min at 350,000 ppm v/v, 3 min at 410,000 ppm v/v, and 2 min at 520,000 ppm v/v.[256] They report that it was difficult to induce good anesthesia in dogs since the concentration needed, 450,000 ppm v/v, is close to a lethal level of 550,000 ppm v/v.[256] Kirwin cites the 450,000 ppm v/v finding for dogs from Stoughton and Lamson.[239]

recommendation: 10-min EC_{50} rat = 200,000 ppm v/v

Other Escape-Impairing Effects and Permanent Injury

Stewart et al. summarize acute and subchronic toxicity tests in healthy human volunteers by whole-body exposures.[67,245,262] They indicate that acute exposures to 250, 500, or 1000 ppm v/v for 1 min to 8 hr "did not produce any untoward physiological effects" as determined by observation, routine hematology, clinical chemistry, EKG, and pulmonary function as well as by cognitive skill and other neurological measurements. They further note that repetitive exposures to 500 ppm v/v for 1, 2, or 8 hr/d, 5 d/wk, for 2 wk also showed no adverse effects.

recommendation: none

R-717: AMMONIA

Lethality

Carpenter et al. indicates that a 4-hr exposure to 2,000 ppm v/v was fatal to two, three, or four of six rats.[184] The ambiguous fraction may exceed 50%. Deichmann and Gerarde cite the 2,000 ppm v/v result, but describe it as a 4-hr LC_{50} rat.[263]

The NIOSH/OSHA "Occupational Safety and Health Guideline for Ammonia" cites the 4-hr LC_{50} rat as 2,000 ppm.[264] and references it to RTECS.[23] RTECS indicates LC_{50} data for a number of species including rats, for which it indicates a 4-hr LC_{50} of 2,000 ppm referenced to Deichmann and Gerarde.[263]

As summarized by the Major Hazards Assessment Panel of the UK Institution of Chemical Engineers (ICE),[265] Kimmerle reviews data from prior studies on the inhalation toxicity of R-717 (ammonia) in animals.[266] He indicates that a 4-hr exposure of rats to 2,000 ppm v/v was not fatal while another at 4,000 ppm v/v was, but does not indicate the quantities of animals involved.[265,266] Kimmerle also notes reports of 2-hr LC_{50}s of 3,420, 4,760, and 10,930 ppm v/v in mice, mice, and rats respectively.[265,266] Applying the ten Berge extrapolation (see page 11) suggests 4-hr LC_{50}s of approximately 2,420, 3,370, and 7,730 ppm v/v.

The 1988 ICE monograph examines twelve studies in mice and rats described as "all known LC_{50} results."[265] Of them, the Carpenter et al. and the Kimmerle studies are the only ones involving 4-hr exposures. Applying the ten Berge extrapolation, the LC_{50}s adjusted to 4-hr exposures range from 2,000 to 8,240 ppm v/v with a mean of 3,960 ppm v/v. The range for the rat studies alone is the same, but the mean increases to 5,400 ppm v/v.

Ludwig et al. cite additional lethality studies for diverse mammals in the NIOSH documentation of the IDLH concentration for ammonia.[11] The added studies include rat data from Alarie and from Back et al.[267,268] Applying the ten Berge extrapolation to them to approximate 4-hr LC_{50}s, they cover a nearly identical range of 2,000-8,230 ppm v/v, excluding two citations from 1928 and 1933 for a single human fatality and for an unspecified mammal (probably the same human incident). The mean for the rat data increases to 6,040 ppm v/v.

Clement Associates documents a detailed assessment of the toxicity of ammonia, prepared for The Fertilizer Institute, that examines 19 studies of the acute inhalation lethality of ammonia in animals.[269] They note the lowest 1-hr LC_{50} values to be 3,796 ppm v/v in mice and 6,586 ppm v/v* in rats.[269] These data correspond to 1,900 and 3,300 ppm v/v with the ten Berge adjustment to 4-hr LC_{50}s.

The Agency for Toxic Substances and Disease Registry (ATSDR), in a toxicity profile of ammonia prepared by Syracuse Research Corporation under contract to Clement Associates, lists two rat studies among nine studies of lethality by acute exposure to ammonia.[270] They include a 15-

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* The cited report is very helpful and well documented, but it is difficult to follow in places due to use of inconsistent factors to convert mg/m^3 to ppm v/v (e.g., 0.7 on page 89 versus 0.78 on page 94 versus 0.71 in other references) and occasional typographical errors (e.g., page 94 shows 5,137 mg/m^3 as both 6,568 and 6,586 ppm v/v).

min LC_{50} rat of 17,401 ppm v/v from Propkop'eva et al.[271] and a 16-hr LC_{50} rat of 1,000 ppm v/v from Weedon et al.,[272] which correspond to 4,350 and 2,000 ppm v/v, respectively, with the ten Berge adjustment to 4-hr.

The U.S. Environmental Protection Agency (EPA) lists eight 10-min and 60-min LC_{50}s in its assessment.[27] It cites the 1-hr LC_{50} as 4,230 ppm v/v in mice, 14,140 ppm v/v in male rats, and 19,770 v/v in female rats in a summary. These data correspond to 2,120, 7,070, and 9,890 ppm v/v, respectively, with the ten Berge adjustment to 4-hr LC_{50}s.

Much of the toxicity data for R-717 predates practical laboratory methods for precise and reliable determination of concentrations and purity. Accordingly, there is considerable dispersion in the data. Appelman et al. document inconsistencies between very early and more recent data.[273]

Tabulae Biologicae indicates the lowest concentration reported as lethal to humans as 5,000 for 5 min,[274] as reported by Ludwig et al.[11] and RTECS.[23]

The lowest 4-hr LC_{50} identified is 2,000 ppm v/v extrapolated from Weedon et al. It is supported by findings from Carpenter et al. and citation by Deichmann and Gerarde, but challenged by a separate finding by Kimmerle. ATSDR, ICE, NIOSH, OSHA, and RTECS cite it, but other agencies such as EPA choose other data (though EPA cites an LC_{50} only slightly higher for mice).

Based on the conflicting finding from Kimmerle and the number of higher LC_{50} findings in more recent studies (notably from Appelman et al.[273] and from Propkop'eva et al.[271]) than the 1940 Weedon et al. and 1949 Carpenter et al. data, it may be appropriate to choose the 4-hr LC_{50} of 3,300 ppm v/v, derived from the lowest LC_{50} found in the detailed Clement Associates assessment. This alternative is still conservative compared to the average of reported LC_{50}s and ALCs.

recommendation: 4-hr LC_{50} rat = 2,000 or 3,300 ppm v/v subject to further review

Cardiac Sensitization

No indication was found to suggest that R-717 causes cardiac sensitization at concentrations less than the 4-hr LC_{50}.

recommendation: exclude from ATEL

Anesthetic Effect

None of the acute inhalation studies that report clinical observations during exposures suggest that ammonia causes an anesthetic effect. In contrast, its sharp odor and irritating effects are prone to cause anyone exposed to attempt quick escape. Appelman et al. report that exposed rats were restless, showed both eye and nasal irritation (e.g., eyes closed with discharges, wet noses), and exhibited dyspnoea (e.g., labored breathing through the mouth).[273] They do not mention any observations indicative of an anesthetic effect for concentrations as high as 38,900, 27,200, 22,700, or 16,100 for 10, 20, 40, or 60 min, respectively.[273]

recommendation: 10-min NOEL = 38,900 ppm v/v

Other Escape-Impairing Effects and Permanent Injury

There are numerous anecdotal accounts of injuries and fatalities from exposures, but there also are accounts of tolerance of low concentrations by technicians accustomed to working with ammonia.[275,276]

Schadeberg et al. conclude that concentrations of 50 ppm v/v or less caused only dryness of the nose in one or two subjects, but did not cause irritation or discomfort in a panel of ten human volunteers exposed (head-only) to ammonia for 5 min.[277] They indicate that three or more subjects reported annoyance to the eyes, nose, mouth, throat, or chest at 72 and 134 ppm v/v with an increase in effects at the higher concentration.[277]

Wallace summarizes subjective observations by seven human volunteers accustomed to working with ammonia to informal exposures for 1-3 min,[278] as summarized by Stoecker.[279] Wallace indicates that concentrations of 150-200 ppm v/v affected their eyes in approximately 1 min, but did not seriously impair their vision and did not affect their breathing.[278,279] 440 ppm v/v affected their eyes more quickly, but not sufficiently to impair vision, while 600 ppm v/v caused their eyes to stream after 30 seconds, but was still breathable.[278,279] 1,000 ppm v/v caused their eyes to streamed instantly, impaired their vision, made breathing intolerable for most of those exposed, and caused skin irritation. 1,500 ppm v/v induced an instant reaction to get out of the area.[278,279]

Verberk indicates that 16 subjects exposed to 50-140 ppm v/v for 2 hr experienced nasal irritation, but no changes to their ventilation capacity,[280] as reported by AIHA.[281] Eight of the subjects found 140 ppm v/v to be intolerable.[280,281]

Johnston et al. report that volunteers experienced decreased respiratory tidal volume in exposures to 205-335 ppm v/v for 30 min and temporary changes in respiratory physiology at 500 ppm v/v for 30 min,[282] as summarized by AIHA.[281]

The International Institute of Ammonia Refrigeration (IIAR) indicates that while the data are not in agreement, accepted response levels include 400 ppm v/v for immediate throat irritation, 1,700 ppm v/v for cough, 2,400 ppm v/v for a threat to life in 30 min, and 5,000-10,000 ppm v/v for a high likelihood of mortality for short exposure.[283]

Barrow et al. determined the RD_{50}* mouse to be of 303 ppm v/v and note that the maximal response for ammonia was achieved within the first two minutes of exposure.[284] Alarie categorizes typical effects at multiples of the RD_{50} as severe injury and possible mortality at 10, not tolerable by humans at 1, some sensory irritation at 0.1, no sensory irritation at 0.01, and no effect of any kind on the respiratory system at 0.001.[267] Zissu reports that no pathological changes were observed from ammonia at 257 ppm (85% of the RD_{50}), but that it induced lesions in the respiratory epithelium following exposures at 711 ppm (235% of the RD_{50}).[285] He notes that the intensity of lesions became more severe with further exposures, progressing from moderate for 4 days, to severe for 9 days, and to very severe for 14 days based on exposures of 6 hr/d for 5 d/wk.[285] Buckley et al. found moderate inflammation to the respiratory epithelium with ammonia exposures, but comment that its ionization in water is comparatively limited resulting in less damage than for other chemicals for which the RD_{50} and water solubility are similar.[286] They conclude that "the value of the mouse sensory irritant model for setting occupa-

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* The median respiratory rate decrease, or RD_{50}, is the concentration that results in 50% decrease in respiratory rate, normally measured in mice.

tional guidelines to sensory irritants is strengthened in that these studies demonstrate the RD_{50} concentration is associated with respiratory tract damage and is not an acceptable concentration for occupational exposures."[286] Kane et al. presents a model to predict human sensory irritation responses based on sensory irritation data from animal tests; they conclude that the emergency exposure limit (EEL) should be set at 30% of the RD_{50}.[287]

Ludwig et al. cite the RD_{50}, but also indicate two limiting concentrations from Silverman et al. and from Henderson and Haggard in the NIOSH documentation for the 1994 IDLH concentration reduction.[11]

Silverman et al. report changes in respiration rate and moderate to severe irritation in humans at rest exposed to 500 ppm v/v, six for 30 min and a seventh for 15 min.[288] They report that the male volunteers exhibited hyperventilation* with cyclic variation during exposures and transient hypoventilation† during recovery following the exposures.[288] They indicate that one subject showed a slight increase in blood pressure and pulse rate.[288] Silverman et al. also report irritation of the nose and throat, hypo-esthesia‡ of the exposed skin, lacrimation,§ and complaints of respiratory irritation.[288] They note that these subjective reactions varied considerably, with some effects persisting for 24 hours after exposures, but were present in all subjects and severe in two.[288]

Henderson and Haggard report that the maximum short exposure tolerance is 300-500 ppm v/v for 30-60 minutes.[289] The American Industrial Hygiene Association (AIHA) *Hygienic Guide* for anhydrous ammonia notes that a concentration of 300-500 ppm v/v is the maximum short-exposure tolerance for 30-60 minutes, 2,500-6000 ppm is considered dangerous to life, and 5,000-10,000 ppm is reported to be fatal.[290]

The Clement Associates assessment concludes that "acute studies in animals have revealed that levels above 280 mg/m^3 (400 ppm) can cause severe damage to the eyes, nose, throat, and respiratory tract."[269]

Among short-term occupational (not emergency) limits, the NIOSH IDLH is 300 ppm v/v (reduced in 1994 from 500 ppm v/v),[15] the NIOSH STEL and the ACGIH TLV-STEL are both 35 ppm v/v TWA for 15 min,[15,291] and the German maximum workplace concentration (MAK) for short-term excursions is 40 ppm v/v for up to 5 min.[292] The OSHA short-term exposure limit (STEL) set in 1989, but vacated in 1992 with all changes since 1971, was 50 ppm v/v TWA for 15 min.[293] Among recognized emergency exposure limits, the NRC Emergency Exposure Guidance Level (EEGL) for single exposures for both 1 and 24 hr is a ceiling** concentration of

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* abnormally high breathing rate

† abnormally low breathing rate

‡ reduced capacity for sensation and feeling

§ abnormal or excessive secretion of tears

** a concentration limit that should not be exceeded at any time

100 ppm v/v.[39] The AIHA ERPG-1, ERPG-2, and ERPG-3* are 25, 200, and 1,000 ppm v/v, respectively, each for 1 hr.[281,294] The ERPG-2 of 200 ppm v/v is the most pertinent of the three levels for present consideration.

Based on the indications from Schadeberg et al., it appears that concentrations below 100 ppm v/v may cause discomfort and temporary effects, but not escape-impairing effects or permanent injury. Verberk indicates that eight of 16 subjects found 140 ppm v/v to be intolerable. By Alarie's criteria, the Barrow findings and resulting RD_{50} at 303 ppm v/v constitute sensory irritation that is "intolerable to humans," but Henderson and Haggard and the AIHA indicate that the maximum short exposure tolerance for 300-500 ppm v/v is 30-60 minutes. Silverman et al. document moderate to severe sensory irritation at 500 ppm v/v for 30 min. Barrow et al., and Buckley et al. document effects at concentrations as low as 300 ppm v/v that border on escape-impairing or permanent. The finding by Clement Associates that levels above 400 ppm v/v can cause severe damage to the eyes, nose, throat, and respiratory tract is unambiguous.

The NRC EEGL of a ceiling of 100 ppm v/v and AIHA ERPG-2 of 200 ppm v/v set a strong precedent, while the Kane suggestion that the EELs should be set at 30% of the RD_{50} yields a similar result. Although they constitute occupational rather than emergency criteria, the NIOSH IDLH of 300 ppm v/v and several lower STELs reinforce them. All of them suggest that an emergency exposure limit less than 300 ppm is appropriate, but the lowest concentration clearly causing permanent injury appears to be 400 ppm v/v while that causing severe sensory irritation in 30 min appears to be in the 300-500 range.

recommendation: 400 ppm v/v subject to further review

- The Emergency Response Planning Guideline (ERPG) concentrations are intended to "assist emergency response personnel planning for catastrophic chemical releases to the community." The ERPG values are "the maximum airborne concentration below which it is believed nearly all individuals could be exposed for 1 hour" without three specified response levels. The ERPG-1 addresses "mild transient adverse health effects or ... perceiving a clearly defined objectionable odor." The ERPG-2 addresses "irreversible or other serious health effects or symptoms that could impair an individual's ability to take protective action." The ERPG-3 addresses "life-threatening health effects."

R-744: CARBON DIOXIDE

Lethality

No LC_{50} or ALC studies in rats were found.

Tabulae Biologicae indicates the lowest concentration reported as lethal to humans as 90,000 ppm v/v for 5 min,[274] as reported by Ludwig et al.[11] and RTECS.[23]

ACGIH considers R-744 (carbon dioxide) to be a simple asphyxiant.[16,24]

recommendation: exclude from ATEL

Cardiac Sensitization

No cardiac sensitization studies or evidence that carbon dioxide causes it were found.

recommendation: exclude from ATEL

Anesthetic Effect

No qualifying animal data were found, but NIOSH notes that carbon dioxide acts as a central nervous system (CNS) depressant and that narcosis may occur when high concentrations of carbon dioxide are inhaled, potentially resulting in respiratory arrest and death.[44] These concerns are further addressed below, based on findings in humans, as other escape-impairing effects.

recommendation: no qualifying animal data

Other Escape-Impairing Effects and Permanent Injury

BOC indicates that carbon dioxide is the most powerful cerebral vasodilator* known.[295]

Brown and Miller indicate that 15 of 17 dogs exposed to 400,000 ppm v/v carbon dioxide for 2 hr or more died upon sudden re-exposure to air,[296] as summarized by NIOSH.[44] Petty et al. indicate that rats exposed to concentrations of carbon dioxide exceeding 400,000 ppm v/v for 20 min experienced arrhythmia 10-55 sec after sudden withdrawal,[297] also as summarized by NIOSH.[44] Caujolle notes that there are cases of instant death at concentrations exceeding 400,000 ppm v/v.[298]

Mukherjee and Singh indicate that 10 male mice exposed to 350,000 ppm v/v for 6 hr experienced changes in their sperm development that resulted in smaller than normal litters,[299] also cited by NIOSH.[44] This finding suggests reproductive toxicity.

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* widening of the blood vessels of the brain

The Aero Medical Association, Friedlander and Hill, Lambertsen, and Sechzer et al. report rapid loss of consciousness by humans at concentrations of 100,000-300,000 ppm v/v,[300-303] as reported by NIOSH.[44]

Dripps and Comroe report that one of 42 subjects who breathed 76,000 ppm v/v for an average of 7.4 min lost consciousness while nine indicated dizziness.[304] They also indicate that three of 31 subjects who breathed 104,000 ppm v/v for an average of 3.8 min lost consciousness while seven indicated faintness and 13 indicated dizziness (each subject may have reported more than one symptom).[304]

Schaefer reports a range of CNS effects in 42 human volunteers exposed to 75,000 ppm v/v carbon dioxide for 15 minutes including restlessness for ten subjects, loss of balance in seven, loss of limb control for four, and mental disorientation for two,[305] as reported by NIOSH.[44] He concludes that exposure to 33,000 v/v and higher depressed the autonomic nervous system.*[305,44]

Brown reports that concentrations of 55,000-124,000 ppm v/v were tolerable to seven male subjects for only short periods of time, ranging from 22 min for 60,000 ppm v/v to 30 sec for 124,000 ppm v/v.[306] He notes that exposed subjects showed increases in respiratory rate, pulse rate, and blood pressure as well as subjective symptoms, including dyspnea,† dizziness, feeling of stupefaction,‡ apprehension of impending collapse, and limited to moderately severe headache. Brown indicates that none of the subjects could have withstood 100,000 ppm v/v for more than 10 min without loss of consciousness, and that increasing the oxygen concentration did not alleviate the toxic effects of high carbon dioxide concentrations.[306]

Storm and Giannetta report that exposures to 40,000 ppm v/v for 2 wk did not impair psychomotor performance in six healthy male volunteers based on tests of complex tracking performance, eye-hand coordination, and problem-solving ability,[307] as reported by NIOSH.[44]

Weybrew describes a test in a male volunteer to investigate the effect of exposure on psychological function,[308] as reported by NIOSH.[44] He reports that an exposure increased from 300-30,000 ppm v/v in 15 hr for 6 days did not show any remarkable treatment-related changes.[308,44]

King tabulates 28 studies of human tolerance to various concentrations of carbon dioxide, with division by the severity of effects.[309] He then plots these responses as functions of exposure duration and concentration to create a response map. For exposures of 10-30 min, it shows concentrations up to approximately 20,000 ppm v/v as "bodily compensatory reactions, below level of perception," up to 40,000 ppm v/v as the "level for perception, distraction, bodily compensatory reactions," and up to 60,000 ppm v/v as "distracting discomfort, bodily compensatory reactions." He further shows regions with failure of compensatory reactions, marked deterioration, and inability to take steps for self preservation at higher concentrations.

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* the part of the nervous system that controls involuntary actions such as breathing and heartbeat

† difficult or labored breathing

‡ reduced sensation, perception, and understanding

Ludwig et al.[11] indicate that the 1994 NIOSH IDLH concentration of 40,000 ppm v/v is based on acute inhalation toxicity data from humans from the Aero Medical Association, Flury and Zernik, and Schaefer.

The Aero Medical Association reference, on the toxicity of chemicals used on aircraft, indicates that concentrations of 50,000-100,000 ppm v/v and higher act as a narcotic and that signs of intoxication may occur after 30 min at 50,000 ppm v/v.[300] It attributes these conclusions to an article from the Council on Pharmacy and Chemistry of the American Medical Association (AMA), but also mentions other sources without identifying them ("and by others"). The AMA report is less specific; it cautions those administering oxygen-carbon dioxide therapy at 50,000 ppm v/v carbon dioxide for longer than 30 min to look for signs of intoxication.[310] It further recommends careful observation from the start for concentrations of 100,000 ppm v/v and notes that carbon dioxide toxicity must be kept in mind after 10-15 min.[310] By implication, the AMA cautions must have been predicated on incidents in which the anesthetic and other toxic affects suggested were observed. The findings discussed above from Schaefer and from Dripps and Comroe support this implication, but they cannot be the source since they were published later.

As reported by Ludwig et al.[11] and further discussed above, Flury and Zernik indicate that exposure to 70,000-100,000 ppm v/v produces unconsciousness in humans,[311] while Schaefer reports that submarine personnel exposed continuously at 30,000 ppm were only slightly affected, provided the oxygen content of the air was maintained at normal concentrations.[312]

Based on the Schaefer indication of only slight effect at 30,000 ppm v/v for continuous (long-term) exposures, Storm and Giannetta finding that 40,000 ppm v/v for 2 wk did not impair psychomotor performance, the Aero indication of narcotic effects as low as 50,000 ppm v/v, and the supporting indications from AMA and from Flury and Zernik, it appears that narcotic effects may begin in humans at 50,000 ppm v/v in 30 min exposures. The Brown findings at 55,000-124,000 ppm v/v, the Schaefer report of CNS effects in humans at 75,000 ppm v/v for 15 minutes, and the Dripps and Comroe findings at 76,000 ppm v/v for 7.4 min and 104,000 ppm v/v for 3.8 minutes show that the effect severities increase in an approximately dose-dependent pattern with increasing concentration. These findings are roughly consistent with the King response map, which shows 40,000-60,000 ppm v/v as distracting in less than 30 min..

recommendation: 50,000 ppm v/v

CAVEATS

The cited data recommendations are not universal, but are limited in relevance to ATEL determination. Other uses may warrant consideration or use of additional or other data.

The data are not complete. The selections and recommendations are based on specific criteria for ATEL determination (see page 19). Redundant and non-qualifying data generally were excluded except to explain or reinforce the recommendations. Appendix 2 (see page 135) tabulates some additional toxicity data.

The data and recommendations are not the result of a consensus determination. Rather this report documents input for consideration by qualified parties in developing guides, standards, codes, and regulations. The primary intended use of the data is to assist the project committees for ASHRAE Standard 34, *Designation and Safety Classification of Refrigerants*, and in turn ASHRAE Standard 15, *Safety Code for Mechanical Refrigeration* (soon to be *Safety Code for Refrigeration*). Indeed, some of the recommended data differ from working and review drafts, prepared by those committees, based on preliminary data from this effort and other sources.

The ARTI Refrigerant Database[22] identifies additional data and data sources for both the refrigerants addressed herein and others. Both this report and the database are intended to assist in locating information on refrigerants, but they are:

- neither a comprehensive nor authoritative reference source,
- not a substitute for independent data collection by users,
- not a substitute for examination of the data, information on how they were arrived at, underlying assumptions, associated caveats, flaws, and omissions in the cited documents, and
- not an endorsement of suitability or accuracy of referenced data and publications.

Safety considerations and other characteristics affecting suitability or desirability may be influenced by a number of factors. Among them are specific application conditions, additives, impurities, catalytic interactions with other materials used, and changes in compounding between one source or batch and another. Similarly, new findings or corrections may supersede previously published data. Neither the report nor the database should be viewed as the source of data for research, design, analysis, or other purposes.

ATEL AND RCL CALCULATIONS

ATEL CALCULATIONS

Table 1 summarizes the toxicity data reviewed on pages 35-85. The sequence of the data columns follows the method as outlined on pages 15-22, with the order of parameters matching the hierarchy for each toxic effect. The last column is the resulting acute toxicity exposure limit (ATEL) as defined on page 18 and calculated as indicated on page 19. The governing parameter (the most restrictive effect when multiplied by the corresponding factor in the calculation method) is underlined to highlight the limiting toxic effect.

As shown in the table, cardiac sensitization is the limiting effect for 17 of the 29 single-compound refrigerants, excluding R-E134, R-245ca, R-600 (n-butane), and R-1270 (propylene) — for which additional data are needed — and also excluding the two blends (R-500 and R-502). Lethality or anesthetic/CNS effect govern for approximately one sixth of the refrigerants. This tally suggests that the ATEL formulation is conservative, since the governing effect is not necessarily lethal or even permanently injuring — even without the built-in diversity and safety factors — for the majority of refrigerants.

Table 1 includes six refrigerants, shown in italics and further noted with a bullet (•) following the refrigerant number, that are not examined on pages 35-85. The values indicated for them are *collateral data*, that is data found during searches performed for the targeted refrigerants (see page 33). Most (not all due to time constraints) of these serendipitous data, for example from toxicity studies examining or comparing multiple chemicals, were cataloged in the ARTI Refrigerant Database[22] (see appendix 2 beginning on page 135) to facilitate future efforts.

Although the present project addressed only 29 refrigerants including two blends (see page 33), some or all of the data needed to calculate ATELs — and from them RCLs — were found for more than 200 others. These data were entered into the ARTI Refrigerant Database. The ATELs and RCLs from the collateral data for these additional refrigerants should be viewed as *provisional*, warranting extra caution in use. Dedicated data searches almost certainly would locate more data, which could raise or lower the provisional ATELs and RCLs. Supplementary NOEL data, if higher for governing effects, could increase the corresponding ATELs and RCLs. Lower LOELs or EC_{50}s could decrease them or disqualify some NOELs. Likewise, targeted searches might disclose other findings pertinent to escape-impairing effects or permanent injuries.

The keyed notes following table 1 recap the parameter definitions and flag estimated or substituted data, for example if based on differing test durations or species. Pages 35-85 provide more complete explanations.

Neither this report nor the tables included in it should be viewed as the source for toxicity data. They summarize data from the referenced studies, which should be examined for suitability if further use is made of the data.

Table 1: Refrigerant Toxicity Data [a] (ppm v/v)

refrig-	lethality		cardiac sensitization		anesthetic/CNS effect					
erant [b]	LC_{50} [c]	ALC [d]	NOEL [e]	LOEL [e]	EC_{50} [f]	LOEL [g]	NOEL [h]	other [i]	ATEL	
11	26 200	--	1 100	4 800	35 000	--	12 500	--	1 100	
12	>800 000	>800 000	40 000	50 000	250 000	--	200 000	22 700	23 000	
14 •	*>390 000*	*>390 000*	*200 000*	--	--	--	*226 000*	--	*110 000*	*j*
22	220 000	--	25 000	50 000	140 000	--	--	--	25 000	
23	>663 000	>663 000	800 000	--	--	--	51 000	300 000	41 000	
32	>760 000	>760 000	200 000	250 000	--	--	49 500	--	40 000	
113	52 500	45 000	2 600	4 850	28 000	--	25 000	--	2 600	
114	255 000	--	--	25 000	250 000	--	100 000	--	20 000	k
115 •	*>800 000*	*>800 000*	--	*150 000*	--	--	*800 000*	--	*120 000*	*j*
116	>800 000	>800 000	200 000	--	--	--	121 000	--	97 000	
123	32 000	32 000	10 300	--	27 000	--	2 500	--	9 100	
124	262 500	>230 000	10 100	25 000	150 000	--	48 000	--	10 000	
125	>769 000	>769 000	75 000	100 000	--	--	709 000	--	75 000	
134	>460 000	>460 000	75 000	100 000	--	--	120 000	--	75 000	
134a	>359 300	>359 300	49 800	75 200	280 000	--	81 000	--	50 000	
E134	>141 000	>141 000	--	--	--	--	18 000	--	0	
141b	61 647	--	2 600	5 200	25 000	--	19 959	--	2 600	
142b	106 000	>100 000	25 000	50 000	250 000	--	--	--	25 000	l
143a	>591 000	>591 000	250 000	300 000	500 000	--	591 000	--	170 000	
152a	>400 000	383 000	50 000	150 000	--	--	100 000	500 000	50 000	
170 •	*>24 838*	*>24 838*	--	*100 000*	--	--	*24 838*	--	*7 000*	*j*
218	>400 000	>400 000	300 000	400 000	--	--	113 000	--	90 000	m
227ea	>788 696	>788 696	70 000	90 000	--	--	105 000	--	70 000	
236fa	>457 000	>457 000	100 000	150 000	110 000	--	20 000	--	55 000	
245ca	--	84 900	--	--	--	100 000	50 000	120 000	0	n
245fa	>203 000	>203 000	34 100	44 000	--	--	50 600	--	34 000	
290	>200 000	--	50 000	100 000	280 000	--	--	--	50 000	o
C318 •	*>800 000*	*>800 000*	--	*100 000*	*>800 000*	--	*800 000*	--	*80 000*	*j*
500	--	--	--	--	--	--	--	--	36 000	p
502	>300 000	>300 000	50 000	100 000	--	--	200 000	--	35 000	pq
600 •	*272 000*	--	--	--	--	--	--	*100 000*	*0*	*j*
600a	142 500	--	25 000	50 000	200 000	--	--	--	25 000	r
717	3 300	--	--	-- s	--	--	38 900	400	400	t
744	-- u	--	--	-- s	--	--	--	50 000	50 000	
1270 •	--	*490 000*	--	--	--	--	*10 000*	*7 200*	*0*	*j,v*

a Data and limitations should be verified in the sources identified on pages 33-86 (or reference 22) before use. The limiting effect is underlined for each refrigerant. Italicized data are *provisional* (see page 87).

b from ANSI/ASHRAE Standard 34 [1]

c 4-hr LC_{50} rat; federal and fire code toxicity classifications are based on a 1-hr LC_{50} rat

d 4-hr ALC rat

e in dogs with epinephrine injection

f 10-min EC_{50} mouse or rat

g lowest anesthetic/CNS LOEL rat during ALC, LC_{50}, or other acute toxicity studies

h highest anesthetic/CNS NOEL rat in any toxicity study not exceeding an acute LOEL

i other escape-impairing or permanently injuring effects, including severe sensory irritation, for short exposures

j data shown for R-14, R-115, R-170, R-C318, R-600, and R-1270 are collateral data; resulting ATELs and RCLs are provisional (see page 87)

k R-114 30-min LC_{50} rat = 720 000 ppm v/v, 2-hr LC_{50} rat > 600 000 ppm v/v

l R-142b 30-min LC_{50} mouse = 300 000 ppm v/v, 4-hr ALC ≈ 128 000 ppm v/v for 2-4 of 6 rats

m R-218 1-hr ALC rat > 800 000 ppm v/v

n R-245ca 30-min ALC mouse = 240 000 ppm v/v

o R-290 15-min LC_{50} rat > 800 000 ppm v/v

p R-500 and R-502 ATEL based on blend calculation for components

q R-502 LC_{50} and ALC documentation is inadequate, but data are conservative for components

r R-600a 15-min LC_{50} rat = 570 000 ppm v/v

s no data, believed to exceed LC_{50} and ALC

t R-717 published LC_{50} rat = 6 586 - 19 671 ppm v/v for 1 hr and 2 000 - 4 067 for 4 hr; conversion of the lowest 1-hr LC_{50} rat to 4-hr yields 3 300, approximately the midpoint of the 4-hr values

u R-744 treated as *simple asphyxiant*; 5-min LC_{Lo} human = 90 000 ppm v/v

v R-1270 6-hr ALC > 400 000 ppm v/v; CS in 2/2 dogs at 100 000 ppm v/v; RD_{50} = 7 200 ppm v/v

• *provisional, see page 87*

The input (toxicity) data are shown to the numerical precision found in the source studies to facilitate comparisons with the source studies or with their discussion on pages 35-85. Such precision is artificial in some cases, since it exceeds the accuracy to which concentrations can be controlled or reliably measured during test exposures. The calculated ATEL concentrations are consistently rounded to two significant digits, even though the implied accuracy of 1% exceeds the quantification certainty.

Four of the ATELs and resulting RCLs are zero, namely for R-E134 and R-245ca, neither of which is believed to be in known commercial use as a refrigerant, and for R-600 (n-butane) and R-1270 (propylene). The ATEL and RCL of zero do not imply either an extreme toxicity hazard for them or that these refrigerants cannot or should not be used, either as single-compound refrigerants or as blend components. Instead, it indicates that necessary data to determine their ATEL concentrations could not be located and possibly or probably do not exist. That in turn suggests that any party promoting their use as refrigerants should provide the missing data, which may require further toxicity testing. The inherent philosophy differs from the legal precept of "innocent until proven guilty." The axiom for potentially hazardous substances is "restrict until proven safe." The ATEL and resulting RCL of zero, if adopted in governing codes or regulations that are consistent with ASHRAE 15, generally would force isolation in a refrigeration machinery room with specified safety provisions.*

* ASHRAE 15 stipulates a number of alternative options for specific circumstances.[2]

Table 2: Refrigerant Toxicity Data with Revisions to ATEL/RCL Method [a] (ppm v/v)

refrig-	lethality		cardiac sensitization		anesthetic/CNS effect					
erant [b]	LC_{50} [c]	ALC [d]	NOEL [e]	LOEL [e]	EC_{50} [f]	LOEL [g]	NOEL [h]	other [i]	ATEL	
11	26 200	--	1 100	4 800	35 000	--	12 500	--	1 100	
12	>800 000	>800 000	40 000	50 000	250 000	--	200 000	22 700	**18 000**	
14 •	*>390 000*	*>390 000*	*200 000*	--	--	--	*226 000*	--	*110 000*	*j*
22	220 000	--	25 000	50 000	140 000	--	--	--	25 000	
23	>663 000	>663 000	800 000	--	--	--	51 000	300 000	41 000	
32	>760 000	>760 000	200 000	250 000	--	--	49 500	--	40 000	
113	52 500	45 000	2 600	4 850	28 000	--	25 000	--	2 600	
114	255 000	--	--	25 000	250 000	--	100 000	--	20 000	k
115 •	*>800 000*	*>800 000*	--	*150 000*	--	--	*800 000*	--	*120 000*	*j*
116	>800 000	>800 000	200 000	--	--	--	121 000	--	97 000	
123	32 000	32 000	10 300	--	27 000	--	2 500	--	9 100	
124	262 500	>230 000	10 100	25 000	150 000	--	48 000	--	10 000	
125	>769 000	>769 000	75 000	100 000	--	--	709 000	--	75 000	
134	>460 000	>460 000	75 000	100 000	--	--	120 000	--	75 000	
134a	>359 300	>359 300	49 800	75 200	280 000	--	81 000	--	50 000	
E134	>141 000	>141 000	--	--	--	--	18 000	--	0	
141b	61 647	--	2 600	5 200	25 000	--	19 959	--	2 600	
142b	106 000	>100 000	25 000	50 000	250 000	--	--	--	25 000	l
143a	>591 000	>591 000	250 000	300 000	500 000	--	591 000	--	170 000	
152a	>400 000	383 000	50 000	150 000	--	--	100 000	500 000	50 000	
170 •	*>24 838*	*>24 838*	--	*100 000*	--	--	*24 838*	--	*7 000*	*j*
218	>400 000	>400 000	300 000	400 000	--	--	113 000	--	90 000	m
227ea	>788 696	>788 696	70 000	90 000	--	--	105 000	--	70 000	
236fa	>457 000	>457 000	100 000	150 000	110 000	--	20 000	--	55 000	
245ca	--	84 900	--	--	--	100 000	50 000	120 000	0	n
245fa	>203 000	>203 000	34 100	44 000	--	--	50 600	--	34 000	
290	>200 000	--	50 000	100 000	280 000	--	--	--	50 000	o
C318 •	*>800 000*	*>800 000*	--	*100 000*	*>800 000*	--	*800 000*	--	*80 000*	*j*
500	--	--	--	--	--	--	--	--	**29 000**	p
502	>300 000	>300 000	50 000	100 000	--	--	200 000	--	35 000	pq
600 •	*272 000*	--	--	--	--	--	--	*100 000*	*0*	*j*
600a	142 500	--	25 000	50 000	200 000	--	--	--	25 000	r
717	3 300	--	--	-- s	--	--	38 900	400	**320**	t
744	-- u	--	--	-- s	--	--	--	50 000	**40 000**	
1270 •	--	*490 000*	--	--	--	--	*10 000*	*7 200*	*0*	*j,v*

a Data and limitations should be verified in the sources identified on pages 33-86 (or reference 22) before use. The limiting effect is underlined for each refrigerant. Italicized data are *provisional* (see page 87) Differences with table 1 are shown in bold type.

b from ANSI/ASHRAE Standard 34 [1]

c 4-hr LC_{50} rat; federal and fire code toxicity classifications are based on a 1-hr LC_{50} rat

d 4-hr ALC rat

e in dogs with epinephrine injection

f 10-min EC_{50} mouse or rat

g lowest anesthetic/CNS LOEL rat during ALC, LC_{50}, or other acute toxicity studies

h highest anesthetic/CNS NOEL rat in any toxicity study not exceeding an acute LOEL

i other escape-impairing or permanently injuring effects, including severe sensory irritation, for short exposures

j data shown for R-14, R-115, R-170, R-C318, R-600, and R-1270 are collateral data; resulting ATELs and RCLs are provisional (see page 87)

k R-114 30-min LC_{50} rat = 720 000 ppm v/v, 2-hr LC_{50} rat > 600 000 ppm v/v

l R-142b 30-min LC_{50} mouse = 300 000 ppm v/v, 4-hr ALC ≈ 128 000 ppm v/v for 2-4 of 6 rats

m R-218 1-hr ALC rat > 800 000 ppm v/v

n R-245ca 30-min ALC mouse = 240 000 ppm v/v

o R-290 15-min LC_{50} rat > 800 000 ppm v/v

p R-500 and R-502 ATEL based on blend calculation for components

q R-502 LC_{50} and ALC documentation is inadequate, but data are conservative for components

r R-600a 15-min LC_{50} rat = 570 000 ppm v/v

s no data, believed to exceed LC_{50} and ALC

t R-717 published LC_{50} rat = 6 586 - 19 671 ppm v/v for 1 hr and 2 000 - 4 067 for 4 hr; conversion of the lowest 1-hr LC_{50} rat to 4-hr yields 3 300, approximately the midpoint of the 4-hr values

u R-744 treated as *simple asphyxiant*; 5-min LC_{Lo} human = 90 000 ppm v/v

v R-1270 6-hr ALC > 400 000 ppm v/v; CS in 2/2 dogs at 100 000 ppm v/v; RD_{50} = 7 200 ppm v/v

• *provisional, see page 87*

Table 2 repeats the data summary with one change, namely ATEL calculation following the several changes presented pages 22-26. The key change is inclusion of a factor to convert the term for other escape-impairing effects and permanent injury—§7.1.1(d)—from an effect level to a guidance level. The consequences of this change are highlighted in bold type.

As indicated in table 2 and directly compared in table 3, this change makes the ATEL for R-744 (carbon dioxide) match the revised 1994 IDLH for it and reduces the difference between the ATEL and the 1994 IDLH for R-12 and R-717 (ammonia).

Subsequent tables in this report are based on the data and ATEL values shown in table 2.

Table 3: Refrigerant Classifications and Exposure Limits [a]

refrig-erant [b]	OSHA/ fire code *toxic* or *highly toxic*? [c]	former UL group [d]	LFL [e] (%)	ASHRAE 34 safety group [b]	IDLH [f] SCP (ppm v/v)	IDLH [f] 1994 (ppm v/v)	ATEL (ppm v/v)	RCL (ppm v/v)	change to ASHRAE 15 [g] *amount* (%)	PEL [h] or ~ (ppm v/v)
11	no	5(a)	nf	A1	10 000 i	2 000	1 100	1 100	-73	C1 000 j
12	no	6	nf	A1	50 000	15 000	18 000	18 000	-55	1 000
14 •	*no*	*6*	*nf*	*A1*	--	--	*111 000*	*69 000*	*+3*	--
22	no	5(a)	nf	A1	50 000 k	--	25 000	25 000	-40	1 000 l
23	no	~6	nf	A1	--	--	41 000	41 000	new	1 000 k
32	no	--	12.7	A2	--	--	40 000	32 000	new	1 000 m
113	no	4-5	nf	A1	4 500	2 000	2 600	2 600	-35	1 000
114	no	6	nf	A1	50 000	15 000	20 000	20 000	-5	1 000
115 •	*no*	*6*	*nf*	*A1*	--	--	*120 000*	*69 000*	*+3*	*1 000 j*
116	no	~6	nf	A1	--	--	97 000	69 000	new	1 000 k
123	no	--	nf	B1	4 000 k	--	9 100	9 100	+810	50 m
124	no	6	nf	A1	--	--	10 000	10 000	new	1 000 m
125	no	--	nf	A1	--	--	75 000	69 000	new	1 000 m
134	no	--	nf	--	--	--	75 000	69 000	new	1 000 k
134a	no	--	nf	A1	50 000 k	--	50 000	50 000	-17	1 000 m
E134	no	--	nf	--	--	--	0	0	new	--
141b	no	--	5.8	--	--	--	2 600	2 600	new	500 m
142b	no	--	6.0	A2	--	--	25 000	15 000	new	1 000 m
143a	no	--	7.0	A2	--	--	170 000	18 000	new	1 000 m
152a	no	--	3.7	A2	--	--	50 000	9 300	+33	1 000 m
170 •	*no*	*5(b)*	*2.9*	*A3*	--	--	*7 000*	*7 000*	*+9*	*1 000*
218	no	--	nf	A1	--	--	90 000	69 000	new	1 000 k
227ea	no	--	nf	--	--	--	70 000	69 000	new	1 000 k
236fa	no	--	nf	A1	--	--	55 000	55 000	new	1 000 m
245ca	no	--	7.1	--	--	--	0	0	new	--
245fa	no	--	--	B1 n	--	--	34 000	34 000	new	300 m
290	no	5(b)	2.0	A3	20 000	2 100	50 000	5 000	+14	2 500
C318 •	*no*	*~6*	*nf*	*A1 o*	--	--	*80 000*	*69 000*	*+3*	--
500	no	5(a)	nf	A1	50 000 k	--	29 000	29 000 p	-49	1 000
502	no	5(a)	nf	A1	50 000 k	--	35 000	35 000 p	-46	1 000
600 •	*no*	*5(b)*	*1.5*	*A3*	--	--	*0*	*0*	*-100*	*800 l*
600a	no	5(b)	1.0	A3	--	--	25 000	2 500	-26	800 q
717	no	2	15.0	B2	500	300	320	320	-36	50 r
744	no	5(a)	nf	A1	50 000	40 000	40 000	40 000	-20	5 000
1270 •	*no*	--	*2.0*	*A3*	--	--	*0*	*0*	*-100*	*375 k*

a Data and limitations should be verified in the sources identified on pages 33-86 (or reference 22) before use. Concentrations shown in this table as % or ppm are v/v in air. Italicized data are *provisional* (see page 87).

b from ANSI/ASHRAE Standard 34 [1]

c 29 CFR 1910 [3] and most model fire codes including the IFC, [12] NFPC, SFPC, and UFC

d comparative life hazard where group 1 is the most toxic and group 6 the least [20]

e determined in accordance with ASHRAE 34 §6.1.3 [1]; the values shown are taken from the referenced sources in the ARTI Refrigerant Database[22] based on the lowest cited there to be conservative (see §7.3.4 on page 20)

f from the Standards Completion Program (SCP) and 1994 NIOSH IDLH revision [11,15]

g from ASHRAE 15 table 1 [2]

h PEL or consistent occupational exposure limit on a time-weighted average (TWA) basis (unless noted C for ceiling) for an 8 hr/d and 40 hr/wk

i The SCP and 1994 IDLHs are 10 000 and 2 000 ppm v/v, respectively;[11,15] ARI recommended reduction of the SCP IDLH to 5 000 ppm v/v.[25]

j The OSHA PEL is 1 000 ppm v/v;[293] ARI recommends C1000 ppm v/v based on the cardiac sensitization potential.[25]

k industry or manufacturer recommendation

l ACGIH Threshold Limit Value - Time-Weighted Average (TLV-TWA)[16]

m AIHA Workplace Environmental Exposure Limit (WEEL)[9]

n currently classified A1 provisional,[1] but a change to B1 is pending

o not currently classified based on withdrawal of an earlier classification as A1,[1] but a change to reinstate the A1 classification is pending

p ATEL and RCL shown for R-500 and R-502 are based on blend calculations for their respective components (see table 4)

q NIOSH Recommended Exposure Limit (REL)[15]

r ACGIH Threshold Limit Value - Time-Weighted Average (TLV-TWA) = 25 ppm v/v[16]

• *provisional, see page 87*

RCL CALCULATIONS AND COMPARISONS

Table 3 compares the ATEL and RCL concentrations to other guideline data. As previously noted, none of the refrigerants shown meet the federal definitions for *toxic* or *highly toxic* chemicals (see page 10). Indeed, most of the refrigerants classified into the *former UL groups* (see page 14) and that are still of interest fall into groups 4-6, indicating comparatively low toxicity; the exception is R-717 (ammonia).

The majority are nonflammable as indicated in the lower-flammability limit (*LFL*) column. The LFLs shown are the lowest identified, as summarized in appendix 2 and in the ARTI Refrigerant Database Reference.[22] Page 98 discusses them further, and table 8 summarizes sensitivity analyses for dispersion in the LFL data. Of the flammable refrigerants, most are primarily used as blend components or in niche or industrial applications. The hydrocarbons — most notably R-600a (isobutane) — and R-717 (ammonia) are exceptions, but their net use is still small particularly in the USA. Appendix 2 and the Database provide further information on the specific and candidate uses of these refrigerants.

Table 3 shows that the proposed ATEL values are similar to the 1994 IDLHs with two exceptions. First, the comparisons fail for flammable refrigerants, since ATELS address only flammability while IDLHs reflect both toxicity and flammability. Second, NIOSH caps IDLHs at 50,000 ppm v/v on the premise that occupational exposure should not or need not exceed that value without use of respirators. These two distinctions are noted in the ATEL definition (see page 18), to suggest a way to adjust ATELs as surrogates for IDLHs when needed for code compliance for refrigerants lacking IDLH values.

The RCL values indicated were calculated following the revised method (see pages 26-30) using the ATELs shown in table 2 (and repeated in table 3 for convenience), the oxygen deprivation limit (ODL) of 69,100 ppm v/v (see page 28), and the flammable concentration limit (FCL) of 25% of the LFLs (see page 28). Like the ATEL concentrations, the RCLs shown here are consistently rounded to two significant digits, even though the implied accuracy of 1% exceeds the quantification certainty.

The column following the RCLs in table 3 compares the RCLs to the concentrations used in ASHRAE 15 to determine the allowed refrigerant *amounts* in occupied spaces (see page 15). This comparison does not reflect any changes that may result in the way ASHRAE 15 and/or codes apply the proposed RCL values. The RCLs generally are lower than the ASHRAE 15 concentrations except for flammable refrigerants. That distinction arises from a difference in the LFL multiplier used, namely 20% in ASHRAE 15 (see note e of table 1 in reference 2) and 25% in the RCL method (see page 28) as well as in most newer fire codes (see reference 12 as an example). The differences for nonflammable refrigerants generally follow from the toxicity data used, more specific criteria for the RCL, inconsistencies in the ASHRAE 15 values, or a small increase in the ODL from 67,000 to 69,100 ppm v/v (see page 28). The RCL method is deemed more rigorous based on explicit criteria to address anesthetic/CNS effects, escape-impairing effects, concentrations causing permanent injury, and for some parameters more conservative multipliers in line with current industrial hygiene practices.

The PEL or consistent measures are included in table 3 for reader convenience, but are not comparable to the RCLs since the former limits address chronic occupational exposures while the latter address acute, emergency exposures (see page 1).

PROPOSED RCL CONCENTRATIONS IN DIMENSIONAL FORM

Tables 4-7 present the proposed RCLs in dimensionless form and in both metric (SI) and inch-pound (IP) units of measure, all rounded to two significant digits. They include the chemical name or blend composition, the proposed ATEL concentrations from table 2, and the comparisons to ASHRAE 15 amounts from table 3 for reference.

Table 4 addresses the single-compound refrigerants from table 2 including those with provisional ATELs. Tables 5 and 6 respectively address zeotropic and azeotropic blends — R-4nn and R-5nn series — with designations in ASHRAE 34 [1] plus a few developmental variants in the same series. Table 7 addresses additional blends with pending applications for designations in ASHRAE 34, that have been discussed in deliberations on the committees responsible for ASHRAE 15 and 34 to examine the RCL approach, and several others used to develop or check the calculation method.

Table 4: RCL Dimensional Unit Conversions [a]

refrigerant [b] designation	chemical name	ATEL (ppm v/v)	RCL (ppm v/v)	change to ASHRAE 15 [c] *amount* (%)	RCL (g/m^3)	RCL (lb/Mcf)
11	trichlorofluoromethane	1 100	1 100	-73	6.2	0.39
12	dichlorodifluoromethane	18 000	18 000	-55	90	5.6
14 •		*110 000*	*69 000*	*+3*	*250*	*16*
22	chlorodifluoromethane	25 000	25 000	-40	89	5.5
23	trifluoromethane	41 000	41 000	-39 *	120	7.3
32	difluoromethane	40 000	32 000	new	68	4.2
113	1,1,2-trichloro-1,2,2-trifluoroethane	2 600	2 600	-35	20	1.2
114	1,2-dichloro-1,1,2,2-tetrafluoroethane	20 000	20 000	-5	140	8.7
115 •	*chloropentafluoroethane*	*120 000*	*69 000*	*+3*	*440*	*27*
116	hexafluoroethane	97 000	69 000	new	390	24
123	2,2-dichloro-1,1,1-trifluoroethane	9 100	9 100	+810	57	3.5
124	2-chloro-1,1,1,2-tetrafluoroethane	10 000	10 000	new	56	3.5
125	pentafluoroethane	75 000	69 000	new	340	21
134	1,1,2,2-tetrafluoroethane	75 000	69 000	new	290	18
134a	1,1,1,2-tetrafluoroethane	50 000	50 000	-17	210	13
E134	bis(difluoromethyl) ether	0	0	new	0	0
141b	1,1-dichloro-1-fluoroethane	2 600	2 600	new	12	0.78
142b	1-chloro-1,1-difluoroethane	25 000	15 000	new	62	3.9
143a	1,1,1-trifluoroethane	170 000	18 000	new	60	3.8
152a	1,1-difluoroethane	50 000	9300	+33	25	1.6
170 •	*ethane*	*7 000*	*7 000*	*+9*	*8.7*	*0.54*
218	octafluoropropane	90 000	69 000	new	530	33
227ea	1,1,1,2,3,3,3-heptafluoropropane	70 000	69 000	new	480	30
236fa	1,1,1,3,3,3-hexafluoropropane	55 000	55 000	+162 *	340	21
245ca	1,1,2,2,3-pentafluoropropane	0	0	-100 *	0	0
245fa	1,1,1,3,3-pentafluoropropane	34 000	34 000	new	190	12
290	propane	50 000	5 000	+14	9.0	0.56
C318 •	*octafluorocyclobutane*	*80 000*	*69 000*	*+3*	*570*	*35*
500	(calculated as blend in table 6)					
502	(calculated as blend in table 6)					
600 •	*n-butane*	*0*	*0*	*-100*	*0*	*0*
600a	isobutane	25 000	2500	-26	6.0	0.37
717	ammonia	320	320	-36	0.22	0.014
744	carbon dioxide	40 000	40 000	-20	72	4.5
1270 •	*propene (propylene)*	*0*	*0*	*-100*	*0*	*0*

a ATEL and RCL concentrations shown in this table are in air. RCLs shown as g/m^3 and lb/Mcf are at sea level. Italicized data are *provisional* (see page 87).

b from ANSI/ASHRAE Standard 34 [1] and the ARTI Refrigerant Database [22]

c from ASHRAE 15 table 1:[2] Where flagged with an asterisk (*) the reference values from ASHRAE 15 are for the refrigerant that this refrigerant replaces in its primary application, so flagged entries in this table differ from the corresponding entries in table 3.

• *provisional, see page 87*

Table 5: RCL Dimensional Unit Conversions for Zeotropic Blends with Designations [a]

refrigerant [b] designation	composition	ATEL (ppm v/v)	RCL (ppm v/v)	change to ASHRAE 15 [c] *amount* (%)	RCL (g/m^3)	RCL (lb/Mcf)
400	R-12/114 (50.0/50.0)	28 000	28 000	new	160	10
400	R-12/114 (60.0/40.0)	26 000	26 000	new	150	9.3
401A	R-22/152a/124 (53.0/13.0/34.0)	20 000	20 000	-50 •	77	4.8
401B	R-22/152a/124 (61.0/11.0/28.0)	21 000	21 000	-48 *	79	4.9
401C	R-22/152a/124 (33.0/15.0/52.0)	17 000	17 000	-58 *	71	4.4
402A	R-125/290/22 (60.0/2.0/38.0)	39 000	39 000	-40 *	160	10
402B	R-125/290/22 (38.0/2.0/60.0)	32 000	32 000	-51 *	120	7.8
403A	R-290/22/218 (5.0/75.0/20.0)	29 000	29 000	-55 *	110	6.9
403B	R-290/22/218 (5.0/56.0/39.0)	34 000	34 000	-48 *	140	8.9
404A	R-125/143a/134a (44.0/52.0/4.0)	130 000	69 000	+6 *	280	17
405A •	*R-22/152a/142b/C318• (45/7/5.5/42.5)*	*32 000*	*32 000*	*-20 **	*150*	*9.2*
406A	R-22/600a/142b (55.0/4.0/41.0)	25 000	25 000	-38 •	92	5.7
	R-22/600a/142b (65.0/4.0/31.0)	25 000	25 000	-38 *	91	5.7
407A	R-32/125/134a (20.0/40.0/40.0)	78 000	69 000	+6 *	260	16
407B	R-32/125/134a (10.0/70.0/20.0)	77 000	69 000	+6 *	290	18
407C	R-32/125/134a (23.0/25.0/52.0)	76 000	69 000	+64 *	240	15
407D	R-32/125/134a (15.0/15.0/70.0)	65 000	65 000	+38 *	240	15
407E	R-32/125/134a (25.0/15.0/60.0)	72 000	69 000	+64 *	240	15
	R-32/125/134a (30.0/10.0/60.0)	66 000	66 000	+57 *	220	14
408A	R-125/143a/22 (7.0/46.0/47.0)	47 000	47 000	+0 •	170	10
409A	R-22/124/142b (60.0/25.0/15.0)	20 000	20 000	-50 *	79	4.9
409B	R-22/124/142b (65.0/25.0/10.0)	20 000	20 000	-50 •	78	4.9
410A	R-32/125 (50.0/50.0)	55 000	55 000	+31 •	160	10
410B	R-32/125 (45.0/55.0)	58 000	58 000	+38 •	180	11
	R-32/125 (32.0/68.0)	71 000	69 000	+21 •	240	15
	R-32/125 (48.0/52.0)	56 000	56 000	+33 *	170	11
411A	R-1270/22/152a (1.5/87.5/11.0)	~ 26 000	~ 26 000	-38% •	86	5.4
411B	R-1270/22/152a (3.0/94.0/3.0)	~ 23 000	~ 23 000	-65% *	80	5.0
	R-1270/22/152a (3/95.5/1.5)	~ 23 000	~ 23 000	-43% •	79	4.9
412A	R-22/218/142b (70.0/5.0/25.0)	26 000	26 000	-45 *	97	6.0
413A	R-218/134a/600a (9.0/88.0/3.0)	49 000	49 000	+23 *	210	13
414A	R-22/124/600a/142b (51/28.5/4.0/16.5)	19 000	19 000	-53 •	76	4.8
414B	R-22/124/600a/142b (50.0/39.0/1.5/9.5)	18 000	18 000	-55 *	73	4.5
416A •	*R-134a/124/600• (59.0/39.5/1.5)*	*~ 21 000*	*~ 21 000*	*-48% •*	*96*	*6.0*
417A •	*R-125/134a/600• (46.6/50.0/3.4)*	*~ 45 000*	*~ 45 000*	*+7% **	*200*	*12*

a ATEL and RCL concentrations shown in this table are in air. RCLs shown as g/m^3 and lb/Mcf are at sea level. Italicized data are *provisional* (see page 87). ATEL and RCL data preceded by a tilda (~) are approximations since toxicity data needed to calculate the ATEL are missing for one or more blend components or because adequate data on the blend flammability to calculate the RCL are not available.

b from ANSI/ASHRAE Standard 34 [1] and the ARTI Refrigerant Database [22]

c from ASHRAE 15 table 1:[2] Where flagged with an asterisk (*) the reference values from ASHRAE 15 are for the refrigerant that this refrigerant replaces in its primary application, so flagged entries in this table differ from the corresponding entries in table 3.

• *provisional, see page 87*

Table 6: RCL Dimensional Unit Conversions for Azeotropic Blends with Designations [a]

refrigerant [b] designation	composition	ATEL (ppm v/v)	RCL (ppm v/v)	change to ASHRAE 15 [c] *amount* (%)	RCL (g/m^3)	RCL (lb/Mcf)
500	R-12/152a (73.8/26.2)	29 000	29 000	-49	120	7.4
501	R-22/12 (75.0/25.0)	27 000	27 000	new	100	6.4
502	R-22/115 (48.8/51.2)	35 000	35 000	-46	160	10
503 •	*R-23/13• (40.1/59.9)*	*0*	*0*	*0*	*0*	*0*
504 •	*R-32/115• (48.2/51.8)*	*53 000*	*41 000*	*new*	*130*	*8.4*
505 •	*R-12/31• (78.0/22.0)*	*0*	*0*	--	*0*	*0*
506 •	*R-31•/114 (55.1/44.9)*	*0*	*0*	--	*0*	*0*
507A	R-125/143a (50.0/50.0)	130 000	69 000	+6 *	280	17
508A	R-23/116 (39.0/61.0)	55 000	55 000	-18 *	220	14
508B	R-23/116 (46.0/54.0)	52 000	52 000	-22 *	200	13
509A	R-22/218 (44.0/56.0)	38 000	38 000	-42 *	190	12

a ATEL and RCL concentrations shown in this table are in air. RCLs shown as g/m^3 and lb/Mcf are at sea level. Italicized data are *provisional* (see page 87). ATEL and RCL data preceded by a tilda (~) are approximations since toxicity data needed to calculate the ATEL are missing for one or more blend components or because adequate data on the blend flammability to calculate the RCL are not available.

b from ANSI/ASHRAE Standard 34 [1] and the ARTI Refrigerant Database [22]

c from ASHRAE 15 table 1:[2] Where flagged with an asterisk (*) the reference values from ASHRAE 15 are for the refrigerant that this refrigerant replaces in its primary application, so flagged entries in this table differ from the corresponding entries in table 3.

• *provisional, see page 87*

Table 7: RCL Dimensional Unit Conversions for Additional Blends without Designations [a]

refrigerant [b] designation	composition	ATEL (ppm v/v)	RCL (ppm v/v)	change to ASHRAE 15 [c] amount (%)	RCL (g/m^3)	RCL (lb/Mcf)
	R-22/152a (52.0/48.0)	34 000	~ 16 000	-60 *	~ 51	~ 3.2
	R-22/152a (60.0/40.0)	33 000	~ 19 000	-53 *	~ 60	~ 3.7
	R-23/22/152a (5.0/90.0/5.0)	27 000	~ 27 000	-58 *	~ 95	~ 5.9
	R-23/22/152a (5.0/80.0/15.0)	29 000	~ 29 000	-31 •	~ 98	~ 6.1
	R-23/32/134a (4.5/21.5/74)	70 000	~ 69 000	+64 *	~ 240	~ 15
	R-32/125/143a (10.0/45.0/45.0)	140 000	~ 29 000	-55 *	~ 110	~ 6.7
	R-32/134a (25.0/75.0)	70 000	~ 67 000	+60 •	~ 230	~ 14
	R-32/134a (30.0/70.0)	65 000	~ 60 000	+43 *	~ 200	~ 12
	R-32/134a (33.8/66.2)	62 000	~ 56 000	+33 •	~ 180	~ 11
	R-32/125/143a/134a (10.0/33.0/36.0/21.0)	110 000	~ 34 000	-19 *	~ 130	~ 7.9
•	*R-32/600• (90.0/10.0)*	*~ 31 000*	*~ 19 000*	*-55 •*	*~ 41*	*~ 2.5*
•	*R-32/600• (95.0/5.0)*	*~ 35 000*	*~ 24 000*	*-43 **	*~ 51*	*~ 3.2*
	R-32/600a (90.0/10.0)	42 000	~ 15 000	-64 *	~ 33	~ 2.1
	R-32/600a (95.0/5.0)	41 000	~ 21 000	-50 •	~ 45	~ 2.8
	R-125/143a/290/22 (42.0/6.0/2.0/50.0)	36 000	~ 36 000	-45 *	~ 140	~ 8.8
	R-134a/142b (80.0/20.0)	41 000	~ 41 000	+3 •	~ 170	~ 11
	R-134a/600a (80.0/20.0)	38 000	~ 8 000	-80 *	~ 29	~ 1.8
	R-218/152a (50.0/50.0)	64 000	~ 12 000	-71 *	~ 49	~ 3.1
	R-290/124/123 (3.0/40.0/57.0)	11 000	~ 11 000	-48 *	~ 62	~ 3.8
	R-290/600a (50.0/50.0)	35 000	~ 3 500	-91 *	~ 7.2	~ 0.45

a ATEL and RCL concentrations shown in this table are in air. RCLs shown as g/m^3 and lb/Mcf are at sea level. Italicized data are *provisional* (see page 87). ATEL and RCL data preceded by a tilda (~) are approximations since toxicity data needed to calculate the ATEL are missing for one or more blend components or because adequate data on the blend flammability to calculate the RCL are not available.

b from ANSI/ASHRAE Standard 34 [1] and the ARTI Refrigerant Database [22]

c from ASHRAE 15 table 1:[2] Where flagged with an asterisk (*) the reference values from ASHRAE 15 are for the refrigerant that this refrigerant replaces in its primary application, so flagged entries in this table differ from the corresponding entries in table 3.

• *provisional, see page 87*

SENSITIVITY ANALYSES FOR THE FLAMMABILITY DATA

Table 8 summarizes sensitivity analyses for the flammability data used to calculate the flammable concentration limit (FCL, see page 28) and in turn the RCL. There is wide dispersion in reported lower-flammability limit (LFL) values for some refrigerants, as can be seen in Appendix 2 (which begins on page 135). Table 8 shows a single LFL for flammable refrigerants with minimal or no LFL dispersion such as R-1270 (see page 266). The table shows both low and high LFLs for refrigerants with clustering at one of them, such as R-32, R-152a, and R-245ca (from pages 163, 214, and 229, respectively).

Table 8: Parametric Analyses for Flammability [a]

refrig-erant [b]	OSHA/ fire code *toxic* or *highly toxic*? [c]	former UL group [d]	LFL [e] (%)	ASHRAE 34 safety group [b]	IDLH [f] SCP (ppm v/v)	IDLH [f] 1994 (ppm v/v)	ATEL (ppm v/v)	RCL (ppm v/v)	change to ASHRAE 15 [g] *amount* (%)	PEL [h] or ~ (ppm v/v)	
32	no	--	12.7	A2	--	--	40 000	32 000	new	1 000	i
			14.0				40 000	35 000	new		
141b	no	--	5.8	--	--	--	2 600	2 600	new	500	i
			7.2				2 600	2 600	new		
			7.6				2 600	2 600	new		
142b	no	--	6.0	A2	--	--	25 000	15 000	new	1 000	i
			6.7				25 000	17 000	new		
			9.0				25 000	23 000	new		
143a	no	--	7.0	A2	--	--	170 000	18 000	new	1 000	i
			7.1				170 000	18 000	new		
			13.0				170 000	33 000	new		
152a	no	--	3.7	A2	--	--	50 000	9 300	+33	1 000	i
			5.1				50 000	13 300	+86		
170 •	*no*	*5(b)*	*2.9*	*A3*	--	--	*7 000*	*7 000*	+9	*1 000*	
			3.0				*7 000*	*7 000*	+9		
			3.3				*7 000*	*7 000*	+9		
245ca	no	--	7.1	--	--	--	0	0	new	--	
			8.3				0	0	new		
290	no	5(b)	2.0	A3	20 000	2 100	50 000	5 000	+14	2 500	
			2.1				50 000	5 300	+20		
			2.37				50 000	5 900	+34		
600 •	*no*	*5(b)*	*1.5*	*A3*	--	--	*0*	*0*	*-100*	*800*	*j*
			1.6				*0*	*0*	*-100*		
			1.9				*0*	*0*	*-100*		
600a	no	5(b)	1.0	A3	--	--	25 000	2 500	-26	800	k
			1.8				25 000	4 500	+32		
			1.9				25 000	4 800	+41		
717	no	2	15.0	B2	500	300	320	320	-36	50	l
			15.1				320	320	-36		
			16.0				320	320	-36		
1270 •	*no*	*--*	*2.0*	*A3*	--	--	*0*	*0*	*-100*	*375*	*m*

a Data and limitations should be verified in the sources identified on pages 33-86 (or reference 22) before use. Concentrations shown in this table as % or ppm are v/v in air. Italicized data are *provisional* (see page 87).

b from ANSI/ASHRAE Standard 34 [1]

c 29 CFR 1910 [3] and most model fire codes including the IFC, [12] NFPC, SFPC, and UFC

d comparative life hazard where group 1 is the most toxic and group 6 the least [20]

e determined in accordance with ASHRAE 34 §6.1.3 [1]; the values shown are taken from the referenced sources in the ARTI Refrigerant Database [22] based on the lowest cited there to be conservative (see §7.3.4 on page 20)

f from the Standards Completion Program (SCP) and 1994 NIOSH IDLH revision [11,15]

g from ASHRAE 15 table 1 [2]

h PEL or consistent occupational exposure limit on a time-weighted average (TWA) basis (unless noted C for ceiling) for an 8 hr/d and 40 hr/wk

i AIHA Workplace Environmental Exposure Limit (WEEL) [9]

j ACGIH Threshold Limit Value - Time-Weighted Average (TLV-TWA) [16]

k NIOSH Recommended Exposure Limit (REL) [15]

l ACGIH Threshold Limit Value - Time-Weighted Average (TLV-TWA) = 25 ppm v/v [16]

m industry or manufacturer recommendation

• *provisional, see page 87*

Table 8 shows a third LFL for some refrigerants. The three values reflect the lowest LFL reported, the most commonly cited value, and the highest LFL reported. They exclude LFLs determined — if known — by methods other than as stipulated in ASHRAE 34 §6.1.3 [1] or determined by that method at elevated temperatures or with high-energy ignition sources. Some of the data still may not conform, since most material safety data sheets (MSDSs) and some publications do not identify the test method. In some cases, the lowest and/or highest LFLs represent suspicious values that depart from clustering in data from other reports. The *tail* is low for R-600a (isobutane), with an isolated indication 1.0% v/v, but nearly all other reports in the range of 1.6-1.8% v/v (as shown on page 256). It is high for R-143a, for which most sources indicate 7.1% v/v or a value in the range of 7.0-7.4% v/v (see page 210), but the documentation for one exposure limit indicates 13.0% v/v.[313] R-142b has outliers at both ends; most sources indicate LFLs of 6.7-7.2% v/v versus a full range 6.0-9.0% v/v (as shown on page 207).

Unlike the toxicity data (see pages 35-85), many of the LFL values shown were taken from MSDSs prepared by manufacturers. The LFL dispersion would be even higher except that several manufacturers revised their MSDSs, in response to preliminary data and RCL summaries distributed in the course of this project and the supported deliberations in the ASHRAE 34 and ISO committees. The modified MSDSs reflect corrections and newer test results that narrow the LFL spread, but the LFL dispersion still is high.

Consistent with the proposed method for RCL determination (see page 15-22 and specifically the provision for conservative data on page 20), tables 3-7 show the RCL based on the lowest reported LFL other than those known to have been determined by nonconforming methods.

As shown in table 8, the LFL dispersion is not an issue for single-compound refrigerants for which the ATEL is more restrictive, for example R-141b and R-717 (ammonia). It still could influence blends of them, though none are known to be in commercial use for these two refrigerants. The ATEL also governs for R-170 ethane using collateral toxicity data (see page 87), but the LFL is likely to become the most restrictive parameter since further toxicity data probably will

raise the ATEL. This refrigerant was not targeted in the data gathering for this project (as explained on page 33). The impact of LFL uncertainty is particularly significant for R-152a and R-600a (isobutane).

CAUTION

Most of the qualifications on data sources, variations in individual susceptibility, aggravating factors, newer data, and guideline misuse indicated for TLVs (see page 16) are applicable to other exposure limits including the ATEL and RCL.

Safety considerations and other characteristics affecting suitability or desirability may be influenced by a number of factors. Among them are specific application conditions, additives, impurities, catalytic interactions with other materials used, and changes in compounding between one source or batch and another. Similarly, new findings or corrections may supersede previously published data. Neither this report nor the Refrigerant Database should be viewed as the source of data, as contrasted to a means to help locate them.

CONCLUSIONS

GENERAL

The toxicity data examined herein provide a consistent basis to set emergency exposure limits to promote safety in use of refrigerants. The report recommends a calculation method, specific data, and proposed limits for common refrigerants for consideration by the committees responsible for ASHRAE 15 and 34 and, in turn, by those developing codes and regulations governing refrigerant use. While the data generally show the alternative refrigerants to be comparable or lower in toxicity than those they replace, and especially so for acute effects, safe use depends on adherence to proper application, handling, and service procedures. The report presents the proposed refrigerant concentration limits (RCLs) in dimensionless form (in ppm v/v) as well as in metric (SI) and inch-pound (IP) units of measure for a total of 99 single-compound refrigerants and zeotropic and azeotropic blends of them.

PROVISIONAL AND APPROXIMATED RCLS

The recommended limits for six of the compounds, included as components in eight of the blends, are provisional. While the scope for this project did not include them, data searches for the targeted refrigerants also found sufficient data to calculate provisional limits for the extra refrigerants. Likewise, these searches also found some or all of the data needed to calculate RCLs for more than 200 other refrigerants and candidate refrigerants. Recognizing that the limits calculated with provisional data could increase or decrease with additional data from focused searches, the provisional limits should be used with caution and warrant reduction by a safety factor of approximately 20% for interim use.

The report also flags seven of the blends as approximations based on estimations in light of insufficient toxicity data, for one or more components for one or more effects included in the ATEL. Only four of these blends have designations and ASHRAE 34 safety classifications. The report also flags 18 blends as approximations based on estimates of their flammability; the flammability data needed may be included in future classification applications. These estimated limits should be used with caution and warrant reduction by a safety factor of approximately 50% for interim use.

The suggested factors of 20 and 50% for the provisional and approximated data are intentionally conservative to protect the public and to provide an incentive for parties interested in those refrigerants to supply the missing information. They are indicative of uncertainty rather than known or suspected increases in hazard. No radical changes to the provisional and approximated RCLs, or at least the majority of them, are likely with the added data.

TOXICITY CLASSIFICATION

Neither ASHRAE 15 nor current model building, fire, and mechanical codes use the toxicity component of the ASHRAE 34 safety classification except to prohibit refrigerants in the B toxic-

ity class from use in "high probability" air-conditioning systems for human comfort. "High" and "low probability" distinguish systems for which leaked refrigerant from a failure is likely or unlikely, respectively, to enter an occupied space, generally that served by the refrigeration system involved. Determination of the cited prohibition by an index of chronic — rather than acute — toxicity is illogical since the underlying concern for this purpose is emergency exposures from failures and catastrophic causes. Indeed, ASHRAE15 §7.4.1 and most codes provide exclusions to this restriction for specified systems with small charges (not exceeding 3 kg, 6.6 lb) in listed equipment.[2]

Both the restriction and exclusions are arbitrary. There is no compelling reason to prohibit use of "high probability" systems using refrigerants in the B toxicity class if loss of the full charge would not exceed the RCL. Likewise, the exclusion amount provides no assurance that a highly toxic refrigerant, if used, would not exceed the RCL in some cases.

Accordingly, the author recommends deletion of the toxicity classification from ASHRAE 34, deletion of the restriction based on chronic toxicity for comfort-conditioning systems from ASHRAE 15, and focus instead — in both standards — on the proposed RCLs to minimize risks of acute toxicity, oxygen deprivation, and flammability.

This conclusion is reinforced by noting that the flammability class included in the ASHRAE 34 safety group is inherently "acute" in nature, that is from a single event rather than a continuing or repeated event. ASHRAE 34 determined the toxicity classification from acute toxicity data until the 1989 revision. It determined classifications by lethality or "serious injury" to guinea pigs from a 2-hr exposure at 25,000 ppm v/v,[314] presumably patterned after the early UL toxicity tests and classifications.[20]

UNCERTAINTIES IN FLAMMABILITY DATA

Although also beyond the scope of the project, the report presents sensitivity analyses to examine the impact of uncertainty in some of the flammability data used to calculate the RCLs. The findings show no or small effect for the majority of flammable refrigerants, but they also reveal two with significant consequence. The recommended limits use the most restrictive lowest LFLs identified to be conservative, but these limits may warrant some relaxation with more investigation of the flammability data used.

The author is aware of an ongoing study to measure the flammability of selected refrigerants by a proposed new method ("34p"). The further testing will add to the information base, but not refute the validity of the current data. The new data may increase the data dispersion for some refrigerants, but cannot reduce it. Accordingly, the author recommends critical review of the current data to examine the reasons for the wide variation, to dismiss data from noncomplying methods, and to document consistent data for use in calculating the flammability component of RCLs.

OXYGEN DEPRIVATION LIMIT

Review of the acute inhalation toxicity studies suggests that the currently used ODL warrants examination. Many studies found for this project report tests in atmospheres exceeding 69,000 ppm v/v refrigerant, for four hours or longer, with no clinical signs. The author recommends careful determination of a justified ODL.

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REFERENCES

These citations are deliberately expanded to show the affiliation of the authors (investigators), if different from the publishers, and to identify the document number (the letters RDB followed by four letters and/or numbers) in the ARTI Refrigerant Database (see reference 4). The authors' affiliations may be helpful in assessing the data. The database number may be useful in searching the database for further information, although the author names or other information also may be used.

1 **Designation and Safety Classification of Refrigerants**, ANSI/ASHRAE Standard 34-1997, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1997 (RDB8601)

Addenda to Number Designation and Safety Classification of Refrigerants, Addenda 34a, 34b, 34c, 34d, and 34f, ASHRAE, 1999 (RDB9710)

Addenda to Number Designation and Safety Classification of Refrigerants, Addenda 34h, 34j, and 34k, ASHRAE, 2000 (RDBA674)

2 **Safety Code for Mechanical Refrigeration**, ASHRAE Standard 15-1994, ASHRAE, August 1994 (RDB4903)

Emergency Interim Standards Action for ANSI/ASHRAE Standard 15-1994, ASHRAE, May 1998 (RDB8617)

Addendum to Safety Code for Mechanical Refrigeration, ASHRAE, Addendum 15c, 2000 (RDBA675)

3 Occupational Safety and Health Administration (OSHA), U.S. Department of Labor, **Health Hazard Definitions** in *Air Contaminants*, 29 CFR §1910.1200, Appendix A, Government Printing Office, Washington, DC, 1 July 2000

4 J. M. Calm (Engineering Consultant), **Refrigerant Safety**, *ASHRAE Journal*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 36(7):17-26, July 1994, with erratum 36(8), August 1994 (RDB4766)

5 R. C. Downing (Consultant, formerly DuPont Chemicals), **Fluorocarbon Refrigerants Handbook**, Prentice Hall, Englewood Cliffs, NJ, 1988 (RDB3960)

6 **Casarett and Doull's Toxicology: The Basic Science of Poisons** (fourth edition), edited by C. Klassen, Pergamon Press, New York, NY, 1991

7 **Programme for Alternative Fluorocarbon Toxicity Testing (PAFT) Toxicology Summaries**, PAFT, Washington, DC, September 1995 (RDB5C39)

8 **Testing to Extremes — Industry's Cooperative Effort to Test the Health and Safety of Selected Fluorocarbon Alternatives to CFCs**, Programme for Alternative Fluorocarbon Toxicity Testing (PAFT), Washington, DC, undated circa 1996 (RDB65E9)

9 **The AIHA 2000 Emergency Response Planning Guidelines and Workplace Environmental Exposure Level Guides Handbook**, document 358-EA-00, American Industrial Hygiene Association (AIHA), Fairfax, VA, 2000 (RDBA948)

10 W. F. ten Berge (DSM, The Netherlands), A. Zwart (TNO-CIVO Toxicology and Nutrition Institute, The Netherlands), and L. M. Appelman (TNO-CIVO), **Concentration-Time Mortality Response Relationship of Irritant and Systematically Acting Vapours and Gases**, *Journal of Hazardous Materials*, 13:301-309, 1986 (RDB6278)

11 H. R. Ludwig, S. G. Cairelli, and J. J. Whalen, **Documentation for Immediately Dangerous to Life or Health Concentrations (IDLHs)**, National Institute for Occupational Safety and Health (NIOSH), U.S. Department of Health and Human Services, Cincinnati, OH, May 1994 (RDB5340)

12 **International Fire Code**; International Code Council (ICC), Falls Church, VA; for the Building Officials and Code Administrators (BOCA) International, Country Club Hills, IL; International Conference of Building Officials (ICBO), Whittier, CA; and Southern Building Code Congress International (SBCCI), Birmingham, AL; table E103.1.3.1, page 369, 1997

13 **Class 6.1 — Poisons**, *International Maritime Dangerous Goods Code,* International Maritime Organization, London, §2.1.5.2.2, page 6007, 1986

14 **Uniform Fire Code**, International Fire Code Institute (IFCI), Whittier, CA, table A-VI-A-1, page 1-319, 1997

15 **NIOSH Pocket Guide to Chemical Hazards**, publication 99-115, National Institute for Occupational Safety and Health (NIOSH), U.S. Department of Health and Human Services, Cincinnati, OH, April 1999 (RDBA670)

16 **2000 Threshold Limit Values for Chemical Substances in the Work Environment**, *2000 TLVs® and BEIs®: Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*, publication 0100, American Conference of Governmental Industrial Hygienists (ACGIH), Cincinnati, OH, 2000 (RDBA936)

17 Commission for the Investigation of Health Hazards of Chemical Compounds in the Work Area, **List of MAK and BAT Values 1996: Maximum Concentrations and Biological Tolerance Values at the Workplace**, report 32, Deutsche Forschungsgemeinschaft [German Research Association] (DFG), Bonn, Germany; VCH Verlagsgesellschaft mbH, Weinheim, Germany, 1996 (RDB7101)

18 Commission for the Investigation of Health Hazards of Chemical Compounds in the Work Area, **Occupational Toxicants: Critical Data Evaluation for MAK Values and Classification of Carcinogens**, edited by D. Henschler, Deutsche Forschungsgemeinschaft [German Research Association] (DFG), Bonn, Germany; VCH Verlagsgesellschaft mbH, Weinheim, Germany; volume 1, September 1990; volume 2, July 1991; volume 3, September 1992; volume 4, July 1992; volume 5, July 1993; volume 6, August 1994; and volume 7, April 1996 (RDB7102)

19 **Designation and Safety Classification of Refrigerants**, ANSI/ASHRAE Standard 34-1989, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA (then in New York, NY), 1989

20 A. H. Nuckolls, **The Comparative Life, Fire, and Explosion Hazards of Common Refrigerants**, Miscellaneous Hazard Report Number 2375, Underwriters' Laboratories Incorporated, Chicago, IL, pages 106-107, 13 November 1933 (RDB4B64)

21 **1996 Threshold Limit Values for Chemical Substances in the Work Environment**, *1996 TLVs® and BEIs®: Threshold Limit Values for Chemical Substances and Physical*

Agents and Biological Exposure Indices, American Conference of Governmental Industrial Hygienists (ACGIH), Cincinnati, OH, 1996 (RDB6901)

22 J. M. Calm, **ARTI Refrigerant Database**, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, July 2000: Some of the data cited herein are from an update being prepared for release on October 2000. Please see www.arti-21cr.org/db on the Internet for database and update information.

23 **Registry of Toxic Effects of Chemical Substances (RTECS®)**, computerized database, National Institute of Occupational Safety and Health (NIOSH), U.S. Department of Health and Human Services, Cincinnati, OH, updated quarterly since June 1971 (RDB4450)

24 **Documentation of the Threshold Limit Values and Biological Exposure Indices** (sixth edition), publication 0206, American Conference of Governmental Industrial Hygienists (ACGIH), Cincinnati, OH, 1991 (RDB5141)

25 J. M. Calm (Engineering Consultant), **Refrigerant Safety Data — Recommendations of the Air-Conditioning and Refrigeration Industry**, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (RDB3A15)

26 **Occupational Safety and Health Guideline for Chemical Hazards (Supplement IV-OHG)**, U.S. Department of Health and Human Services and U.S. Department of Labor, Washington, DC, 1995

27 **Hydrofluorocarbons and Hydrochlorofluorocarbons — Interim Report**, external review draft, U.S. Environmental Protection Agency (EPA), Washington, DC, 15 November 1990 (RDB7234)

28 Meridian Research, Incorporated, **Assessment of Occupational Exposures to Halon Substitutes Used for Fire Protection**, U.S. Environmental Protection Agency (EPA), Washington, DC, 1992 (RDB6B54)

29 **Summary Review of Health Effects Associated with Ammonia: Health Issue Assessment**, report EPA 600/8-89/052F, Office of Health and Environmental Assessment, U.S. Environmental Protection Agency (EPA), Washington, DC, June 1989 (RDB5155)

30 R. Carchman and M. M. Greenberg, **Summary Review of Health Effects Associated with 1,1,2-Trichloro-1,2,2-trifluoroethane (Chlorofluorocarbon 113): Health Issue Assessment**, report EPA 600/8-82-002F, Office of Health and Environmental Assessment, U.S. Environmental Protection Agency (EPA), Washington, DC, January 1983 (RDB6494)

31 **Ammonia Data Book**, International Institute of Ammonia Refrigeration (IIAR), Washington, DC, 1993 (RDB3635)

32 **Fire Protection Guide to Hazardous Materials** (11th edition), National Fire Protection Association (NFPA), Quincy, MA, 1994 (RDB4C56) — includes NFPA 49-1994 (*Hazardous Chemicals Data*), NFPA 325-1994 (*Guide to Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids*), NFPA 491M-1991 (*Manual of Hazardous Chemical Reactions*), and NFPA 704-1990 (*Standard System for the Identification of Fire Hazards of Materials*)

33 H. F. Smith, T. F. Hatch, K. H. Jacobson, M. L. Keplinger, and F. Princi (National Research Council (NRC) Ad Hoc Committee) with revisions by A. J. Lehman, W. G. Fredrick, H. W. Gerarde, H. E. Stokinger, and J. A. Zapp, Jr. (NRC Committee on Toxicology), **Basis for Establishing Emergency Inhalation Exposure Limits Applicable to Military and Space Chemicals**, National Academy of Sciences (NAS), National Academy Press, Washington, DC, 1964 (RDB5A19)

34 National Research Council (NRC) Committee on Toxicology, **Basis for Establishing Guides for Short-Term Exposures of the Public to Air Pollutants**, National Academy Press, Washington, DC, 1971 (RDB7411)

35 National Research Council (NRC) Committee on Toxicology, **Criteria for Short-Term Exposures to Air Pollutants**, National Academy Press, Washington, DC, 1979 (RDB7412)

36 National Research Council (NRC) Committee on Medical and Biological Effects of Environmental Pollutants, **Ammonia**, University Park Press, Baltimore, MD, 1979 (RDB5771)

37 National Research Council (NRC) Committee on Toxicology, **Emergency and Continuous Exposure Limits for Selected Airborne Contaminants**, National Academy Press, Washington, DC, volume 1, April 1984 (RDB7413)

38 National Research Council (NRC) Committee on Toxicology, **Emergency and Continuous Exposure Limits for Selected Airborne Contaminants**, National Academy Press, Washington, DC, volume 2, October 1984 (RDB7414)

39 National Research Council (NRC) Committee on Toxicology, **Emergency and Continuous Exposure Limits for Selected Airborne Contaminants**, National Academy Press, Washington, DC, volume 3, October 1984 (RDB7415)

40 National Research Council (NRC) Committee on Toxicology, **Guideline for Short Term Exposures of the Public to Air Pollutants, IV, Guide for Ammonia**, National Academy Press, Washington, DC, 1987 (RDB5154)

41 K. L. Wong, **Ammonia**, Maximum Allowable Concentrations for Selected Airborne Contaminants in Spacecraft, National Research Council (NRC), Committee on Toxicology, 39-59, 1995 (RDB6A32)

42 National Research Council (NRC) Committee on Toxicology, **Toxicity of Alternatives to Chlorofluorocarbons: HFC-134a and HCFC-123**, National Academy Press, Washington, DC, 1996 (RDB6A01)

43 K. S. Bakshi (National Research Council, NRC), **Toxicity of Alternatives to Chlorofluorocarbons: HFC-134a and HCFC-123**, *Inhalation Toxicity*, 10(10):963-967, October 1998 (RDB9127)

44 **Criteria for a Recommended Standard — Occupational Exposure to Alkanes (C1-C8)**, publication 77-151, National Institute of Occupational Safety and Health (NIOSH), U.S. Department of Health and Human Services (DHS, then the U.S. Department of Health, Education, Welfare, DHEW), Cincinnati, OH, March 1977 (RDBA539)

45 **Criteria for a Recommended Standard - Occupational Exposure to Ammonia**, publication 74-136, National Institute of Occupational Safety and Health (NIOSH), U.S. Department of Health and Human Services, Cincinnati, OH, 1974 (RDB5369)

46 **Criteria for a Recommended Standard — Occupational Exposure to Carbon Dioxide**, publication 76-194, National Institute of Occupational Safety and Health (NIOSH), U.S. Department of Health and Human Services, Cincinnati, OH, August 1976 (RDB5787)

47 J. M. Calm (Engineering Consultant), **The Toxicity of Refrigerants**, *Proceedings of the 1996 International Refrigeration Conference* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, 157-162, July 1996; republished as report DOE/CE/23810-72E, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 1996 (RDB6832)

48 S. D. Morrison, **Inhalation Toxicity of "Freon 11" and of "Freon 11" + 0.3% Nitromethane**, report 53-61, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 25 October 1961 (RDB-65H3)

49 C. E. Barras, **Acute Inhalation Test** [of Trichloromonofluoromethane (Freon® 11)], report 648-74, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 29 October 1974 (RDB5C53)

50 **PAFT Update**, document H-45950, DuPont Chemicals, Wilmington, DE, November 1992 (RDB3909)

51 **Freon® 11**, Material Safety Data Sheet DU000026 (2090FR), DuPont Chemicals, Wilmington, DE, 8 January 1998

52 H. Wada, **Anesthetic Activity and Fatality (F-123, 123a, 124, and 11)**, attachment to 19 May 1977 correspondence to M. B. Berenbaum (Allied Chemical Corporation), Daikin Kogyu Company Limited Chemical Division, Settsu-shi, Osaka, Japan, 16 May 1977 (RDB-A309)

53 D. G. Clark and D. J. Tinston (Imperial Chemical Industries PLC, ICI, UK), **Acute Inhalation Toxicity of Some Halogenated and Nonhalogenated Hydrocarbons**, *Human Toxicology*, 1(3):239-247, 1982 (RDB6110)

54 **Toxicity Summary — Genetron® 11 (Trichloromonofluoromethane), Acute Toxicity and Cardiotoxicity**, Allied Corporation, Morristown, NJ, March 1978 (RDB5144)

55 C. J. Hardy, I. J. Sharman, and D. O. Chanter (Huntingdon Research Centre Limited, HRC, UK), **Assessment of Cardiac Sensitization Potential in Dogs and Monkeys: Comparison of I-141b and F11**, report PWT 86/89437, Pennwalt Corporation, King of Prussia, PA 8 September 1989 (RDB5C63)

56 C. J. Hardy, I. J. Sharman, and G. C. Clark (Huntingdon Research Centre Limited, HRC, UK), **Assessment of Cardiac Sensitization Potential in Dogs: Comparison of HFA 134a and A12**, report CTL/C/2521 (also identified as ISN 250/91169) for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, UK, 11 September 1991 (RDB5B42)

57 C. F. Reinhardt, A. Azar, M. E. Maxfield, P. E. Smith, Jr., and L. S. Mullin (E. I. duPont de Nemours and Company, Incorporated), **Cardiac Arrhythmias and Aerosol "Sniffing"**, *Archives of Environmental Health*, 22(2):265-279, February 1971 (RDB5644)

58 C. J. Hardy, P. C. Kieran, I. J. Sharman, and G. C. Clark (Huntingdon Research Centre Limited, HRC, UK), **Assessment of Cardiac Sensitization Potential in Dogs: Comparison of HFC 125 and Halon 13B1**, report MA-RR-92-1845 (also identified as ALS 11/920116) for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Allied-Signal Incorporated, Morristown, NJ, 10 June 1992 (RDB5755)

59 T. J. Kenny and C. J. Hardy (Huntingdon Research Centre Limited, HRC, UK), **FRIGC™ FR-12™: Assessment of Cardiac Sensitization Potential in Dogs**, report HZL 6/942384, Hazleton Washington, Incorporated, Vienna, VA, 31 May 1994 (RDB7407)

60 D. G. Clark and D. J. Tinston, **Correlation of the Cardiac Sensitizing Potential of Halogenated Hydrocarbons with Their Physiochemical Properties**, *British Journal of Pharmacology*, 49(2):355-357, 1973 (RDB6109)

61 H. J. Trochimowicz and L. S. Mullin, **Cardiac Sensitization Potential (EC_{50}) of Trifluorodichloroethane**, report 132-73, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 30 March 1973 (RDB-6146)

62 W. Weigand, **Untersuchungen über die Inhalationstoxizität von Fluoroderivaten des Methan, Äthan, und Cyclobutan** [Studies of the Inhalation Toxicity of Fluorinated Derivatives of Methane, Ethane and Cyclobutane], *Zentralblatt für Arbeitsmedizin und Arbeitsschutz* [Occupational Medicine and Safety], 21(5):149-156, 1971 (in German, RDB-5365)

63 W. J. Brock, **Toxicology Summary for CFC's HCFC's and HFC's**, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, undated circa 1996 (RDB6452)

64 **Genetron® 11**, MSDS GTRN-0017, Honeywell Incorporated, Morristown, NJ, January 2000

65 D. Lester and L. A. Greenberg (Yale University), **Acute and Chronic Toxicity of Some Halogenated Derivatives of Methane and Ethane**, *Archives of Industrial Hygiene and Occupational Medicine*, 2:335-344, 1950 (RDB5147)

66 R. D. Stewart et al. (Medical College of Wisconsin), **Acute and Repetitive Human Exposure to Fluorotrichloromethane**, report PB-279203/LLC, National Technical Information Service (NTIS), Springfield, VA, 1 December 1975 (RDB6598 from summary)

67 R. D. Stewart, P. E. Newton, E. D. Baretta, A. A. Herrmann, H. V. Forster, and R. J. Soto (Medical College of Wisconsin), **Physiological Response to Aerosol Propellants**, *Environmental Health Perspectives*, 26:275-285, October 1978 (RDB6115)

68 **Genetron® 12**, MSDS GTRN-0018, Honeywell Incorporated, Morristown, NJ, January 2000

69 V. A. Shugaev, **The Toxicology of Freon-12**, *Gigiena i Sanitariya*, Russia (then USSR), 28(6):95-97, 1963 (in Russian, RDB7434 from summary)

70 C. F. Reinhardt, **Cardiac Sensitization**, report 52-69, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 20 March 1969 (RDB6121)

71 C. J. Hardy, P. C. Kieran, and I. J. Sharman (Huntingdon Research Centre Limited, HRC, UK), **Assessment of Cardiac Sensitization Potential (CSP) of a Range of Halogenated Materials**, poster presentation (Spring Meeting, Baltimore, MD, USA), Society of Toxicology (SOT), 1994 (RDB6684)

72 J. Scholz (Farbwerke Hoechst AG, Germany), **New Toxicological Investigations of Certain Types of Freons Used as Propellants for Aerosols and Sprays**, *Fortschritte der biologischen Aerosol-Forschung* [Progress in Biological Research of Aerosols], 4:420-429, 1962 (in German, RDB5355)

73 R. D. Stewart, A. A. Herrmann, E. D. Baretta, H. V. Forster, J. H. Crespo, P. E. Newton, and R. J. Soto (Medical College of Wisconsin), **Acute and Repetitive Human Exposure to Difluorodichloromethane**, report PB-279204/LLC, National Technical Information Service (NTIS), Springfield, VA, April 1976 (RDB6486 from summary)

74 R. W. Reinhold and G. M. Rusch, **Review of the Toxicity of Ten Selected Fluorocarbons**, Department of Toxicology Report MA-127-80-2, AlliedSignal Incorporated, Morristown, NJ, 22 January 1986 (RDB5143)

75 A. Azar, C. F. Reinhardt, M. E. Maxfield, P. E. Smith, Jr., and L. S. Mullin (E. I. duPont de Nemours and Company, Incorporated), **Experimental Human Exposure to Fluorocardon** [sic, Fluorocarbon] **12 (Dichlorodifluoromethane)**, *AIHA Journal*, 33(4):207-216, April 1972 (RDB5358)

76 M. A. Lee and R. C. Graham, untitled toxicity review for Freon® 12 (methane, dichlorodifluoro-), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 19 February 1992 (RDB7525)

77 D. J. Tinston, unpublished data, Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, UK, 1976 (RDB6127 from summary)

78 M. H. Litchfield and E. Longstaff (Imperial Chemical Industries, ICI, plc, UK), **The Toxicological Evaluation of Chlorofluorocarbon 22 (CFC 22)** [sic, HCFC-22], *Fundamentals of Chemical Toxicology*, 22(6):465-475, 1984 (RDB5923)

79 **Chlorodifluoromethane (CAS No. 75-45-6)**, Joint Assessment of Commodity Chemicals (JACC) report 9, European Chemical Industry Ecology and Toxicology Centre (ECETOC), Brussels, Belgium, 19 October 1989 (RDB3718)

80 S. D. Nash, **Inhalation Approximate Lethal Concentration (ALC) of Trifluoromethane**, report 641-80, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 30 September 1980 (RDB6513)

81 S. R. Skaggs and T. A. Moore (New Mexico Engineering Research Institute, NMERI), **Toxicological Properties of Halon Replacements**, *Halon Replacements, Technology and Science* (208th National Meeting, Washington, DC, 21-25 August 1994), ACS Symposium Series 611, American Chemical Society (ACS), Washington, DC, chapter 10, 99-109, 1994 (RDB5526)

82 R. M. Hopkins and J. C. Krantz (Huntingdon Research Center, HRC, USA), Jr., **Anesthesia LXXV. Relative Effects of Haloforms and Epinephrine on Cardiac Automaticity**, *Anesthesia and Analgesia*, 47(1):56-67, January-February 1968 (RDB5136)

83 **Genetron® 23**, MSDS GTRN-0030 V2.94, AlliedSignal Incorporated, Morristown, NJ, January 1997

84 **Freon® 23 Refrigerant**, MSDS DU001064 (2025FR), DuPont Chemicals, Wilmington, DE, 8 January 1998

85 A. Van Poznak and J. F. Artusio, Jr. (New York Hospital and Cornell University Medical College), **Anesthetic Properties of a Series of Fluorinated Compounds I. Fluorinated Hydrocarbons**, *Toxicology and Applied Pharmacology* (TAP), 2(4):363-373, July 1960 (RDB5828)

86 F. Leuschner, B. W. Neumann, and F. Hübscher, **Report on Subacute Toxicological Studies with Several Fluorocarbons in Rats and Dogs by Inhalation**, *Fortschritte der Arzneimittelforschung* [Progress in Drug Research], 33/II(10):1475-1476, 1983 (RDB5607 from summary)

87 D. M. Krentz, M. A. Lee, and R. C. Graham, untitled toxicity review for trifluoromethane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 3 August 1992 (RDB5604)

88 S. R. Skaggs (Pacific Scientific), private communication to identify sources of tabulated data, September 1996

89 S. M. Munley, **An Inhalation Developmental Toxicity Study in Rats**, report 995-96, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 27 February 1997 (RDB7631)

90 S. C. Fagan, A. A. Rahill, G. Balakrishnan, J. R. Ewing, C. A. Branch, and G. G. Brown (Henry Ford Hospital), **Neurobehavioral and Physiological Effects of Trifluoromethane in Humans**, *Journal of Toxicology and Environmental Health*, 44:101-109, 1995 (RDB5737)

91 R. J. Parr-Dobrzanski, **HFC 32: 4-Hour Acute Inhalation Toxicity Study in the Rat**, report CTL/P/3456 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Central Toxicology Laboratory, ICI Chemicals and Polymers Limited, Cheshire, UK, 5 June 1992 (RDB5740)

92 B. L. Moore, **Acute Inhalation Toxicity (FC-32)**, report 698-75, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 18 November 1975 (RDB6171)

93 D. M. Krentz, M. A. Lee, and R. C. Graham, untitled toxicity review for difluoromethane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 15 July 1992 (RDB5862)

94 **Programme for Alternative Fluorocarbon Toxicity Testing (PAFT) Toxicology Summaries**, PAFT, Bristol, United Kingdom, April 1994 (RDB4A66)

95 L. S. Mullin and H. J. Trochimowicz, **Cardiac Sensitization Potential of Difluoromethane**, report 257-73, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 8 June 1973 (RDB6170)

96 R. J. Parr-Dobrzanski, **HFC-32: 28-Day Subacute Inhalation Toxicity Study in the Rat**, report CTL/P/3746, ICI Central Toxicology Laboratory, ICI Chemicals and Polymers Limited, Cheshire, UK, 24 August 1992 (RDB5741)

97 J. W. Sarver, **1,1,2-Trifluoro-1,2,2-trichloroethane: Four-Hour Inhalation Toxicity**, report 104-71, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 7 April 1971 (RDB6804)

98 J. W. Clayton, Jr. (E. I. duPont de Nemours and Company, Incorporated), **The Toxicity of Fluorocarbons with Special Reference to Chemical Constitution**, *Journal of Occupational Medicine*, 4(5):262-273, May 1962 (RDB5169)

99 J. W. Clayton, Jr. (E. I. duPont de Nemours and Company, Incorporated), **Fluorocarbon Toxicity: Past, Present, and Future**, *Journal of the Society of Cosmetic Chemists*, 18:333-350, 27 May 1967 (RDB5C41)

100 **Cardiac Arrhythmias Induced by Epinephrine During Inhalation of Certain Halogenated Hydrocarbons: Cardiac Sensitization**, report 14-69, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1969 (RDB6A04 from summary)

101 C. F. Reinhardt, L. S. Mullin, and M. E. Maxfield (E. I. duPont de Nemours and Company, Incorporated), **Epinephrine-Induced Cardiac Arrhythmia Potential of Some Common Industrial Solvents**, *Journal of Occupational Medicine*, 15(12):953-955, December 1973 (RDB65A0)

102 J. Raventós and P. G. Lemon (Imperial Chemical Industries Limited, UK), **The Impurities of Fluoroethane: Their Biological Properties**, *British Journal of Anaesthesia*, UK, 37(10):716-737, 1965 (RDB6165)

103 J. H. Burn (University of Oxford, UK), **Pharmacological Testing of Anaesthetics**, *Proceedings of the Royal Society of Medicine* (meeting of the Section of Anesthetics, 7 November 1958), UK, 52(2):95-98, February 1959 (RDB6587)

104 J. H. Burn, H. G. Epstein, and P. J. Goodford (University of Oxford, UK), **The Properties of the Anaesthetic Substance 1:1:2-Trifluoro-1:2-dichloroethane**, *British Journal of Anaesthesia*, 31:518-529, 1959 (RDB6586)

105 G. Paulet, **Les Fluorocarbones en Question** [Fluorocarbons at Issue], *European Journal of Toxicology and Environmental Hygiene*, 9(supplement to 7):385-407, 1976 (in French, RDB5179 from summary)

106 R. S. Waritz (E. I. duPont de Nemours and Company, Incorporated), **The Toxicology of Some Commercial Fluorocarbons**, paper 7, *Proceedings of the 2nd Annual Conference on Environmental Toxicology* (31 August - 2 September 1971), report AMRL-TR-71-120, Aerospace Medical Research Laboratory, U.S. Air Force, Wright-Patterson Air Force Base, OH, 85-99, December 1971 (RDB65H1)

107 **Freon® 114**, MSDS DU001061 (3038FR), DuPont Chemicals, Wilmington, DE, 8 January 1998

108 **Genetron® 114**, MSDS GTRN-0028, Honeywell Incorporated, Morristown, NJ, January 2000

109 R. R. Montgomery, M. A. Lee, R. C. Graham, and P. J. Lardear, untitled toxicity review for 1,2-Dichloro-1,1,2,2-tetrafluoroethane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 11 June 1992 (RDB5855)

110 International Programme on Chemical Safety (IPCS), **Fully Halogenated Chlorofluorocarbons**, Environmental Health Criteria (EHC) report 113, World Health Organization (WHO), Geneva, Switzerland, 1990 (RDB5367)

111 S. D. Morrison, **Freon-115 Chloropentafluoroethane (99.91%) and Freon-116 Hexafluoroethane (99.39%): Acute Inhalation Toxicity Studies**, report 41-62, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 19 June 1962 (RDB7616)

112 J. W. Hiddemen (Hazleton Washington, Incorporated, Vienna, VA), **Acute and Ten-Day Inhalation Pyrolysis, and Cardiac Sensitization Studies with Freons 14, 116, 218 and 1301**, report on project 264-107 for Atlantic Research Corporation, included in report for contract DAHC 19-71-C-0026, U.S. Army Research Office, Arlington, VA, 28 February 1972 (RDB7550)

113 E. T. McHale (Atlantic Research Corporation), **Habitable Atmospheres Which Do Not Support Combustion**, in report for contract DAHC 19-71-C-0026, U.S. Army Research Office, Arlington, VA, 15 March 1972 (RDB5C79)

114 L. S. Mullin and H. J. Trochimowicz, **A. Cardiac Sensitization Studies of Hexafluoroethane (F-116), Sulfur Hexafluoride (SF_6), and Chloropentafluoroethane (F-115); B. Literature Review: Toxicity and Areas of Use (F-116 and SF_6)**, report 150-72, Haskell

Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 20 April 1972 (RDB-6120)

115 J. H. Wills, P. Bradley, H. Kao, H. Grace, W. Hull, T. B. Griffin, F. Coulston, and E. S. Harris (Albany Medical College and NASA Manned-Spacecraft Center), **Sensitization of the Heart to Catecholamine-Induced Arrhythmia by Haloalkanes**, abstract 82 (11th Annual Meeting of the Society of Toxicology, SOT), *Toxicology and Applied Pharmacology* (TAP), 22:305-306, 1972 (RDB6118)

116 M. Hughes, unpublished data, Atlantic Research Corporation, 1973 (RDB6119 from summary)

117 M. A. Lee and R. C. Graham, untitled toxicity review for hexafluoroethane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 26 July 1991 (RDB5605)

118 W. J. Brock, private communication by letter, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 21 May 1996

119 R. S. Waritz and J. W. Clayton, **Acute Inhalation Toxicity on 1,1-Dichloro-2,2,2-trifluoroethane (FC-123, Commercial Grade)**, report 16-66, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 4 February 1966 with correction dated 12 May 1966 (RDB6150)

120 J. W. Clayton, Jr. (E. I. duPont de Nemours and Company, Incorporated), **Fluorocarbon Toxicity and Biological Action**, *Fluorine Chemistry Reviews*, 1:197-252, 1967 (RDB5C42)

121 G. T. Hall and B. L. Moore, **1,1-Dichloro-2,2,2-trifluoroethane: Acute Inhalation Toxicity**, report 426-75, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 16 July 1975 (RDB6139)

122 W. B. Coate (Hazleton Laboratories America, Incorporated), **LC_{50} of G123 in Rats**, report M165-162 (FYI report OTS-06890695), Allied Chemical Company, Morristown, NJ, 4 October 1976 (RDB6137 from summary)

123 **1,1-Dichloro-2,2,2-trifluoromethane (HCFC-123, CAS No. 306-83-2)**, Joint Assessment of Commodity Chemicals (JACC) report 33, European Chemical Industry Ecotoxicology and Toxicology Centre (ECETOC), Brussels, Belgium, February 1996 (RDB65E8)

124 International Programme on Chemical Safety (IPCS), **Partially Halogenated Chlorofluorocarbons (Ethane Derivatives)**, Environmental Health Criteria (EHC) report 139, World Health Organization (WHO), Geneva, Switzerland, 1992 (RDB5371)

125 H. J. Trochimowicz (E. I. duPont de Nemours and Company, Incorporated), **Industrial Research on Alternative Fluorocarbons**, *Toxicology Letters*, 68(1-2):25-30, 1993 (RDB-5170)

126 B. H. Robbins (Vanderbilt University School of Medicine), **Preliminary Studies of the Anesthetic Activity of Fluorinated Hydrocarbons**, *Journal of Pharmacology and Experimental Therapeutics*, **86**:197-204, 1946 (RDB5980)

127 L. S. Mullin, **Fluorocarbon 123 (2,2-Dichloro-1,1,1-trifluoroethane): Behavioral Toxicity Testing**, report 941-76, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 10 December 1976 (RDB-6153)

128 H. Wada, **Anesthetic Activity and Fatality (F-123, 123a, 124, and 11)**, attachment to 19 May 1977 correspondence to M. B. Berenbaum (Allied Chemical Corporation), Daikin Kogyu Company Chemical Division, Settsu-shi, Osaka, Japan, 16 May 1977 (RDBA309)

129 L. S. Mullin, **Methods in Behavioral Toxicology, Part I: Testing of Five Industrial Chemicals**, report 776-76, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 19 October 1976 (RDBA945)

130 T. H. S. Burns (St. Thomas's Hospital and the Royal Northern Hospital, UK), J. M. Hall (Guy's Hospital, UK), A. Bracken, and G. Gouldstone (British Oxygen Company, UK), **Fluorine Compounds in Anaesthesia (5): Examination of Six Heavily Halogenated Aliphatic Compounds**, *Anaesthesia*, 17(3):337-343, July 1962 (RDB5939)

131 H. J. Trochimowicz (E. I. duPont de Nemours and Company, Incorporated), **The Toxicology of HCFC-123 (2,2-Dichloro-1,1,1-Trifluoroethane)**, *Proceedings of the European Meeting of the Toxicology Forum* (Toulouse, France, 18-22 September 1989), Société Française de Toxicologie, France, 182-190, 1989 (RDB6145)

132 S. Magda (Solvay Pharmaceuticals, Germany), **Fluorocarbons**, *Toxicology* (edited by H. Marquardt), Academic Press, San Diego, CA, 659-662, 1999 (RDBA526)

133 P. Hoet (Catholic University of Louvain, CUL, Belgium), M. L. Graf, M. Bourdi, L. R. Pohl (National Heart, Lung, and Blood Institute, UK), P. H. Duray (National Cancer Institute, UK), W. Chen, R. M. Peter, S. D. Nelson (University of Washington, USA), N. Verlinden (Beerse, Belgium), D. Lison (CUL), **Epidemic of Liver Disease Caused by Hydrochlorofluorocarbons Used as Ozone-Sparing Substitutes of Chlorofluorocarbons**, *Lancet*, 350(9077):556-559, 23 August 1997 (RDB7C70)

134 W. Johnson, **Unsafe Application of HCFC-123, -124 Blamed for Liver Damage in 9 Workers**, *The Air Conditioning, Heating, and Refrigeration News*, 1-2 and 19, 1 September 1997 (RDB7C74)

135 P. S. Zurer, **Liver Damage Tied to CFC Substitute**, *Chemical and Engineering News*, 25 August 1997 (RDB7C72)

136 T. Takebayashi (Keio University School of Medicine, Japan), I. Kabe, Y. Endo, S. Tanaka (Kitasato University, Japan), H. Miyauchi, K. Nozi, S. Imamiya, K. Takahashi, and K. Omae, **Exposure to 2,2-Dichloro-1,1,1-trifluoroethane (HCFC-123) and Acute Liver Dysfunction: A Causal Inference**, *Journal of Occupational Health*, Japanese Society of Occupational Health, Tokyo, Japan, 40(4):334-338, October 1998 (RDBA927)

137 Gleason and W. B. Coate (Hazleton Laboratories America, Incorporated), **LC_{50} of G124 in Rats**, report MA-RR-89-1450 (also identified as project 165-163), Allied Chemical Company, Morristown, NJ, 4 October 1976 (RDB5806)

138 C. E. Finegan and G. M. Rusch (AlliedSignal Incorporated), **Update: Program for Alternative Fluorocarbon Toxicity Testing**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, 895-904, October 1993 (RDB3A53)

139 **Genetron® 124**, MSDS GTRN-0012, Honeywell Incorporated, Morristown, NJ, January 2000

140 D. P. Kelly, **Four-Hour Inhalation Approximate Lethal Concentration (ALC) of HCFC-124 in Rats**, report 71-90, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 19 June 1990 (RDB6180)

141 **Suva® 124**, MSDS DU002790 (2200FR), DuPont Chemicals, Wilmington, DE, 8 January 1998

142 **1-Chloro-1,2,2,2-tetrafluoroethane (HCFC 124, CAS No. 2837-89-0)**, Joint Assessment of Commodity Chemicals (JACC) report 25, European Chemical Industry Ecotoxicology and Toxicology Centre (ECETOC), Brussels, Belgium, July 1994 (RDB4C02)

143 T. J. Kenny and C. J. Hardy (Huntingdon Research Centre Limited, HRC, UK), **FRIGC™ FR-12™: Assessment of Cardiac Sensitization Potential in Dogs**, report HZL 6/942384, Hazleton Washington, Incorporated, Vienna, VA, 31 May 1994 (RDB7407)

144 **Hydrofluorocarbons and Hydrochlorofluorocarbons**, external review draft of interim report, U.S. Environmental Protection Agency, Washington, DC, 15 November 1990

145 E. Nakayama, K. Nagano, M. Chrishi, S. Katagiri, and O. Motegi (Japan Bioassay Laboratory, JBL, Japan), **Acute Inhalation Toxicity Study of 1,1,1,2,2-Pentafluoroethane (HFC-125) in Rats**, report on study 0184 (also identified as MA-RR-92-1801) for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Japan Industrial Safety and Health Association, Kanagawa, Japan, 18 March 1992 (RDB5754)

146 A. S. Panepinto, **Four-Hour Inhalation Approximate Lethal Concentration (ALC) of HFC-125 in Rats**, report 582-90, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 4 December 1990 (RDB6457)

147 C. J. Hardy, P. C. Kieran, I. J. Sharman, and G. C. Clark (Huntingdon Research Centre Limited, HRC, UK), **Assessment of Cardiac Sensitization Potential in Dogs: Comparison of HFC 125 and Halon 13B1**, report MA-RR-92-1845 (also identified as ALS 11/920116) for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Allied-Signal Incorporated, Morristown, NJ, 10 June 1992 (RDB5755)

148 E. Nakayama, K. Nagano, M. Ohnishi, and O. Motegi (Japan Bioassay Laboratory, JBL, Japan), **Thirteen-Week Inhalation Toxicity Study of 1,1,1,2,2-Pentafluoroethane (HFC-125) in Rats**, report 0197 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Japan Industrial Safety and Health Association, Kanagawa, Japan, 31 August 1993 (RDB5761)

149 D. B. Warheit, **Four-Hour Inhalation Approximate Lethal Concentration (ALC) of HFC-134 in Rats**, report 452-91, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 22 July 1991 revised 7 August 1991 (RDB6188)

150 **HFC-124**, MSDS DU008051 (6043FR), DuPont Chemicals, Wilmington, DE, 18 June 1995

151 Huntingdon Research Centre Limited (HRC), **HFC 134: Assessment of Cardiac Sensitization Potential in Dogs**, report DPT 300/932252, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 21 February 1994 (RDB6802)

152 **Suva® 134a**, MSDS DU000693 (2187FR), DuPont Chemicals, Wilmington, DE, 8 January 1998

153 **Fluorocarbon Gas HFC-134a**, MSDS E(J)G-3200 00116, Daikin Industries Limited Chemical Division, Osaka, Japan, 6 July 1998

154 L. S. Silber, **Acute Inhalation Toxicity Study of Tetrafluoroethane**, report 422-79, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 3 August 1979 (RDB6529)

155 **Meforex® 134a**, Safety Data Sheet sym/ss101, Ausimont S.p.A., Bollate, Italy, 9 April 1996

156 **Forane® 134a**, MSDS 04134, Elf Atochem North America, Incorporated, Philadelphia, PA, 17 July 1999

157 **Genetron® 134a**, MSDS GTRN-0011, Honeywell Incorporated, Morristown, NJ, January 2000

158 **1,1,1,2-Tetrafluoroethane (HFC-134a, CAS No. 811-97-2)**, Joint Assessment of Commodity Chemicals (JACC) report 31, European Chemical Industry Ecology and Toxicology Centre (ECETOC), Brussels, Belgium, February 1995 (RDB6533)

159 M. A. Collins, **HFC 134a: Acute Toxicity in Rats to Tetrafluoroethane**, unpublished data, ICI Chemicals and Polymers Limited, Cheshire, UK, 1984

160 J. Ferguson-Smith, **Hygiene Standard Documentation — HFC 134a**, document HSP/93/02, ICI Chemicals and Polymers Limited, Cheshire, UK, 1993 (RDB5A79)

161 D. J. Tinston, letter to T. D. Browne on **Alternative Arctons**, ICI Chemicals and Polymers Limited, Cheshire, UK, December 1976

162 S. B. Rissolo, **1,1,1,2-Tetrafluoroethane (Freon® 134a): Acute Inhalation Toxicity**, report 190-67, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 2 November 1967 (RDB6525)

163 L. S. Mullin, **Ethane, 1,1,1,2-tetrafluoro-: Cardiac Sensitization**, report 42-79, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 26 January 1979 (RDB6527)

164 M. Shulman and M. S. Sadove (University of Illinois Research and Education Hospitals), **1,1,1,2-Tetrafluoroethane. An Inhalation Anesthetic Agent of Intermediate Potency**, *Anesthesia and Analgesia*, 46(5):629-635, September-October 1967 (RDB7274)

165 D. J. Alexander (Glaxo Research and Development Limited, UK), **Safety of Propellants**, *Journal of Aerosol Medicine*, 8(supplement 1):S29-S34, 1995 (RDB8111)

166 A. Vinegar (ManTech Environmental Technology, Incorporated), R. Cook (U.S. Air Force, USAF), J. D. McCafferty (USAF), M. C. Caracci (Geocenters Incorporated), and G. W. Jepson (ManTech), **Human Inhalation of Halon 1301, HFC-134a, and HFC-227ea for Collection of Pharmacokinetic Data**, Armstrong Laboratory, U.S. Air Force, Wright-Patterson Air Force Base, OH, 19 August 1997 (RDB7C80)

167 **PAFT Statement on Wright Patterson/Armstrong Laboratory Study Involving HFC-134a and HFC-227ea**, press release, Programme for Alternative Fluorocarbon Toxicity Testing (PAFT), Washington, DC, 24 September 1997 (RDB7C81)

168 T. A. Mahoney, **Test Subject Faints After Inhaling HFC-134a in Botched Air Force Exposure Experiments**, *The Air Conditioning, Heating, and Refrigeration News*, 202(8):1-2, 20 October 1997 (RDB7C82)

169 D. A. Keller et al., **HFOC-134E**, report for project MR-9563-1, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 25 March 1994 (RDB6207)

170 R. C. Graham and P. J. Lardear, untitled review of toxicity literature for bis(difluoromethyl) ether, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 15 April 1994 (RDB6206)

171 C. W. Simons, G. J. O'Neill, and J. A. Gribens, **New Aerosol Propellants for Personal Products**, U.S. patent 4,041,148, 9 August 1977 (RDBA944)

172 G. J. O'Neill (Hampshire Chemicals Corporation), **Development of a New Alternative: E-134**, unpublished presentation (*The Global Business Outlook for CFC Alternatives*, Boston, MA, 15-16 June 1993), Hampshire Chemicals Corporation, Nashua, NH, June 1993 (RDB-5550)

173 C. J. Hardy, G. C. Jackson, R. S. Rao, D. J. Lewis, and C. Gopinath (Huntingdon Research Centre Limited, HRC, UK), **HCFC 141b Acute Inhalation Toxicity Study in Rats 4-Hour Exposure**, report PWT 95/881676, Pennwalt Corporation, King of Prussia, PA, 17 July 1989 (RDB5995)

174 J. A. Seckar (Pennwalt Corporation), **The Toxicology of HCFC-141b (1,1-Dichloro-1-fluoroethane)**, *Journal of the American College of Toxicology*, **8**(6):1221, 1989 (RDB7278)

175 C. Doleba-Crowe, **Acute Inhalation Toxicity — 6 Hours (FC 141b)**, report 61-77, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 17 February 1977 (RDB6465)

176 M. A. Lee, D. M. Krentz, and R. C. Graham, untitled toxicity review for ethane, 1,1-dichloro-1-fluoro-, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 24 November 1993 (RDB5868)

177 P. J. M. Janssen (Duphar B.V., The Netherlands), **Acute Inhalation Toxicity Studies on FC 141b in Rats**, report S.8820 (also identified as 55645/61/88), Solvay et Cie S.A., Brussels, Belgium, October 1988 with June 1989 supplement (RDB6463)

178 L. S. Mullin, **Fluorocarbon 141b (Ethane, 1,1-dichloro-1-fluoro): Cardiac Sensitization**, report 957-77, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 23 November 1977 (RDB6467)

179 R. J. Kenny (Huntingdon Research Centre Limited, HRC, UK), **HCFC-1717: Assessment of Cardiac Sensitization Potential in Dogs**, report ALS 57/942811 (also identified as MA-RR-95-2156), AlliedSignal Incorporated, Morristown, NJ, USA, 22 December 1994 (RDB-7206)

180 W. J. Brock (E. I. duPont de Nemours and Company, USA), H. J. Trochimowicz (DuPont), R-J. Millischer (Elf Atochem S.A., France), C. H. Farr (Elf Atochem North America, USA), T. Kawano (Daikin Industries, Japan), and G. M. Rusch (AlliedSignal Incorporated, USA), **Acute and Subchronic Toxicity of 1,1-Dichloro-1-fluoroethane (HCFC-141b)**, *Food and Chemical Toxicology*, 33(6):483-490, June 1995 (RDB65A4)

181 R-J. Millischer (Elf Atochem S.A., France), C. H. de Rooij (Solvay S.A., Belgium), G. M. Rusch (AlliedSignal Incorporated), C. H. Farr (Elf Atochem North America, USA), R. Ben-Dyke (Ben-Dyke Associates Incorporated, USA), C. J. Hardy (Huntingdon Research Centre Limited, HRC, UK), D. J. Lewis (HRC), and G. Hudson-Walker (Pharmaco:LSR, UK), **Evaluation of the Genotoxicity and Chronic Inhalation Toxicity of 1,1-Dichloro-1-**

Fluoroethane (HCFC-141b), *Food and Chemical Toxicology*, 33(6):491-500, June 1995 (RDB65A8)

182 R. H. Davies, R. D. Bagnall, W. Bell, and W. G. M. Jones, **The Hydrogen Bond Proton Donor Properties of Volatile Halogenated Hydrocarbons and Ethers and their Mode of Action in Anesthesia**, *International Journal of Quantum Chemistry: Quantum Biology Symposium*, 3:171-185, 1976 (RDB6555)

183 **Chlorodifluoroethane (1-Chloro-1,1-difluoroethane; HFA-142b, CAS: 75-68-3)**, Joint Assessment of Commodity Chemicals (JACC) report 17, European Chemical Industry Ecology and Toxicology Centre (ECETOC), Brussels, Belgium, February 1991 (RDB3721)

184 C. P. Carpenter, H. F. Smyth, Jr., and U. C. Pozzani (Mellon Institute, University of Pittsburgh), **The Assay of Acute Vapor Toxicity and the Grading and Interpretation of Results on 96 Chemicals**, *Journal of Industrial Hygiene and Occupational Medicine*, 31(6):-343-346, 1949 (RDB5643)

185 F. J. Mecler and P. J. Knapinsky, **Acute Inhalation Toxicity Study in Rats. Isotron 142b**, report for project 20888, Litton Bionetics Incorporated (LBI), Kensington, MD, 1978 (RDB-59A8)

186 L. S. Mullin, **Cardiac Sensitization**, report 354-69, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1969 (RDB6274)

187 D. P. Kelly, **Four-Hour Acute Inhalation Toxicity Study with FC-143a in Rats**, report 283-90, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 6 August 1990 (RDB5C17)

188 S. Cracknell (Life Science Research Limited, LSR, UK), **Forane 143a: Acute Inhalation Toxicity in the Rat**, report 91/ATH007/1159 (also identified as 91/1159), Elf Atochem S.A., Paris - La Défense, France, 4 February 1992 (RDB7450)

189 T. K. Nikijenko and M. S. Tolgskaya (Institute for Hygiene at Work and Occupational Illnesses of the AMS, USSR), **On the Toxico-Pharmamorphological Changes in Animals Under the Effect of Freon®s 141, 142, and 143 and the Intermediates Used in Their Production**, *Gigiena Truda i Professional'nye Zabolevaniya* [Labor Hygiene and Occupational Diseases], Moscow, USSR, 9(10):37-44, 1965 (in Russian, RDB5852 from summary)

190 C. J. Hardy and I. J. Sharman (Huntingdon Research Centre Limited, HRC, UK), **HFC 143a: Assessment of Cardiac Sensitization Potential in Dogs**, report DPT 281/930477 Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 3 June 1993 (RDB5C26)

191 W. J. Brock, H. J. Trochimowicz (E. I. duPont de Nemours and Company, USA), C. H. Farr (Elf Atochem North America, USA), R-J. Millischer (Elf Atochem S.A., France), and G. M. Rusch (AlliedSignal Incorporated, USA), article 0092, **Acute, Subchronic, and Developmental Toxicity and Genotoxicity of 1,1,1-Trifluoroethane (HFC-143a)**, *Fundamental and Applied Toxicology*, 31(2):200-209, June 1996 (RDB6597)

192 B. L. Moore, **Difluoroethane: Acute Inhalation Toxicity**, report 699-75, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 18 November 1975 (RDB5C85)

193 G. Limperos, **Inhalation Toxicity Studies of Various Freon Compounds**, report 2-52, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 26 December 1951 (RDB7737)

194 D. A. Keller, D. C. Roe, and P. H. Lieder (E. I. duPont de Nemours and Company), **Fluoroacetate-Mediated Toxicity of Fluorinated Ethanes**, article 0058, *Fundamental and Applied Toxicology*, 30(2):213-219, April 1996 (RDBA648)

195 **Workplace Environmental Exposure Level Guide — 1,1-Difluoroethane**, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1994 (RDB4B90)

196 N. F. Izmerov, I. V. Sanotsky, and K. K. Siderov, **Toxicometric Parameters of Industrial Toxic Chemicals Under Single Exposure**, USSR State Committee for Science and Technology, Moscow, USSR, 1982 (in Russian, RDB5C91 from summary)

197 D. M. Aviado (University of Pennsylvania School of Medicine), **Toxicity of Propellants**, *Fortschritte der Arzneimittelforschung* [Progress in Drug Research], 18:365-397, 1974 (RDB6593)

198 D. M. Aviado (University of Pennsylvania School of Medicine), **Toxicity of Aerosol Propellants in the Respiratory and Circulatory Systems, X. Proposed Classification**, *Toxicology*, 3(3):321-332, 1975 (RDB5920)

199 J. C. Edwards, **Arcton 152a — Documentation for Hygiene Standard**, ICI Chemicals and Polymers Limited, Cheshire, UK, 17 June 1985 (RDB5A81)

200 M. A. Lee, P. W. Grube, and R. C. Graham, untitled toxicity review for 1,1-difluoroethane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 4 May 1990 (RDB5857)

201 **1,1-Difluoroethane (HFC 152a) Health Effects Information, CAS# 75-37-6**, Elf Atochem North America, Incorporated, Philadelphia, PA, undated circa 1995 (RDB5B59)

202 **Daiflon 152a**, MSDS E(J)G-3200 00117, Daikin Industries Limited Chemical Division, Osaka, Japan, 9 March 1998

203 **HFC-152a**, MSDS DU005704 (1058FR), DuPont Chemicals, Wilmington, DE, 29 June 1998

204 **Forane® 152a**, MSDS for product 04105, Elf Atochem North America, Incorporated, Philadelphia, PA, 8 May 2000

205 **Genetron® 152a**, Material Safety Data Sheet (MSDS) GTRN-0035, Honeywell Incorporated, Morristown, NJ, January 2000

206 D. M. Aviado, **Toxicity of Aerosol Propellants in the Respiratory and Circulatory Systems, X. Proposed Classification**, *Toxicology*, 3(3):321-332, 1975 (RDB5920)

207 D. M. Aviado (University of Pennsylvania School of Medicine), **Comparative Cardiotoxicity of Fluorocarbons**, *Cardiac Toxicology*, edited by T. Balazs, CRC Press, Incorporated, Boca Raton, FL, II:213-222, 1981 (RDB6477)

208 J. W. Hiddeman (Hazleton Washington, Incorporated, Vienna, VA), **Acute and Ten-Day Inhalation, Pyrolysis, and Cardiac Sensitization Studies with Freons 14, 116, 218, and 1301**, report on Hazleton project 264-107 (included in report for contract DAHC 19-71-C-0026), U.S. Army Research Office, Arlington, VA, 18 February 1972 (RDB7550)

209 Huntingdon Research Centre Limited (HRC, UK), report MIN 68/930457, 3M, St. Paul, MN, May 1993 (RDB65F8 from summary)

210 **Product Toxicity Summary Sheet: PF-5030 3M Brand Performance Fluid**, summary 25937, 3M, St. Paul, MN, 22 October 1993 (RDB5703)

211 Huntingdon Research Centre Limited (HRC, UK), report MIN 101/930623, 3M, St. Paul, MN, 23 June 1993 (RDB65F9)

212 Dr. Bury, **ARW-Begründung für HFA-227** [Documentation for Exposure Limit for HFA-227], Hoechst Aktiengesellschaft, Frankfurt am Main, Germany, 26 August 1992 (in German, RDB7116)

213 **EC Safety Data Sheet — Reclin 227**, SDS for substance 45257, Hoechst Aktiengesellschaft, Frankfurt am Main, Germany, 2 November 1995

214 WIL Research Laboratories, Incorporated, **Acute Inhalational Toxicity Screen in Albino Rats with FM-200™**, report on project WIL-12226, Great Lakes Chemical Corporation, West Lafayette, IN, 1991 (RDBA617 from summary)

215 **FM-200™ Toxicological Study Summaries**, Great Lakes Chemical Corporation, West Lafayette, IN, undated, circa 1995 (RDB65F2)

216 **Heptafluoropropane (HFC-227ea) — Priority Existing Chemical 4 Secondary Notification Assessment**, full public report, file EX/5 (NA/64), National Industrial Chemicals Notification and Assessment Scheme (NICNAS), Worksafe Australia, Sidney Australia, 30 July 1999 (RDBA612)

217 WIL Research Laboratories, Incorporated, **An Acute Inhalational Toxicity Screen of FM-200™ in Rats**, report on project WIL-12248, Great Lakes Chemical Corporation, West Lafayette, IN, 1992 (RDBA616 from summary)

218 S. R. Skaggs and T. A. Moore (New Mexico Engineering Research Institute, NMERI), **Toxicological Properties of Halon Replacements**, *Halon Replacements, Technology and Science* (208th National Meeting, Washington, DC, 21-25 August 1994), ACS Symposium Series 611, American Chemical Society (ACS), Washington, DC, chapter 10, 99-109, 1994 (RDB5526)

219 Halon Alternatives Group (HAG), **A Review of the Toxic and Asphyxiating Hazards of Clean Agent Replacements for Halon 1301**, Loss Prevention Council, London, UK, February 1995 (RDBA668)

220 WIL Research Laboratories, Incorporated, **Acute Cardiac Sensitization Study in Dogs with FM-200™ by Inhalation**, report on project WIL-12265, Great Lakes Chemical Corporation, West Lafayette, IN, 1993 (RDBA615 from summary)

221 **Acute Inhalation Toxicity Study of HFC-236fa in Albino Rats**, report WIL-189022, WIL Research Laboratories, Incorporated, circa 1996 (RDB6A94 from summary)

222 D. A. Keller, **Acute Inhalation Toxicity of HFC-236fa and HFC-236ea in the Rat**, report 761-93, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 21 November 1994 (RDB6803)

223 R. J. Hilarski (International Research and Development Corporation, IR&D), **Nose Only Acute Inhalation Toxicity Evaluation on T-6195 in Rats**, report 137-178, 3M Company, St. Paul, MN, 27 September 1995 (RDB6692)

224 **Workplace Environmental Exposure Level Guide — 1,1,1,3,3,3-Hexafluoropropane**, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1998 (RDB8612)

225 C. J. Hardy, P. C. Kieran, and I. J. Sharman (Huntingdon Research Centre Limited, UK), **HFC 236fa: Assessment of Cardiac Sensitization Potential in Dogs**, report DPT 293/931308, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 3 February 1994 (RDB65A5)

226 R. Valentine, D. A. Keller, J. C. Cook, L. B. Biegel, G. S. Elliott, T. W. Slone, S. M. Munley, K. S. Bentley, W. J. Brock (E. I. duPont de Nemours and Company, Incorporated), and G. B. Briggs (Geo-Centers, Incorporated), **Toxicologic Profile of the Alternative Refrigerant HFC-236fa**, *Fundamental and Applied Toxicology*, 30(1/2):291, March 1996 (RDB6A96)

227 **90-Day Inhalation Toxicity: 90-Day Study with HFC-236fa in Rats**, report 211-95, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 12 February 1996 (RDBA306)

228 R. Valentine, **Two-Week Inhalation Toxicity Study with HFC-236fa in Rats**, report 596-94, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 20 June 1995 (RDB6A93)

229 R. D. Bagnall R. D. Bagnall, W. Bell, and K. Pearson (Imperial Chemical Industries Limited, UK), **New Inhalation Anaesthetics: IV — Fluorinated Propanes**, Journal of Fluorine Chemistry, 13(3):209-223, 1979 (RDB5C76)

230 P. W. Grube, untitled toxicity review for 1,1,2,2,3-pentafluoropropane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 24 July 1991 (RDB5859)

231 N. D. Smith (U.S. Environmental Protection Agency, EPA), K. Ratanaphruks, M. W. Tufts, and A. S. Ng (Acurex Environmental Corporation), **R-245ca: A Potential Far-Term Alternative for R-11**, *ASHRAE Journal*, 35(2):19-23, February 1993 (RDB3301)

232 N. D. Smith (U.S. Environmental Protection Agency, EPA), A. S. Ng, M. W. Tufts, A. M. Drago, and K. Ratanaphruks (Acurex Environmental Corporation), **Evaluation of HFC-245fa as a Potential Alternative for R-11 in Low-Pressure Chillers**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC, 24-26 October 1994), Alliance for Responsible Atmospheric Policy, Arlington, VA, 894-901, October 1994 (RDB5805)

233 Report 33-60, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, date 1960 (RDB5C77 from summary)

234 G. C. Jackson (Huntingdon Life Sciences Limited, HLS, UK), **HFC 245fa (493-95A): Acute Inhalation Toxicity in Rats 4-Hour Exposure**, report ALS 104/951746 (also identified as MA-RR-96-2270), AlliedSignal Incorporated, Morristown, NJ, USA, 22 February 1996 (RDB7111)

235 G. C. Jackson (Huntingdon Life Sciences Limited, HLS, UK), **HFC 245fa (513-96A): Acute Inhalation Toxicity in Rats (4-Hour Exposure)**, report ALS 125/961468 (also identified as MA-RR-97-2342), AlliedSignal Incorporated, Morristown, NJ, USA, 27 January 1997 (RDB-7115 from summary)

236 G. M. Rusch (AlliedSignal Incorporated, USA), D. W. Coombs, and C. J. Hardy (Huntingdon Life Sciences Limited, HLS, UK), **The Acute, Genetic, Developmental, and Inhala-**

tion Toxicity of 1,1,1,3,3-Pentafluoropropane, *Toxicological Sciences*, 52(2):289-301, December 1999 (RDB9707)

237 T. J. Kenny (Huntingdon Research Centre Limited, HRC, UK), **HFC 245fa: Assessment of Cardiac Sensitization Potential in Dogs**, report ALS 52/942695 (also identified as MA-RR-94-2151), AlliedSignal Incorporated, Morristown, NJ, USA, 29 November 1994 (RDB7112 from summary)

238 **HFC-245fa**, Material Safety Data Sheet (MSDS) GTRN-0040, Allied Signal Incorporated (with a sticker indicating a name change to Honeywell), Morristown, NJ, January 1999

239 C. J. Kirwin, **Toxicological Review of Propane, Butane, Isobutane, Pentane, and Isopentane**, Phillips Petroleum Company, Bartlesville, OK, November 1976 (RDBA623)

240 **Toxicity Study Summary: Propane (Hydrocarbon Propellant A-108)**, Phillips Petroleum Company, Bartlesville, OK, February 1990 (RDB7624)

241 J. C. Krantz, Jr., C. J. Carr, and J. F. Vitcha (University of Maryland), **Anesthesia XXXI. A Study of Cyclic and Noncyclic Hydrocarbons on Cardiac Automaticity**, *Journal of Pharmacology and Experimental Therapeutics*, 94:315-318, 1948 (RDB6192)

242 D. M. Aviado and M. A. Belej (University of Pennsylvania School of Medicine), **Toxicity of Aerosol Propellants on the Respiratory and Circulatory Systems, I. Cardiac Arrhythmia in the Mouse**, *Toxicology*, 2(1):31-42, 1974 (RDB5854)

243 P. A. Sanders, **Toxicity of Hydrocarbon Propellants**, *Aerosol Age*, 24(1):24-27,44 1979 (RDBA538)

244 W. E. Brown and V. E. Henderson (University of Toronto, Canada), **Experiments with Anesthetic Gases**, *Anesthesia and Analgesia*, 27(1):1-8, 1925 (RDB6108 from summary)

245 R. D. Stewart et al. (Medical College of Wisconsin), **Acute and Repetitive Human Exposure to Isobutane and Propane**, report IASS-CFTA-MCOW-ENVM-BP-77-1, Medical College of Wisconsin and Milwaukee, Milwaukee, WI, April 1977 (RDB6599 from summary)

246 **Freon® 500 Refrigerant**, material safety data sheet DU001075 (2012FR), DuPont Chemicals, Wilmington, DE, 8 January 1998

247 **Forane® 500**, material safety data sheet for product 04008 (revision 1), Elf Atochem North America, Incorporated, Philadelphia, PA, 17 July 1999

248 **Genetron® 500**, material safety data sheet GTRN-0034, Honeywell Incorporated, Morristown, NJ, January 2000

249 J. W. Clayton, Jr., **Freon-502 Refrigerant (Azeotrope of F-22, 48.8% and F-115, 51.2%): Acute Testing**, report 91-62, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 13 December 1962 (RDB-6272)

250 J. W. Clayton, Jr., **Freon-502 Refrigerant (Azeotrope of F-22, 48.8% and F-115, 51.2%): Acute Testing**, report 156-63, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 27 December 1963 (RDB6273)

251 **Genetron® 502**, material safety data sheet GTRN-0031, Honeywell Incorporated, Morristown, NJ, January 2000

252 J. F. Breen and J. E. Wallis, **Report on Refrigerant**, Underwriters Laboratories Incorporated (UL), Northbrook, IL (then Chicago, IL), 19 November 1963 (RDB7654)

253 M. A. Lee, untitled toxicity review for Freon® 502, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 22 May 1992 (RDB5866)

254 V. Valic, Z. Skuric, and E. Zuskin, **Experimental Exposures to Fluorochemicals 12, 22, and 502**, *Rad Jazu*, Yugoslavia, 402(18):229-243, 1982 (RDB8183 not reviewed)

255 **Toxicity Study Summary: Isobutane (A-31 Hydrocarbon Propellant)**, Phillips Petroleum Company, Bartlesville, OK, February 1990 (RDB7625)

256 R. W. Stoughton and P. D. Lamson (Vanderbilt University School of Medicine), **The Relative Anesthetic Activity of the Butanes and Pentanes**, *Journal of Pharmacology and Experimental Therapeutics*, 58:74-77, 1936 (RDB6197)

257 D. M. Aviado, S. Zakhari, and T. Watanabe (University of Pennsylvania School of Medicine), **Non-fluorinated Propellants and Solvents for Aerosols**, edited by L. Golberg, CRC Press, Cleveland, OH, 1977 (RDB6569 from summary)

258 P. A. Bingham, **Toxicity Data on Refrigerants**, private communication by letters, Rhône-Poulenc Chemicals, 7 and 8 May 1996

259 E. E. Sandmeyer, **Aliphatic Hydrocarbons**, *Patty's Industrial Hygiene and Toxicology* (third revised edition), edited by G. D. Clayton and F. E. Clayton, John Wiley and Sons, Incorporated, New York, NY, 2B:3175-3220, 1981 (RDB6290)

260 **Isobutane**, safety data sheet, Rhône-Poulenc Chemicals, Avonmouth, Bristol, UK, December 1993

261 C. F. Reinhardt, **Cardiac Sensitization**, report 52-69, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1969 (RDB6121)

262 R. D. Stewart, A. A. Herrmann, E. D. Baretta, H. V. Forster, J. J. Sikora, and R. J. Soto (Medical College of Wisconsin and S. C. Johnson & Son, Incorporated), **Acute and Repetitive Human Exposure to Isobutane**, *Scandinavian Journal of Work Environment and Health*, 1977(3):234-243, 1977 (RDB5364)

263 W. B. Deichmann and H. W. Gerarde, **Toxicology of Drugs and Chemicals**, Academic Press, New York, NY, 1969 (RDB5266)

264 **Occupational Safety and Health Guideline for Ammonia**; National Institute of Occupational Safety and Health (NIOSH), U.S. Department of Health and Human Services, Cincinnati, OH; Occupational Safety and Health Administration (OSHA), U.S. Department of Labor, Washington, DC; 1992 (RDB5C46)

265 **Ammonia Toxicity Monograph**, The Institution of Chemical Engineers, Warwickshire, UK, 1988 (RDB5151)

266 A. Kimmerle, **JFF/Combustion Technology**, 1:4-51, 1974 (RDB6250 from summary)

267 Y. Alarie (University of Pittsburgh), **Dose-Response Analysis in Animal Studies: Prediction of Human Responses**, *Environmental Health Perspectives* (EHP), 42:9-13, 1981 (RDB6279)

268 K. C. Back, A. A. Thomas, and J. D. MacEwen, **Reclassification of Materials Listed as Transportation Health Hazards**, report TSA-20-72-3, Aerospace Medical Research Laboratory (AMRL), U.S. Air Force, Wright-Patterson Air Force Base, OH, 1972 (RDB7298)

269 Clement Associates, Incorporated, **Health Effects Assessment for Ammonia**, The Fertilizer Institute, Washington, DC, February 1990 (RDB1106)

270 Syracuse Research Corporation, **Toxicological Profile for Ammonia**, report TP-90-03, Agency for Toxic Substances and Disease Registry (ATSDR), Public Health Service, U.S. Department of Health and Human Services, Washington, DC, December 1990 (RDB5156)

271 A. S. Propkop'eva, G. C. Yushkov, and I. O. Ubasheev, **Materials for a Toxicological Characteristic of the Long-Term Effect of Ammonia on the Organisms of Animals After Brief Exposure**, *Gigiena Truda i Professional'nye Zabolevaniya* [Labor Hygiene and Occupational Diseases], USSR, 6:56-57, 1973 (RDB6229 from summary)

272 F. R. Weedon, A. Hartzell, and C. Setterstrom, **Toxicity of Ammonia, Chlorine, Hydrogen Cyanide, Hydrogen Sulfide, and Sulfur Dioxide. V. Animals**, *Contrib. Boyce Thompson Institute*, 11:475-482, 1940 (RDB6256 from summary)

273 L. M. Appelman (TNO-CIVO Toxicology and Nutrition Institute, The Netherlands), W. F. ten Berge (DSM, The Netherlands), and P. G. J. Reuzel (TNO-CIVO), **Acute Inhalation Toxicology Study of Ammonia in Rats with Variable Exposure Periods**, *AIHA Journal*, 43(9):662-665, September 1982 (RDB5152)

274 **Tabulae Biologicae Per.**, 3:231-296, 1933 (in German, RDB6283 from summary)

275 **Ammonia (CAS 7664-41-7)**, chemical hazard summary 37, report C88-1E, Canadian Centre for Occupational Health and Safety (CCOHS), Hamilton, ON, Canada, 1988 (RDB6270)

276 W. S. Ferguson, W. C. Koch, L. B. Webster, and J. R. Gould, **Human Physiological Response and Adaptation to Ammonia**, *Journal of Occupational Medicine* (JOM), 19:319-326, 1977 (RDB6237 from summary)

277 K. J. Schadeberg, J. W. Goode, M. L. Keplinger, and J. C. Calandra (Industrial Bio-Test Laboratories, Incorporated), **Irritation Threshold Evaluation Study with Ammonia**, report IBT 663-03161, International Institute of Ammonia Refrigeration (IIAR), Washington, DC, 23 March 1973 (RDB6A12)

278 D. P. Wallace, **Atmospheric Emissions and Control**, *Ammonia Plant Safety*, 21:51-56, 1979 (RDBA672 from summary)

279 W. F. Stoecker (University of Illinois at Urbana-Champaign), **Growing Opportunities for Ammonia Refrigeration**, *Technical Papers of the 11th Annual Meeting* (12-15 March 1989, Austin, TX), International Institute of Ammonia Refrigeration (IIAR), Washington, DC, March 1989 (RDB4236)

280 M. M. Verberk, **Effect of Ammonia in Volunteers**, *International Archives of Occupational and Environmental Health*, Germany, 39:73-81, 1977 (RDB6A29 from summary)

281 **Emergency Response Planning Guidelines — Ammonia**, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1988 (RDB4B76)

282 J. Johnston, L. Legters, and R. Dailey (Enviro Control, Incorporated), **Biological Effects of Short, High-Level Exposure to Gases: Ammonia**, draft final report under contract DMD 17-79-C-9086, U.S. Army Medical Research and Development Command, Fort Detrick, MD, 1979 (RDB6262 from summary)

283 **Ammonia Data Book**, International Institute of Ammonia Refrigeration (IIAR), Washington, DC, 1993 (RDB3635)

284 C. S. Barrow, Y. Alarie, and M. F. Stock (University of Pittsburgh), **Sensory Irritation and Incapacitation Evoked by Thermal Decomposition Products of Polymers and Comparisons with Known Sensory Irritants**, *Archives of Environmental Health*, 33(2):79-88, March-April 1978 (RDB6231)

285 D. Zissu (Institut National de Recherche et de Sécurité, France), **Histopathological Changes in the Respiratory Tract of Mice Exposed to Ten Families of Airborne Chemicals**, *Journal of Applied Toxicology*, 15(3):207-213, 1995 (RDB6A33)

286 L. A. Buckley, X. Z. Jiang, R. A. James, K. T. Morgan, and C. S. Barrow (Chemical Industry Institute of Toxicology, CIIT), **Respiratory Tract Lesions Induced by Sensory Irritants at the RD_{50} Concentration**, *Toxicology and Applied Pharmacology*, 74(3):417-429, 1984 (RDB6227)

287 L. E. Kane, C. S. Barrow, and Y. Alarie (University of Pittsburgh), **A Short-Term Test to Predict Acceptable Levels of Exposure to Airborne Sensory Irritants**, *AIHA Journal*, 40:207-229, March 1979 (RDB6249)

288 L. Silverman, J. L. Whittenberger, and J. Muller (Harvard School of Public Health), **Physiological Response of Man to Ammonia in Low Concentrations**, *Journal of Industrial Hygiene and Toxicology*, 31(2):74-78, March 1949 (RDB6226)

289 Y. Henderson and H. W. Haggard, **Noxious Gases and the Principles of Respiration Influencing their Action** (second edition), Reinhold Publishing Corporation, New York, NY, 1943 (RDB72A0)

290 **Hygienic Guide Series — Anhydrous Ammonia**, American Industrial Hygiene Association (AIHA), *AIHA Journal*, 32:139-142, 1971 (RDB5775)

291 **2000 Threshold Limit Values for Chemical Substances in the Work Environment**, *2000 TLVs® and BEIs®: Threshold Limit Values for Chemical Substances and Physical Agents; Biological Exposure Indices*, publication 0100, American Conference of Governmental Industrial Hygienists (ACGIH), Cincinnati, OH, 2000 (RDBA936)

292 Commission for the Investigation of Health Hazards of Chemical Compounds in the Work Area, **List of MAK and BAT Values 1996: Maximum Concentrations and Biological Tolerance Values at the Workplace**, report 32, Deutsche Forschungsgemeinschaft [German Research Association] (DFG), Bonn, Germany; VCH Verlagsgesellschaft mbH, Weinheim, Germany, 1996 (RDB7101)

293 Occupational Safety and Health Administration (OSHA) of the U.S. Department of Labor, **Air Contaminants; Rule**, 58 FR 124, *Federal Register*, U.S. Government Printing Office, Washington, DC, 35338-35351, 30 June 1993 (RDB3904)

294 **The AIHA 1999 Emergency Response Planning Guidelines and Workplace Environmental Exposure Level Guides Handbook**, document 358-EA-99, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1999 (RDB9503)

295 *Carbon Dioxide, Gas*, material safety data sheet G-8, BOC Gases Division of the BOC Group, Incorporated, Murray Hill, NJ, 7 June 1996

296 E. B. Brown Jr. and F. Miller, **Ventricular Fibrillation Following a Rapid Fall in Alveolar Carbon Dioxide Concentration**, *American Journal of Physiology*, 169:56-60, 1952 (RDB-A936 from summary)

297 W. C. Petty and T. S. Sulkowski, **Narcosis in the Rat — II. Effects on the ECG**, *Aerospace Medicine*, 42:553-558, 1971 (RDBA937 from summary)

298 F. Caujolle (Centre de Recherches sur les Toxicités du Centre National de la Recherche Scientifique, CNRS, France), **Comparative Toxicity of Refrigerants / Toxicité Comparée des Fluides Frigorigènes**, topical study 13131, *Bulletin of the International Institute of Refrigeration* (IIR), 44(1):20-55, 1964 (RDB7424)

299 D. P. Mukherjee and S. P. Singh, **Effect of Increased Carbon Dioxide in Inspired Air on the Morphology of Spermatozoa and Fertility of Mice**, *Journal of Reproduction and Fertility*, 13:165-167, 1967 (RDBA938 from summary)

300 Committee on Aviation Toxicology, Aero Medical Association, **Aviation Toxicology**, The Blakiston Company, New York NY and Toronto ON, 1953 (RDB72A5)

301 W. J. Friedlander and T. Hill, **EEG Changes During Administration of Carbon Dioxide**, *Diseases of the Nervous System*, 15:71-75, 1954 (RDBA663 from summary)

302 C. J. Lambertsen, **Therapeutic Gases — Oxygen, Carbon Dioxide, and Helium**, *Drill's Pharmacology in Medicine* (fourth edition), McGraw-Hill Book Company, New York, NY, chapter 55, 1971 (RDBA664 from summary)

303 P. H. Sechzer, L. D. Egbert, H. W. Linde, D. Y. Cooper, R. D. Dripps, and H. L. Price, **Effect of CO_2 Inhalation on Arterial Pressure, ECG and Plasma Catecholamines and 17-OH Corticosteroids in Normal Man**, *Journal of Applied Physiology*, 13:454-458, 1960 (RDBA941 from summary)

304 R. D. Dripps and J. H. Comroe, Jr. (University of Pennsylvania and the Hospital of the University of Pennsylvania), **The Respiratory and Circulatory Response of Normal Man to Inhalation of 7.6 and 10.4 Per Cent CO_2 with a Comparison to the Maximal Ventilation Produced by Severe Muscular Exercise, Inhalation of CO_2, and Maximal Voluntary Hyperventilation**, *American Journal of Physiology*, 149:43-51, 1947 (RDBA658)

305 K. E. Schaefer, **The Effects of CO_2 and Electrolyte Shifts on the Central Nervous System**, *Selective Vulnerability of the Brain in Hypoxemia*, edited by J. P. Schade and W. H. McMehemy, Blackwell Scientific Publications, Oxford, UK, 101-123, 1963 (RDBA939 from summary)

306 E. W. Brown (Edgewood Arsenal Medical Corps), **The Physiological Effects of High Concentrations of Carbon Dioxide**, *U.S. Navy Medical Bulletin*, 28:721-734, 1930 (RDB-A655)

307 W. Storm and C. L. Giannetta, **Effects of Hypercapnia and Bedrest on Psychomotor Performance**, *Aerospace Medicine*, 45:431-433, 1974 (RDBA943 from summary)

308 E. B. Weybrew, **An Exploratory Study of the Psychological Effects of Intermittent Exposure to Elevated Carbon Dioxide Levels**, report 647, Submarine Medical Research Laboratory, Bureau of Medicine and Surgery, U.S. Navy, Groton, CT, 1970 (RDBA942)

309 B. G. King (Medical Service, Civil Aeronautics Administration), **High Concentration-Short Time Exposures and Toxicity**, *Journal of Industrial Hygiene and Occupational Medicine*, 31(6):365-375, November 1949 (RDBA660)

310 Council on Pharmacy and Chemistry of the American Medical Association (AMA), **Reports of the Council: Oxygen-Carbon Dioxide Mixtures**, Journal of the American Medical Association, 114(12):1077-1079, 23 March 1940 (RDBA657)

311 F. Flury and F. Zernik, **Schädliche gase, dämpfe, nebel, rauch- und staubarten** [Dangerous Gases, Fumes, Mists, Smokes, and Dusts], Springer-Verlag (then Verlag von Julius Springer), Berlin, Germany, 1931 (in German, RDB72A6 from summary)

312 K. E. Schaefer, **Studies of Carbon Dioxide Toxicity**, report 181, Submarine Medical Research Laboratory, Bureau of Medicine and Surgery, U.S. Department of the Navy, New London, CT, 10:156-189, 1951 (RDB72A8 from summary)

313 **Workplace Environmental Exposure Level Guide — 1,1,1-Trifluoroethane**, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1996 (RDB5C16)

314 **Number Designation of Refrigerants**, ANSI/ASHRAE Standard 34-78, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA (then in New York, NY), 1978

APPENDIX 1: GLOSSARY

acute toxicity	adverse health effects from a short-term, single exposure
ALC	approximate lethal concentration (see page 18)
ACGIH	American Conference of Governmental Industrial Hygienists
AIHA	American Industrial Hygiene Association
anesthetic effect	dulling of the senses, as manifested in loss of the ability to perceive pain and other sensory stimulation, impairment of judgement or mental ability to respond (see page 9)
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
ASHRAE 15	*Safety Code for Mechanical Refrigeration* (see reference 2)
ASHRAE 34	*Designation and Safety Classification of Refrigerants* (see reference 1)
ASHRAE 34 group	refrigerant safety classification (see page13)
ATEL	acute toxicity exposure limit (see page 18)
cardiac sensitization	an acute toxicity effect in which the heart is rendered more sensitive to catecholamine-like compounds, possibly resulting in irregular heart beat (cardiac arrhythmia) that could be fatal (see page 9)
chronic toxicity	adverse health effects from long-term or repeated exposures
collateral data	data found during searches performed for other, targeted refrigerants (see page 87)
CNS	central nervous system (see page 9)
EC_{50}	median effective concentration (see page 10)
EEGL	emergency exposure guidance level set by the NRC for special military purposes
EEL	emergency exposure limit
emergency exposure limit	guidance to limit exposures for unplanned and unintended releases (contrast to *occupational exposure limit*)

FCL	flammable concentration limit (see page 28)
Haber's law	toxic effect of the product of the exposure concentration and duration is constant (see page 18)
IDLH	immediately dangerous to life and health (see page 12)
IEL	industrial exposure limit (see page 13)
lethality	potential to cause death (see page 8)
LC_{50}	median lethal concentration (see page 10)
LC_{Lo}	lowest lethal concentration: the lowest dose of a chemical reported to fatal to animals or humans
LFL	lower-flammability limit
LOEL	lowest observed effect level (see page 10)
MAK	*Maximale Arbeitsplatz Konzentration* (maximum workplace concentration) set by the Deutsche Forschungsgemeinschaft (DFG, the German Research Association)
Mcf	thousand cubic feet
mortality	potential to cause death (see page 8)
MSDS	material safety data sheet
NIOSH	National Institute for Occupational Safety and Health (USA)
NOEL	no observed effect level (see page 10)
NRC	National Research Council
NTP	National Toxicology Program
occupational exposure limit	guidance to limit exposures for work related use of refrigerants (or other chemicals), which assume that potentially affected personnel should be cognizant of the potential for exposures, have special awareness or training, and may employ protective measures or devices (contrast to *emergency exposure limit*)
ODL	oxygen deprivation limit (see page 28)
OEL	occupational exposure limit (see page 13)
OSHA	Occupational Safety and Health Administration (USA)
PEL	permissible exposure limit (see page 13)

ppm	parts per million
ppm v/v	parts per million by volume
provisional ATEL or RCL	ATELs and RCLs determined from collateral data and warranting extra caution in use (see page 87)
RCL	refrigerant concentration limit (see pages 15 and 16)
RD_{50}	median rate decrease, typically refers to concentration resulting in a 50% respiratory rate decrease in mice (see page 11)
REL	recommended exposure limit set by NIOSH (see page REL)
SCP	Standards Completion Program (see page 13)
SDS	safety data sheet
STEL	short term exposure limit
subacute	between acute and chronic, typically in reference to a toxicity study of five days to two weeks by some definitions or anything longer than a single exposure or one day up to six months by others: Some toxicologists avoid the term and include such studies in "subchronic."
subchronic	between acute and chronic, typically in reference to a toxicity study of 15 days to 6 months by some definitions and several days to six months by others
TLV	threshold limit value set by ACGIH (see page 13)
TWA	time-weighted average
UL group	former Underwriters Laboratories refrigerant safety classification (see page 14)
v/v	volume to volume (by volume, see ppm v/v)
WEEL	workplace environmental exposure level guides set by AIHA

APPENDIX 2: REFRIGERANT PROFILES

This appendix presents data summaries from the *ARTI Refrigerant Database*[22] for the 35 refrigerants included in Table 1, namely those addressed on pages 35-85 plus R-14, R-115, R-170 (ethane), R-C318, R-600 (n-butane), and R-1270 (propylene).

ARTI REFRIGERANT DATABASE

The Refrigerant Database is an information system on alternative refrigerants, associated lubricants, and their use in air conditioning and refrigeration. It consolidates and facilitates access to property, compatibility, environmental, safety, application, and other information. It provides corresponding information on older refrigerants, to assist manufacturers and those using alternative refrigerants to make comparisons and determine differences. The underlying purpose is to accelerate phase out of chemical compounds of environmental concern.

The database identifies sources of specific information on R-22, R-23, R-32, R-41, R-116, R-123, R-124, R-125, R-134, R-134a, R-141b, R-142b, R-143a, R-152a, R-218, R-227ea, R-236fa, R-245ca, R-245fa, R-290 (propane), R-C318, R-717 (ammonia), R-718 (water), R-744 (carbon dioxide), R-1270 (propylene). ethers, and others as well as azeotropic and zeotropic blends of these fluids. These blends include R-400, R-401A, R-401B, R-401C, R-402A, R-402B, R-403A, R-403B, R-404A, R-405A, R-406A, R-407A, R-407B, R-407C, R-407D, R-408A, R-409A, R-409B, R-410A, R-410B, R-411A, R-411B, R-412A, R-413A, R-414A, R-414B, R-415A, R-416A, R-500, R-501, R-502, R-503, R-504, R-505, R-506, R-507A, R-508A, R-508B, R-509A, and others for which information is available even though standard designations may not have been assigned yet. It addresses lubricants including alkylbenzene, polyalkylene glycol, polyolester, and other synthetics as well as mineral oils. It also references documents addressing compatibility of refrigerants and lubricants with metals, plastics, elastomers, motor insulation, and other materials used in refrigerant circuits.

The database provides bibliographic citations and abstracts for publications that may be useful in research and design of air-conditioning and refrigeration equipment. The complete documents are not included, though some may be added at a later date. Incomplete citations or abstracts are provided for some documents. They are included to accelerate availability of the information and will be completed or replaced in future updates.

LIMITATIONS

The Refrigerant Database is intended as a means to assist users in locating sources of information on alternative refrigerants. But, the database is:

- neither a comprehensive nor authoritative reference source,
- not a substitute for independent data collection by users,
- not a substitute for examination of the data, information on how they were arrived at, assumptions, and caveats in the cited documents, and

- not an endorsement of suitability or accuracy of the referenced publications.

The information in the database was obtained from published and unpublished sources, or calculated from them, without verification. Some of the data may be imprecise or incorrect, as manifested — in some cases — by inclusion of conflicting data based on disagreement among identified sources. Similarly, errors may have occurred in assembling and processing the database. Users are cautioned to check the data and associated limitations and caveats in the referenced documents and other sources before use, particularly if such use might risk harm to life or property. Newer or more complete data may be available from refrigerant suppliers or elsewhere.

Materials compatibility, properties, safety considerations, and other characteristics affecting suitability or desirability may be influenced by a number of factors. Among them are specific application conditions, preparation such as drying before use, additives including fillers, impurities, catalytic interactions with other materials used, and changes in compounding between one source or batch and another. Similarly, new findings or corrections may supersede previously published data. The database is an aid in locating data that may be pertinent; it is not and should not be viewed as the source of data for research, design, analysis, or other purposes.

DATA SUMMARIES

The parameter descriptions that follow summarize the information included in data summaries for refrigerants, also referred to as *refrigerant profiles*. Each entry consists of the following parts:

- a label to identify and/or explain the data,
- a data value, typically rounded to common representation or limits of precision, generally expressed metric units or dimensionless form (metric units conform to the International System, SI, modified to use the Celsius scale for temperatures in place of the Kelvin scale),
- units of measure if applicable,
- converted data and units in the inch-pound (IP) system for data expressed in metric units,
- qualifying information on the data such as the animal species, exposure duration, and fraction of responses for toxicity test results, exposure periods, or manufacturer identity where the source is a safety data sheet, and
- four-digit alphanumeric Refrigerant Database ("RDB") number (discussed below).

The specific data included for each single-compound refrigerant or blend depend upon availability. Multiple values are cited for the same or related parameters in some cases, for example when conflicting data were published by multiple credible sources. The purpose of the database is to assist users in locating data rather than to endorse or verify specific data or to resolve inconsistencies and conflicts. Older data generally are deleted for simplification when the original source reports later results or when scientific consensus is reported, but that does not suggest endorsement of the newer data. The data values shown are included to assist users, but the primary information for each entry is the four alphanumeric digit "RDB" number in the rightmost column, which indicates the document or other source from which the data were taken.

Those sources may be located by searching for the number prefixed by "RDB" (for example *RDB9901*) in the database.

Identifiers

The refrigerant number shown in the heading is the standard designation based on those assigned by or recommended for addition to ASHRAE 34, *Designation and Safety Classification of Refrigerants*,[1] as well as pending addenda and common industry extensions thereto. These familiar designations are used almost universally, usually preceded by "R-", "R", the word "Refrigerant", composition-designating prefixes (for example "CFC-", "HCFC-", "HFC-", or "HC-"), or manufacturer trade names. Nonstandard and pending designations generally are flagged as such or identified in notes included with the common uses.

The chemical formula indicates the molecular makeup of the single-compound refrigerants, namely those consisting of a single chemical substance. The blend composition is substituted for refrigerant blends, namely those consisting of two or more chemicals that are mixed to obtain desired characteristics. The composition consists of two parts. The first identifies the components, in order of increasing normal boiling points and separated by slashes. The second part, which is enclosed in parentheses, indicates the mass fractions (as percentages) of those components in the same order. The profiles also indicate alternative chemical names, the common and historic names, index numbers for common reference databases, empirical and structural chemical formulae, and standard container colors. Among the identifiers shown are the:

- standard designation following ASHRAE 34 as well as addenda, pending addenda (flagged), and common industry extensions to it (flagged),
- variants using the "R-", "R", "R ", composition-designating prefixes (for example "CFC-", "HCFC-", or "HFC-"),
- common fluorochemical number and variants,
- halon number for chemicals also used or considered as fire suppressants,
- chemical name following the International Union of Pure and Applied Chemistry (IUPAC) convention,
- chemical name following other common conventions,
- common names,
- structural formula following the IUPAC convention,
- structural formula following other common conventions,
- empirical formula following the Hill convention,
- other formulae including some flagged as "not recommended" to enable location by them
- Chemical Abstracts Service (CAS) registry number,
- Beilstein registry number,
- European Inventory of Existing Chemical Substances (EINECS) number,
- Merck index (volume and number),

- National Institute of Occupational Safety and Health (NIOSH) Registry of Toxic Effects of Chemical Substances (RTECS) index number,
- trade name(s),
- historical name(s),
- names used for rule making notices for proprietary refrigerants in U.S. Environmental Protection Agency (EPA) Significant New Alternatives Program (SNAP) notices,
- standard container color name and Pantone number as assigned by Air-Conditioning and Refrigeration Institute (ARI) Guideline N (*Assignment of Refrigeration Container Colors*),
- composition for blends
- both mass and mole formulations for blends, and
- standard mass formulation tolerances for blends with ASHRAE safety classifications.

In some cases, primarily for proprietary blends, additional identifying information is included in the description of common uses.

Common Uses

The uses focus on application as refrigerants followed, if applicable, by terse indications of other applications if known. Limiting considerations such as toxicity, flammability, reactivity, or environmental concerns are cited for some substances.

This section also includes notes on pending changes in standard designations and safety classifications.

Physical Properties

The refrigerant profiles indicate key physical, thermodynamic, and transport properties at representative conditions, including the normal boiling point, 20 °C (68 °F), 60 °C (140 °F), and the critical point.

The molecular mass is a calculated value based on the atomic weights recognized by International Union of Pure and Applied Chemists (IUPAC). It indicates the mass in grams of a mole of the refrigerant or, for blends, the mass-weighted average of a mole of the mixture.

The normal boiling point (NBP) is the temperature at which liquid refrigerant will boil at standard atmospheric pressure, namely 101.325 kPa (14.6959 psia). The NBP and most dimensional units in the tables are shown in both metric (SI) and inch-pound units of measure. Both the bubble point (temperature at which a bubble first appears, hence the temperature at which boiling begins, for a blend) and dew point typically are shown for blends.

The critical temperature (T_c) is the temperature at the critical point of the refrigerant. The T_c values shown for blends are the mass weighted averages of the component T_cs unless actual values have been determined.

The critical pressure (P_c) is the pressure at the critical point.

The NBP and critical properties suggest the application range for which an individual refrigerant might be suitable. Those with extremely low NBP lend themselves to ultra-low temperature refrigeration, for example in cryogenic applications. Those with high NBPs generally are limited to high-temperature applications, such as for use in chillers or high-temperature heat pumps. Both capacity and efficiency decline in a typical vapor-compression (reverse Rankine) cycle, the one most commonly used, when condensing temperatures approach the T_c. The P_c will exceed the operating pressure, except in transcritical cycles, which are uncommon except for R-744 (carbon dioxide).

Environmental Data

The atmospheric lifetime (τ_{atm}) is an indication of the average persistence of the refrigerant, if released into the atmosphere, until it decomposes or reacts with other chemicals. The values shown are composite atmospheric lifetimes. Separate lifetimes also are shown if known for the tropospheric (lower atmosphere where we live), stratospheric (next layer where global depletion of ozone is a concern), and higher layers, since the atmospheric chemistry changes between layers.

The ozone depletion potential (ODP) is a normalized indicator, based on a value of 1.000 for R-11, of the ability of refrigerants (and other chemicals) to destroy stratospheric ozone molecules. The data shown are the modeled values adopted by the international scientific assessment. The ODPs shown for blends are mass-weighted averages. The values shown typically are *modeled ODP* values, the most indicative of environmental impacts. *Semi-empirical* ODP and *regulatory* values adopted in the Montreal Protocol also are indicated for some refrigerants.

The semi-empirical ODPs are calculated values that incorporate adjustments for observed atmospheric measurements. The concept is conceptually more accurate, but it is difficult to measure the data needed for representative adjustments accurately.

The regulatory values generally are required for specific purposes, but may not be updated with newer findings after adoption. The ODP values listed in the annexes to the Montreal Protocol, for example, have not been updated since 1987 for chlorofluorocarbons (CFCs) and 1992 for hydrochlorofluorocarbons (HCFCs). A note in the Protocol indicates that the values "are estimates based on existing knowledge and will be reviewed and revised periodically."

The global warming potential (GWP) is a similar indicator of the potency to warm the planet by action as a greenhouse gas. The values shown are relative to carbon dioxide (CO_2) for an integration period of 100 yr. Both the ODP and GWP are calculated from the τ_{atm}, measured chemical properties, and other atmospheric data. The GWPs shown for blends are mass-weighted averages.

The τ_{atm}, ODP, and GWP values indicated for blends were calculated for the nominal blend compositions.

The database also indicates halocarbon global warming potential (HGWP) and photochemical reactivity at ground level if known.

Safety Data

The safety section is subdivided into classifications, recommended exposure limits, acute (short-term, single exposure) and chronic (long-term, repeated exposure) toxicity data, flammability data, and detection (appearance and odor) information. The exposure limits are further separated into short-term occupational, long-term occupational, and emergency exposures. Depending on the refrigerant, more than 100 parameters — some with differing values for species or exposure durations in toxicity tests — are reported. The following brief summary addresses only the chronic toxicity and flammability indices used to determine standard refrigerant safety classifications.

The first value is an occupational exposure limit, namely the Threshold Limit Value - Time Weighted Average (TLV-TWA) or a consistent measure. It is an indication of chronic (long-term, repeat exposure) toxicity of the refrigerant. Some of the consistent toxicity indices are the workplace Environmental Exposure Level (WEEL) guides and the Permissible Exposure Limit (PEL). These measures indicate adopted limits for workplace exposures for trained personnel for typical workdays and work weeks.

The Lower Flammability Limit (LFL) is the lowest concentration at which the refrigerant will burn in air under prescribed test conditions. It is an indication of flammability. The absence of an LFL or even an indication of nonflammable does not assure that a substance will not burn or exacerbate an existing fire under some conditions, such as when mixed with other *fuels* (such as lubricants) or at elevated pressures and temperatures.

The Heat of Combustion (HOC) is an indicator of how much energy the refrigerant will release when it burns in air, assuming complete reaction to the most stable products in their vapor state. Negative values indicate endothermic reactions (those that require heat to proceed) while positive values indicate exothermic reactions (those that liberate heat).

The ASHRAE Standard 34 safety group is an assigned classification that is based on the TLV-TWA (or consistent measure), LFL, and HOC. It comprises a letter (A or B) that indicates relative toxicity followed by a number (1, 2, or 3) that indicates relative flammability. These classifications are widely used in mechanical and fire construction codes, to determine requirements to promote safe use. Most of these code provisions are based on ASHRAE 15, *Safety Code for Mechanical Refrigeration*.[2]

Production Data

The final section of the refrigerant profiles indicates initial commercialization if known and the last year production is allowed in developed countries under the Montreal Protocol.

R-11

---------- REFRIGERANT DATA SUMMARY ----------

			see
R-11	trichlorofluoromethane		
CFC	CCl3F	CAS number 75-69-4	RDB#

COMMON USE(S)
centrifugal chillers; heat-transfer fluid for low-temperature systems; formerly used as a solvent for system cleaning (e.g., after compressor motor burnout); aerosol propellant often with refrigerant 12; blowing agent for foamed plastics; industrial solvent

IDENTIFIERS

common name(s):	R-11; R11; R 11	
	CFC-11	
	chlorofluorocarbon 11	
	fluorocarbon 11	
	fluorochemical 11; FC 11	
	halocarbon 11	
	halochemical 11	
chemical name (by IUPAC convention):	trichlorofluoromethane	
alternative chemical names/formulae:	methane, trichlorofluoro-	
	fluorotrichloromethane	
	trichloromonofluoromethane	
	CCl3F	
	not recommended: CFCl3; Cl3FC	
CAS number:	75-69-4 (Chemical Abstracts Service registry number)	
Beilstein registry number:	1732469	
EINECS number:	200-892-3 (European Inventory of Existing Chemical Substances)	
Merck Index (volume-number):	12-9770	
NIOSH RTECS number:	PB6125000 (Registry of Toxic Effects of Chemical Substances)	
trade name(s):	Asahi Glass Fron AF-11	
	BOC Gases Halocarbon 11	MSDS
	Daikin Daiflon(R) 11	
	DuPont Freon(R) 11	MSDS
	Elf Atochem Forane(R) 11	MSDS
	Hoechst Frigen(R) 11	
	Honeywell Genetron(R) 11	MSDS
	ICI Arcton(R) 11	MSDS
	Pennwalt/Atochem Isotron(R) 11	
historical name(s):	Allied Corp refrigerant 43	
	AlliedSignal Genetron(R) 11	MSDS
	Carrier Corporation Carrene 2	
	DuPont "Zeron"	
	Hoechst Frigen(R) 9	7744
	Kinetic #11; also K11	
	Montecatini (I) Algofrene 11	7601
	SIC (Italy) Edifren 11	7601
ARI container color / Pantone number:	orange / 021	6601

PHYSICAL

• properties ----------		
molar mass:	137.3672032 g/mol (0.302843 lb/mol)	8820
normal freezing/melting/triple point:	-110.5 °C (-166.8 °F)	8401
• normal boiling point ----------		
temperature:	23.7 °C (74.7 °F)	8401

density, saturated liquid:	1479 kg/m3 (92.35 lb/cf)	8401
density, saturated vapor:	5.85 kg/m3 (0.365 lb/cf)	8401
specific volume, saturated liquid:	0.676 L/kg (0.0108 cf/lb)	8401
specific volume, saturated vapor:	170.9 L/kg (2.7369 cf/lb)	8401
heat of vaporization:	181.4 kJ/kg (78.0 Btu/lb)	8401
velocity of sound, saturated liquid:	736 m/s (2415 ft/s)	8401
velocity of sound, saturated vapor:	138 m/s (452 ft/s)	8401
viscosity, saturated vapor:	10.14 µPa•s (0.01014 cp)	8401
viscosity, saturated liquid:	410 µPa•s (0.410 cp)	8401
thermal conductivity, liquid:	0.0872 W/m•K (0.0504 Btu/hr•ft°F)	8401
thermal conductivity, vapor:	0.0084 W/m•K (0.0049 Btu/hr•ft°F)	8401
• normal pressure, 20 °C (68 °F) -----		
density, liquid:	1488 kg/m3 (12.42 lb/gal)	8401
• normal pressure, 21.1 °C (70 °F) ---		
density, liquid:	1486 kg/m3 (12.40 lb/gal)	8401
• 20 °C (68 °F) ----------		
pressure, saturated vapor:	88.7 kPa (12.86 psia)	8401
density, saturated liquid:	1488 kg/m3 (92.90 lb/cf)	8401
density, saturated vapor:	5.17 kg/m3 (0.323 lb/cf)	8401
specific volume, saturated liquid:	0.672 L/kg (0.0108 cf/lb)	8401
specific volume, saturated vapor:	193.4 L/kg (3.0983 cf/lb)	8401
velocity of sound, saturated liquid:	749 m/s (2456 ft/s)	8401
velocity of sound, saturated vapor:	137 m/s (450 ft/s)	8401
viscosity, saturated liquid:	425 µPa•s (0.425 cp)	8401
viscosity, saturated vapor:	10.0 µPa•s (0.0100 cp)	8401
thermal conductivity, saturatd liquid:	0.0882 W/m•K (0.0510 Btu/hr•ft°F)	8401
thermal conductivity, saturated vapor:	0.00824 W/m•K (0.00476 Btu/hr•ft°F)	8401
• 60 °C (140 °F) ----------		
pressure, saturated vapor:	313 kPa (45.4 psia)	8401
heat of vaporization:	166.9 kJ/kg (71.8 Btu/lb)	8401
• critical point ----------		
temperature:	198.0 °C (388.3 °F)	8401
pressure:	4408 kPa (639.3 psia)	8401
density:	554 kg/m3 (34.6 lb/cf)	8401
specific volume:	1.81 L/kg (0.0289 cf/lb)	8401

ENVIRONMENTAL

average atmospheric lifetime (τatm):	45 yr	9501
ODP (ozone depletion potential):	1.000 (model-derived relative to R 11)	9501
	1.000 (semi-empirical relative to R 11)	9501
	1.0 (estimate used for the Montreal Protocol)	6904
GWP (global warming potential):	4600 relative to CO2 for 100 yr integration	9501
HGWP (halocarbon GWP):	1.000 relative to R 11 for infinite integration period	

SAFETY

• classification ----------		
safety group (ASHRAE Standard 34):	A1	8601
NFPA 704 degrees of hazard (H-F-R-S):	ARI recommendation: 2-0-0	3A15
	BOC Gases: 1-0-0	MSDS
	Honeywell: 2-0-0	MSDS
	health-flammability-reactivity [-special]: 0=no, 4=severe	
NPCA HMIS hazard ratings (H-F-R):	BOC Gases: 1-0-0	MSDS
	DuPont: 1-0-1	MSDS
	Honeywell: 1-0-0	MSDS

	health-flammability-reactivity 0=insignificant, 4=extreme	
UL Comparative Hazard to Life Group:	5(a) in absence of flame or hot objects	4B64
ACGIH carcinogenicity category:	A4, not classifiable as a uman carcinogen	9504
DFG pregnancy risk group:	C (no risk fear below MAK/BAT)	5561
• short-term occupational limit ------		
NIOSH IDLH (immediately dangerous):	2,000 ppm v/v	5204
ARI "IDLH" recommendation:	5,000 ppm v/v for 30 min	3A15
NIOSH SCP IDLH (immediately dangerous:	10,000 ppm v/v for 30 min	3903
• occupational exposure limit --------		
NIOSH REL-C (exposure ceiling):	1,000 ppm v/v (must not exceed)	3903
ACGIH TLV-C (exposure ceiling):	1,000 ppm v/v (must not exceed)	9504
MAK (maximum workplace concentration):	IV: 2,000 ppm v/v momentary 60 min	5561
• long-term occupational limit -------		
OSHA PEL (permissible exposure limit):	1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	3904
exposure limit consistent to OSHA PEL:	ARI PEL-Ceiling: C1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	3A15
MAK (maximum workplace concentration):	1,000 ppm v/v TWA for 8 hr/day 40 (or 42) hr/wk	5561
• emergency exposure limit ----------		
NRC EEGL (emergency exposure level):	1 hr: 1,500 ppm v/v ceiling guidance level for single emergency exposures	7414
	24 hr: 500 ppm v/v ceiling guidance level for single emergency exposures	7414
Acute Toxicity Exposure Limit (ATEL):	1,100 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	1,100 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
Refrigerant Concentration Limit (RCL):	1,100 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	1,100 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
• special-purpose exposure control ---		
NRC CEGL (continuous exposure level):	90 day: 100 ppm v/v ceiling guidance for prolonged exposure in closed environments	7414
• acute (short-term) toxicity --------		
LC50 (lethal concentration, 50%):	rat, 10 min: 120,000 ppm (fatal concentration by inhalation for half of test animals)	A309
	rat, 15 min: 130,000 ppm (fatal concentration by inhalation for half of test animals)	6110
	rat, 4 hr: 26,200 ppm (fatal concentration by inhalation for half of test animals)	5C53
ALC (approximate lethal concentration:	rat, 30 min, 1/1: 100,000 ppm (lowest exposure tested with one or more deaths by inhalation)	5147
	rat, 4 hr, 0/4: >35,600 ppm (lowest exposure tested with	65H3

	one or more deaths by inhalation)	
	rat, 4 hr, 1/4: 66,000 ppm (lowest exposure tested with one or more deaths by inhalation)	65H3
	rat, 4 hr, 3/6: 24,900 ppm (lowest exposure tested with one or more deaths by inhalation)	5C53
oral LD50 (lethal dosage, 50%):	rat, Elf Atochem: >3,725 mg/kg (fatal dose by ingestion for half of test animals)	MSDS
	rat: 3,752 mg/kg (fatal dose by ingestion for half of test animals)	6595
cardiac sensitization (CS) EC50:	dog, 5 min: 12,400 ppm v/v (effective concentration in half of test animals)	6146
	dog, 5 min: 12,500 ppm v/v (effective concentration in half of test animals)	6110
cardiac sensitization threshold/LOEL:	dog 1/12: 3500-6100ppm, ÷4,800 ppm v/v (lowest observed effect level in test animals)	5644
	dog: 5,000 ppm v/v (lowest observed effect level in test animals)	4A66
cardiac sensitization (CS) NOEL:	dog, 5min: 900-1300 ppm, ÷1100 ppm v/v (no observed effect level in test animals)	5644
anesthetic/CNS effect EC50:	rat, 10 min, stimulant: 35,000 ppm v/v (effective concentration in half of test animals)	6110
	rat, 10 min: 54,000 ppm v/v (effective concentration in half of test animals)	A309
anesthetic/CNS effect LOEL:	rat, 2 hr, ?/4: 35,000 ppm v/v (lowest observed effect level in ALC or LC50 studies)	5365
anesthetic/CNS effect NOEL:	rat, 2 hr, 0/4: 12,500 ppm v/v (no observed effect level in ALC or LC50 studies)	5365
• flammability ----------		
LFL-UFL (flammability limits in air):	none (nonflammable as tested)	2525
heat of combustion (by ASHRAE 34-92):	0.9 MJ/kg (387 Btu/lb)	2318
flash point:	ICI: does not flash	MSDS
	none (nonflammable as tested)	3903
autoignition temperature:	>750 °C (>1382 °F)	5931
autodecomposition temperature:	DuPont: >593 °C (>1099 °F)	MSDS
former UL Classification:	nonflammable (withdrawn for revision of the classification system, category SBQT2)	6938
• detection ----------		
appearance:	colorless	7414
odor:	ICI: nearly odorless	MSDS
	faint ethereal	5367
odor sensing, lower threshold:	5 ppm v/v	5141
PRODUCTION		
first commercial use as a refrigerant:	1932 by T. Midgley, associates	5C39
last year production allowed:	1995 in developed countries under the Montreal Protocol	8C01

R-12

---------- REFRIGERANT DATA SUMMARY ----------

			see RDB#
R-12	dichlorodifluoromethane		
CFC	CCl2F2	CAS number 75-71-8	

COMMON USE(S)

refrigerators, freezers, drinking fountains, mobile air conditioners, centrifugal chillers, commercial and transport refrigeration, ice machines, heat pump water heaters; component of refrigerants 400, 500, 501, and 505; direct contact freezing of foods (food freezant); aerosol propellant often with refrigerants 11 or 114; formerly a pharmaceutical propellant including in metered-dose inhalers; foam blowing agent for plastics; formerly diluent for sterilant gas mixtures; formerly a dielectric gas

R-12 was initially synthesized in 1928 by T. Midgley, A. Henne, and R. McNary; it was the first fluorocarbon refrigerant to be commercialized, in 1931.

IDENTIFIERS

common name(s):	R-12; R12; R 12	
	CFC-12	
	chlorofluorocarbon 12	
	fluorocarbon 12	
	fluorochemical 12; FC 12	
	halocarbon 12	
	halochemical 12	
	halon 122	
chemical name (by IUPAC convention):	dichlorodifluoromethane	
alternative chemical names/formulae:	methane, dichlorodifluoro-	
	difluorodichloromethane	
	CCl2F2	
	not recommended: CF2Cl2	
CAS number:	75-71-8 (Chemical Abstracts Service registry number)	
EINECS number:	200-893-9 (European Inventory of Existing Chemical Substances)	
NIOSH RTECS number:	PA8200000 (Registry of Toxic Effects of Chemical Substances)	
trade name(s):	Asahi Glass Fron AF-12	
	Daikin Daiflon(R) 12	
	DuPont Freon(R) 12	MSDS
	Elf Atochem Forane(R) 12	MSDS
	Honeywell Genetron(R) 12	MSDS
	ICI Arcton(R) 12	MSDS
	Solvay Solkane(R) 12	
historical name(s):	Allied Corp refrigerant 142	
	AlliedSignal Genetron(R) 12	MSDS
	Elf Atochem Racon(R) 12	6938
	Eskimon (USSR)	7601
	Hoechst Frigen(R) 12	
	ICI Arcton(R) 6	
	Kinetic #12; also K12	
	Kinetic Chemicals "Freon"	
	Montecatini (I) Algofrene 12	7601
	Nitto (Japan) Col-Flon 12	7601
	Pennwalt/Atochem Isotron(R) 12	
	SIC (Italy) Edifren 12	7601
	Unichemie (NL) Fresane 12	7601

	Union Carbide Ucon(R) 12	7601
	VVB Dresden Frigedohn 12	7601
ARI container color / Pantone number:	white / none	6601
PHYSICAL		
• properties ----------		
molar mass:	120.9129064 g/mol (0.266567 lb/mol)	8820
normal freezing/melting/triple point:	-157.0 °C (-250.7 °F)	8401
• normal boiling point ----------		
temperature:	-29.8 °C (-21.6 °F)	8401
density, saturated liquid:	1487 kg/m3 (92.83 lb/cf)	8401
density, saturated vapor:	6.29 kg/m3 (0.393 lb/cf)	8401
specific volume, saturated liquid:	0.672 L/kg (0.0108 cf/lb)	8401
specific volume, saturated vapor:	159.0 L/kg (2.5469 cf/lb)	8401
heat of vaporization:	166.2 kJ/kg (71.4 Btu/lb)	8401
velocity of sound, saturated liquid:	732 m/s (2403 ft/s)	8401
velocity of sound, saturated vapor:	135 m/s (441 ft/s)	8401
viscosity, saturated liquid:	345 µPa•s (0.345 cp)	8401
viscosity, saturated vapor:	9.56 µPa•s (0.00956 cp)	8401
thermal conductivity, liquid:	0.0868 W/m•K (0.0501 Btu/hr•ft°F)	8401
thermal conductivity, vapor:	0.0073 W/m•K (0.0042 Btu/hr•ft°F)	8401
• normal pressure, 20 °C (68 °F) -----		
density, vapor:	5.130 kg/m3 (0.3203 lb/cf)	8401
• normal pressure, 21.1 °C (70 °F) ---		
density, vapor:	5.109 kg/m3 (0.3190 lb/cf)	8401
• 20 °C (68 °F) ----------		
pressure, saturated vapor:	566.4 kPa (82.15 psia)	8401
density, saturated liquid:	1329 kg/m3 (82.96 lb/cf)	8401
density, saturated vapor:	32.14 kg/m3 (2.006 lb/cf)	8401
specific volume, saturated liquid:	0.753 L/kg (0.0121 cf/lb)	8401
specific volume, saturated vapor:	31.1 L/kg (0.4985 cf/lb)	8401
velocity of sound, saturated liquid:	532 m/s (1744 ft/s)	8401
velocity of sound, saturated vapor:	136 m/s (446 ft/s)	8401
viscosity, saturated liquid:	201 µPa•s (0.201 cp)	8401
viscosity, saturated vapor:	11.6 µPa•s (0.0116 cp)	8401
thermal conductivity, saturatd liquid:	0.0689 W/m•K (0.0398 Btu/hr•ft°F)	8401
thermal conductivity, saturated vapor:	0.01308 W/m•K (0.00756 Btu/hr•ft°F)	8401
• 60 °C (140 °F) ----------		
pressure, saturated vapor:	1522 kPa (220.7 psia)	8401
heat of vaporization:	114.5 kJ/kg (49.2 Btu/lb)	8401
• critical point ----------		
temperature:	112.0 °C (233.5 °F)	8401
pressure:	4136 kPa (599.9 psia)	8401
density:	565 kg/m3 (35.3 lb/cf)	8401
specific volume:	1.77 L/kg (0.0284 cf/lb)	8401
ENVIRONMENTAL		
average atmospheric lifetime (τatm):	100 yr	9501
average tropospheric lifetime (τtrop):	900,000 yr	9B04
ODP (ozone depletion potential):	0.82 (model-derived relative to R 11)	9501
	0.9 (semi-empirical relative to R 11)	9501
	1.0 (estimate used for the Montreal Protocol)	6904
GWP (global warming potential):	10,600 relative to CO2 for 100 yr integration	9501
HGWP (halocarbon GWP):	3.1 relative to R 11 for infinite integration period	5964

SAFETY		
• classification ----------		
safety group (ASHRAE Standard 34):	A1	8601
NFPA 704 degrees of hazard (H-F-R-S):	ARI recommendation: 2-0-0	3A15
	BOC Gases: 1-0-0	MSDS
	Honeywell: 2-0-0	MSDS
	health-flammability-reactivity [-special]: 0=no, 4=severe	
NPCA HMIS hazard ratings (H-F-R):	BOC Gases: 1-0-0	MSDS
	DuPont: 1-0-1	MSDS
	Honeywell: 1-0-0	MSDS
	health-flammability-reactivity 0=insignificant, 4=extreme	
UL Comparative Hazard to Life Group:	6 in absence of flame or hot objects	4B64
ACGIH carcinogenicity category:	A4, not classifiable as a human carcinogen	9504
DFG pregnancy risk group:	C (no risk fear below MAK/BAT)	5561
• short-term occupational limit ------		
NIOSH IDLH (immediately dangerous):	15,000 ppm v/v	5204
NIOSH SCP IDLH (immediately dangerous:	50,000 ppm v/v for 30 min	3903
• occupational exposure limit --------		
MAK (maximum workplace concentration):	IV: 2,000 ppm v/v momentary 60 min	5561
• long-term occupational limit -------		
OSHA PEL (permissible exposure limit):	1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	3904
NIOSH REL (recommendd exposure limit):	1,000 ppm v/v TWA for 10 hr/day and 40 hr/wk	3903
ACGIH TLV-TWA (time-weighted average):	1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	9504
MAK (maximum workplace concentration):	1,000 ppm v/v TWA for 8 hr/day 40 (or 42) hr/wk	5561
• emergency exposure limit ----------		
NRC EEGL (emergency exposure level):	1 hr: 10,000 ppm v/v ceiling guidance level for single emergency exposures	7414
	24 hr: 1,000 ppm v/v ceiling guidance level for single emergency exposures	7414
Acute Toxicity Exposure Limit (ATEL):	18,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
	22,000 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
Refrigerant Concentration Limit (RCL):	18,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
	22,000 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
• special-purpose exposure control ---		
NRC CEGL (continuous exposure level):	90 day: 100 ppm v/v ceiling guidance for prolonged exposure in closed environments	7414
• acute (short-term) toxicity --------		
ALC (approximate lethal concentration:	rat, 3 hr: 620,000 ppm (lowest exposure tested with one or more deaths by inhalation)	7434
	rat, 4 hr, 0/few: >800,000 ppm (lowest exposure tested with one or more deaths by inhalation)	5147
dermal LD50 (lethal dosage, 50%):	rat: >2,000 mg/kg (fatal dose by skin contact for half of	5368

	test animals)	
oral LD50 (lethal dosage, 50%):	rat: >1,000 mg/kg (fatal dose by ingestion for half of test animals)	5C42
cardiac sensitization (CS) EC50:	dog, 5 min: 77,000 ppm v/v (effective concentration in half of test animals)	6110
	dog, 10 min: 120,000 ppm v/v (effective concentration in half of test animals)	6684
cardiac sensitization threshold/LOEL:	dog, 5 min, 5/12: 50,000 ppm v/v (lowest observed effect level in test animals)	5644
cardiac sensitization (CS) NOEL:	dog, 5 min, 0/12: 25,000 ppm v/v (no observed effect level in test animals)	5644
	dog, 5 min, 0/12: 25,000 ppm v/v (no observed effect level in test animals)	6121
	dog, 10 min, 0/5: 40,000 ppm v/v (no observed effect level in test animals)	5B42
anesthetic/CNS effect EC50:	rat, 10 min: stimulant 250,000 ppm v/v (effective concentration in half of test animals)	6110
	rat, 2 hr: 400,000 ppm v/v (effective concentration in half of test animals)	5365
anesthetic/CNS effect LOEL:	human, 14 min, 1/2: 40,000 ppm v/v (lowest observed effect level)	5C45
	human, 80 min 1/1: 20000-40000 ppm v/v (lowest observed effect level)	5C45
	human, ½ hr, 2/2: 9855-10,173 ppm v/v (lowest observed effect level)	5136
	human, min, ?/?: 50,000 ppm v/v (lowest observed effect level)	5271
anesthetic/CNS effect NOEL:	rat, 2 hr: 200,000 ppm v/v (no observed effect level in test animals)	5355
	human, 1 hr, 0/8: 3,913 ppm v/v (no observed effect level)	A535
	human, 2½ hr, 0/2: 1,000-1027 ppm v/v (no observed effect level)	5136
• flammability ----------		
LFL-UFL (flammability limits in air):	none (nonflammable as tested)	0036
heat of combustion (by ASHRAE 34-92):	-0.8 MJ/kg (-344 Btu/lb)	2318
flash point:	none (nonflammable as tested)	3903
autoignition temperature:	>750 °C (>1382 °F)	5931
	BOC Gases: none	MSDS
former UL Classification:	nonflammable (withdrawn for revision of the classification system, category SBQT2)	6938
• detection ----------		
appearance:	colorless	5141
odor:	Honeywell: faint ethereal	MSDS
	nearly odorless	5367

PRODUCTION		
first commercial use as a refrigerant:	1931 by T. Midgley, associates	5C39
last year production allowed:	1995 in developed countries under the Montreal Protocol	8C01

R-14

REFRIGERANT DATA SUMMARY			
R-14	tetrafluoromethane		see
FC	CF4	CAS number 75-73-0	RDB#

COMMON USE(S)
extremely low temperature refrigeration, often in the lowest stage of a multistage, cascaded system; industrial solvent in electronics manufacturing; plasma etchant

IDENTIFIERS		
common name(s):	R-14; R14; R 14 FC-14 carbon tetrafluoride fluorocarbon 14 fluorochemical 14; FC 14 halocarbon 14 halochemical 14 perfluorocarbon 14; "PFC-14"	
chemical name (by IUPAC convention):	tetrafluoromethane	
alternative chemical names/formulae:	methane, tetrafluoro- perfluoromethane tetrafluorocarbon CF4	
CAS number:	75-73-0 (Chemical Abstracts Service registry number)	
EINECS number:	200-896-5 (European Inventory of Existing Chemical Substances)	
NIOSH RTECS number:	FG4920000 (Registry of Toxic Effects of Chemical Substances)	
trade name(s):	BOC Gases Halocarbon 14	MSDS
	Daikin Daiflon(R) 14	MSDS
	DuPont Freon(R) 14	MSDS
	Hoechst Frigen(R) 14	
historical name(s):	Allied Corp refrigerant 340 carbon fluoride	
ARI container color / Pantone number:	yellow-brown (mustard) / 124	6601

PHYSICAL		
• properties		
molar mass:	88.0043128 g/mol (0.194016 lb/mol)	8820
normal freezing/melting/triple point:	-183.6 °C (-298.5 °F)	8401
• normal boiling point		
temperature:	-128.0 °C (-198.5 °F)	8401
density, saturated liquid:	1603 kg/m3 (100.08 lb/cf)	8401
density, saturated vapor:	7.66 kg/m3 (0.478 lb/cf)	8401
specific volume, saturated liquid:	0.624 L/kg (0.0100 cf/lb)	8401
specific volume, saturated vapor:	130.6 L/kg (2.0915 cf/lb)	8401
heat of vaporization:	134.4 kJ/kg (57.8 Btu/lb)	8401
velocity of sound, saturated liquid:	702 m/s (2304 ft/s)	8401
velocity of sound, saturated vapor:	129 m/s (422 ft/s)	8401
viscosity, saturated liquid:	307 µPa•s (0.307 cp)	8401
viscosity, saturated vapor:	8.38 µPa•s (0.00838 cp)	8401
thermal conductivity, liquid:	0.0973 W/m•K (0.0562 Btu/hr•ft°F)	8401
thermal conductivity, vapor:	0.0054 W/m•K (0.0031 Btu/hr•ft°F)	8401

• normal pressure, 20 °C (68 °F) -----		
density, vapor:	3.673 kg/m3 (0.2293 lb/cf)	8401
• normal pressure, 21.1 °C (70 °F) ---		
density, vapor:	3.659 kg/m3 (0.2284 lb/cf)	8401
• critical point ----------		
temperature:	-45.6 °C (-50.2 °F)	8401
pressure:	3750 kPa (543.9 psia)	8401
density:	626 kg/m3 (39.1 lb/cf)	8401
specific volume:	1.60 L/kg (0.0256 cf/lb)	8401
ENVIRONMENTAL		
average atmospheric lifetime (τatm):	50,000 yr	6694
ODP (ozone depletion potential):	0.000 (model-derived relative to R 11)	
GWP (global warming potential):	5700 relative to CO2 for 100 yr integration	9501
HGWP (halocarbon GWP):	700 relative to R 11 for infinite integration period	DW
SAFETY		
• classification ----------		
safety group (ASHRAE Standard 34):	A1	8601
NFPA 704 degrees of hazard (H-F-R-S):	BOC Gases: 1-0-0	MSDS
	Matheson: 1-0-0	MSDS
	health-flammability-reactivity [-special]: 0=no, 4=severe	
NPCA HMIS hazard ratings (H-F-R):	BOC Gases: 1-0-0	MSDS
	DuPont: 1-0-1	MSDS
	health-flammability-reactivity 0=insignificant, 4=extreme	
UL Comparative Hazard to Life Group:	6 in absence of flame or hot objects	0036
• emergency exposure limit ----------		
Acute Toxicity Exposure Limit (ATEL):	provisional: 110,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
Refrigerant Concentration Limit (RCL):	provisional: 69,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
• acute (short-term) toxicity --------		
ALC (approximate lethal concentration:	rat, 15 min, DuPont: 895,000 ppm (lowest exposure tested with one or more deaths by inhalation)	MSDS
	rat, hr, 0/10: >780,000 ppm (lowest exposure tested with one or more deaths by inhalation)	7550
cardiac sensitization threshold/LOEL:	dog, 10 min, 1?/6: 200,000 ppm v/v (lowest observed effect level in test animals)	7550
	dog, 10 min, 3/6: 600,000 ppm v/v (lowest observed effect level in test animals)	7550
cardiac sensitization (CS) NOEL:	dog, 10 min, 0/5: 200,000 ppm v/v (no observed effect level in test animals)	7550
anesthetic/CNS effect LOEL:	rat, 1 hr, 10/10: 780,000 ppm v/v (lowest observed effect level in ALC or LC50 studies)	7550
anesthetic/CNS effect NOEL:	rat, 10 day, 0/20: 226,000 ppm v/v (no observed effect level in subchronic or chronic study)	7550

• flammability ----------		
LFL-UFL (flammability limits in air):	none (nonflammable as tested)	0036
flash point:	DuPont: will not burn	MSDS
autoignition temperature:	BOC Gases: none	MSDS
	DuPont: >1,100 °C (>2,000 °F)	MSDS
• detection ----------		
appearance:	DuPont: clear, colorless	MSDS
odor:	Daikin: faint ethereal odor	MSDS
	DuPont: none	MSDS
	Matheson: odorless	MSDS
PRODUCTION		
first commercial use as a refrigerant:	1955	5C39
last year production allowed:	unrestricted	8C01

R-22

---------- REFRIGERANT DATA SUMMARY ----------

			see
R-22	chlorodifluoromethane		
HCFC	CHClF2	CAS number 75-45-6	RDB#

COMMON USE(S)

most-widely used refrigerant: air conditioners, heat pumps, applied systems, chillers (with piston, scroll, screw, and centrifugal compressors), commercial refrigeration, dehumidifiers; component of refrigerants 401A, 401B, 401C, 402A, 402B, 403A, 403B, 405A, 406A, 409A, 409B, 411A, 411B, 412A, 414A, 414B, 501, 502, 509A, and others; foam blowing agent especially for polystyrenes, polyethylenes, polyurethanes, polyisocyanurates, and phenolics; aerosol propellant for non-food uses; inert ingredient for medical sterilant gases using ethylene oxide (e.g., AlliedSignal Oxyfume(R) 2002); fire suppressant; intermediate to manufacture fluoropolymers

IDENTIFIERS

common name(s):	R-22; R22; R 22	
	HCFC-22	
	not recommended: HFA-22	
	fluorocarbon 22	
	fluorochemical 22; FC 22	
	halocarbon 22	
	halochemical 22	
	hydrochlorofluorocarbon 22	
chemical name (by IUPAC convention):	chlorodifluoromethane	
alternative chemical names/formulae:	methane, chlorodifluoro-	
	difluorochloromethane	
	difluoromonochloromethane	
	monochlorodifluoromethane	
	CHClF2	
	not recommended: ClF2H; CHF2Cl	
CAS number:	75-45-6 (Chemical Abstracts Service registry number)	
Beilstein registry number:	1731036	
EINECS number:	200-871-9 (European Inventory of Existing Chemical Substances)	
NIOSH RTECS number:	PA6390000 (Registry of Toxic Effects of Chemical Substances)	
trade name(s):	Asahi Glass Fron AF-22	
	Ausimont Algofrene(R) 22	
	Ausimont Meforex(R) 22	MSDS
	Daikin Daiflon(R) HCFC-22	MSDS
	DuPont Freon(R) 22	MSDS
	Elf Atochem Forane(R) 22	MSDS
	HRP (UK) HARP(R) 22	
	Honeywell Genetron(R) 22	MSDS
	ICI Arcton(R) 22	CSDS
	Pennwalt/Atochem Isotron(R) 22	
	Solvay Solkane(R) 22	
historical name(s):	Allied Corp refrigerant 141	
	AlliedSignal Genetron(R) 22	MSDS
	Hoechst Frigen(R) 22	
	ICI Arcton(R) 4	
	Kinetic Chemicals Freon 22	
	Montecatini (I) Algofrene 22	7601
	Nitto (Japan) Col-Flon 22	7601

	Union Carbide Ucon(R) 22	7601
	VVB Dresden Frigedohn 22	7601
ARI container color / Pantone number:	light green / 352	6601
PHYSICAL		
• properties ----------		
molar mass:	86.4681464 g/mol (0.190630 lb/mol)	8820
normal freezing/melting/triple point:	-157.4 °C (-251.4 °F)	8401
• normal boiling point ----------		
temperature:	-40.8 °C (-41.5 °F)	8401
density, saturated liquid:	1409 kg/m3 (87.97 lb/cf)	8401
density, saturated vapor:	4.70 kg/m3 (0.294 lb/cf)	8401
specific volume, saturated liquid:	0.710 L/kg (0.0114 cf/lb)	8401
specific volume, saturated vapor:	212.6 L/kg (3.4055 cf/lb)	8401
heat of vaporization:	233.8 kJ/kg (100.5 Btu/lb)	8401
velocity of sound, saturated liquid:	851 m/s (2791 ft/s)	8401
velocity of sound, saturated vapor:	160 m/s (525 ft/s)	8401
viscosity, saturated liquid:	346 µPa•s (0.346 cp)	8401
viscosity, saturated vapor:	9.75 µPa•s (0.00975 cp)	8401
thermal conductivity, liquid:	0.1135 W/m•K (0.0656 Btu/hr•ft°F)	8401
thermal conductivity, vapor:	0.0070 W/m•K (0.0041 Btu/hr•ft°F)	8401
• normal pressure, 20 °C (68 °F) -----		
density, vapor:	3.651 kg/m3 (0.2279 lb/cf)	8401
• normal pressure, 21.1 °C (70 °F) ---		
density, vapor:	3.637 kg/m3 (0.2270 lb/cf)	8401
• 20 °C (68 °F) ----------		
pressure, saturated vapor:	910.0 kPa (131.99 psia)	8401
density, saturated liquid:	1210 kg/m3 (75.53 lb/cf)	8401
density, saturated vapor:	38.48 kg/m3 (2.402 lb/cf)	8401
specific volume, saturated liquid:	0.827 L/kg (0.0132 cf/lb)	8401
velocity of sound, saturated liquid:	565 m/s (1854 ft/s)	8401
velocity of sound, saturated vapor:	161 m/s (529 ft/s)	8401
viscosity, saturated liquid:	175 µPa•s (0.175 cp)	8401
viscosity, saturated vapor:	12.4 µPa•s (0.0124 cp)	8401
thermal conductivity, saturatd liquid:	0.0859 W/m•K (0.0496 Btu/hr•ft°F)	8401
thermal conductivity, saturated vapor:	0.01095 W/m•K (0.00632 Btu/hr•ft°F)	8401
• 60 °C (140 °F) ----------		
pressure, saturated vapor:	2428 kPa (352.1 psia)	8401
heat of vaporization:	139.9 kJ/kg (60.2 Btu/lb)	8401
• critical point ----------		
temperature:	96.2 °C (205.1 °F)	7713
pressure:	4990 kPa (723.7 psia)	0906
density:	524 kg/m3 (32.7 lb/cf)	8401
specific volume:	1.91 L/kg (0.0306 cf/lb)	8401
ENVIRONMENTAL		
average atmospheric lifetime (τatm):	11.8 yr	9501
average stratospheric lifetime (τstr):	210 yr	5508
ODP (ozone depletion potential):	0.034 (model-derived relative to R 11)	5301
	0.05 (semi-empirical relative to R 11)	9501
	0.055 (estimate used for the Montreal Protocol)	6904
GWP (global warming potential):	1900 relative to CO2 for 100 yr integration	9501
HGWP (halocarbon GWP):	0.345 relative to R 11 for infinite integration period	5964
	0.35 relative to R 11 for	6B35

	infinite integration period	
	0.37 relative to R 11 for infinite integration period	4B16
photochemical reactivity (grnd level):	0.6 relative to methane	4511
SAFETY		
• classification ----------		
safety group (ASHRAE Standard 34):	A1	8601
NFPA 704 degrees of hazard (H-F-R-S):	ARI recommendation: 2-0-0	3A15
	Ausimont: 2-0-0	MSDS
	BOC Gases: 1-0-0	MSDS
	Honeywell: 2-1-0	MSDS
	health-flammability-reactivity [-special]: 0=no, 4=severe	
NPCA HMIS hazard ratings (H-F-R):	BOC Gases: 1-0-0	MSDS
	DuPont: 1-0-1	MSDS
	Honeywell: 1-1-0	MSDS
	health-flammability-reactivity 0=insignificant, 4=extreme	
UL Comparative Hazard to Life Group:	5(a) in absence of flame or hot objects	5175
IARC/CIRC human carcinogicity group:	3, not classifiable	8420
ACGIH carcinogenicity category:	A4, not classifiable as a uman carcinogen	9504
DFG pregnancy risk group:	C (no risk fear below MAK/BAT)	5561
• short-term occupational limit ------		
ARI "IDLH" recommendation:	50,000 ppm v/v for 30 min	3A15
NIOSH STEL (short-term exposur limit):	1,250 ppm v/v TWA for 15 min	5204
• occupational exposure limit --------		
MAK (maximum workplace concentration):	IV: 1,000 ppm v/v momentary 60 min	5561
• long-term occupational limit -------		
NIOSH REL (recommendd exposure limit):	1,000 ppm v/v TWA for 10 hr/day and 40 hr/wk	5204
ACGIH TLV-TWA (time-weighted average):	1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	9504
exposure limit consistent to OSHA PEL:	ARI: 1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	3A15
MAK (maximum workplace concentration):	500 ppm v/v TWA for 8 hr/day 40 (or 42) hr/wk	5561
	applies only to pure substance	5561
	see note on R-31 contamination	5561
• emergency exposure limit ----------		
Acute Toxicity Exposure Limit (ATEL):	25,000 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	25,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
Refrigerant Concentration Limit (RCL):	25,000 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	25,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
• acute (short-term) toxicity --------		
LC50 (lethal concentration, 50%):	rat, 15 min: 350,000 ppm (fatal concentration by inhalation for half of test animals)	6110
	rat, 4 hr: 220,000 ppm (fatal concentration by inhalation for half of test animals)	3718
	rat, 4 hr: 220,000 ppm (fatal concentration by inhalation for half of test animals)	6127
ALC (approximate lethal concentration:	rat, 2 hr, 1/4: 300,000 ppm (lowest exposure tested with	5365

	one or more deaths by inhalation)	
cardiac sensitization (CS) EC50:	dog, 5 min: 140,000 ppm v/v (effective concentration in half of test animals)	6110
cardiac sensitization threshold/LOEL:	dog, 5 min, 2/12: 50,000 ppm v/v (lowest observed effect level in test animals)	5644
cardiac sensitization (CS) NOEL:	dog, 5 min, 0/12: 25,000 ppm v/v (no observed effect level in test animals)	5644
	dog, 5 min, 0/12: 25,000 ppm v/v (no observed effect level in test animals)	6121
anesthetic/CNS effect EC50:	rat, 10min: depressant 140,000 ppm v/v (effective concentration in half of test animals)	6110
anesthetic/CNS effect LOEL:	rat, 2 hr, ?/4: 50,000 ppm v/v (lowest observed effect level in ALC or LC50 studies)	5365
• flammability ----------		
LFL-UFL (flammability limits in air):	none (nonflammable as tested)	2525
	none (nonflammable as tested)	5648
heat of combustion (by ASHRAE 34-92):	2.2 MJ/kg (946 Btu/lb)	2318
flash point:	ICI: does not flash	MSDS
	none (nonflammable as tested)	5204
autoignition temperature:	632 °C (1170 °F)	5175
	BOC Gases: none	MSDS
	Solvay: 635 °C (1175 °F)	MSDS
autodecomposition temperature:	DuPont: 632 °C (1170 °F)	MSDS
	Elf Atochem: 480 °C (896 °F)	SDS
former UL Classification:	practically nonflammable (withdrawn for revision of the classification system, category SBQT2)	6938
• detection ----------		
appearance:	Honeywell: clear, colorless	MSDS
odor:	Elf Atochem: faint ether odor	MSDS

PRODUCTION

first commercial use as a refrigerant:	1936 by T. Midgley, associates	
last year production allowed:	2029 in developed countries under the Montreal Protocol	8C01

R-23

---------- REFRIGERANT DATA SUMMARY ----------

R-23	trifluoromethane		see
HFC	CHF3	CAS number 75-46-7	RDB#

COMMON USE(S)
alternative for (and predecessor to) refrigerants 13 and 503 in extremely low temperature refrigeration, primarily in the low stage of cascaded systems; laboratory apparatus and test chambers; industrial refrigeration for gas separation and processes; component of refrigerants 415A, 503, 508A, 508B, and others; coolant in infrared detector cells; blowing agent for urethane foams; fire suppressant to replace halon 1301 (e.g., DuPont Chemicals FE-13); solvent for sterilant gases; plasma etchant

IDENTIFIERS

common name(s):	R-23; R23; R 23	
	HFC-23	
	not recommended: HFA-23	
	fluorocarbon 23	
	fluorochemical 23; FC 23	
	halocarbon 23	
	halochemical 23	
	halon 13	
	hydrofluorocarbon 23	
chemical name (by IUPAC convention):	trifluoromethane	
alternative chemical names/formulae:	methane, trifluoro-	
	fluoroform	
	carbon trifluoride	
	fluoryl	
	methyl trifluoride	
	CHF3	
	not recommended: CF3H	
empirical formula:	CHF3	
CAS number:	75-46-7 (Chemical Abstracts Service registry number)	
EINECS number:	200-872-4 (European Inventory of Existing Chemical Substances)	
NIOSH RTECS number:	PB6900000 (Registry of Toxic Effects of Chemical Substances)	
trade name(s):	BOC Gases Halocarbon 13	MSDS
	Daikin Daiflon(R) 23; DF23	MSDS
	DuPont Freon(R) 23	
	DuPont Suva(R) 23	
	Elf Atochem Forane(R) 23	SDS
	Honeywell Genetron(R) 23	
	ICI Klea(R) 23	MSDS
	Solvay Solkane(R) 23	
historical name(s):	Allied Corp refrigerant 240	
	AlliedSignal Genetron(R) 23	MSDS
	DuPont Freon(R) F-23	5604
	Hoechst Frigen(R) 23	
	Hoechst Reclin(R) 23	
	ICI Arcton(R) 1	
	ICI Arcton(R) 23	
ARI container color / Pantone number:	light blue grey / 428	6601

PHYSICAL		
• properties ----------		
molar mass:	70.0138496 g/mol (0.154354 lb/mol)	8820
normal freezing/melting/triple point:	-155.2 °C (-247.3 °F)	8401
• normal boiling point ----------		
temperature:	-82.1 °C (-115.8 °F)	8401
density, saturated liquid:	1443 kg/m3 (90.09 lb/cf)	8401
density, saturated vapor:	4.65 kg/m3 (0.290 lb/cf)	8401
specific volume, saturated liquid:	0.693 L/kg (0.0111 cf/lb)	8401
specific volume, saturated vapor:	215.0 L/kg (3.4444 cf/lb)	8401
heat of vaporization:	240.7 kJ/kg (103.5 Btu/lb)	8401
velocity of sound, saturated liquid:	806 m/s (2645 ft/s)	8401
velocity of sound, saturated vapor:	165 m/s (542 ft/s)	8401
viscosity, saturated liquid:	392 µPa•s (0.392 cp)	8401
viscosity, saturated vapor:	8.91 µPa•s (0.00891 cp)	8401
thermal conductivity, liquid:	0.1357 W/m•K (0.0784 Btu/hr•ft°F)	8401
thermal conductivity, vapor:	0.0065 W/m•K (0.0037 Btu/hr•ft°F)	8401
• normal pressure, 20 °C (68 °F) -----		
density, vapor:	2.934 kg/m3 (0.1832 lb/cf)	8401
• normal pressure, 21.1 °C (70 °F) ---		
density, vapor:	2.923 kg/m3 (0.1825 lb/cf)	8401
• 20 °C (68 °F) ----------		
pressure, saturated vapor:	4201.9 kPa (609.44 psia)	8401
density, saturated liquid:	776 kg/m3 (48.47 lb/cf)	8401
density, saturated vapor:	285.13 kg/m3 (17.800 lb/cf)	8401
specific volume, saturated liquid:	1.288 L/kg (0.0206 cf/lb)	8401
specific volume, saturated vapor:	3.5 L/kg (0.0562 cf/lb)	8401
velocity of sound, saturated liquid:	162 m/s (530 ft/s)	8401
velocity of sound, saturated vapor:	131 m/s (428 ft/s)	8401
viscosity, saturated liquid:	58 µPa•s (0.058 cp)	8401
viscosity, saturated vapor:	19.1 µPa•s (0.0191 cp)	8401
thermal conductivity, saturatd liquid:	0.0642 W/m•K (0.0371 Btu/hr•ft°F)	8401
thermal conductivity, saturated vapor:	0.04668 W/m•K (0.02697 Btu/hr•ft°F)	8401
• critical point ----------		
temperature:	25.9 °C (78.7 °F)	8401
pressure:	4836 kPa (701.4 psia)	8401
density:	525 kg/m3 (32.8 lb/cf)	8401
specific volume:	1.90 L/kg (0.0305 cf/lb)	8401
ENVIRONMENTAL		
average atmospheric lifetime (τatm):	243 yr	9501
ODP (ozone depletion potential):	<0.0004 (model-derived relative to R 11)	9501
GWP (global warming potential):	14,800 relative to CO2 for 100 yr integration	9501
HGWP (halocarbon GWP):	6 relative to R 11 for infinite integration period	4511
	8.32 relative to R 11 for infinite integration period	DW
SAFETY		
• classification ----------		
safety group (ASHRAE Standard 34):	A1	8601
NFPA 704 degrees of hazard (H-F-R-S):	AlliedSignal: 1-0-1	MSDS
	BOC Gases: 1-0-0	MSDS
	Elf Atochem: 2-0-0	MSDS
	health-flammability-reactivity [-special]: 0=no, 4=severe	
NPCA HMIS hazard ratings (H-F-R):	AlliedSignal: 1-0-1	MSDS

	BOC Gases: 1-0-0	MSDS
	DuPont: 1-0-1	MSDS
	health-flammability-reactivity 0=insignificant, 4=extreme	
UL Comparative Hazard to Life Group:	6 by estimate (not UL test) in absence of flame or hot objects	5906
• long-term occupational limit -------		
exposure limit consistent to OSHA PEL:	AlliedSignal PEL: 1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	MSDS
	DuPont AEL: 1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	5604
	ICI OEL: 1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	5168
• emergency exposure limit ----------		
Acute Toxicity Exposure Limit (ATEL):	41,000 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	41,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
Refrigerant Concentration Limit (RCL):	41,000 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	41,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
• acute (short-term) toxicity --------		
ALC (approximate lethal concentration:	rat, 4 hr, 0/6: >663,000 ppm (lowest exposure tested with one or more deaths by inhalation)	6513
cardiac sensitization (CS) EC50:	dog, 10 min: >500,000 ppm v/v (effective concentration in half of test animals)	6684
cardiac sensitization (CS) NOEL:	dog, 5-10 min, 0/5: 800,000 ppm v/v (no observed effect level in test animals)	5136
	dog: 500,000 ppm v/v (no observed effect level in test animals)	6458
anesthetic/CNS effect LOEL:	dog, 2/2: ?analgesia 800,000 ppm v/v (lowest observed effect level in test animals)	5828
	rat, 4 hr, ?/6: 186,000 ppm v/v (lowest observed effect level in ALC or LC50 studies)	6513
	human, 1/1: analgesia 800,000 ppm v/v (lowest observed effect level)	5828
	human, 4/4: anesthetic 300,000 ppm v/v (lowest observed effect level)	5737
anesthetic/CNS effect NOEL:	rat, 6 hr, 0/25: 51,000 ppm v/v (no observed effect level in ALC or LC50 studies)	7631
• flammability ----------		
LFL-UFL (flammability limits in air):	none (nonflammable as tested)	4511
	none (nonflammable as tested)	5648
heat of combustion (by ASHRAE 34-92):	-12.5 MJ/kg (-5374 Btu/lb)	2318
flash point:	AlliedSignal: no flash point	MSDS
	TOC, DuPont: will not burn	MSDS
autoignition temperature:	765 °C (1409 °F)	3960
	>750 °C (>1382 °F)	5931
	BOC Gases: none	MSDS
autodecomposition temperature:	Elf Atochem: 1150 °C (2102 °F)	SDS
former UL Classification:	nonflammable (withdrawn for	5931

		revision of the classification system, category SBQT2)	
• detection ----------			
	appearance:	DuPont: clear, colorless	MSDS
	odor:	DuPont: slight ethereal	MSDS
		ICI: odorless	CSDS
PRODUCTION			
	last year production allowed:	unrestricted	8C01

R-32

---------- REFRIGERANT DATA SUMMARY ----------

R-32	difluoromethane		see
HFC	CH2F2	CAS number 75-10-5	RDB#

COMMON USE(S)
under consideration as a long-term replacement with equipment redesign for applications once served by refrigerant 22; key blend component in alternatives including refrigerants 407A, 407B, 407C, 407D, 410A, 410B, 504, and others; low critical temperature, comparatively high pressures, and limited flammability impede broad consideration for use alone

IDENTIFIERS

common name(s):	R-32; R32; R 32	
	HFC-32	
	fluorocarbon 32	
	fluorochemical 32; FC 32	
	halocarbon 32	
	halochemical 32	
	hydrofluorocarbon 32	
	not recommended: HFA-32	2909
chemical name (by IUPAC convention):	difluoromethane	
alternative chemical names/formulae:	methane, difluoro-	
	methylene difluoride	
	methylene fluoride	
	carbon fluoride hydride	
	CH2F2	
	not recommended: F2H2; H2F2C; F2H2C	
CAS number:	75-10-5 (Chemical Abstracts Service registry number)	
EINECS number:	200-839-4 (European Inventory of Existing Chemical Substances)	
trade name(s):	Ausimont Meforex(R) 32	
	Daikin fluorocarbon HFC-32	MSDS
	DuPont HFC-32	MSDS
	Elf Atochem Forane(R) 32	MSDS
	Honeywell Genetron(R) 32	MSDS
	ICI Klea(R) 32	MSDS
	Solvay Solkane(R) 32	MSDS
	ZCIRI Kehua (PRC) HFC-32	
historical name(s):	Allied Corp refrigerant 140	
	AlliedSignal Genetron(R) 32	MSDS
	DuPont Freon(R) 32	5862
ARI container color / Pantone number:	none, use light green grey/413 ith red / 185 band	6601

PHYSICAL

• properties ----------		
molar mass:	52.0233864 g/mol (0.114692 lb/mol)	8820
normal freezing/melting/triple point:	-136.8 °C (-214.3 °F)	6B07
• normal boiling point ----------		
temperature:	-51.7 °C (-61.0 °F)	8401
density, saturated liquid:	1213 kg/m3 (75.72 lb/cf)	8401
density, saturated vapor:	2.99 kg/m3 (0.187 lb/cf)	8401
specific volume, saturated liquid:	0.824 L/kg (0.0132 cf/lb)	8401
specific volume, saturated vapor:	334.7 L/kg (5.3611 cf/lb)	8401
heat of vaporization:	381.9 kJ/kg (164.2 Btu/lb)	8401

velocity of sound, saturated liquid:	971 m/s (3185 ft/s)	8401
velocity of sound, saturated vapor:	207 m/s (680 ft/s)	8401
viscosity, saturated liquid:	281 µPa•s (0.281 cp)	8401
viscosity, saturated vapor:	9.25 µPa•s (0.00925 cp)	8401
thermal conductivity, liquid:	0.1901 W/m•K (0.1098 Btu/hr•ft°F)	8401
thermal conductivity, vapor:	0.0083 W/m•K (0.0048 Btu/hr•ft°F)	8401
• normal pressure, 20 °C (68 °F) -----		
density, vapor:	2.192 kg/m3 (0.1368 lb/cf)	8401
• normal pressure, 21.1 °C (70 °F) ---		
density, vapor:	2.183 kg/m3 (0.1363 lb/cf)	8401
• 20 °C (68 °F) ----------		
pressure, saturated vapor:	1474.6 kPa (213.87 psia)	8401
density, saturated liquid:	981 kg/m3 (61.27 lb/cf)	8401
density, saturated vapor:	40.86 kg/m3 (2.551 lb/cf)	8401
specific volume, saturated liquid:	1.019 L/kg (0.0163 cf/lb)	8401
specific volume, saturated vapor:	24.5 L/kg (0.3921 cf/lb)	8401
velocity of sound, saturated liquid:	584 m/s (1915 ft/s)	8401
velocity of sound, saturated vapor:	206 m/s (675 ft/s)	8401
viscosity, saturated liquid:	125 µPa•s (0.125 cp)	8401
viscosity, saturated vapor:	12.7 µPa•s (0.0127 cp)	8401
thermal conductivity, saturatd liquid:	0.1390 W/m•K (0.0803 Btu/hr•ft°F)	8401
thermal conductivity, saturated vapor:	0.01430 W/m•K (0.00826 Btu/hr•ft°F)	8401
• 60 °C (140 °F) ----------		
pressure, saturated vapor:	3933 kPa (570.5 psia)	8401
heat of vaporization:	175.5 kJ/kg (75.5 Btu/lb)	8401
• critical point ----------		
temperature:	78.1 °C (172.6 °F)	8970
	78.2 °C (172.7 °F)	9125
pressure:	5782 kPa (838.6 psia)	8401
density:	424 kg/m3 (26.5 lb/cf)	8401
	429 kg/m3 (26.8 lb/cf)	9125
specific volume:	2.36 L/kg (0.0378 cf/lb)	8401

ENVIRONMENTAL

average atmospheric lifetime (τatm):	5.6 ~1.4 yr	6695
ODP (ozone depletion potential):	0.000 (model-derived relative to R 11)	3B12
GWP (global warming potential):	880 relative to CO2 for 100 yr integration	9501
HGWP (halocarbon GWP):	0.11 relative to R 11 for infinite integration period	4511
	0.13 relative to R 11 for infinite integration period	3730
	0.14 relative to R 11 for infinite integration period	6B35
	ICI: 0.15 relative to R 11 for infinite integration period	CSDS

SAFETY

• classification ----------		
safety group (ASHRAE Standard 34):	A2	8601
NFPA 704 degrees of hazard (H-F-R-S):	Honeywell: 2-2-0 health-flammability-reactivity [-special]: 0=no, 4=severe	MSDS
NPCA HMIS hazard ratings (H-F-R):	AlliedSignal: 2-4-0 97.01	MSDS
	DuPont: 1-4-1	MSDS
	Honeywell: 1-2-0 health-flammability-reactivity 0=insignificant, 4=extreme	MSDS

• long-term occupational limit -------		
AIHA WEEL (workplace envl exp limit):	1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	5C14
• emergency exposure limit ----------		
Acute Toxicity Exposure Limit (ATEL):	40,000 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	40,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
Refrigerant Concentration Limit (RCL):	32,000 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	32,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
• acute (short-term) toxicity --------		
LC50 (lethal concentration, 50%):	rat, 4 hr, 0/10: >520,000 ppm (fatal concentration by inhalation for half of test animals)	5740
ALC (approximate lethal concentration:	rat, 4 hr, 0/6: >760,000 ppm (lowest exposure tested with one or more deaths by inhalation)	6171
cardiac sensitization (CS) EC50:	dog, 10 min: >350,000 ppm v/v (effective concentration in half of test animals)	6684
cardiac sensitization threshold/LOEL:	dog, 10 min, 1/12: 250,000 ppm v/v (lowest observed effect level in test animals)	6170
cardiac sensitization (CS) NOEL:	dog, 10 min, 0/1: 200,000 ppm v/v (no observed effect level in test animals)	6170
anesthetic/CNS effect LOEL:	rat, 4 hr, 10/10: 85,900 ppm v/v (lowest observed effect level in ALC or LC50 studies)	5740
anesthetic/CNS effect NOEL:	rat, 6 hr, 0/10: 49,500 ppm v/v (no observed effect level in subchronic or chronic study)	5741
• flammability ----------		
LFL-UFL (flammability limits in air):	12.7-33.5 % v/v	2525
	14-31 % v/v	4511
	Daikin: 13.3-29.3 % v/v	MSDS
	Elf Atochem: 12.7-33.4 % v/v	SDS
	Honeywell: 12.7-33.4 % v/v	MSDS
LFL-UFL (flammability limits, 95 °C):	11.4-33.8 % v/v	2525
LFL-UFL (with spark ignition):	13.3-29.3 % v/v	5648
	13.5-31.4 % v/v	2525
LFL-UFL (with hot-wire ignition):	14.2-28.9 % v/v	2525
heat of combustion (by ASHRAE 34-92):	9.4 MJ/kg (4034 Btu/lb)	2318
flash point:	Elf Atochem: liquified R-32 is "extremely flammable"	SDS
	Honeywell: gas, not applicable	MSDS
autoignition temperature:	648 °C (1198 °F)	3960
	685 °C (1265 °F)	5C14
	Honeywell: >750 °C (>1382 °F)	MSDS
autodecomposition temperature:	Honeywell: >250°C (>482°F)	MSDS
• detection ----------		
appearance:	colorless	5C14
odor:	slight ethereal	5C14
PRODUCTION		
last year production allowed:	unrestricted	8C01

R-113

---------- REFRIGERANT DATA SUMMARY ----------

			see RDB#
R-113	1,1,2-trichloro-1,2,2-trifluoroethane		
CFC	CCl2FCClF2	CAS number 76-13-1	

COMMON USE(S)
limited use in centrifugal chillers; very limited use in high-temperature heat pumps; aerosol solvent usually propelled with refrigerant 12; widely used as an industrial solvent particularly for cleaning electronic circuit boards and, historically, for dry cleaning; blowing agent

IDENTIFIERS

common name(s):	R-113; R113; R 113	
	CFC-113	
	TTE; TCTFE	
	fluorocarbon 113	
	fluorochemical 113; FC 113	
	halocarbon 113	
chemical name (by IUPAC convention):	1,1,2-trichloro-1,2,2-rifluoroethane	
alternative chemical names/formulae:	ethane, 1,1,2-trichloro-1,2,2-rifluoro-	
	1,1,2-trichlorotrifluoroethane	
	trichlorotrifluoroethane	
	CCl2FCClF2; CCl2F-CClF2	
	not recommended:	
	F2ClCFCl2; CF2Cl-CFCl2	
	FCl2CF2Cl; CFCl2-CF2Cl	
	l2FCCClF2; Cl2FC-CClF2	
	2ClCCFCl2; F2ClC-CFCl2	
	Cl2CCF2Cl; FCl2C-CF2Cl	
empirical formula:	C2Cl3F3	
CAS number:	76-13-1 (Chemical Abstracts Service registry number)	
EINECS number:	200-936-1 (European Inventory of Existing Chemical Substances)	
NIOSH RTECS number:	KJ4000000 (Registry of Toxic Effects of Chemical Substances)	
trade name(s):	Asahi Glass Fron AF-113	
	Daikin Daiflon(R) 113	
	DuPont Freon(R) 113	MSDS
	DuPont Freon(R) TF	MSDS
	Elf Atochem Forane(R) 113	MSDS
	Hoechst Frigen(R) 113	
	Honeywell Genetron(R) 113	MSDS
historical name(s):	Allied Corp refrigerant 226	
	AlliedSignal Genetron(R) 113	MSDS
	Carrier Corporation Carrene 3	
	ICI Arcton(R) 113	
	ICI Arcton(R) 63	
	Union Carbide Ucon(R) 113	7601
	VVB Dresden Frigedohn 113	7601
ARI container color / Pantone number:	dark purple (violet) / 266	6601

PHYSICAL
• properties ----------

molar mass:	187.3747096 g/mol (0.413091 lb/mol)	8820

normal freezing/melting/triple point:	-36.2 °C (-33.2 °F)	8401
• normal boiling point ----------		
temperature:	47.6 °C (117.7 °F)	8401
density, saturated liquid:	1508 kg/m3 (94.15 lb/cf)	8401
density, saturated vapor:	7.42 kg/m3 (0.463 lb/cf)	8401
specific volume, saturated liquid:	0.663 L/kg (0.0106 cf/lb)	8401
specific volume, saturated vapor:	134.7 L/kg (2.1575 cf/lb)	8401
heat of vaporization:	144.3 kJ/kg (62.0 Btu/lb)	8401
velocity of sound, saturated liquid:	626 m/s (2053 ft/s)	8401
velocity of sound, saturated vapor:	119 m/s (390 ft/s)	8401
viscosity, saturated vapor:	10.31 µPa•s (0.01031 cp)	8401
viscosity, saturated liquid:	500 µPa•s (0.500 cp)	8401
thermal conductivity, liquid:	0.0636 W/m•K (0.0368 Btu/hr•ft°F)	8401
thermal conductivity, vapor:	0.0095 W/m•K (0.0055 Btu/hr•ft°F)	8401
• normal pressure, 20 °C (68 °F) -----		
density, liquid:	1575 kg/m3 (13.14 lb/gal)	8401
• normal pressure, 21.1 °C (70 °F) ---		
density, liquid:	1573 kg/m3 (13.12 lb/gal)	8401
• 20 °C (68 °F) ----------		
pressure, saturated vapor:	36.7 kPa (5.32 psia)	8401
density, saturated liquid:	1575 kg/m3 (98.32 lb/cf)	8401
density, saturated vapor:	2.88 kg/m3 (0.180 lb/cf)	8401
specific volume, saturated liquid:	0.635 L/kg (0.0102 cf/lb)	8401
specific volume, saturated vapor:	34.8 L/kg (0.5570 cf/lb)	8401
velocity of sound, saturated liquid:	716 m/s (2348 ft/s)	8401
velocity of sound, saturated vapor:	116 m/s (381 ft/s)	8401
viscosity, saturated liquid:	709 µPa•s (0.709 cp)	8401
viscosity, saturated vapor:	9.5 µPa•s (0.0095 cp)	8401
thermal conductivity, saturatd liquid:	0.0693 W/m•K (0.0400 Btu/hr•ft°F)	8401
thermal conductivity, saturated vapor:	0.00827 W/m•K (0.00478 Btu/hr•ft°F)	8401
• 60 °C (140 °F) ----------		
pressure, saturated vapor:	150 kPa (21.8 psia)	8401
heat of vaporization:	140.2 kJ/kg (60.3 Btu/lb)	8401
• critical point ----------		
temperature:	214.1 °C (417.3 °F)	8401
pressure:	3392 kPa (492.0 psia)	8401
density:	576 kg/m3 (36.0 lb/cf)	0036
specific volume:	1.79 L/kg (0.0286 cf/lb)	8401
ENVIRONMENTAL		
average atmospheric lifetime (τatm):	85 yr	9501
ODP (ozone depletion potential):	0.90 (model-derived relative to R 11)	9501
	0.9 (semi-empirical relative to R 11)	9501
	0.8 (estimate used for the Montreal Protocol)	6904
GWP (global warming potential):	6000 relative to CO2 for 100 yr integration	9501
HGWP (halocarbon GWP):	1.35 relative to R 11 for infinite integration period	5964
SAFETY		
• classification ----------		
safety group (ASHRAE Standard 34):	A1	8601
NFPA 704 degrees of hazard (H-F-R-S):	ARI recommendation: 2-0-0	3A15
	BOC Gases: 1-0-0	MSDS
	Honeywell: 2-0-0	MSDS
	health-flammability-reactivity [-special]: 0=no, 4=severe	

NPCA HMIS hazard ratings (H-F-R):	BOC Gases: 1-0-0	MSDS
	DuPont: 1-0-1	MSDS
	Honeywell: 1-0-0	MSDS
	health-flammability-reactivity 0=insignificant, 4=extreme	
UL Comparative Hazard to Life Group:	between 4 and 5 in absence of flame or hot objects	5174
ACGIH carcinogenicity category:	A4, not classifiable as a uman carcinogen	9504
• short-term occupational limit ------		
NIOSH IDLH (immediately dangerous):	2,000 ppm v/v	5204
NIOSH SCP IDLH (immediately dangerous:	4,500 ppm v/v for 30 min	3903
NIOSH STEL (short-term exposur limit):	1,250 ppm v/v TWA for 15 min	3903
ACGIH TLV-STEL (short-term exp limit):	1,250 ppm v/v TWA for 15 min	9504
• occupational exposure limit --------		
MAK (maximum workplace concentration):	IV: 1,000 ppm v/v momentary 60 min	7101
• long-term occupational limit -------		
OSHA PEL (permissible exposure limit):	1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	3904
NIOSH REL (recommendd exposure limit):	1,000 ppm v/v TWA for 10 hr/day and 40 hr/wk	3903
ACGIH TLV-TWA (time-weighted average):	1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	9504
MAK (maximum workplace concentration):	500 ppm v/v TWA for 8 hr/day 40 (or 42) hr/wk	7101
• emergency exposure limit ----------		
NRC EEGL (emergency exposure level):	1 hr: 1,500 ppm v/v ceiling guidance level for single emergency exposures	7414
	24 hr: 500 ppm v/v ceiling guidance level for single emergency exposures	7414
Acute Toxicity Exposure Limit (ATEL):	2,600 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	2,600 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
Refrigerant Concentration Limit (RCL):	2,600 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	2,600 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
• special-purpose exposure control ---		
NRC CEGL (continuous exposure level):	90 day: 100 ppm v/v ceiling guidance for prolonged exposure in closed environments	7414
• acute (short-term) toxicity --------		
LC50 (lethal concentration, 50%):	mouse, 30 min, 0/10: >100,000 ppm (fatal concentration by inhalation for half of test animals)	6165
	rat, 15 min: 130,000 ppm (fatal concentration by inhalation for half of test animals)	6110
	rat, 4 hr: 52,500 ppm (fatal concentration by inhalation for half of test animals)	6804
ALC (approximate lethal concentration:	mouse, 15 min, 2/10: 110,000 ppm (lowest exposure tested with one or more deaths by inhalation)	6587
	rat, 2 hr: 110,000 ppm (lowest exposure tested with one or	6B56

	more deaths by inhalation)	
	rat, 4 hr, 1/6: 45,000 ppm (lowest exposure tested with one or more deaths by inhalation)	6804
dermal LD50 (lethal dosage, 50%):	rabbit: >11,000 mg/kg (fatal dose by skin contact for half of test animals)	7541
oral LD50 (lethal dosage, 50%):	rat: 43,000 mg/kg (fatal dose by ingestion for half of test animals)	7441
cardiac sensitization (CS) EC50:	dog, 5 min: 7,000 ppm v/v (effective concentration in half of test animals)	6110
cardiac sensitization threshold/LOEL:	dog, 10 min, 10/29: 4,850 ppm v/v (lowest observed effect level in test animals)	65A0
cardiac sensitization (CS) NOEL:	dog, 10 min, 0/12: 2,600 ppm v/v (no observed effect level in test animals)	65A0
anesthetic/CNS effect EC50:	mouse, 30 min: 57,000 ppm v/v (effective concentration in half of test animals)	6165
	rat, 10 min: stimulant 28,000 ppm v/v (effective concentration in half of test animals)	6110
anesthetic/CNS effect LOEL:	mouse, 15 min, 1/10: 50,000 ppm v/v (lowest observed effect level in test animals)	6587
	mouse, 15 min, 9/10: 60,000 ppm v/v (lowest observed effect level in test animals)	6587
anesthetic/CNS effect NOEL:	rat, 2 hr: 25,000 ppm v/v (no observed effect level in ALC or LC50 studies)	5365
• flammability ----------		
LFL-UFL (flammability limits in air):	none (nonflammable as tested)	2525
heat of combustion (by ASHRAE 34-92):	0.1 MJ/kg (43 Btu/lb)	2318
flash point:	DuPont: will not burn	MSDS
	Honeywell: none	MSDS
	ICI: does not flash	MSDS
autoignition temperature:	680 °C (1256 °F)	5174
	BOC Gases: none	MSDS
	Honeywell: 770 °C (1418 °F)	MSDS
autodecomposition temperature:	DuPont: 300 °C (572 °F)	MSDS
former UL Classification:	practically nonflammable (withdrawn for revision of the classification system, category SBQT2)	5931
• detection ----------		
appearance:	BOC Gases: water-white liquid	MSDS
	Honeywell: colorless	MSDS
	colorless	7414
odor:	DuPont: slight ethereal	MSDS
	Honeywell: faint ethereal and	MSDS
	Honeywell: slightly sweetish	MSDS
	nearly odorless	5367
PRODUCTION		
first commercial use as a refrigerant:	1934 by T. Midgley, associates	5C39
last year production allowed:	1995 in developed countries under the Montreal Protocol	8C01

R-114

---------- REFRIGERANT DATA SUMMARY ----------

			see
R-114	1,2-dichloro-1,1,2,2-tetrafluoroethane		
CFC	CClF2CClF2	CAS number 76-14-2	RDB#

COMMON USE(S)
centrifugal chillers especially for naval and heat recovery use; industrial heat pumps; aircraft cooling systems; formerly used in domestic refrigerators, but displaced by refrigerant 12; heat transfer fluid; aerosol propellant especially in personal products; propellant in metered-dose inhalers; blowing agent for foamed plastics

IDENTIFIERS

common name(s):	R-114; R114; R 114	
	CFC-114	
	cryofluorane	5141
	fluorocarbon 114	
	fluorochemical 114; FC 114	
	halocarbon 114	
	halon 242	
chemical name (by IUPAC convention):	1,2-dichloro-1,1,2,2-etrafluoroethane	
alternative chemical names/formulae:	ethane, 1,2-dichloro-1,1,2,2-etrafluoro-	
	1,2-dichlorotetrafluoroethane	
	ethane, 1,2-ichlorotetrafluoro-symmetrical	
	ichlorotetrafluoroethane	5141
	CClF2CClF2; CClF2-CClF2	
	not recommended: CClF2)2	
	F2ClCF2Cl; CF2Cl-CF2Cl	
	lF2CCClF2; ClF2C-CClF2	
empirical formula:	C2Cl2F4	
CAS number:	76-14-2 (Chemical Abstracts Service registry number)	
EINECS number:	200-937-7 (European Inventory of Existing Chemical Substances)	
NIOSH RTECS number:	KI1101000 (Registry of Toxic Effects of Chemical Substances)	
trade name(s):	Asahi Glass Fron AF-114	
	Daikin Daiflon(R) 114	
	DuPont Freon(R) 114	MSDS
	Elf Atochem Forane(R) 114	MSDS
	Hoechst Frigen(R) 114	
	Honeywell Genetron(R) 114	MSDS
	ICI Arcton(R) 114	MSDS
historical name(s):	Allied Corp refrigerant 316	
	AlliedSignal Genetron(R) 114	MSDS
	Kinetic #114; also K114	
	Pechiney Flugene 114	7601
	Union Carbide Ucon(R) 114	7601
	VVB Dresden Frigedohn 114	7601
ARI container color / Pantone number:	dark blue (navy) / 302	6601

PHYSICAL		
• properties ----------		
molar mass:	170.9204128 g/mol (0.376815 lb/mol)	8820
normal freezing/melting/triple point:	-181.3 °C (-294.3 °F)	MSDS
	-94.1 °C (-137.5 °F)	8401
• normal boiling point ----------		
temperature:	3.6 °C (38.5 °F)	8401
density, saturated liquid:	1518 kg/m3 (94.77 lb/cf)	8401
density, saturated vapor:	7.83 kg/m3 (0.489 lb/cf)	8401
specific volume, saturated liquid:	0.659 L/kg (0.0106 cf/lb)	8401
specific volume, saturated vapor:	127.7 L/kg (2.0457 cf/lb)	8401
heat of vaporization:	135.9 kJ/kg (58.4 Btu/lb)	8401
velocity of sound, saturated liquid:	630 m/s (2066 ft/s)	8401
velocity of sound, saturated vapor:	116 m/s (382 ft/s)	8401
viscosity, saturated vapor:	10.03 µPa•s (0.01003 cp)	8401
viscosity, saturated liquid:	357 µPa•s (0.357 cp)	8401
thermal conductivity, liquid:	0.0656 W/m•K (0.0379 Btu/hr•ft°F)	8401
thermal conductivity, vapor:	0.0091 W/m•K (0.0053 Btu/hr•ft°F)	8401
• normal pressure, 20 °C (68 °F) -----		
density, vapor:	7.342 kg/m3 (0.4584 lb/cf)	8401
• normal pressure, 21.1 °C (70 °F) ---		
density, vapor:	7.312 kg/m3 (0.4564 lb/cf)	8401
• 20 °C (68 °F) ----------		
pressure, saturated vapor:	182.0 kPa (26.40 psia)	8401
density, saturated liquid:	1470 kg/m3 (91.76 lb/cf)	8401
density, saturated vapor:	13.59 kg/m3 (0.848 lb/cf)	8401
specific volume, saturated liquid:	0.680 L/kg (0.0109 cf/lb)	8401
specific volume, saturated vapor:	16.0 L/kg (0.2560 cf/lb)	8401
velocity of sound, saturated liquid:	570 m/s (1870 ft/s)	8401
velocity of sound, saturated vapor:	117 m/s (385 ft/s)	8401
viscosity, saturated liquid:	295 µPa•s (0.295 cp)	8401
viscosity, saturated vapor:	10.6 µPa•s (0.0106 cp)	8401
thermal conductivity, saturatd liquid:	0.0620 W/m•K (0.0358 Btu/hr•ft°F)	8401
thermal conductivity, saturated vapor:	0.00999 W/m•K (0.00577 Btu/hr•ft°F)	8401
• 60 °C (140 °F) ----------		
pressure, saturated vapor:	580 kPa (84.1 psia)	8401
heat of vaporization:	112.7 kJ/kg (48.5 Btu/lb)	8401
• critical point ----------		
temperature:	145.7 °C (294.2 °F)	8401
pressure:	3257 kPa (472.4 psia)	8401
density:	580 kg/m3 (36.2 lb/cf)	8401
specific volume:	1.72 L/kg (0.0276 cf/lb)	8401
ENVIRONMENTAL		
average atmospheric lifetime (τatm):	300 yr	6695
ODP (ozone depletion potential):	0.85 (model-derived relative to R 11)	5301
	1.0 (estimate used for the Montreal Protocol)	6904
GWP (global warming potential):	9800 relative to CO2 for 100 yr integration	9501
HGWP (halocarbon GWP):	7.20 relative to R 11 for infinite integration period	DW
SAFETY		
• classification ----------		
safety group (ASHRAE Standard 34):	A1	8601

NFPA 704 degrees of hazard (H-F-R-S):	ARI recommendation: 2-0-0	3A15
	BOC Gases: 1-0-0	MSDS
	Honeywell: 2-0-0	MSDS
	health-flammability-reactivity [-special]: 0=no, 4=severe	
NPCA HMIS hazard ratings (H-F-R):	BOC Gases: 1-0-0	MSDS
	DuPont: 1-0-1	MSDS
	Honeywell: 1-0-0	MSDS
	health-flammability-reactivity 0=insignificant, 4=extreme	
UL Comparative Hazard to Life Group:	6 in absence of flame or hot objects	4B64
ACGIH carcinogenicity category:	A4, not classifiable as a uman carcinogen	9504
• short-term occupational limit ------		
NIOSH IDLH (immediately dangerous):	15,000 ppm v/v	5204
NIOSH SCP IDLH (immediately dangerous:	50,000 ppm v/v for 30 min	3903
• occupational exposure limit --------		
MAK (maximum workplace concentration):	IV: 2,000 ppm v/v momentary 60 min	5561
• long-term occupational limit -------		
OSHA PEL (permissible exposure limit):	1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	3904
NIOSH REL (recommendd exposure limit):	1,000 ppm v/v TWA for 10 hr/day and 40 hr/wk	3903
ACGIH TLV-TWA (time-weighted average):	1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	9504
MAK (maximum workplace concentration):	1,000 ppm v/v TWA for 8 hr/day 40 (or 42) hr/wk	5561
	being examined for changes	7101
• emergency exposure limit ----------		
NRC EEGL (emergency exposure level):	1 hr: 10,000 ppm v/v ceiling guidance level for single emergency exposures	7414
	24 hr: 1,000 ppm v/v ceiling guidance level for single emergency exposures	7414
Acute Toxicity Exposure Limit (ATEL):	20,000 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	20,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
Refrigerant Concentration Limit (RCL):	20,000 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	20,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
• special-purpose exposure control ---		
NRC CEGL (continuous exposure level):	90 day: 100 ppm v/v ceiling guidance for prolonged exposure in closed environments	7414
• acute (short-term) toxicity --------		
LC50 (lethal concentration, 50%):	rat, 30 min: 720,000 ppm (fatal concentration by inhalation for half of test animals)	5179
	rat, hr: >600,000 ppm (fatal concentration by inhalation for half of test animals)	5355
	rat, hr, ElfAtochem: 600,000 ppm (fatal concentration by inhalation for half of test animals)	MSDS
oral LD50 (lethal dosage, 50%):	rat: >2,250 mg/kg (fatal dose by ingestion for half of test	65H5

	animals)	
cardiac sensitization (CS) EC50:	dog, 10 min: 46,000-100,000 ppm v/v (effective concentration in half of test animals)	6684
	dog, 5 min: 25,000-50,000 ppm v/v (effective concentration in half of test animals)	5644
cardiac sensitization threshold/LOEL:	dog, 5 min, 1/12: 25,000 ppm v/v (lowest observed effect level in test animals)	5644
anesthetic/CNS effect EC50:	rat, 10 min: 250,000 ppm v/v (effective concentration in half of test animals)	5855
anesthetic/CNS effect NOEL:	rat, 2 hr: 100,000 ppm v/v (no observed effect level in ALC or LC50 studies)	5365
• flammability ----------		
LFL-UFL (flammability limits in air):	none (nonflammable as tested)	0036
heat of combustion (by ASHRAE 34-92):	-3.1 MJ/kg (-1333 Btu/lb)	2318
flash point:	none (nonflammable as tested)	3903
autoignition temperature:	>750 °C (>1382 °F)	5931
autodecomposition temperature:	DuPont: 593 °C (1099 °F)	MSDS
former UL Classification:	nonflammable (withdrawn for revision of the classification system, category SBQT2)	5931
• detection ----------		
appearance:	colorless	7414
odor:	DuPont: slight ethereal	MSDS
	nearly odorless	5367
PRODUCTION		
first commercial use as a refrigerant:	1933 by T. Midgley, associates	5C39
last year production allowed:	1995 in developed countries under the Montreal Protocol	8C01

R-115

---------- REFRIGERANT DATA SUMMARY ----------

			see
R-115	chloropentafluoroethane		see
CFC	CClF2CF3	CAS number 76-15-3	RDB#

COMMON USE(S)
component of refrigerant 502; limited use as a single-compound refrigerant for refrigerated display cases in Japan; industrial refrigeration with centrifugal (turbo) compressors); dielectric fluid; formerly used, until phased out pursuant to the Montreal Protocol, as an aerosol propellant for foods and other uses, as an aerating agent for foamed or sprayed food products and as a food additive for vapor depression; also formerly used as a plasma etchant

IDENTIFIERS

common name(s):	R-115; R115; R 115	
	CFC-115	
	CPFE	5C41
	fluorocarbon 115	
	fluorochemical 115; FC 115	
	halocarbon 115	
chemical name (by IUPAC convention):	chloropentafluoroethane	
alternative chemical names/formulae:	1-chloro-1,1,2,2,2-pentafluoroethane	
	ethane, chloropentafluoro-	
	ethane, 1-chloro-1,1,2,2,2-pentafluoro-	
	monochloropentafluoroethane	
	CClF2CF3; CClF2-CF3	
	not recommended: F3CClF2; CF3-CClF2; ClF2CCF3; ClF2C-CF3; 3CCClF2; F3C-CClF2	
empirical formula:	C2ClF5	
CAS number:	76-15-3 (Chemical Abstracts Service registry number)	
EINECS number:	200-938-2 (European Inventory of Existing Chemical Substances)	
NIOSH RTECS number:	KH7877500 (Registry of Toxic Effects of Chemical Substances)	
trade name(s):	Asahi Glass Fron AF-115	
	Daikin Daiflon(R) 115	
	DuPont Freon(R) 115	MSDS
	Elf Atochem Forane(R) 115	MSDS
	Honeywell Genetron(R) 115	
	ICI Arcton(R) 115	MSDS
historical name(s):	Allied Corp refrigerant 410	
	AlliedSignal Genetron(R) 115	MSDS
	Hoechst Frigen(R) 115	
ARI container color / Pantone number:	none, use light green grey/413	6601

PHYSICAL

• properties ----------		
molar mass:	154.466116 g/mol (0.340539 lb/mol)	8820
normal freezing/melting/triple point:	-99.4 °C (-146.9 °F)	8401
• normal boiling point ----------		
temperature:	-38.9 °C (-38.1 °F)	8401
density, saturated liquid:	1558 kg/m3 (97.28 lb/cf)	8401

density, saturated vapor:	8.41 kg/m3 (0.525 lb/cf)	8401
specific volume, saturated liquid:	0.642 L/kg (0.0103 cf/lb)	8401
specific volume, saturated vapor:	119.0 L/kg (1.9054 cf/lb)	8401
heat of vaporization:	125.4 kJ/kg (53.9 Btu/lb)	8401
velocity of sound, saturated liquid:	610 m/s (2002 ft/s)	8401
velocity of sound, saturated vapor:	113 m/s (372 ft/s)	8401
viscosity, saturated liquid:	336 µPa•s (0.336 cp)	8401
viscosity, saturated vapor:	9.72 µPa•s (0.00972 cp)	8401
thermal conductivity, liquid:	0.0712 W/m•K (0.0411 Btu/hr•ft°F)	8401
thermal conductivity, vapor:	0.0082 W/m•K (0.0047 Btu/hr•ft°F)	8401
• normal pressure, 20 °C (68 °F) -----		
density, vapor:	6.555 kg/m3 (0.4092 lb/cf)	8401
• normal pressure, 21.1 °C (70 °F) ---		
density, vapor:	6.529 kg/m3 (0.4076 lb/cf)	8401
• 20 °C (68 °F) ----------		
pressure, saturated vapor:	789.3 kPa (114.48 psia)	8401
density, saturated liquid:	1315 kg/m3 (82.07 lb/cf)	8401
density, saturated vapor:	61.82 kg/m3 (3.859 lb/cf)	8401
specific volume, saturated liquid:	0.761 L/kg (0.0122 cf/lb)	8401
specific volume, saturated vapor:	16.2 L/kg (0.2591 cf/lb)	8401
velocity of sound, saturated liquid:	359 m/s (1177 ft/s)	8401
velocity of sound, saturated vapor:	109 m/s (357 ft/s)	8401
viscosity, saturated liquid:	153 µPa•s (0.153 cp)	8401
viscosity, saturated vapor:	12.3 µPa•s (0.0123 cp)	8401
thermal conductivity,. saturatd liquid:	0.0525 W/m•K (0.0303 Btu/hr•ft°F)	8401
thermal conductivity, saturated vapor:	0.01789 W/m•K (0.01034 Btu/hr•ft°F)	8401
• 60 °C (140 °F) ----------		
pressure, saturated vapor:	2078 kPa (301.3 psia)	8401
heat of vaporization:	62.9 kJ/kg (27.1 Btu/lb)	8401
• critical point ----------		
temperature:	80.0 °C (175.9 °F)	8401
pressure:	3120 kPa (452.5 psia)	8401
density:	613 kg/m3 (38.3 lb/cf)	8401
specific volume:	1.63 L/kg (0.0261 cf/lb)	8401
ENVIRONMENTAL		
average atmospheric lifetime (τatm):	1700 yr	6695
ODP (ozone depletion potential):	0.40 (model-derived relative to R 11)	9501
	0.6 (estimate used for the Montreal Protocol)	6904
GWP (global warming potential):	10,300 relative to CO2 for 100 yr integration	9501
HGWP (halocarbon GWP):	36.0 relative to R 11 for infinite integration period	DW
SAFETY		
• classification ----------		
safety group (ASHRAE Standard 34):	A1	8601
NFPA 704 degrees of hazard (H-F-R-S):	BOC Gases: 1-0-0	MSDS
	Elf Atochem: 2-0-0	MSDS
	health-flammability-reactivity [-special]: 0=no, 4=severe	
NPCA HMIS hazard ratings (H-F-R):	BOC Gases: 1-0-0	MSDS
	DuPont: 1-0-1	MSDS
	health-flammability-reactivity 0=insignificant, 4=extreme	
UL Comparative Hazard to Life Group:	6 in absence of flame or hot objects	5931

• long-term occupational limit -------		
NIOSH REL (recommendd exposure limit):	1,000 ppm v/v TWA for 10 hr/day and 40 hr/wk	5204
ACGIH TLV-TWA (time-weighted average):	1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	9504
exposure limit consistent to OSHA PEL:	ICI LTEL: 1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	CSDS
• emergency exposure limit ----------		
Acute Toxicity Exposure Limit (ATEL):	120,000 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	provisional: 120,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
Refrigerant Concentration Limit (RCL):	69,000 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	provisional: 69,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
• acute (short-term) toxicity --------		
ALC (approximate lethal concentration:	rat, 2 hr, 0/4: >600,000 ppm (lowest exposure tested with one or more deaths by inhalation)	5365
	rat, 4 hr, 0/4: >800,000 ppm (lowest exposure tested with one or more deaths by inhalation)	7616
	rat, 4 hr, 0/4: >800,000 ppm (lowest exposure tested with one or more deaths by inhalation)	7617
oral LD50 (lethal dosage, 50%):	dog: >1,200 mg/kg (fatal dose by ingestion for half of test animals)	7239
	rat, DuPont: >1,200 mg/kg (fatal dose by ingestion for half of test animals)	MSDS
cardiac sensitization (CS) EC50:	dog, 10 min: 320,000 ppm v/v (effective concentration in half of test animals)	6684
cardiac sensitization threshold/LOEL:	dog, 5 min, 1/13: 150,000 ppm v/v (lowest observed effect level in test animals)	5644
anesthetic/CNS effect EC50:	rat, 10 min: estimated 250,000 ppm v/v (effective concentration in half of test animals)	A622
anesthetic/CNS effect NOEL:	rat, 2 hr, 0/4: 600,000 ppm v/v (no observed effect level in ALC or LC50 studies)	5365
	rat, 3½-4 hr, 0/4: 800,000 ppm v/v (no observed effect level in ALC or LC50 studies)	7616
• flammability ----------		
LFL-UFL (flammability limits in air):	none (nonflammable as tested)	2250
heat of combustion (by ASHRAE 34-92):	-2.1 MJ/kg (-903 Btu/lb)	2318
flash point:	none (nonflammable as tested)	5204
autoignition temperature:	880 °C (1616 °F)	3960
autodecomposition temperature:	DuPont: >700 °C (>1292 °F)	MSDS
former UL Classification:	nonflammable (withdrawn for revision of the classification system, category SBQT2)	5931

• detection ----------		
appearance:	DuPont: clear, colorless	MSDS
odor:	AlliedSignal: faint ethereal	MSDS
PRODUCTION		
last year production allowed:	1995 in developed countries under the Montreal Protocol	8C01

R-116

---------- REFRIGERANT DATA SUMMARY ----------			
R-116	hexafluoroethane		see
FC	CF3CF3	CAS number 76-16-4	RDB#

COMMON USE(S)
low-temperature applications, alone and as a blend component; component of refrigerants 508A, 508B, and others; under consideration as a fire suppressant; dielectric gas; plasma etchant

IDENTIFIERS

common name(s):	R-116; R116; R 116 FC-116 fluorocarbon 116 fluorochemical 116; FC 116 halocarbon 116 halochemical 116 perfluorocarbon 116; "PFC-116"	
chemical name (by IUPAC convention):	hexafluoroethane	
alternative chemical names/formulae:	ethane, hexafluoro- perfluoroethane 1,1,1,2,2,2-hexafluoroethane ethane, 1,1,1,2,2,2-hexafluoro ethane, perfluoro- CF3CF3; CF3-CF3 not recommended: (CF3)2; 3CCF3; F3C-CF3	
empirical formula:	C2F6	
CAS number:	76-16-4 (Chemical Abstracts Service registry number)	
Beilstein registry number:	1740328	
EINECS number:	200-939-8 (European Inventory of Existing Chemical Substances)	
NIOSH RTECS number:	KI4100000 (Registry of Toxic Effects of Chemical Substances)	
trade name(s):	BOC Gases Halocarbon 116 DuPont Freon(R) 116	MSDS 5605
historical name(s):	Allied Corp refrigerant 500	
ARI container color / Pantone number:	dark grey (battleship) / 424	6601

PHYSICAL

• properties ----------		
molar mass:	138.0118192 g/mol (0.304264 lb/mol)	8820
normal freezing/melting/triple point:	-97.1 °C (-142.9 °F)	8401
• normal boiling point ----------		
temperature:	-78.2 °C (-108.7 °F)	8401
density, saturated liquid:	1604 kg/m3 (100.13 lb/cf)	8401
density, saturated vapor:	9.09 kg/m3 (0.568 lb/cf)	8401
specific volume, saturated liquid:	0.623 L/kg (0.0100 cf/lb)	8401
specific volume, saturated vapor:	110.0 L/kg (1.7620 cf/lb)	8401
heat of vaporization:	116.2 kJ/kg (49.9 Btu/lb)	8401
velocity of sound, saturated liquid:	522 m/s (1712 ft/s)	8401
velocity of sound, saturated vapor:	110 m/s (361 ft/s)	8401
viscosity, saturated liquid:	314 µPa•s (0.314 cp)	8401
viscosity, saturated vapor:	9.18 µPa•s (0.00918 cp)	8401
thermal conductivity, liquid:	0.0691 W/m•K (0.0399 Btu/hr•ft°F)	8401
thermal conductivity, vapor:	0.0075 W/m•K (0.0043	8401

	Btu/hr•ft°F)	
• normal pressure, 20 °C (68 °F) -----		
density, vapor:	5.796 kg/m3 (0.3619 lb/cf)	8401
• normal pressure, 21.1 °C (70 °F) ---		
density, vapor:	5.774 kg/m3 (0.3604 lb/cf)	8401
• critical point ----------		
temperature:	19.9 °C (67.8 °F)	8401
pressure:	3042 kPa (441.2 psia)	8401
density:	622 kg/m3 (38.8 lb/cf)	8401
specific volume:	1.61 L/kg (0.0258 cf/lb)	8401
ENVIRONMENTAL		
average atmospheric lifetime (τatm):	10,000 yr	6694
ODP (ozone depletion potential):	0.000 (model-derived relative to R 11)	
GWP (global warming potential):	11,400 relative to CO2 for 100 yr integration	9501
HGWP (halocarbon GWP):	205 relative to R 11 for infinite integration period	DW
SAFETY		
• classification ----------		
safety group (ASHRAE Standard 34):	A1	8601
NFPA 704 degrees of hazard (H-F-R-S):	BOC Gases: 1-0-0 health-flammability-reactivity [-special]: 0=no, 4=severe	MSDS
NPCA HMIS hazard ratings (H-F-R):	BOC Gases: 1-0-0	MSDS
	DuPont: 1-0-1 health-flammability-reactivity 0=insignificant, 4=extreme	MSDS
UL Comparative Hazard to Life Group:	6 by estimate (not UL test) in absence of flame or hot objects	5906
• long-term occupational limit -------		
exposure limit consistent to OSHA PEL:	DuPont AEL: 1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	5605
	ICI LTEL: 1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	CSDS
• emergency exposure limit ----------		
Acute Toxicity Exposure Limit (ATEL):	97,000 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	97,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
Refrigerant Concentration Limit (RCL):	69,000 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	69,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
• acute (short-term) toxicity --------		
ALC (approximate lethal concentration:	rat, 1 hr, 0/10: >800,000 ppm (lowest exposure tested with one or more deaths by inhalation)	7550
	rat, 4 hr, 0/4: >800,000 ppm (lowest exposure tested with one or more deaths by inhalation)	7616
cardiac sensitization threshold/LOEL:	dog: >200,000 ppm v/v (lowest observed effect level in test animals)	6120
cardiac sensitization (CS) NOEL:	dog: 200,000 ppm v/v (no observed effect level in test animals)	6120

anesthetic/CNS effect LOEL:	rat, 1 hr, 10/10: 780,000 ppm v/v (lowest observed effect level in test animals)	7550
	rat, 2 hr, ?/4: 200,000 ppm v/v (lowest observed effect level in ALC or LC50 studies)	7616
anesthetic/CNS effect NOEL:	rat, 10 day, 0/20: 121,000 ppm v/v (no observed effect level in subchronic or chronic study)	7550
• flammability ----------		
LFL-UFL (flammability limits in air):	none (nonflammable as tested)	2A06
flash point:	none (nonflammable as tested)	2250
autoignition temperature:	870 °C (1598 °F)	3960
	BOC Gases: none	MSDS
	DuPont: >870 °C (>1598 °F)	MSDS
• detection ----------		
appearance:	DuPont: clear, colorless	MSDS
odor:	BOC Gases: odorless	MSDS
	DuPont: slight ethereal	MSDS

PRODUCTION

last year production allowed:	unrestricted	8C01

R-123

---------- REFRIGERANT DATA SUMMARY ----------

R-123	2,2-dichloro-1,1,1-trifluoroethane		see
HCFC	CHCl2CF3	CAS number 306-83-2	RDB#

COMMON USE(S)
most widely used refrigerant in new centrifugal chillers (primary replacement for refrigerants 11 and 113) and retrofit of those designed for refrigerant 11; candidate for high-temperature industrial heat pumps; limited use as a specialty solvent and blend component for solvents; fire suppressant for streaming sytems (e.g., American Pacific "Halotron I", DuPont "FE-232", and NAFG "Blitz") and blend component for flooding systems (e.g., NAFG "NAF-S-III")

IDENTIFIERS

common name(s):	R-123; R123; R 123	
	HCFC-123	
	not recommended: HFA-123	
	fluorocarbon 123	
	fluorochemical 123; FC 123	
	halocarbon 123	
	halochemical 123	
	halon 232	
	hydrochlorofluorocarbon 123	
chemical name (by IUPAC convention):	2,2-dichloro-1,1,1-trifluoro-ethane	
alternative chemical names/formulae:	1,1-dichloro-2,2,2-trifluoro-ethane (not recommended)	
	ethane, 2,2-dichloro-1,1,1-trifluoro-	
	dichlorotrifluoroethane	
	trifluorodichloroethane	
	dichloro(trifluoromethyl)-methane	
	CHCl2CF3; CHCl2-CF3	
	not recommended:	
	CF3CHCl2; CF3-CHCl2	
	Cl2CHCF3; Cl2CH-CF3	
	Cl2HCCF3; Cl2HC-CF3	
	HCL2CCF3; HCl2C-CF3	
empirical formula:	C2HCl2F3	
CAS number:	306-83-2 (Chemical Abstracts Service registry number)	
Beilstein registry number:	1736763	
EINECS number:	206-190-3 (European Inventory of Existing Chemical Substances)	
NIOSH RTECS number:	KI1108000 (Registry of Toxic Effects of Chemical Substances)	
trade name(s):	Asahi Glass Asahiklin AK-123	
	Ausimont Meforex(R) 123	MSDS
	Daikin fluorocarbon HCFC-123	MSDS
	DuPont Suva(R) 123	7212
	Elf Atochem Forane(R) 123	4767
	Honeywell Genetron(R) 123	MSDS
	Solvay Solkane(R) 123	MSDS
	ZCIRI Kehua (PRC) HCFC-123	
historical name(s):	Allied Corp refrigerant 220	
	AlliedSignal Genetron(R) 123	3452
	DuPont Suva(R) Centri-LP	4504

ARI container color / Pantone number:	light blue grey / 428	6601
PHYSICAL		
• properties ----------		
molar mass:	152.9299496 g/mol (0.337153 lb/mol)	8820
normal freezing/melting/triple point:	-107.1 °C (-160.9 °F)	4319
• normal boiling point ----------		
temperature:	27.8 °C (82.1 °F)	7607
density, saturated liquid:	1457 kg/m3 (90.93 lb/cf)	7607
density, saturated vapor:	6.47 kg/m3 (0.404 lb/cf)	7607
specific volume, saturated liquid:	0.687 L/kg (0.0110 cf/lb)	8401
specific volume, saturated vapor:	154.5 L/kg (2.4753 cf/lb)	8401
heat of vaporization:	170.2 kJ/kg (73.2 Btu/lb)	7607
velocity of sound, saturated liquid:	693 m/s (2273 ft/s)	7607
velocity of sound, saturated vapor:	129 m/s (422 ft/s)	7607
viscosity, saturated vapor:	10.84 µPa•s (0.01084 cp)	8401
viscosity, saturated liquid:	404 µPa•s (0.404 cp)	8401
thermal conductivity, liquid:	0.0756 W/m•K (0.0437 Btu/hr•ft°F)	8401
thermal conductivity, vapor:	0.0093 W/m•K (0.0054 Btu/hr•ft°F)	8401
• normal pressure, 20 °C (68 °F) -----		
density, liquid:	1477 kg/m3 (12.32 lb/gal)	7607
• normal pressure, 21.1 °C (70 °F) ---		
density, liquid:	1474 kg/m3 (12.30 lb/gal)	7607
• 20 °C (68 °F) ----------		
pressure, saturated vapor:	75.6 kPa (10.97 psia)	7607
density, saturated liquid:	1477 kg/m3 (92.18 lb/cf)	7607
density, saturated vapor:	4.92 kg/m3 (0.307 lb/cf)	7607
specific volume, saturated liquid:	0.677 L/kg (0.0108 cf/lb)	8401
specific volume, saturated vapor:	203.4 L/kg (3.2578 cf/lb)	8401
velocity of sound, saturated liquid:	723 m/s (2371 ft/s)	7607
velocity of sound, saturated vapor:	128 m/s (420 ft/s)	7607
viscosity, saturated liquid:	443 µPa•s (0.443 cp)	8401
viscosity, saturated vapor:	10.6 µPa•s (0.0106 cp)	8401
thermal conductivity, saturatd liquid:	0.0778 W/m•K (0.0450 Btu/hr•ft°F)	8401
thermal conductivity, saturated vapor:	0.00889 W/m•K (0.00514 Btu/hr•ft°F)	8401
• 60 °C (140 °F) ----------		
pressure, saturated vapor:	286 kPa (41.5 psia)	7607
heat of vaporization:	155.7 kJ/kg (67.0 Btu/lb)	8401
• critical point ----------		
temperature:	183.7 °C (362.6 °F)	7607
	183.8 °C (362.8 °F)	7713
pressure:	3662 kPa (531.1 psia)	3711
density:	550 kg/m3 (34.3 lb/cf)	0915
specific volume:	1.82 L/kg (0.0291 cf/lb)	0915
ENVIRONMENTAL		
average atmospheric lifetime (τatm):	1.4 ñ0.4 yr	6695
average stratospheric lifetime (τstr):	47 yr	5508
ODP (ozone depletion potential):	0.012 (model-derived relative to R 11)	9501
	0.02 (semi-empirical relative to R 11)	9501
	0.02 (estimate used for the Montreal Protocol)	6904
GWP (global warming potential):	120 relative to CO2 for 100 yr integration	9501
HGWP (halocarbon GWP):	0.0185 ±0.0015 relative to R 11 for infinite integration period	5964

photochemical reactivity (grnd level):	4.8 relative to methane	4511
SAFETY		
• classification ----------		
safety group (ASHRAE Standard 34):	B1	8601
NFPA 704 degrees of hazard (H-F-R-S):	ARI recommendation: 2-0-0	3A15
	Ausimont: 2-0-0	MSDS
	Honeywell: 2-1-0	MSDS
NPCA HMIS hazard ratings (H-F-R):	Honeywell: 2-1-0	MSDS
	DuPont: 1-0-1	MSDS
	health-flammability-reactivity 0=insignificant, 4=extreme	
DFG carcinogicity class:	IIIB: suspect, to be evaluated	5561
• short-term occupational limit ------		
ARI "IDLH" recommendation:	4,000 ppm v/v for 30 min	3A15
recommended short-term exposure limit:	DuPont EEL: 1,000 ppm (1 hr)	4C50
	DuPont EEL: 2,500 ppm (1 min)	4C50
• long-term occupational limit -------		
AIHA WEEL (workplace envl exp limit):	50 ppm v/v TWA for 8 hr/day and 40 hr/wk	8611
exposure limit consistent to OSHA PEL:	DuPont AEL: 50 ppm v/v TWA for 8 hr/day and 40 hr/wk	MSDS
	Honeywell PEL: 10 ppm v/v TWA for 8 hr/day and 40 hr/wk	MSDS
• emergency exposure limit ----------		
NRC EEGL (emergency exposure level):	1 min: 1,900 ppm v/v ceiling guidance level for single emergency exposures	6A01
Acute Toxicity Exposure Limit (ATEL):	9,100 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	9,100 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
Refrigerant Concentration Limit (RCL):	9,100 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	9,100 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
• acute (short-term) toxicity --------		
LC50 (lethal concentration, 50%):	mouse, 30 min: 74,000 ppm (fatal concentration by inhalation for half of test animals)	6165
	rat, 10 min: 90,000 ppm (fatal concentration by inhalation for half of test animals)	A309
	rat, 4 hr: 32,000 ppm (fatal concentration by inhalation for half of test animals)	6139
ALC (approximate lethal concentration:	rat, 10 min, 1/4: 72,500 ppm (lowest exposure tested with one or more deaths by inhalation)	A309
	rat, 4 hr, 3/6: 32,000 ppm (lowest exposure tested with one or more deaths by inhalation)	6139
dermal LD50 (lethal dosage, 50%):	rabbit, 24 hr, 0/10: >2,000 mg/kg (fatal dose by skin contact for half of test animals)	6148
	rat, 24 hr, 0/5: >2,000 mg/kg (fatal dose by skin contact for half of test animals)	6147

oral LD50 (lethal dosage, 50%):	rat, 1/1: 9,000 mg/kg (fatal dose by ingestion for half of test animals)	6140
cardiac sensitization (CS) EC50:	dog, 5 min: 19,000 ppm v/v (effective concentration in half of test animals)	6146
cardiac sensitization threshold/LOEL:	dog, 5 min, 4/6: 20,900 ppm v/v (lowest observed effect level in test animals)	6146
cardiac sensitization (CS) NOEL:	dog, 5 min, 0/3: 10,300 ppm v/v (no observed effect level in test animals)	6146
anesthetic/CNS effect EC50:	mouse, 10 min: 27,000 ppm v/v (effective concentration in half of test animals)	5980
	rat, 10 min: 130,000 ppm v/v (effective concentration in half of test animals)	A309
	rat, 10 min: 40,000 ppm v/v (effective concentration in half of test animals)	A622
	rat, 15 min behavioral: 7,080 ppm v/v (effective concentration in half of test animals)	6153
anesthetic/CNS effect LOEL:	g.pig, 10-15 min, ?/10: 10,000 ppm v/v (lowest observed effect level in test animals)	6216
	rat, 15 min, ?/6: 5,237 ppm v/v (lowest observed effect level in test animals)	6153
	rat, 60 min, 1/6: 0 (control) ppm v/v (lowest observed effect level in test animals)	6153
	rat, 60 min, ?/6: 975 ppm v/v (lowest observed effect level in test animals)	6153
	rat, subchronic, ?/?: 5,000 ppm v/v (lowest observed effect level in ALC or LC50 studies)	6145
anesthetic/CNS effect NOEL:	rat, subchronic: >5,000 ppm v/v (no observed effect level in ALC or LC50 studies)	A526
• flammability ----------		
LFL-UFL (flammability limits in air):	none (nonflammable as tested)	2525
heat of combustion (by ASHRAE 34-92):	2.1 MJ/kg (903 Btu/lb)	2318
flash point:	DuPont, TOC: none	MSDS
autoignition temperature:	730 °C (1346 °F)	5C10
	DuPont Suva(R): 730°C (1346°F)	5931
	Elf Atochem: 714°C (1317°F)	6938
	Honeywell: 770 °C (1418 °F)	MSDS
autodecomposition temperature:	Honeywell: >250°C (>482°F)	MSDS
former UL Classification:	practically nonflammable (withdrawn for revision of the classification system, category SBQT2)	6938
• detection ----------		
appearance:	DuPont: clear, colorless	MSDS
odor:	Honeywell: faint ethereal and sweetish odor	MSDS

PRODUCTION		
first commercial use as a refrigerant:	1989	
last year production allowed:	2029 in developed countries under the Montreal Protocol	8C01

R-124

---------- REFRIGERANT DATA SUMMARY ----------

			see
R-124	2-chloro-1,1,1,2-tetrafluoroethane		see
HCFC	CHClFCF3	CAS number 2837-89-0	RDB#

COMMON USE(S)

blend component for refrigerants 401A, 401B, 401C, 409A, 409B, 414A, 414B, 416A, and others; industrial use in applications with high condensing temperatures (to 99 °C, 210 °F), such as air conditioners for overhead crane cabs in steel mills; under limited consideration as an alternative for refrigerant 114 in naval applications; inert ingredient for medical sterilant gases using ethylene oxide (e.g., Honeywell Oxyfume(R) 2002); fire suppressant (e.g., DuPont Chemicals FE-241) to replace halon 1301; limited consideration as a foam blowing agent especially for polystyrenes, polyurethanes, polyisocyanurates, and phenolics

R-124 was first prepared in 1936; efforts followed for several years to find an economical process for its production as a refrigerant, including by fluorination of R 123a and R 123b produced from R 1113.

IDENTIFIERS

common name(s):	R-124; R124; R 124	
	HCFC-124	
	fluorocarbon 124	
	fluorochemical 124; FC 124	
	halocarbon 124	
	halochemical 124	
	halon 241	
	hydrochlorofluorocarbon 124	
chemical name (by IUPAC convention):	2-chloro-1,1,1,2-tetrafluoro-ethane	
alternative chemical names/formulae:	1-chloro-1,2,2,2-tetrafluoro-ethane (not recommended)	
	ethane, 2-chloro-1,1,1,2-tetrafluoro-	
	chlorotetrafluoroethane	
	tetrafluoromonochloroethane	
	CHClFCF3; CHClF-CF3	
	not recommended:	
	CClFHCF3; CClFH-CF3	
	CF3CClFH; CF3-CClFH	
	CF3CHClF; CF3-CHClF	
	HClFCCF3; HClFC-CF3	
empirical formula:	C2HClF4	
CAS number:	2837-89-0 (Chemical Abstracts Service registry number)	
EINECS number:	220-629-6 (European Inventory of Existing Chemical Substances)	
trade name(s):	Asahi Glass Asahiklin AK-124	
	Ausimont Meforex(R) 124	MSDS
	Daikin fluorocarbon HCFC-124	MSDS
	DuPont Suva(R) 124	MSDS
	Elf Atochem Forane(R) 124	MSDS
	Honeywell Genetron(R) 124	MSDS
historical name(s):	Allied Corp refrigerant 310	
	AlliedSignal Genetron(R) 124	MSDS
	Kinetic Chemicals Freon 124	
ARI container color / Pantone number:	deep green (DOT green) / 335	6601

PHYSICAL		
• properties ----------		
molar mass:	136.4756528 g/mol (0.300877 lb/mol)	8820
normal freezing/melting/triple point:	-199.1 °C (-326.5 °F)	8401
• normal boiling point ----------		
temperature:	-12.0 °C (10.5 °F)	8401
density, saturated liquid:	1474 kg/m3 (91.99 lb/cf)	8401
density, saturated vapor:	6.66 kg/m3 (0.415 lb/cf)	8401
specific volume, saturated liquid:	0.679 L/kg (0.0109 cf/lb)	8401
specific volume, saturated vapor:	150.3 L/kg (2.4069 cf/lb)	8401
heat of vaporization:	165.8 kJ/kg (71.3 Btu/lb)	8401
velocity of sound, saturated liquid:	673 m/s (2209 ft/s)	8401
velocity of sound, saturated vapor:	128 m/s (419 ft/s)	8401
viscosity, saturated vapor:	10.08 µPa•s (0.01008 cp)	8401
viscosity, saturated liquid:	371 µPa•s (0.371 cp)	8401
thermal conductivity, liquid:	0.0800 W/m•K (0.0462 Btu/hr•ft°F)	8401
thermal conductivity, vapor:	0.0093 W/m•K (0.0054 Btu/hr•ft°F)	8401
• normal pressure, 20 °C (68 °F) -----		
density, vapor:	5.836 kg/m3 (0.3643 lb/cf)	8401
• normal pressure, 21.1 °C (70 °F) ---		
density, vapor:	5.812 kg/m3 (0.3628 lb/cf)	8401
• 20 °C (68 °F) ----------		
pressure, saturated vapor:	326.9 kPa (47.42 psia)	8401
density, saturated liquid:	1372 kg/m3 (85.68 lb/cf)	8401
density, saturated vapor:	20.28 kg/m3 (1.266 lb/cf)	8401
specific volume, saturated liquid:	0.729 L/kg (0.0117 cf/lb)	8401
specific volume, saturated vapor:	49.3 L/kg (0.7900 cf/lb)	8401
velocity of sound, saturated liquid:	545 m/s (1787 ft/s)	8401
velocity of sound, saturated vapor:	128 m/s (422 ft/s)	8401
viscosity, saturated liquid:	250 µPa•s (0.250 cp)	8401
viscosity, saturated vapor:	11.3 µPa•s (0.0113 cp)	8401
thermal conductivity, saturatd liquid:	0.0697 W/m•K (0.0403 Btu/hr•ft°F)	8401
thermal conductivity, saturated vapor:	0.01132 W/m•K (0.00654 Btu/hr•ft°F)	8401
• 60 °C (140 °F) ----------		
pressure, saturated vapor:	997 kPa (144.6 psia)	8401
heat of vaporization:	123.1 kJ/kg (52.9 Btu/lb)	8401
• critical point ----------		
temperature:	122.2 °C (252.0 °F)	9125
	122.3 °C (252.1 °F)	7714
pressure:	3624 kPa (525.6 psia)	8401
density:	559 kg/m3 (34.9 lb/cf)	7714
	560 kg/m3 (34.9 lb/cf)	7713
	560 kg/m3 (35.0 lb/cf)	8401
	560 kg/m3 (35.0 lb/cf)	9125
specific volume:	1.79 L/kg (0.0286 cf/lb)	8401
ENVIRONMENTAL		
average atmospheric lifetime (τatm):	6.1 ±1.5 yr	6695
average stratospheric lifetime (τstr):	130 yr	5508
ODP (ozone depletion potential):	0.026 (model-derived relative to R 11)	9501
	0.022 (estimate used for the Montreal Protocol)	6904
GWP (global warming potential):	620 relative to CO2 for 100 yr integration	9501
(halocarbon GWP):	0.10 relative to R 11 for infinite integration period	4511
photochemical reactivity (grnd level):	1.2 relative to methane	4511

SAFETY		
• classification ----------		
safety group (ASHRAE Standard 34):	A1	8601
NFPA 704 degrees of hazard (H-F-R-S):	Ausimont: 2-0-0	MSDS
	Honeywell: 2-1-0	MSDS
	health-flammability-reactivity [-special]: 0=no, 4=severe	
NPCA HMIS hazard ratings (H-F-R):	DuPont: 1-0-1	MSDS
	Honeywell: 1-1-0	MSDS
	health-flammability-reactivity 0=insignificant, 4=extreme	
UL Comparative Hazard to Life Group:	6 in absence of flame or hot objects	5176
• long-term occupational limit -------		
AIHA WEEL (workplace envl exp limit):	1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	4B88
• emergency exposure limit ----------		
Acute Toxicity Exposure Limit (ATEL):	10,000 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	10,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
Refrigerant Concentration Limit (RCL):	10,000 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	10,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
• acute (short-term) toxicity --------		
LC50 (lethal concentration, 50%):	rat, 10 min: 44,000 ppm (fatal concentration by inhalation for half of test animals)	A309
	rat, 4 hr: 262,500 ppm (fatal concentration by inhalation for half of test animals)	5170
ALC (approximate lethal concentration:	rat, 10 min, 0/4: >39,900 ppm (lowest exposure tested with one or more deaths by inhalation)	A309
	rat, 10 min, 1/4: 42,500 ppm (lowest exposure tested with one or more deaths by inhalation)	A309
	rat, 4 hr, 0/6: 230,000 ppm (lowest exposure tested with one or more deaths by inhalation)	6180
	rat, 4 hr, 6/6: 300,000 ppm (lowest exposure tested with one or more deaths by inhalation)	6180
cardiac sensitization (CS) EC50:	dog, (source unknown): 40,000 ppm v/v (effective concentration in half of test animals)	7407
cardiac sensitization threshold/LOEL:	dog, 10 min, 4/10: 25,000 ppm v/v (lowest observed effect level in test animals)	5808
cardiac sensitization (CS) NOEL:	dog, 10 min, 0/10: 10,100 ppm v/v (no observed effect level in test animals)	5808
anesthetic/CNS effect EC50:	10 min: 140,000 ppm v/v (effective concentration in half of test animals)	5C39
	rat, 10 min: 150,000 ppm v/v (effective concentration in half of test animals)	A309

anesthetic/CNS effect LOEL:	dog, 10-90 min, ?/6: 400,000 ppm v/v (lowest observed effect level in test animals)	5828
	rat, 30 min, ?/10: 100,000 ppm v/v (lowest observed effect level in test animals)	5806
	rat, 4 hr, ?/6: 160,000 ppm v/v (lowest observed effect level in test animals)	6180
anesthetic/CNS effect NOEL:	rat, 4 hr, 0/6: 48,000 ppm v/v (no observed effect level in test animals)	6180
• flammability ----------		
LFL-UFL (flammability limits in air):	none (nonflammable as tested)	2525
heat of combustion (by ASHRAE 34-92):	0.9 MJ/kg (387 Btu/lb)	2318
flash point:	Elf Atochem: none as tested	SDS
	Honeywell: gas, not applicable	MSDS
	nonflammable	4B88
autoignition temperature:	637 °C (1179 °F)	5176
	Dupont: 715 °C (1319 °F)	MSDS
autodecomposition temperature:	Honeywell: >250°C (>482°F)	MSDS
• detection ----------		
appearance:	Honeywell: clear, colorless	MSDS
odor:	Daikin: faint sweet odor	MSDS
	faint ethereal odor	4B88

PRODUCTION

first commercial use as a refrigerant:	1992	
last year production allowed:	2029 in developed countries under the Montreal Protocol	8C01

R-125

---------- REFRIGERANT DATA SUMMARY ----------			
R-125	pentafluoroethane		see
HFC	CHF2CF3	CAS number 354-33-6	RDB#

COMMON USE(S)
blend component for alternatives including refrigerants 402A, 402B, 404A, 407A, 407B, 407C, 407D, 408A, 410A, 410B, 507A, and others; use as a single-compound refrigerant is limited by low critical temperature; candidate sterilant; fire suppressant to replace halon 1301, especially for aircraft engine and cargo bay areas and for grain elevators (e.g., DuPont Chemicals FE-25 and Fenwal Safety Systems X-PAC)

IDENTIFIERS

common name(s):	R-125; R125; R 125	
	HFC-125	
	fluorocarbon 125	
	fluorochemical 125; FC 125	
	halocarbon 125	
	halochemical 125	
	halon 25	
	hydrofluorocarbon 125	
	not recommended: HFA-125	2909
chemical name (by IUPAC convention):	pentafluoroethane	
alternative chemical names/formulae:	1,1,1,2,2-pentafluoroethane	
	ethane, pentafluoro-	
	ethane, 1,1,1,2,2-pentafluoro-	
	CHF2CF3; CHF2-CF3	
	not recommended:	
	CF2HCF3; CF2H-CF3	
	CF3CF2H; CF3-CF2H	
	CF3CHF2; CF3-CHF2	
	HF2CCF3; HF2C-CF3	
empirical formula:	C2HF5	
CAS number:	354-33-6 (Chemical Abstracts Service registry number)	
EINECS number:	206-557-8 (European Inventory of Existing Chemical Substances)	
trade name(s):	AlliedSignal Genetron(R) 125	MSDS
	Asahi Glass Asahiklin AK-125	
	Ausimont Meforex(R) 125	
	Daikin fluorocarbon HFC-125	MSDS
	DuPont Suva(R) 125 Refrigerant	MSDS
	Elf Atochem Forane(R) 125	MSDS
	ICI Klea(R) 125	MSDS
	Solvay Solkane(R) 125	MSDS
	ZCIRI Kehua (PRC) HFC-125	
historical name(s):	Allied Corp refrigerant 400	
	DuPont Freon(R) 125	6455
ARI container color / Pantone number:	medium brown (tan) / 465	6601

PHYSICAL

• properties ----------		
molar mass:	120.021356 g/mol (0.264602 lb/mol)	8820
normal freezing/melting/triple point:	-100.6 °C (-149.1 °F)	8401
• normal boiling point ----------		
temperature:	-48.1 °C (-54.7 °F)	8401
density, saturated liquid:	1515 kg/m3 (94.58 lb/cf)	8401

density, saturated vapor:	6.80 kg/m3 (0.424 lb/cf)	8401
specific volume, saturated liquid:	0.660 L/kg (0.0106 cf/lb)	8401
specific volume, saturated vapor:	147.2 L/kg (2.3573 cf/lb)	8401
heat of vaporization:	164.0 kJ/kg (70.5 Btu/lb)	8401
velocity of sound, saturated liquid:	698 m/s (2289 ft/s)	8401
velocity of sound, saturated vapor:	128 m/s (419 ft/s)	8401
viscosity, saturated liquid:	406 µPa•s (0.406 cp)	8401
viscosity, saturated vapor:	9.64 µPa•s (0.00964 cp)	8401
thermal conductivity, liquid:	0.0924 W/m•K (0.0534 Btu/hr•ft°F)	8401
thermal conductivity, vapor:	0.0089 W/m•K (0.0051 Btu/hr•ft°F)	8401
• normal pressure, 20 °C (68 °F) -----		
density, vapor:	5.072 kg/m3 (0.3167 lb/cf)	8401
• normal pressure, 21.1 °C (70 °F) ---		
density, vapor:	5.052 kg/m3 (0.3154 lb/cf)	8401
• 20 °C (68 °F) ----------		
pressure, saturated vapor:	1204.5 kPa (174.70 psia)	8401
density, saturated liquid:	1219 kg/m3 (76.08 lb/cf)	8401
density, saturated vapor:	77.83 kg/m3 (4.859 lb/cf)	8401
specific volume, saturated liquid:	0.821 L/kg (0.0131 cf/lb)	8401
specific volume, saturated vapor:	12.8 L/kg (0.2058 cf/lb)	8401
velocity of sound, saturated liquid:	355 m/s (1166 ft/s)	8401
velocity of sound, saturated vapor:	119 m/s (392 ft/s)	8401
viscosity, saturated liquid:	150 µPa•s (0.150 cp)	8401
viscosity, saturated vapor:	13.1 µPa•s (0.0131 cp)	8401
thermal conductivity, saturatd liquid:	0.0619 W/m•K (0.0358 Btu/hr•ft°F)	8401
thermal conductivity, saturated vapor:	0.01472 W/m•K (0.00851 Btu/hr•ft°F)	8401
• 60 °C (140 °F) ----------		
pressure, saturated vapor:	3167 kPa (459.4 psia)	8401
heat of vaporization:	52.5 kJ/kg (22.6 Btu/lb)	8401
• critical point ----------		
temperature:	66.2 °C (151.1 °F)	8401
pressure:	3629 kPa (526.3 psia)	8401
density:	571 kg/m3 (35.7 lb/cf)	8401
specific volume:	1.75 L/kg (0.0280 cf/lb)	8401
ENVIRONMENTAL		
average atmospheric lifetime (τatm):	32.6 ñ11.4 yr	6695
average stratospheric lifetime (τstr):	400 yr	5508
ODP (ozone depletion potential):	<0.00003 (model-derived relative to R 11)	9501
GWP (global warming potential):	3800 relative to CO2 for 100 yr integration	9501
HGWP (halocarbon GWP):	0.58 ±0.07 relative to R 11 for infinite integration period	5964
	0.65 relative to R 11 for infinite integration period	DW
	0.84 relative to R 11 for infinite integration period	4511
	0.90 relative to R 11 for infinite integration period	6B35
	ICI: 0.70 relative to R 11 for infinite integration period	CSDS
photochemical reactivity (grnd level):	0.3 relative to methane	4511
SAFETY		
• classification ----------		
safety group (ASHRAE Standard 34):	A1	8601
NFPA 704 degrees of hazard (H-F-R-S):	Honeywell: 2-1-0 health-flammability-reactivity	MSDS

	[-special]: 0=no, 4=severe	
NPCA HMIS hazard ratings (H-F-R):	DuPont: 1-0-1	MSDS
	Honeywell: 1-1-0	MSDS
	health-flammability-reactivity	
	0=insignificant, 4=extreme	
• long-term occupational limit -------		
AIHA WEEL (workplace envl exp limit):	1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	5C15
exposure limit consistent to OSHA PEL:	Elf Atochem VME: 1000 ppm v/v TWA for 8 hr/day and 40 hr/wk	SDS
• emergency exposure limit ----------		
Acute Toxicity Exposure Limit (ATEL):	75,000 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
Refrigerant Concentration Limit (RCL):	69,000 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	69,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
• acute (short-term) toxicity --------		
LC50 (lethal concentration, 50%):	rat, 4 hr: >769,000 ppm (fatal concentration by inhalation for half of test animals)	5754
ALC (approximate lethal concentration:	rat, 4 hr, 0/10: >769,000 ppm (lowest exposure tested with one or more deaths by inhalation)	5754
cardiac sensitization (CS) EC50:	dog, 10 min: 139,000 ppm v/v (effective concentration in half of test animals)	5755
cardiac sensitization threshold/LOEL:	dog, 10 min, 1/6: 100,000 ppm v/v (lowest observed effect level in test animals)	5755
cardiac sensitization (CS) NOEL:	dog, 10 min, 0/6: 75,000 ppm v/v (no observed effect level in test animals)	5755
anesthetic/CNS effect LOEL:	rat, 4 hr, >5/10: 769,000 ppm v/v (lowest observed effect level in ALC or LC50 studies)	5754
anesthetic/CNS effect NOEL:	rat, 4 hr, 0/5: 709,000 ppm v/v (no observed effect level in test animals)	6457
• flammability ----------		
LFL-UFL (flammability limits in air):	none (nonflammable as tested)	2525
heat of combustion (by ASHRAE 34-92):	-1.5 MJ/kg (-645 Btu/lb)	2318
flash point:	Elf Atochem: none as tested	SDS
	nonflammable	5C15
autoignition temperature:	733 °C (1351 °F)	5931
	Honeywell: >750 °C (>1382 °F)	MSDS
autodecomposition temperature:	Honeywell: >250°C (>482°F)	MSDS
former UL Classification:	practically nonflammable (withdrawn for revision of the classification system, category SBQT2)	5931
• detection ----------		
appearance:	colorless	4C01
odor:	very faint ethereal odor	5C15
PRODUCTION		
last year production allowed:	unrestricted	8C01

R-134

REFRIGERANT DATA SUMMARY			
R-134	1,1,2,2-tetrafluoroethane		see
HFC	CHF2CHF2	CAS number 359-35-3	RDB#

COMMON USE(S)

considered circa 1990-1996 both as a blend component and use as an alternative

IDENTIFIERS

common name(s):	R-134; R134; R 134 HFC-134 fluorocarbon 134 fluorochemical 134; FC 134 halocarbon 134 halochemical 134 hydrofluorocarbon 134	
chemical name (by IUPAC convention):	1,1,2,2-tetrafluoroethane	
alternative chemical names/formulae:	ethane, 1,1,2,2-tetrafluoro- symmetrical tetrafluoroethane CHF2CHF2; CHF2-CHF2 not recommended: CF2HCF2H; CF2H-CF2H HF2CCHF2; HF2C-CHF2	
empirical formula:	C2H2F4	
CAS number:	359-35-3 (Chemical Abstracts Service registry number)	
EINECS number:	206-628-3 (European Inventory of Existing Chemical Substances)	
trade name(s):	DuPont Freon(R) 134	5864
historical name(s):	Allied Corp refrigerant 305	
ARI container color / Pantone number:	none, use light green grey/413	6601

PHYSICAL

• properties		
molar mass:	102.0308928 g/mol (0.224940 lb/mol)	8820
normal freezing/melting/triple point:	-89.0 °C (-128.2 °F)	7601
• normal boiling point		
temperature:	-19.7 °C (-3.5 °F)	2A06
	-19.8 °C (-3.6 °F)	3627
	-23.0 °C (-9.4 °F)	2250
• normal pressure, 20 °C (68 °F)		
density, vapor:	4.343 kg/m3 (0.2711 lb/cf)	4101
• critical point		
temperature:	119.0 °C (246.1 °F)	7713
pressure:	4562 kPa (661.7 psia)	2834
	4615 kPa (669.4 psia)	0918
density:	535 kg/m3 (33.4 lb/cf)	0918
	539 kg/m3 (33.6 lb/cf)	7713
specific volume:	1.87 L/kg (0.0299 cf/lb)	0918

ENVIRONMENTAL

average atmospheric lifetime (τatm):	10.6 +21.2,-10.6 yr	6695
ODP (ozone depletion potential):	0.000 (model-derived relative to R 11)	
GWP (global warming potential):	1200 relative to CO2 for 100 yr integration	9501

HGWP (halocarbon GWP):	0.21 relative to R 11 for infinite integration period	DW
SAFETY		
• classification ----------		
safety group (ASHRAE Standard 34):	none (no application pending)	8601
NPCA HMIS hazard ratings (H-F-R):	DuPont: 1-0-2 health-flammability-reactivity 0=insignificant, 4=extreme	MSDS
• long-term occupational limit -------		
exposure limit consistent to OSHA PEL:	DuPont AEL: 1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	MSDS
• emergency exposure limit ----------		
Acute Toxicity Exposure Limit (ATEL):	75,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
Refrigerant Concentration Limit (RCL):	69,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
• acute (short-term) toxicity --------		
ALC (approximate lethal concentration:	rat, 4 hr, 0/6: >460,000 ppm (lowest exposure tested with one or more deaths by inhalation)	6188
cardiac sensitization threshold/LOEL:	dog, 33%: 100,000 ppm v/v (lowest observed effect level in test animals)	6802
cardiac sensitization (CS) NOEL:	dog, 0%: 75,000 ppm v/v (no observed effect level in test animals)	6802
anesthetic/CNS effect LOEL:	rat, 4 hr, ?/6: 200,000 ppm v/v (lowest observed effect level in ALC or LC50 studies)	6188
anesthetic/CNS effect NOEL:	rat, 4 hr, 0/6: 120,000 ppm v/v (no observed effect level in ALC or LC50 studies)	6188
• flammability ----------		
LFL-UFL (flammability limits in air):	none (nonflammable as tested)	2525
heat of combustion (by ASHRAE 34-92):	4.3 MJ/kg (1849 Btu/lb)	2318
autoignition temperature:	630 °C (1166 °F)	3960
• detection ----------		
appearance:	clear, colorless liquified gas	5864
odor:	slight ethereal odor	5864
PRODUCTION		
first commercial use as a refrigerant:	not known to be commercialized	
last year production allowed:	unrestricted	8C01

R-134a

---------- REFRIGERANT DATA SUMMARY ----------

R-134a	1,1,1,2-tetrafluoroethane		see
HFC	CH2FCF3	CAS number 811-97-2	RDB#

COMMON USE(S)
domestic and commercial refrigeration, automobile air conditioners, transport refrigeration, centrifugal chillers; primary alternative for refrigerants 12 and 500; blend component for alternatives including refrigerants 404A, 407A, 407B, 407C, 407D, 413A, 416A, and others; foam blowing agent especially for polystyrenes, polyurethanes, polyisocyanurates, and phenolics; aerosol propellant; pharmaceutical propellant for metered dose inhalers; fire suppressant, usually as a blend component, for streaming systems (e.g., NAFG "NAF P-III")

IDENTIFIERS

common name(s):	R-134a; R134a; R 134a	
	HFC-134a	
	TFE	7274
	fluorocarbon 134a	
	fluorochemical 134a; FC 134a	
	halocarbon 134a	
	halochemical 134a	
	hydrofluorocarbon 134a	
	not recommended: HFA-134a	
chemical name (by IUPAC convention):	1,1,1,2-tetrafluoroethane	
alternative chemical names/formulae:	ethane, 1,1,1,2-tetrafluoro-	
	CH2FCF3; CH2F-CF3	
	not recommended:	
	CF3CFH2; CF3-CFH2	
	CF3CH2F; CF3-CH2F	
	CFH2CF3; CFH2-CF3	
	F3CCFH2; F3C-CFH2	
	F3CCH2F; F3C-CH2F	
	FCH2CF3; FCH2-CF3	
	H2FCCF3; H2FC-CF3	LPCR
empirical formula:	C2H2F4	
CAS number:	811-97-2 (Chemical Abstracts Service registry number)	
EINECS number:	212-377-0 (European Inventory of Existing Chemical Substances)	
trade name(s):	Asahi Glass Asahiklin AK-134a	
	Ausimont Meforex(R) 134a	MSDS
	Daikin fluorocarbon HFC-134a	MSDS
	DuPont Suva(R) 134a	6739
	Elf Atochem Forane(R) 134a	4768
	HRP (UK) HARP(R) 134a	
	Honeywell Genetron(R) 134a	MSDS
	ICI Klea(R) 134a	6302
	RGI Quick Change (with MO/PAG)	
	Rhodia Isceon 134a	
	Solvay Solkane(R) 134a	MSDS
historical name(s):	Allied Corp refrigerant 300	
	AlliedSignal Genetron(R) 134a	3453
	DuPont Suva(R) Cold-MP	
	DuPont Suva(R) Trans-AC	
	Hoechst Reclin(R) 134a	
	Rhône-Poulenc Isceon 134a	3331
ARI container color / Pantone number:	light blue (sky) / 2975	6601

PHYSICAL		
• properties ----------		
molar mass:	102.0308928 g/mol (0.224940 lb/mol)	8820
normal freezing/melting/triple point:	-103.3 °C (-153.9 °F)	8401
• normal boiling point ----------		
temperature:	-26.1 °C (-14.9 °F)	8401
density, saturated liquid:	1377 kg/m3 (85.94 lb/cf)	8401
density, saturated vapor:	5.26 kg/m3 (0.328 lb/cf)	8401
specific volume, saturated liquid:	0.726 L/kg (0.0116 cf/lb)	8401
specific volume, saturated vapor:	190.2 L/kg (3.0464 cf/lb)	8401
heat of vaporization:	217.0 kJ/kg (93.3 Btu/lb)	8401
velocity of sound, saturated liquid:	742 m/s (2434 ft/s)	8401
velocity of sound, saturated vapor:	146 m/s (478 ft/s)	8401
viscosity, saturated liquid:	384 µPa•s (0.384 cp)	8401
viscosity, saturated vapor:	9.68 µPa•s (0.00968 cp)	8401
thermal conductivity, liquid:	0.1039 W/m•K (0.0600 Btu/hr•ft°F)	8401
thermal conductivity, vapor:	0.0093 W/m•K (0.0054 Btu/hr•ft°F)	8401
• normal pressure, 20 °C (68 °F) -----		
density, vapor:	4.336 kg/m3 (0.2707 lb/cf)	8401
• normal pressure, 21.1 °C (70 °F) ---		
density, vapor:	4.319 kg/m3 (0.2696 lb/cf)	8401
• 20 °C (68 °F) ----------		
pressure, saturated vapor:	571.5 kPa (82.89 psia)	8401
density, saturated liquid:	1225 kg/m3 (76.49 lb/cf)	8401
density, saturated vapor:	27.78 kg/m3 (1.734 lb/cf)	8401
specific volume, saturated liquid:	0.816 L/kg (0.0131 cf/lb)	8401
specific volume, saturated vapor:	36.0 L/kg (0.5766 cf/lb)	8401
velocity of sound, saturated liquid:	530 m/s (1738 ft/s)	8401
velocity of sound, saturated vapor:	145 m/s (476 ft/s)	8401
viscosity, saturated liquid:	211 µPa•s (0.211 cp)	8401
viscosity, saturated vapor:	11.6 µPa•s (0.0116 cp)	8401
thermal conductivity, saturatd liquid:	0.0833 W/m•K (0.0481 Btu/hr•ft°F)	8401
thermal conductivity, saturated vapor:	0.01333 W/m•K (0.00770 Btu/hr•ft°F)	8401
• 60 °C (140 °F) ----------		
pressure, saturated vapor:	1682 kPa (243.9 psia)	8401
heat of vaporization:	139.1 kJ/kg (59.8 Btu/lb)	8401
• critical point ----------		
temperature:	101.1 °C (213.9 °F)	8401
pressure:	4059 kPa (588.7 psia)	8401
density:	512 kg/m3 (32.0 lb/cf)	8401
specific volume:	1.95 L/kg (0.0313 cf/lb)	8401
ENVIRONMENTAL		
average atmospheric lifetime (τatm):	13.6 yr	9501
average stratospheric lifetime (τstr):	210 yr	5508
ODP (ozone depletion potential):	≤0.000015 (model-derived relative to R 11)	9501
	<0.0005 (semi-empirical relative to R 11)	9501
GWP (global warming potential):	1600 relative to CO2 for 100 yr integration	9501
HGWP (halocarbon GWP):	0.28 relative to R 11 for infinite integration period	6739
	ICI: 0.30 relative to R 11 for infinite integration period	CSDS
photochemical reactivity (grnd level):	0.6 relative to methane	4511

SAFETY		
• classification ----------		
safety group (ASHRAE Standard 34):	A1	8601
NFPA 704 degrees of hazard (H-F-R-S):	ARI recommendation: 2-0-0	3A15
	Honeywell: 2-1-0	MSDS
	health-flammability-reactivity [-special]: 0=no, 4=severe	
NPCA HMIS hazard ratings (H-F-R):	Honeywell: 1-1-0	MSDS
	DuPont: 1-0-1	MSDS
	health-flammability-reactivity 0=insignificant, 4=extreme	
DFG pregnancy risk group:	C (no risk fear below MAK/BAT)	7101
• short-term occupational limit ------		
ARI "IDLH" recommendation:	50,000 ppm v/v for 30 min	3A15
• occupational exposure limit --------		
MAK (maximum workplace concentration):	IV: 2,000 ppm v/v momentary 60 min	7101
• long-term occupational limit -------		
AIHA WEEL (workplace envl exp limit):	1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	4B86
exposure limit consistent to OSHA PEL:	ARI: 1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	3A15
MAK (maximum workplace concentration):	1,000 ppm v/v TWA for 8 hr/day 40 (or 42) hr/wk	7101
• emergency exposure limit ----------		
NRC EEGL (emergency exposure level):	1 hr: 4,000 ppm v/v ceiling guidance level for single emergency exposures	6A01
	24 hr: 1,000 ppm v/v ceiling guidance level for single emergency exposures	6A01
Acute Toxicity Exposure Limit (ATEL):	50,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
	50,000 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
Refrigerant Concentration Limit (RCL):	50,000 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	50,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
• special-purpose exposure control ---		
NRC CEGL (continuous exposure level):	90 day: 1,000 ppm v/v ceiling guidance for prolonged exposure in closed environments	6A01
• acute (short-term) toxicity --------		
LC50 (lethal concentration, 50%):	rat, 15 min: >800,000 ppm (fatal concentration by inhalation for half of test animals)	5A79
ALC (approximate lethal concentration:	rat, 30 min, 2/4: 750,000 ppm (lowest exposure tested with one or more deaths by inhalation)	6525
	rat, 4 hr, 0/6: 359,300 ppm (lowest exposure tested with one or more deaths by inhalation)	6529
	rat, 4 hr, 5/6: 566,700 ppm (lowest exposure tested with one or more deaths by inhalation)	6529
cardiac sensitization (CS) EC50:	dog, 10 min: 205,000 ppm v/v (effective concentration in half of test animals)	6684

cardiac sensitization threshold/LOEL:	dog, 10 min, 2/10: 75,200 ppm v/v (lowest observed effect level in test animals)	6527
cardiac sensitization (CS) NOEL:	dog, 10 min, 0/10: 49,800 ppm v/v (no observed effect level in test animals)	6527
anesthetic/CNS effect EC50:	mouse, rapid: 270,000 ppm v/v (effective concentration in half of test animals)	7274
	rat, 10 min: 280,000 ppm v/v (effective concentration in half of test animals)	5A79
anesthetic/CNS effect LOEL:	dog, 1 hr, ?/?: 160,000 ppm v/v (lowest observed effect level in ALC or LC50 studies)	8111
	rat, 4 hr, ?/6: 205,200 ppm v/v (lowest observed effect level in ALC or LC50 studies)	6529
anesthetic/CNS effect NOEL:	dog, 1 hr, 0/?: 80,000 ppm v/v (no observed effect level in ALC or LC50 studies)	8111
	rat, 4 hr, 0/6: 81,000 ppm v/v (no observed effect level in ALC or LC50 studies)	6529
	human, 1 hr, 0/8: 7,600 ppm v/v (no observed effect level)	A535
• flammability ----------		
LFL-UFL (flammability limits in air):	none (nonflammable as tested)	2525
	none (nonflammable as tested)	5648
heat of combustion (by ASHRAE 34-92):	4.2 MJ/kg (1806 Btu/lb)	2318
flash point:	none (nonflammable as tested)	4682
autoignition temperature:	743 °C (1369 °F)	6938
	770 °C (1418 °F)	4682
	Dupont: >743 °C (>1369 °F)	MSDS
former UL Classification:	practically nonflammable (withdrawn for revision of the classification system, category SBQT2)	6938
• detection ----------		
appearance:	clear, colorless gas	4940
odor:	faint ethereal odor	6B26
PRODUCTION		
first commercial use as a refrigerant:	1990	
last year production allowed:	unrestricted	8C01

R-E134

REFRIGERANT DATA SUMMARY			
R-E134	difluoromethoxy-difluoromethane		see
HFE	CHF2-O-CHF2	CAS number 1691-17-4	RDB#

COMMON USE(S)
candidate alternative for refrigerant 114, alone and as a blend component, though believed to have been rejected as such for naval applications based on compatibility tests with air purification systems; examined in early 1990s as a foam-blowing agent or aerosol propellant, but not commercialized; originally identified as an anesthetic to replace halothane, but found to be unsuitable; use as a refrigerant may be covered by U.S. patent 4,961,321

IDENTIFIERS

common name(s):	R-E134; RE134; R E134 HFE-E134; HFOC-E134 fluorochemical E134; FC E134 fluoroether E134; E-134 halochemical E134	
chemical name (by IUPAC convention):	difluoromethoxy- difluoromethane	
alternative chemical names/formulae:	methane, difluoromethoxy- difluoro- bis(difluoromethyl) ether di(difluoromethyl) ether 1,1,3,3-tetrafluorodimethyl ether CHF2OCHF2; CHF2-O-CHF2 not recommended: CF2HOCF2H; CF2H-O-CF2H HF2COCHF2; HF2C-O-CHF2	
empirical formula:	C2H2F4O	
CAS number:	1691-17-4 (Chemical Abstracts Service registry number)	

PHYSICAL

• properties		
molar mass:	118.0302928 g/mol (0.260212 lb/mol)	8820
normal freezing/melting/triple point:	-151.1 °C (-240.0 °F)	5550
• normal boiling point		
temperature:	4.7 °C (40.4 °F)	9318
	5.2 °C (41.3 °F)	8703
	6.2 °C (43.1 °F)	3327
density, saturated liquid:	1425 kg/m3 (88.96 lb/cf)	4101
density, saturated vapor:	5.42 kg/m3 (0.338 lb/cf)	4101
specific volume, saturated liquid:	0.702 L/kg (0.0112 cf/lb)	4101
specific volume, saturated vapor:	184.6 L/kg (2.9570 cf/lb)	4101
velocity of sound, saturated liquid:	734 m/s (2409 ft/s)	4101
velocity of sound, saturated vapor:	142 m/s (466 ft/s)	4101
viscosity, saturated liquid:	395 µPa•s (0.395 cp)	4101
• normal pressure, 20 °C (68 °F)		
density, vapor:	5.084 kg/m3 (0.3174 lb/cf)	4101
• 20 °C (68 °F)		
pressure, saturated vapor:	174.9 kPa (25.37 psia)	4101
density, saturated liquid:	1388 kg/m3 (86.65 lb/cf)	4101
density, saturated vapor:	9.03 kg/m3 (0.564 lb/cf)	4101
specific volume, saturated liquid:	0.721 L/kg (0.0115 cf/lb)	4101
specific volume, saturated vapor:	110.8 L/kg (1.7748 cf/lb)	4101
velocity of sound, saturated liquid:	675 m/s (2215 ft/s)	4101

velocity of sound, saturated vapor:	143 m/s (469 ft/s)	4101
viscosity, saturated liquid:	334 µPa•s (0.334 cp)	4101
viscosity, saturated vapor:	11.0 µPa•s (0.0110 cp)	4101
thermal conductivity, saturatd liquid:	0.0952 W/m•K (0.0550 Btu/hr•ft°F)	4101
thermal conductivity, saturated vapor:	0.01227 W/m•K (0.00709 Btu/hr•ft°F)	4101
• 60 °C (140 °F) ----------		
pressure, saturated vapor:	624 kPa (90.5 psia)	4101
• critical point ----------		
temperature:	141.0 °C (285.8 °F)	1133
	147.1 °C (296.8 °F)	3327
	153.4 °C (308.1 °F)	9318
	153.5 °C (308.3 °F)	3407
	160.8 °C (321.4 °F)	4A58
pressure:	3751 kPa (544.0 psia)	9318
	4228 kPa (613.2 psia)	4101
density:	529 kg/m3 (33.0 lb/cf)	3327
specific volume:	1.89 L/kg (0.0303 cf/lb)	3327
ENVIRONMENTAL		
average atmospheric lifetime (τatm):	19 yr	9A13
	29.7 yr	9501
ODP (ozone depletion potential):	0.000 (model-derived relative to R 11)	9318
GWP (global warming potential):	6900 relative to CO2 for 100 yr integration	9501
SAFETY		
• classification ----------		
safety group (ASHRAE Standard 34):	none (no application pending)	8601
• emergency exposure limit ----------		
Acute Toxicity Exposure Limit (ATEL):	0 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
Refrigerant Concentration Limit (RCL):	0 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
• acute (short-term) toxicity --------		
ALC (approximate lethal concentration:	rat, 30 min, 0/?: >300,000 ppm (lowest exposure tested with one or more deaths by inhalation)	5550
	rat, 2 hr, 0/10: >200,000 ppm (lowest exposure tested with one or more deaths by inhalation)	A944
	rat, 2 hr, 0/?: >200,000 ppm (lowest exposure tested with one or more deaths by inhalation)	5550
	rat, 3 hr, 0/?: >50,000 ppm (lowest exposure tested with one or more deaths by inhalation)	5550
	rat, 3 hr, 0/?: >50,000 ppm (lowest exposure tested with one or more deaths by inhalation)	A944
	rat, 4 hr, 0/3: >95,000 ppm (lowest exposure tested with one or more deaths by inhalation)	6207
cardiac sensitization threshold/LOEL:	monkey, 30min: ~R 11 at 50,000 ppm v/v (lowest observed effect level in test animals)	5550

anesthetic concentration:	mouse, 2 min, ?/?: 307,500 ppm v/v	5550
	mouse, 5 min, ?/?: 182,500 ppm v/v	5550
	mouse, 30 min, ?/?: 130,000 ppm v/v	5550
	mouse, 60 min, ?/?: 100,000 ppm v/v	5550
anesthetic/CNS effect LOEL:	rat, 4 hr, ?/3: 45,000 ppm v/v (lowest observed effect level in ALC or LC50 studies)	6207
anesthetic/CNS effect NOEL:	rat, 4 hr, 0/3: 18,000 ppm v/v (no observed effect level in ALC or LC50 studies)	6207

• flammability ----------

LFL-UFL (flammability limits in air):	none (nonflammable as tested)	5550
autodecomposition temperature:	less than critical temperature	8703

PRODUCTION

first commercial use as a refrigerant:	not known to be commercialized	
last year production allowed:	unrestricted	8C01

R-141b

---------- REFRIGERANT DATA SUMMARY ----------			
R-141b	1,1-dichloro-1-fluoroethane		see
HCFC	CH3CCl2F	CAS number 1717-00-6	RDB#

COMMON USE(S)
considered but not selected as a replacement for refrigerant 11; widely used as a foam blowing agent especially for polyurethanes, flexible polystyrenes, polyisocyanurates, and phenolics; solvent and blend component for solvents; aerosol propellant

IDENTIFIERS

common name(s):	R-141b; R141b; R 141b	
	HCFC-141b	
	not recommended: HFA-141b	
	fluorocarbon 141b	
	fluorochemical 141b; FC 141b	
	halocarbon 141b	
	halochemical 141b	
chemical name (by IUPAC convention):	1,1-dichloro-1-fluoroethane	
alternative chemical names/formulae:	ethane, 1,1-dichloro-1-fluoro-	
	methyl dichlorofluoromethyl	
	CH3CCl2F; CH3-CCl2F	
	not recommended:	
	CCl2FCH3; CCl2F-CH3	
	H3CCCl2F; H3C-CCl2F	
empirical formula:	C2H3Cl2F	
CAS number:	1717-00-6 (Chemical Abstracts Service registry number)	
EINECS number:	404-080-1 (European Inventory of Existing Chemical Substances)	
NIOSH RTECS number:	KI0997000 (Registry of Toxic Effects of Chemical Substances)	
trade name(s):	Asahi Glass Asahiklin AK-141b	
	Ausimont Meforex(R) 141b	MSDS
	DuPont HCFC-141b	MSDS
	Elf Atochem Forane(R) 141b	MSDS
	Honeywell Genetron(R) 141b	MSDS
	ICI Arcton(R) 141b	MSDS
	LaRoche Chemicals R-141b	
	Pennwalt Isotron(R) 141b	
	ZCIRI Kehua (PRC) HCFC-141b	
historical name(s):	Allied Corp refrigerant 2	
	AlliedSignal Genetron(R) 141b	5A33
	DuPont Freon(R) 141b	5868
ARI container color / Pantone number:	none, use light green grey/413	6601

PHYSICAL

• properties ----------		
molar mass:	116.9490232 g/mol (0.257828 lb/mol)	8820
normal freezing/melting/triple point:	-103.3 °C (-153.9 °F)	8401
• normal boiling point ----------		
temperature:	32.0 °C (89.7 °F)	8401
density, saturated liquid:	1220 kg/m3 (76.17 lb/cf)	8401
density, saturated vapor:	4.85 kg/m3 (0.303 lb/cf)	8401
specific volume, saturated liquid:	0.820 L/kg (0.0131 cf/lb)	8401
specific volume, saturated vapor:	206.2 L/kg (3.3024 cf/lb)	8401
heat of vaporization:	223.0 kJ/kg (95.9 Btu/lb)	8401

velocity of sound, saturated liquid:	797 m/s (2616 ft/s)	8401
velocity of sound, saturated vapor:	150 m/s (492 ft/s)	8401
viscosity, saturated liquid:	378 µPa•s (0.378 cp)	8401
viscosity, saturated vapor:	9.45 µPa•s (0.00945 cp)	8401
thermal conductivity, liquid:	0.0920 W/m•K (0.0532 Btu/hr•ft°F)	8401
thermal conductivity, vapor:	0.0099 W/m•K (0.0057 Btu/hr•ft°F)	8401
• normal pressure, 20 °C (68 °F) -----		
density, liquid:	1244 kg/m3 (10.38 lb/gal)	8401
• normal pressure, 21.1 °C (70 °F) ---		
density, liquid:	1242 kg/m3 (10.36 lb/gal)	8401
• 20 °C (68 °F) ----------		
pressure, saturated vapor:	65.0 kPa (9.43 psia)	8401
density, saturated liquid:	1244 kg/m3 (77.66 lb/cf)	8401
density, saturated vapor:	3.21 kg/m3 (0.200 lb/cf)	8401
specific volume, saturated liquid:	0.804 L/kg (0.0129 cf/lb)	8401
specific volume, saturated vapor:	311.7 L/kg (4.9933 cf/lb)	8401
velocity of sound, saturated liquid:	841 m/s (2760 ft/s)	8401
velocity of sound, saturated vapor:	149 m/s (487 ft/s)	8401
viscosity, saturated liquid:	432 µPa•s (0.432 cp)	8401
viscosity, saturated vapor:	9.1 µPa•s (0.0091 cp)	8401
thermal conductivity, saturatd liquid:	0.0958 W/m•K (0.0554 Btu/hr•ft°F)	8401
thermal conductivity, saturated vapor:	0.00930 W/m•K (0.00537 Btu/hr•ft°F)	8401
• 60 °C (140 °F) ----------		
pressure, saturated vapor:	246 kPa (35.7 psia)	8401
heat of vaporization:	208.9 kJ/kg (89.8 Btu/lb)	8401
• critical point ----------		
temperature:	204.2 °C (399.6 °F)	8401
pressure:	4250 kPa (616.4 psia)	8401
density:	460 kg/m3 (28.7 lb/cf)	8401
specific volume:	2.17 L/kg (0.0348 cf/lb)	8401

ENVIRONMENTAL

average atmospheric lifetime (τatm):	9.2 yr	9501
average stratospheric lifetime (τstr):	76 yr	5508
ODP (ozone depletion potential):	0.086 (model-derived relative to R 11)	9501
	0.1 (semi-empirical relative to R 11)	9501
	0.11 (estimate used for the Montreal Protocol)	6904
GWP (global warming potential):	700 relative to CO2 for 100 yr integration	9501
HGWP (halocarbon GWP):	0.0905 ±0.0065 relative to R 11 for infinite integration period	5964
	0.15 relative to R 11 for infinite integration period	4511
	0.16 relative to R 11 for infinite integration period	5B15

SAFETY

• classification ----------		
safety group (ASHRAE Standard 34):	none (no application pending)	8601
NFPA 704 degrees of hazard (H-F-R-S):	Ausimont: 2-0-0	MSDS
	Honeywell: 2-1-0	MSDS
	health-flammability-reactivity [-special]: 0=no, 4=severe	
NPCA HMIS hazard ratings (H-F-R):	DuPont: 2-1-0	MSDS
	Honeywell: 1-1-0	MSDS
	health-flammability-reactivity	

	0=insignificant, 4=extreme	
• long-term occupational limit -------		
AIHA WEEL (workplace envl exp limit):	500 ppm v/v TWA for 8 hr/day and 40 hr/wk	4B87
• emergency exposure limit ----------		
Acute Toxicity Exposure Limit (ATEL):	2,600 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	2,600 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
Refrigerant Concentration Limit (RCL):	2,600 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	2,600 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
• acute (short-term) toxicity --------		
LC50 (lethal concentration, 50%):	mouse, 10 min: 50,000 ppm (fatal concentration by inhalation for half of test animals)	5980
	rat, 4 hr: 61,647 ppm (fatal concentration by inhalation for half of test animals)	5995
ALC (approximate lethal concentration:	rat, 6 hr, 0/6: >42,800 ppm (lowest exposure tested with one or more deaths by inhalation)	6465
	rat, 6 hr, 1/6: 50,200 ppm (lowest exposure tested with one or more deaths by inhalation)	6465
dermal LD50 (lethal dosage, 50%):	rabbit: >2,000 mg/kg (fatal dose by skin contact for half of test animals)	5A80
	rat, 0/10: >2,000 mg/kg (fatal dose by skin contact for half of test animals)	6460
oral LD50 (lethal dosage, 50%):	rat, 0/10: >5,000 mg/kg (fatal dose by ingestion for half of test animals)	5988
cardiac sensitization (CS) EC50:	dog, 10 min: 20,000 ppm v/v (effective concentration in half of test animals)	6684
cardiac sensitization threshold/LOEL:	dog, 10 min, 1/10: 5,200 ppm v/v (lowest observed effect level in test animals)	6467
	dog, 10 min, 1/2: 9,000 ppm v/v (lowest observed effect level in test animals)	5C63
	dog, 10 min, 1/6: 20,000 ppm v/v (lowest observed effect level in test animals)	7206
	monkey, 10 min, 1/2: 5,000 ppm v/v (lowest observed effect level in test animals)	5C63
	monkey, 10 min, 1mild/1: 3,000 ppm v/v (lowest observed effect level in test animals)	5C63
cardiac sensitization (CS) NOEL:	dog, 10 min, 0/10: 2,600 ppm v/v (no observed effect level in test animals)	6467
	dog, 10 min, 0/6: 10,000 ppm v/v (no observed effect level in test animals)	7206
anesthetic/CNS effect EC50:	mouse, 10 min: 25,000 ppm v/v (effective concentration in	5980

	half of test animals)	
anesthetic/CNS effect LOEL:	rat, 1-hr, ?/6: 31,730 ppm v/v (lowest observed effect level in ALC or LC50 studies)	6465
	rat, 4-hr, ?/10: 29,674 ppm v/v (lowest observed effect level in ALC or LC50 studies)	5995
	rat, ?/? depression: 30,000 ppm v/v (lowest observed effect level in ALC or LC50 studies)	7278
anesthetic/CNS effect NOEL:	rat, 6-hr, 0/10: 11,096 ppm v/v (no observed effect level in ALC or LC50 studies)	6463
	rat, 6-hr, 0/160: 19,959 ppm v/v (no observed effect level in subchronic or chronic study)	65A8
• flammability ----------		
LFL-UFL (flammability limits in air):	5.8-17.7 % v/v	5B15
	7.2-18.0 % v/v	2525
	7.3-16.0 % v/v	4511
	7.4-15.5 % v/v	0521
	7.6-17.7 % v/v	5A33
	Ausimont: 7.4-15.5 % v/v	MSDS
	DuPont: 6.4-15.1 % v/v	MSDS
	Elf Atochem: 5.6-17.7% with a	SDS
	Elf Atochem: powerful source	SDS
	Elf Atochem: of energy	SDS
	Honeywell: nonflammable for	MSDS
	Honeywell: spark ignition	MSDS
LFL-UFL (with spark ignition):	9.0-15.4 % v/v	5648
heat of combustion (by ASHRAE 34-92):	8.6 MJ/kg (3697 Btu/lb)	2318
flash point:	CC, DuPont: none	MSDS
	TCC, Elf Atochem: none	MSDS
	TCC, ICI: >82 °C (>180 °F)	MSDS
	none	5A30
autoignition temperature:	550 °C (1022 °F)	5A30
	Dupont: 530 °C (986 °F)	MSDS
	Elf Atochem: 532 °C (990 °F)	SDS
	Honeywell: 550 °C (1022 °F)	MSDS
autodecomposition temperature:	Honeywell: >250°C (>482°F)	MSDS
• detection ----------		
appearance:	clear, colorless liquid	5A33
odor:	faint ethereal odor	5A33
PRODUCTION		
first commercial use as a refrigerant:	blowing agent: December 1990	
last year production allowed:	2029 in developed countries under the Montreal Protocol	8C01

R-142b

---------- REFRIGERANT DATA SUMMARY ----------

			see RDB#
R-142b	1-chloro-1,1-difluoroethane		
HCFC	CH3CClF2	CAS number 75-68-3	

COMMON USE(S)
blend component for refrigerants 405A, 406A, 409A, 409B, 412A, 414A, 414B, and others; degradation product of fluorochemical 141b; foam blowing agent; intermediate in the manufacture of fluorinated products

IDENTIFIERS

common name(s):	R-142b; R142b; R 142b	
	HCFC-142b	
	CDFE	3866
	fluorocarbon 142b	
	fluorochemical 142b; FC 142b	
	halocarbon 142b	
	halochemical 142b	
chemical name (by IUPAC convention):	1-chloro-1,1-difluoroethane	
alternative chemical names/formulae:	2-chloro-2,2-difluoroethane	
	ethane, 1-chloro-1,1-difluoro-	
	difluorochloroethane	
	difluoromonochloroethane	
	alphachloroethylidene fluoride	
	CH3CClF2; CH3-CClF2	
	not recommended:	
	CClF2CH3; CClF2-CH3	
	CF2ClCH3; CF2Cl-CH3	
	CH3CF2Cl; CH3-CF2Cl	
empirical formula:	C2H3ClF2	
CAS number:	75-68-3 (Chemical Abstracts Service registry number)	
Beilstein registry number:	1731584	
EINECS number:	200-891-8 (European Inventory of Existing Chemical Substances)	
NIOSH RTECS number:	KH7650000 (Registry of Toxic Effects of Chemical Substances)	
trade name(s):	Asahi Glass Asahiklin AK-142b	
	Ausimont Meforex(R) 142b	MSDS
	Daikin Daiflon(R) 142b	
	DuPont HCFC-142b	MSDS
	Elf Atochem Forane(R) 142b	MSDS
	Honeywell Genetron(R) 142b	MSDS
historical name(s):	Allied Corp refrigerant 101	3975
	AlliedSignal Genetron(R) 142b	MSDS
	DuPont Freon(R) 142b	5869
	Elf Atochem Isotron(R) 142b	MSDS
	Pennwalt Isotron(R) 142b	
ARI container color / Pantone number:	none, use light green grey/413 with red / 185 band	6601

PHYSICAL

• properties ----------		
molar mass:	100.4947264 g/mol (0.221553 lb/mol)	8820
normal freezing/melting/triple point:	-131.1 °C (-204.1 °F)	8401
• normal boiling point ----------		
temperature:	-9.0 °C (15.8 °F)	8401

density, saturated liquid:	1192 kg/m3 (74.40 lb/cf)	8401
density, saturated vapor:	4.85 kg/m3 (0.303 lb/cf)	8401
specific volume, saturated liquid:	0.839 L/kg (0.0134 cf/lb)	8401
specific volume, saturated vapor:	206.4 L/kg (3.3056 cf/lb)	8401
heat of vaporization:	222.7 kJ/kg (95.8 Btu/lb)	8401
velocity of sound, saturated liquid:	769 m/s (2523 ft/s)	8401
velocity of sound, saturated vapor:	151 m/s (497 ft/s)	8401
viscosity, saturated liquid:	354 µPa•s (0.354 cp)	8401
viscosity, saturated vapor:	8.74 µPa•s (0.00874 cp)	8401
thermal conductivity, liquid:	0.0943 W/m•K (0.0545 Btu/hr•ft°F)	8401
thermal conductivity, vapor:	0.0093 W/m•K (0.0054 Btu/hr•ft°F)	8401
• normal pressure, 20 °C (68 °F) -----		
density, vapor:	4.303 kg/m3 (0.2686 lb/cf)	8401
• normal pressure, 21.1 °C (70 °F) ---		
density, vapor:	4.285 kg/m3 (0.2675 lb/cf)	8401
• 20 °C (68 °F) ----------		
pressure, saturated vapor:	288.0 kPa (41.77 psia)	4801
density, saturated liquid:	1125 kg/m3 (70.22 lb/cf)	8401
density, saturated vapor:	13.01 kg/m3 (0.812 lb/cf)	8401
specific volume, saturated liquid:	0.889 L/kg (0.0142 cf/lb)	8401
specific volume, saturated vapor:	76.9 L/kg (1.2314 cf/lb)	8401
velocity of sound, saturated liquid:	653 m/s (2142 ft/s)	8401
velocity of sound, saturated vapor:	153 m/s (502 ft/s)	8401
viscosity, saturated liquid:	252 µPa•s (0.252 cp)	8401
viscosity, saturated vapor:	9.7 µPa•s (0.0097 cp)	8401
thermal conductivity, saturatd liquid:	0.0832 W/m•K (0.0481 Btu/hr•ft°F)	8401
thermal conductivity, saturated vapor:	0.01117 W/m•K (0.00646 Btu/hr•ft°F)	8401
• 60 °C (140 °F) ----------		
pressure, saturated vapor:	879 kPa (127.5 psia)	8401
heat of vaporization:	175.5 kJ/kg (75.4 Btu/lb)	8401
• critical point ----------		
temperature:	137.1 °C (278.8 °F)	8401
	137.2 °C (278.9 °F)	8322
pressure:	4048 kPa (587.1 psia)	8322
	4123 kPa (598.0 psia)	8401
density:	435 kg/m3 (27.2 lb/cf)	8401
	444 kg/m3 (27.7 lb/cf)	8322
specific volume:	2.21 L/kg (0.0354 cf/lb)	8401
	2.25 L/kg (0.0361 cf/lb)	8322
ENVIRONMENTAL		
average atmospheric lifetime (τatm):	18.5 yr	9501
average stratospheric lifetime (τstr):	220 yr	5508
average tropospheric lifetime (τtrop):	24.8 yr	9B04
ODP (ozone depletion potential):	0.043 (model-derived relative to R 11)	9501
	0.066 (semi-empirical relative to R 11)	9501
	0.065 (estimate used for the Montreal Protocol)	6904
GWP (global warming potential):	2300 relative to CO2 for 100 yr integration	9501
HGWP (halocarbon GWP):	0.36 relative to R 11 for infinite integration period	4511
	0.365 ±0.025 relative to R 11 for infinite integration period	5964
	0.43 relative to R 11 for infinite integration period	4136
photochemical reactivity (grnd level):	0.5 relative to methane	4511

SAFETY		
• classification ----------		
safety group (ASHRAE Standard 34):	A2	8601
NFPA 704 degrees of hazard (H-F-R-S):	Ausimont: 2-4-0	MSDS
	Honeywell: 2-2-0 health-flammability-reactivity [-special]: 0=no, 4=severe	MSDS
NPCA HMIS hazard ratings (H-F-R):	DuPont: 1-4-1	MSDS
	Honeywell: 1-2-0 health-flammability-reactivity 0=insignificant, 4=extreme	MSDS
• occupational exposure limit --------		
MAK (maximum workplace concentration):	IV: 2,000 ppm v/v momentary 60 min	7101
• long-term occupational limit -------		
AIHA WEEL (workplace envl exp limit):	1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	4B89
MAK (maximum workplace concentration):	1,000 ppm v/v TWA for 8 hr/day 40 (or 42) hr/wk	7101
• emergency exposure limit ----------		
Acute Toxicity Exposure Limit (ATEL):	25,000 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	25,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
Refrigerant Concentration Limit (RCL):	15,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
	17,000 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
AIHA ERPG-3 (life-threatening):	25,000 ppm v/v for 1 hr	9503
AIHA ERPG-2 (injurious or impairing):	15,000 ppm v/v for 1 hr	9503
AIHA ERPG-1 (odor or mild effects):	10,000 ppm v/v for 1 hr	9503
• acute (short-term) toxicity --------		
LC50 (lethal concentration, 50%):	rat, 2 hr Elf Atochem: 368,000 ppm (fatal concentration by inhalation for half of test animals)	MSDS
	rat, 4 hr, Honeywell: >128,000 ppm (fatal concentration by inhalation for half of test animals)	MSDS
ALC (approximate lethal concentration:	rat, 30 min, 1/1: 500,000 ppm (lowest exposure tested with one or more deaths by inhalation)	5147
	rat, 2 hr, ?/?: 400,000 ppm (lowest exposure tested with one or more deaths by inhalation)	A622
	rat, 4 hr, (2-4)/6: 128,000 ppm (lowest exposure tested with one or more deaths by inhalation)	5643
	rat, 6 hr, 20%: 400,000 ppm (lowest exposure tested with one or more deaths by inhalation)	59A8
	rat, 16 hr 0/10 day 1: 100,000 ppm (lowest exposure tested with one or more deaths by inhalation)	5147
cardiac sensitization (CS) EC50:	dog, 10 min: 73,000 ppm v/v (effective concentration in half of test animals)	6684

cardiac sensitization threshold/LOEL:	dog, 5 min, 5/12: 50,000 ppm v/v (lowest observed effect level in test animals)	5644
	dog, 5 min, 5/12: 50,000 ppm v/v (lowest observed effect level in test animals)	6274
cardiac sensitization (CS) NOEL:	dog, 5 min, 0/6: 25,000 ppm v/v (no observed effect level in test animals)	5644
	dog, 5 min, 0/6: 25,000 ppm v/v (no observed effect level in test animals)	6274
anesthetic/CNS effect EC50:	mouse, 10 min: 250,000 ppm v/v (effective concentration in half of test animals)	5980
anesthetic/CNS effect LOEL:	rat, 30 min, 1/1: 150,000 ppm v/v (lowest observed effect level in test animals)	5147
• flammability ----------		
LFL-UFL (flammability limits in air):	6.7-14.9 % v/v	4511
	6.9-17.0 % v/v	0525
	7.1-18.6 % v/v	3A58
	7.2-18.2 % v/v	2525
	9.0-14.8 % v/v	4136
	Ausimont: 6.2-18 % v/v	MSDS
	DuPont: 6-15 % v/v	MSDS
	Elf Atochem: 6.9-15.5 % v/v	MSDS
	Elf Atochem: 9.0-14.8 % v/v	SDS
	Honeywell: 8.0-15.4 % v/v	MSDS
LFL-UFL (with spark ignition):	6.8-18.2 % v/v	5648
	8.0-14.3 % v/v	3A58
LFL-UFL (with hot-wire ignition):	8.2-14.7 % v/v	3A58
LFL (with hot-wire ignition):	7.8 % v/v	0525
heat of combustion (by ASHRAE 34-92):	9.8 MJ/kg (4213 Btu/lb)	2318
flash point:	Ato: no flash point as tested	SDS
	Honeywell: gas, not applicable	MSDS
	none	3A58
autoignition temperature:	632 °C (1170 °F)	3A58
	Ausimont: 631.7 °C (1169 °F)	MSDS
autodecomposition temperature:	Honeywell: >250°C (>482°F)	MSDS
• detection ----------		
appearance:	colorless gas	3A58
odor:	nearly odorless to slight ethereal odor	4B89

PRODUCTION

last year production allowed:	2029 in developed countries under the Montreal Protocol	8C01

R-143a

---------- REFRIGERANT DATA SUMMARY ----------

			see
R-143a	1,1,1-trifluoroethane		
HFC	CH3CF3	CAS number 420-46-2	RDB#

COMMON USE(S)
blend component particularly for alternatives to refrigerant 502 including refrigerants 404A, 408A, 507A, and others; degradation product of fluorochemical 141b

IDENTIFIERS

common name(s):	R-143a; R143a; R 143a	
	HFC-143a	
	fluorocarbon 143a	
	fluorochemical 143a; FC 143a	
	halocarbon 143a	
	halochemical 143a	
	hydrofluorocarbon 143a	
	not recommended: HFA-143a	
chemical name (by IUPAC convention):	1,1,1-trifluoroethane	
alternative chemical names/formulae:	ethane, 1,1,1-trifluoro-	
	methyl fluoroform	
	CH3CF3; CH3-CF3	
	not recommended:	
	CF3CH3; CF3-CH3	
	F3CCH3; F3C-CH3	
	H3CCF3; H3C-CF3	
empirical formula:	C2H3F3	
CAS number:	420-46-2 (Chemical Abstracts Service registry number)	
EINECS number:	206-996-5 (European Inventory of Existing Chemical Substances)	
NIOSH RTECS number:	KJ4110000 (Registry of Toxic Effects of Chemical Substances)	
trade name(s):	Ausimont Meforex(R) 143a	MSDS
	Daikin fluorocarbon HFC-143a	MSDS
	DuPont HFC-143a	MSDS
	Elf Atochem Forane(R) 143a	MSDS
	Honeywell Genetron(R) 143a	MSDS
	Solvay Solkane(R) 143a	MSDS
	ZCIRI Kehua (PRC) HFC-143a	
historical name(s):	Allied Corp refrigerant 200	3975
	AlliedSignal Genetron(R) 143a	MSDS
	ICI Arcton(R) 143a	
ARI container color / Pantone number:	none, use light green grey/413 with red / 185 band	6601

PHYSICAL

• properties ----------		
molar mass:	84.0404296 g/mol (0.185277 lb/mol)	8820
normal freezing/melting/triple point:	-111.8 °C (-169.3 °F)	8401
• normal boiling point ----------		
temperature:	-47.2 °C (-53.0 °F)	8401
density, saturated liquid:	1168 kg/m3 (72.90 lb/cf)	8401
density, saturated vapor:	4.76 kg/m3 (0.297 lb/cf)	8401
specific volume, saturated liquid:	0.856 L/kg (0.0137 cf/lb)	8401
specific volume, saturated vapor:	210.1 L/kg (3.3652 cf/lb)	8401
heat of vaporization:	227.1 kJ/kg (97.6 Btu/lb)	8401

velocity of sound, saturated liquid:	776 m/s (2547 ft/s)	8401
velocity of sound, saturated vapor:	155 m/s (508 ft/s)	8401
viscosity, saturated liquid:	284 µPa•s (0.284 cp)	8401
viscosity, saturated vapor:	8.36 µPa•s (0.00836 cp)	8401
thermal conductivity, liquid:	0.1013 W/m•K (0.0585 Btu/hr•ft°F)	8401
thermal conductivity, vapor:	0.0090 W/m•K (0.0052 Btu/hr•ft°F)	8401
• normal pressure, 20 °C (68 °F) -----		
density, vapor:	3.558 kg/m3 (0.2221 lb/cf)	8401
• normal pressure, 21.1 °C (70 °F) ---		
density, vapor:	3.543 kg/m3 (0.2212 lb/cf)	8401
• 20 °C (68 °F) ----------		
pressure, saturated vapor:	1105.7 kPa (160.37 psia)	8401
density, saturated liquid:	951 kg/m3 (59.38 lb/cf)	8401
density, saturated vapor:	49.83 kg/m3 (3.110 lb/cf)	8401
specific volume, saturated liquid:	1.050 L/kg (0.0168 cf/lb)	8401
specific volume, saturated vapor:	20.1 L/kg (0.3215 cf/lb)	8401
velocity of sound, saturated liquid:	438 m/s (1436 ft/s)	8401
velocity of sound, saturated vapor:	147 m/s (482 ft/s)	8401
viscosity, saturated liquid:	123 µPa•s (0.123 cp)	8401
viscosity, saturated vapor:	11.3 µPa•s (0.0113 cp)	8401
thermal conductivity, saturatd liquid:	0.0724 W/m•K (0.0419 Btu/hr•ft°F)	8401
thermal conductivity, saturated vapor:	0.01583 W/m•K (0.00915 Btu/hr•ft°F)	8401
• 60 °C (140 °F) ----------		
pressure, saturated vapor:	2874 kPa (416.9 psia)	8401
heat of vaporization:	94.8 kJ/kg (40.8 Btu/lb)	8401
• critical point ----------		
temperature:	72.9 °C (163.2 °F)	8401
pressure:	3776 kPa (547.7 psia)	8401
density:	433 kg/m3 (27.0 lb/cf)	8401
specific volume:	2.31 L/kg (0.0370 cf/lb)	8401
ENVIRONMENTAL		
average atmospheric lifetime (τatm):	53.5 yr	9501
ODP (ozone depletion potential):	0.000 (model-derived relative to R 11)	3B12
GWP (global warming potential):	5400 relative to CO2 for 100 yr integration	9501
HGWP (halocarbon GWP):	0.74 ±0.02 relative to R 11 for infinite integration period	5964
	0.97 relative to R 11 for infinite integration period	DW
	1.1 relative to R 11 for infinite integration period	4511
photochemical reactivity (grnd level):	0.2 relative to methane	4511
SAFETY		
• classification ----------		
safety group (ASHRAE Standard 34):	A2	8601
NFPA 704 degrees of hazard (H-F-R-S):	Ausimont: 2-4-0	MSDS
	Honeywell: 2-2-0	MSDS
	health-flammability-reactivity [-special]: 0=no, 4=severe	
NPCA HMIS hazard ratings (H-F-R):	DuPont: 1-4-0	MSDS
	Honeywell: 1-2-0	MSDS
	health-flammability-reactivity 0=insignificant, 4=extreme	
• long-term occupational limit -------		
AIHA WEEL (workplace envl exp limit):	1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	5C16

• emergency exposure limit ----------		
Acute Toxicity Exposure Limit (ATEL):	170,000 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	170,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
Refrigerant Concentration Limit (RCL):	18,000 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	18,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
• acute (short-term) toxicity --------		
ALC (approximate lethal concentration:	rat, 4 hr, 0/10: >591,000 ppm (lowest exposure tested with one or more deaths by inhalation)	7450
cardiac sensitization (CS) EC50:	dog, 10 min: 310,000 ppm v/v (effective concentration in half of test animals)	6684
cardiac sensitization threshold/LOEL:	dog, 10 min, 2/5: 300,000 ppm v/v (lowest observed effect level in test animals)	5C26
cardiac sensitization (CS) NOEL:	dog, 10 min, 0/6: 250,000 ppm v/v (no observed effect level in test animals)	6597
anesthetic/CNS effect EC50:	mouse, 10 min: 500,000-600,000 ppm v/v (effective concentration in half of test animals)	5980
anesthetic/CNS effect NOEL:	rat, 4 hr, 0/10: 591,000 ppm v/v (no observed effect level in ALC or LC50 studies)	7450
• flammability ----------		
LFL-UFL (flammability limits in air):	13-17.4 % v/v	5C16
	7.0-19.0 % v/v	2525
	7.4-18.8 % v/v	4785
	DuPont: 7.7-17.4 % v/v	MSDS
	Elf Atochem: 7.1-16.1 % v/v	MSDS
	Elf Atochem: 7.1-16.1 % v/v	SDS
	Solvay: 7.1-16.1 % v/v	MSDS
heat of combustion (by ASHRAE 34-92):	10.3 MJ/kg (4428 Btu/lb)	2318
flash point:	DuPont: -90 °C (-130 °F)	MSDS
	Honeywell: gas, not applicable	MSDS
	no flash point (as tested)	SDS
autoignition temperature:	750 °C (1382 °F)	3960
	Elf Atochem: 750°C (1382°F)	SDS
	Honeywell: >750°C (>1382°F)	MSDS
• detection ----------		
appearance:	DuPont: clear, colorless	MSDS
odor:	Daikin: faint sweet odor	MSDS
	Honeywell: faint ethereal	MSDS
PRODUCTION		
last year production allowed:	unrestricted	8C01

R-152a

---------- REFRIGERANT DATA SUMMARY ----------

R-152a	1,1-difluoroethane		see
HFC	CH3CHF2	CAS number 75-37-6	RDB#

COMMON USE(S)
component of refrigerants 401A, 401B, 401C, 405A, 411A, 411B, 415A, 500, and others; under consideration as a blend component for other refrigerants; under consideration (notably in China) as an alternative for refrigerant 12; flammability limit use as a single compound refrigerant; blowing agent for foams; aerosol propellant alone and in blends

IDENTIFIERS

common name(s):	R-152a; R152a; R 152a	
	HFC-152a	
	DFE	
	fluorocarbon 152a	
	fluorochemical 152a; FC 152a	
	halocarbon 152a	
	halochemical 152a	
	hydrofluorocarbon 152a	
chemical name (by IUPAC convention):	1,1-difluoroethane	
alternative chemical names/formulae:	ethane, 1,1-difluoro-	
	ethylidene difluoride	
	ethylidene fluoride	
	"ethylene fluoride"	
	CH3CHF2; CH3-CHF2	
	not recommended:	
	CF2HCH3; CF2H-CH3	
	CH3CF2H; CH3-CF2H	
	CHF2CH3; CHF2-CH3	
	H3CCHF2; H3C-CHF2	
empirical formula:	C2H4F2	
CAS number:	75-37-6 (Chemical Abstracts Service registry number)	
EINECS number:	200-866-1 (European Inventory of Existing Chemical Substances)	
NIOSH RTECS number:	KI1410000 (Registry of Toxic Effects of Chemical Substances)	
trade name(s):	Asahi Glass Asahiklin AK-152a	
	DuPont HFC-152a	MSDS
	Elf Atochem Forane(R) 152a	MSDS
	Honeywell Genetron(R) 152a	MSDS
	ICI Klea(R) 152a	CSDS
	ZCIRI Kehua (PRC) HFC-152a	
historical name(s):	Allied Corp refrigerant 100	3975
	AlliedSignal Genetron(R) 152a	MSDS
	DuPont FCD-711	7737
	DuPont Freon(R) 152a	
ARI container color / Pantone number:	none, use light green grey/413 with red / 185 band	6601

PHYSICAL
• properties ----------

molar mass:	66.0499664 g/mol (0.145615 lb/mol)	8820
normal freezing/melting/triple point:	-118.6 °C (-181.5 °F)	8401

• normal boiling point ----------		
temperature:	-24.0 °C (-11.2 °F)	8401
density, saturated liquid:	1011 kg/m3 (63.13 lb/cf)	8401
density, saturated vapor:	3.38 kg/m3 (0.211 lb/cf)	8401
specific volume, saturated liquid:	0.989 L/kg (0.0158 cf/lb)	8401
specific volume, saturated vapor:	296.2 L/kg (4.7450 cf/lb)	8401
heat of vaporization:	329.9 kJ/kg (141.8 Btu/lb)	8401
velocity of sound, saturated liquid:	889 m/s (2918 ft/s)	8401
velocity of sound, saturated vapor:	185 m/s (608 ft/s)	8401
viscosity, saturated liquid:	301 µPa•s (0.301 cp)	8401
viscosity, saturated vapor:	8.44 µPa•s (0.00844 cp)	8401
thermal conductivity, liquid:	0.1202 W/m•K (0.0694 Btu/hr•ft°F)	8401
thermal conductivity, vapor:	0.0094 W/m•K (0.0054 Btu/hr•ft°F)	8401
• normal pressure, 20 °C (68 °F) -----		
density, vapor:	2.810 kg/m3 (0.1754 lb/cf)	8401
• normal pressure, 21.1 °C (70 °F) ---		
density, vapor:	2.799 kg/m3 (0.1747 lb/cf)	8401
• 20 °C (68 °F) ----------		
pressure, saturated vapor:	512.9 kPa (74.39 psia)	8401
density, saturated liquid:	912 kg/m3 (56.93 lb/cf)	8401
density, saturated vapor:	15.91 kg/m3 (0.993 lb/cf)	8401
specific volume, saturated liquid:	1.097 L/kg (0.0176 cf/lb)	8401
specific volume, saturated vapor:	62.9 L/kg (1.0068 cf/lb)	8401
velocity of sound, saturated liquid:	673 m/s (2208 ft/s)	8401
velocity of sound, saturated vapor:	186 m/s (611 ft/s)	8401
viscosity, saturated liquid:	172 µPa•s (0.172 cp)	8401
viscosity, saturated vapor:	10.1 µPa•s (0.0101 cp)	8401
thermal conductivity, saturatd liquid:	0.1002 W/m•K (0.0579 Btu/hr•ft°F)	8401
thermal conductivity, saturated vapor:	0.01424 W/m•K (0.00823 Btu/hr•ft°F)	8401
• 60 °C (140 °F) ----------		
pressure, saturated vapor:	1501 kPa (217.7 psia)	8401
heat of vaporization:	229.4 kJ/kg (98.6 Btu/lb)	8401
• critical point ----------		
temperature:	113.2 °C (235.7 °F)	9125
	113.3 °C (235.9 °F)	4121
pressure:	4515 kPa (654.8 psia)	4121
	4517 kPa (655.1 psia)	4B09
density:	368 kg/m3 (23.0 lb/cf)	4B09
	369 kg/m3 (23.0 lb/cf)	9125
specific volume:	2.72 L/kg (0.0435 cf/lb)	4B09
ENVIRONMENTAL		
average atmospheric lifetime (τatm):	1.5 ±0.4 yr	6695
average stratospheric lifetime (τstr):	61 yr	5508
ODP (ozone depletion potential):	0.000 (model-derived relative to R 11)	3B12
GWP (global warming potential):	190 relative to CO2 for 100 yr integration	9501
HGWP (halocarbon GWP):	0.0295 ±0.0035 relative to R 11 for infinite integration period	5964
photochemical reactivity (grnd level):	4.8 relative to methane	4511
SAFETY		
• classification ----------		
safety group (ASHRAE Standard 34):	A2	8601
NFPA 704 degrees of hazard (H-F-R-S):	Honeywell: 2-2-0 health-flammability-reactivity [-special]: 0=no, 4=severe	MSDS
NPCA HMIS hazard ratings (H-F-R):	DuPont: 1-4-1	MSDS

	Honeywell: 1-2-0 health-flammability-reactivity 0=insignificant, 4=extreme	MSDS
• long-term occupational limit -------		
AIHA WEEL (workplace envl exp limit):	1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	4B90
• emergency exposure limit ----------		
Acute Toxicity Exposure Limit (ATEL):	50,000 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	50,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
Refrigerant Concentration Limit (RCL):	9,300 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	9,300 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
• acute (short-term) toxicity --------		
LC50 (lethal concentration, 50%):	rat, 4 hr: >400,000 ppm (fatal concentration by inhalation for half of test animals)	A648
ALC (approximate lethal concentration:	rat, 10-25min, 1/1: 500,000 ppm (lowest exposure tested with one or more deaths by inhalation)	5147
	rat, 10-25min, 1/1: 550,000 ppm (lowest exposure tested with one or more deaths by inhalation)	5147
	rat, 10-25min: 500,000-550,000 ppm (lowest exposure tested with one or more deaths by inhalation)	7424
	rat, 2 hr, 0/2: 200,000 ppm (lowest exposure tested with one or more deaths by inhalation)	7737
	rat, 4 hr, 1/6: 383,000 ppm (lowest exposure tested with one or more deaths by inhalation)	5C85
	rat, 4 hr, 2-4/6: 64,000 ppm (lowest exposure tested with one or more deaths by inhalation)	5643
	rat, 4 hr, 2/6: 437,500 ppm (lowest exposure tested with one or more deaths by inhalation)	5C85
oral LD50 (lethal dosage, 50%):	rat: >1,500 mg/kg (fatal dose by ingestion for half of test animals)	5C84
cardiac sensitization threshold/LOEL:	dog, 5 min, 3/12: 150,000 ppm v/v (lowest observed effect level in test animals)	5644
	dog, 5 min, 3/12: 150,000 ppm v/v (lowest observed effect level in test animals)	6274
cardiac sensitization (CS) NOEL:	dog, 5 min, 0/12: 50,000 ppm v/v (no observed effect level in test animals)	5644
	dog, 5 min, 0/12: 50,000 ppm v/v (no observed effect level in test animals)	6274
anesthetic/CNS effect LOEL:	rat, 30 min, 1/1: 200,000 ppm v/v (lowest observed effect	5147

	level in test animals)	
	rat, 2 hr, ?/2: 100,000 ppm v/v (lowest observed effect level in ALC or LC50 studies)	7737
anesthetic/CNS effect NOEL:	rat, 30 min, 0/1: 100,000 ppm v/v (no observed effect level in test animals)	5147
• flammability ----------		
LFL-UFL (flammability limits in air):	3.9-16.9 % v/v	4511
	4.5-19.8 % v/v	4785
	4.8-20.2 % v/v	2525
	Daikin: 4.0-19.6 % v/v	MSDS
	Elf Atochem: 3.7-16.9 % v/v	MSDS
	Elf Atochem: 3.7-18.0 % v/v	SDS
	Honeywell: 3.7-18.0 % v/v	MSDS
LFL-UFL (flammability limits, 95 °C):	3.8-21.4 % v/v	2525
LFL-UFL (with spark ignition):	4.0-19.6 % v/v	5648
	4.5-19.8 % v/v	2525
LFL-UFL (with hot-wire ignition):	4.8-18.8 % v/v	2525
heat of combustion (by ASHRAE 34-92):	16.9 MJ/kg (7266 Btu/lb)	2318
	17.4 MJ/kg (7472 Btu/lb)	4785
flash point:	Honeywell: not applicable	MSDS
	TOC: <-50 °C (<-58 °F)	4B90
autoignition temperature:	455 °C (851 °F)	3960
autodecomposition temperature:	DuPont: 454 °C (849 °F)	MSDS
• detection ----------		
appearance:	colorless gas	4B90
odor:	slight ethereal odor	4B90

PRODUCTION		
last year production allowed:	unrestricted	8C01

R-170 (ETHANE)

---------- REFRIGERANT DATA SUMMARY ----------

R-170	ethane		see
HC	CH3CH3	CAS number 74-84-0	RDB#

COMMON USE(S)
low stage of cascade refrigeration systems for extremely low temperature industrial systems, primarily in the metal and chemical industries; use is constrained by flammability even though R-170 offers comparatively high system capacities at very low temperatures

IDENTIFIERS

common name(s):	R-170; R170; R 170 HC-170 bimethyl dimethyl hydrocarbon 170 n-C2; n-C2H6	
chemical name (by IUPAC convention):	ethane	
alternative chemical names/formulae:	methyl methane methylmethane ethyl hydride CH3CH3; CH3-CH3 not recommended: (CH3)2	
empirical formula:	C2H6	
CAS number:	74-84-0 (Chemical Abstracts Service registry number)	
Beilstein registry number:	1730716	
EINECS number:	200-814-8 (European Inventory of Existing Chemical Substances)	
Merck Index (volume-number):	12-3767	
NIOSH RTECS number:	KH3800000 (Registry of Toxic Effects of Chemical Substances)	
ARI container color / Pantone number:	none, use light green grey/413 with red / 185 band	6601

PHYSICAL

• properties ----------		
molar mass:	30.06904 g/mol (0.066291 lb/mol)	8820
normal freezing/melting/triple point:	-182.8 °C (-297.0 °F)	8401
• normal boiling point ----------		
temperature:	-88.6 °C (-127.5 °F)	8401
density, saturated liquid:	544 kg/m3 (33.96 lb/cf)	8401
density, saturated vapor:	2.05 kg/m3 (0.128 lb/cf)	8401
specific volume, saturated liquid:	1.838 L/kg (0.0294 cf/lb)	8401
specific volume, saturated vapor:	487.0 L/kg (7.8007 cf/lb)	8401
heat of vaporization:	489.5 kJ/kg (210.4 Btu/lb)	8401
velocity of sound, saturated liquid:	1313 m/s (4308 ft/s)	8401
velocity of sound, saturated vapor:	249 m/s (815 ft/s)	8401
viscosity, saturated liquid:	162 µPa•s (0.162 cp)	8401
viscosity, saturated vapor:	5.86 µPa•s (0.00586 cp)	8401
thermal conductivity, liquid:	0.1931 W/m•K (0.1116 Btu/hr•ft°F)	8401
thermal conductivity, vapor:	0.0102 W/m•K (0.0059 Btu/hr•ft°F)	8401
• normal pressure, 20 °C (68 °F) -----		
density, vapor:	1.260 kg/m3 (0.0787 lb/cf)	8401

• normal pressure, 21.1 °C (70 °F) ---		
density, vapor:	1.255 kg/m3 (0.0784 lb/cf)	8401
• 20 °C (68 °F) ----------		
pressure, saturated vapor:	3766.0 kPa (546.21 psia)	8401
density, saturated liquid:	339 kg/m3 (21.18 lb/cf)	8401
density, saturated vapor:	86.39 kg/m3 (5.393 lb/cf)	8401
specific volume, saturated liquid:	2.947 L/kg (0.0472 cf/lb)	8401
specific volume, saturated vapor:	11.6 L/kg (0.1854 cf/lb)	8401
velocity of sound, saturated liquid:	371 m/s (1219 ft/s)	8401
velocity of sound, saturated vapor:	211 m/s (693 ft/s)	8401
viscosity, saturated liquid:	41 µPa•s (0.041 cp)	8401
viscosity, saturated vapor:	11.6 µPa•s (0.0116 cp)	8401
thermal conductivity, saturatd liquid:	0.0958 W/m•K (0.0554 Btu/hr•ft°F)	8401
thermal conductivity, saturated vapor:	0.03795 W/m•K (0.02193 Btu/hr•ft°F)	8401
• critical point ----------		
temperature:	32.2 °C (89.9 °F)	8401
pressure:	4872 kPa (706.6 psia)	8401
density:	207 kg/m3 (12.9 lb/cf)	8401
specific volume:	4.84 L/kg (0.0775 cf/lb)	8401
ENVIRONMENTAL		
ODP (ozone depletion potential):	0.000 (model-derived relative to R 11)	
GWP (global warming potential):	unknown, but very low: ~20 relative to CO2 for 100 yr integration	
photochemical reactivity (grnd level):	37 relative to methane	4511
SAFETY		
• classification ----------		
safety group (ASHRAE Standard 34):	A3	8601
NFPA 704 degrees of hazard (H-F-R-S):	BOC Gases: 0-4-0	MSDS
	Texaco: 1-4-0	MSDS
	health-flammability-reactivity [-special]: 0=no, 4=severe	
NPCA HMIS hazard ratings (H-F-R):	BOC Gases: 0-4-0	MSDS
	Texaco: 1-4-0	MSDS
	health-flammability-reactivity 0=insignificant, 4=extreme	
UL Comparative Hazard to Life Group:	5(b) in absence of flame or hot objects	4B64
• occupational exposure warnings -----		
ACGIH caution:	simple asphyxiant	9504
• long-term occupational limit -------		
exposure limit consistent to OSHA PEL:	Exxon: 1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	MSDS
	Pennzoil, C1-C4 assumed: 1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	MSDS
	Phillips: 1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	MSDS
• emergency exposure limit ----------		
Acute Toxicity Exposure Limit (ATEL):	7,000 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	provisional: 7,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
Refrigerant Concentration Limit (RCL):	7,000 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	provisional: 7,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950

• acute (short-term) toxicity --------		
ALC (approximate lethal concentration:	rat, 4 hr, 0/10: >24,838 ppm (lowest exposure tested with one or more deaths by inhalation)	7623
cardiac sensitization threshold/LOEL:	dog 10min 2/4: 100,000-250,000 ppm v/v (lowest observed effect level in test animals)	6192
anesthetic/CNS effect NOEL:	rat, 4 hr, 0/10: 24,838 ppm v/v (no observed effect level in ALC or LC50 studies)	7623
• flammability ----------		
LFL-UFL (flammability limits in air):	3.2-12.45 % v/v	6290
	3.3-10.6 % v/v	0036
	BOC Gases: 3.0-12.4 % v/v	MSDS
	Exxon: 3.0-12.5 % v/v	MSDS
	Phillips: 2.9-13.0 % v/v	MSDS
	Texaco: 2.9-13.0 % v/v	MSDS
	Union Carbide: 3.2-12.5 % v/v	MSDS
LFL-UFL (with spark ignition):	2.6-13.9 % v/v	5648
flash point:	-135 °C (-211 °F)	6290
	CC, Exxon: -152 °C (-242 °F)	MSDS
autoignition temperature:	510 °C (950 °F)	4B64
	BOC Gases: 472 °C (882 °F)	MSDS
	Exxon: 515 °C (959 °F)	MSDS
	Texaco: 515 °C (959 °F)	MSDS
• detection ----------		
appearance:	Phillips: colorless	MSDS
odor:	Union Carbide: odorless	MSDS
PRODUCTION		
last year production allowed:	unrestricted	8C01

R-218

---------- REFRIGERANT DATA SUMMARY ----------

			see RDB#
R-218	octafluoropropane		
FC	CF3CF2CF3	CAS number 76-19-7	

COMMON USE(S)
blend component especially for low-temperature alternatives including refrigerants 403A, 403B, 412A, 413A, 509A, and others; fire suppressant for flooding systems (e.g., 3M CEA-308) to replace halon 1301; solvent for precision cleaning

IDENTIFIERS

common name(s):	R-218; R218; R 218	
	FC-218	
	fluorocarbon 218	
	fluorochemical 218; FC 218	
	halocarbon 218	
	halochemical 218	
	perfluorocarbon 218; "PFC-218"	
chemical name (by IUPAC convention):	octafluoropropane	
alternative chemical names/formulae:	perfluoropropane	
	propane, octafluoro-	
	CF3CF2CF3; CF3-CF2-CF3	
	not recommended: CF2(CF3)2; F2C(CF3)2	
empirical formula:	C3F8	
CAS number:	76-19-7 (Chemical Abstracts Service registry number)	
EINECS number:	200-941-9 (European Inventory of Existing Chemical Substances)	
NIOSH RTECS number:	TZ5255000 (Registry of Toxic Effects of Chemical Substances)	
trade name(s):	3M Performance Fluid PF-5030	
	AlliedSignal Genetron(R) 218	
	BNFL Flutec(R) 218	
	BOC Gases H-218	MSDS
	BOC Gases Octafluoropropane	MSDS
	DuPont Freon(R) 218	
	ICI PFC 218	
	Rhodia Isceon 218	
historical name(s):	Allied Corp refrigerant 700	
	Rhône-Poulenc Isceon 218	
ARI container color / Pantone number:	none, use light green grey/413	6601

PHYSICAL

• properties ----------		
molar mass:	188.0193256 g/mol (0.414512 lb/mol)	8820
normal freezing/melting/triple point:	-160.1 °C (-256.3 °F)	8814
	-183.0 °C (-297.4 °F)	3331
• normal boiling point ----------		
temperature:	-36.6 °C (-33.9 °F)	8814
density, saturated liquid:	1611 kg/m3 (100.55 lb/cf)	8814
density, saturated vapor:	10.20 kg/m3 (0.637 lb/cf)	8814
specific volume, saturated liquid:	0.621 L/kg (0.0099 cf/lb)	8814
specific volume, saturated vapor:	98.1 L/kg (1.5708 cf/lb)	8814
heat of vaporization:	105.3 kJ/kg (45.3 Btu/lb)	3331
	106.5 kJ/kg (45.8 Btu/lb)	8814
velocity of sound, saturated liquid:	542 m/s (1777 ft/s)	8814

velocity of sound, saturated vapor:	101 m/s (332 ft/s)	8814
viscosity, saturated liquid:	317 µPa•s (0.317 cp)	8814
viscosity, saturated vapor:	9.80 µPa•s (0.00980 cp)	8814
thermal conductivity, liquid:	0.0556 W/m•K (0.0321 Btu/hr•ft°F)	8814
thermal conductivity, vapor:	0.0091 W/m•K (0.0052 Btu/hr•ft°F)	8814
• normal pressure, 20 °C (68 °F) -----		
density, vapor:	7.996 kg/m3 (0.4992 lb/cf)	8814
• normal pressure, 21.1 °C (70 °F) ---		
density, vapor:	7.963 kg/m3 (0.4971 lb/cf)	8814
• 20 °C (68 °F) ----------		
pressure, saturated vapor:	758.5 kPa (110.01 psia)	8814
density, saturated liquid:	1354 kg/m3 (84.51 lb/cf)	8814
density, saturated vapor:	73.45 kg/m3 (4.585 lb/cf)	8814
specific volume, saturated liquid:	0.739 L/kg (0.0118 cf/lb)	8814
specific volume, saturated vapor:	13.6 L/kg (0.2181 cf/lb)	8814
velocity of sound, saturated vapor:	307 m/s (1008 ft/s)	8814
	95 m/s (312 ft/s)	8814
viscosity, saturated liquid:	142 µPa•s (0.142 cp)	8814
viscosity, saturated vapor:	12.3 µPa•s (0.0123 cp)	8814
thermal conductivity, saturatd liquid:	0.0424 W/m•K (0.0245 Btu/hr•ft°F)	8814
thermal conductivity, saturated vapor:	0.01336 W/m•K (0.00772 Btu/hr•ft°F)	8814
• 60 °C (140 °F) ----------		
pressure, saturated vapor:	2021 kPa (293.2 psia)	8814
heat of vaporization:	45.2 kJ/kg (19.4 Btu/lb)	8401
• critical point ----------		
temperature:	71.9 °C (161.4 °F)	8814
pressure:	2680 kPa (388.7 psia)	8814
density:	627 kg/m3 (39.1 lb/cf)	7713
	628 kg/m3 (39.2 lb/cf)	8814
specific volume:	1.59 L/kg (0.0255 cf/lb)	8814
ENVIRONMENTAL		
average atmospheric lifetime (τatm):	2600 yr	6694
ODP (ozone depletion potential):	0.000 (model-derived relative to R 11)	
GWP (global warming potential):	8600 relative to CO2 for 100 yr integration	9501
HGWP (halocarbon GWP):	40.9 relative to R 11 for infinite integration period	DW
SAFETY		
• classification ----------		
safety group (ASHRAE Standard 34):	A1	8601
NFPA 704 degrees of hazard (H-F-R-S):	3M: 1-0-0	MSDS
	BOC Gases: 1-0-0	MSDS
	health-flammability-reactivity [-special]: 0=no, 4=severe	
NPCA HMIS hazard ratings (H-F-R):	3M: 0-0-0	MSDS
	BOC Gases: 1-0-0	MSDS
	health-flammability-reactivity 0=insignificant, 4=extreme	
• long-term occupational limit -------		
exposure limit consistent to OSHA PEL:	Rhône-Poulenc: 1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	ltr
• emergency exposure limit ----------		
Acute Toxicity Exposure Limit (ATEL):	90,000 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	90,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
Refrigerant Concentration Limit (RCL):	69,000 ppm v/v (preliminary	34u

	based on ASHRAE 34u draft)	
	69,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
• acute (short-term) toxicity --------		
LC50 (lethal concentration, 50%):	rat, 1 hr, 0/10: >800,000 ppm (fatal concentration by inhalation for half of test animals)	7550
	rat, 4 hr, 0/10: >110,000 ppm (fatal concentration by inhalation for half of test animals)	65F8
	rat, 10 day, 0/20: >113,000 ppm (fatal concentration by inhalation for half of test animals)	7550
cardiac sensitization (CS) EC50:	dog, 10 min: >400,000 ppm v/v (effective concentration in half of test animals)	6684
cardiac sensitization threshold/LOEL:	dog, 2/8: 400,000 ppm v/v (lowest observed effect level in test animals)	65F9
cardiac sensitization (CS) NOEL:	dog, 0/6: 300,000 ppm v/v (no observed effect level in test animals)	65F9
anesthetic/CNS effect LOEL:	rat, 1 hr, 10/10: 800,000 ppm v/v (lowest observed effect level in ALC or LC50 studies)	7550
anesthetic/CNS effect NOEL:	rat, 10 day, 0/20: 113,000 ppm v/v (no observed effect level in subchronic or chronic study)	7550
• flammability ----------		
LFL-UFL (flammability limits in air):	none (nonflammable as tested)	2525
flash point:	BOC Gases: none	MSDS
autoignition temperature:	BOC Gases: none	MSDS
• detection ----------		
appearance:	Rhône-Poulenc: colorless	MSDS
odor:	BNFL Fluorochemicals: odorless	MSDS
	BOC Gases: faintly sweet odor	MSDS
PRODUCTION		
last year production allowed:	unrestricted	8C01

R-227ea

---------- REFRIGERANT DATA SUMMARY ----------

R-227ea	1,1,1,2,3,3,3-heptafluoropropane		see
HFC	CF3CHFCF3	CAS number 431-89-0	RDB#

COMMON USE(S)

candidate to replace refrigerants 12B1 and 114 in refrigeration, high-temperature heat pumps, and air-conditioning systems with high condensing temperatures (up to 90 °C, 194 °F) such as for crane cabs in steel mills; under consideration as a blend component in alternatives for refrigerants 12, 22, 114, and 502; under consideration in high-speed, centrifugal chillers with capacities a low as 100 kW (30 ton); under consideration as a heat transfer fluid to replace refrigerant 11; filling medium for temperature sensing bulbs; working fluid in organic rankine cycles (ORCs); fire suppressant (e.g., Great Lakes FM-200) for flooding applications; propellant for pharmaceutical aerosols and metered dose inhalers (e.g., Hoechst/Solvay HFA 227 Pharma); under consideration as a blend component (with ethylene oxide) as a medical sterilant

IDENTIFIERS

common name(s):	R-227ea; R227ea; R 227ea	
	HFC-227ea	
	not recommended: HFA-227ea	
	fluorochemical 227ea; FC 227ea	
	halon 37	
chemical name (by IUPAC convention):	1,1,1,2,3,3,3-heptafluoropropane	
alternative chemical names/formulae:	propane, 1,1,1,2,3,3,3-heptafluoro-	
	2H-heptafluoropropane	A612
	CF3CHFCF3; CF3-CHF-CF3	
	not recommended: CF3CFHCF3; CF3-CFH-CF3	
empirical formula:	C3HF7	
CAS number:	431-89-0 (Chemical Abstracts Service registry number)	
EINECS number:	207-079-2 (European Inventory of Existing Chemical Substances)	
trade name(s):	Great Lakes FM-200	
	Solvay Reclin(R) 227	
	Solvay Solkane(R) 227ea	
	ZCIRI Kehua (PRC) HFC-227ea	
historical name(s):	Hoechst Reclin(R) 227	3A66
	Hoechst Refrigerant R 227	3A66
ARI container color / Pantone number:	none, use light green grey/413	6601

PHYSICAL

• properties ----------		
molar mass:	170.0288624 g/mol (0.374849 lb/mol)	8820
normal freezing/melting/triple point:	-126.8 °C (-196.2 °F)	3408
	-131.1 °C (-204.1 °F)	3728
• normal boiling point ----------		
temperature:	-15.6 °C (3.9 °F)	8401
density, saturated liquid:	1541 kg/m3 (96.21 lb/cf)	8401
density, saturated vapor:	8.47 kg/m3 (0.528 lb/cf)	8401
specific volume, saturated liquid:	0.649 L/kg (0.0104 cf/lb)	8401
specific volume, saturated vapor:	118.1 L/kg (1.8923 cf/lb)	8401
heat of vaporization:	135.9 kJ/kg (58.4 Btu/lb)	8401

velocity of sound, saturated liquid:	552 m/s (1811 ft/s)	8401
velocity of sound, saturated vapor:	111 m/s (365 ft/s)	8401
viscosity, saturated liquid:	441 µPa•s (0.441 cp)	8401
viscosity, saturated vapor:	9.83 µPa•s (0.00983 cp)	8401
thermal conductivity, liquid:	0.0641 W/m•K (0.0370 Btu/hr•ft°F)	8401
thermal conductivity, vapor:	0.0098 W/m•K (0.0057 Btu/hr•ft°F)	8401
• normal pressure, 20 °C (68 °F) -----		
density, vapor:	7.284 kg/m3 (0.4547 lb/cf)	8401
• normal pressure, 21.1 °C (70 °F) ---		
density, vapor:	7.253 kg/m3 (0.4528 lb/cf)	8401
• 20 °C (68 °F) ----------		
pressure, saturated vapor:	388.8 kPa (56.39 psia)	8401
density, saturated liquid:	1407 kg/m3 (87.83 lb/cf)	8401
density, saturated vapor:	31.04 kg/m3 (1.938 lb/cf)	8401
specific volume, saturated liquid:	0.711 L/kg (0.0114 cf/lb)	8401
specific volume, saturated vapor:	32.2 L/kg (0.5161 cf/lb)	8401
velocity of sound, saturated liquid:	417 m/s (1368 ft/s)	8401
velocity of sound, saturated vapor:	110 m/s (361 ft/s)	8401
viscosity, saturated liquid:	262 µPa•s (0.262 cp)	8401
viscosity, saturated vapor:	11.2 µPa•s (0.0112 cp)	8401
thermal conductivity, saturatd liquid:	0.0546 W/m•K (0.0315 Btu/hr•ft°F)	8401
thermal conductivity, saturated vapor:	0.01228 W/m•K (0.00710 Btu/hr•ft°F)	8401
• 60 °C (140 °F) ----------		
pressure, saturated vapor:	1182 kPa (171.5 psia)	8401
heat of vaporization:	86.9 kJ/kg (37.4 Btu/lb)	8401
• critical point ----------		
temperature:	102.8 °C (217.0 °F)	7713
pressure:	2980 kPa (432.2 psia)	8401
density:	580 kg/m3 (36.2 lb/cf)	3408
specific volume:	1.72 L/kg (0.0276 cf/lb)	3408

ENVIRONMENTAL

average atmospheric lifetime (τatm):	36.5 ±7.3 yr	6695
average tropospheric lifetime (τtrop):	40 yr	5804
	estimated: 63-72 yr	8312
ODP (ozone depletion potential):	0.000 (model-derived relative to R 11)	
GWP (global warming potential):	3800 relative to CO2 for 100 yr integration	9501
HGWP (halocarbon GWP):	0.69 relative to R 11 for infinite integration period	8101

SAFETY

• classification ----------		
safety group (ASHRAE Standard 34):	none (no application pending)	8601
• long-term occupational limit -------		
exposure limit consistent to OSHA PEL:	Hoechst internal guide: 1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	mfr
• emergency exposure limit ----------		
Acute Toxicity Exposure Limit (ATEL):	70,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
Refrigerant Concentration Limit (RCL):	69,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
• acute (short-term) toxicity --------		
LC50 (lethal concentration, 50%):	rat, 4 hr, 0%: >110,000 ppm (fatal concentration by inhalation for half of test animals)	7116
	rat, 4 hr, 0/10: >788,696 ppm	A616

	(fatal concentration by inhalation for half of test animals)	
	rat, 4 hr, 0/6: >121,267 ppm (fatal concentration by inhalation for half of test animals)	A617
	rat, 4 hr: >788,696 ppm (fatal concentration by inhalation for half of test animals)	65F2
	rat, 4 hr: >800,000 (rounded) ppm (fatal concentration by inhalation for half of test animals)	5526
	rat, 4 hr: >800,000 (rounded) ppm (fatal concentration by inhalation for half of test animals)	A668
	rat, 4½hr w break 0%: >241,188 ppm (fatal concentration by inhalation for half of test animals)	A617
cardiac sensitization (CS) EC50:	dog, 30 min: 140,000 ppm v/v (effective concentration in half of test animals)	65F2
cardiac sensitization threshold/LOEL:	dog, 30 min, 1/10: 90,000 ppm v/v (lowest observed effect level in test animals)	A615
cardiac sensitization (CS) NOEL:	dog, 30 min, 0/10: 70,000 ppm v/v (no observed effect level in test animals)	A615
	dog, 30 min, 0/10: 90,000 ppm v/v (no observed effect level in test animals)	65F2
	dog, ? epinephrine: 50,000 ppm v/v (no observed effect level in test animals)	7116
anesthetic/CNS effect LOEL:	dog, 1 hr, ?/4: 150,000 ppm v/v (lowest observed effect level in ALC or LC50 studies)	7116
	rat, 4 hr, 6/6: 121,267 ppm v/v (lowest observed effect level in ALC or LC50 studies)	A617
	rat, 4 hr, ?/?: 110,000 ppm v/v (lowest observed effect level in ALC or LC50 studies)	7116
anesthetic/CNS effect NOEL:	dog, 1 hr, 0/4: 50,000 ppm v/v (no observed effect level in ALC or LC50 studies)	7116
	rat, 6 hr, 0/10: 105,000 ppm v/v (no observed effect level in subchronic or chronic study)	65F2
• flammability ----------		
LFL-UFL (flammability limits in air):	none (nonflammable as tested)	3726
heat of combustion (by ASHRAE 34-92):	3.3 MJ/kg (1398 Btu/lb)	4785
flash point:	Great Lakes: nonflammable gas	MSDS
autodecomposition temperature:	>700 °C (>1292 °F)	A612
• detection ----------		
appearance:	colorless gas	A612
odor:	Great Lakes: odorless	MSDS
	Hoechst: ether-like	MSDS
	odorless	A612

PRODUCTION
first commercial use as a refrigerant: January 1996
last year production allowed: unrestricted 8C01

R-236fa

---------- REFRIGERANT DATA SUMMARY ----------

			see
R-236fa	1,1,1,3,3,3-hexafluoropropane		
HFC	CF3CH2CF3	CAS number 690-39-1	RDB#

COMMON USE(S)
alternative for refrigerant 114, primarily for aftermarket use to retrofit centrifugal chillers on surface ships and in nuclear power plants; under consideration for use in heat-recovery chillers, high temperature and industrial heat pumps, and high condensing temperature air-conditioners; fire suppressant (e.g., DuPont Chemicals FE-36); semiconductor manufacturing

IDENTIFIERS

common name(s):	R-236fa; R236fa; R 236fa HFC-236fa not recommended: HFA-236fa fluorocarbon 236fa fluorochemical 236fa; FC 236fa halocarbon 236fa halochemical 236fa hexafluoropropane hydrofluorocarbon 236fa	
chemical name (by IUPAC convention):	1,1,1,3,3,3-hexafluoropropane	
alternative chemical names/formulae:	propane, 1,1,1,3,3,3- hexafluoro- bis(trifluoromethyl)methane bistrifluoromethylmethane 2,2-dihydroperfluoropropane CF3CH2CF3; CF3-CH2-CF3	
empirical formula:	C3H2F6	
CAS number:	690-39-1 (Chemical Abstracts Service registry number)	
NIOSH RTECS number:	TZ4043332 (Registry of Toxic Effects of Chemical Substances)	
trade name(s):	3M(TM) HFG-3236	MSDS
	3M(TM) HFG-3236fa	6B05
	AlliedSignal Genetron(R) 236fa	MSDS
	DuPont Suva(R) 236fa	MSDS
ARI container color / Pantone number:	none, use light green grey/413	6601

PHYSICAL

• properties ----------		
molar mass:	152.0383992 g/mol (0.335187 lb/mol)	8820
normal freezing/melting/triple point:	-93.6 °C (-136.5 °F)	8401
• normal boiling point ----------		
temperature:	-1.4 °C (29.4 °F)	8401
density, saturated liquid:	1445 kg/m3 (90.19 lb/cf)	8401
density, saturated vapor:	7.14 kg/m3 (0.446 lb/cf)	8401
specific volume, saturated liquid:	0.692 L/kg (0.0111 cf/lb)	8401
specific volume, saturated vapor:	140.0 L/kg (2.2423 cf/lb)	8401
heat of vaporization:	160.3 kJ/kg (68.9 Btu/lb)	8401
velocity of sound, saturated liquid:	624 m/s (2048 ft/s)	8401
velocity of sound, saturated vapor:	122 m/s (399 ft/s)	8401
viscosity, saturated liquid:	356 µPa•s (0.356 cp)	8401
viscosity, saturated vapor:	9.96 µPa•s (0.00996 cp)	8401
thermal conductivity, liquid:	0.0724 W/m•K (0.0418 Btu/hr•ft°F)	8401

thermal conductivity, vapor:	0.0106 W/m•K (0.0061 Btu/hr•ft°F)	8401
• normal pressure, 20 °C (68 °F) -----		
density, vapor:	6.542 kg/m3 (0.4084 lb/cf)	8401
• normal pressure, 21.1 °C (70 °F) ---		
density, vapor:	6.514 kg/m3 (0.4066 lb/cf)	8401
• 20 °C (68 °F) ----------		
pressure, saturated vapor:	229.6 kPa (33.31 psia)	6B05
density, saturated liquid:	1376 kg/m3 (85.93 lb/cf)	8401
density, saturated vapor:	15.58 kg/m3 (0.973 lb/cf)	8401
specific volume, saturated liquid:	0.727 L/kg (0.0116 cf/lb)	8401
specific volume, saturated vapor:	64.2 L/kg (1.0278 cf/lb)	8401
velocity of sound, saturated liquid:	545 m/s (1789 ft/s)	8401
velocity of sound, saturated vapor:	122 m/s (400 ft/s)	8401
viscosity, saturated liquid:	270 µPa•s (0.270 cp)	8401
viscosity, saturated vapor:	10.7 µPa•s (0.0107 cp)	8401
thermal conductivity, saturatd liquid:	0.0662 W/m•K (0.0382 Btu/hr•ft°F)	8401
thermal conductivity, saturated vapor:	0.01198 W/m•K (0.00692 Btu/hr•ft°F)	8401
• 60 °C (140 °F) ----------		
pressure, saturated vapor:	765 kPa (110.9 psia)	8401
heat of vaporization:	122.6 kJ/kg (52.7 Btu/lb)	8401
• critical point ----------		
temperature:	124.9 °C (256.9 °F)	7714
pressure:	3200 kPa (464.1 psia)	8401
density:	551 kg/m3 (34.4 lb/cf)	8401
specific volume:	1.81 L/kg (0.0291 cf/lb)	8401
ENVIRONMENTAL		
average atmospheric lifetime (τatm):	226 yr	9501
average tropospheric lifetime (τtrop):	estimated: 77-218 yr	8312
ODP (ozone depletion potential):	0.000 (model-derived relative to R 11)	
GWP (global warming potential):	9400 relative to CO2 for 100 yr integration	9501
HGWP (halocarbon GWP):	3.79 relative to R 11 for infinite integration period	8101
	4.2 relative to R 11 for infinite integration period	6B05
SAFETY		
• classification ----------		
safety group (ASHRAE Standard 34):	A1	34e
NFPA 704 degrees of hazard (H-F-R-S):	AlliedSignal: 2-0-0 health-flammability-reactivity [-special]: 0=no, 4=severe	MSDS
NPCA HMIS hazard ratings (H-F-R):	AlliedSignal: 2-0-0	MSDS
	DuPont: 1-0-1	MSDS
	health-flammability-reactivity 0=insignificant, 4=extreme	
• long-term occupational limit -------		
AIHA WEEL (workplace envl exp limit):	1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	8612
exposure limit consistent to OSHA PEL:	DuPont AEL: 1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	MSDS
• emergency exposure limit ----------		
Acute Toxicity Exposure Limit (ATEL):	100,000 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	55,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
Refrigerant Concentration Limit (RCL):	55,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
	69,000 ppm v/v (preliminary	34u

	based on ASHRAE 34u draft)	
• acute (short-term) toxicity --------		
LC50 (lethal concentration, 50%):	mouse, 10 min: 440,000 ppm (fatal concentration by inhalation for half of test animals)	5980
	rat, 4 hr: >457,000 ppm (fatal concentration by inhalation for half of test animals)	6A94
cardiac sensitization threshold/LOEL:	dog, 10 min, 2/6: 150,000 ppm v/v (lowest observed effect level in test animals)	65A5
cardiac sensitization (CS) NOEL:	dog, 10 min, 0/6: 100,000 ppm v/v (no observed effect level in test animals)	65A5
anesthetic/CNS effect EC50:	mouse, 10 min: 110,000 ppm v/v (effective concentration in half of test animals)	5980
anesthetic/CNS effect LOEL:	rat, 4 hr, ?/4: 189,275 ppm v/v (lowest observed effect level in ALC or LC50 studies)	6803
	rat, 6 h/d 14wk 6-8/10: 50,300 ppm v/v (lowest observed effect level in ALC or LC50 studies)	A306
anesthetic/CNS effect NOEL:	rat, 4 hr, 0/4: 133,939 ppm v/v (no observed effect level in ALC or LC50 studies)	6803
	rat, 2-week, 0/4: 5,020 ppm v/v (no observed effect level in subchronic or chronic study)	6A93
	rat, 6 h/d 14 wk, 0/20: 20,000 ppm v/v (no observed effect level in subchronic or chronic study)	A306
	rat, day 1 of 2wk, 0/4: 20,000 ppm v/v (no observed effect level in subchronic or chronic study)	6A93
• flammability ----------		
LFL-UFL (flammability limits in air):	none (nonflammable as tested)	6B05
flash point:	3M: none	MSDS
autodecomposition temperature:	AlliedSignal: >250°C (>482°F)	MSDS
• detection ----------		
appearance:	DuPont: colorless	MSDS
odor:	3M: faint ethereal	MSDS
PRODUCTION		
first commercial use as a refrigerant:	October 1996	
last year production allowed:	unrestricted	8C01

R-245ca

REFRIGERANT DATA SUMMARY			
R-245ca	1,1,2,2,3-pentafluoropropane		see
HFC	CH2FCF2CHF2	CAS number 679-86-7	RDB#

COMMON USE(S)
considered as an alternative for refrigerants 11 and 123 circa 1992, constrained by marginal flammability; also considered for use as a foam blowing agent

IDENTIFIERS

common name(s):	R-245ca; R245ca; R 245ca HFC-245ca fluorocarbon 245ca fluorochemical 245ca; FC 245ca halocarbon 245ca halochemical 245ca hydrofluorocarbon 245ca	
chemical name (by IUPAC convention):	1,1,2,2,3-pentafluoropropane	
alternative chemical names/formulae:	propane, 1,1,2,2,3-pentafluoro- CH2FCF2CHF2; CH2F-CF2-CHF2 not recommended: CF2HCF2CFH2; CF2H-CF2-CFH2 CFH2CF2CF2H; CFH2-CF2-CF2H CHF2CF2CH2F; CHF2-CF2-CH2F FCH2CF2CHF2; FCH2-CF2-CHF2	
empirical formula:	C3H3F5	
CAS number:	679-86-7 (Chemical Abstracts Service registry number)	

PHYSICAL

• properties		
molar mass:	134.047936 g/mol (0.295525 lb/mol)	8820
normal freezing/melting/triple point:	-73.4 °C (-100.1 °F)	3301
• normal boiling point		
temperature:	25.1 °C (77.2 °F)	8401
density, saturated liquid:	1386 kg/m3 (86.53 lb/cf)	8401
density, saturated vapor:	5.74 kg/m3 (0.358 lb/cf)	8401
specific volume, saturated liquid:	0.722 L/kg (0.0116 cf/lb)	8401
specific volume, saturated vapor:	174.3 L/kg (2.7922 cf/lb)	8401
heat of vaporization:	201.0 kJ/kg (86.4 Btu/lb)	8401
velocity of sound, saturated liquid:	655 m/s (2150 ft/s)	8401
velocity of sound, saturated vapor:	136 m/s (446 ft/s)	8401
viscosity, saturated vapor:	10.16 µPa•s (0.01016 cp)	8401
viscosity, saturated liquid:	542 µPa•s (0.542 cp)	8401
thermal conductivity, liquid:	0.0873 W/m•K (0.0505 Btu/hr•ft°F)	8401
thermal conductivity, vapor:	0.0123 W/m•K (0.0071 Btu/hr•ft°F)	8401
• normal pressure, 20 °C (68 °F)		
density, liquid:	1399 kg/m3 (11.67 lb/gal)	8401
• normal pressure, 21.1 °C (70 °F)		
density, liquid:	1396 kg/m3 (11.65 lb/gal)	8401
• 20 °C (68 °F)		
pressure, saturated vapor:	82.9 kPa (12.02 psia)	8401
density, saturated liquid:	1399 kg/m3 (87.32 lb/cf)	8401
density, saturated vapor:	4.75 kg/m3 (0.296 lb/cf)	8401
specific volume, saturated liquid:	0.715 L/kg (0.0115 cf/lb)	8401
specific volume, saturated vapor:	210.7 L/kg (3.3744 cf/lb)	8401

velocity of sound, saturated liquid:	674 m/s (2210 ft/s)	8401
velocity of sound, saturated vapor:	135 m/s (444 ft/s)	8401
viscosity, saturated liquid:	584 µPa•s (0.584 cp)	8401
viscosity, saturated vapor:	10.0 µPa•s (0.0100 cp)	8401
thermal conductivity, saturatd liquid:	0.0889 W/m•K (0.0513 Btu/hr•ft°F)	8401
thermal conductivity, saturated vapor:	0.01187 W/m•K (0.00686 Btu/hr•ft°F)	8401
• 60 °C (140 °F) ----------		
pressure, saturated vapor:	327 kPa (47.5 psia)	8401
heat of vaporization:	180.6 kJ/kg (77.6 Btu/lb)	8401
• critical point ----------		
temperature:	174.4 °C (346.0 °F)	7714
pressure:	3935 kPa (570.7 psia)	8401
density:	524 kg/m3 (32.7 lb/cf)	7714
specific volume:	1.91 L/kg (0.0306 cf/lb)	7714
ENVIRONMENTAL		
average atmospheric lifetime (τatm):	6.6 ±2.3 yr	6695
average tropospheric lifetime (τtrop):	6.3 yr	5804
	estimated: 1.3-3 yr	8312
ODP (ozone depletion potential):	0.000 (model-derived relative to R 11)	
GWP (global warming potential):	720 relative to CO2 for 100 yr integration	9501
HGWP (halocarbon GWP):	0.13 relative to R 11 for infinite integration period	8101
SAFETY		
• classification ----------		
safety group (ASHRAE Standard 34):	none (no application pending)	8601
• emergency exposure limit ----------		
Acute Toxicity Exposure Limit (ATEL):	0 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
Refrigerant Concentration Limit (RCL):	0 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
• acute (short-term) toxicity --------		
ALC (approximate lethal concentration:	mouse, 30 min, 1/>2: 240,000 ppm (lowest exposure tested with one or more deaths by inhalation)	5C76
	mouse, 30 min, 1/?: 240,000 ppm (lowest exposure tested with one or more deaths by inhalation)	5C76
	rat, 4 hr: >993 ppm (lowest exposure tested with one or more deaths by inhalation)	5805
anesthetic/CNS effect LOEL:	mouse, 30 min, 1/>2: 100,000 ppm v/v (lowest observed effect level in test animals)	5C76
	mouse, 5or10 min, ?/?: 100,000 ppm v/v (lowest observed effect level in test animals)	5C77
anesthetic/CNS effect NOEL:	mouse, 5or10 min, 0/?: 50,000 ppm v/v (no observed effect level in test animals)	5C77
• flammability ----------		
LFL-UFL (flammability limits in air):	7.1-14.8 % v/v	4785
	8.3-12.8 % v/v	5B15
	none (nonflammable as tested)	2A01
heat of combustion (by ASHRAE 34-92):	7.1 MJ/kg (3052 Btu/lb)	6501
	8.4 MJ/kg (3616 Btu/lb)	4785
flash point:	none	5B15

PRODUCTION

first commercial use as a refrigerant:	not known to be commercialized	
last year production allowed:	unrestricted	8C01

R-245fa

---------- REFRIGERANT DATA SUMMARY ----------

R-245fa	1,1,1,3,3-pentafluoropropane		see
HFC	CHF2CH2CF3	CAS number 460-73-1	RDB#

COMMON USE(S)

under consideration as an alternative for refrigerants 11 and 123 for use in centrifugal chillers; constrained by higher pressure (still low pressure, but sufficient to require compliance with requirements for pressure vessels) and - particularly with single-stage compressors and in typical capacities - lower efficiency; candidate to replace fluorochemical 141b as a foam blowing agent, alone and in azeotropic mixtures with hydrocarbons

Note: ASHRAE SSPC 34 proposed revision of the safety classification from "A1 provisional" to B1 on 2000.02.06 in light of the new WEEL of 300 ppm v/v, adopted by AIHA in January 2000. The revision is subject to a review and approval procedure now underway; actual assignment will not occur until published in an addendum or revision to ANSI/ASHRAE Standard 34-1997.

IDENTIFIERS

common name(s):	R-245fa; R245fa; R 245fa	
	HFC-245fa	
	fluorocarbon 245fa	
	fluorochemical 245fa; FC 245fa	
	halocarbon 245fa	
	halochemical 245fa	
	hydrofluorocarbon 245fa	
chemical name (by IUPAC convention):	1,1,1,3,3-pentafluoropropane	
alternative chemical names/formulae:	propane, 1,1,1,3,3-pentafluoro-	
	CHF2CH2CF3; CHF2-CH2-CF3	
	not recommended:	
	CF2HCH2CF3; CF2H-CH2-CF3	
	CF3CH2CF2H; CF3-CH2-CF2H	
	CF3CH2CHF2; CF3-CH2-CHF2	
empirical formula:	C3H3F5	
CAS number:	460-73-1 (Chemical Abstracts Service registry number)	
trade name(s):	Honeywell HFC-245fa	MSDS
historical name(s):	AlliedSignal Genetron(R) 245fa	mfr
	AlliedSignal HFC-245fa	MSDS
ARI container color / Pantone number:	none, use light green grey/413	6601

PHYSICAL

• properties ----------		
molar mass:	134.047936 g/mol (0.295525 lb/mol)	8820
normal freezing/melting/triple point:	-102.1 °C (-151.8 °F)	3408
	-80.0 °C (-112.0 °F)	MSDS
	< -160.0 °C (< -256 °F)	5A34
• normal boiling point ----------		
temperature:	14.9 °C (58.8 °F)	8401
	15.1 °C (59.2 °F)	8324
density, saturated liquid:	1366 kg/m3 (85.26 lb/cf)	8401
density, saturated vapor:	5.92 kg/m3 (0.370 lb/cf)	8401
specific volume, saturated liquid:	0.732 L/kg (0.0117 cf/lb)	8401
specific volume, saturated vapor:	16.9 L/kg (0.2705 cf/lb)	8401
heat of vaporization:	196.7 kJ/kg (84.6 Btu/lb)	8401

velocity of sound, saturated liquid:	715 m/s (2346 ft/s)	8401
velocity of sound, saturated vapor:	134 m/s (439 ft/s)	8401
viscosity, saturated liquid:	464 µPa•s (0.464 cp)	8401
viscosity, saturated vapor:	9.99 µPa•s (0.00999 cp)	8401
thermal conductivity, liquid:	0.0841 W/m•K (0.0486 Btu/hr•ft°F)	8401
thermal conductivity, vapor:	0.0117 W/m•K (0.0067 Btu/hr•ft°F)	8401
• 20 °C (68 °F) ----------		
pressure, saturated vapor:	123.8 kPa (17.96 psia)	8401
density, saturated liquid:	1352 kg/m3 (84.42 lb/cf)	8401
density, saturated vapor:	7.16 kg/m3 (0.447 lb/cf)	8401
specific volume, saturated liquid:	0.740 L/kg (0.0118 cf/lb)	8401
specific volume, saturated vapor:	14.0 L/kg (0.2238 cf/lb)	8401
velocity of sound, saturated liquid:	693 m/s (2272 ft/s)	8401
velocity of sound, saturated vapor:	134 m/s (441 ft/s)	8401
viscosity, saturated liquid:	432 µPa•s (0.432 cp)	8401
viscosity, saturated vapor:	10.2 µPa•s (0.0102 cp)	8401
thermal conductivity, saturatd liquid:	0.0826 W/m•K (0.0477 Btu/hr•ft°F)	8401
thermal conductivity, saturated vapor:	0.01208 W/m•K (0.00698 Btu/hr•ft°F)	8401
• 60 °C (140 °F) ----------		
pressure, saturated vapor:	464 kPa (67.2 psia)	8401
heat of vaporization:	168.4 kJ/kg (72.4 Btu/lb)	8401
• critical point ----------		
temperature:	154.1 °C (309.3 °F)	7714
pressure:	3640 kPa (527.9 psia)	8401
	4433 kPa (643.0 psia)	8324
density:	517 kg/m3 (32.3 lb/cf)	7714
specific volume:	1.93 L/kg (0.0310 cf/lb)	7714
ENVIRONMENTAL		
average atmospheric lifetime (τatm):	7.6 yr	9709
	8.4 yr	8323
	8.8 yr	5442
average tropospheric lifetime (τtrop):	8.6 yr	5805
	estimated: 7-11 yr	8312
ODP (ozone depletion potential):	0.000 (model-derived relative to R 11)	
GWP (global warming potential):	760 relative to CO2 for 100 yr integration	9709
	820 relative to CO2 for 100 yr integration	8101
	990 relative to CO2 for 100 yr integration	ETF
HGWP (halocarbon GWP):	0.18 relative to R 11 for infinite integration period	8101
	0.24 relative to R 11 for infinite integration period	5B15
SAFETY		
• classification ----------		
safety group (ASHRAE Standard 34):	A1 provisional	34h
	B1 proposed as a revision on 2000.06.25	34am 34am
NFPA 704 degrees of hazard (H-F-R-S):	AlliedSignal: 2-0-1 health-flammability-reactivity [-special]: 0=no, 4=severe	MSDS
NPCA HMIS hazard ratings (H-F-R):	AlliedSignal: 2-0-1 health-flammability-reactivity 0=insignificant, 4=extreme	MSDS
• long-term occupational limit -------		
AIHA WEEL (workplace envl exp limit):	300 ppm v/v TWA for 8 hr/day	

	and 40 hr/wk	
• emergency exposure limit ----------		
Acute Toxicity Exposure Limit (ATEL):	34,000 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	34,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
Refrigerant Concentration Limit (RCL):	34,000 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	34,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
• acute (short-term) toxicity --------		
ALC (approximate lethal concentration:	mouse, 4 hr, 0/10: >101,300 ppm (lowest exposure tested with one or more deaths by inhalation)	9707
	rat, 4 hr, 0/10: >203,000 ppm (lowest exposure tested with one or more deaths by inhalation)	7111
dermal LD50 (lethal dosage, 50%):	rabbit: >2,600 mg/kg (fatal dose by skin contact for half of test animals)	7113
cardiac sensitization threshold/LOEL:	dog, 10 min, 1/4: 44,000 ppm v/v (lowest observed effect level in test animals)	9707
cardiac sensitization (CS) NOEL:	dog, 0/6: 20,000 ppm v/v (no observed effect level in test animals)	7112
	dog, 10 min, 0/3: 54,100 ppm v/v (no observed effect level in test animals)	9707
	dog, 10 min, 0/4: 34,100 ppm v/v (no observed effect level in test animals)	9707
anesthetic/CNS effect LOEL:	mouse, 4 hr, 10/10: 101,300 ppm v/v (lowest observed effect level in ALC or LC50 studies)	9707
	rat, 4 hr, 10/10: 116,000 ppm v/v (lowest observed effect level in ALC or LC50 studies)	7115
	rat, 4 hr, 10/10: 143,000 ppm v/v (lowest observed effect level in ALC or LC50 studies)	7111
anesthetic/CNS effect NOEL:	rat, 6 hr, 0/20: 50,600 ppm v/v (no observed effect level in subchronic or chronic study)	9707
• flammability ----------		
LFL-UFL (flammability limits in air):	none (not flammable as tested)	6B20
	none (not flammable as tested)	7114
heat of combustion (by ASHRAE 34-92):	6.1 MJ/kg (2618 Btu/lb)	UL
flash point:	none	6B20
autoignition temperature:	704 °C (1299 °F)	UL
	AlliedSignal: 412 °C (774 °F) for 500 and 160 ml flasks	MSDS MSDS
autodecomposition temperature:	AlliedSignal: >250°C (>482°F)	MSDS
former UL Classification:	practically nonflammable (withdrawn for revision of the classification system, category SBQT2)	UL
• detection ----------		
appearance:	AlliedSignal: colorless volatile liquid	MSDS

odor:	AlliedSignal: faint ethereal	MSDS
	and sweetish odor	MSDS
PRODUCTION		
first commercial use as a refrigerant:	projected: 2001-2003	
last year production allowed:	unrestricted	8C01

R-290 (PROPANE)

---------- REFRIGERANT DATA SUMMARY ----------

R-290	propane		see
HC	CH3CH2CH3	CAS number 74-98-6	RDB#

COMMON USE(S)

blend component for alternatives to refrigerants 12, 22, and 502 including 402A, 402B, 403A, and 403B; limited use in industrial refrigeration; primary use is as a fuel as a principal component of liquified petoleum gas (LPG); feedstock for organic synthesis of other compounds; thermobulb fill for temperature and pressure control sensors; selective solvent for removal of anphaltic components from high-boiling fractions of crude oil

Natural propane contains approximately 96% actual propane and 4% other hydrocarbons and contaminants. Some commercial grades of propane include 0-50 ppm v/v oderants such as methyl mercaptan and thiopane.

IDENTIFIERS

common name(s):	R-290; R290; R 290 HC-290 bottled gas hydrocarbon 290 n-C3; n-C3H8 n-propane; normal-propane	
chemical name (by IUPAC convention):	propane	
alternative chemical names/formulae:	dimethyl methane dimethylmethane; CH2(CH3)2 propyl hydride CH3CH2CH3; CH3-CH2-CH3	
empirical formula:	C3H8	
CAS number:	74-98-6 (Chemical Abstracts Service registry number)	
EINECS number:	200-827-9 (European Inventory of Existing Chemical Substances)	
NIOSH RTECS number:	TX2275000 (Registry of Toxic Effects of Chemical Substances)	
trade name(s):	Calor Gas (UK) CARE 40 Ecozone BV (NL) Ecool-PRO	
ARI container color / Pantone number:	none, use light green grey/413 with red / 185 band	6601

PHYSICAL

• properties ----------		
molar mass:	44.09562 g/mol (0.097214 lb/mol)	8820
normal freezing/melting/triple point:	-187.3 °C (-305.1 °F)	8401
• normal boiling point ----------		
temperature:	-42.1 °C (-43.8 °F)	8401
density, saturated liquid:	581 kg/m3 (36.29 lb/cf)	8401
density, saturated vapor:	2.42 kg/m3 (0.151 lb/cf)	8401
specific volume, saturated liquid:	1.721 L/kg (0.0276 cf/lb)	8401
specific volume, saturated vapor:	413.4 L/kg (6.6225 cf/lb)	8401
heat of vaporization:	425.4 kJ/kg (182.9 Btu/lb)	8401
velocity of sound, saturated liquid:	1158 m/s (3800 ft/s)	8401
velocity of sound, saturated vapor:	218 m/s (716 ft/s)	8401
viscosity, saturated liquid:	197 µPa•s (0.197 cp)	8401
viscosity, saturated vapor:	6.47 µPa•s (0.00647 cp)	8401

thermal conductivity, liquid:	0.1294 W/m•K (0.0747 Btu/hr•ft°F)	8401
thermal conductivity, vapor:	0.0114 W/m•K (0.0066 Btu/hr•ft°F)	8401
• normal pressure, 20 °C (68 °F) -----		
density, vapor:	1.865 kg/m3 (0.1164 lb/cf)	8401
• normal pressure, 21.1 °C (70 °F) ---		
density, vapor:	1.858 kg/m3 (0.1160 lb/cf)	8401
• 20 °C (68 °F) ----------		
pressure, saturated vapor:	836.2 kPa (121.29 psia)	8401
density, saturated liquid:	500 kg/m3 (31.23 lb/cf)	8401
density, saturated vapor:	18.10 kg/m3 (1.130 lb/cf)	8401
specific volume, saturated liquid:	1.999 L/kg (0.0320 cf/lb)	8401
specific volume, saturated vapor:	55.2 L/kg (0.8850 cf/lb)	8401
velocity of sound, saturated liquid:	754 m/s (2473 ft/s)	8401
velocity of sound, saturated vapor:	217 m/s (711 ft/s)	8401
viscosity, saturated liquid:	102 µPa•s (0.102 cp)	8401
viscosity, saturated vapor:	8.5 µPa•s (0.0085 cp)	8401
thermal conductivity, saturatd liquid:	0.0954 W/m•K (0.0551 Btu/hr•ft°F)	8401
thermal conductivity, saturated vapor:	0.01838 W/m•K (0.01062 Btu/hr•ft°F)	8401
• 60 °C (140 °F) ----------		
pressure, saturated vapor:	2116 kPa (306.9 psia)	8401
heat of vaporization:	258.4 kJ/kg (111.1 Btu/lb)	8401
• critical point ----------		
temperature:	96.7 °C (206.1 °F)	7713
pressure:	4248 kPa (616.1 psia)	8401
density:	221 kg/m3 (13.8 lb/cf)	7713
specific volume:	4.54 L/kg (0.0726 cf/lb)	7713
ENVIRONMENTAL		
ODP (ozone depletion potential):	0.000 (model-derived relative to R 11)	
GWP (global warming potential):	unknown, but very low: ~20 relative to CO2 for 100 yr integration	
HGWP (halocarbon GWP):	~0 relative to R 11 for infinite integration period	
photochemical reactivity (grnd level):	220 relative to methane	4511
SAFETY		
• classification ----------		
safety group (ASHRAE Standard 34):	A3	8601
NFPA 704 degrees of hazard (H-F-R-S):	BOC Gases: 1-4-0 Texaco: 1-4-0 health-flammability-reactivity [-special]: 0=no, 4=severe	MSDS MSDS
NPCA HMIS hazard ratings (H-F-R):	BOC Gases: 1-4-0 Texaco: 1-4-0 health-flammability-reactivity 0=insignificant, 4=extreme	MSDS MSDS
UL Comparative Hazard to Life Group:	5(b) in absence of flame or hot objects	4B64
• short-term occupational limit ------		
NIOSH IDLH (immediately dangerous):	2,100 ppm v/v based on 10% of LEL	5204
NIOSH SCP IDLH (immediately dangerous:	20,000 ppm v/v for 30 min	3903
• occupational exposure limit --------		
MAK (maximum workplace concentration):	IV: 2,000 ppm v/v momentary 60 min	5561
• long-term occupational limit -------		
OSHA PEL (permissible exposure limit):	1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	3904

NIOSH REL (recommendd exposure limit):	1,000 ppm v/v TWA for 10 hr/day and 40 hr/wk	3903
ACGIH TLV-TWA (time-weighted average):	2,500 ppm v/v TWA for 8 hr/day and 40 hr/wk	9504
exposure limit consistent to OSHA PEL:	Exxon: 1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	MSDS
	Texaco: 1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	MSDS
MAK (maximum workplace concentration):	1,000 ppm v/v TWA for 8 hr/day 40 (or 42) hr/wk	5561
	being examined for changes	7101
• emergency exposure limit ----------		
Acute Toxicity Exposure Limit (ATEL):	50,000 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	50,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
Refrigerant Concentration Limit (RCL):	5,000 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	5,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
• acute (short-term) toxicity --------		
LC50 (lethal concentration, 50%):	rat, 15 min: >800,000 ppm (fatal concentration by inhalation for half of test animals)	6110
ALC (approximate lethal concentration:	rat, 4 hr, 0/10: >12,190 ppm (lowest exposure tested with one or more deaths by inhalation)	7624
dermal LD50 (lethal dosage, 50%):	>100,000 mg/kg (fatal dose by skin contact for half of test animals)	A623
cardiac sensitization (CS) EC50:	dog, 5 min: 180,000 ppm v/v (effective concentration in half of test animals)	6110
cardiac sensitization threshold/LOEL:	dog, 5 min, 2/12: 100,000 ppm v/v (lowest observed effect level in test animals)	6274
cardiac sensitization (CS) NOEL:	dog, 5 min, 0/6: 50,000 ppm v/v (no observed effect level in test animals)	6274
	dog, 5 min, 0/6: 50,000 ppm v/v (no observed effect level in test animals)	5644
anesthetic/CNS effect EC50:	rat, 10min: depressant 280,000 ppm v/v (effective concentration in half of test animals)	6110
anesthetic/CNS effect LOEL:	animal?, few min, ?/?: 100,000 ppm v/v (lowest observed effect level in test animals)	A623
anesthetic/CNS effect NOEL:	animal?, "brief", ?/?: 10,000 ppm v/v (no observed effect level in test animals)	A538
	animal?, 10 min, 0/?: 10,000 ppm v/v (no observed effect level in test animals)	A623
• flammability ----------		
LFL-UFL (flammability limits in air):	2.1-9.5 % v/v	5204
	2.1-9.6 % v/v	2525
	2.2-9.5 % v/v	A538
	2.37-9.5 % v/v	6290
	Ecozone: 2.0-10.0 % v/v	mfr
	Texaco: 2.3-9.5 % v/v	MSDS

heat of combustion (by ASHRAE 34-92):	50.3 MJ/kg (21625 Btu/lb)	2318
flash point:	-105 °C (-157 °F)	4906
	BOC Gases: -104 °C (-156 °F)	MSDS
	Exxon: -17.8 °C (0 °F)	MSDS
autoignition temperature:	450 °C (842 °F)	5608
	466 °C (871 °F)	4B64
	510 °C (950 °F)	4904
	BOC Gases: 480 °C (896 °F)	MSDS
	Texaco: 468 °C (874 °F)	MSDS
autodecomposition temperature:	650 °C (1202 °F)	6569
• detection ----------		
appearance:	colorless	5608
odor:	pure R-290 is odorless	5167
odor sensing, lower threshold:	with usual contaminants 20,000 ppm v/v	5167

PRODUCTION

last year production allowed:	unrestricted	8C01

R-C318

---------- REFRIGERANT DATA SUMMARY ----------

			see
R-C318	octafluorocyclobutane		
FC	-CF2-CF2-CF2-CF2-	CAS number 115-25-3	RDB#

COMMON USE(S)

very limited former use in air conditioning in high ambient temperatures, such as overhead crane cabs in steel mills; component of refrigerant 405A; use constrained by concern with toxicity from perfluoroisobutene (PFIB, fluorochemical 1318), an isolog that may form in storage or use; use also constrained by concern with the high global warming potential (GWP); dielectric gas (e.g., DuPont Zyron(R) C318); limited former use as an aerosol propellant and antiseptic; fomrer use as a food propellant; limited medical use for surgical injection to treat retinal detachment

Note: Based on an application submitted in May 1998 and a revision submitted in May 1999, SSPC 34 proposed a safety classification of A1 on 20 June 1999. The proposed classification is subject to a review and approval procedure now underway; actual assignment will not occur until published in an addendum or revision to ANSI/ASHRAE Standard 34-1997.

IDENTIFIERS

common name(s):	R-C318; RC318; R C318	
	FC-318	
	"PFC-C318"	
	OFCB	
	fluorocarbon C318	
	fluorochemical C318; FC C318	
	halochemical C318	
	propellant C318	
chemical name (by IUPAC convention):	octafluoroyclobutane	
	perfluoroyclobutane	
alternative chemical names/formulae:	cyclobutane, octafluoro-	
	perfluorocyclobutane	
	cyclooctafluorobutane	
	octafluoroycloalkane	
	perfluorocycloalkane	
	-CF2-CF2-CF2-CF2-	
	-CF2CF2CF2CF2-	
	c-CF2-CF2-CF2-CF2-	
	cyclo-CF2-CF2-CF2-CF2-	
	not recommended: c-C4F8; cyclic C4F8; -(CF2)4-	
empirical formula:	C4F8	
CAS number:	115-25-3 (Chemical Abstracts Service registry number)	
NIOSH RTECS number:	GU1779500 (Registry of Toxic Effects of Chemical Substances)	
trade name(s):	BNFL Flutec(R) "R-318"	
	Daikin Daiflon(R) C318	
	DuPont Freon(R) C-318	MSDS
	Hoechst Frigen(R) C318	
ARI container color / Pantone number:	none, use light green grey/413	6601

PHYSICAL

• properties ----------		
molar mass:	200.0300256 g/mol (0.440991 lb/mol)	8820

normal freezing/melting/triple point:	-39.8 °C (-39.6 °F)	8401
• normal boiling point ----------		
temperature:	-6.0 °C (21.2 °F)	8401
density, saturated liquid:	1615 kg/m3 (100.83 lb/cf)	8401
density, saturated vapor:	9.54 kg/m3 (0.596 lb/cf)	8401
specific volume, saturated liquid:	0.619 L/kg (0.0099 cf/lb)	8401
specific volume, saturated vapor:	104.8 L/kg (1.6788 cf/lb)	8401
heat of vaporization:	116.8 kJ/kg (50.2 Btu/lb)	8401
velocity of sound, saturated liquid:	553 m/s (1814 ft/s)	8401
velocity of sound, saturated vapor:	104 m/s (342 ft/s)	8401
viscosity, saturated vapor:	10.22 µPa•s (0.01022 cp)	8401
viscosity, saturated liquid:	341 µPa•s (0.341 cp)	8401
thermal conductivity, liquid:	0.0567 W/m•K (0.0328 Btu/hr•ft°F)	8401
thermal conductivity, vapor:	0.0102 W/m•K (0.0059 Btu/hr•ft°F)	8401
• normal pressure, 20 °C (68 °F) -----		
density, vapor:	8.588 kg/m3 (0.5362 lb/cf)	8401
• normal pressure, 21.1 °C (70 °F) ---		
density, vapor:	8.552 kg/m3 (0.5339 lb/cf)	8401
• 20 °C (68 °F) ----------		
pressure, saturated vapor:	265.5 kPa (38.51 psia)	8401
density, saturated liquid:	1518 kg/m3 (94.78 lb/cf)	8401
density, saturated vapor:	23.93 kg/m3 (1.494 lb/cf)	8401
specific volume, saturated liquid:	0.659 L/kg (0.0106 cf/lb)	8401
specific volume, saturated vapor:	41.8 L/kg (0.6695 cf/lb)	8401
velocity of sound, saturated liquid:	456 m/s (1495 ft/s)	8401
velocity of sound, saturated vapor:	104 m/s (342 ft/s)	8401
viscosity, saturated liquid:	243 µPa•s (0.243 cp)	8401
viscosity, saturated vapor:	11.2 µPa•s (0.0112 cp)	8401
thermal conductivity, saturatd liquid:	0.0512 W/m•K (0.0296 Btu/hr•ft°F)	8401
thermal conductivity, saturated vapor:	0.01191 W/m•K (0.00688 Btu/hr•ft°F)	8401
• 60 °C (140 °F) ----------		
pressure, saturated vapor:	839 kPa (121.7 psia)	8401
heat of vaporization:	86.0 kJ/kg (37.0 Btu/lb)	8401
• critical point ----------		
temperature:	115.2 °C (239.4 °F)	8401
pressure:	2778 kPa (402.9 psia)	8401
density:	620 kg/m3 (38.7 lb/cf)	8401
specific volume:	1.61 L/kg (0.0258 cf/lb)	8401
ENVIRONMENTAL		
average atmospheric lifetime (τatm):	3200 yr	6694
ODP (ozone depletion potential):	0.000 (model-derived relative to R 11)	
GWP (global warming potential):	11,200 relative to CO2 for 100 yr integration	9501
SAFETY		
• classification ----------		
safety group (ASHRAE Standard 34):	none (application pending)	34c
	A1 proposed 1999.06.20	34q
NFPA 704 degrees of hazard (H-F-R-S):	BOC Gases: 0-0-0 health-flammability-reactivity [-special]: 0=no, 4=severe	MSDS
NPCA HMIS hazard ratings (H-F-R):	BOC Gases: 0-0-0	MSDS
	DuPont: 1-0-1	MSDS
	health-flammability-reactivity 0=insignificant, 4=extreme	
UL Comparative Hazard to Life Group:	6 by estimate (not tested) in absence of flame or hot objects	5906

• long-term occupational limit -------		
exposure limit consistent to OSHA PEL:	DuPont AEL: 1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	MSDS
• emergency exposure limit ----------		
Acute Toxicity Exposure Limit (ATEL):	80,000 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	80,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
Refrigerant Concentration Limit (RCL):	69,000 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	69,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
• acute (short-term) toxicity --------		
LC50 (lethal concentration, 50%):	rat, 4 hr: >800,000 ppm (fatal concentration by inhalation for half of test animals)	5169
ALC (approximate lethal concentration:	rat, 4 hr, 0/2: 792000-804000 ppm (lowest exposure tested with one or more deaths by inhalation)	7736
	rat, 4 hr, 0/6: >800,000 ppm (lowest exposure tested with one or more deaths by inhalation)	7216
LCLo (lethal concentration, lowest):	mouse, 2 hr,BOC Gases: 780,000 ppm (fatal concentration by inhalation for even one test animal)	MSDS
cardiac sensitization (CS) EC50:	dog, 5 min: 250,000-500,000 ppm v/v (effective concentration in half of test animals)	5644
cardiac sensitization threshold/LOEL:	dog, 5 min, 1/12: 100,000 ppm v/v (lowest observed effect level in test animals)	5644
	dog, 5 min, 1/12: 100,000 ppm v/v (lowest observed effect level in test animals)	6121
	dog, 5 min, 1/6: 150,000 ppm v/v (lowest observed effect level in test animals)	6121
anesthetic/CNS effect EC50:	mouse, 10 min, 0/6: >800,000 ppm v/v (effective concentration in half of test animals)	5A25
	mouse, 10 min, 0/6: >~798,000 ppm v/v (effective concentration in half of test animals)	7736
anesthetic/CNS effect NOEL:	rat, 4 hr, 0/6: 800,000 ppm v/v (no observed effect level in ALC or LC50 studies)	7216
• flammability ----------		
LFL-UFL (flammability limits in air):	none (nonflammable as tested)	2525
flash point:	BOC Gases: none	MSDS
	TOC, DuPont: will not burn	MSDS
autoignition temperature:	BOC Gases: none	MSDS
• detection ----------		
appearance:	DuPont: clear colorless gas	MSDS
odor:	BOC Gases: odorless	MSDS
	DuPont: none	MSDS
	Liquid Carbonic: slightly ethereal	MSDS

PRODUCTION		
first commercial use as a refrigerant:	1961	5C39
last year production allowed:	unrestricted	8C01

R-500

---------- REFRIGERANT DATA SUMMARY ----------

			see RDB#
R-500 azeotrope	R-12/152a (73.8/26.2) binary blend	CAS number 56275-41-3	

COMMON USE(S)
centrifugal chillers, heat pump water heaters, transport refrigeration; use as a refrigerant may be covered by U.S. patent 2,492,725 (C. Ashley, 27 December 1949)

Note: This azeotrope was first introduced to achieve the same capacity in equipment operated on 50 Hz current as refrigerant 12 with 60 Hz current [see RDB 2C04].

IDENTIFIERS

common name(s):	R-500; R500; R 500	2909
	CFC/HFC-500	2909
	not CFC-500 or HCFC-500	2909
CAS number:	56275-41-3 (Chemical Abstracts Service registry number)	
trade name(s):	Asahi Glass Fron AF-500	
	Daikin Daiflon(R) 500	
	DuPont Freon(R) 500	MSDS
	Elf Atochem Forane(R) 500	MSDS
	Hoechst Frigen(R) 500	
	Honeywell Genetron(R) 500	MSDS
historical name(s):	AlliedSignal Genetron(R) 500	MSDS
	Carrier Corporation Carrene 7	
	ICI Arcton(R) 500	
ARI container color / Pantone number:	yellow / 109	6601

PHYSICAL

• nominal blend formulation ----------		
composition:	R-12/152a	2909
component weight fractions:	73.8 / 26.2 %	2909
component mole fractions:	60.610 / 39.390 %	8820
azeotropic temperature:	0.0 °C (32.0 °F)	2909
• properties ----------		
molar mass:	99.30230 g/mol (0.218924 lb/mol)	8820
normal freezing/melting/triple point:	-158.9 °C (-254.0 °F)	0036
• normal boiling point ----------		
bubble point temperature:	-33.6 °C (-28.5 °F)	8401
dew point temperature:	-33.6 °C (-28.5 °F)	8401
maximum temperature glide:	0.00 °C (0.0 °F)	8401
density, saturated liquid:	1319 kg/m3 (82.35 lb/cf)	8401
density, saturated vapor:	5.27 kg/m3 (0.329 lb/cf)	8401
specific volume, saturated liquid:	0.758 L/kg (0.0121 cf/lb)	8401
specific volume, saturated vapor:	189.8 L/kg (3.0400 cf/lb)	8401
heat of vaporization:	202.5 kJ/kg (87.0 Btu/lb)	8401
velocity of sound, saturated liquid:	762 m/s (2502 ft/s)	8401
velocity of sound, saturated vapor:	148 m/s (484 ft/s)	8401
viscosity, saturated liquid:	319 µPa•s (0.319 cp)	8401
viscosity, saturated vapor:	9.21 µPa•s (0.00921 cp)	8401
thermal conductivity, liquid:	0.0951 W/m•K (0.0549 Btu/hr•ft°F)	8401
thermal conductivity, vapor:	0.0076 W/m•K (0.0044 Btu/hr•ft°F)	8401
• normal pressure, 20 °C (68 °F) -----		
density, vapor:	4.213 kg/m3 (0.2630 lb/cf)	8401

• normal pressure, 21.1 °C (70 °F) ---		
density, vapor:	4.196 kg/m3 (0.2619 lb/cf)	8401
• 20 °C (68 °F) ----------		
pressure, liquid (bubble point):	670.6 kPa (97.26 psia)	8401
pressure, vapor (dew point):	668.8 kPa (97.00 psia)	8401
density, saturated liquid:	1158 kg/m3 (72.32 lb/cf)	8401
density, saturated vapor:	32.02 kg/m3 (1.999 lb/cf)	8401
specific volume, saturated liquid:	0.863 L/kg (0.0138 cf/lb)	8401
specific volume, saturated vapor:	31.2 L/kg (0.5003 cf/lb)	8401
velocity of sound, saturated liquid:	528 m/s (1732 ft/s)	8401
velocity of sound, saturated vapor:	148 m/s (485 ft/s)	8401
viscosity, saturated liquid:	172 µPa•s (0.172 cp)	8401
viscosity, saturated vapor:	11.4 µPa•s (0.0114 cp)	8401
thermal conductivity, saturatd liquid:	0.0744 W/m•K (0.0430 Btu/hr•ft°F)	8401
thermal conductivity, saturated vapor:	0.01178 W/m•K (0.00681 Btu/hr•ft°F)	8401
• 60 °C (140 °F) ----------		
pressure, liquid (bubble point):	1809 kPa (262.4 psia)	8401
pressure, vapor (dew point):	1801 kPa (261.2 psia)	8401
heat of vaporization:	129.7 kJ/kg for liquid and vapor both at nominal composition (55.8 Btu/lb)	8401
	127.1 kJ/kg coexisting liquid and vapor at bubble-point pressure (54.6 Btu/lb)	8401
• critical point ----------		
temperature:	102.1 °C (215.8 °F)	8401
pressure:	4173 kPa (605.2 psia)	8401
density:	492 kg/m3 (30.7 lb/cf)	8401
specific volume:	2.03 L/kg (0.0326 cf/lb)	8401
ENVIRONMENTAL		
ODP (ozone depletion potential):	0.605 mass-weighted average (model-derived relative to R 11)	9501
	0.664 mass-weighted average (semi-empirical relative to R 11)	9501
GWP (global warming potential):	7870 mass-weighted average relative to CO2 for 100 yr integration	9501
HGWP (halocarbon GWP):	2.0 mass-weighted average relative to R 11 for infinite integration period	7214
	2.2 mass-weighted average relative to R 11 for infinite integration period	DW
SAFETY		
• classification ----------		
safety group (ASHRAE Standard 34):	A1	8601
NFPA 704 degrees of hazard (H-F-R-S):	ARI recommendation: 2-0-0	3A15
	Honeywell: 2-1-0	MSDS
	health-flammability-reactivity [-special]: 0=no, 4=severe	
NPCA HMIS hazard ratings (H-F-R):	DuPont: 1-0-1	MSDS
	Honeywell: 1-1-0	MSDS
	health-flammability-reactivity 0=insignificant, 4=extreme	
UL Comparative Hazard to Life Group:	5(a) in absence of flame or hot objects	0036
• short-term occupational limit ------		
ARI "IDLH" recommendation:	50,000 ppm v/v for 30 min	3A15

• long-term occupational limit -------		
exposure limit consistent to OSHA PEL:	ARI: 1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	3A15
	components are PEL 1,000 / WEEL 1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	3904 4B90
• emergency exposure limit ----------		
Acute Toxicity Exposure Limit (ATEL):	29,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
Refrigerant Concentration Limit (RCL):	29,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
	36,000 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
• flammability ----------		
LFL-UFL (flammability limits in air):	none (nonflammable as tested)	0036
	none (nonflammable as tested)	5648
flash point:	DuPont: will not burn	MSDS
	Honeywell: gas, not applicable	MSDS
autoignition temperature:	386 °C (727 °F)	5931
autodecomposition temperature:	DuPont: <445 °C (<833 °F)	MSDS
former UL Classification:	practically nonflammable (withdrawn for revision of the classification system, category SBQT2)	6938
• detection ----------		
appearance:	DuPont: clear, colorless	MSDS
odor:	Honeywell: faint ethereal	MSDS
PRODUCTION		
first commercial use as a refrigerant:	circa 1950	
last year production allowed:	1995 based on refrigerant 12 in developed countries under the Montreal Protocol	8C01

R-502

---------- REFRIGERANT DATA SUMMARY ----------			
R-502 azeotrope	R-22/115 (48.8/51.2) binary blend	CAS number 39432-81-0	see RDB#
COMMON USE(S)	low-temperature commercial, industrial, and transport refrigeration; high stage of multistage, cascaded systems for extremely low temperatures; limited use in appliances; limited use in air-source heat pumps, particularly those that are heating only hydronic		
IDENTIFIERS			
	common name(s):	R-502; R502; R 502	2909
		HCFC/CFC-502	2909
		not CFC-502 or HCFC-502	2909
	CAS number:	39432-81-0, 039432-81-0 (Chemical Abstracts Service registry number)	
	trade name(s):	Asahi Glass Fron AF-502	
		Daikin Daiflon(R) 502	
		DuPont Freon(R) 502	MSDS
		Elf Atochem Forane(R) 502	MSDS
		HRP (UK) HARP(R) 502	
		Hoechst Frigen(R) 502	
		Honeywell Genetron(R) 502	MSDS
		ICI Arcton(R) 502	MSDS
		ZCIRI Kehua (PRC) R-502	
	historical name(s):	AlliedSignal Genetron(R) 502	MSDS
	ARI container color / Pantone number:	light purple (lavender) / 251	6601
PHYSICAL			
• nominal blend formulation ----------			
	composition:	R-22/115	2909
	component weight fractions:	48.8 / 51.2 %	2909
	component mole fractions:	62.999 / 37.001 %	8820
	azeotropic temperature:	19.0 °C (66.2 °F)	2909
• properties ----------			
	molar mass:	111.62783 g/mol (0.246097 lb/mol)	8820
• normal boiling point ----------			
	bubble point temperature:	-45.3 °C (-49.5 °F)	8401
	dew point temperature:	-45.0 °C (-49.0 °F)	8401
	maximum temperature glide:	0.04 °C (0.1 °F)	8401
	density, saturated liquid:	1485 kg/m3 (92.72 lb/cf)	8401
	density, saturated vapor:	6.21 kg/m3 (0.388 lb/cf)	8401
	specific volume, saturated liquid:	0.673 L/kg (0.0108 cf/lb)	8401
	specific volume, saturated vapor:	161.0 L/kg (2.5795 cf/lb)	8401
	heat of vaporization:	173.3 kJ/kg (74.5 Btu/lb)	8401
	velocity of sound, saturated liquid:	728 m/s (2387 ft/s)	8401
	velocity of sound, saturated vapor:	136 m/s (445 ft/s)	8401
	viscosity, saturated liquid:	340 µPa•s (0.340 cp)	8401
	viscosity, saturated vapor:	9.73 µPa•s (0.00973 cp)	8401
	thermal conductivity, liquid:	0.0906 W/m•K (0.0523 Btu/hr•ft°F)	8401
	thermal conductivity, vapor:	0.0070 W/m•K (0.0041 Btu/hr•ft°F)	8401
• normal pressure, 20 °C (68 °F) -----			
	density, vapor:	4.718 kg/m3 (0.2945 lb/cf)	8401
• normal pressure, 21.1 °C (70 °F) ---			
	density, vapor:	4.699 kg/m3 (0.2934 lb/cf)	8401

• 20 °C (68 °F) ----------		
pressure, liquid (bubble point):	1015.1 kPa (147.23 psia)	8401
pressure, vapor (dew point):	1014.6 kPa (147.16 psia)	8401
density, saturated liquid:	1237 kg/m3 (77.20 lb/cf)	8401
density, saturated vapor:	57.93 kg/m3 (3.616 lb/cf)	8401
specific volume, saturated liquid:	0.809 L/kg (0.0130 cf/lb)	8401
specific volume, saturated vapor:	17.3 L/kg (0.2765 cf/lb)	8401
velocity of sound, saturated liquid:	429 m/s (1406 ft/s)	8401
velocity of sound, saturated vapor:	132 m/s (433 ft/s)	8401
viscosity, saturated liquid:	152 µPa•s (0.152 cp)	8401
viscosity, saturated vapor:	12.7 µPa•s (0.0127 cp)	8401
thermal conductivity, saturatd liquid:	0.0649 W/m•K (0.0375 Btu/hr•ft°F)	8401
thermal conductivity, saturated vapor:	0.01150 W/m•K (0.00665 Btu/hr•ft°F)	8401
• 60 °C (140 °F) ----------		
pressure, liquid (bubble point):	2630 kPa (381.4 psia)	8401
pressure, vapor (dew point):	2630 kPa (381.4 psia)	8401
heat of vaporization:	86.0 kJ/kg for liquid and vapor both at nominal composition (37.0 Btu/lb)	8401
	86.2 kJ/kg coexisting liquid and vapor at bubble-point pressure (37.0 Btu/lb)	8401
• critical point ----------		
temperature:	80.7 °C (177.3 °F)	8401
pressure:	4018 kPa (582.8 psia)	8401
density:	569 kg/m3 (35.5 lb/cf)	8401
specific volume:	1.76 L/kg (0.0282 cf/lb)	8401
ENVIRONMENTAL		
ODP (ozone depletion potential):	0.221 mass-weighted average (model-derived relative to R 11)	9501
	0.229 mass-weighted average (semi-empirical relative to R 11)	9501
GWP (global warming potential):	6200 mass-weighted average relative to CO2 for 100 yr integration	9501
HGWP (halocarbon GWP):	19 mass-weighted average relative to R 11 for infinite integration period	DW
	3.75 relative to R 11 for infinite integration period	4510
SAFETY		
• classification ----------		
safety group (ASHRAE Standard 34):	A1	8601
NFPA 704 degrees of hazard (H-F-R-S):	ARI recommendation: 2-0-0	3A15
	Honeywell: 2-1-0 health-flammability-reactivity [-special]: 0=no, 4=severe	MSDS
NPCA HMIS hazard ratings (H-F-R):	DuPont: 1-0-1	MSDS
	Honeywell: 1-1-0 health-flammability-reactivity 0=insignificant, 4=extreme	MSDS
UL Comparative Hazard to Life Group:	5(a) in absence of flame or hot objects	0036
• short-term occupational limit ------		
ARI "IDLH" recommendation:	50,000 ppm v/v for 30 min	3A15
• long-term occupational limit -------		
NIOSH REL (recommendd exposure limit):	none, both components 1,000 ppm v/v TWA for 10 hr/day and	5204

	40 hr/wk	
ACGIH TLV-TWA (time-weighted average):	none, both components 1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	9504
exposure limit consistent to OSHA PEL:	ARI: 1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	3A15
• emergency exposure limit ----------		
Acute Toxicity Exposure Limit (ATEL):	35,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
Refrigerant Concentration Limit (RCL):	35,000 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	35,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
• acute (short-term) toxicity --------		
LC50 (lethal concentration, 50%):	rat, 4 hr, Honeywell: >300,000 ppm (fatal concentration by inhalation for half of test animals)	MSDS
ALC (approximate lethal concentration:	rat, 2 hr, 0/4: >200,000 ppm (lowest exposure tested with one or more deaths by inhalation)	6272
cardiac sensitization threshold/LOEL:	dog, 5 min, 5/12: 100,000 ppm v/v (lowest observed effect level in test animals)	5644
	dog, 5 min, 5/12: 100,000 ppm v/v (lowest observed effect level in test animals)	6274
cardiac sensitization (CS) NOEL:	dog, 10 min, 0/6: 50,000 ppm v/v (no observed effect level in test animals)	5644
	dog, 10 min, 0/6: 50,000 ppm v/v (no observed effect level in test animals)	6274
• flammability ----------		
LFL-UFL (flammability limits in air):	none (nonflammable as tested)	2525
	none (nonflammable as tested)	5648
flash point:	Honeywell: gas, not applicable	MSDS
	ICI: does not flash	MSDS
autoignition temperature:	704 °C (1299 °F)	3960
former UL Classification:	practically nonflammable (withdrawn for revision of the classification system, category SBQT2)	5931
• detection ----------		
appearance:	DuPont: clear, colorless	MSDS
odor:	Honeywell: faint ethereal	MSDS
PRODUCTION		
first commercial use as a refrigerant:	1961	5C39
last year production allowed:	1995 based on refrigerant 115 in developed countries under the Montreal Protocol	8C01

R-600 (n-BUTANE)

---------- REFRIGERANT DATA SUMMARY ----------

			see RDB#
R-600	n-butane		
HC	CH3-CH2-CH2-CH3	CAS number 106-97-8	

COMMON USE(S)
blend component with fluorocarbons and other hydrocarbons as alternatives to refrigerants 12 and 500, among them refrigerants 416A and others; refrigerant in hydraulic refrigeration systems; use is constrained by flammability concerns; primary uses are as a fuel, aerosol propellant, and feedstock for solvents, rubbers, and plastics

IDENTIFIERS

common name(s):	R-600; R600; R 600 HC-600 "R-3-11-0" (in Russia) hydrocarbon 600 n-C4; n-C4H10 n-butane; normal-butane	
chemical name (by IUPAC convention):	butane	
alternative chemical names/formulae:	1-butane diethyl ethyl-ethyl methylethylmethane butyl hydride CH3CH2CH2CH3; CH3-CH2-CH2-CH3; CH3(CH2)2CH3; CH3-(CH2)2-CH3	
empirical formula:	C4H10	
CAS number:	106-97-8 (Chemical Abstracts Service registry number)	
NIOSH RTECS number:	EJ4200000 (Registry of Toxic Effects of Chemical Substances)	
ARI container color / Pantone number:	none, use light green grey/413 with red / 185 band	6601

PHYSICAL

• properties ----------		
molar mass:	58.12220 g/mol (0.128138 lb/mol)	8820
normal freezing/melting/triple point:	-138.3 °C (-216.9 °F)	3209
• normal boiling point ----------		
temperature:	-0.5 °C (31.0 °F)	8401
heat of vaporization:	385.8 kJ/kg (165.9 Btu/lb)	8401
• normal pressure, 20 °C (68 °F) -----		
density, vapor:	2.496 kg/m3 (0.1558 lb/cf)	8401
• normal pressure, 21.1 °C (70 °F) ---		
density, vapor:	2.486 kg/m3 (0.1552 lb/cf)	8401
• 20 °C (68 °F) ----------		
pressure, saturated vapor:	208.1 kPa (30.18 psia)	8401
density, saturated liquid:	578 kg/m3 (36.11 lb/cf)	8401
density, saturated vapor:	5.33 kg/m3 (0.333 lb/cf)	8401
specific volume, saturated liquid:	1.729 L/kg (0.0277 cf/lb)	8401
specific volume, saturated vapor:	187.8 L/kg (3.0075 cf/lb)	8401
velocity of sound, saturated liquid:	923 m/s (3029 ft/s)	8401
velocity of sound, saturated vapor:	202 m/s (663 ft/s)	8401
viscosity, saturated liquid:	167 µPa•s (0.167 cp)	8401
viscosity, saturated vapor:	7.5 µPa•s (0.0075 cp)	8401
thermal conductivity, saturatd liquid:	0.1089 W/m•K (0.0629 Btu/hr•ft°F)	8401
thermal conductivity, saturated vapor:	0.01584 W/m•K (0.00915	8401

	Btu/hr•ft°F)	
• 60 °C (140 °F) ----------		
pressure, saturated vapor:	639 kPa (92.7 psia)	8401
heat of vaporization:	320.8 kJ/kg (137.9 Btu/lb)	8401
• critical point ----------		
temperature:	152.0 °C (305.6 °F)	8401
pressure:	3796 kPa (550.6 psia)	8401
density:	228 kg/m3 (14.2 lb/cf)	8401
specific volume:	4.38 L/kg (0.0702 cf/lb)	0036
ENVIRONMENTAL		
ODP (ozone depletion potential):	0.000 (model-derived relative to R 11)	
GWP (global warming potential):	unknown, but very low: ~20 relative to CO2 for 100 yr integration	
HGWP (halocarbon GWP):	~0 relative to R 11 for infinite integration period	
photochemical reactivity (grnd level):	320 relative to methane	4511
SAFETY		
• classification ----------		
safety group (ASHRAE Standard 34):	A3	8601
NFPA 704 degrees of hazard (H-F-R-S):	BOC Gases: 1-4-0 health-flammability-reactivity [-special]: 0=no, 4=severe	MSDS
NPCA HMIS hazard ratings (H-F-R):	BOC Gases: 1-4-0 health-flammability-reactivity 0=insignificant, 4=extreme	MSDS
UL Comparative Hazard to Life Group:	5(b) in absence of flame or hot objects	4B64
• occupational exposure limit --------		
MAK (maximum workplace concentration):	IV: 2,000 ppm v/v momentary 60 min	5561
• long-term occupational limit -------		
NIOSH REL (recommendd exposure limit):	800 ppm v/v TWA for 10 hr/day and 40 hr/wk	5204
ACGIH TLV-TWA (time-weighted average):	800 ppm v/v TWA for 8 hr/day and 40 hr/wk	9504
MAK (maximum workplace concentration):	1,000 ppm v/v TWA for 8 hr/day 40 (or 42) hr/wk	5561
	being examined for changes	7101
• emergency exposure limit ----------		
Acute Toxicity Exposure Limit (ATEL):	0 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	provisional: 0 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
Refrigerant Concentration Limit (RCL):	provisional: 0 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
• acute (short-term) toxicity --------		
LC50 (lethal concentration, 50%):	mouse, 2 hr: 280,000 ppm (fatal concentration by inhalation for half of test animals)	A538
	mouse, 2 hr: 281,000 ppm (fatal concentration by inhalation for half of test animals)	5363
	rat, 2 hr: 280,000 ppm (fatal concentration by inhalation for half of test animals)	A538
	rat, 4 hr: 272,000 ppm (fatal	5363

	concentration by inhalation for half of test animals)	
	rat, ? hr: 280,000 ppm (fatal concentration by inhalation for half of test animals)	A623
ALC (approximate lethal concentration:	mouse, 2 hr, 0/10: >220,000 ppm (lowest exposure tested with one or more deaths by inhalation)	6197
	mouse, 2 hr, 4/10: 270,000 ppm (lowest exposure tested with one or more deaths by inhalation)	6197
LCLo (lethal concentration, lowest):	dog, ? min, ?/?: 200000-250000 ppm (fatal concentration by inhalation for even one test animal)	6197
cardiac sensitization threshold/LOEL:	dog 10min 2/2: 100,000-250,000 ppm v/v (lowest observed effect level in test animals)	6192
anesthetic/CNS effect LOEL:	animal?, 10 min, ?/?: 100,000 ppm v/v (lowest observed effect level in test animals)	A623
	dog, ? min, ?/?: 200000-250000 ppm v/v (lowest observed effect level in test animals)	6197
	dog, ? min, ?/?: 250,000 ppm v/v (lowest observed effect level in test animals)	A623
	mouse, 1minavg,10/10: 220,000 ppm v/v (lowest observed effect level in test animals)	6197
	mouse, 25minavg, 6/ 6: 130,000 ppm v/v (lowest observed effect level in test animals)	6197
	human, 10 min, ?/?: 100,000 ppm v/v (lowest observed effect level)	6290
• flammability ----------		
LFL-UFL (flammability limits in air):	1.5-10.1 % v/v	2525
	1.6-8.4 % v/v	5204
	1.7-10.3 % v/v	9516
	BOC Gases: 1.8-8.4 % v/v	MSDS
	Exxon: 1.9-8.5 % v/v	MSDS
	Phillips: 1.9-8.5 % v/v	MSDS
	Scott: 1.9-8.5 % v/v	MSDS
heat of combustion (by ASHRAE 34-92):	49.5 MJ/kg (21281 Btu/lb)	2318
flash point:	CC, BOC Gases: -73.9°C(-101°F)	MSDS
	CC, Exxon: -60 °C (-76 °F)	MSDS
	not applicable for gas	5204
autoignition temperature:	430 °C (806 °F)	4B64
	510 °C (950 °F)	4906
	BOC Gases: 420 °C (788 °F)	MSDS
	Exxon: 405 °C (761 °F)	MSDS
autodecomposition temperature:	BOC Gases: 435 °C (815 °F)	MSDS
• detection ----------		
appearance:	Exxon: colorless gas	MSDS
odor:	BOC Gases: odorless	MSDS
	Exxon: faint disagreeable odor	MSDS
	Phillips: none	MSDS
	Scott: faint, sweet odor	MSDS
odor sensing, lower threshold:	50,000 ppm v/v	6290

PRODUCTION
last year production allowed: unrestricted 8C01

R-600a (ISOBUTANE)

---------- REFRIGERANT DATA SUMMARY ----------

			see RDB#
R-600a	isobutane		
HC	CH(CH3)2-CH3	CAS number 75-28-5	

COMMON USE(S)
used in small refrigeration systems including household refrigerators in the 1920s and early 1930s; re-emerged in the 1990s as a blend component with fluorocarbons and other hydrocarbons as alternatives to refrigerants 12 and 500, among them refrigerants 406A, 413A, 414A, 414B, and others; fuel; blend component for aerosol propellants; feedstock for petrochemicals

IDENTIFIERS

common name(s):	R-600a; R600a; R 600a HC-600a hydrocarbon 600a i-C4; i-C4H10 iso-C4; iso-C4H10	
chemical name (by IUPAC convention):	isobutane	
alternative chemical names/formulae:	propane, 2-methyl- isomethylpropane methylpropane, iso 2-methylpropane, (CH3)2CH-CH3 trimethylmethane, CH(CH3)3 CH3CH(CH3)CH3, CH3-CH(CH3)-CH3	
empirical formula:	C4H10	
CAS number:	75-28-5 (Chemical Abstracts Service registry number)	
NIOSH RTECS number:	TZ4300000 (Registry of Toxic Effects of Chemical Substances)	
trade name(s):	Calor Gas (UK) CARE 10 Diversified CPC Aeron A-31 Ecozone BV (NL) Ecool-ISO	MSDS
historical name(s):	"R-601" (nonstandard number) "R601" (nonstandard number) Copeland Products Freezol	2113 2113 2113
ARI container color / Pantone number:	none, use light green grey/413 with red / 185 band	6601

PHYSICAL

• properties ----------		
molar mass:	58.12220 g/mol (0.128138 lb/mol)	8820
normal freezing/melting/triple point:	-159.6 °C (-255.3 °F)	8401
• normal boiling point ----------		
temperature:	-11.6 °C (11.1 °F)	8401
density, saturated liquid:	594 kg/m3 (37.06 lb/cf)	8401
density, saturated vapor:	2.83 kg/m3 (0.176 lb/cf)	8401
specific volume, saturated liquid:	1.685 L/kg (0.0270 cf/lb)	8401
specific volume, saturated vapor:	353.7 L/kg (5.6664 cf/lb)	8401
heat of vaporization:	366.7 kJ/kg (157.6 Btu/lb)	8401
velocity of sound, saturated liquid:	1008 m/s (3308 ft/s)	8401
velocity of sound, saturated vapor:	197 m/s (645 ft/s)	8401
viscosity, saturated liquid:	228 µPa•s (0.228 cp)	8401
viscosity, saturated vapor:	6.64 µPa•s (0.00664 cp)	8401
thermal conductivity, liquid:	0.1121 W/m•K (0.0648 Btu/hr•ft°F)	8401
thermal conductivity, vapor:	0.0126 W/m•K (0.0073 Btu/hr•ft°F)	8401

• normal pressure, 20 °C (68 °F) -----		
density, vapor:	2.485 kg/m3 (0.1551 lb/cf)	8401
• normal pressure, 21.1 °C (70 °F) ---		
density, vapor:	2.475 kg/m3 (0.1545 lb/cf)	8401
• 20 °C (68 °F) ----------		
pressure, saturated vapor:	301.8 kPa (43.77 psia)	8401
density, saturated liquid:	557 kg/m3 (34.77 lb/cf)	8401
density, saturated vapor:	7.90 kg/m3 (0.493 lb/cf)	8401
specific volume, saturated liquid:	1.796 L/kg (0.0288 cf/lb)	8401
specific volume, saturated vapor:	126.6 L/kg (2.0284 cf/lb)	8401
velocity of sound, saturated liquid:	838 m/s (2749 ft/s)	8401
velocity of sound, saturated vapor:	198 m/s (651 ft/s)	8401
viscosity, saturated liquid:	160 µPa•s (0.160 cp)	8401
viscosity, saturated vapor:	7.6 µPa•s (0.0076 cp)	8401
thermal conductivity, saturatd liquid:	0.0978 W/m•K (0.0565 Btu/hr•ft°F)	8401
thermal conductivity, saturated vapor:	0.02110 W/m•K (0.01219 Btu/hr•ft°F)	8401
• 60 °C (140 °F) ----------		
pressure, saturated vapor:	868 kPa (125.9 psia)	8401
heat of vaporization:	285.2 kJ/kg (122.6 Btu/lb)	8401
• critical point ----------		
temperature:	134.7 °C (274.5 °F)	8401
pressure:	3640 kPa (527.9 psia)	8401
density:	224 kg/m3 (14.0 lb/cf)	8401
specific volume:	4.46 L/kg (0.0714 cf/lb)	8401
ENVIRONMENTAL		
ODP (ozone depletion potential):	0.000 (model-derived relative to R 11)	
GWP (global warming potential):	unknown, but very low: ~20 relative to CO2 for 100 yr integration	
HGWP (halocarbon GWP):	~0 relative to R 11 for infinite integration period	
SAFETY		
• classification ----------		
safety group (ASHRAE Standard 34):	A3	8601
NFPA 704 degrees of hazard (H-F-R-S):	Matheson: 1-4-0	MSDS
	Pennzoil: 0-4-0	MSDS
	Texaco: 1-4-0 health-flammability-reactivity [-special]: 0=no, 4=severe	MSDS
NPCA HMIS hazard ratings (H-F-R):	Texaco: 1-4-0 health-flammability-reactivity 0=insignificant, 4=extreme	MSDS
UL Comparative Hazard to Life Group:	5(b) in absence of flame or hot objects	0036
• short-term occupational limit ------		
recommended short-term exposure limit:	Rhône-Poulenc: 750 ppm(10 min)	MSDS
• occupational exposure limit --------		
MAK (maximum workplace concentration):	IV: 2,000 ppm v/v momentary 60 min	5561
• long-term occupational limit -------		
NIOSH REL (recommendd exposure limit):	800 ppm v/v TWA for 10 hr/day and 40 hr/wk	5204
exposure limit consistent to OSHA PEL:	Pennzoil, C1-C4 assumed: 1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	MSDS
	Rhône-Poulenc OES: 600 ppm v/v TWA for 8 hr/day and 40 hr/wk	MSDS
MAK (maximum workplace concentration):	1,000 ppm v/v TWA for 8 hr/day 40 (or 42) hr/wk	5561

	being examined for changes	7101
• emergency exposure limit ----------		
Acute Toxicity Exposure Limit (ATEL):	25,000 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	25,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
Refrigerant Concentration Limit (RCL):	2,500 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
	4,300 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
• acute (short-term) toxicity --------		
LC50 (lethal concentration, 50%):	mouse, 2 hr: 410,000 ppm (fatal concentration by inhalation for half of test animals)	A538
	mouse, 2 hr: 520,000 ppm (fatal concentration by inhalation for half of test animals)	6569
	rat, 15 min: 570,000 ppm (fatal concentration by inhalation for half of test animals)	6110
ALC (approximate lethal concentration:	mouse, 2 hr, 0/10: >350,000 ppm (lowest exposure tested with one or more deaths by inhalation)	6197
	mouse, 2 hr, 6/10: 410,000 ppm (lowest exposure tested with one or more deaths by inhalation)	6197
LCLo (lethal concentration, lowest):	dog, ? min, ?/?: 550,000 ppm (fatal concentration by inhalation for even one test animal)	6197
cardiac sensitization (CS) EC50:	dog, 5 min: 70,000 ppm v/v (effective concentration in half of test animals)	6110
cardiac sensitization threshold/LOEL:	dog, 5 min, 4/12: 50,000 ppm v/v (lowest observed effect level in test animals)	5644
cardiac sensitization (CS) NOEL:	dog, 5 min, 0/12: 25,000 ppm v/v (no observed effect level in test animals)	5644
	dog, 5 min, 0/12: 25,000 ppm v/v (no observed effect level in test animals)	6121
anesthetic/CNS effect EC50:	rat, 10 min: stimulant 200,000 ppm v/v (effective concentration in half of test animals)	6110
anesthetic/CNS effect LOEL:	dog, ? min, ?/?: 450,000 ppm v/v (lowest observed effect level in test animals)	A623
	dog, ? min, ?/?: 450,000 ppm v/v (lowest observed effect level in test animals)	6197
	mouse, 17 minavg: 6/6: 200,000 ppm v/v (lowest observed effect level in test animals)	6197
	mouse, 26 minavg, 6/6: 230,000 ppm v/v (lowest observed effect level in test animals)	6197
	mouse, 60 minavg, 6/6: 150,000	6197

anesthetic/CNS effect NOEL:	ppm v/v (lowest observed effect level in test animals) human, 8 hr, 0/8: 1,000 ppm v/v (no observed effect level)	5364
• flammability ----------		
LFL-UFL (flammability limits in air):	1.7-9.7 % v/v	2525
	1.9-10.0 % v/v	9516
	Ecozone: 1-8.5 % v/v	mfr
	Pennzoil: 1.8-8.5 % v/v	MSDS
	Phillips: 1.8-8.4 % v/v	MSDS
	Texaco: 1.8-8.4 % v/v	MSDS
heat of combustion (by ASHRAE 34-92):	49.3 MJ/kg (21195 Btu/lb)	9516
	49.4 MJ/kg (21238 Btu/lb)	2318
flash point:	-83 °C (-117 °F)	6290
	Matheson CC: -88 °C (-126 °F)	MSDS
	Pennzoil: -83 °C (-117 °F)	MSDS
	Phillips: -83 °C (-117 °F)	MSDS
	Texaco: -118 °C (-181 °F)	MSDS
	not applicable for gas	5204
autoignition temperature:	530 °C (986 °F)	4906
	Pennzoil: 462.2 °C (864 °F)	MSDS
	Rhône-Poulenc: 420 °C (788 °F)	MSDS
	Texaco: 460.0 °C (860 °F)	MSDS
former UL Classification:	flammable (withdrawn for revision of the classification system, category SBQT2)	UL
• detection ----------		
appearance:	Phillips: colorless	MSDS
odor:	Matheson: slight petroleum	MSDS
	Phillips: none	MSDS
	Rhône-Poulenc: virtually odorless	MSDS
PRODUCTION		
first commercial use as a refrigerant:	1920s by E Copeland, H Edwards	2113
	1923 by J DeRemer	6104
	1923 by Savage Arms Company	6104
last year production allowed:	unrestricted	8C01

R-717 (AMMONIA)

REFRIGERANT DATA SUMMARY			
R-717	ammonia		see
inorganic	NH3	CAS number 7664-41-7	RDB#

COMMON USE(S)
chillers, widely used in industrial refrigeration; wide use as a fertilizer; intermediate to manufacture synthetic fibers, plastics, and explosives; cleaning solvent; ammonia is found in water, soil, and air - it is a natural decomposition product of decaying manure, plants, and animals

IDENTIFIERS

common name(s):	R-717; R717; R 717 anhydrous ammonia nitro-sil	
chemical name (by IUPAC convention):	ammonia	
alternative chemical names/formulae:	NH3; less commonly H3N	
CAS number:	7664-41-7 (Chemical Abstracts Service registry number)	
NIOSH RTECS number:	BO0875000 (Registry of Toxic Effects of Chemical Substances)	
historical name(s):	spirit of hartshorn	5C46
ARI container color / Pantone number:	none, use light green grey/413 with red / 185 band	6601

PHYSICAL

• properties ----------		
molar mass:	17.03056 g/mol (0.037546 lb/mol)	8820
normal freezing/melting/triple point:	-77.7 °C (-107.8 °F)	8401
• normal boiling point ----------		
temperature:	-33.3 °C (-28.0 °F)	8401
density, saturated liquid:	682 kg/m3 (42.57 lb/cf)	8401
density, saturated vapor:	0.89 kg/m3 (0.056 lb/cf)	8401
specific volume, saturated liquid:	1.466 L/kg (0.0235 cf/lb)	8401
specific volume, saturated vapor:	1242.2 L/kg (19.8981 cf/lb)	8401
heat of vaporization:	1369.5 kJ/kg (588.8 Btu/lb)	8401
velocity of sound, saturated liquid:	1768 m/s (5801 ft/s)	8401
velocity of sound, saturated vapor:	386 m/s (1267 ft/s)	8401
viscosity, saturated liquid:	255 µPa•s (0.255 cp)	8401
viscosity, saturated vapor:	8.05 µPa•s (0.00805 cp)	8401
thermal conductivity, liquid:	0.6666 W/m•K (0.3851 Btu/hr•ft°F)	8401
thermal conductivity, vapor:	0.0210 W/m•K (0.0121 Btu/hr•ft°F)	8401
• normal pressure, 20 °C (68 °F) -----		
density, vapor:	0.716 kg/m3 (0.0447 lb/cf)	8401
• normal pressure, 21.1 °C (70 °F) ---		
density, vapor:	0.713 kg/m3 (0.0445 lb/cf)	8401
• 20 °C (68 °F) ----------		
pressure, saturated vapor:	857.5 kPa (124.37 psia)	8401
density, saturated liquid:	610 kg/m3 (38.09 lb/cf)	8401
density, saturated vapor:	6.70 kg/m3 (0.418 lb/cf)	8401
specific volume, saturated liquid:	1.639 L/kg (0.0263 cf/lb)	8401
specific volume, saturated vapor:	149.2 L/kg (2.3900 cf/lb)	8401
velocity of sound, saturated liquid:	1385 m/s (4542 ft/s)	8401
velocity of sound, saturated vapor:	405 m/s (1328 ft/s)	8401
viscosity, saturated liquid:	138 µPa•s (0.138 cp)	8401
viscosity, saturated vapor:	9.7 µPa•s (0.0097 cp)	8401

thermal conductivity, saturatd liquid:	0.4999 W/m•K (0.2888 Btu/hr•ft°F)	8401
thermal conductivity, saturated vapor:	0.02552 W/m•K (0.01474 Btu/hr•ft°F)	8401
• 60 °C (140 °F) ----------		
pressure, saturated vapor:	2616 kPa (379.4 psia)	8401
heat of vaporization:	997.3 kJ/kg (428.8 Btu/lb)	8401
• critical point ----------		
temperature:	132.3 °C (270.1 °F)	8401
pressure:	11333 kPa (1643.7 psia)	8401
	11336 kPa (1644.2 psia)	9701
density:	225 kg/m3 (14.0 lb/cf)	8401
	235 kg/m3 (14.7 lb/cf)	9701
specific volume:	4.26 L/kg (0.0682 cf/lb)	9701
	4.44 L/kg (0.0712 cf/lb)	8401

ENVIRONMENTAL

ODP (ozone depletion potential):	0.000 (model-derived relative to R 11)	
GWP (global warming potential):	unknown, but very low: <1 relative to CO2 for 100 yr integration	

SAFETY

• classification ----------		
safety group (ASHRAE Standard 34):	B2	8601
NFPA 704 degrees of hazard (H-F-R-S):	ARI recommendation: 3-1-0 health-flammability-reactivity [-special]: 0=no, 4=severe	3A15
NPCA HMIS hazard ratings (H-F-R):	BOC Gases: 3-1-0 health-flammability-reactivity 0=insignificant, 4=extreme	MSDS
UL Comparative Hazard to Life Group:	2 in absence of flame or hot objects	4B64
DFG pregnancy risk group:	C (no risk fear below MAK/BAT)	7101
• short-term occupational limit ------		
NIOSH IDLH (immediately dangerous):	300 ppm v/v	5204
NIOSH SCP IDLH (immediately dangerous:	500 ppm v/v for 30 min	3903
OSHA STEL (short-term exposure limit):	50 ppm v/v TWA for 15 min (set in 1989, but vacated in 1992)	5204
NIOSH STEL (short-term exposur limit):	35 ppm v/v TWA for 15 min	3903
ACGIH TLV-STEL (short-term exp limit):	35 ppm v/v TWA for 15 min	9504
recommended short-term exposure limit:	DuPont EEL: 500 ppm (<10 min)	MSDS
	DuPont EEL: 300 ppm (10-60min)	MSDS
	DuPont EEL: 500 ppm (ceiling)	MSDS
• occupational exposure limit --------		
MAK (maximum workplace concentration):	I: 40 ppm v/v momentary for 5 min	7101
• long-term occupational limit -------		
OSHA PEL (permissible exposure limit):	50 ppm v/v TWA for 8 hr/day and 40 hr/wk	3904
NIOSH REL (recommendd exposure limit):	25 ppm v/v TWA for 10 hr/day and 40 hr/wk	3903
ACGIH TLV-TWA (time-weighted average):	25 ppm v/v TWA for 8 hr/day and 40 hr/wk	9504
exposure limit consistent to OSHA PEL:	DuPont AEL: 25 ppm v/v TWA for 8 hr/day and 40 hr/wk	MSDS
MAK (maximum workplace concentration):	20 ppm v/v TWA for 8 hr/day 40 (or 42) hr/wk	7101
• emergency exposure limit ----------		
NRC EEGL (emergency exposure level):	1 hr: 100 ppm v/v ceiling guidance level for single emergency exposures	5154
	24 hr: 100 ppm v/v ceiling	5154

	guidance level for single emergency exposures	
Acute Toxicity Exposure Limit (ATEL):	300 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	320 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
Refrigerant Concentration Limit (RCL):	300 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	320 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
AIHA ERPG-3 (life-threatening):	1,000 ppm v/v for 1 hr	4B76
AIHA ERPG-2 (injurious or impairing):	200 ppm v/v for 1 hr	4B76
AIHA ERPG-1 (odor or mild effects):	25 ppm v/v for 1 hr	4B76
• acute (short-term) toxicity --------		
LC50 (lethal concentration, 50%):	rat, 30 min: 23,472 ppm (fatal concentration by inhalation for half of test animals)	6278
	rat, 1 hr: 7,338 ppm (fatal concentration by inhalation for half of test animals)	6230
	rat, 1 hr: 7,338-11,590 ppm (fatal concentration by inhalation for half of test animals)	5340
	rat, 1 hr: 11,342 ppm (fatal concentration by inhalation for half of test animals)	6229
	rat, 1 hr: 16,600 ppm (fatal concentration by inhalation for half of test animals)	5152
	rat, 4 hr: 2,000 ppm (fatal concentration by inhalation for half of test animals)	5266
	rat, 4 hr: 2,000 ppm (fatal concentration by inhalation for half of test animals)	5C46
	rat, 4 hr: 4,067 ppm (fatal concentration by inhalation for half of test animals)	5151
LCL50 (lowest published LC50 value):	rat, 1 hr: 6,586 ppm	1106
ALC (approximate lethal concentration:	rat, 4 hr, 2-4/6: 2,000 ppm (lowest exposure tested with one or more deaths by inhalation)	5643
	rat, 4 hr, ?/?: >2,000 ppm (lowest exposure tested with one or more deaths by inhalation)	6250
LCLo (lethal concentration, lowest):	human, 5 min: 5,000 ppm (published fatal concentration to one or more humans)	6283
	human, rapid: 5,000-10,000 ppm (published fatal concentration to one or more humans)	7424
oral LD50 (lethal dosage, 50%):	rat, using NH4OH: 350 mg/kg (fatal dose by ingestion for half of test animals)	6267
anesthetic/CNS effect NOEL:	rat, 10 min, 0/10: 38,900 ppm v/v (no observed effect level in test animals)	5152
respiratory RD50 (response dose 50%):	mouse, 30 min: 303 ppm v/v (50% decrease in respiratory rate in test animals)	6249

• flammability ----------		
LFL-UFL (flammability limits in air):	15-16 - 25-28 % v/v	3635
	15-28 % v/v	4908
	16-25 % v/v	4757
	16-25 % v/v	5C46
	at 100% RH: 15.95-26.55 % v/v	6350
	in dry air: 15.15-27.35 % v/v	4B60
	match ignition: 14.8-33.4 % v/v	2525
LFL (with spark ignition):	15.1 % v/v	2525
LFL (with hot-wire ignition):	15.1 % v/v	2525
heat of combustion (by ASHRAE 34-92):	22.5 MJ/kg (9673 Btu/lb)	2318
flash point:	none (nonflammable as tested)	3903
autoignition temperature:	651 °C (1204 °F)	4757
	BOC Gases: 690 °C (1274 °F)	MSDS
autodecomposition temperature:	DuPont: 400-500 °C (842-932°F)	MSDS
• detection ----------		
appearance:	colorless	5C46
odor:	penetrating and pungent odor	5C46
odor sensing, lower threshold:	5-50 ppm v/v	3635
PRODUCTION		
first commercial use as a refrigerant:	1859 by F. Carre (absorption)	2115
	1869 by C. Linde (compression)	2113
last year production allowed:	unrestricted	8C01

R-744 (CARBON DIOXIDE)

---------- REFRIGERANT DATA SUMMARY ----------

R-744	carbon dioxide		see
inorganic	CO2	CAS number 124-38-9	RDB#

COMMON USE(S)
industrial refrigerant, first used in 1866 and still in use; component of air (0.033 ñ0.001 %, 330 ppm, in dry atmospheric air); frozen carbon dioxide (dry ice) is used as a coolant for temporary storage at refrigerated conditions; propellant; fire suppressant; carbonation of beverages

IDENTIFIERS

common name(s):	R-744; R744; R 744 carbon dioxide; "carbon oxide" dry ice (when frozen)	
chemical name (by IUPAC convention):	carbon dioxide	
alternative chemical names/formulae:	CO2	
CAS number:	124-38-9 (Chemical Abstracts Service registry number)	
EINECS number:	204-696-9 (European Inventory of Existing Chemical Substances)	
NIOSH RTECS number:	FF6400000 (Registry of Toxic Effects of Chemical Substances)	
trade name(s):	Khladon 744	
historical name(s):	carbonic acid anhydride	
	carbonic acid gas	5787
	carbonic anhydride	2113
ARI container color / Pantone number:	none, use light green grey/413	6601

PHYSICAL

• properties ----------		
molar mass:	44.0095 g/mol (0.097024 lb/mol)	8820
normal freezing/melting/triple point:	-56.6 °C (-69.8 °F)	3209
• normal boiling point ----------		
temperature:	-78.4 °C (-109.1 °F)	8401
heat of vaporization:	572.9 kJ/kg (246.3 Btu/lb)	3208
• normal pressure, 20 °C (68 °F) -----		
density, vapor:	1.839 kg/m3 (0.1148 lb/cf)	8401
• normal pressure, 21.1 °C (70 °F) ---		
density, vapor:	1.832 kg/m3 (0.1144 lb/cf)	8401
• 20 °C (68 °F) ----------		
pressure, saturated vapor:	5721.6 kPa (829.85 psia)	8401
density, saturated liquid:	774 kg/m3 (48.33 lb/cf)	8401
density, saturated vapor:	192.32 kg/m3 (12.006 lb/cf)	8401
specific volume, saturated liquid:	1.292 L/kg (0.0207 cf/lb)	8401
specific volume, saturated vapor:	5.2 L/kg (0.0833 cf/lb)	8401
velocity of sound, saturated liquid:	341 m/s (1119 ft/s)	8401
velocity of sound, saturated vapor:	198 m/s (649 ft/s)	8401
viscosity, saturated liquid:	67 µPa•s (0.067 cp)	8401
viscosity, saturated vapor:	17.3 µPa•s (0.0173 cp)	8401
thermal conductivity, saturatd liquid:	0.0712 W/m•K (0.0412 Btu/hr•ft°F)	8401
thermal conductivity, saturated vapor:	0.01894 W/m•K (0.01094 Btu/hr•ft°F)	8401
• critical point ----------		
temperature:	31.1 °C (87.9 °F)	3209
pressure:	7384 kPa (1071.0 psia)	8401

density:	469 kg/m3 (29.2 lb/cf)	8401
specific volume:	2.13 L/kg (0.0342 cf/lb)	8401
ENVIRONMENTAL		
average atmospheric lifetime (τatm):	variable: >50 yr	6694
ODP (ozone depletion potential):	0.000 (model-derived relative to R 11)	
GWP (global warming potential):	1 relative to CO2 for 100 yr integration	9501
HGWP (halocarbon GWP):	0.00076 relative to R 11 for infinite integration period	6307
SAFETY		
• classification ----------		
safety group (ASHRAE Standard 34):	A1	8601
NFPA 704 degrees of hazard (H-F-R-S):	ARI recommendation: 2-0-0	3A15
	Amerex: 1-0-0	MSDS
	BOC Gases: 1-0-0	MSDS
	health-flammability-reactivity [-special]: 0=no, 4=severe	
NPCA HMIS hazard ratings (H-F-R):	Amerex: 1-0-0	MSDS
	BOC Gases: 1-0-0	MSDS
	DuPont: 1-0-0	MSDS
	health-flammability-reactivity 0=insignificant, 4=extreme	
UL Comparative Hazard to Life Group:	5(a) in absence of flame or hot objects	4B64
• short-term occupational limit ------		
NIOSH IDLH (immediately dangerous):	40,000 ppm v/v	5204
NIOSH SCP IDLH (immediately dangerous:	50,000 ppm v/v for 30 min	3903
NIOSH STEL (short-term exposur limit):	30,000 ppm v/v TWA for 15 min	3903
ACGIH TLV-STEL (short-term exp limit):	30,000 ppm v/v TWA for 15 min	9504
• occupational exposure limit --------		
MAK (maximum workplace concentration):	IV: 10000 ppm v/v momentary 60 min	5561
• long-term occupational limit -------		
OSHA PEL (permissible exposure limit):	5,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	3904
NIOSH REL (recommendd exposure limit):	5,000 ppm v/v TWA for 10 hr/day and 40 hr/wk	3903
ACGIH TLV-TWA (time-weighted average):	5,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	9504
MAK (maximum workplace concentration):	5,000 ppm v/v TWA for 8 hr/day 40 (or 42) hr/wk	5561
	being examined for changes	7101
• emergency exposure limit ----------		
Acute Toxicity Exposure Limit (ATEL):	40,000 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	40,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
Refrigerant Concentration Limit (RCL):	40,000 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	40,000 ppm v/v (preliminary based on ASHRAE 34u draft)	A950
• acute (short-term) toxicity --------		
LCLo (lethal concentration, lowest):	human, instant: 400,000 ppm (published fatal concentration to one or more humans)	7424
	human, 5-min: 90,000 ppm (published fatal concentration to one or more humans)	6283
anesthetic/CNS effect LOEL:	human, 3.8 min 13/31: 104,000 ppm v/v (lowest observed effect level)	A658

	human, 5 min, ?/3: 55,000 ppm v/v (lowest observed effect level)	A657
	human, 7.4 min, 9+/42: 76,000 ppm v/v (lowest observed effect level)	A658
	human, 10 min caution: 100,000 ppm v/v (lowest observed effect level)	A657
	human, 15 min, <22/42: 75,000 ppm v/v (lowest observed effect level)	A939
	human, 30 min caution: 50,000 ppm v/v (lowest observed effect level)	A657
	human, 30 min: 50,000-100,000 ppm v/v (lowest observed effect level)	72A5
	human, >50,000 ppm v/v (lowest observed effect level)	7424
• flammability ----------		
LFL-UFL (flammability limits in air):	none (nonflammable as tested)	2525
flash point:	none (nonflammable as tested)	3903
autoignition temperature:	BOC Gases: none	MSDS
autodecomposition temperature:	BOC Gases: 1700 °C (3092 °F)	MSDS
• detection ----------		
appearance:	colorless	6280
odor:	odorless	5141

PRODUCTION

first commercial use as a refrigerant:	1869 by T. S. C. Lowe	2113
last year production allowed:	unrestricted	8C01

R-1270 (PROPYLENE)

---------- REFRIGERANT DATA SUMMARY ----------

R-1270	propene		see
HC	$CH_3CH=CH_2$	CAS number 115-07-1	RDB#

COMMON USE(S)
component of refrigerants 411A and 411B; very limited use as an industrial refrigerant; further use as a single-compound refrigerant is constrained by its flammability; aerosol propellant, alone or as a blend component; widely used feedstock to produce plastics, alcohols, gasoline, synthetic rubbers, and other chemical products; considered as an anesthetic agent in the 1920s, but not widely used due to depression of the heart function

Revision of the safety classification for this refrigerant was proposed on 1998.01.18. The revision is subject to a review and approval procedure; assignment will not occur until published in an addendum or revision to ANSI/ASHRAE Standard 34-1997.

IDENTIFIERS

common name(s):	R-1270; R1270; R 1270 HC-1270 hydrocarbon 1270	
alternative chemical names/formulae:	propene; propylene 1-propene; 1-propylene methylethene methylethylene $CH_3CH=CH_2$; $CH_3-CH=CH_2$ not recommended: $CH_2=CHCH_3$; $CH_2=CH-CH_3$ CH_3CHCH_2; $H_3CCH=CH_2$; $H_3C-CH=CH_2$; $H_3CCH=CH_2$	
empirical formula:	C_3H_6	
CAS number:	115-07-1 (Chemical Abstracts Service registry number)	
NIOSH RTECS number:	UC6740000 (Registry of Toxic Effects of Chemical Substances)	
ARI container color / Pantone number:	none, use light green grey/413 with red / 185 band	6601

PHYSICAL

• properties ----------		
molar mass:	42.07974 g/mol (0.092770 lb/mol)	8820
normal freezing/melting/triple point:	-185.2 °C (-301.4 °F)	8401
• normal boiling point ----------		
temperature:	-47.7 °C (-53.8 °F)	8401
density, saturated liquid:	609 kg/m3 (38.02 lb/cf)	8401
density, saturated vapor:	2.36 kg/m3 (0.147 lb/cf)	8401
specific volume, saturated liquid:	1.642 L/kg (0.0263 cf/lb)	8401
specific volume, saturated vapor:	424.2 L/kg (6.7944 cf/lb)	8401
heat of vaporization:	439.2 kJ/kg (188.8 Btu/lb)	8401
velocity of sound, saturated liquid:	1169 m/s (3835 ft/s)	8401
velocity of sound, saturated vapor:	224 m/s (735 ft/s)	8401
viscosity, saturated liquid:	244 µPa•s (0.244 cp)	8401
viscosity, saturated vapor:	5.84 µPa•s (0.00584 cp)	8401
thermal conductivity, liquid:	0.1573 W/m•K (0.0909 Btu/hr•ft°F)	8401
thermal conductivity, vapor:	0.0104 W/m•K (0.0060 Btu/hr•ft°F)	8401

• normal pressure, 20 °C (68 °F) -----		
density, vapor:	1.776 kg/m3 (0.1109 lb/cf)	8401
• normal pressure, 21.1 °C (70 °F) ---		
density, vapor:	1.769 kg/m3 (0.1104 lb/cf)	8401
• 20 °C (68 °F) ----------		
pressure, saturated vapor:	1019.9 kPa (147.92 psia)	8401
density, saturated liquid:	513 kg/m3 (32.03 lb/cf)	8401
density, saturated vapor:	21.44 kg/m3 (1.338 lb/cf)	8401
specific volume, saturated liquid:	1.949 L/kg (0.0312 cf/lb)	8401
specific volume, saturated vapor:	46.6 L/kg (0.7471 cf/lb)	8401
velocity of sound, saturated liquid:	727 m/s (2387 ft/s)	8401
velocity of sound, saturated vapor:	223 m/s (730 ft/s)	8401
viscosity, saturated liquid:	106 µPa•s (0.106 cp)	8401
viscosity, saturated vapor:	7.7 µPa•s (0.0077 cp)	8401
thermal conductivity, saturatd liquid:	0.1113 W/m•K (0.0643 Btu/hr•ft°F)	8401
thermal conductivity, saturated vapor:	0.08639 W/m•K (0.04991 Btu/hr•ft°F)	8401
• 60 °C (140 °F) ----------		
pressure, saturated vapor:	2533 kPa (367.3 psia)	8401
heat of vaporization:	249.7 kJ/kg (107.3 Btu/lb)	8401
• critical point ----------		
temperature:	92.4 °C (198.4 °F)	8401
pressure:	4665 kPa (676.6 psia)	8401
density:	223 kg/m3 (13.9 lb/cf)	8401
specific volume:	4.48 L/kg (0.0717 cf/lb)	8401
ENVIRONMENTAL		
ODP (ozone depletion potential):	0.000 (model-derived relative to R 11)	
SAFETY		
• classification ----------		
safety group (ASHRAE Standard 34):	A3	8601
	B3(revision)proposed1998.01.18	34i
NFPA 704 degrees of hazard (H-F-R-S):	Ashland: 1-4-1	MSDS
	BOC Gases: 1-4-1	MSDS
	DuPont: 1-4-1	MSDS
	Phillips: 1-4-1	MSDS
	Texaco: 1-4-1	MSDS
	health-flammability-reactivity [-special]: 0=no, 4=severe	
NPCA HMIS hazard ratings (H-F-R):	BOC Gases: 0-4-0	MSDS
	DuPont: 0-4-2	MSDS
	Texaco: 1-4-1	MSDS
	health-flammability-reactivity 0=insignificant, 4=extreme	
IARC/CIRC human carcinogicity group:	3, not classifiable	2428
ACGIH carcinogenicity category:	A4, not classifiable as a human carcinogen	9504
DFG carcinogicity class:	being examined for new entry	7101
• occupational exposure warnings -----		
ACGIH caution:	simple asphyxiant	9504
• long-term occupational limit -------		
exposure limit consistent to OSHA PEL:	Exxon: 1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	MSDS
	Greencool: 375 ppm v/v TWA for 8 hr/day and 40 hr/wk	MSDS
	Phillips: 1,000 ppm v/v TWA for 8 hr/day and 40 hr/wk	MSDS
• emergency exposure limit ----------		
Acute Toxicity Exposure Limit (ATEL):	0 ppm v/v (preliminary based on ASHRAE 34u draft)	34u
	provisional: 0 ppm v/v	A950

	(preliminary based on ASHRAE 34u draft)	
Refrigerant Concentration Limit (RCL):	provisional: 0 ppm v/v	A950
	(preliminary based on ASHRAE 34u draft)	
• acute (short-term) toxicity --------		
ALC (approximate lethal concentration:	rat, 2 hr, ?/?: 650,000 ppm (lowest exposure tested with one or more deaths by inhalation)	65B9
	rat, 6 hr, 0/?: >400,000 ppm (lowest exposure tested with one or more deaths by inhalation)	65B9
cardiac sensitization threshold/LOEL:	dog 10min 2/2: 100,000-250,000 ppm v/v (lowest observed effect level in test animals)	6192
anesthetic concentration:	human, 2.25 min: 64,000 ppm v/v	6A64
anesthetic/CNS effect LOEL:	mouse, 1 min, ?/?: 500,000 ppm v/v (lowest observed effect level in test animals)	6A70
	rat, 15-20 min, 1/1: 400,000 ppm v/v (lowest observed effect level in test animals)	65B9
anesthetic/CNS effect NOEL:	mouse, 6 hr/d chronic: 9,957 ppm v/v (no observed effect level in test animals)	7534
	rat, 6 hr/d chronic: 9,891 ppm v/v (no observed effect level in test animals)	7534
	rat, 6 hr/d subchronic: 10,000 ppm v/v (no observed effect level in test animals)	7534
• flammability ----------		
LFL-UFL (flammability limits in air):	2.0-11.0 % v/v	6290
	Exxon: 2.0-11.1 % v/v	MSDS
	Phillips: 2.0-10 % v/v	MSDS
flash point:	-108 °C (-162 °F)	6290
	Ashland: -40 °C (-40 °F)	MSDS
autoignition temperature:	DuPont: 460 °C (860 °F)	MSDS
	Exxon: 458 °C (856 °F)	MSDS
	Texaco: 497 °C (927 °F)	MSDS
• detection ----------		
appearance:	colorless	6290
odor:	BOC Gases: mild olefinic odor	MSDS
	Phillips: mild, sour odor	MSDS
	Texaco: odorless	MSDS
	practically odorless	6290
odor sensing, lower threshold:	DuPont: 10-60 ppm v/v	MSDS
PRODUCTION		
last year production allowed:	unrestricted	8C01

APPENDIX 3: TOXICITY SUMMARIES

This appendix presents toxicity summaries from the *ARTI Refrigerant Database*,[22] most of them prepared in 1995 with minor updates since then.

R-11

REFRIGERANT TOXICITY SUMMARY

			see
R-11	trichlorofluoromethane		
CFC	CCl3F	CAS number 75-69-4	RDB#

R-11 has extremely low toxicity by skin contact or ingestion, but it can cause frostbite if splashed on the skin, drying and redness with repeated or prolonged contact, and mild irritation to the eyes. It has very low toxicity by inhalation and is neither carcinogenic nor mutagenic. Animal tests show no developmental or reproductive effects. R-11 is, however, a comparatively potent cardiac sensitizer to adrenaline and depresses the cardiopulmonary and central nervous systems with exposures at high concentrations. /1-9/ 5873 5B47 7414 5141

OCCUPATIONAL EXPOSURE LIMITS

The Occupational Safety and Health Administration (OSHA) promulgated a Permissible Exposure Limit (PEL) of 1,000 ppm for R-11. The National Institute for Occupational Health and Safety (NIOSH) and American Conference of Governmental Industrial Hygienists (ACGIH) adopted a Recommended Exposure Limit Ceiling (REL-C) and a Threshold Limit Value - Ceiling (TLV-C), respectively, of 1,000 ppm. The Air-Conditioning and Refrigeration Institute (ARI) also recommends a ceiling concentration limit (PEL-C) of 1,000 ppm. 3904 3903 6901 3A15

GENERAL CAUTIONS

More recent and/or more complete information may be found in Material Safety Data Sheets (MSDSs), provided by the chemical supplier(s), and in other toxicology references. Inhalation of high concentrations of refrigerant vapors is harmful. Anesthetic effects including loss of consciousness, heart irregularities, or death may result. Intentional misuse or deliberate inhalation ("sniffing") may cause death without warning. Massive leaks or spills also may pose an asphyxiation hazard, by displacing air, in confined or inadequately ventilated locations. This refrigerant is heavier than air, and leakage may accumulate in low areas.

NATIONAL RESEARCH COUNCIL (NRC) COMMITTEE ON TOXICOLOGY
SUMMARY OF TOXICITY INFORMATION (October 1984) 7414

EFFECTS ON HUMANS: Inhalation of fluorocarbons during the years 1960-1970 was a prominent cause of abusive death among teenagers. Severe cardiac arrhythmia - resulting from light plane anesthesia and intensified by hypercapnia, stress, or activity - was suggested as an explanation for 110 cases of sudden sniffing death (Bass, 1970). Typically, a person would spray the Freon [fluorocarbon] into a paper bag from a commercial aerosol product and inhale it; after a few breaths and a short excitement period, death might occur. Fluorocarbons are thought to sensitize the heart to asphyxia-induced sinus bradycardia, atrioventricular block, and ventricular T-wave depression (Haj et al., 1980). 6722 7422

Accidental ingestion of FC-11 occurred when a healthy man mistook a bottle in a refrigerator for a bottle of plain water. This resulted in freezing, tissue necrosis, and multiple perforations of the stomach. The patient recovered after surgery to remove the damaged tissue (Haj et al., 1980) 7422

Labeled FC-11 administered to four healthy males by inhalation of a single breath held for 5 s was eliminated rapidly. Results in humans

appeared to parallel those in rats in more detailed studies (Williams et al., 1974). The investigators found rapid transfer of FC-11 to blood followed by distribution to fat, from which release was slow. 7429
Mergner et al. (1975) exposed a male and a female volunteer to radiolabeled FC-11 at 1,000 ppm for 7-17 min. Recovery of administered radioactivity in exhaled air was essentially complete (99% and 79%). 5C72
Errors in collection of rapidly eliminated gases account for the differences from 100%. Only a very small fraction of the administered radioactivity (less than 0.2%) was exhaled as [14]CO2 or excreted as nonvolatile urinary activity. The impurities in FC-11 – namely chloroform and carbon tetrachloride – known to be metabolized could account for all the radioactivity found in urine and exhaled CO2 after exposure to FC-11.

Cardiac effects have been studied in healthy subjects and patients with bronchopulmonary disease. None of the subjects exhibited cardiotoxic effects (Fabel et al., 1972). 6726

Human volunteers were exposed to FC-113 (similar to FC-11) at 500 or 1,000 ppm for 6 h/d, 5 d/wk during a 2-wk period. No adverse changes were seen in performance of complex mental tasks, clinical status, or results of biochemical tests. Breath analysis did not reveal a significant buildup of FC-113 (Reinhardt et al., 1971). 6496

EFFECTS ON ANIMALS: FC-11 has not shown appreciable oral toxicity in rats and dogs in either acute or chronic studies (Haskell Laboratory, 1970; NCI, 1978). The chronic investigations include 1-mo, 90-d, and 2-yr studies. FC-11 was tested on the intact skin of mice. It was well tolerated by the skin, but retarded the recovery of wounds and burns and regrowth of hair (Quevauviller, 1960; Quevauviller et al., 1963). Dermal application of FC-11 to rabbit skin did not produce any lesions (Scholz, 1962). Transient conjunctival irritation was observed after application of FC-11 solution to the rabbit eye. No irreversible eye damage was seen (Haskell Laboratory, 1970; Kudo et al., 1971). 5C59 7427 7428 6128 5355 5C54 7426

The LC50 of FC-11 for rats in a 4-hour exposure is 26,200 ppm (Haskell Laboratory, 1970). A 30-min exposure of rats at 50,000 ppm caused no signs of intoxication. Similar exposure at higher concentrations caused clinical signs of central nervous system depression. Concentrations of 100,000 ppm or more were fatal after less than 30 min (Lester and Greenberg, 1950). Acute exposure of other species of laboratory animals produced similar effects (Caujolle, 1964; Haskell Laboratory, 1970; Nuckolls, 1933; Scholz, 1962). 5C53 5147 7424 5C59 4B64 5355

Rats, guinea pigs, monkeys, and dogs were continuously (24 h/d) exposed to FC-11 at approximately 1,000 ppm for 90 d. One monkey died on day 78, but its death was not definitely linked to exposure to FC-11. No other animals were affected. No compound-related pathological changes were observed. Another group of animals was exposed at 10,250 ppm, 8 h/d, 5 d/wk for 6 wk without adverse effects (Jenkins et al, 1970). 5C60
In another study, dogs, cats, guinea pigs, and rats were exposed to FC-11 for 3.5 h/d, 5 d/wk, for 4 wk; the dogs were exposed at 12,500 ppm, and the other animals at 25,000 ppm. No microscopic evidence of damage to the lungs, heart, spleen, liver, or kidneys was seen (Scholz, 1962). 5355

Rats and mice exposed to FC-11 at 1,000 or 5,000 ppm for lifetime showed no evidence of carcinogenicity or other adverse health effects (C. Maltoni, unpublished). 6570

FC-11, like other chlorofluorocarbons and hydrocarbons, was capable of sensitizing the beagle heart to exogenous epinephrine in standard 5-min cardiac sensitization screening studies. A 5-min cardiac-sensitization

screening test consists of a control intravenous injection of epinephrine at 8 µg/kg, followed later by a 5-min exposure to fluorocarbon and then a challenge with 8 µg/kg intravenously. Manifestation of arrhythmia (multiple consecutive ventricular beats), which is considered to pose a serious threat to life, or cardiac arrest (ventricular fibrillation) constitutes a positive test. The lowest concentration that elicited a marked response in exposed dogs was 5,000 ppm. A concentration of 1,000 ppm was ineffective. Dogs exposed while running on a treadmill (to increase their circulating epinephrine) were not sensitized at concentrations up to 10,000 ppm (Mullin et al., 1972). 5360

Azar et al. (1973) studied nonanesthetized dogs and reported that 5357
the average blood concentrations of FC-11 associated with cardiac sensitization were 28.6 µg/L in arterial and 19.7 µg/L in venous blood.

Belej and Aviado (1975) studied cardiopulmonary toxicity of propel- 59A4
lants in anesthetized dogs. They concluded that FC-11, unlike eight other halocarbon propellants studied, produced bronchodilation, rather than bronchoconstriction. It also reduced pulmonary compliance and respiratory minute volume. FC-11 had the greatest tachycardiac effect of all compounds studied. Effects of FC-11 on the circulatory 5C69
system were summarized by Aviado (1975, 1978). 7423

In a bioassay supported by the National Cancer Institute (1978), 7427
oral FC-11 was not carcinogenic in rats or mice. No significant increase in tumor formation was seen in a study that used subcutaneous injection (Epstein et al., 1967). Additionally, FC-11 has not been 7425
shown to be mutagenic in the Salmonella typhimurium reverse-mutation bioassay (C. F. Reinhardt, Haskell Laboratory, personal communica- 5C58
tion). No embryotoxic fetotoxic, or teratogenic effect of FC-11 was shown in a study with pregnant rats and rabbits; the animals were exposed for 2 h/d to 200,000 ppm of a FC-11/FC-12 (1:9) mixture from day 4 to 16 of gestation for rats and from day 5 to 20 for rabbits 5179
(Paulet, 1976). Blake and Mergner (1974) investigation studied the 5C70
biotransformation of 14C-labelled FC-11 (8,000-12,000 ppm) in male and female beagles after a short (6-20 min) inhalation. Essentially all the inhaled fluorocarbon was recovered in the exhaled air within 1 h. Only traces of radioactivity were found in urine or exhaled CO2. The investigators concluded that FC-11 is relatively refractory to biotransformation after a short inhalation exposure and that it is rapidly exhaled chemically unaltered.

OTHER

Human volunteers exposed to R-11 at 2,800-27,000 ppm for 15-60 seconds exhibited acute reduction of ventilatory lung capacity, bradycardia, increased variability in heart rate, and effects on their electrocardiograms. /3/

ADDITIONAL REFERENCES

1. Freon(R) 11, Material Safety Data Sheet (MSDS) DU000026 (2090FR), DuPont Chemicals, Wilmington, DE, 8 January 1998
2. Used Refrigerant 11, MSDS 3090FR, DuPont Chemicals, Wilmington, DE, 21 January 1992
3. Forane(R) 11, MSDS 04011, Elf Atochem North America, Incorporated, Philadelphia, PA, 3 November 1999
4. Forane(R) 11 Reclaim, MSDS 04411.5, Elf Atochem North America, Incorporated, Philadelphia, PA, 15 October 1996
5. Fluorotrichloromethane, MSDS 309, Genium Publishing Corporation, Schenectady, NY, February 1986
6. Genetron(R) 11, MSDS GTRN-0017, Honeywell Incorporated, Morristown, NJ, January 2000
7. Arcton(R) 11, MSDS 232, ICI Klea, Wilmington, DE, 23 January 1998

8. Arcton(R) 11, Chemical Safety Data Sheet (CSDS) revision 04, ICI Klea, Runcorn, Cheshire, UK, April 1997
9. Fluorotrichloromethane, MSDS OHS0990, Occupational Health Services, Incorporated (OHS), New York, NY, 14 July 1993

R-12

REFRIGERANT TOXICITY SUMMARY

			see
R-12	dichlorodifluoromethane		
CFC	CCl2F2	CAS number 75-71-8	RDB#

R-12 has extremely low toxicity by skin contact or ingestion, but it can cause frostbite if splashed on the skin, drying and redness with repeated or prolonged contact, and mild irritation to the eyes. It has very low toxicity by inhalation and is neither carcinogenic nor mutagenic. Animal tests show no developmental or reproductive effects. R-12 is, however, a cardiac sensitizer to adrenaline and produces a rapid anesthetic effect at high concentrations. /1-8/ Tests in humans showed no ill effects at 1,000 ppm v/v R-12 in air for up to eight hours; R-12 is quickly eliminated from the body in exhaled air. 5B48 7525

OCCUPATIONAL EXPOSURE LIMITS

The Occupational Safety and Health Administration (OSHA), National Institute for Occupational Health and Safety (NIOSH), American Conference of Governmental Industrial Hygienists (ACGIH), and Deutsche Forschungsgemeinschaft (DFG) [German Research Association] have all adopted recommended chronic exposure limits - the Permissible Exposure Limit (PEL), Recommended Exposure Limit (REL), Threshold Limit Value - Time-Weighted Average (TLV-TWA), and Maximale Arbeitsplatz Konzentration (MAK), respectively - of 1,000 ppm v/v on a time-weighted-average basis for an 8-10 hour workday and 40-42 hour workweek. 3904 3903 6901 5561

GENERAL CAUTIONS

More recent and/or more complete information may be found in Material Safety Data Sheets (MSDSs), provided by the chemical supplier(s), and in other toxicology references. Inhalation of high concentrations of refrigerant vapors is harmful. Anesthetic effects including loss of consciousness, heart irregularities, or death may result. Intentional misuse or deliberate inhalation ("sniffing") may cause death without warning. Massive leaks or spills also may pose an asphyxiation hazard, by displacing air, in confined or inadequately ventilated locations. This refrigerant is heavier than air, and leakage may accumulate in low areas.

NATIONAL RESEARCH COUNCIL (NRC) COMMITTEE ON TOXICOLOGY
SUMMARY OF TOXICITY INFORMATION (October 1984) 7414

EFFECTS ON HUMANS: Of 34 cases of sudden death reported to the medical examiner of Dallas, Texas, to be due to abusive, deliberate use of products that can be inhaled, 16 involved fluorocarbons (Garriott and Petty, 1980). The victims were mainly white males aged 13-30 (mean, 18.4). FC-11 and FC-114 were used in addition to FC-12, and many products contained mixtures of FC-11 and FC-12. The sequence of events has been summarized by Aviado (1978) as follows: sensitization of the heart to prearrhythmic effects of epinephrine, depression of myocardial contractility, reduction in cardiac output, and irritation of mucosa in upper and lower respiratory tract that causes an increase in sympathetic and vagal impulses to the heart. 7431 7430

Azar et al. (1972) exposed two human volunteers to FC-12 at 1,000 and 10,000 ppm for 2.5 h. Each volunteer was exposed twice at each concentration. Electrocardiographic monitoring and psychomotor performance tests revealed no adverse effects of exposure at 1,000 ppm. At 10,000 ppm, there was only a 7% reduction in psychomotor-test score. 5358

Rapid elimination from the lungs occurred when exposure stopped. The investigators concluded that a single brief exposure (up to 2.5 h) to FC-12 at 10,000 ppm could be tolerated without adverse health effects.

Kehoe (1943) reported that exposure to FC-12 at up to 60,000 ppm was tolerated for 80 min by one subject. When exposed at 40,000 ppm for 14 min and then at 20,000 ppm for 66 min, a second subject developed EEG changes and had slurred speech and decreased scores in psychologic tests. At 110,000 ppm, amnesia and cardiac arrythmia occurred within about 10 min. 5C45

Mergner et al. (1975) exposed a male and female volunteer to radio-labelled FC-12 at 1,000 ppm for 7-17 min. Recovery of administered radioactivity in exhaled air was essentially complete. Radioactivity in urine and exhaled CO2 together amounted to less than 0.2% of administered radioactivity. 5C72

EFFECTS ON ANIMALS: FC-12 has not shown appreciable oral toxicity in laboratory animals in either acute or chronic exposures. These included 18-wk rat and dog feeding studies (fed at 160-379 mg/kg per day) and 2-yr rat feeding studies (up to 150 mg/kg per day) (Haskell Laboratory, 1955a; Hood, 1956; Sherman, 1974; Sherman and Barnes, 1966). 65H5 7526 7433 65H8

No skin irritation was observed after contact of the gas with the skin of rats, rabbits, or guinea pigs. Transient eye irritation followed application of a 50% solution to rabbit eyes. Treated eyes were normal 24 h later. No eye irritation was seen after an aerosol mixture containing FC-12 was sprayed into the eyes of rabbits (Haskell Laboratory, 1955b; Hood, 1956). 7527 7526

The lethal concentration of FC-12 for rats in a 3-h exposure was 620,000 ppm (Shugaev, 1963). Two-hour exposure at 600,000 ppm was lethal to rats, but not to guinea pigs (Scholz, 1962). Central nervous system effects were observed in all exposed species. In rats exposed for 30 min, there were no reactions at 200,000 ppm (Lester and Greenberg, 1950). At higher concentrations, the following effects were observed: muscular twitching and tremors at 300,000-400,000 ppm, loss of postural reflex at 500,000 ppm, and loss of righting reflex at 600,000 ppm. Guinea pigs were similarly affected at 200,000-300,000 ppm (Nuckolls, 1933). Mice survived a 24-h exposure at 10,000 ppm, but microscopic examination revealed nonspecific lung changes (Quevauviller et al., 1963). 7434 5355 5147 4B64 6128

Rats, guinea pigs, monkeys, rabbits, and dogs were exposed to FC-12 continuously at 810 ppm for 90 d (Prendergast et al., 1967). Although 2 of 15 rats and 1 of 15 guinea pigs died during exposure, there were no visible signs of toxicity. During the course of the experiment - which involved tests of several other chemicals, such as trichloroethylene, carbon tetrachloride, and other fluorocarbons - 7 of 304 control rats and 2 of 34 control guinea pigs died. Pathologic examination revealed focal necrosis in the livers of the guinea pigs. This change was thought to be due to the continuous nature of the exposure or the high degree of susceptibility of the guinea pig. No pathologic changes were seen in the tissues of the other four species. In another experiment, test animals were exposed at 840 ppm for 8 h/d, 5 d/wk, for 6 wk (Nuckolls, 1933). No signs of toxicity were seen, and pathologic examination revealed changes similar to those seen in the continuous study (Nuckolls, 1933). At higher concentrations, toxic signs indicative of CNS effects were observed on repeated exposure (Sayers et al., 1930; Scholz, 1962; Watanabe and Aviado, 1975). In addition, rats and mice exposed to FC-12 at 1,000 and 5,000 ppm for 104 wk showed no evidence of carcinogenicity (C. Maltoni, unpublished). 5C44 4B64 4B64 5356 5355 5A74 6570

FC-12, like other chlorofluorocarbons and hydrocarbons, is capable of sensitizing the beagle heart to exogenous epinephrine in standard 5-min cardiac-sensitization screening studies. The concentration needed to elicit marked responses in 50% of exposed dogs is 80,000 ppm (Clark and Tinston, 1973). Dogs exposed to FC-12 while running on a treadmill to increase their own epinephrine concentration were sensitized at concentrations over 100,000 ppm (Mullin, 1970; Mullin et al., 1972). 6109 6522 5360

Lessard et al. (1978) reported that epinephrine perfusion induced cardiac arrhythmia in rabbits and dogs breathing gas mixtures of 79% FC-12 and 21% 02. After 5 min of inhalation, arterial blood contained FC-12 at 0.8 mg/L in rabbits and 0.7 mg/L in dogs. 7432

Blake and Mergner (1974) studied the biotransformation and elimination of FC-12 in beagles after exposure to radiolabeled FC-12 (8,000-12,000 ppm, v/v). Essentially all the inhaled air was recovered in the exhaled air within 1 h. Only traces of radioactivity were found in urine or exhaled C02. All tissues contained measurable concentrations of nonvolatile radioactivity 24 h after exposure, but together represented less than 1% of the administered dose. It was not possible to determine whether this radioactivity was associated with metabolites of FC-12 or with unavoidable radiolabeled impurities present in the administered gas mixture. The investigators concluded that FC-12 is relatively refractory to biotransformation after a short inhalation exposure and that it is rapidly exhaled in its unaltered form. 5C70

ADDITIONAL REFERENCES

1. Freon(R) 12, Material Safety Data Sheet (MSDS) DU001065 (2022FR), DuPont Chemicals, Wilmington, DE, 8 January 1998
2. Used Refrigerant 12, MSDS 3035FR, DuPont Chemicals, Wilmington, DE, 8 October 1992
3. Forane(R) 12, MSDS 04012, Elf Atochem North America, Incorporated, Philadelphia, PA, 17 July 1999
4. Forane(R) 12 Reclaim, MSDS 04412.5, Elf Atochem North America, Incorporated, Philadelphia, PA, 17 October 1996
5. Dichlorodifluoromethane, MSDS, Genium Publishing Corporation Schenectady, NY, February 1986
6. Genetron(R) 12, MSDS GTRN-0018, Honeywell Incorporated, Morristown, NJ, January 2000
7. Arcton(R) 12, MSDS 230, ICI Klea, Wilmington, DE, 23 January 1998
8. Arcton(R) 12, Chemical Safety Data Sheet (CSDS) revision 04, ICI Klea, Runcorn, Cheshire, UK, April 1997
9. Dichlorodifluoromethane, MSDS 06880, Occupational Health Services, Incorporated (OHS), New York, NY, 24 March 1993

R-22

REFRIGERANT TOXICITY SUMMARY

			see RDB#
R-22	chlorodifluoromethane		
HCFC	CHClF2	CAS number 75-45-6	

R-22 has an extremely low order of acute toxicity; its lethal concentration (4-hr LC50 rat) exceeds 200,000 ppm. 3718

OCCUPATIONAL EXPOSURE LIMITS

The American Conference of Governmental Industrial Hygienists (ACGIH) adopted a Threshold Limit Value - Time-Weighted Average (TLV-TWA) of 1,000 ppm in 1990. 5141

GENERAL CAUTIONS

More recent and/or more complete information may be found in Material Safety Data Sheets (MSDSs), provided by the chemical supplier(s), and in other toxicology references. Inhalation of high concentrations of refrigerant vapors is harmful. Anesthetic effects including loss of consciousness, heart irregularities, or death may result. Intentional misuse or deliberate inhalation ("sniffing") may cause death without warning. Massive leaks or spills also may pose an asphyxiation hazard, by displacing air, in confined or inadequately ventilated locations. This refrigerant is heavier than air, and leakage may accumulate in low areas.

INHALATION

R-22 is rapidly equilibrated in tissues; it is eliminated from the blood in expired air, with a half life of a few minutes. Inhalation and blood concentrations are linearly correlated over a wide range. Metabolism is limited if it occurs at all, making toxicological activities from formation of reactive intermediates unlikely. 3718

Lethal concentrations are documented for several animal species and exposure durations. Tests with rats for four hours indicate an LC50 of 220,000 ppm and a minimum lethal concentration (MLC) of 250,000 ppm. A two hour exposure at 200,000 ppm was not lethal. 90 minute tests with dogs showed concentrations of 395,000 and 690,000 ppm to be not lethal and lethal, respectively. Exposures at 200,000 for five minutes were not lethal to monkeys. 3718

High concentrations of R-22 produce stimulation followed by depression of the central nervous system (CNS) and finally asphyxiation. The minimum concentration capable of altering the reflex response of rabbits is 11,000-20,000 ppm. Concentrations of 75,000-100,000 ppm for two hours produce excitation or changes in equilibrium in rats and guinea pigs. Narcosis results at 200,000 ppm, and mortality at 300,000 and 400,000 ppm. The minimum lethal concentration for mice is 370,000 ppm for two hour exposures. 5141

Guinea pigs exposed to 180,000-226,000 ppm showed occasional chewing movements, rapid breathing, convulsive tremors, slight lachrymation (eye tearing) and nasal discharge, and inability to stand or walk after five minutes. Stupor was evident at 30 minutes, and prostration and audible breathing at one hour. These effects intensified with exposures of up to two hours, but the animals survived. They recovered within one day, and appeared to be normal for the remainder of a ten-day observation period. No pathological conditions were noted in one animal autopsied after two days. Similar tests at 10,000-11,000 ppm

and 24,000-27,000 ppm resulted in minimal effects, such as occasional chewing movements and slight lachrymation. The responses progressed with increased exposures of 51,000-117,000 ppm. 5175

Guinea pigs exposed to concentrations of 10,000 and 25,000 ppm in the presence of gas flames, to test the effects of decomposition products, showed increasing responses and were killed within 29 minutes. Similar tests at 51,000 ppm and hot electric range units showed lesser responses, but two of three animals died 12 minutes and 51 hours, respectively, after the test. 5175

Animal tests for concentrations of 50,000-700,000 ppm indicate effects to the CNS, liver, lungs, kidneys, and spleen as well as cardiac sensitization, decreased gain in body weight, and partial anesthesia /1,2,10,11/. Chronic inhalation of 50,000 ppm produced a small, but statistically significant increase in fibrosarcomas (a malignant connective-tissue tumor) and zymbal gland tumors in male rats, but not in female rats or male or female mice /1-3,8,10/. No carcinogenic effects were seen at 1,000 or 10,000 ppm in either species /1-3/. Rats given R-22 orally showed no increased incidence of tumors /3/. R-22 is mutagenic in bacterium salmonella cultures, but not in mammalian cell cultures or in animal assays with mice and rats /1-3/. 3718

Concentrations of 25,000 ppm or more reduce heart efficiency. 5178
Cardiac sensitization to epinephrine has been observed at concentrations of 50,000 ppm /10,11/. R-22 also increases the sensitivity of the heart to adrenalin, possibly resulting in rapid tachycardia (heartbeat), cardiac arrhythmias (irregular heartbeat), and depression of cardiac function /3,6/. Individuals with preexisting CNS or cardiovascular diseases may have increased susceptibility to the toxicity of excessive exposures /1-3/. 3718

A slight, but significant increase in developmental toxicity (e.g., eye malformations and decreased fetal weights) occurs in the offspring of rats exposed to 50,000 ppm, a concentration that also is maternally toxic. No effects on the maternal rats or their offspring are seen at 100 or 1,000 ppm./1-4,6/ Developmental toxicity studies in rabbits at 100, 1,000, and 50,000 ppm were negative /1,2/.

Few indications of adverse health effects to humans have been 3718
reported in more than 50 years of R-22 use. One group of surveyed 5141
hospital workers, who were chronically exposed to 300 ppm, indicated increased heart palpitations, a subjective symptom. 3718

SKIN OR EYE CONTACT

R-22 is not a skin sensitizer, though contact with liquid R-22 or 3718
escaping vapor may cause frostbite or local freezing /8,10,11/ and slight irritation to the skin and eyes /11/. It is unlikely that R-22 will be absorbed through the skin /6/.

INGESTION

Ingestion also is unlikely due to the high volatility of the compound /1-4,6,8-11/. Frostbite damage to the lips, mouth, and mucous membranes as well as nausea and vomiting may occur if swallowed /8,10/.

NIOSH-OSHA OCCUPATIONAL SAFETY AND HEALTH GUIDELINE (OSHG, "OHG") TOXICOLOGY SUMMARY (1995) 6286

EFFECTS ON ANIMALS: Chlorodifluoromethane causes depression of the nervous system, cardiac arrhythmias, and asphyxiation. The LC50 in the rat is 35 parts per hundred (pph) (350,000 ppm) for a 15-min exposure; acutely poisoned animals exhibited altered sleep times, stumbling, and

respiratory depression before death. Mice exposed for 2-hr periods showed a maximum tolerated concentration of 320,000 ppm, and a minimum fatal level of 370,000 ppm. Rats and pigs exposed by inhalation to airborne concentrations of 75,000 to 100,000 ppm chlorodifluoromethane for 2-hr showed excitation and/or changes in equilibrium; narcosis occurred at 200,000 ppm and death occurred at 300,000 and 400,000 ppm. Dogs exposed to a 50,000 ppm concentration of chlorodifluoromethane developed cardiac sensitization; exposure to 25,000 ppm did not cause this effect. The minimum concentration capable of altering the reflex response in rabbits varied between 11,000 and 20,000 ppm. In 2-hr exposures to guinea pigs, the highest concentration tested (200,000 ppm) did not cause death, while 50,000 ppm produced mild clinical changes, and minimal effects were noted at 25,000 ppm. In a 4-week study in which rats, guinea pigs, dogs, and cats were exposed to a 50,000 ppm concentration of chlorodifluoromethane for twenty 3.5 hr episodes, no clinical, biochemical, or pathological effects were observed. Rats, mice, and rabbits were exposed for 6 hr/day, 6 days/week for 10 months to 14,000 ppm chlorodifluoromethane. In another experiment, rats and mice were exposed to 2,000 ppm of this substance for the same period. No effects were noted in animals exposed at the lower concentration, but at 14,000 ppm alterations occurred in body weight, physiological endurance, and hematological characteristics; pathological changes were noted in the lungs, central nervous system, heart, liver, kidneys, and spleen. In one inhalation bioassay in rats, males exposed to the highest concentration administered showed only a marginal increase in the incidence of subcutaneous fibrosarcomas and Zymbal-gland tumors, and negative results were obtained for females. Based on this study, the International Agency for Research on Cancer (IARC) has concluded that the evidence for chlorodifluoromethane's carcinogenicity in animals is limited.

4450 5141 5141 5141 5141 5141

EFFECTS ON HUMANS: Chlorodifluoromethane can effect the heart; at very high concentrations it is an asphyxiant. A study of hospital personnel exposed to 300 ppm chlorodifluoromethane during tissue freezing procedures revealed a 3½-fold increase in the incidence of palpitations in exposed individuals over the incidence in nonexposed hospital personnel. An epidemiologic study involving workers exposed to chlorofluorocarbons, including chlorodifluoromethane, showed no increased mortality due to heart, circulatory, or malignant disorders. A small study of 539 refrigeration workers exposed to a mixture of chlorofluorocarbons, including chlorodifluoromethane, for at least 6 month and followed for up to 30 years was inconclusive, leading IARC to conclude that the evidence for the carcinogenicity of this substance in humans is inadequate.

5167 5159 5159

ADDITIONAL REFERENCES

1. Freon(R) 22, Material Safety Data Sheet (MSDS) DU000025 (2008FR), DuPont Chemicals, Wilmington, DE, 8 January 1998
2. Used Refrigerant 22, MSDS, DuPont Chemicals, Wilmington, DE, 8 October 1992
3. Forane(R) 22, MSDS 04022, Elf Atochem North America, Incorporated, Philadelphia, PA, 21 September 1999
4. Forane(R) 22 Reclaim, MSDS 04422, Elf Atochem North America, Incorporated, Philadelphia, PA, 30 December 1996
5. Forane(R) 22, Safety Data Sheet (SDS) 00055, Elf Atochem S.A., Paris La Défense, France, 17 August 1998
6. Chlorodifluoromethane, MSDS, Genium Publishing Corporation, Schenectady, NY, February 1986
7. Genetron(R) 22, MSDS GTRN-0026, Honeywell Incorporated, Morristown, NJ, January 2000
8. Arcton(R) 22, Chemical Safety Data Sheet (CSDS), ICI Klea, Runcorn, Cheshire, UK, April 1997

9. Arcton(R) 22, MSDS 254, ICI Americas Incorporated, Wilmington, DE, 15 April 1998
10. MSDS 04760, Occupational Health Services, Incorporated (OHS), New York, NY, 14 July 1993
11. Solkane(R) 22, MSDS, Solvay Fluor und Derivate GmbH, Hannover, Germany, 5 August 1996

R-23

REFRIGERANT TOXICITY SUMMARY

			see RDB#
R-23	trifluoromethane		
HFC	CHF3	CAS number 75-46-7	

The toxicity of hydrofluorocarbons (HFCs) is generally lower than for corresponding brominated and chlorinated hydrocarbons, based in part on the higher stability of the carbon-fluorine bond. Overall, R-23 has very low toxicity. 5137 5604

OCCUPATIONAL EXPOSURE LIMITS

AlliedSignal, DuPont, and ICI have adopted recommended occupational exposure limits of 1000 ppm for 8 and 12 hour, time-weighted average (TWA) exposures, identified by DuPont as an Acceptable Exposure Limit (AEL) /1-3,6-7/.

GENERAL CAUTIONS

More recent and/or more complete information may be found in Material Safety Data Sheets (MSDSs), provided by the chemical supplier(s), and in other toxicology references. Inhalation of high concentrations of refrigerant vapors is harmful. Anesthetic effects including loss of consciousness, heart irregularities, or death may result. Intentional misuse or deliberate inhalation ("sniffing") may cause death without warning. Massive leaks or spills also may pose an asphyxiation hazard, by displacing air, in confined or inadequately ventilated locations. This refrigerant is heavier than air, and leakage may accumulate in low areas.

INHALATION

Inhalation studies for R-23 with baboons (papio anubis) identified a dose-response effect for respiratory rate, electroencephalogram, and cardiac sinus rate, which exhibited a stepwise decrease from 100,000 ppm. No spontaneous arrhythmias were noted, and arterial blood pressure remained unchanged at any level. Intravenous epinephrine infusions induced transient cardiac arrhythmia in one animal at 700,000 ppm. R-23 appears to induce mild dose-related physiological changes, indicative of an anesthetic effect, at inspired concentrations of 300,000 or more. These data suggest that R-23 may be safe to humans, without significant adverse acute effects, at concentrations up to 300,000 ppm. 5158

No deaths occurred in rats exposed to concentrations of 18,900, 186,000, and 663,000 ppm for four hours. No evidence of clinical toxicity were noted at 18,900 ppm. The animals showed reduced response to sound at 186,000 ppm, suggesting an anesthetic effect. The rats showed no response to sound, breathing difficulties, and sluggishness at 663,000 ppm; one exhibited compulsive gnawing on its basket. The animals showed mild weight loss after exposures, but recovered after one-two days. 5604

No compound-related pathologic changes were found by histologic examination following exposures of rats to 10,000 ppm or beagles at 5,000 ppm for six hours per day over 90 days. 5607

No deaths, clinical signs of toxicity, or changes revealed by pathological examinations were found in guinea pigs exposed to 200,000 ppm for two hours. Likewise, no signs of toxicity or pathological changes were observed for exposures of 30,000 ppm for six hours. 5604

No cardiac sensitization was observed in female, mongrel dogs exposed to concentrations of 800,000 ppm and 810,000 ppm for 5-10 minutes followed by an epinephrine challenge. Tests on beagles receiving adrenaline injections showed no positive responses in concentrations up to 300,000 ppm in air or 500,000 with auxiliary oxygen. A mixture of R-23/125 at 36.5/63.5% volume in air was found to induce cardiac sensitization in one of six beagles, with fatal results following adrenaline injections. 5136 5604

DuPont indicates a 4-hour, lethal concentration (LC50) of >663,000 ppm in rats /2/. ICI cites a 2-hour LC of >200,000 ppm for rats and an effective concentration (EC50) of >500,000 ppm for cardiac sensitization /7/.

R-23 exposures at 900,000 ppm cause distinct, but not complete, narcosis. 5606

Unspecified, higher concentrations may cause central nervous system (CNS) depression with headache, dizziness, tremor, drowsiness, disorientation, incoordination, giddiness, lightheadedness, and unconsciousness /7/. Shortness of breath, nausea, and vomiting also may occur /7/. No corroborating source studies were found for these indications; they may be generic to similar compounds rather than specific to R-23.

Like other fluorocarbons, R-23 may decompose into toxic fumes, with a sharp, acrid odor when exposed to flames or red-hot metals. 5140

SKIN OR EYE CONTACT

As with all low boiling point liquids, skin contact may cause frostbite. Excessive contact with fluorocarbons also may cause defatting of the skin. 5140

Skin contact also may cause blisters and numbness. Eye contact may cause blurred vision /8/.

INGESTION

Ingestion is unlikely due to the high volatility of the compound. Freeze burns will result /5,9/. R-23 is expected to be totally unreactive in biological systems and is not expected to be metabolized if it entered the bloodstream /3/.

OTHER

Increased mutation rates were observed in progeny of flies (drosophilia melanogaster) exposed to R-23 in high concentration tests (980,000 ppm for ten minutes). Ames assays results were negative, suggesting - but not conclusively indicating - that R-23 is not mutagenic /1-3,5/. 5139

ADDITIONAL REFERENCES

1. Genetron(R) 23, Material Safety Data Sheet (MSDS) GTRN-0030 V2.94, AlliedSignal Incorporated, Morristown, NJ, January 1997
2. Freon(R) 23 Refrigerant, MSDS DU001064 (2025FR), DuPont Chemicals, Wilmington, DE, 8 January 1998
3. D. M. Krentz, M. A. Lee, and R. C. Graham, untitled toxicity review for trifluoromethane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 3 August 1992 5604
4. Forane(R) 23, Safety Data Sheet (SDS) 00451, Elf Atochem S.A., Paris La Défense, France, 18 August 1998

5. Klea(R) 23, Chemical Safety Data Sheet (CSDS), ICI Chemicals and Polymers Limited, Runcorn, UK, December 1992
6. Klea(R) 23, CSDS revision 04, ICI Klea, Runcorn, Cheshire, UK, April 1997
7. Toxicology Summary for FC 23 (Trifluoromethane), ICI Chemicals and Polymers Limited, Runcorn, UK, 21 September 1994 5168
8. MSDS 09970, Occupational Health Services, Incorporated (OHS), New York, NY, 24 March 1993
9. Solkane(R) 23, MSDS, Solvay Fluor und Derivate GmbH, Hannover, Germany, 31 January 1996

R-32

---------- REFRIGERANT TOXICITY SUMMARY ----------

R-32	difluoromethane	see
HFC	CH2F2 CAS number 75-10-5	RDB#

The toxicity of hydrofluorocarbons (HFCs) is generally lower than for corresponding brominated and chlorinated hydrocarbons, based in part on the higher stability of the carbon-fluorine bond. Test results show that R-32 has very low acute and subchronic inhalation toxicity, is not a developmental toxicant, and is not mutagenic. 5137 65E9

OCCUPATIONAL EXPOSURE LIMITS

The American Industrial Hygiene Association adopted a Workplace Environmental Exposure Level (WEEL) Guide of 1,000 ppm, for an 8-hour exposure based on a time-weighted average (TWA), in 1996. 5C14

GENERAL CAUTIONS

More recent and/or more complete information may be found in Material Safety Data Sheets (MSDSs), provided by the chemical supplier(s), and in other toxicology references. Inhalation of high concentrations of refrigerant vapors is harmful. Anesthetic effects including loss of consciousness, heart irregularities, or death may result. Intentional misuse or deliberate inhalation ("sniffing") may cause death without warning. Massive leaks or spills also may pose an asphyxiation hazard, by displacing air, in confined or inadequately ventilated locations. This refrigerant is heavier than air, and leakage may accumulate in low areas.

PAFT TOXICOLOGY SUMMARY (September 1995) 5C39
included with permission of PAFT

HFC-32 is one of a series of fluorocarbon alternatives being studied as part of the Programme for Alternative Fluorocarbon Toxicity Testing (PAFT). HFC-32 is being considered primarily as an alternative, in blends, for refrigeration systems.

HFC-32 has very low toxicity by inhalation. The lowest concentration that causes mortality in experimental animals - the approximate lethal concentration (ALC) - for a 4-hour exposure is greater than 760,000 ppm (76%). Anaesthetic-like effects, such as lethargy and incoordination, are observed in rats at very high inhalation concentrations (greater than 110,000 ppm).

As with many other halocarbons and hydrocarbons, inhalation of HFC-32 followed by intravenous injection of epinephrine, which simulates human stress reactions, results in a cardiac sensitization response in experimental screening studies with dogs. This cardiac sensitization response is observed at approximately 350,000 ppm of HFC-32, a level well above expected exposures. By comparison, a cardiac sensitization response is observed with CFC-11 at approximately 5,000 ppm, and with CFC-12 at approximately 50,000 ppm.

In repeated inhalation exposure studies, the low toxicity of HFC-32 continues to be evident. No adverse effects were observed in rats exposed by inhalation at concentrations of up to 50,000 ppm for up to 90 days.

Inhalation developmental toxicity studies with rats and rabbits have been completed. The results indicate that HFC-32 is not teratogenic,

and does not cause fetal effects at inhalation concentrations of up to 50,000 ppm.

In genetic toxicity testing, HFC-32 was not mutagenic in an Ames assay, a Chinese Hamster Lung (CHL) assay, or a chromosomal aberration study with human lymphocytes. These studies were in vitro assays. Also, HFC-32 was not active in an in vivo mouse micronucleus study.

Metabolism studies with HFC-32 have indicated only very low levels of metabolism (less than 0.5%).

The testing of HFC-32 under PAFT V has been completed. The results are summarized below.

- HFC-32 has very low acute and subchronic inhalation toxicity.
- HFC-32 is not a developmental toxicant.
- HFC-32 is not mutagenic.

An exposure limit of 1,000 ppm (8-hour time-weighted average) for HFC-32 has been recommended by the American Industrial Hygiene Association's Workplace Environmental Exposure Limit (WEEL) Committee.

As for all chemicals, PAFT recommends that exposures be kept to a practicable minimum.

ECETOC JOINT ASSESSMENT OF COMMODITY CHEMICALS (JACC) TOXICOLOGY SUMMARY (May 1995) 5C13
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In animals less than 1% of inhaled difluoromethane is metabolized. The majority of inhaled material is exhaled unchanged. Metabolized difluoromethane is eliminated as CO2 and fluoride. There is no significant formation of carboxyhaemoglobin indicating that carbon monoxide formation is not a metabolic pathway.

Acute inhalation toxicity is very low with no mortality seen in the rat after 4 hours exposure to 550,000 ppm. Signs of depression of the nervous system were apparent only at concentrations of 86,000 ppm and above. In the dog there was no evidence of cardiac sensitization in response to exogenous epinephrine challenge at difluoromethane exposure concentrations up to 350,000 ppm, the highest concentration tested.

Inhalation studies in rats with difluoromethane for 4 and 13 weeks at concentrations up to 50,000 ppm produced no toxic effects.

Difluoromethane was not teratogenic to the rat or rabbit. Evidence of minimal fetal and maternal toxicity in the rat, and maternal toxicity in the rabbit was seen at 50,000 ppm.

Difluoromethane was not mutagenic both in in vitro and in vivo studies using bacteria, mammalian cell lines and in the mouse micronucleus assay.

ADDITIONAL REFERENCES

1. HFC-32, MSDS DU005983 (6027FR), DuPont Chemicals, Wilmington, DE, 26 June 1998
2. Forane(R) 32, MSDS 04132.3, Elf Atochem North America, Incorporated, Philadelphia, PA, 29 January 1998
3. Forane(R) 32, Safety Data Sheet (SDS) 01736, Elf Atochem S.A., Paris La Défense, France, 25 July 1996
4. Genetron(R) 32, Material Safety Data Sheet (MSDS) GTRN-0025,

Honeywell Incorporated, Morristown, NJ, January 2000
5. Klea(R) 32, MSDS 259 revision D, ICI Klea, Wilmington, DE, 21 October 1998
6. Methylene Fluoride, MSDS OHS14937, Occupational Health Services, Incorporated (OHS), New York, NY, 24 March 1993
7. Solkane(R) 32, MSDS, Solvay Fluor und Derivate GmbH, Hannover, Germany, 4 October 1996

R-113

---------- REFRIGERANT TOXICITY SUMMARY ----------

R-113	1,1,2-trichloro-1,2,2-trifluoroethane	see
CFC	CCl2FCClF2 CAS number 76-13-1	RDB#

R-113 has very low toxicity by skin contact or ingestion, but it can cause frostbite if splashed on the skin, drying and redness with repeated or prolonged contact, and mild irritation to the eyes. It has very low toxicity by inhalation and is neither carcinogenic nor mutagenic. Animal tests show no developmental or reproductive effects. R-113 is, however, a comparatively potent cardiac sensitizer to adrenaline and depresses the cardiopulmonary and central nervous systems with exposures at high concentrations. /1-8/ 7541 5874 5644 5141

OCCUPATIONAL EXPOSURE LIMITS

The Occupational Safety and Health Administration (OSHA), National Institute for Occupational Health and Safety (NIOSH), and American Conference of Governmental Industrial Hygienists (ACGIH) have adopted recommended chronic exposure limits - the Permissible Exposure Limit (PEL), Recommended Exposure Limit (REL), and Threshold Limit Value - Time-Weighted Average (TLV-TWA) respectively - of 1,000 ppm v/v on a time-weighted-average (TWA) basis for an 8-10 hour workday and 40 hour workweek. The Deutsche Forschungsgemeinschaft (DFG) [German Research Association] adopted a Maximale Arbeitsplatz Konzentration (MAK) of 500 ppm basis for an 8-10 hour workday and 40-42 hour workweek. NIOSH and OSHA recommend a short-term exposure limit (STEL) of 1,250 ppm v/v TWA for 15 min. 3904 3903 6901 5561 3903 6901

GENERAL CAUTIONS

More recent and/or more complete information may be found in Material Safety Data Sheets (MSDSs), provided by the chemical supplier(s), and in other toxicology references. Inhalation of high concentrations of refrigerant vapors is harmful. Anesthetic effects including loss of consciousness, heart irregularities, or death may result. Intentional misuse or deliberate inhalation ("sniffing") may cause death without warning. Massive leaks or spills also may pose an asphyxiation hazard, by displacing air, in confined or inadequately ventilated locations. This refrigerant is heavier than air, and leakage may accumulate in low areas.

NIOSH-OSHA OCCUPATIONAL HEALTH GUIDELINE (OHG)
TOXICOLOGY SUMMARY (September 1978) 6291

1,1,2-Trichloro-1,2,2-trifluoroethane vapor is a narcotic. In guinea pigs exposed to 25,000 ppm, nasal irritation was rapidly apparent and incoordination occurred at 50,000 ppm after 30 minutes; death occurred after one hour at this level. In dogs, cardiac sensitization to epinephrine occurred at concentrations of 5,000 to 10,000 ppm. The liquid produced no irritation on the abraded or intact skin of guinea pigs; in the eyes of rabbits it produced mild conjunctivitis and minimal corneal dullness, which were reversible. In experimental human studies, exposure to 4,500 ppm for 30 to 100 minutes resulted in significant impairment in tests of manual dexterity and vigilance; subjects reported loss of concentration and a tendency to somnolence which disappeared 15 minutes after the exposure ended; at 1,500 ppm no effects were observed. More prolonged human exposures of 6 hours daily, 5 days per week for 2 weeks at concentrations of approximately 500 and 1,000 ppm resulted in no adverse effects, with the exception of mild throat irritation on the first day; there was no decrement in

performance of manual tasks. The liquid dissolves the natural oils of the skin, and dermatitis may occur as a result of repeated contact.

NATIONAL RESEARCH COUNCIL (NRC) COMMITTEE ON TOXICOLOGY
SUMMARY OF TOXICITY INFORMATION (October 1984) 7414

EFFECTS ON HUMANS: Exposure of the skin of human subjects to FC-113 resulted in localized numbness followed by transient erythema after exposure stopped (Reinhardt and Schultze, 1968). End-tidal air 7443
samples demonstrated that some solvent had been absorbed through the skin.

Human exposure at 1,500 ppm produced no effects after 2.75 h (Stopps and McLaughlin, 1967). Signs indicative of CNS involvement were 7445
seen after 30 min of exposure at 2,500 ppm. These slight decreases in psychomotor performance were reversible and disappeared by 15 min after exposure stopped.

Human volunteers were exposed at 500 or 1,000 ppm for 6 h/d, 5 d/wk, during a 2-wk period. No adverse changes were seen in performance of complex mental tasks, clinical status, or results of biochemical tests. Breath analysis did not reveal a significant buildup of FC-113 (Reinhardt et al., 1971). 6496

EFFECTS ON ANIMALS: FC-113 has very low acute oral toxicity, with an LD50 in rats of 43 g/kg (Michaelson and Huntsman, 1964). Its 7441
lethal dose after application to the skin of rabbits is greater than 11 g/kg, the largest feasible dose. Mild irritation results from contact with the skin and eyes (Haskell Laboratory, 1963; Reinke, 6B57
1962).

Exposure to FC-113 at 50,000-60,000 ppm has proved lethal to rats after 4 h. Signs of toxicity indicative of CNS involvement were 7437
incoordination, tremors, irregular respiration, and convulsions 7439
(Bodganowicz, 1973; Dashiell, 1971; Sarver, 1971). 6804

Rats were exposed at an average concentration of 2,520 ppm, 7 h/d, 5 d/wk, for 6 wk (Limperos, 1954). No signs of toxicity were seen 7440
throughout the experiment.

Other groups of laboratory animals were similarly exposed at up to 7438
5,100 ppm without effect (Carter et al., 1970; Philadelphia Naval 7456
Shipyard, 1952; Steinberg et al., 1969). In a limited study 7444
involving six rats exposed at 12,000 ppm for up to 24 mo, a slight sleepiness was observed and disappeared immediately after daily exposure stopped (Desoille et al., 1968). Rats were exposed by 6B56
inhalation for 6 hr a day, 5 d/wk, for 104 wk. Exposures were at 0, 2,000, 10,000, and 20,000 ppm (v/v). No significant toxic effects were observed, and no evidence of carcinogenicity was seen (C. F. Reinhardt, personal communication). 6730

FC-113, like other chlorofluorocarbons and hydrocarbons, is capable of sensitizing the beagle heart to exogenous epinephrine in standard 5-min cardiac-sensitization screening studies. A concentration of 5,000 ppm can sensitize 25-35% of exposed dogs; 2,500 ppm is ineffective 6109
(Clark and Tinston, 1973; Reinhardt et al., 1973). However, dogs 65A0
exposed while running on a treadmill (to increase their own epinephrine concentration) were not sensitized at concentrations up to 20,000 7442
ppm (Mullin et al., 1971; Trochimowicz et al., 1974). 5361

FC-113 is analogous to FC-11 with regard to its pharmacokinetics and metabolism. It has a short half-life in the body, is not metabolized to any significant extent, and is rapidly expelled through the lungs upon removal from exposure (C. F. Reinhardt, personal communication).

ADDITIONAL REFERENCES

1. Freon(R) 113, Material Safety Data Sheet (MSDS) DU000126 (2026FR), DuPont Chemicals, Wilmington, DE, 8 January 1998
2. Used Refrigerant 113, MSDS 2106FR, DuPont Chemicals, Wilmington, DE, 11 August 1992
3. Forane(R) 113, MSDS 04013, Elf Atochem North America, Incorporated, Philadelphia, PA, 3 November 1999
4. Forane(R) 113 Reclaim, MSDS 04413, Elf Atochem North America, Incorporated, Philadelphia, PA, 1 June 1995
5. Trichlorotrifluoroethane, MSDS 314, Genium Publishing Corporation, Schenectady, NY, February 1986
6. Genetron(R) 113, MSDS GTRN-0027, Honeywell Incorporated, Morristown, NJ, January 2000
7. Arcton(R) 113, MSDS 0133, ICI Americas Incorporated, Wilmington, DE, 25 February 1994
8. 1,1,2-Trichloro-1,2,2-trifluoromethane, MSDS 26370, Occupational Health Services, Incorporated (OHS), New York, NY, 14 July 1993

R-114

---------- REFRIGERANT TOXICITY SUMMARY ----------

R-114	1,2-dichloro-1,1,2,2-tetrafluoroethane	see
CFC	CClF2CClF2 CAS number 76-14-2	RDB#

R-114 has extremely low toxicity by skin contact or ingestion, but it can cause frostbite if splashed on the skin, drying and redness with repeated or prolonged contact, and mild irritation to the eyes. It has extremely low toxicity by inhalation and is neither carcinogenic nor mutagenic. Animal tests show no developmental or reproductive effects. R-114 is, however, a cardiac sensitizer to adrenaline and produces an anesthetic effect at high concentrations. /1-10/ Tests in humans showed no ill effects at 20,000 ppm v/v R-114 in air and that most is excreted in exhaled air within minutes. 5855 5B51 7414 7449

OCCUPATIONAL EXPOSURE LIMITS

The Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL), National Institute for Occupational Health and Safety (NIOSH) Recommended Exposure Limit (REL), and American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value - Time-Weighted Average (TLV-TWA) for R-114 are 1,000 ppm v/v. 3904 3903 5901

GENERAL CAUTIONS

More recent and/or more complete information may be found in Material Safety Data Sheets (MSDSs), provided by the chemical supplier(s), and in other toxicology references. Inhalation of high concentrations of refrigerant vapors is harmful. Anesthetic effects including loss of consciousness, heart irregularities, or death may result. Intentional misuse or deliberate inhalation ("sniffing") may cause death without warning. Massive leaks or spills also may pose an asphyxiation hazard, by displacing air, in confined or inadequately ventilated locations. This refrigerant is heavier than air, and leakage may accumulate in low areas.

NIOSH-OSHA OCCUPATIONAL HEALTH GUIDELINE (OHG)
TOXICOLOGY SUMMARY (September 1978) 6287

Refrigerant 114 vapor is a respiratory irritant and causes asphyxia at extremely high concentrations. Exposure to 200,000 ppm for 16 hours was fatal to dogs, while single 8-hour exposures produced tremors and convulsions, but no fatalities. Repeated exposures at 140,000 to 160,000 ppm for 8 hours caused incoordination, tremors, and occasional convulsions, but all dogs survived. At 47,000 ppm guinea pigs developed respiratory irritation. Sniffing aerosols of fluorochlorinated hydrocarbons has caused sudden death by cardiac arrest, probably due to sensitization of the myocardium. The liquid spilled on the skin may produce frostbite.

INHALATION

An investigation of toxicity to mice and rats concluded that R-114 has no acute toxicity or deleterious effect at concentrations of 100,000 ppm or less. The lethal concentration was found to be approximately 700,000 ppm. Exposures at 100,000 ppm for 2½ hours per day, five days per week, for two weeks found no change in weight, blood granules, or pulmonary lesions. Slight weight loss, an increase in lymphocytes, and congestive and exudative pulmonary lesions were observed at 200,000

ppm. No indications of chronic toxicity were found for 10,000 ppm exposures for 2½ hours per day, five days per week, for two months. 5172

NATIONAL RESEARCH COUNCIL (NRC) COMMITTEE ON TOXICOLOGY
SUMMARY OF TOXICITY INFORMATION (October 1984) 7414

EFFECTS ON HUMANS: Human exposures to FC-114 at up to 20,000 ppm have shown it to be poorly absorbed and rapidly excreted. Warning signs of overexposure are dizziness, headache, and a tingling sensation (Dollery et al., 1970; Morgan et al., 1972a,b; Paulet, 1970; Paulet and Desbrousses, 1969; Paulet et al., 1969). 6725 7448 5C73 7449 5172 5370

EFFECTS ON ANIMALS: FC-114 has not shown appreciable oral toxicity in laboratory animals in either acute or subchronic studies (Griffith and Sherman, 1969; Haskell Laboratory, 1955a; Quevauviller, 1965; Sherman, 1972). Administration of a foam propelled by FC-114 or of the gas itself to the skin or eyes of guinea pigs and rabbits has resulted in only mild transient irritation (Haskell Laboratory, 1955b; Hood, 1967; Quevauviller et al., 1964). 5A70 65H5 5A72 5A71 7447 65H6 5368

Underwriters' Laboratories, Inc., (1933) has placed FC-114 in Category 6 of its classification of life hazards. This category contains the least toxic gases and vapors; i.e., they do not appear to produce injury or death in test animals as a result of exposures at 200,000 ppm for about 2 h. 4B64

The lethal concentration of FC-114 for rats in a 2-h exposure is greater than 600,000 ppm, and for guinea pigs, greater than 500,000 ppm (Scholz, 1962). The LC50 in mice exposed for 30 min is 700,000 ppm (Paulet and Desbrousses, 1969). A dog survived an 8-h exposure a 200,000 ppm, but a 16-h exposure was lethal to another dog (Yant et al., 1932). Exposure of dogs at 150,000 ppm for 24 h was not lethal and resulted only in a loss of appetite (Yant et al., 1932). Exposure at 200,000 ppm caused pupillary dilation, convulsions, opisthotonus, and unconsciousness in dogs. However, exposure at 400,000-600,000 ppm was necessary to cause mild CNS effects in rats and guinea pigs. Recovery was rapid and complete in all species. 5355 5172 5359 5359

FC-114, like other chlorofluorocarbons and hydrocarbons, is capable of sensitizing the beagle heart to exogenous epinephrine in standard 5-min cardiac-sensitization screening studies. The concentration needed to elicit marked responses in 50% of a group of beagle is 45,000 ppm (Reinhardt et al., 1971). However, dogs exposed to FC-114 while running on a treadmill to increase their own epinephrine concentration were not sensitized until exposures reached 50,000-100,000 ppm. In another endogenous-epinephrine study, a concentration of 800,000 ppm (80% FC-113:20% oxygen) was shown to sensitize the beagle heart after its epinephrine concentration was increased by fright (Mullin et al., 1972). 5644 5360

Rats and mice were expostd- at 200,000 ppm for 2.5 h/d, 5 d/wk, for 2 wk (Paulet and Desbrousses, 1969). Slight blood and body-weight changes were seen, as well as slight evidence of lung irritation. Exposure at 100,000 ppm had no effect, even after 2 mo of exposure (Paulet and Desbrousses, 1969). Dogs and guinea pigs were exposed at 141,600 ppm for 8 h/d for 21 d (Yant, 1933). The severity of the clinical signs attributable to CNS effects decreased during the 21 d of exposure. In the dogs, slight hematologic changes were observed, but the measures in question returned to normal 15-17 d after exposure; no gross pathologic changes were seen. 5172 5172 5173

No effects were seen in dogs, cats, guinea pigs, or rats exposed at 100,000 ppm for 3.5 h per exposure for 20 exposures (Scholz, 1962). 5355

No effects were seen in rats and rabbits exposed at 10,000 Ppm for 2 h/d, 5 d/wk, during 8-9 mo (Desoille et al., 1973). 5362

ADDITIONAL REFERENCES

1. Freon(R) 114, Material Safety Data Sheet (MSDS) DU001061 (3038FR), DuPont Chemicals, Wilmington, DE, 8 January 1998
2. Used Refrigerant 114, MSDS 2112FR, DuPont Chemicals, Wilmington, DE, 22 June 1992
3. Forane(R) 114, MSDS 04014, Elf Atochem North America, Incorporated, Philadelphia, PA, 17 July 1999
4. Forane(R) 114 Reclaim MSDS 04414, Elf Atochem North America, Incorporated, Philadelphia, PA, 28 July 1997
5. Dichlorotetrafluoroethane, MSDS 572, Genium Publishing Corporation, Schenectady, NY, December 1985
6. Arcton(R) 114, MSDS 240 revision G, ICI Klea, Wilmington, DE, 23 January 1998
7. Genetron(R) 114, MSDS GTRN-0028, Honeywell Incorporated, Morristown, NJ, January 2000
8. Arcton(R) 114, Chemical Safety Data Sheet (CSDS) revision 04, ICI Klea, Runcorn, Cheshire, UK, April 1997
9. 1,2-Dichlorotetrafluoroethane, MSDS 06980, Occupational Health Services, Incorporated (OHS), New York, NY, 24 March 1993
10. Racon(R) 114, MSDS, Racon Incorporated (now part of Elf Atochem North America, Incorporated), Wichita, KS, 7 April 1989

R-115

REFRIGERANT TOXICITY SUMMARY

R-115	1-chloro-1,1,2,2,2-pentafluoroethane		
CFC	CClF2CF3	CAS number 76-15-3	see

R-115 has an extremely low order of acute toxicity; its lethal concentration (4-hr LC50 rat) exceeds 800,000 ppm. 5C41

OCCUPATIONAL EXPOSURE LIMITS

The Occupational Safety and Health Administration (OSHA) has not promulgated a Permissible Exposure Limit (PEL) for R-115. The 3904
The National Institute for Occupational Health and Safety (NIOSH) has established a Recommended Exposure Limit (REL) of 1,000 ppm as a time-weighted average for up to a 10-hr work day and a 40 hr work week. 5204
This limit is based on the risk of cardiac, skin, central nervous system, and respiratory effects associated with exposure to R-115. 6288
The American Conference of Governmental Industrial Hygienists (ACGIH) adopted a Threshold Limit Value - Time-Weighted Average (TLV-TWA) of 1,000 ppm in 1981. 5901

GENERAL CAUTIONS

More recent and/or more complete information may be found in Material Safety Data Sheets (MSDSs), provided by the chemical supplier(s), and in other toxicology references. Inhalation of high concentrations of refrigerant vapors is harmful. Anesthetic effects including loss of consciousness, heart irregularities, or death may result. Intentional misuse or deliberate inhalation ("sniffing") may cause death without warning. Massive leaks or spills also may pose an asphyxiation hazard, by displacing air, in confined or inadequately ventilated locations. This refrigerant is heavier than air, and leakage may accumulate in low areas.

NIOSH-OSHA OCCUPATIONAL SAFETY AND HEALTH GUIDELINE (OSHG, "OHG") TOXICOLOGY SUMMARY (1995) 6288

EFFECTS ON ANIMALS: In animals, chloropentafluoroethane affects the heart and respiratory system at very high doses. Early studies in experimental animals showed that inhalation of a chloropentafluoroethane concentration of approximately 200,000 ppm caused confusion, pulmonary irritation, tremors, and occasionally coma. At a concentration of 190,000 ppm, chloropentafluoroethane caused cessation of respiration (apnea) in rats exposed from 4 to 26 min. Rats exposed at 800,000 ppm plus 20% oxygen for 4 hr showed no clinical effects of histopathology. Rats and guinea pigs exposed at 600,000 ppm chloropentafluoroethane in oxygen for 2 hr and guinea pigs exposed at 200,000 ppm chloropentafluoroethane in air for varying intervals up to 2 hr showed no adverse clinical signs. Studies with anesthetized dogs, rats, and monkeys showed that, under certain conditions, exposures of 100,000 to 200,000 ppm chloropentafluoroethane may increase blood pressure, accelerate heart rate, cause myocardial depression, or 5141
change pulmonary mechanics. Species differences in sensitivity are great. Monkeys do not show respiratory or circulatory effects when exposed to a 200,000 ppm concentration of chloropentafluoroethane; dogs show no respiratory depression when exposed to 200,000 ppm but do show bronchoconstriction, decreased compliance, sensitization of the heart to epinephrine, tachycardia, myocardial depression, and 5167
hypotension when inhaling 100,000 to 250,000 ppm chloropentafluoroethane; rats show bronchospasm, decreased compliance, and respiratory stimulation after inhalation of 100,000 ppm chloropentafluoroethane.

Rats, mice, rabbits, and dogs that received 90 exposures, 6 hr daily, to 100,000 ppm chloropentafluoroethane showed no adverse effects, and rats, guinea pigs, dogs, and cats exposed to 200,000 ppm chloropentafluoroethane for 3½ hr/day, 5 days/week for 4 weeks showed no adverse effects after cessation of exposure. 5141

EFFECTS ON HUMANS: In humans, chloropentafluoroethane can affect the heart, central nervous system, and skin. The neurological effects of chlorofluorocarbon exposure were evaluated in 27 refrigeration repair workers and 14 aged-matched control workers from a local union of plumbers, pipefitters, and insulation workers. Personal air samples taken on two worker-participants over the course of a typical work shift showed average exposures of 1.4 ppm chlorodifluoromethane [refrigerant 22] and 2.2 ppm chloropentafluoroethane. No peripheral neuropathy was seen among the study subjects, and there was no significant difference in mean nerve conduction velocities between study and reference subjects; however, lightheadedness and palpitations were reported significantly more often by refrigeration workers than by controls. The defatting effects of fluorocarbons such as chloropentafluoroethane, when in prolonged or repeated contact with the skin, may cause dermatologic problems, and contact of the skin with liquified chloropentafluoroethane may cause frostbite. 5167

ADDITIONAL REFERENCES

1. Genetron(R) 115 (Chloropentafluoroethane), Product Safety Data Sheet, AlliedSignal Incorporated, Morristown, NJ, May 1989
2. Freon(R) 115 Refrigerant, Material Safety Data Sheet (MSDS) DU002791 (2018FR), DuPont Chemicals, Wilmington, DE, 8 January 1998
3. Forane(R) 115, MSDS 04016, Elf Atochem North America, Incorporated, Philadelphia, PA, 1 June 1995
4. Arcton(R) 115, MSDS 276 revision G, ICI Klea, Wilmington, DE, 23 January 1998
5. Arcton(R) 115, Chemical Safety Data Sheet (CSDS) revision 03, ICI Klea, Runcorn, Cheshire, UK, April 1997
6. Chloropentafluoroethane, MSDS 04810, Occupational Health Services, Incorporated (OHS), New York, NY, 14 July 1993

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response to HCFC-123, were observed in some studies, but these effects occurred at high concentrations (i.e., 10,000-20,000 ppm).

A two-year inhalation study with HCFC-123 has been completed. Exposure concentrations for rats were 0, 300, 1,000, and 5,000 ppm. During the study, slight reductions in body weight were observed at the two higher concentrations, and decreases in cholesterol and triglyceride concentrations were observed at all exposure levels. After one year of exposure, no changes in compound-related tissue pathology were observed at any of the concentrations tested.

At the end of the study, an increase in benign tumours was observed in the liver, pancreas, and testis (Leydig cells) of the treated rats. However, no malignant tumours attributable to exposure to HCFC-123 were observed and there was no increased mortality in the groups treated with HCFC-123. An independent review of the pathology findings supported this conclusion. None of the benign tumours observed were life-threatening, and all occurred near the end of the study. To understand the biological significance of these tumours, mechanistic studies were conducted to examine the possible relationship of certain biochemical processes to the development of the tumours. Preliminary results suggest that certain enzyme activity in the liver of the rat may partially explain the occurrence of liver tumours, and changes in certain hormone levels may be responsible for the development of testicular tumours. Studies investigating any biological relevance of the tumours to humans are being conducted.

Several genetic toxicity studies have also been completed with HCFC-123. These studies included the Ames assay, chromosomal aberration study with human lymphocytes, in vivo mouse micro-nucleus, in vivo chromosomal aberration study, and unscheduled DNA synthesis. Based on the weight of evidence from all in vivo and in vitro studies, HCFC-123 is not genotoxic. In only one study, which utilized an in vitro culture of human lymphocytes, did HCFC-123 cause changes in the genetic material. However, a similar study with rat lymphocytes in vivo did not show the same response. Therefore, the overall evidence from these genotoxicity studies and the results from long-term studies suggest that HCFC-123 does not produce malignant tumours in experimental animals and is not genotoxic.

The results from developmental toxicity studies with HCFC-123 show that this material does not have embryotoxic or teratogenic effects in rats or rabbits. At high concentrations (10,000 ppm and greater), anaesthetic-like effects and reduced body weights are observed in pregnant animals. At these high concentrations, slight fetal effects are also evident. Reproduction and neurotoxicity studies on rats have been completed. HCFC-123 was not neurotoxic nor did it cause adverse reproductive effects. In a two-generation reproduction study, rats were exposed to HCFC-123 concentrations of 30, 100, 300, or 1,000 ppm. No effects on reproduction were observed in rats at any exposure concentration. During the period of maternal milk production (lactation), a slight decrease in the pup body weight gain and increases in liver weight were observed at 30 ppm or greater. This effect was only seen when the pups were being nursed and may be related to a depression of triglycerides.

HCFC-123 is oxidatively metabolized by the body following inhalation exposure, as suggested by a slight increase in urinary fluoride levels. Also, trifluoroacetic acid (TFA) was detected following HCFC-123 administration.

The testing of HCFC-123 under PAFT I has been completed. The results are summarized below.

- HCFC-123 has low acute dermal and inhalation toxicity.
- HCFC-123 caused an increased incidence of benign, but not life-threatening, tumors in animals following long-term exposure.
- HCFC-123 is not a developmental toxicant.
- HCFC-123 does not affect reproductive performance.
- HCFC-123 is not genotoxic.

Several PAFT companies have set occupational exposure limits for HCFC-123, typically at 10 or 30 ppm (8-hour time-weighted average). [DuPont and Elf Atochem North America have recommended exposure limits to 50 ppm v/v /1,3/; Elf Atochem S.A. (France) and Honeywell have recommended a limit of 10 ppm /4,5/. The American Industrial Hygiene Association (AIHA) has published a Workplace Environmental Exposure Limit (WEEL) of 50 ppm v/v.] 8611

As for all chemicals, PAFT recommends that exposures be kept to a practicable minimum.

ECETOC JOINT ASSESSMENT OF COMMODITY CHEMICALS (JACC) TOXICOLOGY SUMMARY (February 1996) 65E8
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Dichlorotrifluoroethane would not be considered to be readily biodegradable. Studies conducted in algae, Daphnia, and rainbow trout indicated a moderate level of toxicity to aquatic organisms. The octanol/water partition coefficient (log Pow=2.0-2.8) is indicative of a low potential to bioaccumulate.

Studies in rodents indicate that dichlorotrifluoroethane is easily absorbed via the respiratory route and undergoes a biphasic uptake. It is distributed in all organs and is more concentrated in the liver. About 90% of unchanged dichlorotrifluoroethane was eliminated via the lungs. The rest was metabolised to trifluoroacetic acid which was excreted in the urine. Small amounts of trifluoroacetylated proteins were detected in exposed rats.

Dichlorotrifluoroethane has a low order of acute toxicity. Its oral approximate lethal dose in rats was 9,000 mg/kg; its 4-hour inhalation LC50 was 200,000 mg/m3 [32,000 ppm v/v] in rats and 178,000 mg/m3 [28,500 ppm] in hamsters. Its dermal LD50 in rats and rabbits was greater than 2,000 mg/kg. The primary effect was a rapidly reversible central nervous depression. After a few minute's exposure it induced pre-narcotic effects at 31,300 mg/m3 [5,000 ppm] and anaesthesia at 129,000 mg/m3 [20,600 ppm] in rats.

Liquid dichlorotrifluoroethane did not induce skin irritation in rabbit or skin sensitization in guinea pigs but it caused moderate eye irritation in rabbits.

Repeated inhalation exposure studies in rats exposed 6 h/d, 5 d/wk, for 4 to 13 weeks, to vapour levels of up to 125,000 mg/m3 [20,000 ppm], have resulted in body weight decreases and liver weight increases but with minimal adverse histological findings. Dichlorotrifluoroethane was found to cause a marked drop in serum cholesterol, triglyceride and glucose levels at 1,880 mg/m3 [300 ppm] and above. Signs of CNS depressing effects were seen during exposure periods above 6,250 mg/m3 [1,000 ppm]. However, there was no evidence of neurotoxicity when specific testing for neurobehavioral and nervous tissue histology were performed in a 13-week neurotoxicity study in rats.

Dichlorotrifluoroethane elicited cardiac sensitization to adrenaline in dogs acutely exposed by inhalation at a concentration of 119,000 mg/m3 [19,000 ppm]. The no-effect-level was 62,500 mg/m3 [10,000 ppm].

No clear effects were seen in serum steroid hormone and CCK levels in rats and guinea pigs exposed to dichlorotrifluoroethane. In rats dichlorotrifluoroethane produced minimal decreases in testicular luteinizing hormone and testosterone levels under stimulation conditions only. Dichlorotrifluoroethane was found to induce liver peroxisome proliferation in rats. Its proliferating potential is weak and may be due to its metabolism to trifluoroacetic acid.

Dichlorotrifluoroethane was not teratogenic or embryotoxic to rats and rabbits exposed by inhalation at concentrations of 31,300 and 62,500 mg/m3 [5,000 and 10,000 ppm] which induced slight maternal toxicity.

In a two-generation inhalation study conducted with dichlorotrifluoroethane in rats exposed 6 h/d, 7 d/wk at concentrations ranging from 188 to 6,250 mg/m3 [30 to 1,000 ppm], there were no effects on mating performance or offspring survival. Growth retardation was observed in pups during nursing at all test concentrations, but normal growth was restored in the post-weaning phase.

Dichlorotrifluoroethane was inactive in several in vitro studies including a series of Salmonella typhimurium assays, a Saccharomyces cerevisiae assay and a cell transformation assay. It was active only in the human lymphocyte chromosome aberration assay. Dichlorotrifluoroethane was clearly inactive in a series of in vivo studies, including mouse micronucleus, rat chromosome aberration and rat unscheduled DNA synthesis. In conclusion, dichlorotrifluoroethane is not genotoxic in vivo and therefore does not have toxicologically significant genotoxicity.

Rats were exposed 6 h/d, 5 d/wk for 2 years by inhalation in a lifetime study to concentrations of 1,875, 6,250, and 31,300 mg/m3 [300, 1,000, and 5,000 ppm]. Compared to controls, survival was significantly improved in an exposure related pattern in all exposed groups. Significantly depressed body weights and levels of serum trigylcerides, glucose and cholesterol were observed. Compound-related increased incidences of benign tumours were observed in the liver, testis, and pancreas. These tumours were a continuum from hyperplasia and occurred late in life. It is thought that they are related with non-genotoxic mechanisms associated with the peroxisome proliferating potential of dichlorotrifluoroethane or with hormonal disturbances occurring in senescent rats. Considering they occurred late in life and were benign, the relevance of these findings is questionable in terms of carcinogenic risk to man.

ADDITIONAL REFERENCES

1. Suva(R) 123, Material Safety Data Sheet (MSDS) DU002798 (2190FR), DuPont Chemicals, Wilmington, DE, 29 June 1998
2. Used Refrigerant 123, MSDS, DuPont Chemicals, Wilmington, DE, 11 March 1992
3. Forane(R) 123, MSDS 04123, Elf Atochem North America, Incorporated, Philadelphia, PA, 3 November 1999
4. Forane(R) 123, Safety Data Sheet (SDS) 00940, Elf Atochem S.A., Paris La Défense, France, 23 April 1998
5. Genetron(R) 123, MSDS GTRN-0013, Honeywell Incorporated, Morristown, NJ, January 2000
6. Arcton(R) 123, Chemical Safety Data Sheet, ICI Chemicals & Polymers, Runcorn, UK, April 1990
7. 2,2-Dichloro-1,1,1-trifluoroethane, MSDS, Occupational Health Services (OHS), New York, NY, Incorporated, 17 November, 1992
8. Solkane(R) 123, MSDS, Solvay Fluor und Derivate GmbH, Hannover, Germany, 8 August 1995

R-124

REFRIGERANT TOXICITY SUMMARY

			see
R-124	2-chloro-1,1,1,2-tetrafluoroethane		see
HCFC	CHClFCF3	CAS number 2837-89-0	RDB#

Test results show that R-124 has very low acute and subchronic inhalation toxicity. Lifetime exposures neither produced signs of chronic toxicity nor caused any tumors. R-124 is not a developmental toxicant nor is it genotoxic. 65E9

OCCUPATIONAL EXPOSURE LIMITS

The American Industrial Hygiene Association adopted a Workplace Environmental Exposure Level (WEEL) Guide of 1,000 ppm, for an 8-hour exposure based on a time-weighted average (TWA), in 1992. 4B88

GENERAL CAUTIONS

More recent and/or more complete information may be found in Material Safety Data Sheets (MSDSs), provided by the chemical supplier(s), and in other toxicology references. Inhalation of high concentrations of refrigerant vapors is harmful. Anesthetic effects including loss of consciousness, heart irregularities, or death may result. Intentional misuse or deliberate inhalation ("sniffing") may cause death without warning. Massive leaks or spills also may pose an asphyxiation hazard, by displacing air, in confined or inadequately ventilated locations. This refrigerant is heavier than air, and leakage may accumulate in low areas.

PAFT TOXICOLOGY SUMMARY (September 1995) 5C39
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HCFC-124 is one of a series of fluorocarbon alternatives being tested by the Programme for Alternative Fluorocarbon Toxicity Testing (PAFT). HCFC-124 is considered primarily as an alternative in specialized refrigeration systems.

HCFC-124 has very low acute toxicity by inhalation. The lowest concentration that causes mortality in experimental animals - the approximate lethal concentration (ALC) - for a 4-hour exposure is between 230,000 and 300,000 ppm in rats. Similar exposure levels cause toxicity in other species, such as the guinea pig. During inhalation exposure to very high concentrations, anaesthetic-like effects, such as weakness and incoordination, are observed. The 10-minute exposure concentration that causes these effects (EC50 for nervous system effects) in experimental animals is about 140,000 ppm. Similar anaesthetic-like effects are observed with many other fluorocarbons in acute inhalation studies.

As with many other halocarbons and hydrocarbons, inhalation of HCFC-124, followed by intravenous injection of epinephrine, which simulates human stress reactions, results in a cardiac sensitization response in experimental screening studies with dogs. This cardiac sensitization response is observed at approximately 25,000 ppm of HCFC-124, a level well above expected exposures. By comparison, a cardiac sensitization response is observed with CFC-11 at approximately 5,000 ppm.

Longer term studies of up to 90 days in duration have also been conducted with HCFC-124. Only changes in clinical chemistry parameters (e.g., triglycerides) and anaesthetic-like effects were noted. These

were observed only in the 90-day study. No other effects were evident in any of these studies at concentrations of up to 50,000 ppm. In a 90-day study with mice, inhalation exposures caused an increase in beta-oxidation (indicative of peroxisome proliferation) and a decrease in triglycerides. No other toxic effects were noted in this 90-day study.

A two-year inhalation study with HCFC-124 was conducted with exposure concentrations of 0, 2,000, 10,000 and 50,000 ppm. No adverse effects were noted during the study, and no compound-related grossly visible or microscopic changes were observed at any HCFC-124 exposure level. The no-observed-adverse-effect level (NOAEL) was 50,000 ppm.

Several genetic toxicity studies have also been completed with HCFC-124. Studies conducted with HCFC-124 include the Ames assay, mouse micronucleus, and in vitro chromosomal aberration with human lymphocytes. Based on the evidence from all in vitro and in vivo studies, HCFC-124 is not genotoxic.

The results from developmental toxicity studies with HCFC-124 show that this material does not have embryotoxic or teratogenic effects in rats or rabbits. At very high concentrations (e.g., 50,000 ppm), anaesthetic-like effects and reduced body weights were observed in pregnant animals. However, no fetal effects were observed at these high, maternally toxic concentrations.

HCFC-124 is oxidatively metabolized by the body following inhalation exposure, as suggested by a slight increase in urinary fluoride levels. Also, trifluoroacetic acid (TFA) has been detected following HCFC-124 administration. The rate of metabolism appears to be low.

The testing of HCFC-124 under PAFT III is now complete. The results are summarized below.

- HCFC-124 has very low acute and subchronic inhalation toxicity.
- HCFC-124 is not tumourigenic.
- HCFC-124 is not a developmental toxicant.
- HCFC-124 is not genotoxic.

An exposure limit of 1,000 ppm (8-hour time-weighted average) has been recommended by the American Industrial Hygiene Association, Workplace Environmental Exposure Limit (WEEL) Committee.

As for all chemicals, PAFT recommends that exposures be kept to a practicable minimum.

ADDITIONAL REFERENCES

1. Meforex(R) 124, Safety Data Sheet sym/ss76, Ausimont S.p.A., Bollate, Italy, 11 March 1997
2. Suva(R) 124, Material Safety Data Sheet (MSDS) DU002790 (2200FR), DuPont Chemicals, Wilmington, DE, 8 January 1998
3. Used Refrigerant 124, MSDS 6008FR, DuPont Chemicals, Wilmington, DE, 23 February 1993
4. Forane(R) 124, MSDS 04124, Elf Atochem North America, Incorporated, Philadelphia, PA, 28 July 1999
5. Forane(R) 124, Safety Data Sheet (SDS) 01446, Elf Atochem S.A., Paris La Défense, France, 19 December 1997
6. Genetron(R) 124, MSDS GTRN-0012, Honeywell Incorporated, Morristown, NJ, January 2000

7. 1,1,1,2-Tetrafluoro-2-chloroethane, MSDS OHS63246, Occupational Health Services, Incorporated (OHS), New York, NY, 24 March 1993

R-125

---------- REFRIGERANT TOXICITY SUMMARY ----------

R-125	pentafluoroethane		see
HFC	CHF2CF3	CAS number 354-33-6	RDB#

The toxicity of hydrofluorocarbons (HFCs) is generally lower than for corresponding brominated and chlorinated hydrocarbons, based in part on the higher stability of the carbon-fluorine bond. Toxicity test results indicate that R-125 has negligible acute and subchronic inhalation toxicity, is not a developmental toxicant, and is not genotoxic. 5137 65E9

OCCUPATIONAL EXPOSURE LIMITS

The American Industrial Hygiene Association adopted a Workplace Environmental Exposure Level (WEEL) Guide of 1,000 ppm, for an 8-hour exposure based on a time-weighted average (TWA), in 1996. 5C15

GENERAL CAUTIONS

More recent and/or more complete information may be found in Material Safety Data Sheets (MSDSs), provided by the chemical supplier(s), and in other toxicology references. Inhalation of high concentrations of refrigerant vapors is harmful. Anesthetic effects including loss of consciousness, heart irregularities, or death may result. Intentional misuse or deliberate inhalation ("sniffing") may cause death without warning. Massive leaks or spills also may pose an asphyxiation hazard, by displacing air, in confined or inadequately ventilated locations. This refrigerant is heavier than air, and leakage may accumulate in low areas.

PAFT TOXICOLOGY SUMMARY (September 1995) 5C39
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HFC-125 is one of a series of fluorocarbon alternatives being tested by the Programme for Alternative Fluorocarbon Toxicity Testing (PAFT). HFC-125 is considered primarily as an alternative for refrigeration systems.

HFC-125 has very low acute toxicity by inhalation. The lowest concentration that causes mortality in experimental animals – the approximate lethal concentration (ALC) – for a 4-hour exposure is greater than 800,000 ppm (80%) with added oxygen. Even at these high inhalation concentrations, no clinical signs of toxicity are evident.

As with many other halocarbons and hydrocarbons, inhalation of HFC-125, followed by intravenous injection of epinephrine, which simulates human stress reactions, results in a cardiac sensitization response in experimental screening studies with dogs. This cardiac sensitization response is observed at approximately 100,000 ppm of HFC-125, a level well above expected exposures. By comparison, a cardiac sensitization response is observed with CFC-11 at approximately 5,000 ppm.

In repeated inhalation exposure studies, the low toxicity of HFC-125 continued to be evident. No adverse effects were observed in rats exposed by inhalation at concentrations of up to 50,000 ppm for up to 90 days.

Inhalation developmental toxicity studies with rats and rabbits have been completed. The results indicate that HFC-125 is not teratogenic

and does not cause fetal effects at inhalation concentrations up to 50,000 ppm.

In genetic toxicity testing, HFC-125 was not mutagenic in an Ames assay, Chinese Hamster Ovary assay, or chromosomal aberration study with human lymphocytes. These studies were in vitro assays. Also, HFC-125 was not active in an in vivo mouse micronucleus study.

Metabolism studies with HFC-125 have not detected any metabolism.

The testing of HFC-125 under PAFT III is now complete. The results are summarized below.

- HFC-125 has very low acute and subchronic inhalation toxicity.
- HFC-125 is not a developmental toxicant.
- HFC-125 is not genotoxic.

An exposure limit for HFC-125 of 1,000 ppm (8-hour time-weighted average) has been recommended by the American Industrial Hygiene Association, Workplace Environmental Exposure Limit (WEEL) Committee. 5C15

As for all chemicals, PAFT recommends that exposures be kept to a practicable minimum.

ECETOC JOINT ASSESSMENT OF COMMODITY CHEMICALS (JACC) TOXICOLOGY SUMMARY (May 1994) 4C01
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In limited metabolic studies in vivo in the rat, the metabolism of pentafluoroethane was negligible. Toxicokinetic studies are in progress.

The acute inhalation toxicity of pentafluoroethane is very low. The 4-hour LC50 in the rat is greater than 3,928,000 mg/m3 (800,000 ppm). During the exposure, the only clinical signs were ataxia, decrease of locomotor activity, and dyspnoea.

As with many other fluorocarbons, inhalation of high concentration of pentafluoroethane, followed by an intravenous epinephrine challenge to simulate stress, can induce a cardiac sensitization response in dogs. The threshold concentration for this effect was 491,000 mg/m3 (100,000 ppm) and the No Observed Effect Concentration (NOEC) was 368,250 mg/m3 (75,000 ppm).

Exposures by inhalation up to 245,000 mg/m3 (50,000 ppm) 5 days a week for 4 to 13 consecutive weeks, did not induce any toxic effect and the NOEC was greater that 245,000 mg/m3 (50,000 ppm).

Developmental studies by inhalation route were carried out in both rats and rabbits. No evidence of embryotoxicity or teratogenicity was seen even at exposure levels as high as 245,000 mg/m3 (50,000 ppm).

Pentafluoroethane was not mutagenic both in vitro and in vivo studies using bacteria, mammalian cell lines and in the mouse micronucleus assay.

There are no reported effects of pentafluoroethane in man.

An occupational exposure limit (8-hour time-weighted average) of 1,000 ppm (4,910 mg/m3) is recommended by producers.

ADDITIONAL REFERENCES

1. HFC-125, Material Safety Data Sheet (MSDS) DU002868 (3020FR), DuPont Chemicals, Wilmington, DE, 25 June 1998
2. Forane(R) 125, MSDS 04387, Elf Atochem North America, Incorporated, Philadelphia, PA, 17 July 1999
3. Forane(R) 125, Safety Data Sheet (SDS) 01447, Elf Atochem S.A., Paris La Défense, France, 17 April 1996
4. Klea(R) 125, MSDS 280 revision F, ICI Klea, Wilmington, DE, 11 March 1999
5. Genetron(R) 125, MSDS GTRN-0024, Honeywell Incorporated, Morristown, NJ, January 2000
6. Klea(R) 125, Chemical Safety Data Sheet (CSDS) revision 05, ICI Klea, Runcorn, Cheshire, UK, April 1997
7. Solkane(R) 125, MSDS, Solvay Fluor und Derivate GmbH, Hannover, Germany, 8 August 1995

R-134a

REFRIGERANT TOXICITY SUMMARY

			see RDB#
R-134a	1,1,1,2-tetrafluoroethane		
HFC	CH2FCF3	CAS number 811-97-2	

The toxicity of hydrofluorocarbons (HFCs) is generally lower than for corresponding brominated and chlorinated hydrocarbons, based in part on the higher stability of the carbon-fluorine bond. Toxicity test results indicate that R-134a has very low acute and subchronic inhalation toxicity. An increased incidence of benign tumors was observed in animals following long-term exposure to high concentrations. These tumors did not affect life expectancy; they are common in rats, but not humans. R-134a did not cause any chronic toxicity and is neither a developmental toxicant nor genotoxic. 5137 65E9

OCCUPATIONAL EXPOSURE LIMITS

The American Industrial Hygiene Association adopted a Workplace Environmental Exposure Level (WEEL) Guide of 500 ppm, for an 8-hour exposure based on a time-weighted average (TWA), in 1992. 4B87

GENERAL CAUTIONS

More recent and/or more complete information may be found in Material Safety Data Sheets (MSDSs), provided by the chemical supplier(s), and in other toxicology references. Inhalation of high concentrations of refrigerant vapors is harmful. Anesthetic effects including loss of consciousness, heart irregularities, or death may result. Intentional misuse or deliberate inhalation ("sniffing") may cause death without warning. Massive leaks or spills also may pose an asphyxiation hazard, by displacing air, in confined or inadequately ventilated locations. This refrigerant is heavier than air, and leakage may accumulate in low areas.

PAFT TOXICOLOGY SUMMARY (September 1995) 5C39
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HFC-134a is one of a series of fluorocarbon alternatives being studied as part of the Programme for Alternative Fluorocarbon Toxicity Testing (PAFT). HFC-134a is being considered as an alternative for refrigeration and air conditioning, medical dose delivery systems, and as a foam blowing agent.

HFC-134a has very low acute inhalation toxicity. The lowest concentration that causes mortality in rats - the approximate lethal concentration (ALC) - for a 4-hour exposure is greater than 500,000 ppm. Anaesthetic-like effects, such as lethargy and incoordination, are observed in rats at very high inhalation concentrations (greater than 200,000 ppm).

As with many other halocarbons and hydrocarbons, inhalation of HFC-134a followed by intravenous injection of epinephrine, which simulates human stress reactions, results in a cardiac sensitization response in experimental screening studies with dogs. This cardiac sensitization response is observed at approximately 75,000 ppm of HFC-134a, a level well above expected exposures. By comparison, a cardiac sensitization response is observed with CFC-12 at approximately 50,000 ppm.

Longer term studies have also been conducted with HFC-134a. No significant toxicological effects were observed in rats following

inhalation exposure for up to one year at concentrations up to 50,000 ppm.

At the end of the two-year inhalation study, no effects were observed in body weights, in-life measurements, clinical observations or clinical chemistry, or haematology. Except for the testis of male rats, no grossly visible or microscopic changes were observed in the any of the HFC-134a exposed rats. At 50,000 ppm, an increased incidence of hyperplasia (cell growth) and benign tumours of Leydig cells was observed on microscopic examination of the testis. No malignant tumours attributable to exposure to HFC-134a were observed. An independent review of the pathology findings supported these conclusions. None of the benign tumours were life-threatening, and all occurred near the end of the study. No effects were observed at lower concentrations in this two-year study; the no-observed-effect level (NOEL) was 10,000 ppm.

Several genetic toxicity studies with HFC-134a have been completed. These included a bacterial reverse mutation (Ames) test, an in vitro chromosomal aberration study with human lymphocytes, and a cytogenetics assay with Chinese Hamster Lung Cell (CHL). In vivo studies included cytogenetics, mouse micronucleus, and a dominant lethal study in the mouse. Evidence from all in vitro and in vivo studies clearly indicates that HFC-134a is not genotoxic. Furthermore, these data and data obtained from the two-year inhalation study suggest that the increased incidence of benign tumours observed in the two-year inhalation study is not due to an effect on genetic material.

Results from inhalation developmental toxicity studies indicate that HFC-134a does not cause teratogenic effects in rats or rabbits. At inhalation concentrations of 300,000 ppm, slight maternal toxicity and embryotoxicity, evidenced by a decrease in fetal body weights, were observed in rats. Lower fetal body weights of rats and rabbits have been observed at 50,000 ppm with slight maternal toxicity; lower maternal body weights were also observed in rats at this concentration. In an additional study, no fetal effects were observed in rabbits at inhalation concentrations of up to 40,000 ppm.

Although not metabolized to any significant extent in animals, HFC-134a is oxidatively metabolized following inhalation exposure, as suggested by a slight increase in urinary fluoride levels. However, the rate of metabolism of HFC-134a is very low, and about 99% of an inhaled dose is eliminated unchanged.

The testing of HFC-134a under PAFT I has been completed. The results are summarized below.

- HFC-134a has very low acute and subchronic inhalation toxicity.
- HFC-134a caused an increased incidence of benign tumours in animals following long-term exposure to high concentrations.
- HFC-134a is not a developmental toxicant.
- HFC-134a is not genotoxic.

An exposure limit of 1,000 ppm (8-hour time-weighted average) has been recommended by the American Industrial Hygiene Association, Workplace Environmental Exposure Limit (WEEL) Committee.

As for all chemicals, PAFT recommends that exposures be kept to a practicable minimum.

ADDITIONAL REFERENCES

1. Meforex(R) 134a, Safety Data Sheet sym/ss101, Ausimont S.p.A., Bollate, Italy, 9 April 1996
2. Suva(R) 134a, Material Safety Data Sheet (MSDS) DU000693 (2187FR), DuPont Chemicals, Wilmington, DE, 8 January 1998
3. Used Refrigerant 134a, MSDS 3025FR, DuPont Chemicals, Wilmington, DE, 23 February 1993
4. Forane(R) 134a, MSDS 04134, Elf Atochem North America, Incorporated, Philadelphia, PA, 17 July 1999
5. Forane(R) 134a - Reclaim, MSDS 04434, Elf Atochem North America, Incorporated, Philadelphia, PA, 29 January 1998
6. Forane(R) 134a, Safety Data Sheet (SDS) 00941, Elf Atochem S.A., Paris La Défense, France, 19 October 1998
7. Genetron(R) 134a, MSDS GTRN-0011, Honeywell Incorporated, Morristown, NJ, January 2000
8. Klea(R) 134a, MSDS 274 revision I, ICI Americas, Incorporated, Wilmington, DE, 20 April 1998
9. Klea(R) 134a, Chemical Safety Data Sheet (CSDS) revision 05, ICI Klea, Runcorn, Cheshire, UK, April 1997
10. Isceon 134a, Safety Data Sheet, Rhône-Poulenc Chemicals Limited, Bristol, UK, 15 April 1994
11. Solkane(R) 134a, MSDS, Solvay Fluor und Derivate GmbH, Hannover, Germany, 22 August 1995

R-E134

REFRIGERANT TOXICITY SUMMARY

			see RDB#
R-E134	bis(difluoromethyl) ether		
HFE	CHF2-O-CHF2	CAS number 1691-17-4	

Only limited testing, mostly to gauge its anesthetic value, has been performed for R-E134. Long-term testing is still required. The results thus far suggest that R-E134 has very low toxicity.

OCCUPATIONAL EXPOSURE LIMITS

No recommended exposure limits were found for R-E134.

GENERAL CAUTIONS

More recent and/or more complete information may be found in Material Safety Data Sheets (MSDSs), provided by the chemical supplier(s), and in other toxicology references. Inhalation of high concentrations of refrigerant vapors is harmful. Anesthetic effects including loss of consciousness, heart irregularities, or death may result. Intentional misuse or deliberate inhalation ("sniffing") may cause death without warning. Massive leaks or spills also may pose an asphyxiation hazard, by displacing air, in confined or inadequately ventilated locations. This refrigerant is heavier than air, and leakage may accumulate in low areas.

INHALATION

Exposure tests with unspecified animals found that R-E134 barely induced anesthesia after 30 minutes at 130,000 ppm. The animals were anesthetized after five minutes at 180,000 ppm, but not deeply; they regained consciousness in approximately two minutes. They were anesthetized after two minutes at 300,000 ppm, but recovered in approximately two minutes. No signs of distress that would indicate respiratory or other irritation or a convulsant effect were noted. Rapid recovery from high concentrations and deep anesthesia suggests low solubility in and quick removal from body tissues. The low residence time reduces the probability of metabolism, resultant formation of toxic products, or interference with metabolic pathways. The test animals showed no ill effects over a period of one week, and the autopsy results were negative. R-E134 was deemed unattractive as an anesthetic based on the high concentrations required to induce and maintain anesthesia. 5550

Rats exposed to 50,000 ppm R-E134 and 950,000 ppm oxygen for one week showed no obvious adverse effects during or after the exposure. No gross abnormalities were found during necropsy. 5550

Cardiac sensitization studies found R-E134 to be between R-21 and R-22 in arrythmogenic properties, but that it behaved more like R-11 after epinephrine challenges. The tests were conducted with cynomolgus monkeys for 30 minute exposures at 50,000 ppm with 950,000 ppm oxygen. R-12, R-21, and R-22 caused irregular heart beats. All of the compounds except R-12 predisposed the monkeys to spontaneous cardiac sensitization and sensitized them to epinephrine challenges. Most of the specimens were not sensitized by R-12. 5550

SKIN OR EYE CONTACT

As with all low boiling point liquids, skin contact may cause frostbite. Excessive contact with fluorocarbons also may cause defatting of the skin. 5140

INGESTION

No information was found, but ingestion is unlikely with a normal boiling point of 6 øC (43 øF).

OTHER

Ames assays results were negative, suggesting – but not conclusively indicating – that R-E134 is not mutagenic. 5550

R-141b

---------- REFRIGERANT TOXICITY SUMMARY ----------

			see
R-141b	1,1-dichloro-1-fluoroethane		see
HCFC	CH3CCl2F	CAS number 1717-00-6	RDB#

Test results show that R-141b has low acute and subchronic inhalation toxicity. R-141b caused an increased incidence of benign tumors in animals following long-term exposure to high concentrations. These tumors did not affect life expectancy and are unique to rodents. R-141b did not cause any chronic toxicity. It is not a developmental or reproductive toxicant, and it not genotoxic. 65E9

OCCUPATIONAL EXPOSURE LIMITS

The American Industrial Hygiene Association adopted a Workplace Environmental Exposure Level (WEEL) Guide of 500 ppm, for an 8-hour exposure based on a time-weighted average (TWA), in 1992. 4B87

GENERAL CAUTIONS

More recent and/or more complete information may be found in Material Safety Data Sheets (MSDSs), provided by the chemical supplier(s), and in other toxicology references. Inhalation of high concentrations of refrigerant vapors is harmful. Anesthetic effects including loss of consciousness, heart irregularities, or death may result. Intentional misuse or deliberate inhalation ("sniffing") may cause death without warning. Massive leaks or spills also may pose an asphyxiation hazard, by displacing air, in confined or inadequately ventilated locations. This refrigerant is heavier than air, and leakage may accumulate in low areas.

PAFT TOXICOLOGY SUMMARY (September 1995) 5C39
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HCFC-141b is one in a series of fluorocarbon alternatives being tested by the Programme for Alternative Fluorocarbon Toxicity Testing (PAFT). HCFC-141b is primarily an alternative to CFC-11 as a foam-blowing agent, but may also be used as a solvent in cleaning applications.

Data from acute toxicity studies demonstrated that HCFC-141b has very low acute toxicity. HCFC-141b is not a skin irritant and is only a mild eye irritant. Skin application of HCFC-141b at high doses (2,000 mg/kg body weight) produces no adverse effects. Oral administration of HCFC-141b at high doses (5,000 mg/kg body weight) does not cause any mortality. Therefore, the oral LD50 is greater than 5,000 mg/kg body weight. HCFC-141b also has very low acute inhalation toxicity as measured by the concentration that causes 50% mortality in experimental animals, the LC50. The 4-hour exposure LC50 for HCFC-141b is 62,000 ppm in rats. Anaesthetic-like effects are observed at high concentrations.

As with many other halocarbons and hydrocarbons, inhalation of HCFC-141b followed by intravenous injection of epinephrine, which simulates human stress reactions, results in a cardiac sensitization response in experimental screening studies with dogs. This cardiac sensitization response is observed with HCFC-141b at approximately 5,000 ppm, a level well above expected exposures. Similarly, a cardiac sensitization response is observed with CFC-11 at approximately 5,000 ppm.

Longer term studies of up to 90 days in duration have also been conducted with HCFC-141b. In these studies, only slight changes in clinical chemistry parameters (e.g., cholesterol) and slight anaesthetic-like effects were observed. No other effects were evident in any of these studies at concentrations of up to 20,000 ppm. The no-observed-effect level (NOEL) in these studies was about 8,000 ppm.

A two-year inhalation study with HFC-141b was conducted at exposure concentrations of 0, 1,500, 5,000 and 20,000 ppm. During the study, no significant adverse effects were noted, although at the highest concentrations, slightly lower body weights were observed in male rats. Except for the testis of male rats, no grossly visible or microscopic changes were noted in any of the HCFC-141b treated animals. In the testis, an increase in hyperplasia (cell growth) and benign tumours of Leydig cells was observed in the 5,000 and 20,000 ppm groups. No malignant tumours attributable to HCFC-141b were observed. An independent review of the pathology findings supported these conclusions. None of the benign tumours were life-shortening, and all occurred near the end of the study. No effects were observed at lower concentrations in this two-year study; the NOEL was 1,500 ppm.

Several genetic toxicity studies have also been completed with HCFC-141b. Based on the evidence from all in vitro and in vivo studies, HCFC-141b is not mutagenic. Studies conducted with HCFC-141b included Ames, in vitro chromosomal aberration with human lymphocytes, and mouse micronucleus. HCFC-141b was active only at very high exposures in the Chinese Hamster ovary chromosomal aberration study. However, the overall evidence suggests that HCFC-141b is not genotoxic.

The results from developmental toxicity studies with HCFC-141b show that this material does not have embryotoxic effects in rats and rabbits at inhalation concentrations of 8,000 ppm and 1,400 ppm, respectively. In studies conducted in rats (at levels up to 20,000 ppm) and in rabbits (at levels up to 12,600 ppm), no teratogenic effects were seen. In a reproduction study, results suggest that HCFC-141b caused a slight reduction in litter size and total litter weight at 20,000 ppm. The NOEL was 8,000 ppm for the pups, and 2,000 ppm for the adults.

Metabolism studies suggest that HCFC-141b is oxidatively metabolized, although the rate of metabolism appears to be low.

The testing of HCFC-141b under PAFT II has been completed. The results are summarized below.

- HCFC-141b has low acute and subchronic inhalation toxicity.
- HCFC-141b caused an increased incidence of benign, but not life-threatening, tumours in animals following long-term exposure to high concentrations.
- HCFC-141b is not a developmental toxicant.
- HCFC-141b does not affect reproductive performance.
- HCFC-141b is not genotoxic.

An exposure limit of 500 ppm (8-hour time-weighted average) has been recommended by the American Industrial Hygiene Association, Workplace Environmental Exposure Limit (WEEL) Committee.

As for all chemicals, PAFT recommends that exposures be kept to a practicable minimum.

ADDITIONAL REFERENCES

1. Meforex(R) 141b, Material Safety Data Sheet (MSDS), Ausimont USA, Incorporated, Thorofare, NJ, 2 November 1998
2. HCFC-141b, MSDS DU000694 (042114688), DuPont Chemicals, Wilmington, DE, 29 June 1998
3. Forane(R) 141b, MSDS 04089, Elf Atochem North America, Incorporated, Philadelphia, PA, 3 November 1999
4. Forane(R) 141b, Safety Data Sheet (SDS) 00995, Elf Atochem S.A., Paris La Défense, France, 19 December 1997
5. Genetron(R) 141b, MSDS GTRN-0015, Honeywell Incorporated, Morristown, NJ, January 2000
6. Arcton(R) 141b, MSDS 6733, ICI Klea, Wilmington, DE, 16 March 1995
7. Arcton(R) 141b, Chemical Safety Data Sheet (CSDS) revision 02-UK00, ICI Klea, Runcorn, Cheshire, UK, December 1995

R-225ca, R-225cb

REFRIGERANT TOXICITY SUMMARY

R-225ca	3,3-dichloro-1,1,1,2,2-pentafluoropropane		
HCFC	$CHCl_2CF_2CF_3$	CAS number 422-56-0	
R-225cb	1,3-dichloro-1,1,2,2,3-pentafluoropropane		see
HCFC	$CHClFCF_2CClF_2$	CAS number 507-55-1	RDB#

Studies of R-225ca and R-225cb indicate that these compounds have very low acute oral, dermal, and inhalation toxicity. Exposures in the range of 600-1,000 ppm with R-225ca produced effects on the liver in rodents, but minor effects in a primate. Exposures in the range of 1,000-5,000 ppm with R-225cb resulted in only marginal effects in rodents or in a primate. Neither isomer was found to be genotoxic. 65E9

GENERAL CAUTIONS

More recent and/or more complete information may be found in Material Safety Data Sheets (MSDSs), provided by the chemical supplier(s), and in other toxicology references. Inhalation of high concentrations of refrigerant vapors is harmful. Anesthetic effects including loss of consciousness, heart irregularities, or death may result. Intentional misuse or deliberate inhalation ("sniffing") may cause death without warning. Massive leaks or spills also may pose an asphyxiation hazard, by displacing air, in confined or inadequately ventilated locations. R-225ca and R-225cb are heavier than air, and leakage may accumulate in low areas.

PAFT TOXICOLOGY SUMMARY (September 1995) 5C39
included with permission of PAFT

HCFC-225ca and HCFC-225cb (two isomers of dichloropentafluoropropane) are two of a series of fluorocarbon alternatives being tested by the Programme for Alternative Fluorocarbon Toxicity Testing (PAFT). HCFC-225ca and HCFC-225cb are being considered primarily as alternatives to CFC-113 as a solvent in cleaning applications. The isomers have been commercialized as a 45/55 weight percent mixture of HCFC-225ca and HCFC-225cb. Testing has been conducted on the separate isomers to allow characterization of the toxicity of each isomer and of the mixed isomer products.

Data from acute toxicity studies demonstrate that HCFC-225ca and HCFC-225cb have very low acute toxicity. Neither isomer causes eye irritation nor dermal toxicity in standardized tests; skin application of both isomers at high doses (2,000 mg/kg body weight) produces no adverse effects. Oral administration of either isomer at high doses (5,000 mg/kg body weight) does not cause any mortality. Therefore, the oral LD50s are greater than 5,000 mg/kg body weight. Both isomers also have very low acute inhalation toxicity as measured by the concentration that causes 50% mortality in experimental animals, the LC50. The 4-hour exposure LC50s for both isomers are approximately 37,000 ppm in rats. Anaesthetic-like effects are observed in rats at high inhalation concentration (greater than 5,000 ppm).

As with many other halocarbons and hydrocarbons, inhalation of HCFC-225ca and HCFC-225cb followed by intravenous injection of epinephrine, which simulates human stress reactions, results in a cardiac sensitization response in experimental screening studies with dogs. This cardiac sensitization response is observed at approximately 15,000 ppm for the mixture of HCFC-225ca/ HCFC-225cb (45/55 weight percent) and 20,000 ppm for HCFC-225cb, which are levels well above expected

exposures. By comparison, a cardiac sensitization response is observed with CFC-113 at approximately 5,000 ppm.

In 28-day inhalation studies with rats, the activity and responsiveness of the animals was reduced at exposures of 5,000 ppm or greater for each isomer. Toxicity was otherwise confined to the liver; liver enlargement and induction of peroxisomes was seen following treatment with either of the isomers. HCFC-225ca was more potent than HCFC-225cb in eliciting these liver effects.

To investigate the biological relevance of the liver toxicity to humans, comparative repeated inhalation studies have been conducted with rats, hamsters, guinea pigs and marmosets. In 14-day exposure studies with rats, hamsters and guinea pigs, the liver effects were also observed in rodents, while no such effects were observed in guinea pigs. In the 28-day study with marmosets, exposure to HCFC-225ca at 1,000 ppm caused effects on the liver, such as slight fat deposition associated with changes in serum biochemical parameters. In the same study, exposure to HCFC-225cb at 5,000 ppm caused somnolence during exposure and an increase of cytochrome P-450, indicative of an adaptive response to HCFC-225cb. However, no liver enlargement was seen and virtually no peroxisomal induction was observed with either isomer.

Several genetic studies have also been completed with both isomers. These studies included an Ames assay, in vitro chromosomal aberration with Chinese Hamster Lung (CHL) and human lymphocyte, and in vivo unscheduled DNA synthesis assay. Based on the weight of evidence from all in vitro and in vivo studies, neither isomer is mutagenic. In only one study, which utilized an in vitro culture of human lymphocyte, did HCFC-225ca cause changes in the genetic materials while HCFC-225cb elicited a marginal response. However, the overall evidence from these studies implies that neither isomer is genotoxic.

Pharmacokinetic studies with rats indicated that either isomer found in blood is rapidly eliminated on termination of exposure.

The testing of HCFC-225ca and HCFC-225cb under PAFT IV has been completed. The results are summarized below.

- HCFC-225ca and HCFC-225cb have low acute oral, dermal and inhalation toxicity.
- Exposure in the range of 650 to 1,000 ppm with HCFC-225ca produced effects on the liver in rodents, but a minor effect in a primate.
- Exposures in the range of 1,000 to 5,000 ppm with HCFC-225cb resulted in only marginal effects in rodents or a primate.
- Neither isomer is genotoxic.

As for all chemicals, PAFT recommends that exposures be kept to a practicable minimum.

R-290 (PROPANE)

REFRIGERANT TOXICITY SUMMARY

			see RDB#
R-290	propane		
HC	CH3CH2CH3	CAS number 74-98-6	

R-290 (propane) is essentially non-toxic in concentrations below 1,000 ppm, and no symptoms result from brief exposures to 10,000 ppm. The primary hazard for propane is flammability. 5609

OCCUPATIONAL EXPOSURE LIMITS

The Occupational Safety and Health Administration (OSHA) has set a Permissible Exposure Limit (PEL) of 1,000 ppm, on a time-weighted average (TWA) basis for an 8 hour shift of a 40 hour workweek, for R-290. 3904 The American Conference of Governmental Industrial Hygienists (ACGIH) classifies R-290 as a "simple asphyxiant." ACGIH adopted a Threshold Limit Value - Time-Weighted Average (TLV-TWA) of 1,000 ppm in 1966, but deleted it in 1970. 5141 ACGIH proposed a new TLV-TWA of 2,500 ppm for comment in 1996. 6901

GENERAL CAUTIONS

More recent and/or more complete information may be found in Material Safety Data Sheets (MSDSs), provided by the chemical supplier(s), and in other toxicology references. Inhalation of high concentrations of refrigerant vapors is harmful. Anesthetic effects including loss of consciousness, heart irregularities, or death may result. Intentional misuse or deliberate inhalation ("sniffing") may cause death without warning. Massive leaks or spills also may pose an asphyxiation hazard, by displacing air, in confined or inadequately ventilated locations. This refrigerant is heavier than air, and leakage may accumulate in low areas.

INHALATION

Concentrations exceeding 10,000 ppm can cause headaches, loss of concentration, and tiredness due to central nervous system (CNS) depression. Breathing pure propane will cause immediate loss of consciousness and almost immediate death /3/.

Guinea pigs exposed to concentrations of 22,000-29,000 ppm exhibited sniffing and chewing movements during 5 minute exposures, but recovered quickly. They also showed irregular rates of breathing during longer exposures, from 30 minutes to two hours. The same results were found at concentrations of 47,000-55,000 ppm, along with indications of mild stupor for 30 minute exposures and increased stupor for longer durations. The animals appeared to be normal during 7-10 day observations after exposures. An autopsy of one specimen, a week after the two hour exposure at 47,000-55,000 ppm, showed no pathological conditions to the vital organs. 4B64

Guinea pigs exposed to concentrations of up to 55,000 ppm for 1-2 hours showed tremors after five minutes, then nausea, retching, and stupefaction. All survived, and no significant tissue damage was found by autopsy. Brief exposures to 10,000 ppm caused no symptoms in human subjects; 100,000 ppm produced slight dizziness in a few minutes of exposure, but was not noticeably irritating to the eyes, nose, or respiratory tract. Reports from accidental overexposures cite disorientation, excitation, excessive salivation, headache, and vomiting. 5608 5609

Concentrations of 630,000 ppm in air induced mild anesthesia in tested cats. 5177

Propane exhibits some anesthetic action and is mildly irritating to the mucous membranes. Rapid respiration, dyspnea, ataxia, diminished alertness, emotional instability, rapid fatigue, nausea, vomiting, prostration, loss of consciousness, and convulsions may occur depending on the duration of exposure and concentration. Deep coma may occur at concentrations near those that induce simple asphyxiation. 5141

Effects at high concentrations include cardiac sensitization, analgesia, irregular respiration, and hypertension. No animal test reports for carcinogenic, developmental, or reproductive hazards are available /5/.

SKIN OR EYE CONTACT

No effects are reported from gas exposures. As with all low boiling point liquids, skin contact may cause frostbite. Liquid splashes will cause serious cold burns to the eyes. 5609 5140

INGESTION

Ingestion is unlikely due to the high volatility of the compound.

OTHER

Tests in bacteria cell cultures were negative, suggesting – but not conclusively indicating – that R-290 is not mutagenic /5/.

ADDITIONAL REFERENCES

1. Propane, Material Safety Data Sheet (MSDS) 93617000, Exxon Chemical Americas, Houston, TX, 1 March 1995
2. Propane (Refrigeration Grade), MSDS US057840, Phillips Chemical Company, Bartlesville, OK, 31 August 1993
3. Propane, Chemical Safety Data Sheet, Rhône-Poulenc Chemicals, Avonmouth, Bristol, UK, undated (received 16 December 1992
4. Propane, MSDS 60001, Texaco Natural gas Plants and Liquids Division, Tulsa, OK, 5 July 1995
5. "Suva" HP80 (R-402A), MSDS 6003FR, DuPont Chemicals, Wilmington, DE, 1 August 1994 [R-402A is a blend containing R-290]

R-600 (n-BUTANE

---------- REFRIGERANT TOXICITY SUMMARY ----------

			see
R-600	n-butane		
HC	CH3CH2CH2CH3	CAS number 106-97-8	RDB#

R-600 is comparatively nontoxic./1-3/ Like other simple hydrocarbons, it can irritate the eyes, mucous membranes, and respiratory system at high concentrations./1/ Inhalation of high concentrations may cause dizziness, disorientation, incoordination, narcosis, nausea, or narcotic effects. R-600 may displace oxygen, posing an asphyxiation hazard, if released in a confined space. The effects from oxygen deficiency may include rapid breathing, diminished mental alertness and judgement, impaired muscular coordination, depression of all sensations, emotional instability, and fatigue. As asphyxiation progresses, nausea, vomiting, prostration, and loss of consciousness may result leading to convulsions, coma, and death./1/ Oxygen deficiency during pregnancy has produced developmental abnormalities in humans and experimental animals./1/

GENERAL CAUTIONS

More recent and/or more complete information may be found in Material Safety Data Sheets (MSDSs), provided by the chemical supplier(s), and in other toxicology references. Inhalation of high concentrations of refrigerant vapors is harmful. Anesthetic effects including loss of consciousness, heart irregularities, or death may result. Intentional misuse or deliberate inhalation ("sniffing") may cause death without warning. Massive leaks or spills also may pose an asphyxiation hazard, by displacing air, in confined or inadequately ventilated locations. This refrigerant is heavier than air, and leakage may accumulate in low areas.

NIOSH-OSHA OCCUPATIONAL HEALTH GUIDELINE (OHG)
TOXICOLOGY SUMMARY (1992) 5C48

EFFECTS ON ANIMALS: Contact with liquid n-butane can cause frostbite. This gas is also an anesthetic and asphyxiant in animals at very high concentrations. Although n-butane was mildly to moderately irritating to rabbit skin, it did not produce ocular or respiratory tract irritation. However direct contact with liquid n-butane can cause frostbite. Anesthetized dogs concomitantly exposed to 5,000 ppm developed hermodynamic changes (decreased myocardial contractility, stroke volume, cardiac output, and left ventricular and aortic pressures). 5167 Dogs exposed to 10,000 ppm for 2 hr or 200,000 ppm for 2 min were hypersensitized to epinephrine-induced ventricular fibrillation. Exposures of dogs to 150,000 to 900,000 ppm for 10 min also caused heart sensitization to epinephrine-induced arrhythmias. The anesthetic concentration for n-butane is 250,000 ppm in dogs 5167 and 220,000 ppm for 1 min or 130,000 for 25 min in mice. The 30-min LC50 for mice is approximately 285,000 ppm, but the 15 min LC50 for rats is about 275,000 ppm. n-Butane was not mutagenic in the Salmonella typhimurium assay.

EFFECTS ON HUMANS: A transient blurring of vision resulted when n-butane was accidentally sprayed into the eyes from a cigarette lighter. However, contact of the eyes or skin with n-butane does not normally cause irritation, but contact with the liquified form may cause 5167 frostbite of the eyes or skin. Exposure to 10,000 ppm for 10 min may lead to drowsiness, but does not appear to cause systemic effects, 5167 A 2-year-old girl developed seizures, hypotension, and recurrent ventricular tachycardia following inhalation of an aerosol spray from a

can containing a mixture of n-butane, isobutane, and propane. Progressive bilateral pulmonary infiltrates consistent with hydrocarbon pneumonitis developed in a "fire breather" following inhalation of unignited fumes from a butane lighter. Exposures of volunteers to 1,000 ppm for 8 hr or 500 ppm for 8 hr/day, 5 days/week for 2 weeks did not induce toxicity. Intentional inhalation abuse of n-butane for 1 year by a 16-year-old girl caused her to suffer from visual hallucinations, increased irritability, and social withdrawal. Exposure to n-butane at very high concentrations can affect the central nervous system, causing narcosis and asphyxiation. 5141 5167

ADDITIONAL REFERENCES

1. N-Butane, Material Safety Data Sheet (MSDS) G-17, BOC Gases Division of the BOC Group, Incorporated, Murray Hill, NJ, 7 June 1996
2. Butane, Material Safety Data Sheet (MSDS), Exxon Chemical Americas, Houston, TX, 27 March 1995
3. n-Butane (Pure Grade), MSDs US003448, Phillips Chemical Company, Bartlesville, OK, 30 April 1993

R-717 (AMMONIA)

REFRIGERANT TOXICITY SUMMARY

			see RDB#
R-717	ammonia		
inorganic	NH3	CAS number 7664-41-7	

GENERAL CAUTIONS

More recent and/or more complete information may be found in Material Safety Data Sheets (MSDSs), provided by the chemical supplier(s), and in other toxicology references. Inhalation of high concentrations of refrigerant vapors is harmful.

NIOSH-OSHA OCCUPATIONAL HEALTH GUIDELINE (OHG)
TOXICOLOGY SUMMARY (1992) 5C46

EFFECTS ON ANIMALS: Ammonia is a severe irritant of the eyes, respiratory tract, and skin. Liquified ammonia can induce freezing, burns, and corrosion of tissues. Exposure of guinea pigs to 5,000 to 6,000 ppm for 30 to 120 minute induced blindness. 4B76 The approximate 1-hr LC50 for cats and rabbits was 9,900 ppm. This concentration induced severe bronchial damage, alveolar congestion, edema atelectasis, hemorrhage, and emphysema in the animals that died. The 4-hr LC50 in rats is 2,000 ppm, and the oral LD50 is 350 mg/kg. In mice, the RD50 (the concentration capable of reducing respiratory rate by 50%) was approximately 300 ppm. Continued exposure for 6 hr/day for 5 days produced nasal lesions including hypertrophy, hyperplasia, epithelial erosion, ulceration, and necrosis. Continuous exposure to ammonia for several weeks at 658 ppm produced marked eye irritation in dogs and rabbits and corneal opacity in rabbits. 5C51 Rats similarly exposed developed interstitial pneumonitus with calcification of the bronchi and renal tubules, epithelial proliferation of the renal tubules, myocardial fibrosis, and fatty liver. Rats, guinea pigs, dogs, rabbits, and monkeys exposed to 1,100 ppm for 8 hr/day, 4B76 5 days/week for 6 weeks showed signs of moderate eye and nasal irritation but no signs of systemic poisoning. Although all monkeys, dogs, and rabbits survived a continuous 90-day exposure to 680 ppm, this exposure was fatal to 13 of 15 rats and 4 of 15 guinea pigs. 4B76 No clinically significant findings were detected at autopsy in rats continuously exposed to 180 ppm for 90 days. 5167

EFFECTS ON HUMANS: Ammonia gas is severely irritating to the eyes and to the moist skin and mucous membranes of humans. In contact with the eyes, liquid and anhydrous ammonia causes severe damage that may lead to blindness. 5C50 When in contact with the skin, liquified ammonia can cause freezing and third-degree burns. 5167 Two volunteers exposed to ammonia at approximately 24 ppm showed signs of mild nasal irritation on clinical examination. Five of six volunteers exposed to 30 or 50 ppm for 10 min reported mild to moderate upper respiratory tract irritation. 5167 At 130 ppm, however, volunteers experienced lacrimation and nose and throat irritation; one volunteer experienced pulmonary irritation. 5167 Exposure of humans to 500 ppm for 30 min caused changes in respiratory rate, and exposure to 1,720 produced coughing in exposed individuals. 4B76 Accidental exposure to ammonia gas or the vapors of ammonia at high concentrations (approximately 2,500 to 6,500 ppm) for up to 2 hr induced chemical pneumonitus, burns (eyes, face, and mouth), severe local edema, dyspnea, progressive cyanosis, and 5167 5C50 death. Death is normally caused by either suffocation or pulmonary edema. 5167 In near-lethal cases, residual effects may include visual impairment, decreased pulmonary function, and hoarseness. 5167

NOTE: While the LD50 concentration indicated in the preceding NIOSH-OSHA Toxicology Summary is widely cited in the literature, it was measured in tests using ammonium hydroxide (ammonia-water solution, NH4OH). A paper on the study notes that the LD50 was calculated for ammonia. 6267

ADDITIONAL REFERENCES

1. Ammonia, Material Safety Data Sheet (MSDS) G-11, BOC Gases Division of the BOC Group, Incorporated, Murray Hill, NJ, 1 July 1996
2. Ammonia, MSDS DU000002 (6007CR), DuPont Chemicals, Wilmington, DE, 27 August 1993
3. Ammonia, MSDS, Hawkeye Chemical Company, 20 March 1992
4. Ammonia, Anhydrous, MSDS OHS01050, MDL Information Systems, Incorporated, San Leandro, CA, 28 June 1996
5. Ammonia, Anhydrous-Refrigeration Grade, MSDS, Unocal Corporation, Los Angeles, CA, 30 August 1995
6. Anhydrous Ammonia, MSDS, General Electric Company, November 1979
7. Anhydrous Ammonia, MSDS, Genium Publishing Corporation, Schenectady, NY, August 1985
8. Anhydrous Ammonia, MSDS, Hill Brothers Chemical Company, 8 January 1991
9. Anhydrous Ammonia, MSDS, LaRoche Industries Incorporated, January 1991

R-744 (CARBON DIOXIDE)

---------- REFRIGERANT TOXICITY SUMMARY ----------

			see
R-744	carbon dioxide		
inorganic	CO2	CAS number 124-38-9	RDB#

While the toxicity of R-744 is comparatively low, its potential to displace air, inhalation effects, pressure ruptures and releases, and freezing from contact with its liquid form pose hazards. Carbon dioxide is the most powerful cerebral vasodilator known./2/ It is a rapid acting, acute respiratory stimulant at low concentrations. Succeedingly higher concentrations will, in addition, produce effects on the central nervous system. They include headache, dizziness, muscular spasm, and loss of consciousness. Brief exposures at a concentration of 30,000 ppm do not appear to present a toxic hazard in terms of respiratory stimulant or central nervous system effects. This concentration is recommended as a ceiling limit for up to a 10-minute exposure. Prolonged exposure to carbon dioxide at a concentration of 10,000 ppm results in physiological changes, limited to renal and respiratory compensatory mechanisms that do not result in any apparent adverse symptomatology. At higher concentrations, work-related exercise will exaggerate the respiratory stimulant as well as other physiologic effects of carbon dioxide, resulting in undesirable side effects. 5787

Carbon dioxide is present in the atmosphere at approximately 300 ppm. It is a normal body constituent and respiratory stimulant./3/

OCCUPATIONAL EXPOSURE LIMITS

The Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL) for R-744 is 5,000 ppm on a time-weighted average (TWA) basis for an 8 hour shift of a 40 hour workweek. The 3904
American Conference of Governmental Industrial Hygienists (ACGIH) adopted a Threshold Limit Value - Time-Weighted Average (TLV-TWA) of 5,000 ppm in 1948 and a Threshold Limit Value - Short-Term Exposure 5141
Limit (TLV-STEL) of 30,000 ppm in 1986. 5901

GENERAL CAUTIONS

More recent and/or more complete information may be found in Material Safety Data Sheets (MSDSs), provided by the chemical supplier(s), and in other toxicology references. Inhalation of high concentrations of refrigerant vapors is harmful. Anesthetic effects including loss of consciousness, heart irregularities, or death may result. Intentional misuse or deliberate inhalation ("sniffing") may cause death without warning. Massive leaks or spills also may pose an asphyxiation hazard, by displacing air, in confined or inadequately ventilated locations. This refrigerant is heavier than air, and leakage may accumulate in low areas.

NIOSH-OSHA OCCUPATIONAL HEALTH GUIDELINE (OHG)
TOXICOLOGY SUMMARY (September 1978) 6280

Carbon dioxide gas is an asphyxiant, a potential respiratory stimulant, and both a stimulant and depressant of the CNS [Central Nervous System]. Respiratory volume is doubled at 4% [40,000 ppm] carbon dioxide and redoubled at 5% [50,000 ppm]. Increases in heart rate and blood pressure have been noted at 7.6% [76,000 ppm] and dyspnea, headache, dizziness, and sweating occur if exposure at that level is prolonged. At 10% [100,000 ppm] and above, prolonged exposure can result in unconsciousness. Above 11% [110,000 ppm, unconsciousness

occurs in 1 minute or less. Numerous human fatalities have occurred after persons entered fermentation vats, wells, and silos where oxygen had been largely replaced by carbon dioxide. Exposure to very high concentrations, 25 to 30% [250,000 to 300,000 ppm], may cause convulsions. Carbon dioxide at room temperature will not injure the skin, but frostbite may result from the solid or liquid phases.

RELATED TOXICOLOGICAL INFORMATION

Oxygen deficiency during pregnancy has produced developmental abnormalities in humans and experimental animals. Exposure of female rats to 60,000 ppm (6%) carbon dioxide for 24 hr has produced toxic effects to the embryo and fetus in pregnant rats. Toxic effects also have been observed in other mammalian species at similar concentrations./2/

ADDITIONAL REFERENCES

1. Carbon Dioxide, Material Safety Data Sheet (MSDS), Amerex Corporation, Trussville, AL, 1 February 1996
2. Carbon Dioxide, Gas, MSDS G-8, BOC Gases Division of the BOC Group, Incorporated, Murray Hill, NJ, 7 June 1996
3. Carbon Dioxide, MSDS 6077CR, DuPont Chemicals, Wilmington, DE, 29 August 1993
4. Carbon Dioxide, MSDS, Genium Publishing Corporation, Schenectady, NY, April 1986
5. Carbon Dioxide, MSDS, Union Carbide Corporation, 8 October 1991

APPENDIX 4: TOXICITY REFERENCES

This appendix presents toxicity citations from the *ARTI Refrigerant Database*[22] that primarily address toxicity. The current version of Database provides more than 1400 citations addressing refrigerant toxicity.

SAFETY

P. J. Baldock (Imperial Chemical Industries PLC, ICI, UK), **Accidental Releases of Ammonia: An Analysis of Reported Incidents**, *AIChE Loss Prevention Symposium*, American Institute of Chemical Engineers (AIChE), New York, NY, 13:, 1980 (RDB7535)

R-717, safety, accidents involving human exposures

J. Berghmans and H. Duprez (Katholieke Universiteit Leuven, Belgium), **Safety Aspects of CO_2 Heat Pumps**, *Heat Pumps — a Benefit for the Environment* (proceedings of the Sixth International Energy Agency (IEA) Heat Pump Conference, Berlin, Germany, 31 May - 2 June 1999), Verlags- und Wirtschaftsgesellschaft der Elektrizitätswerke m.b.H. (VWEW-Verlag), Frankfurt am Main, Germany, posters tab 5, May 1999 (10 pages with 10 figures and 1 table, RDB9838)

analyzes the safety risks of R-744 (carbon dioxide) by quantitative risk analysis (QRA) and compares them to other refrigerant options; addresses toxicity, leakage scenarios, boiling liquid expanding vapor explosion (BLEVE), dynamic room concentrations, and pressure explosions; concludes that the risks related to R-744 use in heat pumps are low and acceptable provided the charge is limited so concentrations upon full charge release are less than 50,000 ppm v/v

T. Brown, D. M. Holder, and A. J. Gigiel (University of Bristol, UK), **Safety Aspects of Air Cycle Refrigeration and Heat Pump Systems**, *Proceedings of the 19th International Congress of Refrigeration* (The Hague, The Netherlands, 20-25 August 1995), International Institute of Refrigeration (IIR), Paris, France, IVb:742-747, 1995 (6 pages with 1 figure and 2 tables, RDB7915)

factors that affect the operational safety of air (R-729) cycle systems including component or piping failure from pressure, failure of high-speed rotary components (turbine compressors or expanders), noise, and contamination; concludes that hazards are ordinary

J. M. Calm (Engineering Consultant), **Refrigerant Safety**, *ASHRAE Journal*, 36(7):17-26, July 1994; erratum, 36(8), August 1994 (10 pages with 3 figures and 2 tables, available from JMC as RDB-4766)

This article outlines safety concerns and summarizes safety data for refrigerants, with emphasis on those used in chillers. It briefly reviews the history of refrigeration, noting that nearly all of the early refrigerants were flammable, toxic, or both, and that some also were highly reactive. It describes the discovery of organic fluorides as refrigerants, by Thomas Midgley in 1926, and the first toxicity tests. The article reviews the commercial introduction and growth of fluorocarbon refrigerants. It then describes the attributes of ideal refrigerants, noting that none exist or are likely to be found. The article summarizes toxicity concerns and several reasons for increased attention to them. A table provides a glossary of safety terminology including common indices used to quantify recommended exposure limits and concentrations that pose recognized risks. Among them are the Acceptable Exposure Limit (AEL), Immediately Dangerous to Life or Health (IDLH), Industrial Exposure Limit (IEL), Lethal Concentration for 50% of specimens (LC_{50}), No Observed Effect Level (NOEL), Occupational Exposure Limit (OEL), Permissible Exposure Level (PEL), Recommended Exposure Limit (REL), Short-Term Exposure Limit (STEL), Threshold Limit Value (TLV), and Workplace Environmental Exposure Level (WEEL). Flammability limits also are addressed includ-

ing the lower and upper flammability limits (LFL and UFL, respectively). The article then summarizes toxicity data for R-123 and R-134a, and relates the R-123 data to measured concentrations in machinery rooms. It also explains other hazards, including the potential for irritation, corrosive effects, asphyxiation, narcosis, and other physiological effects. A table compares safety indicators for R-11, R-12, R-22, R-123, R-134a, and R-717 (ammonia) including acute, subchronic, and chronic toxicity, cardiac sensitization response level, mutagenicity, carcinogenicity, and teratogenicity. The paper then summarizes the safety classifications and the recommended installation, handling, and service procedures found in ASHRAE standards 34 and 15, respectively. The article concludes that the new, alternative refrigerants can be used with comparable or higher safety than those they replace. It notes that the alternatives have been subjected to more stringent qualification criteria and testing. The article also indicates that more care is needed with all refrigerants.

T. Dierckx and J. Berghmans (Katholieke Universiteit Leuven, Belgium), **Safety Aspects of Working Fluids**, *Energy Efficiency and Global Warming Impact* (proceedings of the meetings of Commissions B1 and B2, Ghent, Belgium 12-14 May 1993), International Institute of Refrigeration (IIR), Paris, France, 293-300, 1993 (8 pages with 1 figure and 3 tables, RDB5323)

R-11, R-12, R-22, R-23, R-32, R-125, R-134a, R-142a (possibly intended to be R-143a), R-290 (propane), and R-717 (ammonia) as potential replacements for R-12; R-124 (cited as R-124(a)) and R-227 (probably R-227ea) as potential replacements for R-114; R-21, R-30, R-123, R-132a, and R-133 as potential replacements for R-11; flammability; toxicity

R. E. Dufour and A. J. Perkins, **The Comparative Life, Fire, and Explosion Hazards of Trifluorotrichloroethane ("Freon-113")**, Miscellaneous Hazard Report 3072, Underwriters Laboratories Incorporated, Northbrook, IL (then Chicago, IL), 7 April 1941 (22 pages with 6 tables, RDB5174)

R-113, toxicity, flammability, stability

L. Fluer (Fluer, Incorporated, and HMEx, Incorporated), **Hazardous Materials Classification Guide**, edited by J. M. Shapiro, International Fire Code Institute (IFCI), Whittier, CA, 1993 (818 pages with 1 table, RDB3965)

This book provides guidance for classification of hazards for approximately 3,500 chemicals for use with building and fire safety codes. The volume also explains the fundamentals of hazard classification and provides a cross-reference between more than 7,000 chemical names and Chemical Abstract Service (CAS) registry numbers. A table, forming most of the book, lists the chemicals by CAS number (or pseudo-number for mixtures). It also identifies their chemical and/or trade names as well as common names for verification. Each entry provides the physical state (solid, liquid, or gaseous) at 20 °C (68 °F), concentration, indication of listing under the U.S. Environmental Protection Agency (EPA) *List of Extremely Hazardous Substances* (40 CFR 355 §302 and §304), information for warning placards, and physical and health hazard categories. The placard information follows the National Fire Protection Agency Standard 704-1985 *Standard System for the Identification of the Fire Hazards of Materials*. It includes recommended hazard identification rating numbers for health, flammability, and reactivity as well as a designator for special hazards. The physical categories identified include aerosols, combustible dusts and fibers, flammable and oxidizing cryogenics, explosives, flammable and combustible liquids, flammable gases, organic peroxides, oxidizers, pyrophorics, unstable reactives, and water reactives. The health hazards addressed are carcinogenic, corrosive, irritant, other health hazard, radioactive, sensitizer, and toxic/highly toxic. An introductory section explains the criteria, data sources, classification approach, and assigned hazard levels for each. The guide covers R-11, R-12, R-12B2, R-13, R-14, R-21, R-22, R-23, R-30, R-113, R-114, R-115, R-116, R-123, R-134a, R-152a, R-290 R-C318, R-500, R-503, R-717 (ammonia), and R-744 (carbon dioxide), R-1132a, and a number of mineral oil lubricants among the other chemicals. [see RDB3966 for software version]

L. Fluer (Fluer, Incorporated, and HMEx, Incorporated), **HMEx Assistant — The Hazardous Materials Expert**, International Fire Code Institute (IFCI), Whittier, CA, version 1.02, 1993 (software package with 72 page user's manual, RDB3966)

This software provides guidance for classification of hazards for approximately 3,500 chemicals for use with building and fire safety codes. The software enables look-up by chemical, commercial, or common names; Chemical Abstract Service (CAS) registry numbers (or

pseudo-number for mixtures); or *Registry of Toxic Effects of Chemical Substances* (RTECS®) codes. The entries indicate the physical state (solid, liquid, or gaseous) at 20 °C (68 °F), concentration, indication of listing under the U.S. Environmental Protection Agency (EPA) *List of Extremely Hazardous Substances* (40 CFR 355 §302 and §304), information for warning placards, and physical and health hazard categories. The placard information follows the National Fire Protection Agency Standard 704-1985 *Standard System for the Identification of the Fire Hazards of Materials*. It includes recommended hazard identification rating numbers for health, flammability, and reactivity as well as a designator for special hazards. The physical categories identified include aerosols, combustible dusts and fibers, flammable and oxidizing cryogenics, explosives, flammable and combustible liquids, flammable gases, organic peroxides, oxidizers, pyrophorics, unstable reactives, and water reactives. The health hazards addressed are carcinogenic, corrosive, irritant, other health hazard, radioactive, sensitizer, and toxic/highly toxic. The entries also identify the classifier and reviewer for each chemical according to initials or codes. A companion user's manual provides installation instructions and explains the criteria, data sources, classification approach, and assigned hazard levels. The software covers R-11, R-12, R-12B2, R-13, R-14, R-21, R-22, R-23, R-30, R-113, R-114, R-115, R-116, R-123, R-134a, R-152a, R-290 R-C318, R-500, R-503, R-717 (ammonia), and R-744 (carbon dioxide), R-1132a, and a number of mineral oils among the other chemicals. [see RDB3965 for printed version]

K. J. M. Ham and J. Gansevoort (Netherlands Organization for Applied Scientific Research, TNO, The Netherlands), **Risk Analysis for Ammonia Refrigeration Systems**, *Proceedings of the 19th International Congress of Refrigeration* (The Hague, The Netherlands, 20-25 August 1995), International Institute of Refrigeration (IIR), Paris, France, IVa:678-686, 1995 (9 pages with 2 figures, RDB7911)

hazards associated with R-717 (ammonia) use; review of Dutch safety regulations for ammonia refrigerating installations; prior evaluations indicate that many existing systems do not meet these requirements, that many were never inspected or fully tested, and that complete replacement of the installation would be required to obtain approvals; requirements for a Quantified Risk Assessment (QRA); proposed code of practice to obtain approvals for nonconforming systems

International Programme on Chemical Safety (IPCS), **Partially Halogenated Chlorofluorocarbons (Ethane Derivatives)**, Environmental Health Criteria (EHC) report 139, World Health Organization (WHO), Geneva, Switzerland, 1992 (134 pages with 1 figure and 16 tables, RDb5371)

R-123, R-123, R-124, R-132b, R-133a, R-141b, R-142b: identification; summary properties; analytical methods; sources of human and environmental exposure; environmental transport, distribution, and transformation; environmental levels and human exposure; kinetics and metabolism; effects on laboratory mammals; in vitro tests; effects on humans; effects on other organisms in the laboratory and field; evaluation of human health risks and effects on the environment; recommendations for protection of human health and the environment

R. W. James, **Safe Use of Refrigerants for Process Applications**, *Journal of Loss Prevention in the Process Industries*, 7(6):492-500, 1994 (9 pages, RDBA666)

discusses safety issues related to refrigerant use in process operations with focus on hydrocarbons and R-717 (ammonia) as potential replacements for fluorochemicals; discusses hazards from accidental refrigerant releases including toxic decomposition products when refrigerant vapors contact flames or hot surfaces, suffocation resulting from refrigerants in confined spaces, narcotic and cardiac effects, fire, freezing of tissues, corrosive attack on sensitive tissues such as the eyes, or impact damage resulting from component or equipment failure; discusses safety standards and codes; examines refrigerant charge limits in equipment based room volume, occupancy, and maximum allowable concentrations; discusses safety precautions including restricting access to rooms where refrigerating equipment is installed, work practices for maintaining and repairing equipment, protecting against noise and vibration exposure, design criteria, pressure release during fires, ventilation, alarm systems, and safety checks

G. J. Koster (Grenco Refrigeration B.V., The Netherlands), **A Way to Safe Use of Ammonia**, *Proceedings of the 19th International Congress of Refrigeration* (The Hague, The Netherlands, 20-25 August 1995), International Institute of Refrigera-

tion (IIR), Paris, France, IVa:641-645, 1995 (5 pages with 3 tables, RDB7908)

advocates use of R-717 (ammonia) as an environmentally-safe refrigerant; factors affecting application including regulations

R. J. Lewis, Sr., **Hazardous Chemicals Desk Reference** (fourth edition), VNR / John Wiley and Sons, Incorporated, New York, NY, 1997 (1,760 pages, RDB8361)

safety profiles and hazard ratings for chemicals: flammability, toxicity, and other safety data

A. Lindborg (Frigoscandia AB, Sweden), **Ammonia the Obvious Refrigerant**, *Proceedings of the 19th International Congress of Refrigeration* (The Hague, The Netherlands, 20-25 August 1995), International Institute of Refrigeration (IIR), Paris, France, IVa:646-651, 1995 (6 pages with 4 tables, RDB7909)

advocates use of R-717 (ammonia) as a "natural" refrigerant; physical and physiological effects of ammonia; public perceptions of ammonia

W. E. Stewart, R. W. Clark (University of Missouri-Kansas City), L. A. Stickler, and C. K. Saunders (Inter-Mountain Research), **Gaseous Ammonia Dispersion: Comparison of Experimental Data with Two Predictive Models**, paper 3924, *Transactions* (Annual Meeting, San Diego, CA, 24-28 June 1995), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 101(2):497-501, 1995 (4 pages with 4 figures and 1 table, RDB6362)

R-717, safety, validation of dispersion models, DEGADIS (DEnse GAs DISpersion model), SLAB

R. J. M. van Gerwen (Netherlands Organization for Applied Scientific Research, TNO, The Netherlands), **Safety Aspects of Natural Working Fluids**, *IEA Heat Pump Center Newsletter — CFC and HFC Replacement*, International Energy Agency (IEA) Heat Pump Center (HPC), Sittard, The Netherlands, 13(1):19-21, March 1995 (3 pages with 1 figure, RDB5684)

R-717, hydrocarbons, accidents, risk assessment

R. J. M. van Gerwen and C. M. A. Jansen, **Risk Assessment of the Use of Flammable Refrigerants**, report 8327-24191, Netherlands Organization for Applied Scientific Research (TNO), Apeldoorn, The Netherlands, June 1994 (RDB5686)

safety, flammability, accidents

P. G. J. M. van Dijck, untitled report on the flammability of R-245fa, report 96D2/2344, Prins Maurits Laboratory, TNO [Netherlands Organization for Applied Scientific Research], Rijswijk, The Netherlands, 20 December 1996 (6 pages with 1 figure and 1 table, available from JMC as RDB7114)

investigation of the flammability of R-245fa in concentrations of 0-15% in air in a vertical, vapor-explosion burette using a 6.25 J (0.0059 Btu) spark for ignition: concludes that R-245fa is nonflammable as tested; an annex describes the apparatus, test procedure, and deviations from the test prescribed in EC Directive 92/69/EEC

R. J. M. van Gerwen and H. Koffijberg (Netherlands Organization for Applied Scientific Research, TNO, The Netherlands), **Natural Refrigerants: Applications and Risks**, *Proceedings of the 19th International Congress of Refrigeration* (The Hague, The Netherlands, 20-25 August 1995), International Institute of Refrigeration (IIR), Paris, France, IVb:790-796, 1995 (7 pages with 1 figure and 3 tables, RDB7920)

status of R-717 (ammonia) use in the Netherlands, primarily in food processing with a 50% share (65% by refrigerant amount) with an average of 7.5 kg/kW (4.8 lb/ton) and ice skating rinks with a 75% share; use in commercial refrigeration and chillers is limited by safety regulations, but there are new indirect systems incorporating secondary heat transfer fluids; hydrocarbons have not been used for 40 years except R-290/600 (propane/butane) in domestic refrigerators; broader application of hydrocarbons, in almost all appliances starting in 1995 and transport refrigeration is expected based on quantified risk assessment (QRA) findings; review of ammonia accident data cites 37 accidents (5 in the Netherlands) with 152 injuries and 2 fatalities (1 in the Netherlands); 196 additional accidents with 185 injuries and 17 fatalities are noted for Norway and Japan; QRA methods and accepted individual and societal risk criteria are summarized for Australia, Hong Kong, the Netherlands, and the United Kingdom; discusses directives and standards for safety in the Netherlands and more broadly in Europe

Aard en omvang van het gebruik van ammoniak als koudemiddel in de Nederlandse Voedings- en Genotmiddelenindustrie, Netherlands Organization for Applied Scientific Research

(TNO), Apeldoorn, The Netherlands, May 1992 (RDB5495)

accident statistics with use of ammonia (R-717) as a refrigerant in the Netherlands, safety

Addenda to Design and Safety Classifications of Refrigerants [the title of the revised standard actually is *Designation and Safety Classification of Refrigerants*, the word *Design* should be *Designation* and the word *Classifications* should be singular], ANSI/ASHRAE Addenda 34h-2000, 34j-2000, and 34k-2000 (Addenda to ANSI/ASHRAE 34-1997), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 2000 [first distributed June 2000] (6 pages with 1 tables, RDBA674)

addendum 34h adds a provisional safety classification of A1 for R-245fa and editorial changes to the table with refrigerant data and safety classifications; 34j modifies the submission requirements for toxicity information for designation and classification applications; 34k deletes the requirements for proof of commercialization for blends for such applications; these addenda revise ANSI/ASHRAE Standard 34-1997 [see RDB8601]

Addenda to Number Designation and Safety Classification of Refrigerants [the title of the revised standard actually is "Designation and Safety Classification of Refrigerants", the word "Number" was deleted in the 1997 revision], ANSI/ASHRAE Addenda 34a, 34b, 34c, 34d, and 34f (Addenda to ANSI/ASHRAE 34-1997), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1999 [first distributed June 1999] (8 pages with 2 tables, RDB9710)

Addendum 34a deletes some refrigerants that were never or are no longer used to focus the standard on refrigerants in current use or expected to be used in the future. It corrects the chemical formulae and names cited for some refrigerants, though this information is indicated as informational only and not a part of the standard. Addendum 34b adds R-413A, R-218/134a/600a (9.0/88.0/3.0), and both a safety classification and tolerances for it. Addendum 34c deletes the safety classifications for R-C318 and R-405A based on insufficient toxicity data. Addendum 34d deletes a previous requirement for submission of recommended NFPA 704 Hazard Signals from applications for designation and classification. Addendum 34f adds R-407E, R-32/125/134a (25.0/15.0/60.0), and both a safety classification and tolerances for it. Addendum 34e adds a safety classification for R-236fa. These addenda revise ANSI/ASHRAE Standard 34-1997 [see RDB8601].

Designation and Safety Classification of Refrigerants, ANSI/ASHRAE Standard 34-1997, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 1997 [first distributed June 1998] (22 pages with 1 figure and 7 tables, RDB8601)

This voluntary, consensus standard describes a shorthand way of naming refrigerants and classifies them according to potential hazards. It is intended to establish a simple means of referring to common refrigerants, instead of using the chemical name, formula, or trade name. It also establishes a uniform system for assigning unambiguous reference numbers, composition-designating prefixes for refrigerants, and safety classifications based on toxicity and flammability, both as formulated and under worst-case of fractionation conditions. This standard is widely cited in construction codes and provides the classifications used in ASHRAE Standard 15, *Safety Code for Mechanical Refrigeration*, to specify safety requirements for refrigerant use. This version supersedes ANSI/ASHRAE Standard 34-1992 and earlier editions.

Equipment, Design, and Installation of Ammonia Mechanical Refrigerating Systems, ANSI/IIAR Standard 2-1992, International Institute of Ammonia Refrigeration (IIAR), Washington, DC, December 1992 (40 pages with 2 figures and 5 tables, RDB4757)

This voluntary, consensus standard is intended to serve as guide to the design, manufacture, installation, and use of mechanical refrigerating systems employing R-717 (anhydrous ammonia). It applies to closed mechanical refrigerating systems in industrial occupancies. Its provisions represent minimum requirements for the areas addressed, to minimize property damage or loss and risks to persons. The standard comprises a foreword, introduction, definitions, and sections on equipment, machinery room design, and installation. The equipment provisions cover compressors, evaporative condensers, pressure reliefs, shell-and-tube condensers, double-pipe condensers, pressure vessels, evaporators, refrigerant pumps, refrigerant valves, pressure-relief devices, piping, testing, materials, and ultimate strength requirements. Most of these topics identify specific design criteria, nameplate data, and testing. The provisions for machinery rooms cover room layout, open flames, ventilation, archi-

tectural features, location, electrical, and piping. The installation topics include materials selection, piping, joints, pipe hangers and supports, pressure-relief protection, foundations and equipment supports, system testing, and ammonia handling and storage. The standard concludes with lists of references and their sources, an appendix on emergency discharge of ammonia refrigerant, and two drawings detailing emergency control stations. This version supersedes ANSI/IIAR Standard 2-1984 and earlier editions.

Genetron® AZ-20 (R-410A) Safety Overview, bulletin G525-084, AlliedSignal Incorporated, Morristown, NJ, December 1996 (2 pages with 1 table, limited copies available from JMC as RDB7110)

This bulletin complements the Material Safety Data Sheet (MSDS) with discussion of health and safety information for use of R-410A. A table shows the composition to be R-32/125 (50/50). Discussion of its toxicity notes that data for the components were developed under the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), and that review of the results shows low toxicity in animals for both R-32 and R-125. AlliedSignal recommends an occupational exposure limit (OEL) of 1,000 ppm on an 8-hr time-weighted average (TWA) basis; the bulletin discusses concerns with oxygen displacement, asphyxiation, cardiac sensitization, and overexposure. Ingestion is noted as causing discomfort in the gastrointestinal tract, some of the effects of inhalation, and necrosis from freezing tissue. The vapor can irritate the skin and eyes while the liquid can freeze them on contact; suggestions are given for care in such cases. The bulletin discusses evacuation in response to leaks and recovery procedures. It identifies the ASHRAE Standard 34 safety classification as A1/A1, the Underwriter's Laboratory (UL) rating as *practically nonflammable*, and U.S. Department of Transportation (DOT) consideration as *nonflammable* (Green label). The bulletin cautions that R-410A can become combustible in air at elevated pressures and recommends against mixing or leak testing with air. It notes that R-410A can decompose at high temperatures, such as those found in open flames and red- or white-hot metals, yielding toxic, corrosive, and irritating compounds as well as pungent and irritating vapors. The refrigerant is described as stable at normal operating conditions, but contact with freshly abraded aluminum and active metals should be avoided. The bulletin concludes with a discussion of pressures, noting that those for R-410A are approximately 60% higher than for R-22. Suggested ratings are given for hoses and equipment used with R-410A. AlliedSignal's product name for R-410A is Genetron® AZ-20.

Guidelines for Ammonia Machinery Room Ventilation, IIAR bulletin 111, International Institute of Ammonia Refrigeration (IIAR), Washington, DC, October 1991 (24 pages with 1 figure, RDB4760)

This bulletin provides guidance for ventilation systems for machinery rooms using ammonia in industrial refrigeration facilities. The recommended design scheme and minimum ventilation levels are applicable to systems with large quantities of ammonia, exceeding several thousand pounds, but may not be appropriate for smaller systems or those for other applications. The bulletin identifies reference sources, including major codes and standards, used to prepare the guidelines. It then summarizes ventilation requirements to be classified as a "Non-Hazardous (Unclassified) Location" under the National Fire Protection Association (NFPA) Standard 70, National Electrical Code (NEC). It specifically addresses continuously operated mechanical exhaust, independent emergency ventilation, and minimum volume requirements, A section on recommended design schemes reviews the steps to determine code minimums and outlines the design process. The document also addresses operation and maintenance. A worksheet to facilitate calculations, system illustration, and design example are provided.

Hazardous Chemicals Data, publication 49, National Fire Protection Association (NFPA), Quincy, MA, 1994 (170 pages, RDB6709)

flammability, toxicity, reactivity, safety classifications

History of Accidents in Ammonia Refrigeration Facilities in Japan (1951-1990), High Pressure Gas Safety Institute of Japan, 1991 (RDB5451)

R-717 (ammonia), safety

Kirk-Othmer Encyclopedia of Chemical Technology (third edition), John Wiley and Sons, Incorporated, New York, NY, 1978-1984 (RDB5165)

reference for flammability, toxicity, reactivity, and other safety data

Ongevallen met Ammoniak Koelinstallaties [Accidents with Ammonia Refrigeration Systems], Netherlands Organization for Applied Scientific

Research (TNO), Apeldoorn, The Netherlands, 28 May 1991 (RDB5496)

R-717 (ammonia), safety

Proctor & Hughes' Chemical Hazards of the Workplace (fourth edition), edited by G. J. Hathaway, N. H. Proctor, and J. P. Hughes, VNR / John Wiley and Sons, Incorporated, New York, NY, 1996 (720 pages, RDB8360)

widely cited reference on chemicals that pose occupational hazards: identifiers, acute and chronic toxicity, flammability, and other safety data

Refrigerant Safety Data — Recommendations of the Air-Conditioning and Refrigeration Industry, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993 (32 pages with 6 tables, available from JMC as RDB3A15)

The report provides toxicity and flammability data on refrigerants as well as recommended hazard categories and safety data. This information is needed to meet requirements for refrigerant use under the Uniform Fire Code (UFC) and Uniform Mechanical Code (UMC). The refrigerants addressed include R-11, R-12, R-22, R-113, R-114, R-123, R-134a, R-500, R-502, R-717 (ammonia), and R-744 (carbon dioxide). The information addressed includes Permissible Exposure Level (PEL), Immediately Dangerous to Life or Health (IDLH), and Lower Flammability Limit (LFL) values needed to set alarm and automatic shutdown levels. Where unavailable from sources prescribed by the UFC and/or UMC, surrogate values — established on a consistent basis — are offered. The report also provides hazard categories determined in accordance with the UFC and hazard signals determined in accordance with the UFC, UFC Standard 79-3, and National Fire Protection Association (NFPA) Standard 704-90. The report summarizes data assembled by industry experts, critically examined at a meeting convened solely for this purpose, and subsequently reviewed by the participants and others. The report provides an extensive list of references used to assemble the data. It also identifies the participants, contributors, and reviewers.

Refrigerants (SLGV), *Electrical Appliance and Utilization Equipment*, Underwriters Laboratories Incorporated (UL), Northbrook, IL, 1023-1025, 1996 (3 pages, RDB6938)

These listings cover refrigerants intended for use in air-conditioning and refrigerating equipment. The refrigerants have been classified for flammability only; pressure hazards were not evaluated. The listings cover product versions of R-11, R-12, R-22, R-123, R-134a, R-404A, R-407A, R-407B, R-407C, R-408A, R-409A, R-410A, R-500, R-507A, and R-508A. The listings indicate the UL flammability group (nonflammable, practically nonflammable, or flammable) following UL Standard 2182, *Refrigerants* and the ignition temperature if below 750 °C (1382 °F). They also indicate the chemical constituents, phase as shipped, and container types.

Addendum to Safety Code for Mechanical Refrigeration, ANSI/ASHRAE Addendum 15c-2000 (Addendum to ANSI/ASHRAE 15-1994), American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, 2000 [first distributed June 2000] (14 pages with 4 tables, RDBA675)

addendum 15c adds definitions, provisions, and data for pressure-relief valve piping for refrigerants; it also adds an appendix that documents a method to determine equivalent piping lengths; this addendum revises ANSI/ASHRAE Standard 15-1994 [see RDB4903]

Emergency Interim Standards Action for ANSI/ASHRAE Standard 15-1994, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, June 1998 (1 page, RDB8617)

this Emergency Interim Standards Action (EISA) changes the allowed test gases for field pressure testing of refrigeration systems to avoid gases or mixtures of gases that may become flammable; this EISA revises ANSI/ASHRAE Standard 15-1994 [see RDB4903]

Safety Code for Mechanical Refrigeration, ANSI/ASHRAE Standard 15-1994, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, August 1994 (RDB4903)

This voluntary, consensus standard specifies safety requirements for design, construction, installation, and operation of refrigerating systems, to establish safeguards for life, limb, health, and property. It applies to mechanical refrigerating systems and heat pumps used in identified occupancies. It also covers components added after adoption, refrigerant conversions, and replacement of parts and components with new ones that are not identical in function. This standard is widely incorporated

into construction codes, either by reference or by transcription with amendments. It identifies occupancy, system, and refrigerant safety classifications, the last by reference to ANSI/ASHRAE Standard 34-1992. It then prescribes restrictions on refrigerant use, including the maximum quantities of individual refrigerants that may be used for specific occupancies and systems. It also prescribes safety standards for design and construction of equipment and systems, operation, testing, and general requirements. Minimum safety devices, labeling, and tests also are specified. Appendices address the maximum allowable concentrations for blends, guidelines for emergency discharge of refrigerants, worst case fractionation, and a method for calculating the discharge capacity of pressure-relief devices for positive displacement compressors. A final appendix provides a cross-reference between paragraph numbers in the previous and current versions of this standard. This version supersedes ANSI/ASHRAE Standard 15-1992 and earlier editions.

Safety of Suva Refrigerants, document AS-1 (H-27530-3), DuPont Chemicals, Wilmington, DE, January 1994 (6 pages with 1 table, RDB4C48)

This bulletin reviews considerations for safe use of refrigerants by providing answers to common questions. It outlines the introduction of alternative refrigerants and associated testing. It briefly reviews the collaborative Programme for Alternative Fluorocarbon Toxicity Testing (PAFT) and individual programs and findings for specific refrigerants. The document discusses the flammability of R-123, R-124, R-125, and R-134a, noting that they are neither flammable nor explosive, but can become so when mixed with gases that are. The document notes that mixtures of R-134a with more than 60% air (by volume) can become flammable at raised pressures and temperatures. It counsels against use of refrigerant-air mixtures for leak testing. The document then addresses inhalation toxicity and the potential for suffocation. It explains the DuPont Acceptable Exposure Limit (AEL), a time-weighted average (TWA) concentration for an 8 or 12 hour day or 40 hour week, to which nearly all workers may be repeatedly exposed without adverse effects. It also explains Emergency Exposure Limit (EEL) values as airborne concentrations of brief duration which should not result in permanent adverse effects or interfere with escape in the event of a major release or spill. The document discusses symptoms of exposure to high refrigerant concentrations, cardiac sensitization, suffocation, safety measures for enclosed areas, dangers of deliberate inhalation, detection by odor, and guidance when a large spill or leak occurs. It goes on to address special requirements for R-123. The chemical formulae, boiling points, AELs, and EELs are tabulated for R-123, R-124, R-125, and R-134a. The bulletin provides general advice on skin and eye contact with refrigerants, frostbite, pressure hazards, handling and disposal of cylinders, brazing or welding of pipes in air-conditioning and refrigeration systems, and decomposition. It concludes with specific cautions. The document identifies related bulletins that may be helpful and recommends familiarization with the Material Safety Data Sheet (MSDS) provided for the refrigerant to be used. DuPont's product names are Suva® Centri-LP and Suva® 123 for R-123, Suva® 124 for R-124, and Suva® 125 for R-125. It identifies R-134a as Suva® Cold-MP, Suva® Trans A/C, and Suva® 134a.

Sax's Dangerous Properties of Industrial Materials (ninth edition), edited by R. J. Lewis, Sr. (revision of publication by N. I. Sax), VNR / John Wiley and Sons, Incorporated, New York, NY, 1996 (3 volumes totaling more than 2,454 pages, RDB6106)

widely cited reference for flammability, toxicity, and other safety data

Unfallverhütungsvorschrift UVV 20, Kälteanlagen [Accident Prevention Regulations UVV 20, Refrigerating Plants], Federal Republic of Germany, Köln, Germany (RDB4681)

refrigerant safety requirements

TOXICITY

B. E. Abreu (University of California Medical School), Auerbach, Thuringer, and Peoples, *Journal of Pharmacology and Experimental Therapeutics* (JPET), 80:139 ff, 1944 (RDB7290)

anesthetic effect of chlorine, bromine, and iodine derivatives of the methane and ethylene series of hydrocarbons, toxicity — as reported in RDB5980

B. E. Abreu (University of California Medical School), *Anesthesiology*, 2:393 ff, 1941 (RDB-7291)

anesthetic effect of chlorine, bromine, and iodine derivatives of the methane and ethylene

series of hydrocarbons, toxicity — as reported in RDB5980

J. Adir, D. A. Blake, and G. W. Mergner, **Pharmacokinetics of Fluorocarbons 11 and 12 in Dogs and Humans**, *The Journal of Clinical Pharmacology*, 15:760-770, 1975 (11 pages, RDB5C74)

inhalation toxicity of R-11 and R12; biochemistry; biotransformation; elimination

J. Adir, D. A. Blake, and G. W. Mergner (University of Maryland), **Kinetics of Uptake and Elimination of Trichlorofluoromethane (F-11) and Dichlorodifluoromethane (F-12) in Beagles and Humans**, abstract 171 (13th Annual Meeting of the Society of Toxicology (SOT), Washington, DC, 10-14 March 1974), *Toxicology and Applied Pharmacology* (TAP), 29(1):142-143, July 1974 (2 pages with no figures or tables, RDB59A9)

kinetics of uptake and elimination of R-11 and R-12 based on blood concentration in 6 beagles and 2 humans; concludes that the kinetics of these chemicals are consistent with their blood solubilities, oil-water partition characteristics, and other physiologic considerations

Y. Alarie and J. E. Luo, **Sensory Irritation by Airborne Chemicals: A Basis to Establish Acceptable Levels of Exposures**, *Toxicology of the Nasal Passages* (based on the Seventh Chemical Industry Institute of Toxicology, CIIT, Conference on Toxicology, Raleigh, NC, 22-23 February 1984), edited by C. S. Barrow, Hemisphere Publishing Corporation, Washington, DC, 91-100, 1986 (10 pages with 5 figures and 1 table, RDB6285)

acute toxicity, sensory irritation, prediction of acceptable levels, TLV-TWA predictions based on RD_{50}, RD_{50} values for 40 industrial chemicals, among which are 303 ppm for R-717 (ammonia) and 117 ppm for R-764 (sulfur dioxide)

Y. Alarie (University of Pittsburgh), **Dose-Response Analysis in Animal Studies: Prediction of Human Responses**, *Environmental Health Perspectives* (EHP), 42:9-13, 1981 (5 pages with 2 figures and 4 tables, RDB6279)

acute toxicity, dependence on exposure durations for irritation and lethal concentration measures, prediction of the levels and types of responses in humans at various multiples of the RD_{50} value found in mice, regression to TLV-TWA, RD_{50} values for 25 airborne, sensory irritants: Among them are 303 ppm for R-717 (ammonia) and 117 ppm for R-764 (sulfur dioxide). The effects indicated at multiples of the RD_{50} are severe injury and possible mortality at 10, intolerable to humans at 1, some sensory irritation at 0.1, no sensory irritation at 0.01, and no effect of any kind on the respiratory system at 0.001

Y. Alarie (University of Pittsburgh), **Bioassay for Evaluating the Potency of Airborne Sensory Irritants and Predicting Acceptable Levels of Exposure in Man**, *Food and Cosmetics Toxicology*, 19:623-626, 1981 (RDB6557)

health effects, toxicity, RD_{50}, TLV, R-717, R-764

Y. Alarie, L. E. Kane, and C. S. Barrow (University of Pittsburgh), **Sensory Irritation: A Basis to Establish Acceptable Exposure to Airborne Chemical Irritants**, *Principles and Practice of Industrial Toxicology*, edited by A. Reeves, John Wiley and Sons, Incorporated, New York, NY, 1980 (RDB6504)

health effects, toxicity, RD_{50}

Y. Alarie, **Sensory Irritation by Airborne Chemicals**, *Critical Reviews in Toxicology*, Chemical Rubber Company (CRC), Cleveland, OH, 2:299-366, 1973 (RDB6503)

acute toxicity, sensory irritation

Y. Alarie, I. Wikisaka, and S. Oka, **Sensory Irritation by Sulfur Dioxide and Chlorobenzylidene Malononitrile**, *Environmental Physiology and Biochemistry*, 3:53-74, 1973 (22 pages, RDB6506)

acute toxicity of R-764 (sulfur dioxide); sensory irritation RD_{50} = 117 ppm — as reported in RDB6557

M. W. Anders (University of Rochester Medical Center), **Metabolism and Toxicity of Hydrochlorofluorocarbons: Current Knowledge and Needs for the Future**, *Environmental Health Perspectives* (EHP), 96:185-191, 1991 (7 pages, RDB5935)

toxicity of R-123, R-125, and others; mutagenicity

K. Andersson and B. Johansson, **Measurement of Fluorocarbon (Freon) Contents in Different Working Environments**, report IVL B743, Inst. Vatten Luftvardsforsk, Göteborg, Sweden, 1983 (RDB7227)

measurements of refrigerant concentration in field conditions; safety; toxicity

M. E. Andersen, M. L. Gargas, R. A. Jones, and L. J. Jenkins, Jr., **Determination of the Kinetic**

Constants for Metabolism of Inhaled Toxicants In Vivo Using Gas Uptake Measurements, *Toxicology and Applied Pharmacology* (TAP), 54:100-116, 1980 (17 pages, RDB7254)

toxicity of R-114 and others; teratology

M. Antti-Poika, J. Heikkila, and L. Saarinen, **Cardiac Arrhythmias During Occupational Exposure to Fluorinated Hydrocarbons**, *British Journal of Industrial Medicine*, 47:138-140, 1990 (3 pages, RDBA935)

cardiac sensitization; toxicity

C. Aranyi, W. J. O'Shea, C. A. Halder, C. E. Holdsworth, and B. Y. Cockrell, **Absence of Hydrocarbon-Induced Nephropathy in Rats Exposed Subchronically to Volatile Hydrocarbon Mixtures Pertinent to Gasoline**, *Toxicology and Industrial Health*, 2(1):85-98, 1986 (14 pages, RDB6194)

tests of subchronic inhalation toxicity by exposure of male and female F-344 rats to a 50/50 mixture by weight of R-600a (isobutane) and R-601a (isopentane) — R-600a/601a (50/50) for 6 hr/d, 5 d/wk, for 13 wk: no significant, treatment-related effects were found and there was no evidence of nephropathy at the end of the study, though mild kidney effects were seen at an interim sacrifice point at 28 days — as reported in RDB7621

D. M. Aviado, **Fluorine-Containing Organic Compounds**, *Patty's Industrial Hygiene and Toxicology* (fourth edition), edited by G. D. Clayton and F. E. Clayton, John Wiley and Sons, Incorporated, New York, NY, 2B:1179-1204, 1994 (26 pages, RDB7231)

summary toxicity data and outline of toxicological considerations for fluorocarbons using R-11 as a prototype; also addresses comparative toxicity of R-12, R-21, R-22, R-113, R-114, R-115, R-142b, R-152a, R-C318; animal models for evaluation of fluorocarbon toxicity

D. M. Aviado (University of Pennsylvania School of Medicine), **Comparative Cardiotoxicity of Fluorocarbons**, *Cardiac Toxicology*, edited by T. Balazs, CRC Press, Incorporated, Boca Raton, FL, II:213-222, 1981 (10 pages with 1 figure and 3 tables, RDB6477)

detailed review of the cardiotoxicity of R-11; comparisons for R-12, R-13, R-21, R-22, R-23, R-31, R-113, R-114, R-115, R-123, R-124, R-132b, R-133a, R-142b, R-152a, R-1113, and R-1114, toxicity

D. M. Aviado (University of Pennsylvania School of Medicine), **Effects of Fluorocarbons, Chlorinated Solvents, and Inosine on the Cardiopulmonary System**, *Environmental Health Perspectives* (EHP), 26:207-215, 1978 (9 pages, RDB7423)

toxicity of R-11 and others

D. M. Aviado (University of Pennsylvania School of Medicine), **Physiological and Biochemical Responses to a Specific Group of Inhalants: Concluding Remarks**, *Federation Proceedings*, Federation of the American Society of Experimental Biologists, 37:2508-2509, 1978 (2 pages, RDB7430)

R-11, R-12, R-114, mixtures of them, and others, health effects, toxicity: sequence of events in deaths from cardiac sensitization from abuse of fluorocarbon aerosols (many also used as refrigerants) in "sniffing;" sensitization of the heart to prearrhythmic effects of epinephrine, depression of myocardial contractility, reduction in cardiac output, and irritation of mucosa in the upper and lower respiratory tract that causes an increase in sympathetic and vagal impulses to the heart — as reported in RDB7414

D. M. Aviado, S. Zakhari, and T. Watanabe (University of Pennsylvania School of Medicine), **Nonfluorinated Propellants and Solvents for Aerosols**, edited by L. Golberg, CRC Press, Cleveland, OH, 1977 (118 pages, Rdb6569)

health effects, interactions, and toxicity of R-30, R-140a, R-290 (propane), R-600 (n-butane), R-600a (isobutane), R-1120, ethanol, A-46 (R-290/600a/600 (17.1/80.4/2.5)), and others with comparative data for R-11, R-12, and R-114; cites inhalation toxicity data for R-600 of 2-hr LC_{50} mouse = 680 mg/l [281,000 ppm v/v] and 4-hr LC_{50} rat = 658 mg/l [272,000 ppm v/v] from Shugaev [see RDB5363])

D. M. Aviado (University of Pennsylvania School of Medicine), **Preclinical Pharmacology and Toxicology of Halogenated Solvents and Propellants**, monograph 15, National Institute of Drug Abuse Research, chapter 10, 164-184, 1977 (21 pages, RDB7247)

toxicity of R-114 and others

D. M. Aviado, S. Zakhari (University of Pennsylvania School of Medicine, USA), J. A. Simaan (American University of Beirut, Lebanon), and A. G. Ulsamer (U.S. Consumer Products Safety Commission, CPSC, USA), **Methyl Chloroform and Trichloroethylene in the Environment**, ed-

ited by L. Golberg, CRC Press, Cleveland, OH, 1976 (RDB7292)

toxicity of R-140a and R-1120; comparative data to other chemicalss

D. M. Aviado and J. Drimal (University of Pennsylvania School of Medicine), **Five Fluorocarbons for Administration of Aerosol Bronchodilators**, *Journal of Clinical Pharmacology*, 15(1/2):116-128, 1975 (13 pages with 4 figures and 3 tables, RDB6122)

investigates separate toxic effects on the upper (nose, pharynx, and larynx) and lower (lungs) respiratory tracts for R-11, R-12, R-114, R-115, and R-C318 administered by tracheal cannulas inserted in anesthetized dogs; responses measured by pulmonary resistance and compliance, heart rate, and aortic blood pressure; concludes that the three fluorochemicals widely used in aerosols, namely R-11, R-12, and R-114, elicit both bradycardia (slow heart rate) and tachycardia (relatively rapid heart rate) and induce bronchoconstriction or bronchodilation when inspired in large doses; also found that R-115 and R-C318 do not elicit any change in heart rate and produce only bronchodilation; recommends further study of the R-115 and R-C318 as potential replacements if the other three prove to be linked to deaths from use and abuse of aerosols

D. M. Aviado and D. G. Smith (University of Pennsylvania School of Medicine), **Toxicity of Aerosol Propellants in the Respiratory and Circulatory Systems, VIII. Respiration and Circulation in Primates**, *Toxicology*, 3(2):241-252, 1975 (12 pages, RDB5735)

toxicity of R-11, R-12, R-23, R-115, R-C318, and others

D. M. Aviado (University of Pennsylvania School of Medicine), **Toxicity of Aerosol Propellants in the Respiratory and Circulatory Systems, X. Proposed Classification**, *Toxicology*, 3(3):321-332, 1975 (12 pages with 2 tables, RDB5920)

R-11, R-12, R-21, R-22, R-30, R-113, R-114, R-115, R-140 or R-140a, R-142b, R-152a, R-290, R-C318, R-600a, and R-1140; toxicity: classifies propellants based on relative pressure and toxicity, the latter primarily effects on the respiratory and circulatory systems and the levels at which cardiac arrhythmias were produced; classifications include low-pressure propellants of high toxicity (R-11, R-21, R-30, R-113, and R-140 or R-140a), low-pressure propellants of intermediate toxicity (R-114, R-142b, R-C318, and R-600a); high-pressure propellants of intermediate toxicity (R-12, R-22, R-290, and R-1140), and high-pressure propellants of low toxicity (R-115 and R-152a); discussion of animal models for evaluation of acute toxicity, noting that the unanesthetized dog with epinephrine injection is 5-10 times more sensitive to propellants (many of which also used as refrigerants) than the anesthetized dog without injection of epinephrine

D. M. Aviado and M. A. Belej (University of Pennsylvania School of Medicine), **Toxicity of Aerosol Propellants in the Respiratory and Circulatory Systems, V. Ventricular Function in the Dog**, *Toxicology*, 3:79-86, 1975 (8 pages with 2 figures and 2 tables, RDB5C80)

toxicity of R-11, R-113, R-115, R-152a, and R-C318; concludes that "there is no available propellant for aerosols that is devoid of cardiodepressant action"

D. M. Aviado (University of Pennsylvania School of Medicine), **Toxicity of Aerosols with Special Reference to the Role of Propellants in Asthmatic Deaths**, *The Journal of Clinical Pharmacology*, 15:86-104, 1975 (19 pages, RDB65F6)

toxicity

D. M. Aviado (University of Pennsylvania School of Medicine), **Toxicity of Propellants**, *Fortschritte der Arzneimittelforschung* [Progress in Drug Research], Birkhäuser Verlag, Basel, Switzerland, 18:365-397, 1974 (35 pages, RDB6593)

toxicity of R-11, R-12, R-21, R-22, R-30, R-113, R-114 or R-114a, R-140a, R-142b, R-152a, R-290, R-C318, R-600a, R-1140, and others; health effects; toxicity: review of available information on the toxicity of 15 aerosol propellants (many also used as refrigerants); respiratory and cardiovascular effects on animals

D. M. Aviado (University of Pennsylvania School of Medicine), **Toxicity of Propellants**, *Proceedings of the Fourth Annual Conference on Environmental Toxicology*, Elsevier/North Holland, Amsterdam, The Netherlands, 16-19 October 1974 (RDB6594)

toxicity of R-152a and others

D. M. Aviado and M. A. Belej (University of Pennsylvania School of Medicine), **Toxicity of Aerosol Propellants on the Respiratory and Circulatory Systems, I. Cardiac Arrhythmia in the Mouse**, *Toxicology*, 2(1):31-42, 1974 (12 pages with 2 figures and 3 tables, RDB5854)

observes that when "aerosols were first introduced in the 1950s, the refrigerants were examined for possible use as propellants"; reports of fatalities from use or abuse of aerosols led to reexamination of their toxicity; cardiac sensitization, without and with epinephrine injection, in male mice anesthetized with sodium pentobarbitol: R-11, R-12, R-21, R-22, R-30, R-113, R-114, R-115, R-140 or R-140a, R-142b, R-152a, R-290, R-C318, R-600a, and R-1140; compares findings for mice to cardiac sensitization data for dogs based on published tests by others (see RDB5644) noting that R-12, R-142b, and R-152a sensitize dogs but not mice (no chemicals are identified that sensitize mice but not dogs); toxicity classifications for R-10, R-11, R-12, R-20, R-21, R-22, R-40, R-40B1, R-113, R-114, R-115, R-140 or R-140a, R-142b, R-152a, R-160, R-160B1, R-290, R-C318, R-600a, R-611, R-717, R-744, R-764, R-1140, and others

D. M. Aviado (University of Pennsylvania School of Medicine), **Cardiopulmonary Effects of Fluorocarbon Compounds**, paper 4, *Proceedings of the 2nd Annual Conference on Environmental Toxicology* (31 August - 2 September 1971), report AMRL-TR-71-120, Aerospace Medical Research Laboratory, U.S. Air Force, Wright-Patterson Air Force Base, OH, 31-39, December 1971 (9 pages with 4 figures, available from NTIS as document AD-751426, RDB6736)

R-11, R-12, and R-114; examines relation of cardiopulmonary toxicity to irritation of the sensory receptors in respiratory passages by tests on anesthetized dogs; identifies biological defense mechanisms to prevent entrance into and absorption of an irritant vapor by the lungs; observes that fluorocarbon compounds can cause depression of ventricular function

A. Azar, H. J. Trochimowicz, J. B. Terrill, and L. S. Mullin (E. I. duPont de Nemours and Company, Incorporated), **Blood Levels of Fluorocarbon Related to Cardiac Sensitization**, *AIHA Journal*, 34(3):102-109, 1973 (8 pages, RDB5357)

toxicity of R-11 and others

A. Azar (E. I. duPont de Nemours and Company, Incorporated), **Cardiac Sensitization of Fluorocarbon Propellants**, presentation at the Conference of Toxic Hazards of Halocarbon Propellants, U.S. Food and Drug Administration (FDA), Washington, DC, 16 July 1971 (23 pages with 3 figures and 7 tables, RDB6596)

toxicity of R-11, R-12, and R-114; cardiac sensitization

K. C. Back, A. A. Thomas, and J. D. MacEwen, **Reclassification of Materials Listed as Transportation Health Hazards**, report TSA-20-72-3, Aerospace Medical Research Laboratory (AMRL), U.S. Air Force, Wright-Patterson Air Force Base, OH, 1972 (RDB7298)

R-717 (ammonia) and others, health effects, toxicity: for ammonia, 1-hr LC_{50} mouse = 4,837 ppm v/v and 1-hr LC_{50} rat = 7,338 ppm v/v — as reported in RDB5340

R. D. Bagnall, W. Bell, K. Pearson, and A. Jeater (Imperial Chemical Industries Limited, UK), **New Inhalation Anaesthetics: III — Fluorinated Aliphatic Ethers**, *Journal of Fluorine Chemistry*, 13:123-140, 1979 (8 pages, RDB8311)

toxicity of hydrofluoroethers; anesthetic effects of R-E245ca2 and others — as reported in RDB7B15

G. N. Bakhishev, **Relation of the Toxicity of Some Halogenated Aliphatic Hydrocarbons to Their Electronic Structure**, *Gigiena Truda i Professional'nye Zabolevaniya* [Labor Hygiene and Occupational Diseases], Moscow, Russia (then USSR), 1:39-40, 1980 (2 pages in Russian, RDB5820)

toxicity of R-23 and others

K. S. Bakshi (National Research Council, NRC), **Toxicity of Alternatives to Chlorofluorocarbons: HFC-134a and HCFC-123**, *Inhalation Toxicity*, 10(10):963-967, October 1998 (5 pages with 1 table, RDB9127)

summarizes a detailed assessment (see RDB6A01) by the Board on Environmental Studies and Toxicology of the toxicities of R-123 and R-134a: provides recommendations to set emergency exposure guidance level (EEGL) concentrations for both and a continuous exposure guidance level (CEGL) for R-134a; recommends a 1 hr EEGL for R-134a of 4,000 ppm v/v based on the no-observed-adverse-effect level (NOAEL) in cardiac sensitization tests, divided by an uncertainty factor of 10 for interspecies variability; recommends a 24 hr EEGL for R-134a of 1,000 ppm based on a NOAEL of 10,000 ppm for ferotoxicity effects (slight retardation of skeletal ossification) in rats divided by an uncertainty factor of 10; recommends a 90-day CEGL for R-134a of 900 ppm based on a NOAEL of 50,000 ppm for a 2-yr chronic toxicity study in rats divided by an uncertainty factor

of 10, a factor of 4 for exposures of 24 hr/d instead of 6 hr/d, and a factor of 5/7 for exposures of 7 d/wk instead of the tested 5 d/wk; recommends a 1-min EEGL for R-123 of 1,900 ppm based on a cardiac sensitization EC_{50} dog of 19,000 ppm divided by an uncertainty factor of 10; differences in the time periods for the R-123 and R-134a exposure levels addressed reflect proposed uses of R-134a as a refrigerant on submarines, versus R-123 as a fire suppressant to replace halon 12 in flight-line extinguishers with very quick discharges

R. E. Bales (Tracor Jitco, Incorporated), **Fluorocarbons — Industrial Hygiene Survey**, publication PB-297772, National Institute of Occupational Safety and Health (NIOSH), U.S. Department of Health, Education, and Welfare (DHEW), Cincinnati, May 1978; republished as **Fluorocarbons — An Industrial Hygiene Survey of Worker Exposure in Four Facilities**, publication 79-101, NIOSH, Cincinnati, OH, October 1978 (50 pages with 2 figures and 8 tables, available from NTIS, RDB5824)

concentrations of R-10, R-11, R-12, R-13, R-13B1, R-22, R-23, R-30, R-113, R-114, R-115, R-116, R-140a, R-142b, R-152a (possibly R-152, incorrectly identified in the report as "CH_3F-CH_3F"), R-1110, R-1120, R-1132a, and others including toxic decomposition products in industrial sites: the plants surveyed (A) manufacture R-11, R-12, R-115, and R-116, package them, R-13B1, R-22, R-113, R-114, R-142b, R-152a, R-1132a, and other chemicals and intermediates, (B) produce R-11 and R-12 and package them and R-503 separately or with other gases, (C) use R-12 and R-113 to charge refrigeration compressors and degrease parts, respectively, and (D) produce R-764 and amines and package them with and other materials with R-11 and R-12 in aerosol spray cans for solvent, insecticide, and other uses; report shows worker exposure levels to be less than permissible levels on a time-weighted average basis for each of the sites, but identifies recommendations to minimize further exposures

S. M. Barlow and F. M. Sullivan, **Fluorocarbons**, *Reproductive Hazards of Industrial Chemistry*, Academic Press, London, UK, 326-333, 1982 (8 pages, RDB5171)

toxicity of R-11, R-12, R-21, R-22, R-31, R-112, R-113, R-114, R-115, and others

H. Bartsch, C. Malaveille, A.-M. Camus, G. Martel-Planche, G. Brun, A. Hautefeuille, N. Sabadie, A. Barbin, T. Kuroki, C. Drevon, C. Piccoli, and P. Montesano, **Validation and Comparative Studies of 180 Chemicals with Salmonella-Typhimurium Strains and V-79 Chinese Hamster**, *Mutation Research*, 78(1):1-50 (possibly 76:1-50), 1980 (50 pages, RDB5922)

toxicity of R-22 and others

R. C. Baselt and R. H. Cravey, **A Fatal Case Involving Trichlorofluoromethane and Dichlorodifluoromethane**, *Journal of Forensic Science*, 13(3):407-410, 1968 (4 pages, RDB6721)

toxicity of R-11 and R-12; accident involving human exposure — as reported in RDB6138

M. A. Belej and D. M. Aviado (University of Pennsylvania School of Medicine), **Cardiopulmonary Toxicity of Propellants for Aerosols**, presented at the Fifth International Pharmacological Congress (San Francisco, 23-28 July 1972); republished in *The Journal of Clinical Pharmacology*, 15(1/2):105-115, January 1975 (11 pages with 3 figures and 3 tables, RDB59A4)

R-11, R-12, R-21, R-114, R-115, R-123B1, R-142b, R-152a, R-C318, and R-600a as propellants; cardiopulmonary effects, bronchopulmonary and cardiovascular toxicity: concludes that all of the propellants cause acceleration of the heart rate; shows that R-11 has a significantly greater impact on blood pressure and heart rate in 30 anesthetized mongrel dogs while R-152a had the least effect

M. A. Belej, D. G. Smith, and D. M. Aviado (University of Pennsylvania School of Medicine), **Toxicity of Aerosol Propellants in the Respiratory and Circulatory Systems, IV. Cardiotoxicity in the Monkey**, *Toxicology*, 2(4):381-395, 1974 (15 pages, RDB5178)

toxicity of R-22, R-23, R-115, R-600a (isobutane), and others

M. A. Belej and D. M. Aviado (University of Pennsylvania School of Medicine), *Federation Proceedings*, Federation of the American Society of Experimental Biologists, 32:814, 1973 (1 page, RDB5C62)

toxicity of R-12 and others

R. Benigni, M. Cotta-Ramusino, and C. Andreoli, **Relationship Between Chlorofluorocarbon Chemical Structure and Their Salmonella Mutagenicity**, *Journal of Toxicology and Environmental Health*, 34(3):397-408, 1991 (12 pages, RDB5778)

quantitative analysis of the relationship between chemical structure and Salmonella mu-

tagenicity of R-32, R-114, R-115, R-124, R-125, R-134a, R-143a, R-152a, and others: molecules were characterized by both molecular orbital and physical chemical parameters; results of the analysis indicate that mutagenicity is correlated with both the free energy of binding to biological receptors and the energy of the highest occupied molecular orbit; concludes that fluorochemical mutagenicity is determined more by the rate of initial activation than by the rate of DNA attack since the same two factors favor catalyzed metabolism by cytochrome P-450

A. G. Berends (Solvay Duphar, The Netherlands), C. G. de Rooij (Solvay S.A., Belgium), S. Shin-ya (Asahi Glass Company, Limited, Japan), and R. S. Thompson (Zeneca, UK), **Biodegradation and Ecotoxicity of HFCs and HCFCs**, *Archives of Environmental Contamination Toxicology*, 36(2):146-151, February 1999 (6 pages, RDB9B44)

summarizes results of closed-bottle tests of the biodegradation of R-32, R-123, R-124, R-125, R-134a, R-141b, R-225ca, and R-225cb; found that these chemicals are not readily biodegradable since less than 60% was removed after 28 days; summarizes standard acute toxicity tests with R-123, R-141b, and R-225ca using algae, water fleas, and fish revealed EC_{50} values in the range of 17-126 mg/L; similar tests of R-134a found EC_{50} concentrations of 450-980 mg/L; fish studies with R-141b and R-225ca revealed bioaccumulation factors of <3 and 15-64, respectively; a study with plants revealed no effect from R-141b on seed germination and growth of wheat (Triticum aestivum), radish (Raphanus sativus), and cress (Lepidium sativum); concludes that hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs) are not very toxic to aquatic organisms and terrestrial plants; also concludes that there was no evidence for any aerobic biodegradation for most of the HFCs and HCFCs

M. C. Bindal et al., **Quantitative Correlation of Anesthetic Potencies of Halogenated Hydrocarbons with Boiling Points and Molecular Connectivity**, *Fortschritte der Arzneimittelforschung* [Progress in Drug Research], Birkhäuser Verlag, Basel, Switzerland, 30(2):234-236, 1980 (3 pages, RDB6184)

toxicity of R-124 and others

D. A. Blake and G. W. Mergner (University of Maryland), **Are Fluorocarbon Propellants Metabolized? Studies in ^{14}C-Labeled Trichlorofluoromethane (F-11) and Dichlorodifluoromethane (F-12) in Beagles and Humans**, abstract 170 (13th Annual Meeting of the Society of Toxicology (SOT), Washington, DC, 14 March 1974), *Toxicology and Applied Pharmacology* (TAP), 29(1):142, July 1974 (1 page with no figures or tables, RDB59A7)

investigation of biotransformation of R-11 and R-12 in 5 male and female beagles and 4 humans after a 7-20 minute inhalation; found that essentially all of the chemicals was recovered in unaltered form from exhaled air within one hour and, therefore, that R-11 and R-12 are refractory to biotransformation

H. M. Bolt (University of Dortmund, Germany) and J. T. Borlak (Fraunhofer Institute, Germany), **Halogenated Hydrocarbons**, *Toxicology*, edited by H. Marquardt, Academic Press, San Diego, CA, 645-657, 1999 (13 pages with 8 figures and 1 table, RDBA525)

reviews the toxicity of common halocarbons with focus on those used as solvents; addresses R-10 (carbon tetrachloride), R-20 (chloroform), R-30 (methylene chloride), R-140 (1,1,2-trichloroethane), methyl chloroform), R-140a (methyl chloroform), R-1110 (PER, perchloroethylene), R-1120 (TRI, trichloroethylene), R-1130a (vinylidene chloride), and R-1140 (vinyl chloride); also briefly addresses R-11, R-13, R-21, R-22, R-31, R-112, R-113, R-123B1 (halothane), R-130, R-142b, R-150, R-150B2, and R-260B2; discussion emphasizes exposure limits, underlying metabolism of the chemicals, and chemical similarities

W. Braker and A. L. Mossman, **Nontoxic Halogenated Aliphatic Hydrocarbons and Halogenated Fluorocarbons**, *Effects of Exposure to Toxic Gases — First Aid and Medical Treatment*, edited by W. Braker and A. L. Mossman, 71-73, 1970 (3 pages, RDB7224)

toxicity fluorochemicals; safety

W. T. Brashear, M. M. Ketcha, D. L. Pollard, C. S. Godin, H. F. Leahy, P. P. Lu, E. R. Kinkead, and R. E. Wolfe (ManTech Environmental Technology, Incorporated), **Metabolite Identification of Halon Replacement Compounds**, report AL-TR-1992-0078, Armstrong Laboratory, U.S. Air Force, Wright-Patterson Air Force Base, OH, June 1992 (36 pages with 13 figures and 8 tables, available from JMC as RDB6B50)

metabolism of R-123, R-124, R-142b, R-51-14 (perfluorohexane) by groups of Fischer 344 and Sprague-Dawley rats from exposures at 10,000

ppm v/v in air for 2 hr: biochemistry, health effects, toxicity

W. J. Brock and H. J. Trochimowicz (E. I. duPont de Nemours and Company), **Use of Acute Inhalation Toxicity Data in Setting Emergency Exposure Limits**, *EUROTOX'97, Diversification in Toxicology: Man and Environment* (proceedings of the XXXVI European Congress of Toxicology, EuroTox, Århus, Denmark, 25-28 June 1997), Nordic Pharmacological Society, Copenhagen Denmark, 1997; abstract P4-38 republished in *Pharmacology and Toxicology*, 80(supplement III):117, 1997 (1 page with no figures or tables, RDBA621)

describes an approach and data assembled to set recommended emergency escape concentrations (EECs), to ensure safe egress from situations where a large release has occurred; notes that acute toxicity data were obtained for R-32, R-123, R-125, R-134a, and R-141b in the Program for Alternative Fluorocarbon Toxicity Testing (PAFT); all showed low inhalation toxicity with LC_{50}s of 32,000 to >800,000 ppm v/v; indicates that these compounds, like many halocarbons and hydrocarbons, can sensitize the heart to an intravenous epinephrine challenge; the concentrations that induce cardiac sensitization in these compounds were 5,000-250,000 ppm v/v; based on these data, the authors recommended EEC concentrations of 1,000-50,000 ppm v/v

W. J. Brock and H. J. Trochimowicz, **Use of Acute Inhalation Toxicity Data in Setting Emergency Exposure Limits**, presentation at *EUROTOX'97, Diversification in Toxicology: Man and Environment* (XXXVI European Congress of Toxicology, EuroTox, Århus, Denmark, 25-28 June 1997), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1997 (18 pages with 18 presentation charts, RDBA622)

presents data and criteria to set recommended emergency escape concentrations (EECs) to ensure safe egress from situations where a large release has occurred; notes that acute toxicity data were obtained for R-32, R-123, R-125, R-134a, and R-141b in the Program for Alternative Fluorocarbon Toxicity Testing (PAFT); all showed low inhalation toxicity with LC_{50}s of 32,000 to >800,000 ppm v/v; indicates that these compounds, like many halocarbons and hydrocarbons, can sensitize the heart to an intravenous epinephrine challenge; the concentrations that induce cardiac sensitization in these compounds were 5,000-250,000 ppm v/v; based on these data, the authors recommended EEC concentrations of 1,000-50,000 ppm v/v; tabulates the chemical formulae, normal boiling point (NBP) temperatures, median or approximate lethal concentrations (LC_{50} or ALC), cardiac sensitization threshold, and 10-min median effective concentrations (EC_{50}) for anesthetic effects for R-11, R-12, R-13, R-13B1, R-22, R-23, R-32, R-113, R-114, R-115, R-123, R-124, R-125, R-134a, R-141b, R-142b, R-143a, R-152a, R-225cb, and R-236fa; outlines EEC criteria involving these data and other escape impairing effects; tabulates proposed EEC concentrations for these refrigerants

W. J. Brock, **Toxicology Summary for CFC's HCFC's and HFC's**, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, undated circa 1996 (RDB6452)

R-11, R-12, R-22, R-23, R-30, R-32, R-113, R-114, R-115, R-123, R-123B1, R-124, R-125, R-134a, R-140a, R-141b, R-143a, R-152a, R-236fa, R-43-10, R-717, R-1110, R-1120; tabular summary of toxicity indicators including ALC/LC_{50}, cardiac sensitization threshold, anesthetic concentration, subchronic NOEL/NOAEL, *in vitro* mutagenicity, in vivo mutagenicity, developmental toxicity, chronic and oncogenicity (carcinogenicity and tumors), and AEL/TLV

R. S. Brody, T. Watanabe, and D. M. Aviado (University of Pennsylvania School of Medicine), **Toxicity of Aerosol Propellants on the Respiratory and Circulatory Systems, III. Influence of Bronchopulmonary Lesion on Cardiopulmonary Toxicity in the Mouse**, *Toxicology*, 2:173-184, 1974 (12 pages, RDB5C66)

toxicity of R-11, R-12, R-152a, and others; cardiac sensitization

W. E. Brown (University of Toronto, Canada), **Experiments with Anesthetic Gases Propylene, Methane, Dimethyl-Ether**, *Journal of Pharmacology and Experimental Therapeutics* (JPET), 23:485-496, 1924 (8 pages with no figures or tables, RDB6A61)

experimental study in cats to evaluate the effectiveness R-50, R-E170, and R-1270, as anesthetic agents by inhalation; toxicity: R-50 produces general anesthesia, but only in concentrations exceeding 850,000 ppm; 900,000 ppm caused irregular respiration; R-E170 produces general anesthesia with concentrations

of 650,000 ppm, but is unpleasant to take; R-1270 induces anesthesia in cats at 370,000-500,000 ppm; effect is sustainable with 200,000-310,000 ppm; some toxic effects were noted above 400,000 ppm; 500,000 ppm produced anesthesia in humans in 2 minutes; recovery was complete

W. E. Brown and V. E. Henderson (University of Toronto, Canada), **Experiments with Anesthetic Gases**, *Anesthesia and Analgesia*, 27(1):1-8, 1925 or *Journal of Pharmacology and Experimental Therapeutics* (JPET), 27:1 ff, 1925 (8/? pages, RDB6108)

anesthetic effect and toxicity of hydrocarbons including R-290 and others

R. M. Burgison, W. E. O'Malley, C. K. Heisse, J. W. Forest, and J. C. Krantz, Jr., **Anesthesia. XLVI. Fluorinated Ethylenes and Cardiac Arrhythmias Induced by Epinephrine**, *Journal of Pharmacology and Experimental Therapeutics* (JPET), 114:470-472, 1955 (3 pages, RDB6568)

R-1111, R-1113, R-1114, R-1122 or R-1122a, R-1130c, R-1130t, R-1132 or R-1132a, and others, cardiac sensitization, toxicity as reported in RDB5644

J. H. Burn, H. G. Epstein, and P. J. Goodford (University of Oxford, UK), **The Properties of the Anaesthetic Substance 1:1:2-Trifluoro-1:2-dichloroethane**, *British Journal of Anaesthesia*, 31:518-529, 1959 (12 pages with 7 figures and 4 tables, RDB6586)

reports toxicity tests in mice and dogs to assess the potentials of R-123a, R-123B1 (halothane), and ether as medical anesthetic agents

J. H. Burn (University of Oxford, UK), **Pharmacological Testing of Anaesthetics**, *Proceedings of the Royal Society of Medicine* (meeting of the Section of Anesthetics, 7 November 1958), UK, 52(2):-95-98, February 1959 (4 pages with 2 tables, RDB6587)

reports toxicity tests in mice to compare the potentials R-112, R-113, and R-123B1 (halothane) to ether as medical anesthetic agents [R-112 and R-113 are identified only as compounds "A" and "B" in this paper, but are revealed RDB6586]

T. H. S. Burns (St. Thomas's Hospital and the Royal Northern Hospital, UK), J. M. Hall (Guy's Hospital, UK), A. Bracken, and G. Gouldstone (formerly British Oxygen Company Limitred), **Fluorine Compounds in Anaesthesia (9): Examination of Six Aliphatic Compounds and Four Ethers**, *Anaesthesia*, 37:278-284, 1982 (7 pages with 1 table, RDB6B51)

R-123, R-133al1, R-227ca, R-318, R-E347pce2, R-E356pee2, R-41-12, R-51-14, and others, anesthetic effect, toxicity: 6 mice smoothly and deeply anesthetized by 80,000 ppm v/v in 1 min 10 sec, 2 mice died in 16 min and 2 more died in 17 min when the concentration had fallen to 53,000 ppm; R-318 exposures resulted in muscle spasms and death to 1 of 4 mice at "high concentration" for 25 min

T. H. S. Burns (St. Thomas's Hospital and the Royal Northern Hospital, UK), J. M. Hall (Guy's Hospital, UK), A. Bracken, and G. Gouldstone (British Oxygen Company, UK), **Fluorine Compounds in Anaesthesia (6): Examination of 14 Heavily Halogenated Ring Compounds**, *Anaesthesia*, 19:167-176, 1964 (10 pages, RDB-7560)

cyclic halocarbons possibly including R-C270 and R-C318, anesthetic effect, toxicity

T. H. S. Burns (St. Thomas's Hospital and the Royal Northern Hospital, UK), J. M. Hall (Guy's Hospital, UK), A. Bracken, and G. Gouldstone (British Oxygen Company, UK), **Fluorine Compounds in Anaesthesia (5): Examination of Six Heavily Halogenated Aliphatic Compounds**, *Anaesthesia*, 17(3):337-343, July 1962 (7 pages with 1 table, RDB5939)

anesthetic effect, toxicity: R-123 10-min anesthetic LOEL mouse = 40,000 ppm v/v, 40-min anesthetic LOEL mouse = 30,000 ppm; R-125 anesthetic NOEL mouse at 930,000 ppm; R-235cb; R-235cbB1; R-1113

T. H. S. Burns (St. Thomas's Hospital and the Royal Northern Hospital, UK), J. M. Hall (Guy's Hospital, UK), A. Bracken, and G. Gouldstone (British Oxygen Company, UK), **Fluorine Compounds in Anaesthesia (4): Examination of an Ethane and Four Ethers**, *Anaesthesia*, 16:440-444, 1961 (5 pages, RDB7559)

anesthetic effect, toxicity

T. H. S. Burns (St. Thomas's Hospital and the Royal Northern Hospital, UK), J. M. Hall (Guy's Hospital, UK), A. Bracken, G. Gouldstone (British Oxygen Company, UK), and D. S. Newland, **An Investigation of New Fluorine Compounds in Anaesthesia (1)**, *Anaesthesia*, 16:3-18, 1961 (16 pages, RDB65B4)

anesthetic effect, toxicity

J. M. Calm (Engineering Consultant), **Toxicity Data to Determine Refrigerant Concentration Limits**, report DOE/CE/23810-110, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, September 2000 (534 pages with 9 tables, RDBA950)

This report reviews toxicity data, identifies sources for them, and presents resulting exposure limits for refrigerants for consideration by qualified parties in developing safety guides, standards, codes, and regulations. It outlines a method to calculate an acute toxicity exposure limit (ATEL) and from it a recommended concentration limit (RCL) for emergency exposures. The report focuses on acute toxicity with particular attention to lethality, cardiac sensitization, anesthetic and central nervous system (CNS) effects, and other escape-impairing effects. It addresses R-11, R-12, R-22, R-23, R-32, R-113, R-114, R-116, R-123, R-124, R-125, R-134, R-134a, R-E134, R-141b, R-142b, R-143a, R-152a, R-218, R-227ea, R-236fa, R-245ca, R-245fa, R-290, R-500, R-502, R-600a, R-717, and R-744. It summarizes additional data for R-14, R-115, R-170 (ethane), R-C318, R-600 (n-butane), and R-1270 (propylene) to enable calculation of limits for blends incorporating them. The report summarizes the data and related safety information, including classifications and flammability data. It also presents a series of tables with proposed ATEL and RCL concentrations — in dimensionless form and the latter also in both metric (SI) and inch-pound (IP) units of measure — for both the cited refrigerants and 66 zeotropic and azeotropic blends. They include common refrigerants such as R-404A, R-407C, R-410A, R-507A, and others. Appendices provide profiles for the cited single-compound refrigerants and for R-500 and R-502 as well as narrative toxicity summaries for common refrigerants. The primary intended use of the data is to assist the committees responsible for ASHRAE Standard 34, *Designation and Safety Classification of Refrigerants*, and in turn ASHRAE Standard 15, *Safety Code for Mechanical Refrigeration*. The report includes an extensive set of references. [see RDB6832 for background]

J. M. Calm (Engineering Consultant), **The Toxicity of Refrigerants**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, 157-162, July 1996; republished as report DOE/CE/23810-72E, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 1996 (6 pages with 1 table, available from JMC as RDB6832)

This paper presents toxicity data and exposure limits for refrigerants. The data address both acute (short-term, single exposure) and chronic (long-term, repeated exposure) effects, with emphasis on the former. The refrigerants covered include those in common use for the last decade, those used as components in alternatives, and selected candidates for future replacements. Specifically addressed are R-11, R-12, R-22, R-23, R-32, R-113, R-114, R-115, R-116, R-123, R-124, R-125, R-134a, R-141b, R-142b, R-143a, R-152a, R-218, R-290, R-C318, R-600, R-600a, R-717, R-744, and R-1270. The paper also reviews the toxicity indicators used in both safety standards and building, mechanical, and fire codes. Data are tabulated for the LC_{50}, cardiac sensitization NOEL and LOEL, anesthetic/CNS EC_{50}, respiratory RD_{50}, IDLH (both from the Standards Completion Program and from the 1994 revisions), PEL, UL group, and Standard 34 safety classifications. The paper outlines current classification methods for refrigerant safety and relates them to standard and code usage. [see RDBA950 for update]

D. D. Campbell, J. E. Lockey, N. Petajan, B. J. Gunter, and W. H. Rom, **Health Effects Among Refrigeration Repair Workers Exposed to Fluorocarbons**, *British Journal of Industrial Medicine*, 43(2):107-111, 1986 (5 pages, RDB5946)

toxicity of R-12, R-502, and others in humans; clinical report of exposures; safety

R. D. Cane, N. Buchanan, and M. Miller, **Pulmonary Oedema Associated with Hydrocarbon Inhalation**, *Intensive Care Medicine*, 3:31-33, 1977 (3 pages, RDB8121)

toxicity of hydrocarbons in humans

C. P. Carpenter, H. F. Smyth, Jr., and U. C. Pozzani (Carnegie-Mellon Institute, then the Mellon Institute, University of Pittsburgh), **The Assay of Acute Vapor Toxicity and the Grading and Interpretation of Results on 96 Chemicals**, *Journal of Industrial Hygiene and Occupational Medicine*, 31(6):343-346, 1949 (4 pages with 2 tables, RDB5643)

R-130, R-140, R-142b, R-150, R-150a, R-152a, R-161, R-717, R-1112a, R-1113, R-1120, R-1130a, R-1132a, and others: LC_{50} (widely referenced)

C. J. Carr, R. M. Burgison, J. F. Vitcha, and J. C. Krantz, Jr. (University of Maryland), **Anesthesia XXXIV. Chemical Constitution of Hydrocarbons and Cardiac Automaticity**, *Journal of Pharmacology and Experimental Therapeutics* (JPET), 97:1-3, 1949 (3 pages, RDB7404)

describes toxicity tests to determine the cardiac sensitization potential of hydrocarbons (HC) mixed with oxygen in dogs with epinephrine hydrochloride injections before and approximately 10 minutes into exposures

W. H. Chambers et al., **An Investigation of the Toxicity of Proposed Fire Extinguishing Fluids**, report 23, Medical Division, Chemical Corps, U.S. Army Chemical Center, October 1950 (RDBA656)

toxicity of R-744 (carbon dioxide) and others

F. Caujolle (Centre de Recherches sur les Toxicités du Centre National de la Recherche Scientifique, CNRS, France), **Comparative Toxicity of Refrigerants / Toxicité Comparée des Fluides Frigorigènes**, topical study 13131, *Bulletin of the International Institute of Refrigeration* (IIR), 44(1):-20-55, 1964 (36 pages with 5 figures and 1 table, in English and French, RDB7424)

comparative toxicity, concern levels, exposure symptoms, health effects, and other data for R-11, R-12, R-12B1, R-13, R-13B1, R-14, R-20, R-21, R-22, R-23, R-30, R-40, R-112, R-113, R-11, R-114B2, R-115, R-116, R-140a, R-160, R-160B1, R-C318, R-600, R-600a, R-601, R-601a, R-602, R-602a, R-744, R-717, R-764, R-1113, R-1114, R-1130, R-1140, R-1216, and others

F. Cavender, **Aliphatic Hydrocarbons**, *Patty's Industrial Hygiene and Toxicology* (fourth edition), edited by G. D. Clayton and F. E. Clayton, John Wiley and Sons, Incorporated, New York, NY, 2B:1221-1266, 1994 (46 pages, RDB7619)

summarizes toxicity data for R-600a (isobutane) and others

S. Chang, H. A. Lincoff, D. J. Coleman, W. Fuchs, and M. E. Farber, **Perfluorocarbon Gases in Vitreous Surgery**, *Ophthalmology*, 92(5):651-656, 1985 (6 pages, RDB7633

toxicity of R-116 and R-218: summarizes treatment of 56 patients with complicated retinal detachments by vitreous surgery using perfluorocarbon (PFC) gases, noted as capable of greater expansion and longevity compared to R-7146 (sulfur hexafluoride); the retinas of 31 patients (55.4%) were attached at 6 months after the disappearance of the gas; complications included increased intraocular pressure, which was usually transient, and gas-induced lens opacities

J. L. Chapel and G. Thomas, **Aerosol Inhalation for "Kicks"**, *Modern Medicine*, 67:378 ff, 1970 (RDB7218)

"sniffing" and associated deaths, abuse

F. A. Charlesworth, **The Fate of Fluorocarbons, Inhaled or Ingested**, *Food and Chemical Toxicology* (FCT), 13(5):572-574, October 1975 (3 pages with 1 table, RDB5940)

compares the blood levels from metered-dose inhaler (MDI) and food aerosol use to the cardiac-sensitization (CS), inhalation concentrations of R-11, R-12, R-113, R-114, R-115: concludes that the blood concentrations from aerosol use are far below the CS levels; notes that while the average elimination half-life of the fluorochemicals is very short (13.7 seconds for R-11 and 14.8 seconds for R-12) is very short, the biological half-life is longer due to rapid distribution and absorption in tissues

M. B. Chenoweth and C. L. Hake (Dow Chemical Company), **The Smaller Halogenated Aliphatic Hydrocarbons**, publication unknown, 363-398, circa 1962 (36 pages with no figures or tables, RDB7128)

summarizes the toxicity of selected halogenated compounds with focus on potential as anesthetic agents; addresses R-10, R-20, R-20B3, R-30, R-31, R-40, R-40B1, R-123B1, R-130, R-140a, R-150, R-150a, R-150B2, R-160, R-E252cb1, R-1110, R-1120, R-1140, and others; summarizes literature review covering 1955-1961

M. B. Chenoweth (Edgewood Arsenal Medical Research Laboratory, U.S. Army), **Ventricular Fibrillation Induced by Hydrocarbons and Epinephrine**, *Journal of Industrial Hygiene and Toxicology*, 28(4):151-158, July 1946 (8 pages with 9 figures and 1 table, RDB65A2)

presents qualitative tests of cardiac sensitization to epinephrine in anesthetized dogs by exposures to R-50 (methane), R-600 (n-butane), R-602 (hexane), R-603 (heptane), benzene, xylene, toluene, petroleum ether, and gasoline; found that heptane and benzene were the most potent and that gasoline and the cyclic compounds were nearly as effective, but all of these "solvents" produced cardiac sensitization; also presents rough quantitative tests for R-600 and gasoline, with concentrations estimated by a

"hot-wire analyzer" [see note below]; notes that R-C270 (cyclopropane), petroleum ether, benzene, R-10 (carbon tetrachloride), R-20 (chloroform), R-30 (methylene chloride), R-40 (methyl chloride), R-160 (ethyl chloride), bromine analogues of the cited chlorocarbons, DDT also are capable of cardiac sensitization based on other studies; toxicity [hot-wire analyzers were used to estimate concentrations of combustible gases, but were not precise instruments.]

W. L. Chiou and J. H. Hsiao, **Fluorocarbon Aerosol Propellants V: Binding Interaction with Human Albumin**, *Journal of Pharmaceutical Sciences*, 64:1052-1054, 1975 (3 pages, RDB7256)

toxicity of R-114 and others; teratology

W. L. Chiou and J. H. Hsiao, **Thermodynamic Aspect of the Interaction of Bovine Albumin**, *Pharmacology*, 13:128-136, 1975 (9 pages, RDB7257)

toxicity of R-114 and others; teratology

W. L. Chiou, *Research Communications in Chemical Pathology and Pharmacology*, 7(4):679-686, 1974 (8 pages, RDB7542)

toxicity of R-114 and others; biochemistry; decomposition

W. L. Chiou and S. Niazi, **A Simple and Ultra-Sensitive Head-Space Gas Chromatographic Method for the Assay of Fluorocarbon Propellants in Blood**, *Research Communications in Chemical Pathololgy and Pharmacology*, 6(2):481-498, 1973 (RDB8131)

describes a laboratory method to quantify fluorochemical propellant (and refrigerant) concentrations in blood

D. G. Clark and D. J. Tinston (Imperial Chemical Industries PLC, ICI, UK), **Acute Inhalation Toxicity of Some Halogenated and Nonhalogenated Hydrocarbons**, *Human Toxicology*, 1(3):239-247, 1982 (9 pages with 4 tables, RDB6110)

presents acute inhalation toxicity findings for R-10, R-11, R-12, R-12B1, R-13, R-13B1, R-20, R-22, R-30, R-112, R-113, R-114B2, R-140a, R-290 (propane), R-600a (isobutane), R-1120, and R-1140; addresses lethality, LC_{50} data, central nervous system (CNS) effects, anesthetic EC_{50} data, cardiac sensitization (CS), and CS EC_{50} data

D. G. Clark and D. J. Tinston (Imperial Chemical Industries Limited, ICI, UK), **Correlation of the Cardiac Sensitizing Potential of Halogenated Hydrocarbons with Their Physiochemical Properties**, *British Journal of Pharmacology*, 49(2):355-357, 1973 (3 pages with 1 table, RDB6109)

the potencies for cardiac sensitization to adrenaline in dogs for R-10, R-11, R-12, R-13, R-13B1, R-21, R-30, R-112, R-113, R-114, R-123B1, R-140a, R-290, and R-1140 were found to be directly related to their saturated vapor pressures: the ratio of the partial pressure at the EC_{50} for cardiac sensitization to the saturated vapor pressure at 37 °C (98.6 °F) was approximately constant (0.01-0.03), despite sensitization concentrations that differed 700-fold and values of partial pressures that differed 300-fold; findings suggest that cardiac sensitization is probably a structurally nonspecific action that is an example of physical toxicity; paper notes that none of the halogenated hydrocarbons studied produced cardiac arrhythmias on inhalation without adrenaline, but all sensitized the heart at sufficiently high concentrations; paper also notes that a post exposure injection of adrenaline never resulted in arrhythmias, even when it followed a challenge injection that had caused arrhythmias, as the chemicals are rapidly eliminated from the body; this observations indicates that sensitization is a transient phenomenon dependent on temporary interactions and not on structural damage to the heart; a table presents the sensitization EC_{50} and physical property data

D. G. Clark and D. J. Tinston (Imperial Chemical Industries PLC, ICI, UK), **Cardiac Effects of Isoproternol, Hypoxia, Hypercapnia and Fluorocarbon Propellants and their Use in Asthma Inhalers**, *Annals of Allergy*, 30(9):536-541, 1972, also RDB5367] (6 pages, RDB6724)

cardiac sensitization to epinephrine of R-11, R-12, and others; indicates a LOEL for R-11 at 12,500 ppm v/v and a LOEL for R-12 at 70,000-80,000 ppm v/v — as reported in RDB5143 and RDB5367

D. G. Clark and D. J. Tinston (Imperial Chemical Industries Limited, ICI, UK), **The Influence of Fluorocarbon Propellants on the Arrhythmogenic Activities of Adrenaline and Isoprenaline**, *Proceedings of the XIIIth Meeting of the European Society for the Study of Drug Toxicology*, 13:212-217, 1972 (6 pages, RDB5A68)

R-11, R-12, R-114, and others, cardiac sensitization, toxicity as reported in RDB5141 and RDB7525

D. G. Clark and D. J. Tinston (Imperial Chemical Industries Limited, ICI, UK), *British Medical Journal*, UK, III:113-114, 1971 (2 pages, RDB7543)

toxicity of R-114 and others

J. W. Clayton, Jr. (E. I. duPont de Nemours and Company, Incorporated), **Highlights of Fluorocarbon Toxicology**, *Laboratory Diagnosis of Diseases Caused by Toxic Agents*, edited by F. W. Sunderman, Warren H. Green, Incorporated, Saint Louis, MO, chapter 21A, 199-214, 1970 (6 pages, RDB8192)

toxicity of fluorochemical refrigerants

J. W. Clayton, Jr. (E. I. duPont de Nemours and Company, Incorporated), **Fluorocarbon Toxicity: Past, Present, and Future**, *Journal of the Society of Cosmetic Chemists*, 18:333-350, 27 May 1967 (18 pages with 8 tables, RDB5C41)

R-10, R-11, R-12, R-12B1, R-12B2, R-13, R-13B1, R-14, R-20, R-21, R-22, R-23, R-30, R-40, R-112, R-112a, R-113, R-114, R-115, R-116, R-122, R-123, R-124a, R-125, R-133a, R-133aB1, R-142, R-142B1, R-226cb, R-226cbB1, R-234cb, R-235ca, R-235cc, R-C318, toxicity, historical evolution of toxicity classification

J. W. Clayton, Jr. (E. I. duPont de Nemours and Company, Incorporated), **Fluorocarbon Toxicity and Biological Action**, *Fluorine Chemistry Reviews*, 1:197-252, 1967; republished in *Toxicity of Anaesthetics*, edited by Fink, Williams and Williams Publishers, 1968 (56 pages with 5 figures and 36 tables, RDB5C42)

R-10, R-11, R-12, R-12B1, R-12B2, R-13, R-13B1, R-14, R-20, R-21, R-22, R-23, R-30, R-40, R-112, R-112a, R-113, R-114, R-115, R-116, R-122, R-123, R-124a, R-125, R-133a, R-133aB1, R-142, R-142B1, R-226cb, R-226cbB1, R-234cb, R-235ca, R-235cc, R-C318, toxicity (acute inhalation, biological action, chronic, oral, skin, and eye), historical evolution of toxicity classification; comprehensive summary and outline of attempts to link toxicity to chemical structure; indicates that substitution of fluorine for hydrogen or other halogens produces a chemically more stable compound and reduces toxicity

J. W. Clayton, Jr. (E. I. duPont de Nemours and Company, Incorporated) **The Mammalian Toxicology of Organic Compounds Containing Fluorine**, chapter 9, *Handbuch der experimentellen Pharmakologie* [Handbook of Experimental Pharmacology], edited by O. Eichler, A. Farah, H. Herken, and A. D. Welch, Springer-Verlag, Berlin, Germany, XX/1:459-500, 1966 (42 pages, RDB6590)

toxicity review of fluorine chemicals as reported in RDB5C42

J. W. Clayton, Jr. (E. I. duPont de Nemours and Company, Incorporated), **The Toxicity of Fluorocarbons with Special Reference to Chemical Constitution**, *Journal of Occupational Medicine*, 4(5):262-273, May 1962; republished as bulletin S-22, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, April 1965 (12 pages with 10 figures and 9 tables, RDB5169)

R-10, R-11, R-12, R-13, R-14, R-20, R-21, R-22, R-23, R-30, R-40, R-112, R-113, R-114, R-115, R-116, R-124a, R-133a, R-133aB1, R-142, R-142B1, R-217ba, R-226cb, R-226cbB1, R-234cb, R-235ca, R-235cc, R-C318, R-752 (SF_4), R-7146 (SF_6), R-7122 (S_2F_{10}), R-1110, R-1112, R-1113, R-1114, R-1120, R-1130, R-1132a, R-1216, R-1318, fluoroelastomer (Viton A and B), monofluoroacetic acid, polyfluoroalcohols, polytetrafluoroethylene (PTFE) resin, and others; decomposition, toxicity

M. A. Collins (ICI Chemicals and Polymers Limited, UK) and P. A. Bingham (Rhône-Poulenc Chemicals, now Rhodia Organique Fine Limited, UK), **Overview of the Chronic Toxicity of Haloethanes**, *EUROTOX'97, Diversification in Toxicology: Man and Environment* (proceedings of the XXXVI European Congress of Toxicology, EuroTox, Århus, Denmark, 25-28 June 1997), Nordic Pharmacological Society, Copenhagen Denmark, 1997; abstract P5-15, republished in *Pharmacology and Toxicology*, 80(supplement III):127-128, 1997 (2 pages with no figures or tables, RDB-A644)

outlines a two-year study of the chronic toxicity of R-123, R-124, R-134a, and R-141b in rats; notes that R-124 showed no effects even at the limit concentration of 50,000 ppm v/v; R-123, R-134a, and R-141b exposures resulted in increased incidences of Leydig cell hyperplasia and benign adenoma at 300, 50,000, and 5,000 ppm v/v; R-123 also caused increased incidence of hepatic adenoma at 300 ppm and pancreatic acinar cell adenoma at 1,000 ppm v/v; survival was not affected with any of the compounds and survival actually increased with increasing R-123 exposure concentrations; hypotheses suggested that these tumors types are of limited or no relevance to human risk assessment, spurring further mechanistic studies; while metabolic changes were found in cultured

cells, the *in vitro* tests found no consistent pattern indicating the mechanism of Leydig cell

M. A. Collins (ICI Chemicals and Polymers Limited, UK), D. J. Tinston (ICI), and C. J. Hardy (Huntingdon Research Centre Limited, HRC, UK), **Studies on the Acute Toxicity of a Number of Hydrofluorocarbons**, *Proceedings of the Sixth International Congress of Toxicology* (Rome, Italy, 28 June - 3 July 1992), International Union of Toxicology, June 1992 (RDB5B43)

toxicity of R-125 and other HFC refrigerants; cardiac sensitization

M. Combaz (Compagnie Française de Raffinage, France), **Les intoxications par gaz en raffinerie de pétrole (1969 à 1974)** [Gas Intoxications in a Petroleum Refinery (1969 to 1974)], *Staub-Reinhalt. Luft.*, 36(1):15-19, January 1976 (5 pages with 1 figure and 1 table, in French, RDB6A62)

toxicity summary of 40 incidents of narcotic effects in humans by gases in a refinery during a five year period: of the accidents, exposures to R-1150 and R-1270 accounted for two of them; no acute lung edema or fatalities resulted in any of the incidents, but paper recommends use of respiratory masks for dangerous tasks

Committee on Aviation Toxicology, Aero Medical Association, **Aviation Toxicology**, The Blakiston Company, New York NY and Toronto ON, 1953 (RDB72A5)

reference on the toxicity of chemicals used on aircraft; for R-744 (carbon dioxide), indicates that concentrations of 50,000-100,000 ppm v/v and higher act as a narcotic in humans and that signs of intoxication may occur after 30 min at 50,000 ppm v/v [see RDBA657 for further information]

Commission for the Investigation of Health Hazards of Chemical Compounds in the Work Area, **List of MAK and BAT Values 1996: Maximum Concentrations and Biological Tolerance Values at the Workplace**, report 32, Deutsche Forschungsgemeinschaft [German Research Association] (DFG), Bonn, Germany; VCH Verlagsgesellschaft mbH, Weinheim, Germany, 1996 (208 pages with 3 figures and 12 tables, RDB7101)

English language version of the *MAK- und BAT-Werte-Liste*; maximale Arbeitsplatz Konzentration [maximum workplace concentration] and biologischer Arbeitsstoff-Toleranz-Wert [biological tolerance value]; German occupational exposure limits for approximately 600 chemicals including R-10, R-11, R-12, R-12B2, R-13, R-13B1, R-20, R-20B3, R-21, R-22, R-30, R-30B1, R-31, R-40, R-40B1, R-40I1, R-110, R-112, R-112a, R-113, R-114, R-123, R-123B1, R-130, R-134a (new entry), R-140, R-140a, R-140B2, R-142b, R-150, R-150a, R-160, R-160B1, R-E170, R-270da, R-290, R-600, R-600a, R-601, R-601a, R-601b, R-602, R-610, R-611 (revised), R-630, R-717 (revised), R-744, R-744A, R-746, R-764, R-7146, R-1110, R-1120, R-1130, R-1130a, R-1130c, R-1130t, R-1132a, R-1140, R-1150, and others; classification of carcinogenic, embryotoxicant, and sensitizing substances

Commission for the Investigation of Health Hazards of Chemical Compounds in the Work Area, **Occupational Toxicants: Critical Data Evaluation for MAK Values and Classification of Carcinogens**, edited by D. Henschler, Deutsche Forschungsgemeinschaft [German Research Association] (DFG), Bonn, Germany; VCH Verlagsgesellschaft mbH, Weinheim, Germany; volume 1, September 1990 (400 pages with 15 figures and 95 tables); volume 2, July 1991 (349 pages with 42 figures and 65 tables); volume 3, September 1992 (379 pages with 12 figures and 82 tables); volume 4, July 1992 (385 pages with 11 figures and 95 tables); volume 5, July 1993 (389 pages with 8 figures and 77 tables); volume 6, August 1994 (368 pages with 10 figures and 69 tables); and volume 7, April 1996 (440 pages with 11 figures and 83 tables); (RDB7102)

analysis of available toxicity data used to set maximale Arbeitsplatz Konzentration [maximum workplace concentration] (MAK) values and carcinogenicity classifications; description of known effects, identification of inadequacies in the data, and recommendations for further research: volume 6 addresses R-13B1, R-717 (ammonia), and others; volume 7 addresses R-10B3, R-160, R-160B1, R-160I1, R-630, and others

P. Conzen and M. Nuscheler, **New Inhalation Anaesthetics**, *Anaesthesist*, 45:674-693, 1996 (20 pages, RDB8313)

toxicity of hydrofluoroethers (HFE) used as anesthetics and potentially as refrigerants

W. A. Cook, **Maximal Allowable Concentrations of Industrial Atmospheric Contaminants**, *Industrial Medicine*, 14:936 ff, 1945 (RDB6168)

first exposure standards (Maximum Allowable Concentration, MAC) for fluoroalkanes, ranged from 5,000 ppm for R-11 to 100,000 ppm for R-12 as reported in RDB5C41

F. Coulston and T. B. Griffin, *Physiological and Toxicological Aspects of Combustion* (proceedings of international symposium), 151-164, 1976 (14 pages, RDB6576)

inhalation toxicity of R-116 and others

P. J. Cox, L. J. King, and D. V. Parke, **A Comparison of the Interactions of Trichlorofluoromethane and Carbon Tetrachloride with Hepatic Cytochrome P-450**, *Biochemical Journal*, 130:87P ff, 1972 (RDB8133)

toxicity of R-10 and R-11; biochemistry; metabolism, pharmacokinetics

J. R. Creech (Geocenters Incorporated), R. K. Black (Geocenters), B. L. Garrity (Geocenters), R. Abbas (Geocenters), L. Dong (Geocenters), R. J. Williams (U.S. Air Force Armstrong Laboratory, USAF-AL), and J. N. McDougal (USAF-AL), **Inhalation Uptake and Metabolism of Iodohalogenated Compounds CF_3I, $C_6F_{13}I$, and C_3F_7I**, report AL/OE-TR-1995-0089, Armstrong Laboratory, U.S. Air Force, Wright-Patterson Air Force Base, OH, 1995 (RDB8414)

inhalation toxicity, metabolism, and pharmacokinetics of R-13I1, R-217caI1, and R-51-13I1 (probably R-51-13mccccI1), which are candidates to replace halon 1301 (R-13B1) and also under consideration as refrigerants

J. R. Creech, R. K. Black, S. K. Neurath, M. C. Caracci (Geocenters Incorporated), R. J. Williams (U.S. Air Force Armstrong Laboratory, USAF-AL), and A. Vinegar (ManTech Environmental Technology, Incorporated), **Inhalation Uptake and Metabolism of Proposed Halon 1301 Replacement: HFC-125, and FC-218** *The Toxicologist*, Society of Toxicology (SOT), 15(1):271 ff, 1995 (RDB7C83)

inhalation toxicity, metabolism, and pharmacokinetics of R-125 and R-218 as replacements for R-13B1 (also used as refrigerants)

J. R. Creech, R. K. Black, S. K. Neurath, M. C. Caracci (Geocenters Incorporated), R. J. Williams (U.S. Air Force Armstrong Laboratory, USAF-AL), G. W. Jepson, and A. Vinegar (ManTech Environmental Technology, Incorporated), **Inhalation Uptake and Metabolism of Halon 1301 Replacement Candidates HFC-227ea, HFC-125, and FC-218**, report AL/OE-TR-1995-0022, Armstrong Laboratory, U.S. Air Force, Wright-Patterson Air Force Base, OH, 1995 (RDB7C84)

inhalation toxicity, metabolism, and pharmacokinetics of R-125, R-218, and R-227ea as replacements for R-13B1 (also used as refrigerants)

R. Culik and D. P. Kelly, **Embryotoxic and Teratogenic Studies in Rats with Inhaled Dichlorofluoromethane (Freon® 21) and 2,2-Dichloro-1,1,1-Trifluoroethane (FC-123)**, report 227-76, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1976 (RDB6156)

R-21 and R-123, developmental and reproductive toxicity: tests of R-123 at 10,000 ppm suggest a fetotoxic effect in the offspring of exposed female rats, but the results were not statistically significant and no other concentration was tested — as reported in RDB6B52

T. Dalhamn, **Studies on SO_2, NO_2 and NH_3: Effect on Ciliary Activity in Rabbit Trachea of Single in Vitro Exposure and Resorption in Rabbit Nasal Cavity**, *Acta Physiologica Scandinavica*, 58:287-291, 1963 (RDB6A47)

R-717 (ammonia), R-746 (nitrogen dioxide), and R-764 (sulfur dioxide), health effects, toxicity

T. Dalhamn, **Freon som orsak till förgiftningsfall** [Freon as a Cause of Toxicity], paper 11012, *Nordisk Hygienisk Tidskrift*, 39:165-169, 1958 (5 pages with 2 tables, RDB7205)

R-11, R-12, R-22, R-113, health effects, toxicity, and toxicity of decomposition products in open flames; cites two cases of alleged phosgene poisoning from use of R-12 as an aerosol propellant; one involved a leak in the presence of an acetylene flame, and the other, which was fatal, the use of an aerosol insecticide; see RDB5C40 for discussion of this paper

T. Dalhamn, **Mucous Flow and Ciliary Activity in the Trachea of Healthy Rats and Rats Exposed to Respiratory Irritant Gases (SO_2, H_3N, HCHO). VIII. The Reaction of the Tracheal Ciliary Activity to Single Exposure to Respiratory Irritant Gases and Studies of the pH**, *Acta Physiologica Scandinavica*, 36(supplement 123):-93-105, 1956 (13 pages, RDB6A46)

toxicity of R-717, R-764, and others

T. Dalhamn, **Mucous Flow and Ciliary Activity in the Trachea of Healthy Rats and Rats Exposed to Respiratory Irritant Gases (SO_2, H_3N, HCHO). A Functional and Morphologic (Light Microscopic and Electron Microscopic) Study, with Special Reference to Technique**, *Acta*

Physiologica Scandinavica, 36(supplement 123):-161 ff, 1956 (RDB6A08)

toxicity of R-717, R-764, and others

R. H. Davies, R. D. Bagnall, W. Bell, and W. G. M. Jones (Imperial Chemical Industries Limited, UK), **The Hydrogen Bond Proton Donor Properties of Volatile Halogenated Hydrocarbons and Ethers and Their Mode of Action in Anesthesia**, *International Journal of Quantum Chemistry: Quantum Biology Symposium*, 3:171-185, 1976 (15 pages with 7 figures and 1 table, RDB6555)

toxicity of R-142b and others; indicates a 30-min LC_{50} mouse = 300,000 ppm for R-142b — as reported in RDB3721

R. H. Davies, R. D. Bagnall, and W. G. M. Jones (Imperial Chemical Industries Limited, UK), **Quantitative Interpretation of Phase Effects in Anesthesia**, *International Journal of Quantum Chemistry: Quantum Biology Symposium*, 1:201-212, 1974 (12 pages, RDB59A6)

toxicity of R-124, R-142b, and others; indicates and anesthetic effect, 30-min EC_{50} mouse = 230,000 ppm for R-142b — as reported in RDB5869

W. Dekant (Universität Würzburg, Germany), **Toxicology of Chlorofluorocarbon Replacements**, *Environmental Health Perspectives* (EHP), 104(supplement 1):75-83, March 1996 (9 pages with 5 figures and 2 tables, Rdb8123)

R-123, R-124, R-125, R-134a, and R-141b show only a low potential for skin and eye irritation; R-123 affects the liver and R-134a and R-141b the testes, including tumor formation, in long-term inhalation studies for very high concentrations; all of these alternatives are, to varying extents, biotransformed, mainly by cytochrome P450-catalyzed oxidation of carbon-hydrogen bonds; the resulting acyl halides are hydrolyzed to yield excretable carboxylic acids; halogenated aldehydes that are formed may be further oxidized to halogenated carboxylic acids or alcohols, found as metabolites in the urine of exposed test rats; the chronic toxicity of these alternatives is unlikely to be of relevance for humans exposed during production and use of these chemicals; further research is required for a better understanding of the chronic toxicity of R-123 and the mechanisms involved

W. B. Deichmann and H. W. Gerarde, **Toxicology of Drugs and Chemicals**, Academic Press, New York, NY, 1969 (Rdb5266)

general reference on toxicity; cites a 4-hr LC_{50} rat of 2,000 ppm for R-717 (ammonia)

C. G. de Rooij (misspelled "Ronij" in the document, Solvay S.A., Belgium), S. Shin-ya (Asahi Glass Company, Limited, Japan), R. S. Thompson (Zeneca, UK), and A. G. Berends (Solvay Duphar, The Netherlands), **Environmental Toxicity Studies with HFCs and HCFCs**, *EUROTOX'97, Diversification in Toxicology: Man and Environment* (proceedings of the XXXVI European Congress of Toxicology, EuroTox, Århus, Denmark, 25-28 June 1997), Nordic Pharmacological Society, Copenhagen Denmark, 1997; abstract P5-15, republished in *Pharmacology and Toxicology*, 80(supplement III):138, 1997 (1 page with no figures or tables, RDBA645)

biodegradation, ecotoxicity, and impacts on aquatic life of R-32, R-123, R-124, R-125, R-134a, R-141b, R-225ca, and R-225cb

J. V. Dilley et al., **Fluoride Ion Excretion by Male Rats After Inhalation of One of Several Fluoroethylenes or Hexafluoropropene** *Toxicology and Applied Pharmacology* (TAP), 27(3):582-590, 1974 (RDB6579)

toxicity of R-116, R-1216, and others; male rats exposed to R-1216 in air showed increased urinary fluoride after exposures and necrosis of renal tubules; metabolism

T. DiPaolo et al., **Molecular Connectivity Study of Halocarbon Anesthetics**, *Journal of Pharmaceutical Sciences*, 68(1):39-42, 1979 (4 pages, RDB6185)

anesthetic effects of R-124 and others; toxicity of fluorocarbon refrigerants

K. T. Dishart, **The Synthesis and Evaluation of Some New Fluorinated Inhalation Anesthetics**, National Meeting (Chicago), American Chemical Society (ACS), Columbus, OH, September 1961 (RDB5907)

anesthetic effects of R-226cb, R-226cbB1, R-226daB1, R-244ca, R-244caB1, R-245ca, and others; toxicity

E. C. Dittman and E. Etschenberg, **Endoanesthetic and Narcotic Activity in Halogenated Methane Derivatives**, *European Journal of Pharmacology*, 24(3):389-398, 1973 (10 pages, RDB-5821)

anesthetic effects of R-23 and others; toxicity

D. E. Dodd, A. D. Ledbetter, and A. D. Mitchell (ManTech Environmental Technology, Incorpo-

rated), **Genotoxicity Testing of Halon Replacement Candidates Trifluoroiodomethane (CF_3I) and 1,1,1,2,3,3,3-Heptafluoropropane (HFC-227ea) Using the Salmonella Typhimurium and L5178Y Mouse Lymphoma Mutation Assays and Mouse Micronucleus Test**, *Inhalation Toxicology*, 9:111-131, 1997 (21 pages, RDB8415)

toxicity tests of R-13I1 and R-227ea

D. E. Dodd, W. T. Brashear, and A. Vinegar (ManTech Environmental Technology, Incorporated), **Metabolism and Pharmacokinetics of Selected Halon Replacement Candidates**, *Toxicology Letters*, 68(1-2):37-47, May 1993 (11 pages, RDB6212)

toxicity tests of the metabolism of a series of chemicals and of the pharmacokinetics of R-123: the metabolism tests addressed R-12B1, R-123, R-124, R-142b, R-51-14 in Fischer 344 and Sragues-Dawley rats exposed for 2 hr; animals exposed to R-123 and R-124 excreted trifluoroacetic acid (TFA) in their urine; urinary bromide and fluoride levels increased for animals exposed to R-12B1 and R-124, respectively; small amounts of R-133a and R-1122a were detected in the livers of rats exposed to R-123; animals exposed to R-142b excreted chlorodifluoroacetic acid in their urine, but no volatile metabolytes were found in tissues; no metabolites were found in the urine or tissues of animals exposed to R-51-14; no remarkable differences were found between the two strains of rats; paper concludes that the results are consistent with proposed oxidative and reductive pathways of metabolism for these chemicals; pharmacokinetic tests of R-123 were based on inhalation exposures with rats at 100, 1,000, and 10,000 ppm; blood concentrations of R-123 fell sharply following exposures; TFA levels rose for approximately 5 hr and then declined gradually; saturation of R-123 metabolism was estimated with a physiologically-based pharmacokinetic (PBPK) model to occur at approximately 2,000 ppm

R. E. Doherty and D. M. Aviado (University of Pennsylvania School of Medicine), **Toxicity of Aerosol Propellants in the Respiratory and Circulatory Systems, VI. Influence of Cardiac and Pulmonary Vascular Lesions in the Rat**, *Toxicology*, Elsevier/North Holland, Amsterdam, The Netherlands, 3(2):213-224, 1975 (12 pages, RDB5C81)

toxicity of R-12, R-152a, and others; cardiac sensitization

C. T. Dollery, **Absorption and Fate of Isoproterenol and Fluorocarbons Inhaled from Pressurized Aerosols**, *Proceedings of the 28th Annual Congress* (Dallas, TX, 8 March 1972), 1972 (RDB7243)

fluorochemical toxicity

C. T. Dollery, J. Gragg, and M. C. R. Path, **Sniffing Syndrome**, *British Medical Journal*, 2:334 ff, 1971 (RDB7297)

fluorocarbon abuse; potential for human fatalities

C. T. Dollery, G. H. Draffen, D. S. Davies, F. M. Williams, and M. E. Conolly, **Blood Concentrations in Man of Fluorinated Hydrocarbons After Inhalation of Pressurized Aerosols**, paper 7684, *Lancet*, UK, 2(7684):1164-1166, 1970 (6 pages, RDB6725)

effects of inhalation in humans of R-12, R-114, and others; toxicity: no adverse effects from R-12 at aerosol bronchodilator doses in healthy adults or asthmatic patients — as reported in RDB5143

C. T. Dollery, F. M. Williams, G. H. Draffen, G. Wise, H. Sahyoun, J. W. Paterson, and S. R. Walker, **Arterial Blood Levels of Fluorocarbons in Asthmatic Patients Following Use of Pressurized Aerosols**, *Clinical Pharmacology and Therapeutics*, 15:59-66, 1973 (8 pages, RDB8119)

fluorochemical blood levels in humans; pharmacokinetics, toxicity; based on a study for use as metered-dose inhaler (MDI) aerosol propellants (compounds also are used as refrigerants)

R. C. Downing (Consultant, formerly DuPont Chemicals), **Refrigerant Toxicology**, *Refrigerating Service and Contracting* (RSC), 31-32, January 1987 (2 pages with 2 tables, RDB6850)

review of refrigerant inhalation risks for technicians; indicates that fluorocarbon refrigerants are low in toxicity, do not accumulate in the body, and are not metabolized or broken down to any extent; still recommends to avoid breathing them if possible; notes that the decomposition products of fluorocarbons are toxic, but there is no evidence of phosgene ($COCl_2$) formation in decomposition; identifies hydrochloric (HCl) and hydrofluoric acids (HF) as the primary decomposition products, sometimes with small amounts of chlorine gas (Cl_2); these acids have a very acrid, acidic odor at very low concentrations that serves as a warning of decomposition; reviews the historical as-

sociation of phosgene with fluorocarbon decomposition, noting that other carbonyl halides, notably carbonyl fluoride (COF_2) and carbonyl chlorofluoride (COClF), were misidentified as phosgene in early studies; explains that actual phosgene formation is doubtful based on relative bond strengths of carbon fluorine and carbon-chlorine bonds; explains and presents the ACGIH Threshold Limit Value (TLV) concentrations for HCl, HF, COClF, and phosgene; reviews other studies on the decomposition of refrigerants by lit cigarettes that found miniscule decomposition of R-11 and R-22; concludes that these chemicals do not pose a greater health hazard to smokers than nonsmokers

R. C. Downing and D. Madinabeitia (E. I. duPont de Nemours and Company, Incorporated), **The Toxicity of Fluorinated Hydrocarbon Aerosol Propellants**, *Aerosol Bulletin*, Federation of European Aerosol Associations, February-April 1960; republished in *Aerosol Age*, 5(9):25 ff, September 1960; republished as bulletin A-52 (A-82784), E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, August 1972 (8 pages with 1 figure and 5 tables, RDB5C40)

R-11, R-12, R-22, R-113, decomposition products (phosgene / $COCl_2$, hydrochloric acid / HCl, hydrofluoric acid / HF, chlorine Cl_2, others), refrigerants, toxicity

H. N. Doyle and R. E. Bales (Tracor Jitco, Incorporated), **Fluorocarbons — Industrial Hygiene Survey Report: E. I. duPont de Nemours and Co., Inc., Deepwater, New Jersey**, National Institute of Occupational Safety and Health (NIOSH), U.S. Department of Health, Education, and Welfare (DHEW), Cincinnati, January 1977 (20 pages with 1 figure and 6 tables, available from NTIS, RDB7364)

concentrations of R-10, R-11, R-12, R-22, R-30, R-113, R-114, R-115, R-116, R-142b, R-152a (possibly R-152, incorrectly identified in the report as "CH_3F-CH_3F"), R-1132a, and others at a chemical manufacturing site: plant (Chambers Works) manufactures diverse chemicals, among them R-11, R-12, R-115, and R-116; it also package these chemicals and R-22, R-113, R-114, R-142b, R-152a, and R-1132a; report concludes that the predominant opportunities for exposures are associated with packaging operations; samples collected by personal samplers worn by plant operators show the concentrations of R-22 to be 0.1-0.3 ppm and for all other fluorocarbons less than 20 ppm; appends a synopses and data tables prepared by W. E. Neeld, which concludes that there was no indication of increased morbidity or mortality among 22 fluorocarbon workers compared to 44 controls based on a 19-year retrospective study

L. M. Dzubow, **Histologic and Temperature Alterations Induced by Skin Refrigerants**, *Journal of the American Academy of Dermatology*, 12(5/1):796-809, 1985 (14 pages, RDB7259)

toxicity of R-114 and others

C. Edling, C. G. Olson, G. Ljungkvist, A. Oliv, and B. Soderholm, **Cardiac Arrhythmia in Refrigerator Repairmen Exposed to Fluorocarbons**, *British Journal of Industrial Medicine*, UK, 47(3):207-212, 1990 (6 pages, RDB7226)

cardiac sensitization R-12 and others

C. Edling and C. G. Olson, **Health Risks with Exposure to Fluorocarbons**, University Hospital, Uppsala, Sweden, 1988 (in Swedish, RDB8141)

toxicity of fluorochemical refrigerants

C. Edling and P. Sderkvist, **Criteria Group for Occupational Standards: Fluorocarboner**, *Arbete och Hlsa*, 26:1-38, 1982 (38 pages, RDB6B55)

toxicological review of R-11, R-12, R-22, and R-113; metabolism, acute effects on the central nervous system and the heart; cardiac sensitization in the dog, monkey, mouse and rat; reports heart palpitations in humans after long-term exposure to R-22; liver effects (lipid droplets) found after chronic exposures to R-12, R-22, and R-113

A. Edmonds, **Toxicity of Vaporizing Liquids**, *Annals of Occupational Hygiene*, 9:235 ff, 1966 (RDB8115)

toxicity of fluorochemicals

M. J. Ellenhorn and D. G. Barceloux, **Aerosol Propellants**, *Medical Toxicology, Diagnosis and Treatment of Human Poisoning*, Elsevier Publishing Company, Incorporated, New York, NY, 528 ff, 1988 (RDB5947)

toxicity

M. J. Ellenhorn and D. G. Barceloux, **Fluorocarbons**, *Medical Toxicology, Diagnosis and Treatment of Human Poisoning*, Elsevier Publishing Company, Incorporated, New York, NY, 884 ff, 1988 (RDB5948)

toxicity

M. J. Ellenhorn and D. G. Barceloux, **Inhalant Abuse**, *Medical Toxicology, Diagnosis and Treatment of Human Poisoning*, Elsevier Publishing Company, Incorporated, New York, NY, 841 ff, 1988 (RDB5949)

toxicity

H. B. Elkins and L. Levine (Division of Occupational Hygiene, Massachusetts Department of Labor and Industries), **Decomposition of Halogenated Hydrocarbon Vapors by Smoking**, *Journal of Industrial Hygiene and Toxicology*, 21(6):221-225, June 1939 (5 pages with 2 tables, RDB6773)

reports experiments to determine the extent of decomposition of halocarbons, including some used as refrigerants, passing through lighted cigarettes and cigars; describes the experimental and analytical methods used; tabulates tested concentrations and measured bromides and chlorides for R-10, R-12, R-160B1, R-1120, R-1130B2, and dichlorobenzene; addresses tolerable phosgene levels and influences of dusts and humidity; notes warning properties of hydrochloric acid, a primary decomposition product representing 80% of decomposition chlorides, at concentrations of 10 ppm; concludes that the extent of decomposition of the cited compounds in smoking cigarettes or cigars in the presence of their vapors "is of a low order and does not constitute a health hazard"; toxicity

S. S. Epstein, E. Arnold, J. Andrea, W. Bass, and Y. Bishop, *Toxicology and Applied Pharmacology* (TAP), 23:288 ff, 1972 (RDBA671)

toxicity of hydrocarbons

S. S. Epstein, S. Joshi, J. Andrea, P. Clapp, H. Falk, and N. Mantel, **Synergistic Toxicity and Carcinogenicity of 'Freons' and Piperonyl Butoxide**, *Nature*, 214:526-528, 1967 (3 pages, RDB7425)

toxicity of R-11 and others; no significant increase in tumor formation was found with subcutaneous injection of R-11 — as reported in RDB7414

L. Eriksson, J. Johnsson, and R. Berglind, **External Validation of a QSAR for the Acute Toxicity of Halogenated Aliphatic Hydrocarbons**, *Environmental Toxicology and Chemistry*, 12:1185-1192, 1993 (8 pages, RDB7262)

teratology of R-114 and others; toxicity

L. Eriksson, J. Johnsson, M. Sjostrom, and S. Wold, **A Strategy for Ranking Environmentally Occurring Chemicals. Part V: The Development of Two Genotoxicity QSARs for halogenated Aliphatics**, *Environmental Toxicology and Chemistry*, 10:585-596, 1991 (12 pages, RDB7263)

teratology of R-114 and others; toxicity

L. Eriksson, J. Johnsson, S. Hellberg, F. Lindoren, et al., **A Strategy for Ranking Environmentally Occurring Chemicals. Part III: Multivariate Quantitative Structure-Activity Relationships for Halogenated Aliphatics**, *Environmental Toxicology and Chemistry*, 9:, 1990 (RDB7264)

teratology of R-114 and others; toxicity

H. Fabel, R. Wettengel, and W. Hartmann, **Myocardial Ischemia and Arrhythmias Due to the Use of Pressurized Aerosols in Man**, *Deutsch Med. Wochenschrift* [German Medical Weekly], Germany, 97:428-431, 1972 (4 pages, RDB6726)

acute inhalation toxicity of R-12/11 (60/40) in humans; cardiac sensitization; no change in EKGs — as reported in RDB5143

L. T. Fairhall, **Industrial Toxicology** (second edition), Williams and Wilkins, Baltimore, MD, 1957 (RDBA629)

reference on toxicity; indicates that R-12 has little if any anesthetic or toxic action — as reported in RDB5358

L. T. Fairhall, **Industrial Toxicology** Williams and Wilkins, Baltimore, MD, 1949 (RDB5987)

reference on toxicity

Federation of the American Societies for Experimental Biology (FASEB), **Evaluation of the Health Aspects of Nitrogen, Helium, Propane, n-Butane, iso-Butane, and Nitrous Oxide as Gases Used in Foods**, Bureau of Food, U.S. Department of Health and Human Services (DHS, then the U.S. Department of Health, Education, Welfare, DHEW), Washington, DC, March 1979 (RDBA541)

toxicity of R-290 (propane), R-600 (n-butane), R-600a (isobutane), R-704 (helium), R-728 (nitrogen), and R-744A (nitrous oxide) for food uses, some of which also are used as refrigerants

A. T. Fidler, E. L. Baker, and R. Letz, **The Neurobehavioral Effects of Occupational Exposure to Organic Solvents Among Construction Painters**, *British Journal of Industrial Medicine*, 1:211-228, 1987 (18 pages, RDB5838)

inhalation toxicity

C. E. Finegan and G. M. Rusch (AlliedSignal Incorporated), **Update: Program for Alternative Fluorocarbon Toxicity Testing**, *Stratospheric Ozone Protection for the 90's* (proceedings of the International CFC and Halon Alternatives Conference, Washington, DC), Alliance for Responsible CFC Policy, Arlington, VA, 895-904, October 1993 (10 pages with 12 tables, available from JMC as RDB3A53)

summary of the status and findings of the Program for Alternative Fluorocarbon Toxicity Testing (PAFT); addresses the toxicity of R-32, R-123, R-124, R-125, R-141b, R-134a, R-225ca, and R-225cb [see RDB7464 for update]

N. C. Flowers, R. C. Hand, and L. G. Horan (Helen Dwight Reid Educational Foundation), **Concentrations of Fluoroalkanes Associated with Cardiac Conduction System Toxicity**, *Archives of Environmental Health*, 30(7):353-360, 1975 (8 pages, RDB5C65)

toxicity of R-11, R-12, and others; cardiac effects and sensitization

F. Flury, **Moderne gewerbliche Vergiftungen in pharmakologisch-toxikologischer Hinsight** [Pharmacological-Toxicological Aspects of Intoxicants in Modern Industry], *Archiv für Experimentelle Pathologie und Pharmakologie*, 138:65-82, 1928 (18 pages, RDB7299)

general reference on toxicity; cites a 5-min LC_{Lo} mammal of 5,000 ppm v/v for R-717 (ammonia) — as reported in RDB5340

S. Fogel, **Sudden Death and Fluorocarbon-Containing Aerosols**, *Canadian Medical Association Journal*, Ottawa, Canada, 114:671-672, 1976 (2 pages, RDB7530)

R-12 and others, toxicity, accident involving human exposure

V. C. Foltz and R. Fuerst, **Mutation Studies with Drosophila Malanogaster Exposed to Four Fluorinated Hydrocarbon Gases**, *Environmental Research*, 7(3):275-285, 1974 (11 pages, RDB-5139)

mutagenicity of R-23, R-152a, and others; toxicity — as reported in RTECS

R. B. Forney, Jr., and R. N. Harger, **Reaction of Mice from Acute Exposure to Various Concentrations of Methane, Ethane, Propane, and Butane in Air, or in Oxygen**, *Proceedings of the Sixth International Meeting of Forensic Sciences* (Edinburgh, Scotland), 1972 (12 pages, RDB7462)

R-50, R-170, R-290, R-600, health effects, toxicity: anesthetic properties of R-50 (methane) — as reported in RDB7413

S. A. Friedman, M. Cammarato, and D. M. Aviado (University of Pennsylvania School of Medicine), **Toxicity of Aerosol Propellants on the Respiratory and Circulatory Systems, II. Respiratory and Bronchopulmonary Effects in the Rat**, *Toxicology*, 1(4):345-355, 1973 (11 pages with 2 figures and 4 tables, RDB6191)

toxicity of R-11, R-12, R-21, R-114, R-115, R-C318, and R-600a; classifies propellants (many of which also are used as refrigerants) into three classes, namely those that induce arrythmia and sensitize the heart to epinephrine (R-11 and R-21), those that sensitize the heart to epinephrine-induced arrythmia (R-114, R-115, R-C318, and R-600a), and those that do not induce arrythmia or sensitize the heart to epinephrine (R-12) in anesthetized rats; recommends against continued use of R-11 and R-21 as propellants; exposures to R-12 at 360,000 ppm v/v produced apnea and finally death, but did not cause arrhythmias [RDB6138 notes that this death may have been due to the anesthetic (diallylbarbituric acid and urethane)]

R. Fuerst and S. Stephens, **Effects of Gases and Gamma Irradiation on Neurospora Crassa**, *Develop. Ind. Microbiology*, 11:301-310, 1970 (19 pages, RDB5C83)

toxicity of R-152a and others; mutagenicity; mutagenic potential

R. Fuerst and M. M. Landry, *Develop. Ind. Microbiology*, 8:305-312, 1966 (8 pages, RDB6130)

toxicity; mutagenicity; mutagenic potential

M. Furuya, **Experimental Chlorofluorohydrocarbon Poisoning**, *Tokyo Jikeikai Ika Daigaku Zasshi*, Japan, 94(6):1201-1214, 1979 (14 pages in Japanese, RDB8142)

health effects, toxicity

S. C. Gad et al., **Correlation of Ocular and Dermal Irritancy of Industrial Chemicals**, *Journal of Toxicology Cutaneous Ocular Toxicol.*, 5(3):195-214, 1986 (20 pages, RDB6133)

toxicity of R-152a and others

S. Garb and M. B. Chenoweth, **Studies on Hydrocarbon-Epinephrine Induced Ventricular Fibrillation**, *Journal of Pharmacology and Experimental Therapeutics* (JPET), 94:12-18, 1948 (7 pages, RDB8143)

summarizes studies of cardiac sensitization by inhalation exposures; inducement of ventricular fibrillation (very rapid and irregular contractions of the ventricles of the heart resulting in loss of synchronization between the heartbeat and pulse beat); health effects; toxicity

M. L. Gargas, P. G. Seybold, and M. E. Andersen, **Modeling the Tissue Solubilities and Metabolic Rate Constant (V_{max}) of Halogenated Methanes, Ethanes, and Ethylenes, 17th Conference on Toxicology** (Dayton, OH, 3-5 November 1987); republished IN *Toxicology Letters*, Elsevier/North-Holland Biomedical Press, Amsterdam, The Netherlands, 43(1-3):235-256, 1988 (22 pages, RDB5776)

R-30, R-32, R-1120, R-1130, R-1140, and others: toxicity

M. L. Gargas, H. J. Clewell III, and M. E. Andersen, **Metabolism of Inhaled Dihalomethanes in Vivo: Differentiation of Kinetic Constants for Two Independent Pathways**, *Toxicology and Applied Pharmacology* (TAP), 82(2):211-223, 1986 (13 pages, RDB5780)

R-32 and others, toxicity

S. Garrett and R. Fuerst, **Sex-Linked Mutations in Drosophila after Exposure to Various Mixtures of Gas Atmospheres**, *Environmental Research*, 7(3):286-293, 1974 (8 pages, RDB5819)

R-23, R-152a, and others; mutagenicity, inhalation toxicity

J. Garriott and C. S. Perry (Medical Examiner, Dallas TX), **Death from Inhalant Abuse: Toxicological and Pathological Evaluation of 34 Cases**, *Clinical Toxicology*, 16:305-315, 1980 (11 pages, RDB7431)

R-11, R-12, R-114, mixtures of them, and others, health effects, toxicity: analysis of 34 deaths after cardiac sensitization from deliberate abuse of inhalants, 16 of which were attributed to fluorocarbon aerosols (many also used as refrigerants), by "sniffing" as reported in RDB7414

E. M. Gause and J. R. Rowlands, **Effects of Fluorocarbon Inhalants upon Alveolar Macrophages**, *Proceedings of the Western Pharmacology Society*, 19:373-380, 1976 (8 pages, RDB5822)

r-12, R-23, and others, health effects, toxicity

T. L. Giguz, **Vliianie malykh kontsentratsii ammiaka i okislov azota na podrostkovipri proizvodstvennom obuchenii ikh na predpriiatiiakh khimicheskoi promyshlennosti** [Effect of Low Concentrations of Ammonia and Nitrogen Oxides on Adolescents during Vocational Training at Plants in the Chemical Industry], *Gigiena i Sanitariya*, Moscow, Russia (then USSR, 33(9):100-102, September 1968; also cited by some authors as appearing in *Hyg. Sanitariya*, 7:431-434, 1968 (3/4 pages, RDB6A49)

R-717, R-746, and others, health effects, toxicity: study of chronic, occupational exposures of humans; 140 students aged 16-19 exposed to ammonia as well as nitrogen oxides in a fertilizer factory experienced an 11% increase in respiratory tract disorders and a 27% increase in xeroderma (disease of the skin characterized by dryness and roughness) in the first year, compared to 85 students in the same vocational school not exposed to ammonia or nitrogen oxides; diseases of the upper respiratory tract and skin increased by 24 and 36%, respectively, in the second year; groups of 34 students with 3 hour shifts in the factory were then compared to a control group of 26 students; the exposed group showed increases in gamma globulin and decreases in serum albumen together with changes in fat metabolism; author suggested that there is stress on the hepatic functions that could be ascribed to low concentrations of ammonia as reported in RDB1106; limitations to the study, including unknown prior health of the subjects and possible causes other than ammonia are discussed in RDB1106

R. Gill, S. Hatchett, C. Broster, M. Osselton, J. Ramsey, H. Wilson, and A. Wilcox, **The Response of Evidential Breath Alcohol Testing Instruments with Subjects Exposed to Organic Solvents and Gases. I. Toluene, 1,1,1-Trichloroethane, and Butane**, *Sci. Law*, 31:187-200, 1991 (4 pages, RDB7B44)

R-140a, R-600, pharmacokinetics, elimination, inhalation toxicity in humans

J. H. Glover and H. W. Hodgson, **An Investigation of New Fluorine Compounds in Anaesthesia (3)**, *Anaesthesia*, 16:333 ff, 1961 (RDB65B6)

anesthetic effect, toxicity

J. H. Glover and H. W. Hodgson, **An Investigation of New Fluorine Compounds in Anaesthesia (2)**, *Anaesthesia*, 16:19 ff, 1961 (RDB65B5)

anesthetic effect, toxicity

A. E. Goldsmith et al., *Cancer Detection and Prevention*, 4(1-4):109-115, 1981 (7 pages, RDB-5784)

R-744 (carbon dioxide) and others, health effects, toxicity

S. Gosseye, M.-C. Golaire, and J.-C. Larroche, **Cerebral, Renal, and Splenic Lesions Due to Fetal Anoxia and their Relationships to Malformations**, *Dev. Med. Child. Neurol.*, 24:510-518, 1982 (9 pages, RDB7B45)

R-600, reproductive toxicity, fetal death following an attempted suicide using butane, toxicity in humans

R. E. Gosselin, R. P. Smith, and H. C. Hodge, **Fluorocarbon Refrigerants and Propellants**, *Clinical Toxicology of Commercial Products* (fifth edition), Williams and Wilkins, Baltimore, MD, 11-159, 1984 (148 pages, RDB5177)

reference for toxicity data

V. Graff-Lonnevig, **Diurnal Expiratory Flow After Inhalation of Freons and Genoterol in Childhood Asthma**, *Journal of Allergy and Clinical Immunology*, 64:534-538, 1979 (5 pages, RDB8144)

health effects, toxicity

W. M. Grant, **Toxicology of the Eye** (third edition), Charles C. Thomas Publishers, Springfield, IL, 1986 (RDB5C51)

refrigerants and other chemicals, toxicity as reported in RDB5C46

T. Green, **The Metabolic Activation of Dichloromethane and Chlorofluoromethane in a Bacterial Mutation Assay Using Salmonella-Typhimurium**, *Mutation Research*, 118(4):277-288, 1983 (12 pages, RDB6480)

R-30, R-31, and others, toxicity, mutagenicity

T. B. Griffin and F. Coulston, **Study of Toxicological Evaluation of Fire Suppressants and Extinguishers**, report CR-147658, National Aeronautics and Space Administration (NASA), Washington, DC, 31 March 1975 (RDB6571)

R-116 and others, toxicity: rabbits exposed to 50,000 ppm atmospheres of R-116 showed low absorption which was quickly eliminated; 4-hr ALC rat >800,000 ppm — as reported in RDB6687

T. B. Griffin, J. L. Byard, and F. Coulston, **Toxicological Responses to the Halogenated Hydrocarbons**, *Proceedings of the Symposium on Application of Halogenated Fire Extinguishing Agents* (Washington, DC, 11-12 April 1972), National Academy of Science (NAS), Washington, DC, 136-147, 1972 (12 pages, RDB6578)

R-116, R-C318, and others, toxicity

R. Guillern et al., **Effect of Chlorofluoromethanes on Ciliary Activity of the Respiratory Epithelium**, *Ann. Pharm. Français*, France, 18:542-544, 1960 (3 pages in French, RDB7546)

R-114 and others, health effects, sensory irritation, toxicity

C. A. Halder et al., **Gasoline Vapor Exposures. Part I.**, *AIHA Journal*, 47(3):164-172, 1986 (9 pages, RDB6189)

R-600, R-600a, R-601, R-601a, health effects, toxicity, inhalation studies in rats

C. A. Halder, G. S. Van Gorp, N. S. Hatoum, and t. M. Warne, **Gasoline Vapor Exposures. Part II. Evaluation of the Nephrotoxicity of the Major C4/C5 Hydrocarbon Components**, *AIHA Journal*, 47(3):173-175, 1986 (3 pages, RDB6190)

tests of subchronic inhalation toxicity by exposure of Sprague-Dawley rats to 4,437 ppm of a blend of R-600 (n-butane), R-600a (isobutane), R-601 (n-pentane), and R-601a (isopentane) — R-600a/600/601a/601 (25/25/25/25) — for 6 hr/d, 5 d/wk, for 3 wk: no clinical signs of distress or evidence of kidney lesions were found; hematology and clinical chemistry were within norm — as reported in RDB7621

G. T. Hall, **Two-Week Inhalation Toxicity Study (HFA 132b and HFA 124)**, report 727-76, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1976 (RDB6179)

R-124 and R-132b, health effects, toxicity, subchronic inhalation study: R-124 anesthetic LOEC rat = 100,000 ppm as reported in RDB5863

Halon Alternatives Group, **A Review of the Toxic and Asphyxiating Hazards of Clean Agent Replacements for Halon 1301**, Loss Prevention Council, London, UK, February 1995 (24 pages with 4 tables, RDBA668)

compares the toxicity and asphyxiation potentials of six commercial fire suppressants (some also used as refrigerants) as alternatives for R-13B1; they include R-23 (DuPont FE-13), R-227ea (Great Lakes Chemical FM-200), R-31-10 (3M CEA 410), R-728/740 (50/50) (Ginge Kerr Argonite), R-728/740/744 (52/40/8) (Ansul Inergen), and R-740 (Preussag Fire Protection

Argon); discusses criteria for asphyxiation and maximum duration of oxygen diminished concentrations; tabulates the typical use concentrations, median lethal concentrations (4-hr LC_{50} for an unidentified species), central nervous system (CNS) effects, cardiac sensitization, respiratory sensitization, genotoxicity, and developmental toxicity; recommends "safe use criteria" (the maximum recommended concentration for systems on automatic control for occupied areas); indicates those recommendations as 60,000 ppm v/v for R-13B1, 170,000 ppm v/v (may be raised to 290,000 ppm v/v with pending data) for R-23, 90,000 ppm v/v for R-227ea (Great Lakes Chemical FM-200), and 290,000 ppm v/v for R-31-10; discusses the criteria and terminology used for the assessment

A. Hamilton and H. L. Hardy, **Industrial Toxicology** (second edition), Paul B. Hoeber, Incorporated, New York, NY, 1949 (RDB5574)

toxicity of refrigerants

P. L. Hanst, J. W. Spence, And F. R. Clay (U.S. Environmental Protection Agency), **Chlorofluoromethanes: Their Thermal Stability in Passing Through Cigarettes**, *AIHA Journal*, 39:772-776, September 1978 (5 pages with 4 figures, RDB-6775)

refrigerants, toxicity: test for decomposition of R-11 at 2,000 ppm and R-22 at 2,500 ppm on passing through lit cigarettes; no carbonyl chloride (phosgene), carbonyl fluoride, or carbonyl chlorofluoride was found at a sensitivity of 0.1% of the starting material; documents the reactions that might yield the toxic carbonyl halides, experimental methods, and measured infrared spectra; found no measurable decomposition of the chlorofluoromethane compounds with simulated smoking; concludes that chlorofluoromethane pollutants in a room do not pose a greater health hazard for smokers than nonsmokers

C. J. Hardy, P. C. Kieran, and I. J. Sharman (Huntingdon Research Centre Limited, HRC, UK), **Assessment of Cardiac Sensitization Potential (CSP) of a Range of Halogenated Materials**, poster presentation (Spring Meeting, Baltimore, MD, USA), Society of Toxicology (SOT), 1994 (10 pages with 4 figures and 1 table, RDB6684)

cardiac sensitization potential (CSP) in beagle dogs; method modification to predetermine appropriate adrenaline challenge for individual animals; presents [widely accepted] test regime for CSP measurement; 10-min EC_{50} dog was 10,000-20,000 ppm for R-11, 120,000 ppm for R-12, 250,000 for R-13B1, >500,000 ppm for R-23, >350,000 ppm for R-32, 170,000 ppm for R-125, 205,000 ppm for R-134a, 20,000 ppm for R-141b, ~310,000 ppm for R-143a, >400,000 ppm for R-218, >400,000 ppm for R-31-10, >170,000 ppm (maximum attainable vapor concentration) for R-51-14, and >230,000 (maximum attainable vapor concentration) for perfluoro-N-methyl morpholine; examines relation to normal boiling point and to molecular composition with data from the current and prior studies; concludes that "although cardiac sensitization is likely to be an example of physical toxicity and is related to the physiochemical properties of a material, the [normal] boiling point alone cannot be used as a predictor"; also concludes that "halogenated alkanes in which >75% of the halogens are fluorine are likely to be of low CSP and that halogenated alkanes in which ≥50% of the halogens are chlorine are likely to be of high CSP"; finally concludes that "knowledge of the molecular formula and the boiling point may, together, allow some indication of likely CSP" as a guide for animal studies

C. J. Hardy et al., **Halon 13B1, Freon 23, Mixture of Freon 23 and HFC 125: Assessment of Cardiac Sensitization Potential in Dogs**, report DPT 273/921009, Huntingdon Research Centre Limited (HRC), Cambridgeshire, UK, 15 March 1993 (42 pages, RDB6458)

toxicity tests for cardiac sensitization in beagle dogs with administration of adrenaline by intravenous injection before and during inhalation; R-11 LOEL (100%) at 20,000 ppm v/v; R-13B1 NOEL at 100,000 ppm, LOEL (17%) at 150,000 ppm, EC_{50} at 250,000 ppm; R-23 NOEL at 500,000 ppm with auxiliary oxygen; R-23/125 (36.5/63.5 v/v) LOEL (1/6) at 100,000 ppm

C. J. Hardy, P. C. Kieran, I. J. Sharman, and G. C. Clark (Huntingdon Research Centre Limited, HRC, UK), **Assessment of Cardiac Sensitization Potential in Dogs: Comparison of HFC 125 and Halon 13B1**, report MA-RR-92-1845 (also identified as ALS 11/920116) for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), AlliedSignal Incorporated, Morristown, NJ, 10 June 1992 (44 pages, RDB5755)

toxicity tests to determine the cardiac sensitization potential in male beagle dogs with intravenous injection of adrenaline five minutes before and, with a challenge injection, midway into a

10 minute inhalation exposure through a face mask: R-11 LOEL (1/2) at 20,000 ppm v/v; R-13B1 NOEL (0/6) at 150,000 ppm with a questionable response not deemed as positive, LOEL (2/6) at 200,000 ppm, and EC_{50} at 250,000 ppm; R-125 NOEL (0/6) at 75,000 ppm, LOEL (1/6) at 100,000 ppm, and EC_{50} at 139,000 ppm

C. J. Hardy, I. J. Sharman, and G. C. Clark (Huntingdon Research Centre Limited, HRC, UK), **Assessment of Cardiac Sensitization Potential in Dogs: Comparison of HFA 134a and A12**, report CTL/C/2521 (also identified as ISN 250/91169) for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, UK, 11 September 1991 (62 pages with 11 figures and 4 tables, Rdb5B42)

toxicity tests of cardiac sensitization in beagle dogs by inhalation with an intravenous administration of an epinephrine challenge; for R-11, NOEL 0/2 = 15,000 and LOEL 2/2 = 20,000 ppm v/v; for R-12 NOEL 0/6 = 80,000 ppm, LOEL 3/3 = 160,000 (3 dogs disqualified for struggling and convulsions), and EC_{50} >80,000 and <160,000 ppm v/v; for R-134a NOEL 0/6 = 40,000, LOEL 2/6 = 80,000 ppm, and EC_{50} >160,000 and <320,000 ppm; concentrations indicated are of the test chemical in air except that the air was enriched for the two highest concentrations to maintain 21% oxygen levels; report documents preliminary tests to determine appropriate levels of adrenaline doses for each dog and also scoring criteria since some ventricular tachycardia (a series or run of unifocal ectopic beats) were observed in tests with air and therefore not compound related; the criterion adopted for positive responses was appearance of five or more multifocal ventricular ectopic beats or ventricular fibrillation (very rapid and irregular contractions of the ventricles of the heart resulting in loss of synchronization between the heartbeat and pulse beat); report indicates measured blood levels measured during tests of up to 84.2 µg/ml for R-12 and up to 188.5 µg/ml for R-134a; concentrations were determined with an infrared gas analyzer; the report indicates Good Laboratory Practice (GLP) compliance

C. J. Hardy, I. J. Sharman, and D. O. Chanter (Huntingdon Research Centre Limited, HRC, UK), **Assessment of Cardiac Sensitization Potential in Dogs and Monkeys: Comparison of I-141b and F11**, report PWT 86/89437, Elf Atochem North America (then Pennwalt Corporation), King of Prussia, PA, 8 September 1989 (50 pages with 7 figures and 7 tables, RDB5C63)

documents a cardiac sensitization study in beagle dogs and cynomolgus monkeys; R-11 tests in dogs found a NOEL at 9,000 ppm v/v and LOEL at 13,000 ppm v/v; R-141b tests in dogs found a LOEL at 9,000 ppm v/v (the lowest concentration tested); R-11 tests in monkeys found a LOEL at 6,000 ppm v/v based on one marked and one mild responses of the two animals tested; R-141b tests in monkeys found a mild response at 3,000 ppm v/v and a marked response in the same animal at 5,000 ppm v/v as well as a questionable response in a second monkey at 5,000 ppm v/v, but no response at 7,500 ppm v/v; both monkeys showed marked responses at 10,000 ppm v/v; report deemed the LOEL monkey to be 5,000-10,000 ppm v/v for both dogs and monkeys; study concluded that the potential to cause cardiac sensitization is similar for R-11 and R-141b; toxicity data

J. W. Harris, J. P. Jones, J. L. Martin, A. C. LaRosa, M. J. Olson (General Motors Research Laboratories), L. R. Pohl, and M. W. Anders (University of Rochester Medical Center), **Pentahaloethane-Based Chlorofluorocarbon Substitutes and Halothane: Correlation of In Vivo Hepatic Protein Trifluoroacetylation and Urinary Trifluoroacetic Acid Excretion with Calculated Enthalpies of Activation**, *Chemical Research in Toxicology*, 5(5):720-725, September 1992 (6 pages, RDB5942)

toxicity of R-123, R-123B1 (halothane), R-125, R-134a, and others; metabolism; health effects

W. S. Harris, **Aerosol Propellants are Toxic to the Heart**, *Journal of the American Medical Association* (JAMA), 223:1508-1509, 1973 (2 pages, RDB8147)

toxicity of R-114 and others used as aerosol propellants (and also as refrigerants); cardiac sensitization; cardiotoxicity; health effects

W. S. Harris, **Toxic Effects of Aerosol Propellants on the Heart**, *Annals of Internal Medicine*, 131:162-166, 1973 (5 pages, RDB7248)

R-114 and others used as aerosol propellants (and also as refrigerants), cardiac sensitization, health effects, toxicity

W. S. Harris, **Cardiac Effects of Halogenated Hydrocarbons**, *Proceedings of the Symposium on Application of Halogenated Fire Extinguishing Agents* (Washington, DC, 11-12 April 1972), Na-

tional Academy of Science (NAS), Washington, DC, 114-126, 1972 (13 pages, available from NTIS as document AD-751426, RDB8148)

R-114 and others used as fire suppressants (and also as refrigerants), cardiac sensitization, health effects, toxicity

W. S. Harris, **Cardiac Toxicity of Aerosol Propellants**, *Proceedings of the 2nd Annual Conference on Environmental Toxicology* (31 August - 2 September 1971), report AMRL-TR-71-120, Aerospace Medical Research Laboratory, U.S. Air Force, Wright-Patterson Air Force Base, OH, 23-29, December 1971 (7 pages, available from NTIS as document AD-751426, RDB7249)

R-114 and others used as aerosol propellants (and also as refrigerants), cardiac sensitization, health effects, toxicity

W. S. Harris, S. M. Kilen, G. J. Taylor, and S. Levitsky, **Evidence from Animals and Man that Freon Depresses Myocardial Contractility**, *Circulation*, 44(supplement II):119 ff, 1971 (RDB-8149)

cardiac effects of aerosol propellants (and also as refrigerants), health effects, toxicity

J. K. Haseman, D. D. Crawford, J. E. Huff, G. A. Boorman, E. E. McConnell (National Institute of Environmental Health Sciences), **Results From 86 Two-Year Carcinogenicity Studies Conducted by the National Toxicology Program**, *Journal of Toxicology and Environmental Health*, 14(5-6):621-640, 1984 (20 pages with 5 tables, RDB6A80)

summary findings of toxicity tests for 86 chemicals to examine their carcinogenic potentials: majority were based on 2-yr feeding or gavage experiments involving groups of 50 male and female Fischer 344/N rats and B6C3F mice; the liver was the most frequent site of cancer in the animals tested; males were more prone to neoplasia in rats while females were in mice; 50% of the 86 chemicals showed carcinogenic effects, including R-30B1, R-120, R-150B2, R-260daB2, R-270da, and R-1120; 6% showed equivocal evidence of carcinogenicity; 42% gave no evidence of carcinogenicity including R-1130a and R-1270; and 2% of the studies were regarded as inadequate

H. W. Hays, **Etiology of Cardiac Arrhythmias**, *Proceedings of the 3rd Annual Conference on Environmental Toxicology*, report 7737166, National Technical Information Service (NTIS), Springfield, VA, 173-183, 1972 (11 pages, available from NTIS, RDB8152)

fluorochemical health effects, cardiac sensitization, toxicity

J. Healy and O. W. Van Auken, **Comparison of the Effects of Three Fluorocarbons on Certain Bacteria**, *Canadian Journal of Microbiology*, 21(2):221-226, 1975 (6 pages, RDB5921)

R-22 and others, toxicity

H. Hermann and J. Vial, **Nouvelles Syncopes Cardiaques par Association Toxique de l'Adrénaline et de Divers Produits Organiques Volatils** [New Cardiac Sensitization by Toxic Effect of Adrenaline and Various Volatile Organic Compounds], *Compte Rendu Société de Biol.*, Paris, France, 119:1316-1317, July 1935 (2 pages, RDB-6564)

identifies R-10 as having intermediate potency as a cardiac sensitizer; identifies R-30, R-40, R-40B1, R-40I1, R-150, R-160B1, R-160I1, and other chemicals as weak cardiac-sensitizing agents as reported in RDB5644

J. W. Hiddeman (Hazleton Washington, Incorporated, Vienna, VA), **Acute and Ten-Day Inhalation, Pyrolysis, and Cardiac Sensitization Studies with Freons 14, 116, 218, and 1301**, report on project 264-107 (included in report for contract DAHC 19-71-C-0026), U.S. Army Research Office, Arlington, VA, 18 February 1972 (103 pages with 1 figure and 27 tables, RDB7550)

reports tests of the acute inhalation toxicity in groups of ten male Sprague-Dawley albino rats for 1-hr; provides details of the tests for R-13B1 at 560,000 and 770,000 ppm v/v, R-14 at 780,000 ppm v/v, R-116 at 800,000 ppm v/v, and R-218 at 800,000 ppm v/v all with oxygen plus a control group with air (R-729); indicates no mortality in any of the exposures, but changes in behavior of all treated animals; also reports tests of the subchronic inhalation toxicity in groups of ten male and ten female Sprague-Dawley albino rats and with 10 male and 10 female guinea pigs for 24-hr/d for 10 days; indicates the measured mean concentrations as 51,000 ppm v/v for R-13B1, 226,000 ppm v/v for R-14, 121,000 ppm v/v for R-116, and 113,000 ppm v/v for R-218 all with oxygen enrichment to maintain a 20% level and notes similar tests of a control group with air; states that behavior was normal and there were no manifestations of toxicity except that five guinea pigs appeared to be ill and were sacrificed for necropsy before completing the full

term to avoid transmission of a suspected respiratory disease to other animals; of them one was in the control group, one in R-116, and two in R-218; indicates that these deaths were not considered to be compound-related; also reports pyrolysis studies to evaluate the toxicity of decomposition products from use of the subject gases to quench a fire; notes compound-specific behavioral and hematological changes, but no mortalities or remarkable gross or histopathological changes; also reports a cardiac sensitization study for R-14 in six male beagles; concludes that R-14 did not cause arrhythmias at the tested concentrations of 200,000 and 600,000 ppm v/v, but that it did sensitize 3 of 6 dogs at 600,000 ppm v/v as manifested by occasional preventricular contractions (OPVC) after the epinephrine challenges; notes that 1 of 6 dogs also experienced OPVC after the epinephrine challenge during the 200,000 ppm v/v exposure, but could no conclusively attribute it to sensitization since the same dog showed a similar response to epinephrine under control conditions without R-14 exposure

G. Hodson-Walker (Pharmaco-LSR Limited, UK), G. M. Rusch (AlliedSignal Incorporated, USA), and F. M. H. Debets (Akzo Chemicals International B.V. The Netherlands), **Mutagenicity Testing of a Number of CFC Replacements. Methodology and Results**, presented at the Sixth International Conference on Environmental Mutagens (Melbourne, Australia, February 1993); presented at the 24th Annual Meeting of the Environmental Mutagen Society (Norfolk, VA, April 1993); published in *Environmental and Molecular Mutagenesis*, 21(supplement 22):28 ff, 1993 (4 pages with 8 figures and 1 table, Rdb65D3)

mutagenicity tests of R-123, R-124, R-125, R-141b, and R-1131a by Ames Assay, chromosome aberration studies, and — for R-125 — mouse bone-marrow micronucleus tests by nose-only exposures: identifies concentrations resulting in toxicity and concludes that the five hydrochlorofluorocarbons (HCFCs) tested showed no evidence of mutagenic activity except that R-123 showed clastogenic (chromosome-damaging) activity in human lymphocytes, R-141b showed clastogenic activity in CHO-KI cells, and R-1131a was positive in the Ames test; presents a new method for testing gas- and water-insoluble, volatile liquids

P. Hoet (Catholic University of Louvain, CUL, Belgium), M. L. Graf (also shown as Graff), M. Bourdi, L. R. Pohl (National Heart, Lung, and Blood Institute, UK), P. H. Duray (National Cancer Institute, UK), W. Chen, R. M. Peter, S. D. Nelson (University of Washington, USA), N. Verlinden (Beerse, Belgium), D. Lison (CUL), **Epidemic of Liver Disease Caused by Hydrochlorofluorocarbons Used as Ozone-Sparing Substitutes of Chlorofluorocarbons**, *Lancet*, UK, 350(9077):556-559, 23 August 1997 (4 pages with 3 figures, RDB-7C70)

toxicity findings following accidental human exposures to a blend of R-290/124/123 (reported in this article as R-124/123) in an industrial plant: reports an investigation of liver disease in nine workers affected to various degrees following repeated exposures; metabolism of both R-123 and R-124 produces reactive trifluoroacetyl halide intermediates, which have been implicated in the hepatotoxicity of R-123B1 (halothane); a liver biopsy for one of the workers showed hepatocellular necrosis that was prominent in perivenular zone three and extended focally from portal tracts to portal tracts and centrilobular areas (bridging necrosis); immunohistochemical stainings in the same worker showed the presence of trifluoroacetyl-adducted proteins in surviving hepatocytes; autoantibodies that react with human liver cytochrome P450 2E1 and P58 protein disulphide isomerase isoform were detected by serum tests in five of six affected workers; concludes that repeated exposure of human beings to R-123 and R-124 can result in serious liver injury and notes while that the exact mechanism of hepatotoxicity is unknown, the findings suggest involvement of trifluoroacetyl-altered liver proteins; the authors suggest that safer alternatives are needed [Subsequent investigation of the accident indicates that the refrigerant involved was R-290/124/123. It was used in a direct-expansion air conditioner serving the cab and controls of an overhead gantry crane. The system had been retrofitted from R-114 to the blend, but the old, incompatible hoses were not changed. The leak persisted for several months without repairs, despite repeated requirements for refrigerant recharge, and no leak detector was installed. The concentrations to which the affected workers, all crane operators, were exposed could not be determined, but calculations indicate that they far exceeded recommended exposure limits. The liver biopsy reported was performed on only one of the workers, for whom no prior medical history was available. See RDB7C71 - RDB7C75 for further information.]

D. B. Hood, **Skin and Eye Irritation Tests with Aerosol Hair Sprays**, report 31-56, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1956 (RDB7526)

R-11 and R-12, dermal contact toxicity for aerosol propellants [also used as refrigerants], irritation as reported in RDB7414 and RDB7525

B. K. Hoover and R. C. Graham, **A Table of Acute Oral and Dermal LD_{50}'s and Inhalation LC_{50}'s for Fluorocarbon-11, 12, 22, 113, 114, 115, and 152a**, report OTS-0520424 (also numbered OTS-0520425), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 11 May 1978 (8 pages, RDB6595)

summary table of acute oral, dermal, and inhalation toxicity data for six fluorochemical refrigerants indicates: for R-11, LC_{50} = 26,200 ppm, LD_{50} oral rat >3,752 mg/kg; for R-12, LC_{50} >800,000 ppm, LD_{50} oral rat >1,000 mg/kg; for R-22, ALC = 300,000 ppm; for R-113, LC_{50} = 56,000-68,000 ppm, LD_{50} dermal rabbit >11,000 mg/kg, LD_{50} oral rat = 43,000 mg/kg; for R-114, LC_{50} = 600,000 ppm, LD_{50} oral rat >2,250 mg/kg; for R-115, LC_{50} >800,000 ppm; for R-152a, LC_{50} = 383,000 ppm; time period and test species for LC_{50} and ALC data is not indicated

D. K. Hoover, K. O. Yu, R. K. Black, G. W. Jepson (ManTech Environmental Technology, Incorporated), and J. W. Fisher (U.S. Air Force Armstrong Laboratory, USAF-AL), **Kinetic Evaluation of Halon 1211, HCFC-123, HCFC-142b, and HCFC-124 Using Gas Uptake Methods**, abstract (SOT 31st Annual Meeting, February 1992), *The Toxicologist*, 12(1):353, 1992 (1 page, RDB7289)

R-12B1, R-123, R-142b, R-124, biochemistry, health effects, toxicity

R. M. Hopkins and J. C. Krantz, Jr. (Huntingdon Research Center, HRC, USA), **Anesthesia LXXV. Relative Effects of Haloforms and Epinephrine on Cardiac Automaticity**, presented at the *51st Annual Meeting of the Federation of American Society for Experimental Biology* (Pharmacology Sessions, Chicago, 19 April 1967), 1967; republished in *Anesthesia and Analgesia*, 47(1):56-67, January-February 1968 (12 pages with 5 figures and 4 tables, RDB5136)

tests of the cardiac sensitization potential of R-20 (chloroform), R-20B3 (bromoform), R20I3 (iodoform), R-23 (fluoroform), and R-50 (methane); tests of R-23 and R-50 were conducted by inhalation at concentrations of 800,000 and 810,000 ppm v/v, respectively, in oxygen for 5-10 min with an epinephrine challenge; reports that neither caused sensitization as tested despite a prior qualitative finding of sensitization for R-50 (see RDB65A2); also reports tests with intravenous administration of R-20, R-20B2, and R-20I3 in anesthetized and unanesthetized dogs with epinephrine challenges; summarizes estimates of the mean molar concentrations evoking sensitization for these three compounds; toxicity tests

A. Inserra, M. Donpe, and V. Timpanaro, **Blood Dyscrasia and Experimental Poisoning with Propane and Butane**, *Folia Med.*, Italy, 51:779 ff, 1968 (RDB7410)

R-290, R-600, R-290/600, toxicity, as reported in RDB6569

N. F. Izmerov, I. V. Sanotsky, and K. K. Siderov, **Toxicometric Parameters of Industrial Toxic Chemicals Under Single Exposure**, USSR State Committee for Science and Technology, Moscow, USSR, 1982 (in Russian, RDB5C91)

toxicity of R-141b, R-152a, and others — as reported in RDB4450 and RDB5868; 2-hr LC_{50} mouse for R-152a = 369,000 ppm v/v — as reported in RDB4450 and RDB4B90

D. Jack, **Sniffing Syndrome**, *British Medical Journal*, 2:708-709, 1971 (2 pages, RDB8153)

fluorocarbon abuse, potential for human fatalities

W. Johnson, **Unsafe Application of HCFC-123, -124 Blamed for Liver Damage in 9 Workers**, *The Air Conditioning, Heating, and Refrigeration News*, 1-2 and 19, 1 September 1997 (3 pages with no figures or tables, limited copies available from JMC as RDB7C74)

provides further information on the underlying incident and subsequent investigations in response to an article in *The Lancet* (see RDB-7C70) on exposures of workers to R-124/123 [actually R-290/124/123]: summarizes the incident, points made in the article, and reactions from informed industry sources; quotes E. L. Smithart (The Trane Company, USA), R. Rubenstein (Environmental Protection Agency, EPA, USA), P. Hoet (Catholic University of Louvain, Belgium), G. R. Rusch (AlliedSignal Incorporated, USA), W. R. Brock (DuPont Chemicals, USA), and J. M. Calm (Engineering Consultant, USA); the information presented indicates that the application was not typical

and did not conform to recognized safety standards; also notes that the exposures exceeded recommended limits and would not have occurred if accepted practices had been followed and attention paid to the required system recharges

R. T. Johnstone and S. E. Miller, **Occupational Diseases and Industrial Medicine**, W. B. Saunders Company, Philadelphia, PA, 1961 (RDB-5C43)

fluorocarbon inhalation effects, oxygen deprivation, toxicity

B. C. Karpov, **Lethal and Threshold Concentration of Freons**, *Tr. Leningrad Sanit. Gigien. Med. Inst.*, 241:128-137, 1963; English translation published in *Industrial Hygiene and Occupational Pathology*, U.S. Department of Commerce, Washington, DC, 118 ff, 1965 (10 pages in Russian, RDB5976)

R-141b and others, toxicity as reported in RDB-6365]

D. A. Keller, D. C. Roe, and P. H. Lieder (E. I. duPont de Nemours and Company), **Fluoroacetate-Mediated Toxicity of Fluorinated Ethanes**, article 0058, *Fundamental and Applied Toxicology*, 30(2):213-219, April 1996 (7 pages with 4 figures and 1 table, RDBA648)

summarizes tests of the inhalation toxicity for 1-(di)halo-2-fluoroethanes including R-142a (1-chloro-1,2-difluoroethane), R-151 (1-chloro-2-fluoroethane), R-151B1 (1-bromo-2-fluoroethane), and R-152 (1,2-difluoroethane); notes that these compounds are highly toxic by inhalation even though reported in the literature to be nontoxic or of low toxicity; all four compounds had 4-hr approximate lethal concentrations (ALCs) of 100 ppm v/v or less in rats; exposed rats showed clinical signs of fluoroacetate toxicity (lethargy, hunched posture, and convulsions); R-142a, R-152, R-151, and R-151B1 increased concentrations of citrate in serum and heart tissue, a hallmark of fluoroacetate intoxication; analyses confirmed the presence of fluoroacetate in the urine of exposed rats; analyses also found fluorocitrate, a condensation product of fluoroacetate and oxaloacetate, in the kidney and concentration-related elevation of serum and heart citrate in rats exposed to 0-1000 ppm v/v R-152 1,2-difluoroethane; indicates that metabolism of 1,2-difluoroethane by cytochrome P450 (most likely CYP2E1) is suspected; experimental evidence indicates that the metabolism of the toxic fluoroethanes is initiated at the carbon-hydrogen bond, with metabolism to fluoroacetate via an aldehyde or an acyl fluoride; the results of these studies show that 1-(di)halo-2-fluoroethanes are highly toxic to rats and should be considered a hazard to humans unless demonstrated otherwise; the paper notes that R-152a (1,1-difluoroethane), in contrast, has very low acute toxicity with a 4-hr LC_{50} of >400,000 ppm in rats

D. A. Keller, **Acute Inhalation Toxicity of HFC-236fa and HFC-236ea in the Rat**, report 761-93, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 21 November 1994 (9 pages with 2 tables, RDB6803)

toxicity of R-236ea and R-236fa by whole-body exposures of young adult male, Charles River rats at target concentrations of 15,000, 25,000, 50,000, and 100,000 ppm v/v R-236ea and at 150,000 and 200,000 ppm v/v R-236fa (the means of actual concentrations determined by gas chromatography (GC) were 13,586, 23,588, 45,813, and 84,927 ppm v/v for R-236ea and 133,939 and 189,275 for R-236fa); oxygen level in the air was maintained at 21±3%; concluded that both isomers can cause sleep induction (narcosis); for R-236ea, 4-hr ALC rat is >85,000 ppm v/v and NOEL and LOEL for narcosis are 14,000 and 24,000 ppm, respectively; for R-236fa, 4-hr ALC rat is >189,000 ppm and NOEL and LOEL for symptoms of narcosis (lack of response to sound) are 134,000 and 189,000 ppm, respectively; toxicity data

D. P. Kelly, R. Culik, H. J. Trochimowicz, and W. E. Fayerweather (E. I. duPont de Nemours and Company, Incorporated), **Inhalation Teratology Studies on Three Fluorocarbons**, abstract 170 (Seventeenth Annual Meeting of the Society of Toxicology, SOT), *Toxicology and Applied Pharmacology* (TAP), 45(1):293, 1978 (1 page with no figures or tables, RDB5827)

toxicity of R-123, R-142b, and others

D. P. Kelly, **Two-Week Inhalation Toxicity Studies**, report 149-76, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1 March 1976 (4 pages with no figures or tables, RDB6158)

reports subchronic inhalation toxicity tests of R-21 and R-123; rats exposed to 10,000 ppm v/v R-123 for 6 hr/d, 5 d/wk, for 2 weeks showed

signs suggestive of anesthesia — as reported in RDB6153 and RDB6941; no adverse hematological, clinical chemical, urine analytical, or histopathological effects were found as reported in RDB6941

T. J. Kenny, C. K. Shepherd, and C. J. Hardy (Huntingdon Research Centre Limited, HRC, UK), **Iodotrifluoromethane and Iodoheptafluoropropane: Assessment of Cardiac Sensitization Potential in Dogs**, report AL/OE-TR-1995-0031, Armstrong Laboratory, U.S. Air Force, Wright-Patterson Air Force Base, OH, 1995 (RDB8418)

toxicity tests to determine the cardiac sensitization potential of R-13I1 and R-217bal1 in dogs

C. J. Kirwin (Phillips Petroleum Company), W. C. Thomas, and V. F. Simmon (Stanford Research Institute), **In Vitro Microbiological Mutagenicity Studies of Hydrocarbon Propellants**, *Journal of the Society of Cosmetic Chemists*, 31(7):367-370, December 1980 (4 pages, RDB6111)

summarizes tests of the mutagenic potential of hydrocarbon propellants [also used as refrigerants] by Ames assay in *Salmonella typhimurium*, with and without metabolic activation; addresses R-290 (propane), R-600 (n-butane), 2 samples of R-600a (isobutane), R-601 (n-pentane), and R-601a (isopentane); although some toxicity was observed with the higher molecular weight hydrocarbons, none of the five tested compounds was found to be mutagenic — as reported in RDB6A83 and RDB7621

C. J. Kirwin, **Toxicological Review of Propane, Butane, Isobutane, Pentane, and Isopentane**, Phillips Petroleum Company, Bartlesville, OK, November 1976 (10 pages with no figures or tables, RDBA623)

summarizes the toxicity of R-290 (propane), R-600 (n-butane), R-600a (isobutane), R-601 (pentane), and R-601a (isopentane) as candidates to replace chlorofluorocarbons (CFCs) as aerosol propellants [and as refrigerants]; addresses skin and eye irritation, median lethal concentrations (LC_{50}), anesthetic potential, chronic exposure effects, pharmacologic effects, the toxicology of blends, Threshold Limit Values (TLV), authorization for food use, and mutagenicity; indicates that very high concentrations of paraffinic hydrocarbons are necessary to produce alterations in normal body functions and that no permanent alterations are induced by these chemicals; notes that the toxic properties of these chemicals are not manifest until levels that exceed fire hazard concentrations; also notes that these hydrocarbons can act as simple asphyxiants

A. E. Kozbakova, **Comparative Toxicity of Chlorinated and Fluorinated Methane and Ethane Derivatives**, *Gigiena Truda i Professional'nye Zabolevaniya* [Labor Hygiene and Occupational Diseases], Moscow, Russia (then USSR), 20(11):-38-41, 1976 (4 pages in Russian, RDB7547)

R-21 as reported in RDB5340; R-114 and others, health effects, toxicity

J. C. Krantz, Jr., and F. G. Rudo, **The Fluorinated Anesthetics**, chapter 10, *Handbuch der experimentellen Pharmakologie* [Handbook of Experimental Pharmacology], edited by O. Eichler, A. Farah, H. Herken, and A. D. Welch, Springer-Verlag, Berlin, Germany, XX(1):501-564, 1966 (64 pages, RDB6589)

R-113a, R-114, and others, toxicity review of fluorine chemicals: R-113a anesthetic concentration at 60,000 ppm) as reported in RDB5143

J. C. Krantz, Jr., **The Rationale of the Use of Fluorinated Hydrocarbons and Ethers as Volatile Anesthetic Agents**, *Anesthesia and Analgesia*, 44:260 ff, March-April 1965 (RDBA627)

anesthetic effects and toxicity of hydrocarbons, fluorochemicals, and fluoroethers

J. C. Krantz, Jr., C. J. Carr, and J. F. Vitcha (University of Maryland), **Anesthesia XXXI. A Study of Cyclic and Noncyclic Hydrocarbons on Cardiac Automaticity**, *Journal of Pharmacology and Experimental Therapeutics* (JPET), 94:315-318, 1948 (4 pages with 1 figure and 1 table, RDB6192)

toxicity tests to determine the cardiac sensitization potential of hydrocarbons mixed with oxygen in dogs with epinephrine hydrochloride injections before and approximately 10 minutes into exposures: the number of dogs sensitized at concentrations of 100,000-250,000 ppm was 2/4 for R-170, 3/3 for R-290, 2/2 for R-C390, 2/2 for R-600, 2/2 for R-600a, 0/12 for R-1150, and 2/2 for R-1270; the number sensitized at 150,000-900,000 ppm was 2/3 for R-C41-10 and 3/3 for R-601a; data also are provided for cis-trans-butene-2, cyclobutene, and 2,2-dimethylbutane; concludes that while R-1150 does not produce sensitization, the remaining 11 hydrocarbons tested do; also concludes that cyclobutane and cyclobutene produce excellent anesthetic syndromes, the other hydrocarbons tested are unsatisfactory anesthetic agents in the dog

H. Kubler, **Physiological Properties of Propellants**, *Journal of the Society of Cosmetic Chemists*, 14:341-351, 1963 (11 pages, RDB6737)

R-114 and others, toxicity

K. Kudo, S. Toida, S. Matsuura, T. Sasaki, and H. Kawamura, **Comparison of Freon-11S and Freon 11. Acute, Subacute Toxicity and Irritation of Mucous Membrane**, *Toho Igakkai Zasshi*, Japan, 18(2):363-367, 1971 (5 pages, RDB7426)

R-11, health effects, toxicity as reported in RDB7414

C. J. Lambertsen, **Therapeutic Gases — Oxygen, Carbon Dioxide, and Helium**, *Drill's Pharmacology in Medicine* (fourth edition), McGraw-Hill Book Company, New York, NY, chapter 55, 1971 (RDBA664)

toxicity and therapeutic uses of R-704 (helium), R-732 (oxygen), and R-744 (carbon dioxide); indicates that inhalation by humans of carbon dioxide at 100,000 ppm v/v for 1.5 min causes neurologic effects including eye flickering, psychomotor excitation, and myoclonic twitches (involuntary contractions of muscles); also indicates increasing effects at higher concentrations including unconsciousness and convulsions at 300,000 ppm v/v in oxygen in less than 2 minutes — as reported in RDB5787

M. M. Landry and R. Fuerst, **Gas Ecology of Bacteria**, *Develop. Ind. Microbiology*, 9:370-388, 1967 (19 pages, RDB6112)

R-116, R-152a, R-290, R-C318, R-1270, and others; mutagenic potential, toxicity; R-1270 is not mutagenic in *Escherichia coli*, but protects against mutations as reported in RDB6A59

W. R. Lee, S. Abrahamson, R. Valencia, E. S. von Halle, F. E. Wurgler, and S. Zimmering, **The Sex-Linked Recessive Lethal Test for Mutagenesis in Drosophila Malanogaster Exposed to Four Fluorinated Hydrocarbon Gases** (Report of the U.S. Environmental Protection Agency, EPA, Gene-Tox Program), *Mutation Research*, 123:183-279, 1983 (97 pages, RDB6592)

R-152a and others, mutagenicity, toxicity

D. Lester and L. A. Greenberg (Yale University), **Acute and Chronic Toxicity of Some Halogenated Derivatives of Methane and Ethane**, *Archives of Industrial Hygiene and Occupational Medicine*, 2:335-344, 1950 (10 pages with 9 tables, RDB5147)

R-11, R-12, R-132bB2, R-142b, R-152a, R-1132a, and R-1141, toxicity: acute exposures of rats, for 30 min, to concentrations of 0-80% by volume, dominant clinical response found to be narcosis evidenced by disappearance of various reflexes at increasing concentrations, death when occurring appeared to be due to respiratory failure, recommends maximum allowable concentrations; chronic exposures of rats for 16 hr/d; provides data for ALC, complete anesthesia, recommended maximum allowable exposures; subchronic toxicity data for R-142b and R-152a exposures at 100,000 ppm v/v; attempts to correlate toxic effects to boiling points

G. Limperos, **Inhalation Toxicity Studies of Various Freon Compounds**, report 2-52, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 26 December 1951 (5 pages with 3 tables, RDB7737)

preliminary acute inhalation toxicity tests of R-12B2, R-12B1, R-13B1, and R-152a (identified in the report as "Brom-12," "Chlorbrom-12," "Brom-13," and "Freon-152," respectively) in groups of two male albino rats by whole body exposures: for R-12B1, 2/2 rats died in 6-7 min at 100,000 ppm, severe convulsions but no deaths resulted at 57,000 ppm, violent trembling but no deaths resulted at 11,500 ppm for 6 hr, 17,000 ppm for 2 hr, and 19,000 ppm for 3 hr, and no toxic effects were observed at 10,000 ppm for 2 hr; for R-12B1, 2 of 2 rats died at 500,000 ppm for 5 min (possibly with some asphyxiation effect), violent trembling and occasional convulsions but no deaths resulted at 140,000 ppm for 1 hr, occasional nervous movements but not deaths resulted at 62,000 ppm, and no toxic effects were observed at 31,000 ppm for 1 hr; for R-13B1, no toxic effects, gross or microscopic pathology, or deaths resulted at either 200,000 ppm for 2 hr or 300,000 ppm for 40 min; for R-152a, occasional trembling and incoordination, but no gross or microscopic pathology or deaths resulted at either 100,000 or 200,000 ppm, and no toxic effects were observed at 74,000 ppm for 1-3/4 hr; R-C316 and R-C317 produced no detectable cumulative toxic effects nor any pathology in groups of 10 rats exposed in subchronic studies to 10,000 ppm for 6 hr for at least 40 exposures

H. A. Lincoff and I. Kreissig, **Intravitreal Behavior of Perfluorocarbons**, *Dev. Ophthalmology*, 2:17-23, 1981 (7 pages, RDB5C78)

R-116, R-218, R-C318, and others; ophthalmological effects, toxicity

R. C. Lind, A. J. Gandolfi, and P. D. Hall (University of Arizona College of Medicine), **Biotransformation and Hepatotoxicity of HCFC-123 in the Guinea Pig: Potentiation of Hepatic Injury by Prior Glutathione Depletion**, *Toxicology and Applied Pharmacology* (TAP), 134(1):175-181, September 1995 (7 pages, RDB7C75)

acute toxicity of R-123: 4-hr tests in male outbred Hartley guinea pigs by inhalation exposures to 10,000 ppm v/v R-123 in oxygen enriched (400,000 ppm v/v) air; animals were injected 24 hr before exposures with either a pretreatment to deplete hepatic glutathione or a control solution; R-123 caused minimal liver injury with only 1 of 8 control animals displaying confluent zone 3 necrosis; glutathione depletion potentiated injury producing submassive to massive liver necrosis in some animals; this potentiation was associated with a 36% increase in covalent binding of reactive R-123 intermediates to hepatic protein; plasma concentrations of the metabolites trifluoroacetic acid (TFA) and fluoride ion indicate that these results were not due to alterations in the biotransformation of R-123; R-123 also was found to cause a decrease in liver glutathione concentrations following exposure; concludes that R-123 inhalation [at high concentations] can cause acute hepatic injury in the guinea pig that is worsened by low hepatic glutathione concentrations

G. T. Linteris (National Institute of Standards and Technology, NIST), **Acid Gas Production in Inhibited Propane-Air Diffusion Flames**, *Halon Replacements, Technology and Science* (208th National Meeting, Washington, DC, 21-25 August 1994), ACS Symposium Series 611, American Chemical Society (ACS), Washington, DC, 225-242, 1995 (8 pages, RDB6209)

R-13B1, R-22, R-116, R-124, R-134a, R-218, R-227ea, R-236fa, R-31-10, R-C318, R-410A, decomposition in flames, reaction kinetics, potential formation of corrosive byproducts containing hydrofluoric and hydrochloric acids (HF and HCl)

J. Little (Imperial Chemical Industries Limited (ICI), UK), **The Formation of Phosgene by the Action of Hot Surfaces and Its Absence When Tobacco Is Smoked in Atmospheres Containing Chlorinated Hydrocarbon Vapours**, *British Journal of Industrial Medicine*, 12:304-308, 1955 (5 pages, RDB7260)

refrigerants, toxicity: cites cautions of and disagreement by others on phosgene formation from inhaled gases in cigarette smoking and the secondary danger of formation around a glowing cigarette tip; presents an experimental study of smoking to detect phosgene at concentrations 0.05 ppm (indicated as a tenth the tolerance limit): no phosgene was detected at a continuous smoking rate selected between the average and peak identified in other studies; moreover, phosgene was not detected in the effluent even when cigarettes were smoked in atmospheres that contained phosgene, attributed by further study to absorption by the tars in cigarette smoke; tests to detect phosgene in the air surrounding cigarettes found none to a detection level of 0.1 ppm in atmospheres containing R-10, R-20, R-130, R-1110, R-1120, or 0.2-20 ppm phosgene; concludes that while phosgene does form when chlorine-containing solvent vapors contact surfaces >400 °C (752 °F), phosgene was not found in inhaled gases from cigarettes or the air surrounding glowing tips and that phosgene added to the atmosphere was destroyed by passage through the cigarette being smoked

F. Leuschner, B. W. Neumann, and F. Hübscher, **Report on Subacute Toxicological Studies with Several Fluorocarbons in Rats and Dogs by Inhalation**, *Fortschritte der Arzneimittelforschung* [Progress in Drug Research], 33/II(10):1475-1476, 1983 (2 pages, RDB5607)

R-22, R-23 (subchronic NOAEL rat = 10,000 ppm, subchronic NOAEL dog = 5,000 ppm, as reported in RDB5604), and others, toxicity

E. Longstaff (ICI Chemicals and Polymers, UK), **Carcinogenic and Mutagenic Potential of Several Fluorocarbons**, *Living in a Chemical World: Occupational and Environmental Significance of Industrial Carcinogens*, edited by C. Maltoni and I. J. Selikoff, Annals of the New York Academy of Sciences, New York, NY, 534:283-298, 1988 (16 pages, RDB7225)

R-12 and others, carcinogenicity, mutagenicity, toxicity

E. Longstaff, M. Robinson, C. Bradbrook, J. A. Styles, and I. F. H. Purchase (ICI Chemicals and Polymers, UK), **Genotoxicity and Carcinogenicity of Fluorocarbons: Assessment by Short-Term in Vitro Tests and Chronic Exposure in**

Rats, *Toxicology and Applied Pharmacology* (TAP), 72(1):15-31, 1984 (32 pages, RDB5781)

R-32, R-123, R-124, R-134, R-134a, R-142b, R-143a, R-152a, and others; negative carcinogenic findings, toxicity as reported in RDB4B90, RDB5367, RDB5862, RDB5870, RDB5C16, and RDB6686

E. Longstaff, M. Robinson, C. Bradbrook, J. A. Styles, and I. F. H. Purchase (ICI Chemicals and Polymers, UK), **Carcinogenicity of Chlorofluorocarbons. Assessment by Short-Term in Vitro Tests and Chronic Exposure in Rats**, *The Toxicologist*, 2:106 ff, 1982 (RDB6276)

toxicity

E. Longstaff, **Fluorocarbons: A Summary Report of the Findings from Short-Term Predictive Tests and Long-Term Rat Carcinogenicity Studies**, ICI Chemicals and Polymers, Macclesfield, Cheshire, UK, 1982 (RDB5B68)

toxicity

N. Loprieno and A. Abbondandolo, **Comparative Mutagenic Evaluation of Some Industrial Compounds**, *Proceedings of the Symposium on Short-Term Testing for Systematic Detection of Carcinogenicity*, edited by K. H. Norpoth and R. C. Garner, Springer-Verlag, Berlin, Germany, 333-356, 1980 (24 pages, RDB5930)

R-22 and others, health effects, toxicity, mutagenicity: findings for R-22 were negative as reported in RDB5923

R. G. Love et al., *Annals of Occupational Hygiene*, 22(1):43-54, 1979 (12 pages, RDB5785)

R-744 (carbon dioxide) and others, health effects, toxicity

G. Lu, S. L. Johnson, M. S. Ling, and J. C. Krantz, Jr., **Anesthesia. XLI. The Anesthetic Properties of Certain Fluorinated Hydrocarbons and Ethers**, *Anesthesiology*, 14:466-472, 1953 (7 pages, RDB65B7)

anesthetic effect, toxicity: found that some hydrogen content appears to be essential for anesthetic activity in fluorinated hydrocarbons — as reported in RDB5828

G. H. W. Lucas, **Study of the Fate and Toxicity of Bromine and Chlorine Containing Anesthetics**, *Journal of Pharmacology and Experimental Therapeutics* (JPET), 34:223 ff, 1928 (RDBA628)

indicates that some brominated hydrocarbons are readily decomposed in the body — as reported in RDB5136

H. R. Ludwig, S. G. Cairelli, and J. J. Whalen, **Documentation for Immediately Dangerous to Life or Health Concentrations (IDLHs)**, National Institute for Occupational Safety and Health (NIOSH), U.S. Department of Health and Human Services, Cincinnati, OH, May 1994 (available from NTIS as document PB-94-195047, RDB5340)

This publication documents the criteria and information sources used to determine the National Institute for Occupational Safety and Health (NIOSH) Immediately Dangerous to Life or Health (IDLH) concentrations. It addresses approximately 400 substances.

B. T. Luke et al., **Theoretical Investigation of the Anaerobic Reduction of Halogenated Alkanes by Cytochrome P-450. 2. Vertical Electron Affinities of Chlorofluoromethanes as a Measure of Their Activity**, *Journal of the American Chemical Society*, 110(11):3396-3400 (5 pages, RDB-5777)

toxicity, fluorocarbons

A. Z. Lure and Z. I. Pleshkova, **Comparative Characteristics of the Incidence of Upper Respiratory Tract Mucous Membrane Disease in Workers of Different Shops of a Fluorocarbon Production Plant**, *Zh. Ushn. Nos. Gorl. Bolezn.*, 3:47-50, 1977 (4 pages in Russian, RDB8162)

fluorochemical refrigerants and others, effects of human exposures, toxicity

S. Magda (Solvay Pharmaceuticals, Germany), **Fluorocarbons**, *Toxicology*, edited by H. Marquardt, Academic Press, San Diego, CA, 659-662, 1999 (4 pages with 2 figures and 1 table, RDB-A526)

reviews the toxicity of fluorochemicals R-32, R-123, R-124, R-125, R-134a, R-141b, R-225ca, and R-225cb investigated in the Programme for Alternative Fluorocarbon Toxicity Testing (PAFT); tabulates the median lethal concentrations (LC_{50}) and no observed effect levels (LOEL) from acute studies and the lowest observed adverse effect level (LOAEL, identified in the paper as the "lowest toxic concentration") and NOEL from subchronic and chronic studies; notes that fluorocarbons have very low acute toxicity by inhalation; also notes that the symptoms generally are reversible effects on the central nervous system (CNS); also indicates that the alternative fluorocarbons are

prone to induce cardiac sensitization, but at levels well above expected human exposures; notes that increased benign tumors were observed in two-year animal studies following exposures to R-123, R-134a, and R-141b, but none were life threatening, all occurred late in life, and the overall evidence suggests that the incidence was not due to genotoxic effects; introduction briefly recaps concerns with chlorinated and brominated fluorochemicals for stratospheric ozone depletion; figures illustrate the catalytic chemical reactions involved and comparative ozone depletion potentials [based on data from 1987 and 1990 for chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) respectively]

G. Malinverno (Ausimont S.p.A., Italy), W. J. Brock (E. I. duPont de Nemours and Company, USA), and S. Magda (Solvay Pharmaceuticals, Germany), **Reproduction Studies with HCFC Alternatives**, *EUROTOX'97, Diversification in Toxicology: Man and Environment* (proceedings of the XXXVI European Congress of Toxicology, EuroTox, Århus, Denmark, 25-28 June 1997), Nordic Pharmacological Society, Copenhagen Denmark, 1997; abstract P4-38 republished in *Pharmacology and Toxicology*, 80(supplement III):139-140, 1997 (2 pages with no figures or tables, RDBA647)

summarizes studies of the developmental toxicities of R-32, R-123, R-124, R-125, R-134a, and R-141b along with reproductive toxicities of R-123 and R-141b; indicates that no developmental toxicity was seen for any tested compound and that the no observed effect level (NOEL) for R-141b was determined to be 2000 ppm v/v; also summarizes a two-generation reproduction study of R-123 in rats based on inhalation exposures of 30 to 1000 ppm v/v; indicates that no adverse effects on reproductive performance were observed; describes a cross-fostering study in rats to investigate the mechanism for a decrease in body weight gain in offspring; attributes the effects to trifluoroacetic acid (TFA) content in milk from nursing rather than developmental toxicity; outlines a further study in Rhesus monkeys exposed to 1000 ppm v/v in which no effects were seen in mothers or offspring, though TFA was detected in both maternal and offspring blood

G. Malinverno and G. Bargigia (Ausimont S.p.A., Italy), **Reproductive Toxicity and Teratogenicity of Alternatives to Current CFCs**, *Proceedings of the Sixth International Congress of Toxicology* (Rome, Italy, 28 June - 3 July 1992), International Union of Toxicology, June 1992 (RDB5B45)

toxicity of R-125 and others

C. Maltoni, G. Lefermine, D. Tivoli, and G. Perino, **Long-Term Carcinogenicity Bioassays of Three Chlorofluorocarbons (Trichlorofluoromethane, FC11; Dichlorodifluoromethane, FC12; and Chlorodifluoromethane, FC22) Administered by Inhalation to Sprague-Dawley Rats and Swiss Mice**, *Annals of the New York Academy of Science (Living in a Chemical World)*, 534:261-282, 1988 (22 pages, RDB6570)

toxicity of R-11, R-12, and R-22; 104-week inhalation study in the rat and 78-week inhalation study in the mouse; findings negative

C. Maltoni, A. Ciliberti, and D. Carretti (Institute of Oncology F. Addarii, Italy), **Experimental Contributions in Identifying Brain Potential Carcinogens in the Petrochemical Industry**, *Annals of the New York Academy of Science*, 381:216-249, 1982 (34 pages with 29 tables, RDB7743)

inhalation toxicity tests to determine the incidence of brain tumors in Sprague-Dawley (and for R-1140 also Wistar) rats from exposures to selected chemicals, among them R-11 (1,000 and 5,000 ppm for 4 hr/d, 5 d/wk, for 104 wk), R-12 (1,000 and 5,000 ppm for 4 hr/d, 5 d/wk, for 104 wk), R-22 (1,000 and 5,000 ppm for 4 hr/d, 5 d/wk, for 104 wk), R-150, R-1130a, R-1140, and R-1270 (200, 1,000, and 5,000 ppm for 7 hr/d, 5 d/wk, for 104 wk): of those listed above, only R-1140 was found to produce brain tumors, which were observed following extended exposures exceeding 500 ppm v/v; paper also reports ingestion tests for similar purposes with Sprague-Dawley rats for R-1120, R-1130a, R-1132a, R-1140, and others; none of the compounds tested by ingestion seemed to produce brain tumors

G. Marier, G. H. MacFarland, and P. Dussalt, **A Study of Blood Fluorocarbon Levels Following Exposure to a Variety of Household Aerosols**, *Household and Personal Products Industry*, 10(12):68, 70, 92, and 99, 1973 (4 pages, RDB-7540)

R-12 and others, health effects, toxicity: blood levels of R-12 were below detection limits in normal subjects using household aerosols as reported in RDB5141

T. Marti, **Note sur l'intoxication par le freon** [Note on the Narcotic Effect of Fluorochemicals], *Ann. Med. Legale, Criminol., Police Sci., Med. So-*

ciale, Toxicol., 28:147-148, 1948 (2 pages, RDB-7221)

toxicity of R-12; abuse; "sniffing"

J. L. Martin (National Institute of Health, NIH), J. W. Harris (Johns Hopkins Medical Institutions), A. C. LaRosa, M. J. Olson (General Motors Research Laboratories), M. W. Anders (University of Rochester Medical Center), and L. R. Pohl, **Metabolism in Vivo of Halothane and the Chlorofluorocarbon Substitutes HCFC-123, HCFC-124, and HFC-125 to Trifluoroacetylated Liver Protein Adducts**, abstract 151, *The Toxicologist*, 12:62, 1992 (1 page with no figures or tables, RDB6B53)

toxicity of R-123, R-123B1 (halothane), R-124, and R-125: rats exposed to 10,000 ppm v/v R-123 or R-123B1 produced nearly identical levels of trifluoroacetylated (TFA) liver proteins; much lower levels were found for similar exposures to R-124 or R-125; urinary trifluoroacetic acid excretion correlated with the postexposure levels of TFA adducts; concludes that R-124 and R-125 may be safer alternatives than R-123 because they produce lower TFA neoantigen concentrations, since halothane hepatitis may be mediated by an immune response directed against TFA proteins in the livers of susceptible individuals

D. A. McClure, **Failure of Fluorocarbon Propellants to Alter the Electrocardiogram of Mice and Dogs**, *Toxicology and Applied Pharmacology* (TAP), 22(2):221-230, 1972 (10 pages, RDB7295)

cardiac sensitization of R-12 and others; toxicity

A. E. M. McLean, **Chlorofluorocarbons — In the Can, In Man, and In the Environment**, *British Journal of Clinical Pharmacology*, 4(6):663-666, 1977 (4 pages, RDB7265)

toxicity of R-114 and others; teratology

E. T. McHale (Atlantic Research Corporation), **Habitable Atmospheres Which Do Not Support Combustion**, report for contract DAHC 19-71-C-0026 (also identified as ARC report 41-5521), U.S. Army Research Office, Arlington, VA, 15 March 1972 (154 pages with 5 figures and 37 tables, RDB5C79)

presents a study of use R-13B1, R-14, R-116, R-218 in mixtures with air to evaluate atmospheres that do not support combustion of ordinary materials, but allow humans to live and function normally for extended periods; examines two modes, one with continuous use of the special atmospheres and one in which the agents were used to quench on-going fires in a situation where personnel must remain in the post-fire environment; concludes that the second mode probably is not feasible because of noxious decomposition products and smoke; indicates that flammability and toxicological studies offer favorable indications for the first mode; embeds a detailed report on toxicity tests of the four chemicals (see RDB7550 for further summary); notes that those tests address acute and ten-day, animal inhalation studies in which no adverse physiological effects were found and R-14 cardiac sensitization with only mild effects under severe conditions

W. D. McNally, **A Case of Phosgene Poisoning**, *Industrial Medicine*, 6:539 ff, 1937 (RDB6774)

refrigerants, toxicity: asserts that phosgene is formed when R-1120 (trichloroethylene) passes through burning tobacco in smoking

W. J. Meek, H. R. Hathaway, and O. S. Orth, **The Effects of Ether, Chloroform, and Cyclopropane in Cardiac Automaticity**, *Journal of Pharmacology and Experimental Therapeutics* (JPET), 61:240-252, 1937 (13 pages, RDB6562)

cardiac sensitization of R-20 (chloroform), R-C270 (cyclopropane), and ether (probably R-610); toxicity

J. Mendelhoff (possibly Mendeloff), **Death After Repeated Exposures to Refrigerant Gases**, *Archives of Industrial Hygiene and Occupational Medicine*, 6:518-524, 1952 (7 pages, RDB7222)

toxicity of R-12 and others; accidents; fatalities

G. W. Mergner (University of Maryland), D. A. Blake (Johns Hopkins University), and M. Helrich (University of Maryland), **Biotransformation and Elimination of ^{14}C-Trichlorofluoromethane (FC 11) and ^{14}C-Dichlorodifluoromethane (FC 12) in Man**, *Anesthesiology*, 42(3):345-351, March 1975 (7 pages with 4 figures and 1 table, RDB-5C72)

biochemistry and elimination tests of radiolabeled R-11 and R-12 in 2 human volunteers by inhalation of 1,000 ppm v/v for 7-17 min: recovery in exhaled air in the female and male was 99.5 and 79.4%, respectively, for of R-11 and 95.4 and 103.2% for R-12 (errors in collection of rapidly eliminated gases account for the differences from 100%); only a very small fraction of the administered radioactivity (less than 0.2%) was found in urine or exhaled carbon dioxide; total metabolites were less than 0.2% of

the administered dose and insufficient to allow determination of possible metabolites; paper notes that the trace levels of metabolites could be products of impurities, namely chloroform and carbon tetrachloride

Meridian Research, Incorporated, **Assessment of Occupational Exposures to Halon Substitutes Used for Fire Protection**, U.S. Environmental Protection Agency (EPA), Washington, DC, 1992 (RDB6B54)

toxicity of R-123 and others

K. W. Miller, W. D. M. Paton, E. B. Smith, and R. A. Smith (Department of Pharmacology and Physical Chemistry Laboratory, UK), **Physiochemical Approaches to the Mode of Action of General Anesthetics**, *Anesthesiology*, 36(4):339-351, April 1972 (13 pages with 3 figures and 6 tables, RDB6129)

R-12, R-14, R-20, R-116, R-123B1, R-142B1, R-218, R-C270, R-744A (nitrous oxide), R-7146 (sulfur hexafluoride), and others, anesthetic effect, inhalation toxicity

R-J. Millischer (Elf Atochem S.A., France) and J. D. Wade (ICI Chemicals and Polymers, Limited, UK), **Final Update of the Program for Alternative Fluorocarbon Toxicity Testing (PAFT)**, *EUROTOX'97, Diversification in Toxicology: Man and Environment* (proceedings of the XXXVI European Congress of Toxicology, EuroTox, Århus, Denmark, 25-28 June 1997), Nordic Pharmacological Society, Copenhagen Denmark, 1997; abstract P5-13 republished in *Pharmacology and Toxicology*, 80(supplement III):126-127, 1997 (2 pages with no figures or tables, RDBA643)

summarizes the 10-year Program for Alternative Fluorocarbon Toxicity Testing (PAFT) by 14 manufacturers of chlorofluorocarbons from Europe, America, and Asia to investigate the toxicity of alternatives including R-32, R-123, R-124, R-125, R-141b, R-134a, R-225ca, and R-225cb; discusses the cooperation needed; mentions that more that 200 reports were produced by 14 laboratories around the world covering acute, subacute, and chronic toxicity as well as genotoxicity, reproductive toxicity, carcinogenicity, and metabolism; notes that complementary research studies were designed to address additional questions that surfaced

R-J. Millischer (Elf Atochem S.A., France) and C. H. Farr (Elf Atochem North America, USA), **Genetic Toxicity and Carcinogenicity of Fluorinated CFC Substitutes Studied within the Programme for Alternative Fluorocarbon Toxicity Testing**, *Proceedings of the Sixth International Congress of Toxicology* (Rome, Italy, 28 June - 3 July 1992), International Union of Toxicology, June 1992; republished in *Toxicology Letters Supplement*, Elsevier/North-Holland Biomedical Press, Amsterdam, The Netherlands, 87-88, 1992 (RDB-5B46)

genetic toxicity and carcinogenicity of R-32, R-123, R-124, R-125, R-134a, R-141b, R-225ca, R-225cb

P. Montel, **Toxicité des gas dans l'industrie et leur détection** [Toxicity of Gases in Industry and their Detection], *Archives des Maladies Professionelles de Médecine du Travail et de Securité Sociale*, France, 33(9):493-496, 1972 (4 pages, in French, RDBA540)

toxicity; detection methods

R. R. Montgomery and C. F. Reinhardt, **Toxicity of Fluorocarbon Propellants**, *Handbook of Aerosol Technology*, edited by P. Saunders, Van Nostrand-Reinhold Publishers, New York, NY, 1979 (RDB65F7)

toxicity

A. F. Moore for the Cosmetic, Toiletry, and Fragrance Association (CTFA) Cosmetic Ingredient Review (CIR) Expert Panel, **Safety Assessment of Isobutane, Isopentane, n-Butane, and Propane**, *Journal of the American College of Toxicology* (JACT), 1(4):127-142, 1982 (26 pages with 5 tables, RDB6113)

summarizes a safety assessment of selected hydrocarbon (HC) aerosol propellants that also are used as refrigerants; they include R-290 (propane), R-600 (n-butane), R-600a (isobutane), and R-601a (isopentane); discusses and tabulates summary chemical and physical properties; describes uses, derivations, common impurities, commercial purity grades, and standard containers for transport; tabulates concentrations in representative cosmetic formulations; summarizes toxicology data from a literature review and limited inputs from the CTFA membership; outlines data on mutagenicity concluding that none of the subject HCs was mutagenic by Ames assays with or without metabolic activation; discusses anesthetic effects from a published study [see RDB6197]; summarizes eye and skin irritation and tabulates primary dermal irritation data for the individual compounds and combinations of them; summarizes acute and chronic inhalation toxicity studies in animals; summarizes clinical

acute inhalation studies in humans; summarizes recommended exposure limits; concludes that the four HCs examined are considered safe as cosmetic ingredients on the basis of the information presented and then present use; notes that R-600 causes drowsiness in humans at concentrations of 10,000 ppm for 10 min as reported in RDB6A83

A. Morgan, A. Black, and D. R. Belcher, **Studies on the Absorption of Halogenated Hydrocarbons and their Excretion in Breath Using ^{38}Cl Tracer Techniques**, *Annals of Occupational Hygiene*, 15(2-4):273-283, 1972 (11 pages, RDB-7448)

inhalation toxicity of R-11, R-12, R-114, and others

A. Morgan, A. Black, M. Walsh, and D. R. Belcher, **The Absorption and Retention of Inhaled Fluorinated Hydrocarbon Vapours**, *International Journal of Applied Radiat. Isotopes*, 23(6):285-291, 1972 (7 pages, RDB5C73)

inhalation toxicity of R-11, R-12, R-114, and others

M. Morita, A. Miki, H. Kazama, and M. Sakata, **Case Reports of Deaths Caused by Freon Gas**, *Forensic Science*, 10(3):253-260, 1977 (8 pages, RDB8151)

fatal human exposures involving fluorochemicals (some of which are used as refrigerants); health effects; toxicity

L. E. Morris, M. H. Noltensmeyer, J. M. White, Jr., **Epinephrine Induced Cardiac Irregularities in the Dog During Anesthesia with Trichloroethylene, Cyclopropane, Ethyl Chloride, and Chloroform**, *Anesthesiology*, 14:153-158, 1953 (6 pages, RDB6563)

toxicity tests for cardiac sensitization by R-20 (chloroform), R-160 (ethyl chloride), R-C270 (cyclopropane), and R-1120 (1,1,2-trichloroethene

S. D. Morrison, **Freon-115 Chloropentafluoroethane (99.91%) and Freon-116 Hexafluoroethane (99.39%): Acute Inhalation Toxicity Studies**, report 41-62, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 19 June 1962 (2 pages with 1 table, RDB-7616)

tests of the acute inhalation toxicity of R-115 and R-116 in groups of 4 male ChR-CD rats exposed to 200,000 ppm v/v R-115 in air for 2 hr, 800,000 ppm v/v R-115 in oxygen for 3½-4 hr, 200,000 ppm v/v R-116 in air for 2 hr, or 800,000 ppm v/v R-116 in oxygen for 4 hr: no deaths resulted; animals exposed to R-115 showed modified depth of respiration, but no other effect; no interference was found in body weight gain; exposed animals showed marginal signs of intoxication; animals exposed to R-116 showed deep and rapid breathing as well as — at 200,000 ppm — obvious discomfort and irregular breathing and at 800,000 ppm cutaneous vasodilation; rats exposed to 200,000 ppm failed to gain weight on the day after exposure while those exposed to 800,000 ppm showed weight loss for one day after exposure; findings suggest a 3½-4 hr ALC rat of >800,000 ppm v/v for R-115 and a 4 hr ALC rat of >800,000 ppm v/v for R-116

L. S. Mullin, **Methods in Behavioral Toxicology, Part I: Testing of Five Industrial Chemicals**, report 776-76, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 19 October 1976 (33 pages with no figures or tables, RDB-A945)

toxicity tests to determine the concentrations at which behavioral effects occur for whole-body exposures of groups of 6 male Charles River CD rats; describes the test methods used for other studies pertinent to refrigerants

L. S. Mullin, A. Azar, C. F. Reinhardt, P. E. Smith, Jr., and E. F. Fabryka (E. I. duPont de Nemours and Company, Incorporated), **Halogenated Hydrocarbon-Induced Cardiac Arrhythmias Associated with Release of Endogenous Epinephrine**, *American Industrial Hygiene Conference* (Toronto, ON, Canada, May 1971); republished in *AIHA Journal*, 33(6):389-396, June 1972 (8 pages with 3 figures and 3 tables, RDB5360)

R-11, R-12, R-114, toxicity: compares cardiac abnormalities produced by endogenous epinephrine with those produced by exogenous epinephrine in beagle dogs; the results show that higher concentrations are needed to sensitize a dog's heart to the action of its own circulating level of epinephrine, raised by exercise, than by experimental injection; the observed responses were fewer and less severe; paper notes that the wide differences cannot be extrapolated directly to humans, but they suggest a sufficient margin of safety based on tests by epinephrine injection; paper also notes that humans could develop cardiac arrhythmias under conditions of stress, such as fear, anxiety, or

exertion, by exposures to unusually high levels of propellant (many of which also are used as refrigerants) vapors

L. S. Mullin and H. J. Trochimowicz, **A. Cardiac Sensitization Studies of Hexafluoroethane (F-116), Sulfur Hexafluoride (SF_6), and Chloropentafluoroethane (F-115); B. Literature Review: Toxicity and Areas of Use (F-116 and SF_6)**, report 150-72, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 20 April 1972 (17 pages with 4 tables, RDB6120)

R-116, cardiac sensitization, toxicity as reported in RDB5605

L. S. Mullin, A. Azar, C. F. Reinhardt, P. E. Smith, Jr., and E. F. Fabryka, **Halogenated Hydrocarbon-Induced Cardiac Arrhythmias Associated with Release of Endogenous Epinephrine**, report 279-71, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1971 (21 pages, RDB7442)

toxicity of R-11, R-12, R-113, R-114, and others; cardiac sensitization — as reported in RDB7414

L. S. Mullin, **Cardiac Sensitization — Fright Exposures**, report 81-70, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1970 (5 pages, RDB6522)

toxicity of R-12, R-142b, R-C318 and others; effect of frightening noise to stimulate the release of endogenous epinephrine in cardiac sensitization as reported in RDB5869 and RDB7215

L. S. Mullin, **Cardiac Sensitization**, report 354-69, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1969 (3 pages with 1 table, RDB6274)

reports toxity tests to determine cardiac sensitization levels in dogs for R-E170 (dimethyl ether), R-142b, R-152a, R-290 (propane), R-502, R-1110 (perchloroethylene), and R-1140 (vinyl chloride) [see RDB5644 for further description of the test method and findings]

L. S. Mullin, **Cardiac Sensitization: Fright/Treadmill Studies**, report 325-69, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1969 (RDB6B46)

cardiac sensitization, toxicity

W. Nastainczyk, H. J. Ahr, and V. Ullrich, **The Mechanism of the Reductive Dehalogenation of Polyhalogenated Compounds by Microsomal Cytochrome P-450**, *Advances in Experimental Med. Biol.*, 136A:799-808, 1982 (10 pages, RDB-8163)

fluorochemical refrigerants, biochemistry, health effects, metabolism, pharmacokinetics, toxicity

W. Nastainczyk, H. J. Ahr, and V. Ullrich, **The Reductive Metabolism of Halogenated Alkanes by Liver Microsomal Cytochrome P-450**, *Biochemical Pharmacology*, UK, 31(3):391-396, 1982 (6 pages, RDB8164)

fluorochemical refrigerants, biochemistry, health effects, mutagenicity, pharmacokinetics, teratogenicity, toxicity

National Research Council (NRC) Committee on Toxicology, **Toxicity of Alternatives to Chlorofluorocarbons: HFC-134a and HCFC-123**, National Academy of Sciences (NAS), National Academy Press, Washington, DC, 1996 (134 pages with 7 figures and 21 tables, RDB6A01)

R-123, R-134a, assessment by the Board on Environmental Studies and Toxicology: briefly reviews the history of "cardiac sensitization" concern arising from "sniffing" and industrial fatalities; examination of the standard dog cardiac sensitization test, using a sequence of start with face mask in place at 0 minutes, administer epinephrine injection at 2 minutes, begin test chemical exposure by inhalation at 7 minutes, administer challenge injection of epinephrine at 12 minutes, and stop at 17 minutes; concludes that the test is effective, but overpredicts the potential for a chemical to induce cardiac arrhythmia under normal or physiological levels of endogenous epinephrine; recommends that the mechanism of cardiac sensitization be determined and that a more sensitive test be developed; examines toxicity data for R-123 and R-134a and sets recommended emergency exposure guidance level (EEGL) concentrations for both and a continuous exposure guidance level (CEGL) for the former; differences in the time periods for the R-123 and R-134a exposure levels addressed reflect proposed uses of R-134a as a refrigerant on submarines, versus R-123 as a fire suppressant to replace halon 12 in flight-line extinguishers with very quick discharges; recommends a 1 hr EEGL for R-134a of 4,000 ppm v/v based on

the no-observed-adverse-effect level (NOAEL) in cardiac sensitization tests, divided by an uncertainty factor of 10 for interspecies variability; recommends a 24 hr EEGL for R-134a of 1,000 ppm based on a NOAEL of 10,000 ppm for ferotoxicity effects (slight retardation of skeletal ossification) in rats divided by an uncertainty factor of 10; recommends a 90-day CEGL for R-134a of 900 ppm based on a NOAEL of 50,000 ppm for a 2-yr chronic toxicity study in rats divided by an uncertainty factor of 10, a factor of 4 for exposures of 24 hr/d instead of 6 hr/d, and a factor of 5/7 for exposures of 7 d/wk instead of the tested 5 d/wk; recommends a 1-min EEGL for R-123 of 1,900 ppm based on a cardiac sensitization EC_{50} dog of 19,000 ppm divided by an uncertainty factor of 10; appendices and attachments provide supporting documentation of toxicity data for R-123, R-123B1, and R-134a

National Research Council (NRC) Committee on Toxicology, **Emergency and Continuous Exposure Limits for Selected Airborne Contaminants**, National Academy of Sciences (NAS), National Academy Press, Washington, DC, volume 8, 1988 (78 pages with 1 figure and 6 tables, available from NTIS as document PB-89-174726, RDB-7420)

examines the toxicity and other health effects of R-1120 and lithium chromate; recommends Emergency Exposure Guidance Level (EEGL) and Continuous Exposure Guidance Level (CEGL) concentrations

National Research Council (NRC) Committee on Toxicology, **Emergency and Continuous Exposure Limits for Selected Airborne Contaminants**, National Academy of Sciences (NAS), National Academy Press, Washington, DC, volume 7, 1987 (78 pages with 8 tables, RDB7419)

examines the toxicity and other health effects of R-717 (ammonia), hydrogen chloride, lithium bromide, and toluene; recommends Emergency Exposure Guidance Level (EEGL) and Continuous Exposure Guidance Level (CEGL) concentrations; the EEGL for ammonia is 100 ppm v/v for both 1 hr and 24 hr

National Research Council (NRC) Committee on Toxicology, **Emergency and Continuous Exposure Limits for Selected Airborne Contaminants**, National Academy of Sciences (NAS), National Academy Press, Washington, DC, volume 6, 1986 (64 pages with 7 tables, available from NTIS as document PB-86-145158, RDB7418)

examines the toxicity and other health effects of hydrazine, monomethylhydrazine, and 1,1-dimethylhydrazine; recommends Emergency Exposure Guidance Level (EEGL) and Continuous Exposure Guidance Level (CEGL) concentrations; presents a method for cancer risk assessment for emergency exposures

National Research Council (NRC) Committee on Toxicology, **Emergency and Continuous Exposure Limits for Selected Airborne Contaminants**, National Academy of Sciences (NAS), National Academy Press, Washington, DC, volume 5, 1985 (64 pages with 7 tables, available from NTIS as document PB-86-145158, RDB7417)

examines the toxicity and other health effects of hydrazine, monomethylhydrazine, and 1,1-dimethylhydrazine; recommends Emergency Exposure Guidance Level (EEGL) and Continuous Exposure Guidance Level (CEGL) concentrations; presents a method for cancer risk assessment for emergency exposures

National Research Council (NRC) Committee on Toxicology, **Emergency and Continuous Exposure Limits for Selected Airborne Contaminants**, National Academy of Sciences (NAS), National Academy Press, Washington, DC, volume 4, 1985 (120 pages with 1 figure and 14 tables, available from NTIS as document PB-85-239630, RDB7416)

examines the toxicity and other health effects of R-728 (nitrogen), R-744A (nitrous oxide), R-746 (nitrogen dioxide), aluminum oxide, carbon monoxide, ethylene glycol, hydrogen sulfide, methanol, and tetroxide; announces a change in nomenclature from Emergency Exposure Limit (EEL) to Emergency Exposure Guidance Level (EEGL) and Continuous Exposure Limit (CEL) to Continuous Exposure Guidance Level (CEGL) to avoid confusion with limits set by regulatory agencies

National Research Council (NRC) Committee on Toxicology, **Emergency and Continuous Exposure Limits for Selected Airborne Contaminants**, National Academy of Sciences (NAS), National Academy Press, Washington, DC, volume 3, October 1984 (32 pages with 4 tables, RDB7415)

recommended Emergency Exposure Limit (EEL) and Continuous Exposure Limit (CEL) concentrations in enclosed environments, not intended for application in general industrial settings or as exposure limits for the general public; this volume addresses R-13B1; defines EEL as "a ceiling limit for an unpredictable sin-

gle exposure, usually lasting 60 minutes or less, and never more than 24 h — an occurrence expected to be rare in the lifetime of any person" addressing nonincapacitating, reversible effects; defines CEL as "a ceiling limit to avoid adverse health effects, either immediate or delayed, and to avoid degradation in crew performance that might endanger the objectives of a particular mission;" summarizes the physical and chemical properties, occurrence, use, acute and chronic toxicity information, inhalation exposure limits set by others, recommended exposure limits, recommended further research, and references for each chemical; prepared for the U.S. Department of Defense (DOD) and National Aeronautics and Space Administration (NASA) to update previous and to recommend new exposure limits for selected chemicals; EELs and CELs do not take into consideration the possible effects of exposure on hypersensitive people [EEL and CEL concentrations were subsequently renamed Emergency Exposure Guidance Level (EEGL) and Continuous Exposure Guidance Level (CEGL), respectively — see RDB7416]

National Research Council (NRC) Committee on Toxicology, **Emergency and Continuous Exposure Limits for Selected Airborne Contaminants**, National Academy of Sciences (NAS), National Academy Press, Washington, DC, volume 2, October 1984 (134 pages with 11 tables, RDB-7414)

recommended Emergency Exposure Limit (EEL) and Continuous Exposure Limit (CEL) concentrations in enclosed environments, not intended for application in general industrial settings or as exposure limits for the general public; this volume addresses for chlorine, chlorine trifluoride, ethanolamine, R-11, R-12, R-21, R-113, R-114, isopropyl alcohol, phosgene, sodium hydroxide, R-764 (sulfur dioxide), R-1130a (vinylidene chloride), and xylene; defines EEL as "a ceiling limit for an unpredictable single exposure, usually lasting 60 minutes or less, and never more than 24 h — an occurrence expected to be rare in the lifetime of any person" addressing nonincapacitating, reversible effects; defines CEL as "a ceiling limit to avoid adverse health effects, either immediate or delayed, and to avoid degradation in crew performance that might endanger the objectives of a particular mission;" summarizes the physical and chemical properties, occurrence, use, acute and chronic toxicity information, inhalation exposure limits set by others, recommended exposure limits, recommended further research, and references for each chemical; prepared for the U.S. Department of Defense (DOD) and National Aeronautics and Space Administration (NASA) to update previous and to recommend new exposure limits for selected chemicals; EELs and CELs do not take into consideration the possible effects of exposure on hypersensitive people [EEL and CEL concentrations were subsequently renamed Emergency Exposure Guidance Level (EEGL) and Continuous Exposure Guidance Level (CEGL), respectively — see RDB7416]

National Research Council (NRC) Committee on Toxicology, **Emergency and Continuous Exposure Limits for Selected Airborne Contaminants**, National Academy of Sciences (NAS), National Academy Press, Washington, DC, volume 1, April 1984 (122 pages with 24 tables, available from NTIS as document AD-4142-13318, RDB-7413)

recommended Emergency Exposure Limit (EEL) and Continuous Exposure Limit (CEL) concentrations in enclosed environments, not intended for application in general industrial settings or as exposure limits for the general public; this volume addresses for acetone, acrolein, arsine, carbon disulfide, R-20 (chloroform), fluorine, mercury vapor, R-50 (methane), R-748 (ozone), and sulfuric acid; defines EEL as "a ceiling limit for an unpredictable single exposure, usually lasting 60 minutes or less, and never more than 24 h — an occurrence expected to be rare in the lifetime of any person" addressing nonincapacitating, reversible effects; defines CEL as "a ceiling limit to avoid adverse health effects, either immediate or delayed, and to avoid degradation in crew performance that might endanger the objectives of a particular mission;" summarizes the physical and chemical properties, occurrence, use, acute and chronic toxicity information, inhalation exposure limits set by others, recommended exposure limits, recommended further research, and references for each chemical; prepared for the U.S. Department of Defense (DOD) and National Aeronautics and Space Administration (NASA) to update previous and to recommend new exposure limits for selected chemicals; EELs and CELs do not take into consideration the possible effects of exposure on hypersensitive people [EEL and CEL concentrations were subsequently renamed Emergency Exposure Guidance Level (EEGL) and

Continuous Exposure Guidance Level (CEGL), respectively — see RDB7416]

National Research Council (NRC) Committee on Toxicology, **Criteria for Short-Term Exposures to Air Pollutants**, National Academy of Sciences (NAS), National Academy Press, Washington, DC, 1979 (15 pages, RDB7412)

definitions, applicability, principles, and criteria for recommended Emergency Exposure Limit (EEL), Short-Term Public Limit (STPL), and Short-Term Public Emergency Limit (SPEL) concentrations: R-11, R-12, R-113, R-114, R-764 (sulfur dioxide), R-1130a (vinylidene chloride), and others

National Research Council (NRC) Committee on Toxicology, **Basis for Establishing Guides for Short-Term Exposures of the Public to Air Pollutants**, National Academy of Sciences (NAS), National Academy Press, Washington, DC, 1971 (15 pages, RDB7411)

definitions, applicability, and criteria for recommended Emergency Exposure Limit (EEL), Short-Term Public Limit (STPL), and Public Emergency Limit (PEL) [later renamed the Short-Term Public Emergency Limit (SPEL)] concentrations: R-11, R-12, R-113, R-114, R-764 (sulfur dioxide), R-1130a (vinylidene chloride), and others

S. Niazi and W. L. Chiou, **Fluorocarbon Aerosol Propellants VI: Interspecies Differences in Solubilities in Blood and Plasma and their Possible Implications in Toxicity Studies**, *Journal of Pharmaceutical Sciences*, 64(9):1538-1541, 1975 (3 pages, RDB7258)

R-12, R-114, and others, health effects, toxicity

M. S. Nick, **Freon-115®, Highest Purity (99.99%), Freon-115®, Commercial Composite (99.98%), and Freon-115®/Freon-C318® (20/80): Acute Inhalation Toxicity**, report 11-65, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 5 February 1965 (2 pages with 1 table, RDB7617)

tests of the acute toxicity of R-115 and R-115/C318 (20/80) by inhalation exposure of groups of 4 male ChR-CD rats to concentrations of 800,000 ppm v/v in oxygen for 4 hr: no deaths resulted, but animals exposed to R-115 exhibited rapid and deep respiration and inactivity; animals exposed to the R-115/C318 blend exhibited deep respiration and slightly red extremities; recovery was immediate following all exposures anno interference was found with body weight gain; no compound-related effects were found by microscopic pathological examinations at necropsy; findings suggest a 4 hr ALC rat >800,000 ppm v/v for both R-115 and R-115/C318 (20/80)

T. K. Nikijenko and T. A. Kochetkova, **Effect of Some Hydrochlorofluorocarbons on the Thyroid (Experimental Study)**, *Toksikologiya Novykh Promyshlennykh Khimicheskikh Veshchestva* [Toxicology of New Industrial Chemical Substances], Moscow, Russia (then USSR), 9:175-182, 1967 (8 pages in Russian, RDB5853)

toxicity of R-141b, R-142b, and other HCFCs

T. K. Nikijenko and M. S. Tolgskaya (Institute for Hygiene at Work and Occupational Illnesses of the AMS, USSR), **On the Toxico-Pharmamorphological Changes in Animals Under the Effect of Freon®s 141, 142, and 143 and the Intermediates Used in Their Production**, *Gigiena Truda i Professional'nye Zabolevaniya* [Labor Hygiene and Occupational Diseases], Moscow, Russia (then USSR), 9(10):37-44, 1965 (8 pages in Russian, RDB5852)

toxicity of R-141b, R-142b, and R-143a

Occupational Safety and Health Administration (OSHA) of the U.S. Department of Labor, **Air Contaminants; Rule**, 58 FR 124, *Federal Register*, U.S. Government Printing Office, Washington, DC, 35338-35351, 30 June 1993 (14 pages, available from JMC as RDB3904)

This rule revokes the *Final Rule* exposure limits in Table Z-1-A (*Limits for Air Contaminants*) of 29 CFR 1910.1000. It leaves the *Permissible Exposure Limits* (PELs) included in Table Z-1 before 1989, also published as Transitional Limits in table Z-1-A, in effect. Tables Z-2 and Z-3 (*Mineral Dusts*) also remain in effect. The rule reviews the court decision leading to this action and provides the three tables for enforcement of the action. A number of refrigerants are covered. PEL values are provided for R-10, R-11, R-12, R-12B2, R-13B1, R-20B3, R-21, R-30, R-40, R-40B1, R-40I1, R-110, R-112, R-112a, R-113, R-114, R-130, R-140, R-140a, R-160, R-160a, R-160B1, R-290, R-601, R-602, R-610, R-611, R-630, R-717, R-744, R-746, R-748, R-764, R-7146, R-1110, R-1120, and others. This rule is subject to revision and may have been amended or withdrawn.

Occupational Safety and Health Administration (OSHA) of the U.S. Department of Labor, Code of

Federal Regulations, **Air Contaminants**, 29 CFR Part 1910, U.S. Government Printing Office, as published at 54 FR 2920, 19 January 1989 (RDB-3905)

Permissible Exposure Limit (PEL) values: This regulation is subject to revision and may have been amended or withdrawn.

H. J. Oettel, *Zentr. Gewerbehyg. Unfallverhutl.*, Germany, 28:131 ff., 1941 (RDB6944)

toxicity of R-290 (propane), R-600 (n-butane), R-600a (isobutane), R-601a (isopentane), and others; contact with the skin may result in frostbite; effects on skin and eyes — as reported in RDBA538

H. J. Oettel, *Archiv für Experimentelle Pathologie und Pharmakologie*, 183:641-696, 1936 (2 pages, RDB6195)

toxicity of R-290 (propane), R-600 (n-butane), R-600a (isobutane), R-601a (isopentane), and others; effects on skin and eyes — as reported in RDBA538

H. J. Oettel, *Bericht 8 Intern. Kongr. Unfallmed. Bercifekrankh.*, Germany, 2:1228 ff, 1936 (RDB-6A87)

toxicity of R-290 (propane), R-600 (n-butane), R-600a (isobutane), R-601a (isopentane), and others; effects on skin and eyes — as reported in RDBA538

L. Olander, A. Colmsjo, B. Holmberg, S. Krantz, and U. Landstrom, **Occupational Implications of the Chlorofluorocarbon Ban in Sweden**, *American Journal of Industrial Medicine*, 19(6):818-826, 1991 (9 pages, RDB6B58)

toxicity of chlorofluorocarbon (CFC) and alternative refrigerants; noise and vibration levels for refrigeration and freezing equipment; handling; additional problems including increased energy use both to manufacture the substitutes and for their use

R. S. Oremland (U.S. Geological Survey, USGS), D. J. Lonergan (University of Massachusetts), C. W. Culbertson (USGS), and D. R. Lovley (University of Massachusetts), **Microbial Degradation of Hydrochlorofluorocarbons ($CHCl_2F$ and $CHCl_2CF_3$) in Soils and Sediments**, *Applied and Environmental Microbiology*, 62(5):1818-1821, May 1996 (4 pages with 4 figures, RDB7C69)

ecotoxicity of R-21 and R-123: examines the ability of microorganisms to degrade trace levels of these chemicals; for R-21, methanotroph-linked oxidation was observed in aerobic soils and anaerobic degradation in freshwater and salt marsh sediments; for R-123, microbial degradation was observed in anoxic freshwater and salt marsh sediments, and recovery of R-133a indicates the involvement of reductive dechlorination; no degradation of R-123 was observed in aerobic soils; concludes that degradation at low (parts per billion) concentrations suggests that bacteria may remove hydrochlorofluorocarbons (HCFCs) from the atmosphere, but further study is needed to assess this ability and its global significance as a sink for HCFCs

H. Oujesky and L. Job, **Effects of Five Gaseous Atmospheres on the Survival Rate of DNA Synthesis in Escherichia Coli**, *Develop. Ind. Microbiology*, 18:451-456, 1977 (6 pages, RDB6514)

toxicity of R-12, R-23, and others; biochemical studies; mutagenicity

H. Oujesky and R. Fuerst, **Effects of Freon®s and Genetron®s on DNA Polymerase from E. Coli**, *Develop. Ind. Microbiology*, 15:405-410, 1974 (6 pages, RDB5C82)

mutagenicity of R-23, R-152a, R-C318, and others; toxicity

H. Oujesky and I. Bhagat, **Response of Staphylococcus Aureus to Atmospheres of Freon®s and Genetron®s**, *Develop. Ind. Microbiology*, 14:229-237, 1973 (9 pages, RDB5823)

toxicity of R-23, R-152a, and others; mutagenicity

J. W. Patterson, M. F. Studlow, and S. R. Walker, **Blood Levels of Fluorinated Hydrocarbons in Asthmatic Patients After Inhalation of Pressurized Aerosols**, *Lancet*, UK, 2:565-568, 1971 (3 pages, RDB6728)

toxicity of R-12 and others; fluorochemical blood levels in humans; pharmacokinetics; based on a study for use as aerosol propellants (compounds also are used as refrigerants)

G. Paulet, **Les Fluorocarbones en Question** [Fluorocarbons at Issue], *European Journal of Toxicology and Environmental Hygiene*, 9(supplement to 7):385-407, 1976 (23 pages in French, RDB5179)

R-12, R-114, and others, toxicity: for R-114, 30-min LC_{50} rat = 720,000 ppm as reported in RDB5340

G. Paulet, **The Fluorocarbons at Issue**, *Aerosol Report*, 16(2):44-49,52, 1977 (7 pages, RDB6126)

R-12, R-114, and others, inhalation toxicity

G. Paulet, **The Fluorocarbons at Issue**, *Aerosol Report*, 16(1):22-30, 1977 (9 pages, RDB6125)

R-12, R-114, and others, inhalation toxicity

G. Paulet and Y. Lessard, **Actions of Fluorocarbons 12 (Difluorodichloromethane) and 11 (Monofluorotrichloromethane) on Smooth Muscle**, *Compte Rendu des Séances de la Société Biol.* [Proceedings of the Meeting of the Biological Society], Paris, France, 169(3):665-671, 1975 (7 pages, in French, RDB7531)

R-11 (trichlorofluoromethane), R-12 (dichlorodifluoromethane), health effects, toxicity

G. Paulet, G. Roncin, E. Vidal, P. Toulouse, and J. Dassonville, **Fluorocarbon and General Metabolism in the Rat, Rabbit, and Dog**, *Toxicology and Applied Pharmacology* (TAP), 34:197-203, 1975 (7 pages, RDB5142)

R-12 and others, health effects, toxicity

G. Paulet, J. Lanoë, A. Thos, P. Toulouse, and J. Dassonville (Laboratoire de Physiologie Médicale, U.E.R. Médicales et Pharmaceutiques, France), **Fate of Fluorocarbons in the Dog and Rabbit After Inhalation**, *Toxicology and Applied Pharmacology* (TAP), 34(2):204-213, November 1975 (10 pages with 6 figures and 5 tables, RDB5C71)

R-11 and R-12, toxicity: inhalation of R-11 at 25,000 and 50,000 ppm, R-12 at 200,000 and 500,000 ppm, and R-12/11 (90/10) at 250,000 and 900,000 ppm by anesthetized dogs and rabbits through tracheal cannula with oxygen adjusted to 200,000 ppm; animals were tested for these chemicals in their exhaled air, blood, bile, cerobrospinal fluid, and urine to measure elimination; concluded that the chemicals diffuse quickly in the body fluids, but that elimination is completed in 20-50 minutes, 98% of it through the pulmonary system

G. Paulet, S. Desbrousses, and E. Vidal, **Absence d'Effet Teratogene des Fluorocarbons Chez le Rat et le Lapin** [Absence of Teratogenic Effect in the Rat and Rabbit], *Archives des Maladies Professionelles de Médecine du Travail et de Securité Sociale*, France, 35:658 ff, 1974 (in French, RDB-7539)

R-11, R-12, R-12/11 (90/10), and others, genetic and reproductive effects, teratogenicity, toxicity: no effect in rats and rabbits at 300,000 ppm R-12/11 (90/10) for 13-16 2-hr exposures as reported in RDB5141

G. Paulet, **Action of Fluorohydrocarbons Used in Aerosols: Problems of Their Retention by the Organism After Inhalation**, *Trib. CEBEDEAU*, 23(324):487-497, 1970 (11 pages, RDB-7449)

R-114 and others, health effects, toxicity

G. Paulet, *Aerosol Report*, 8(12):612-622, 1969 (11 pages, RDB5148)

R-114 and others, health effects, toxicity

G. Paulet, **De l'action des hydrocarbures chlorofluorés sur l'organisme** [On the Effect of Chlorofluorocarbons on Organisms], *Labo-Pharma. Probl. Tech.*, France, 180:74-78, 1969 (RDB8168)

CFC biochemistry, fluorocarbons, toxicity

G. Paulet, R. Chevrier, J. Paulet, M. Duchene, and J. Chappet, **De la rétention des fréons par les poumons et les voies aériennes** [On the Retention of Fluorocarbons by the Lungs and Air Passages], *Archives des Maladies Professionelles de Médecine du Travail et de Securité Sociale*, France, 30(3):101-120, 1969 (20 pages, in French, RDB5370)

R-12 and others, biochemistry, fluorocarbons, toxicity

G. Paulet and R. Chevrier, **Modalités de l'élimination par l'air expiré du fluorane 11 inhalé. Étude chez l'homme et chez l'animal** [Mechanisms of Elimination of Inhaled R-11 by Expired Air. Human and Animal Study], *Archives des Maladies Professionelles de Médecine du Travail et de Securité Sociale*, France, 30(4-5):251-256, 1969 (in French, RDB7296)

biochemistry, fluorocarbons, toxicity

J. A. Prendergast, R. A. Jones, L. J. Jenkins, Jr., and J. Siegel (National Naval Medical Center, U.S. Navy), **Effects on Experimental Animals of Long Term Inhalation of Trichloroethylene, Carbon Tetrachloride, 1,1,1-Trichloroethane, Dichlorodifluoromethane, and 1,1-Dichloroethylene**, *Toxicology and Applied Pharmacology* (TAP), 10(2):270-289, March 1967 (20 pages with 1 figure and 4 tables, RDB5C44)

R-10, R-12, R-140a with 8% inhibitor, R-1120, R-1130a, subchronic inhalation toxicity: effects of long-term inhalation exposure to develop data pertinent to human exposures in submarines; continuous exposures of rats, guinea pigs, monkeys and dogs for 90 days and repeated exposures for 8 hr/d, 5 d/wk, for 6 weeks; 2 of 15 rats and 1 guinea pig died during continuous exposures to R-12 at 840 ppm

(3,997 mg/m^3); 1 of 15 rats died in the repeated exposures to R-12 at 4,136 mg/m^3; no other signs of toxicity were observed for R-12, suggesting that the mortality was not treatment related

K. Pennington and R. Fuerst (Helen Dwight Reid Educational Foundation), **Biochemical and Morphological Effects of Various Gases on Rabbit Erythrocytes**, *Archives of Environmental Health*, 22(4):476-481, 1971 (6 pages, RDB6131)

R-50, R-152a and others; biochemical studies, toxicity

H. Peter, J. G. Filser, L. V. Sventpály, and H. J. Wiegand (Universität Dortmund, Germany), **Different Pharmacokinetics of Dichlorodifluoromethane (CFC 21)** [HCFC-21] **and Chlorodifluoromethane (CFC 22)** [HCFC-22], *Archives of Toxicology*, 58:282-283, 1986 (2 pages, RDB-A533)

toxicity of R-21 and R-22; carcinogenicity; mutagenicity; health effects from exposures; animal studies

Z. Petrovic, **Abuse of Inhalants, Solvents, and Volatile Substances**, *Psihijatr Danas*, 16(3-4):273-280, 1984 (8 pages, RDB7549)

human exposures, sudden sniffing deaths from abusive use of aerosol products also used as refrigerants

A. Poklis, **Determination of Fluorocarbon 11 and Fluorocarbon 12 in Postmortem Tissues: A Case Report**, *Forensic Science*, 5(1):53-60, 1975 (8 pages, RDB6729)

fatal human exposures involving R-11 and R-12, sudden sniffing death from abusive use of aerosol products

C. L. Potter et al., **Effects of Inhaled Chlorotrifluoroethylene and Hexafluoropropene on the Rat Kidney** *Toxicology and Applied Pharmacology* (TAP), 59(3):431 ff, 1981 (RDB8125)

tests of acute inhalation toxicity of R-1113 and R-1216 by exposures of male Fischer 344 rats: rats exposed to concentrations of 380-1200 ppm exhibited dose-related, proximal tubular necrosis, diuresis, increases in urinary fluoride, urinary lactic dehyrogenase (LDH) activity, serum creatinine, and blood urea nitrogen

I. F. H. Purchase, E. Longstaff, J. Ashby, J. A. Styles, D. Anderson, P. A. Lefevre, and F. R. Westwood (ICI Chemicals and Polymers, UK), **An Evaluation of Six Short-Term Tests for Detecting Organic Chemical Carcinogens**, *British Journal of Cancer*, 37:873 ff, 1978 (RDB6277)

toxicity, carcinogenicity

A. Quevauviller, **Hygiene et Securité des Pulseurs pour Aerosols Médicamentaux** [Hygiene and Safety of Propellants for Medicated Aerosols], *Prod. Probl. Pharm.*, 20(1):14-29, 1965 (16 pages in French, RDB5A72)

R-12, R-114, and others, toxicity, eye and skin irritation

A. Quevauviller, M. Schrenzel, and V. Ngoc Huyen, **Tolérance Locale (Peau, Muqueuses, Plaies, Brûlures) Chez l'Animal aux Hydrocarbures Chlorofluores** [Local Tolerance (Skin, Mucous Membranes, Sores, and Burns) of Animals to Chlorofluorohydrocarbons], *Therapie*, 19:247-263, 1964 (17 pages in French, RDB5368)

R-12, R-22, R-114, and others, toxicity, eye and skin irritation, hydrochlorofluorocarbons (HCFC): daily dose of R-12 tolerated by rats for a period of 23-33 days as reported in RDB65H1

A. Quevauviller, J. Billon, J. Longuet, and R. Pierre, **Tolerance of the Lungs of Mice to Fluorinated Hydrocarbons**, *Ann. Pharm. Français*, France, 27(1):25-28, 1969 (4 pages, RDB7237)

R-12, R-115, and others, toxicity

A. Quevauviller, M. Chaigneau, and M. Schrenzel, **Experimental Studies with Mice on Tolerance of the Lungs Mice to Chlorofluorinated Hydrocarbons**, *Ann. Pharm. Français*, France, 21(11):727-734, 1963 (8 pages in French, RDB-6128)

R-11, R-12, R-22 and others, toxicity, hydrochlorofluorocarbons (HCFC)

A. Quevauviller, **Skin Tolerance of Chlorofluoromethanes Used as Propellants in Cosmetology**, *Parfum. Cosmet. Savons*, France, 3:228-230, 1960 (3 pages in French, RDB7428)

R-11 and others, health effects when used as an aerosol propellant, toxicity: well tolerated by the skin, but retarded recovery from wounds and burns as well as regrowth of hair as reported in RDB7414

J. Ramsey, H. R. Anderson, K. Bloor, and R. J. Flanagan, **An Introduction to the Practice, Prevalence, and Chemical Toxicology of Volatile Substance Abuse**, *Human Toxicology*, 8(4):261-269, 1989 (9 pages, RDB7455)

reviews abuse of volatile substance by "sniffing", noting that it results in approximately 100 deaths per year in the UK and that the victims are mostly teenagers, come from all social classes, and are 90% males: 3½-10% of young people in the UK have at least experimented and 0.5-1% are current users; many products are involved, but approximately 20 solvents, adhesives, fuels, and aerosol propellants (some of which also are used as refrigerants) are commonly encountered; specifically identifies toluene, chlorinated solvents such as R-140a (methyl chloroform), R-600 butane, and hydrocarbon and halogenated hydrocarbon propellants as abused substances; acute hazards varies with the compound, product, and mode of abuse; chronic toxicity is difficult to assess, partly because of the diversity of substances involved, but some long-term abusers suffer permanent damage to the central nervous system (CNS), heart, liver, and kidneys; preventive measures including guidelines for sale of the products involved, education, and legislation have had little impact

A. G. Rauws, M. Olling, and A. E. Wibowo, **Determination of Fluorochlorocarbons in Air and Body Fluids**, *Journal of Pharmacy and Pharmacology*, UK, 25(9):718-722, 1973 (5 pages, RDB-7548)

R-114 and others, health effects, toxicity

J. Raventós and P. G. Lemon (Imperial Chemical Industries Limited, UK), **The Impurities of Fluoroethane: Their Biological Properties**, *British Journal of Anaesthesia*, UK, 37(10):716-737, 1965 (22 pages with 20 figures and 6 tables, RDB-6165)

examines the anesthetic potential, lethality, and other toxicity effects of impurities found in R-123B1 (halothane); tabulates the 30-min LC_{50} and 30-min AC_{50} (median anesthetic concentration) based on tests in groups of ten mice for R-11B1, R-20, R-113, R-113aB1, R-113aB2, R-123, R-123B1, R-123B2, R-132b, R-133a, R-133aB1, R-161, R-C326, R-1316, R-1326t, and R-1326tB1; indicates the 30-min LC_{50} mouse and 30-min AC_{50} (median anesthetic concentration) mouse in ppm v/v as >100,000 and 57,000 for R-113 and 74,000 and 24,000 for R-123, respectively

H. Reichelt, **Toxicity and Mode of Action of Practically Important Fluorocarbons, Prevention and Treatment of Exposures**, *Zeitschrift für die gesamte Hygiene und ihre Grenzgebiete*, 30(4), 1984 (RDB7238)

R-115 and others, health effects, toxicity

C. F. Reinhardt, L. S. Mullin, and M. E. Maxfield (E. I. duPont de Nemours and Company, Incorporated), **Epinephrine-Induced Cardiac Arrhythmia Potential of Some Common Industrial Solvents**, *Journal of Occupational Medicine*, 15(12):953-955, December 1973 (3 pages with 1 figure and 1 table, RDB65A0)

cardiac sensitization in beagle dogs for 5-minute exposures with epinephrine challenge provides NOEL, LOEL, and EC_{50} data; R-30 0/12 dogs sensitized at 20,000 nominal (17,900 mean of analytical) ppm v/v; R-113 0/12 at 2,500 (2,600), 10/29 at 5,000 (4,850), and 3/4 at 10,000 (9,250) ppm; R-140a 0/12 at 2,500 (2,300), 3/18 at 5,000 (5,100), and 12/12 at 10,000 (10,650) ppm; R-1110 0/12 at 10,000 (10,400) ppm; R-1120 1/12 at 5,000 (4,350) and 7/12 at 10,000 (9,750) ppm; central nervous system effects above 20,000 (17,900) ppm with R-30 and 10,000 (10,400) ppm with R-1110 precluded cardiac sensitization tests at higher concentrations; toxicity

C. F. Reinhardt, L. S. Mullin, and M. E. Maxfield (E. I. duPont de Nemours and Company, Incorporated), **Halocarbon-Epinephrine-Induced Cardiac Arrhythmia Potential of Some Common Industrial Solvents**, abstract 81 (11th Annual Meeting of the Society of Toxicology (SOT), Williamsburg, VA, 5-9 March 1972), *Toxicology and Applied Pharmacology* (TAP), 22(2):305, June 1972 (1 page with no figures or tables, RDB6558)

cardiac sensitization in beagle dogs with epinephrine challenge, toxicity; reports no sensitization at 20,000 ppm with R-30 or at 10,000 ppm with R-1110; response at 5,000-10,000 with R-113 (possibly R-113a), R-140a, and R-1120; central nervous system effects above 20,000 ppm with R-30 and 10,000 ppm with R-1110 precluded cardiac sensitization tests at higher concentrations

C. F. Reinhardt, A. Azar, M. E. Maxfield, P. E. Smith, Jr., and L. S. Mullin (E. I. duPont de Nemours and Company, Incorporated), **Cardiac Arrhythmias and Aerosol 'Sniffing'**, *Archives of Environmental Health*, 22(2):265-279, February 1971 (15 pages with 4 figures and 7 tables, RDB-5644)

toxicity tests to determine the cardiac sensitization potential in male beagle dogs with intravenous injection of epinephrine five minutes be-

fore and, with a challenge injection, midway into a 10 minute exposure for R-11, R-12, R-22, R-114, R-115, R-142b, R-152a, R-E170, R-290, R-C318, R-502, R-600a, R-1140, and others

C. F. Reinhardt, **Cardiac Sensitization**, report 52-69, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1969 (3 pages with 1 table, RDB6121)

toxicity tests to determine the cardiac sensitization potential of R-12, R-22, R-114, R-115, R-140a, R-C318, and R-600a in male beagle dogs with intravenous injection of epinephrine five minutes before and, with a challenge injection, midway into a 10 minute exposure; also describes a modified test of R-12 in which the oxygen concentration was reduced to a low level (8.4% v/v) deliberately as well as control case with reduced oxygen alone; concludes that the combination of hypoxia and the R-12 exposure probably increases sensitization to epinephrine while hypoxia alone does not, but notes that the number of animals tested was insufficient for a firm conclusion; discusses the R-C318 tests at 500,000 ppm v/v noting that the oxygen concentration for it was slightly less than 10% v/v, but notes a similar result (83.3 marked responses) for a repeat with oxygen enrichment to 20%

R. W. Reinhold and G. M. Rusch, **Review of the Toxicity of Ten Selected Fluorocarbons**, Department of Toxicology Report MA-127-80-2, AlliedSignal Incorporated, Morristown, NJ, 22 January 1986 (RDB5143)

R-12, R-32, R-113, R-113a, R-114, R-114a, R-123, R-123a, R-134a, R-142b, toxicity

B. R. Rennick, S. D. Malton, G. K. Moe, and M. H. Seevers, **Induction of Idioventricular Rhythms by 1,1,1-Trichloroethane and Epinephrine**, *Federation Proceedings*, Federation of the American Society of Experimental Biologists, 8:327 ff, March 1949 (RDB65A3)

examines the potential of R-140a to induce cardiac sensitization; health effects; toxicity

C. Reynolds (Tulane University of Louisiana), **Propylene, Ethylene, Nitrous Oxid**[e] **and Ether: Some Comparative Investigations**, Fifth Annual Meeting of the Southern Association of Anesthetists (Atlanta, GA, 16-17 November 1926); republished in *Anesthesia and Analgesia*, 6:121-124, June 1927 (4 pages with 2 figures, RDB6A73)

examines the potential of R-744A (nitrous oxide), R-1150 (ethene, ethylene), R-1270 (propene, propylene), and ether (possibly R-610) as anesthetic agents; indicates the minimum anesthetic concentration (MAC) in mice for an unspecified time as 900,000 ppm v/v for R-744A [SEE NOTE BELOW], 900,000 ppm v/v for R-1150, and 400,000 ppm v/v for R-1270; indicates the minimum lethal concentration (MLC) in mice for an unspecified time as 2,700,000 ppm v/v for R-744A, 1,460,000 ppm v/v for R-1150, and 650,000 ppm v/v for R-1270; indicates that R-1270 produces complete analgesia in white mice at 500,000 ppm v/v that can be maintained by 400,000 ppm v/v; R-1270 causes a drop in blood pressure at 650,000 ppm v/v and death at 750,000-800,000 ppm v/v in mice as well as cardiac effects in dogs above 250,000 ppm v/v without mention of epinephrine challenges; inhalation toxicity [NOTE: The paper presents concentrations as percentages. Their meaning is unclear since it discusses and plots multiple concentrations exceeding 100% and as high as 270%, yet seems to recognize the need to maintain approximately 20% oxygen in some instances. Not only are concentrations exceeding 100% or 1,000,000 ppm inherently contradictory, but exposures at 90% treatment concentrations should have resulted in asphyxiation.]

C. Reynolds (Tulane University of Louisiana), **Comparative Studies of Propylene, Ethylene, Nitrous Oxide, and Ether**, *Journal of Pharmacology and Experimental Therapeutics* (JPET), 27(2):93-99, 1926 (7 pages with 1 figure and 2 tables, RDB6A74)

compares the inhalation toxicity of R-1270 (propene, propylene) as a candidate anesthetic agent to that of R-744A (nitrous oxide), R-1150 (ethene, ethylene), and ether (possibly R-610); notes that the R-1270 samples for some tests were impure, but reasons that a pure sample probably probably would not be more toxic; tabulates prior test exposures and resulting liver effects (staining, fatty degeneration, and fatty infiltration) of the four gases in mice; describes the effects of R-1150 and R-1270 on frog and turtle hearts, virgin and pregnant guinea pig uteri, and duedenal tissue from rabbits

L. K. Riggs (E. R. Squibb and Sons), **Anesthetic Properties of the Olefine Hydrocarbons, Ethylene, Propylene, Butylene, and Amylene**, *Journal of the American Pharmaceutical Association*,

14(5):380-387, May 1925 (8 pages with 1 figure and 3 tables, RDB65B9)

anesthetic effect in rats, toxicity: R-1150 results in light anesthesia in 1 of 1 rats at 900,000 ppm v/v in oxygen in 18-20 min and no other toxic symptoms in 3 hours, deep anesthesia [oxygen deprivation?] at 950,000 ppm within 1 min; R-1270 produces light anesthesia in 1 of 1 rats at 400,000 ppm within 15 min and no other toxic symptoms in 6 hr [implies 6-hr ALC rat 0/? exceeds 400,000 ppm], deep anesthesia at 550,000 ppm in 3-6 min, and death in rats at 650,000 ppm v/v with 25% oxygen and 10% nitrogen in 2 hr [implies 2-hr ALC rat ?/? = 650,000 ppm]; butylene; amylene

L. K. Riggs (E. R. Squibb and Sons), **The Physiologic Properties of Some Unsaturated Hydrocarbons**, *Proceedings of the Society of Experimental Biology and Medicine*, New York, NY, 22:269-270, 1924-1925 (2 pages, RDB7738)

R-1150, R-1270, and others, health effects, toxicity: examination of ethylene and propylene as general anesthetic agents

W. F. Riker, F. Depierre, J. Roberts, B. B. Roy, and J. Reilly, **The Epinephrine and Hydrocarbon-Epinephrine Disturbances in the Cat**, *Journal of Pharmacology and Experimental Therapeutics* (JPET), 114:1 ff, 1955 (RDBA946)

toxicity study of hydrocarbons (HC) for cardiac sensitization

B. H. Robbins (Vanderbilt University School of Medicine), **Preliminary Studies of the Anesthetic Activity of Fluorinated Hydrocarbons**, *Journal of Pharmacology and Experimental Therapeutics* (JPET), 86:197-204, 1946 (8 pages with 3 tables, RDB5980)

tests for anesthetic effect in mice exposed to 46 fluorinated hydrocarbons for 10 minutes in a rotating bottle, including R-20, R-123 (EC_{50} = 27,000 ppm v/v), R-123B2, R-132b, R-132bB1ß, R-133a, R-133aB1, R-13al1, R-141b (EC_{50} = 25,000), R-142, R-142b (EC_{50} = 250,000), R-142B1, R-143a (EC_{50} = 500,000-600,000), R-223da, R-236fa (EC_{50} = 110,000), R-243ab, R-243db, R-243fa, R-243dbB2, R-252dc, R-252dcB1ß, R-252fc, R-253dbB1, R-253fb, R-261fc, R-262ca, R-262caB1, R-262db, R-262fc, R-263fb, R-E263fb1, R-365mfc, R-374, R-392, R-610, R-1243a, R-1372, and others; also tests for 10-min LC_{50} mouse for most of them; also tests of 18 of them for effects on the blood pressure and heart rhythm in anesthetized dogs; recommends consideration of R-123B2, R-243db, R-253dbB1, and R-262db as possible anesthetic agents

R. Rubenstein (U.S. Environmental Protection Agency, EPA), **Human Health and Environmental Toxicity Issues for Evaluation of Halon Replacements**, *Toxicology Letters*, 68(1-2):21-24, 1993 (4 pages with 3 tables, RDB5950)

R-22, R-22B1, R-23, R-32, R-123, R-124, R-125, R-134a, R-227ea, R-31-10, R-51-14, R-718 (water), R-744 (carbon dioxide), and others: brief summary of the approach used by the U.S. Environmental Protection Agency (EPA) for health hazard assessment of alternative fire suppressants (many of which also are used as refrigerants); tabulates criteria, qualitative suitability (acceptable, unacceptable, or pending) in occupied and unoccupied areas, and qualitative suitability for consumer, commercial, industrial, or military use

G. M. Rusch (Honeywell Incorporated), **Toxicological Evaluations of Alternative Fluorocarbons**, *Drug and Chemical Toxicology*, 23(1):27-40, 2000 (14 pages, RDBA925)

inhalation, subchronic, and chronic toxicity of R-123, R-141b, and others; also addresses metabolism, genotoxicity, teratology, gas-uptake pharmacokinetics, and reproductive toxicity

G. M. Rusch (Honeywell Incorporated, then AlliedSignal Incorporated) and H. J. Trochimowicz (E. I. duPont de Nemours and Company), **Occupation Exposure Limits for Alternate Refrigerants**, *EUROTOX'97, Diversification in Toxicology: Man and Environment* (proceedings of the XXXVI European Congress of Toxicology, EuroTox, Århus, Denmark, 25-28 June 1997), Nordic Pharmacological Society, Copenhagen Denmark, 1997; abstract P4-38 republished in *Pharmacology and Toxicology*, 80(supplement III):138-139, 1997 (2 pages with no figures or tables, RDBA646)

discusses assessments of toxicity data to set occupational exposure limits for alternative fluorochemicals; notes suggested permissible exposure limits [Workplace Environmental Exposure Level (WEEL) Guides] of 1000 ppm v/v for R-32, R-124, R-125, and R-142b, 500 ppm v/v for R-141b; 250 ppm v/v for R-225cb, and 25 ppm v/v for R-225ca; indicates that the results for R-123 are still under review

G. M. Rusch (AlliedSignal Incorporated), **Update: Program for Alternative Fluorocarbon Toxicity**

Testing, publication unknown, circa January 1996 (13 pages with 13 tables, RDB7464)

summary of the status and findings of the Program for Alternative Fluorocarbon Toxicity Testing (PAFT); addresses the toxicity of R-32, R-123, R-124, R-125, R-141b, R-134a, R-225ca, and R-225cb

G. M. Rusch (AlliedSignal Incorporated), **Toxicity Studies with New Refrigerant Gases**, abstract 324, *The Toxicologist*, 11(1):102, February 1991 (1 page with no figures or tables, RDB6551)

summary of ongoing studies for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT): reduced response to noise, probably indicating light anesthesia, was noted in a 4-week inhalation study [species not indicated] with R-124 at concentrations up to 50,000 ppm, but this effect cleared within minutes following exposures; transient, depressed response to noise also was seen in an ongoing, 3-month inhalation study with exposures of up to 50,000 ppm R-124 [species not indicated]; R-124 was not active in the Ames, cytogenetics, or in vivo micronucleus assays; no developmental effects were found in teratology studies in the rat at concentrations up to 50,000 ppm; no treatment-related effects were observed in a 3-month inhalation study [species not indicated] with R-134a even for exposures of 50,000 ppm; a chronic toxicity study is underway; R-134a did not induce unscheduled DNA synthesis and was not active in the Ames, cytogenetics, or in vivo micronucleus assays; no developmental effects were found in teratology studies in the rabbit with R-134a at concentrations up to 40,000 ppm

G. M. Rusch (AlliedSignal Incorporated), **Results from the Program for Alternative Fluorocarbon Toxicology Testing Activities**, *FCKW — Ausstieg wohin?* [CFC — Phaseout Whereto?] (proceedings of the 8. DECHEMA-Fachgespräch Umweltschutz [Eighth DECHEMA Colloquium on Environmental Protection], Bonn, Germany, 2-3 May 1990), Deutsche Gesellschaft für Chemisches Apparatewesen (DECHEMA), Chemische Technik und Biotechnologie e.V., Frankfurt am Main, Germany, 245-261, 1990 (17 pages with text and 17 presentation charts, RDB65F4)

summary of the structure, tests, findings, and plans of the Program for Alternative Fluorocarbon Toxicity Testing (PAFT); addresses the toxicity of R-123, R-124, R-125, R-134a, R-141b [see RDB3A53 for update]

A. G. Salmon, J. A. Nash, C. M. Walklin, and R. B. Freedman (Imperial Chemical Industries Limited, ICI), **Dechlorination of Halocarbons by Microsomes and Vesicular Reconstituted Cytochrome P-450 Systems Under Reductive Conditions**, *British Journal of Industrial Medicine*, 42(5):305-311, 1981 (7 pages, RDB8171)

biochemistry, toxicity of chlorinated halochemical refrigerants

A. G. Salmon, R. B. Jones, and W. C. Mackrodt (Imperial Chemical Industries Limited, ICI), **Microsomal Dechlorination of Chloroethanes: Structure-Reactivity Relations**, *Xenobiotica*, 11(11):723-734, 1981 (12 pages, RDB8172)

biochemistry, toxicity of chlorinated halochemical refrigerants

P. A. Sanders (Industrial Hydrocarbons, Incorporated), **Toxicity of Hydrocarbon Propellants**, *Aerosol Age*, 24(1):24-27,44, January 1979 (5 pages with 8 tables, RDBA538)

toxicity of R-290 (propane), R-600 (n-butane), R-600a (isobutane), R-601 (n-pentane), R-601a (isopentane) for propellant uses (some of them also are used as refrigerants)

E. E. Sandmeyer, **Aliphatic Hydrocarbons**, *Patty's Industrial Hygiene and Toxicology* (third revised edition), edited by G. D. Clayton and F. E. Clayton, John Wiley and Sons, Incorporated, New York, NY, 2B:3175-3220, 1981 (46 pages with 4 tables, RDB6290)

R-50 (methane), R-170 (ethane), R-290 (propane), R-600 (butane), R-600a (isobutane), R-601 (pentane), R-601a (isopentane), R-601b (neopentane), R-602 (hexane), R-1150 (ethylene), R-1270 (propylene), and others; health effects, toxicity

E. Schaefer, *Experientia*, 38(10):1163-1168, 1982 (6 pages, RDB5786)

R-744 (carbon dioxide) and others, health effects, toxicity

R. E. Schroeder (Pharmaco-LSR, Incorporated), P. E. Newton, G. M. Rusch (AlliedSignal Incorporated), and H. J. Trochimowicz (E. I. duPont de Nemours and Company), **Inhalation Developmental Toxicity Studies with HCFC-123 and HCFC-124 in the Rabbit**, *Teratology*, 51(3):196, March 1995; presented at the joint 35th Annual Meeting of the Teratology Society (Newport Beach, CA, 24-29 June 1995) and the 19th Annual Meeting of the Neurobehavioral Teratology Society

(New-port Beach, CA, 25-28 June 1995), 1995 (1 page, RDB7632)

developmental toxicity studies of R-123 and R-124 in rabbits: groups of 20-24 female New Zealand White rabbits were naturally mated and exposed by whole-body inhalation to concentrations of 0, 500, 1,500, or 5,000 ppm v/v R-123 in air and to 0, 5,000, 15,000, or 50,000 ppm v/v R-124 for 6 hr/d during days 6-18 of gestation; in-life observations included periodic measurements of body weight, food consumption, and clinical signs; animals were sacrificed on day 30 of gestation; maternal toxicity was evidenced by reduced weight gain and food consumption during the treatment period at all exposure levels for R-123, but no developmental toxicity was seen; no maternal or developmental toxicity was seen at the 5,000 and 15,000 ppm exposure levels for R-124; maternal toxicity was indicated from a decrease in in-chamber activity and a slight reduction in food consumption during exposures to 50,000 ppm R-124, but no developmental toxicity was seen; concludes that the NOEL for developmental toxicity was 5,000 and 50,000 ppm v/v for R-123 and R-124, respectively

J. Scholz and W. Weigand (Farbwerke Hoechst AG, Germany), *Zentralblatt für Arbeitsmedizin, Arbeitsschutz* [Occupational Medicine and Safety], 14:129 ff, 1964 (RDB6B42)

[Frigen®] R-11, R-12, R-13B1, R-113, R-114, narcotic effect, toxicity as reported in RDB6365

J. Scholz (Farbwerke Hoechst AG, Germany), **New Toxicological Investigations of Certain Types of Freons Used as Propellants for Aerosols and Sprays**, *Fortschritte der biologischen Aerosol-Forschung* [Progress in Biological Research of Aerosols], 4:420-429, 1962 (10 pages with 10 figures and 2 tables, in German, Rdb5355)

[Frigen®] R-11, R-12, R-113, R-114, narcotic effect, toxicity

J. Scholz (Farbwerke Hoechst AG, Germany), **Progress in Biological Research of Aerosols 1957-1961**, proceedings of the Aerosol Congress (Stuttgart, Germany, 1961), F. K. Schattaver Verlag, Germany, 1961 (in German, RDB8170)

toxicity of fuorochemicals used as aerosol propellants (and as refrigerants)

L. Shargel and R. Koss, **Determination of Fluorinated Hydrocarbon Propellants in Blood of Dogs After Aerosol Administration**, *Journal of Pharmaceutical Sciences*, 61(9):1445-1449, 1972 (5 pages, RDB7242)

fluorocarbon elimination from the bloodstream, toxicity

F. E. Shipway (Guy's Hospital, UK), **Acetylene, Ethylene, and Propylene**, *Lancet*, UK, 1:1126-1130, 30 May 1925 (5 pages with 3 tables, RDB-6A82)

surgical tests of the effectiveness and toxicity of acetylene, R-1150, and R-1270 as anesthetic agents

B. B. Shugaev (Yaroslavl Medical Institute, USSR), **Concentrations of Hydrocarbons in Tissues as a Measure of Toxicity**, *Archives of Environmental Health*, 18:878-882, 1969 (5 pages with 2 figures and 6 tables, RDB5363)

toxicity of R-600 (n-butane), butadiene, hexene, isobutylene, isoprene, and styrene: 2-hr LC_{50} mouse and 4-hr LC_{50} rat data; for R-600, 2-hr LC_{50} mouse = 680 mg/l [281,000 ppm v/v]; 4-hr LC_{50} rat = 658 mg/l [272,000 ppm v/v]

B. B. Shugaev, **Distribution and Toxicity of Aliphatic Hydrocarbons in Body Tissues**, *Farmakol. Toksikol.*, Russia (then USSR), 31(3):360-363, 1968 (4 pages, RDB6A89)

R-600, health effects, metabolism, toxicity

B. B. Shugaev, **Combined Action of Aliphatic Hydrocarbons, Such as Butane and Isobutylene, with Reference to Their Effective Concentration in Brain Tissue**, *Farmakol. Toksikol.*, Russia (then USSR), 30(1):102-105, 1967 (4 pages, RDB6A90)

R-600, health effects, toxicity: 2-hr LC_{50} mouse = 286,000 ppm; 4-hr LC_{50} rat = 277,000 ppm as reported in RDB6A83

E. Siegel and S. Wason, **Sudden Death Caused by Inhalation of Butane and Propane**, *New England Journal of Medicine*, 323(6):1638 ff, December 1990 (RDB7451)

deaths of two children (ages 11 and 15) from inhalation of R-290 (propane) and R-600 (n-butane): concludes that although inhalation of butane and propane has been largely unreported in the United States, there is an urgent need for preventive efforts, directed at teenagers, with an emphasis on the risk of sudden death from "sniffing" hydrocarbons; abuse, health effects, toxicity

A. Silverglade, **Cardiac Toxicity of Aerosol Propellants**, *Journal of the American Medical Associ-*

ation (JAMA), 222:827-828, 1972 (2 pages, RDB-7403)

cardiac sensitization, toxicity

J. A. Simaan and D. M. Aviado (University of Pennsylvania School of Medicine), **Hemodynamic Effects of Aerosol Propellants, III. Vascular Resistance in Canine Hind Limb**, *Toxicology*, 5(3):287-295, 1976 (9 pages, RDB7251)

R-12, R-114, and others, health effects, toxicity

J. A. Simaan and D. M. Aviado (University of Pennsylvania School of Medicine), **Hemodynamic Effects of Aerosol Propellants, I. Cardiac Depression in the Dog**, *Toxicology*, 5(2):127-138, 1975 (12 pages with 1 figure and 4 tables, RDB-6123)

R-11, R-12, R-114, R-152a, and R-C318, cardiac sensitization in anesthetized mongrel dogs, health effects, toxicity: inhalation of fluorocarbons cased a depression of myocardial concontractility, aortic hypotension, decrease in cardiac output, and increase in pulmonary vascular resistance; LOEL that elicited these changes are 10,000 ppm for R-11, 100,000 ppm for R-12, and 25,000 ppm for R-114; concentrations of 200,000 ppm did not influence these hemodynamic parameters for R-152a and R-C318

J. A. Simaan and D. M. Aviado (University of Pennsylvania School of Medicine), **Hemodynamic Effects of Aerosol Propellants, II. Pulmonary Circulation in the Dog**, *Toxicology*, 5(2):139-146, 1975 (8 pages, RDB6124)

R-12, R-114 and others, cardiac sensitization, health effects, toxicity

V. F. Simmon and S. Wiest (Stanford Research Institute), **In Vitro Microbiological Studies Mutagenicity Studies of Phillips Petroleum Company Hydrocarbon Propellants and Aerosols**, Phillips Petroleum Company, Bartlesville, OK, 13 May 1977 (RDBA310)

toxicity study of R-600a (isobutane), R-601 (n-pentane), R-601a (isopentane), and others

V. F. Simmon (Stanford Research Institute), **Studies of Hydrocarbon Propellants**, Phillips Petroleum Company, Bartlesville, OK, 14 February 1977 (RDBA669)

toxicity study of R-600a (isobutane), R-601 (n-pentane), R-601a (isopentane), and others

S. R. Skaggs and T. A. Moore (New Mexico Engineering Research Institute, NMERI), **Toxicological Properties of Halon Replacements**, *Halon Replacements, Technology and Science* (208th National Meeting, Washington, DC, 21-25 August 1994), ACS Symposium Series 611, American Chemical Society (ACS), Washington, DC, chapter 10, 99-109, 1994 (11 pages with 3 tables, RDB-5526)

toxicity: indicates a 15-min LC_{50} rat of 274,000 ppm for R-13I1; 4-hr ALC rat concentrations of 663,000 ppm for R-23, 230,000 ppm for R-124, >800,000 ppm for R-125, and >800,000 ppm for R-31-10 ("PFC-410"); 4-hr LC_{50} rat concentrations of 100,000-130,000 ppm for R-12B1, 32,000 ppm for R-123, >800,000 ppm for R-227ea, and >800,000 ppm for R-51-14; also indicates NOAEL levels for cardiac sensitization of 50,000-100,000 ppm for R-12B1, 70,000 ppm for R-13B1, 2,000 ppm for R-13I1, 300,000 ppm for R-23, 10,000 ppm for R-123, 10,000 ppm for R-124, 75,000 ppm for R-125, 90,000 ppm for R-227ea, 400,000 ppm for R-31-10, and >400,000 ppm for R-51-14; also tabulates developmental toxicity NOAEL and subchronic (13-week) inhalation toxicity NOAEL; data sources are not explicit

Z. Skuric, E. Zuskin, and V. Valic, **Effects of Aerosols in Common Use on the Ventilatory Capacity of the Lung**, *Int. Arch. Arbeitsmedizin* [International Archives of Occupational Medicine], 34:137-149, 1975 (13 pages, RDB8177)

health effects of fluorochemical aerosol propellants (also used as refrigerants); toxicity

T. E. Slater, **A Note on the Relative Toxic Activities of Tetrachloromethane and Trichlorofluoromethane on the Rat**, *Biochemical Pharmacology*, UK, 14(2):178-181, 1965 (3 pages, RDB-5C52)

R-10 and R-11, ingestion toxicity as reported in RDB5141, RDB5367, and RDB7296

F. A. Smith, W. L. Downs, H. C. Hodge, and E. A. Maynard (University of Rochester School of Medicine and Dentistry), **Screening of Fluorine-Containing Compounds for Acute Toxicity**, *Toxicology and Applied Pharmacology* (TAP), 2(1):54-58, January 1960 (5 pages, RDB5908)

R-51-12 and other fluorine-containing organic and inorganic compounds, health effects, acute toxicity

H. F. Smith, T. F. Hatch, K. H. Jacobson, M. L. Keplinger, and F. Princi (National Research Council (NRC) Ad Hoc Committee) with revisions by A. J. Lehman, W. G. Fredrick, H. W. Gerarde, H. E.

Stokinger, and J. A. Zapp, Jr. (NRC Committee on Toxicology), **Basis for Establishing Emergency Inhalation Exposure Limits Applicable to Military and Space Chemicals**, National Academy of Sciences (NAS), National Academy Press, Washington, DC, 1964 (10 pages with no figures or tables, RDB5A19)

rationale for emergency inhalation exposure limits for new chemicals for military and space applications: notes that no authoritative source exists to establish emergency exposure levels; also notes that derivation of short-term exposure limits, based on a factor representing the ratio of exposure periods, from existing ACGIH Threshold Limit Values (TLVs), does not take into consideration conditions of exposure that differ from industrial patterns or the body systems involved; characterizes occupational exposures as predictable, controlled by quantity and distance limits, and allowing use of personal protective equipment; characterizes nonoccupational exposures as unavoidable, unpredictable, and rare; notes that the eventual occurrence of nonoccupational exposures is not a certainty and that there is justification for exposing individuals to some degree of risk; encourages promulgation of lists of Occupational and Nonoccupational Emergency Exposure Limits; defines an Emergency Exposure Limit (EEL) "for short-term exposure to an airborne contaminant as a concentration which, when inhaled for a specified brief period, rare in the lifetime of any individual, is believed not to result in a period of disability or interfere with the performance of his assigned task;" notes that "sensory comfort of the individual is not a necessary concern" and that no selected value shall "produce danger from flammability of combustible aerosols, or result in substantial impairment of vision or visibility, or the ability to breath;" recommends procedures to avoid second exposures without medical consultation; recommends against incorporation of safety factors, suggesting that they be applied by the specialist using the limit guides and familiarity with the application rather than by toxicologists setting the limits; outlines the toxicological data required to promulgate EELs including identification of target organs and effects, dose-duration response data extending (in both directions) beyond the time intervals for which limits are to be promulgated, and certain (unspecified) exposure data for orientation purposes

J. K. Smith and M. T. Case, **Subacute and Chronic Toxicity Studies of Fluorocarbon Propellants in Mice, Rats, and Dogs**, *Toxicology and Applied Pharmacology* (TAP), 26(3):438-443, 1973 (6 pages, RDB8176)

toxicity of fluorochemicals used as aerosol propellants (and also as refrigerants); health effects

S. L. Smith, W. R. Webb, L. W. Fabian, and V. D. Hagaman, **Cardiac Excitability in Ether, Cyclopropane, and Halothane Anesthesia**, *Anesthesiology*, 23:766 ff, 1962 (RDB5576)

toxicity tests for cardiac sensitization by R-123B1 (halothane), R-C270 (cyclopropane), and ether

R. Snyder, **Ethel Browning's Toxicity and Metabolism of Industrial Solvents** (second edition), Elsevier, New York, NY, 1987 (RDBA534)

toxicity of solvents some of which also are used as refrigerants

F. E. Speizer, D. H. Wegman, and A. Ramirez, **Palpitation Rates Associated with Fluorocarbon Exposure in a Hospital Setting**, *New England Journal of Medicine*, 292:624-626, 1975 (3 pages, RDB5366)

fluorocarbons, toxicity

L. J. Standley and T. L. Bott, **Trifluoroacetate, an Atmospheric Breakdown Product of Hydrofluorocarbon Refrigerants: Biomolecular Fate in Aquatic Organisms**, *Environmental Science and Technology*, 32(4):469-475, 15 February 1998 (7 pages, RDBA926)

measurements of the xenobiotic trifluoroacetate incorporation into biomolecules for aquatic organisms, ranging from microbes to macroinvertebrates, and plants; biodegradation; ecotoxicity

S. Stephens et al., **Phenotypic and Genetic Effects in Neurospora Crassa Produced by Selected Gases and Gases Mixed with Oxygen**, *Develop. Ind. Microbiology*, 12:346-353, 1971 (8 pages, RDB6515)

R-23 and others; mutagenicity, toxicity, biochemical studies

R. D. Stewart, P. E. Newton, E. D. Baretta, A. A. Herrmann, H. V. Forster, and R. J. Soto (Medical College of Wisconsin), **Physiological Response to Aerosol Propellants**, *Environmental Health Perspectives* (EHP), 26:275-285, October 1978 (11 pages with 10 tables, RDB6115)

summarizes acute and subchronic toxicity tests in healthy human volunteers by whole-body exposure to R-11, R-12, R-290 (propane), and R-600a (isobutane); acute exposures to 250, 500, or 1000 ppm v/v for 1 min to 8 hr "did not produce any untoward physiological effects" as determined by observation, routine hematology, clinical chemistry, EKG, and pulmonary function as well as by cognitive skill and other neurological measurements; repetitive exposures to 1,000 ppm v/v for 1-10 hr/d, 5 d/wk, for 2-4 wk also showed no adverse effects except with R-11; the R-11 exposures yielded minor decrements in several cognitive tests, but no change in pulmonary function or alteration of in cardiac rhythm

R. D. Stewart et al. (Medical College of Wisconsin), **Acute and Repetitive Human Exposure to Isobutane and Propane**, report IASS-CFTA-MCOW-ENVM-BP-77-1, Department of Environmental Medicine, Medical College of Wisconsin and Milwaukee, Milwaukee, WI, April 1977 (available from NTIS as report PB-279205/LLC, RDB6599)

toxicity tests of aerosol propellants (some of which also are used as refrigerants) in human volunteers; addresses the health effects of R-290 (propane) and R-600a (isobutane)

R. D. Stewart, A. A. Herrmann, E. D. Baretta, H. V. Forster, J. H. Crespo, P. E. Newton, and R. J. Soto (Medical College of Wisconsin), **Human Exposure to Aerosol Propellants**, Department of Environmental Medicine, Medical College of Wisconsin and Milwaukee, Milwaukee, WI, 17 May 1977 (available from NTIS, RDB7620)

toxicity tests of aerosol propellants (some of which also are used as refrigerants) in human volunteers; addresses the health effects of R-12, R-290 (propane), R-600 (n-butane), R-600a (isobutane), and others

R. W. Stoughton and P. D. Lamson (Vanderbilt University School of Medicine), **The Relative Anesthetic Activity of the Butanes and Pentanes**, *Journal of Pharmacology and Experimental Therapeutics* (JPET), 58:74-77, 1936 (4 pages with 1 table, RDB6197)

summarizes tests of the average time to induce light anesthesia (taken as loss of ability to maintain an upright position in a bottle rotating at 14 rpm), complete anesthesia, and lethality in mice by acute inhalation of selected hydrocarbons (HCs) and one ether as a reference; complete anesthesia occurred with exposures to R-C270 (cyclopropane) in 3 minutes at 130,000 ppm v/v, 1½ min at 150,000 ppm, and 1¼ min at 180,000 ppm; light anesthesia was evident with exposures to R-600 (n-butane) for 25 min at 130,000 ppm v/v and 1 min at 220,000 ppm v/v; notes that R-600 "required a concentration of about 20-25 per cent for relaxation, but this caused death after a short time"; light anesthesia was evident for exposures to R-600a (isobutane) for 60 min at 150,000 ppm v/v, 17 min at 200,000 ppm v/v, and 26 min at 230,000 ppm v/v [these data do not suggest a dose-dependent pattern or challenge the reliability of the study]; light anesthesia was evident with exposures to R-601 (n-pentane) for 10 min at 70,000 ppm v/v, 3 min at 80,000 ppm v/v, and 1.3 min at 90,000 ppm v/v; light anesthesia was evident with exposures to R-601a (isopentane) for 11.6 min at 90,000 ppm v/v, 3.9 min at 110,000 ppm v/v, and 2.2 min at 120,000 ppm v/v; light anesthesia was evident with exposures to R-601b (neopentane) for 30 min at 200,000 ppm v/v; light anesthesia was evident with exposures to "ether" (probably R-610) for 3 min at 50,000 ppm v/v but not at 35,000 ppm v/v; notes that all of these substances produced considerable excitement in mice during anesthesia, but that mice that did not die from the exposures recovered very quickly, usually in 1 or 2 min; tests for anesthesia in dogs found that R-C270 induced deep anesthesia with ease, but that it was difficult to induce deep anesthesia with R-600, R-600a, or R-601a; paper indicates the dog testing was insufficient for accuracy; toxicity

H. C. Struck and E. B. Plattner, **Study of Pharmacological Properties of Certain Saturated Fluorocarbons**, *Journal of Pharmacology and Experimental Therapeutics* (JPET), 68:217-219, 1940 (RDB7126)

R-31-10, R-C41-10, mixed depressant and excitant effects, anesthesia

M. Stupfel et al., **Comparative Acute Toxicity, in Male and Female Mice, of Several Air Pollutants: Automobile Exhaust Gas, Nitrogen Oxides, Sulfur Dioxide, Ozone, Ammonia, and Carbon Dioxide**, *C. R. Soc. Biol.*, 165(9):1869-1872, 1971 (4 pages, RDB5817)

R-717, R-744, R-748, R-764, health effects, toxicity

T. Takano and Y. Miyazaki, *Toxicological Sciences*, 7(2):143-149, 1992 (7 pages, RDB5971)

biochemical study of R-125, R-134, and others; toxicity

G. J. Taylor and W. S. Harris, **Cardiac Toxicity of Aerosol Propellants**, *Journal of the American Medical Association* (JAMA), 214(1):81-85, 1970 (5 pages, RDB6B43)

R-12 and others: initial linkage of cardiac sensitization to fatalities from use or abuse of fluoroalkane propellants also used as refrigerants (see RDB5854); nasal inhalation of aerosols by mice

W. F. ten Berge (DSM, The Netherlands), A. Zwart, and L. M. Appelman (TNO-CIVO Toxicology and Nutrition Institute, The Netherlands), **Concentration-Time Mortality Response Relationship of Irritant and Systematically Acting Vapours and Gases**, *Journal of Hazardous Materials*, 13:301-309, 1986 (9 pages with 7 figures and 4 tables, RDB6278)

This article presents an analysis of mortality data, to determine time-dependent relations for lethal acute concentrations in various species for 20 chemicals. The maximum likelihood estimates of regression coefficients, variances, and covariances and chi-square confidence predictor were determined by probit analysis of the raw data from previously published toxicity studies. The results show that the product of exposure and time (c·t) is not always a good parameter for predicting mortality response (Haber's rule). The product of exposure to the power of n and time predicts the response well, where n ranges from 0.8 to 3.5 for 20 studied substances. Among them are n=2.8 for R-10, n=1.6 for R-30B1, n=2.0 for R-717 (ammonia), n=3.5 for R-746 (nitrogen dioxide), n=2.0 for R-1110, and n=0.8 for R-1120. These results estimate the LC_{50} for a specified period from data taken for another exposure duration.

R. C. Terrell, L. Speers, A. J. Szur, T. Ucciardi, and J. F. Vitcha (Air Reduction Company, Incorporated, Airco), **General Anesthetics. 3. Fluorinated Methyl Ethyl Ethers as Anesthetic Agents**, *Journal of Medicinal Chemistry*, 15(6):604-606, 1972 (3 pages with 2 tables, RDB-8318)

toxicity of fluoroether (FE), hydrofluoroether (HFE), and other halogenated ether candidates

R. C. Terrell, L. Speers, A. J. Szur, J. Treadwell, and T. R. Ucciardi (Air Reduction Company Incorporated), **General Anesthetics. 1. Halogenated Methyl Ethyl Ethers as Anesthetic Agents**, *Journal of Medicinal Chemistry*, 14(6):517-519, 1971 (3 pages with 1 table, RDB7461)

toxicity tests of 51 halogenated ethers, including 36 newly-synthesized compounds, for anesthetic effects in mice: among those tested are R-236ca1 (light anesthesia at 125,000 ppm v/v), R-E245fa1 (very weak anesthetic at 100,000 ppm v/v), R-E254cb1 (convulsant at 25,000 ppm v/v), R-E254fa1 (very weak anesthetic at 50,000 ppm v/v), and R-E263fb1 (weak anesthetic properties by injection); concludes that those ethers having one hydrogen atom with at least two halogens other than fluorine or having two hydrogen with at least one bromine or one chlorine were the most potent as anesthetics [the reverse of which suggests that ethers containing only hydrogen and fluorine should have weaker anesthetic properties]

J. B. Terrill (E. I. duPont de Nemours and Company, Incorporated), **Determination of Fluorocarbon Propellant in Blood and Animal Tissues**, *AIHA Journal*, 33(11):736-744, November 1972 (9 pages, RDB7240)

R-12, R-115, and others, health effects, toxicity

B. Thiessen and O. F. Pedersen, **Effect of Freon Inhalation on Maximal Expiratory Flows and Heart Rhythym after Treatment with Salbutamol and Ipratropium Bromide**, *European Journal of Respiratory Diseases*, 61(3):156-161, 1980 (6 pages, RDB7405)

R-12 and others, health effects, toxicity

H. J. Trochimowicz (E. I. duPont de Nemours and Company, Incorporated), **Industrial Research on Alternative Fluorocarbons**, *Toxicology Letters*, 68(1-2):25-30, 1993 (6 pages with 5 tables, RDB-5170)

R-123, R-124, R-125, R-134a, R-141b, R-142b, R-152a, R-E170 (DME), R-225ca, R-225cb: brief review of candidate alternatives for refrigerants and other chlorofluorocarbons and halons; overview of the Programme for Alternative Fluorocarbons Toxicity Testing (PAFT); brief summaries of findings for R-123, R-124, R-125, and R-134a indicate 4-hr LC_{50} rat concentrations as 32,000, 262,500, >800,000, and >500,000 ppm v/v, respectively, and 5-min cardiac sensitization thresholds in dogs at 20,000, 25,000, 100,000, and 75,000 ppm, respectively

H. J. Trochimowicz (E. I. duPont de Nemours and Company, Incorporated) and T. Kawano (Daikin Industries, Limited), **Subchronic Inhalation Toxicity Studies on Seven Alternative Fluorocar-**

bons, *Proceedings of the Sixth International Congress of Toxicology* (Rome, Italy, 28 June - 3 July 1992), International Union of Toxicology, June 1992 (RDB5B44)

R-125 and other refrigerants

H. J. Trochimowicz (E. I. duPont de Nemours and Company, Incorporated), **The Toxicology of Certain Gaseous Fluorocarbons**, *Proceedings of the 2nd International Symposium on Gaseous Dielectrics*, edited by L. G. Christophoran, Pergamon Press, Oxford, UK, 450 ff, 1980 (RDB6489)

R-22 and others, health effects, toxicity

H. J. Trochimowicz, J. P. Lyon, D. P. Kelly, and T. Chiu (E. I. duPont de Nemours and Company, Incorporated), **Ninety-Day Inhalation Toxicity Studies on Two Fluorocarbons**, abstract 164, *Toxicology and Applied Pharmacology* (TAP), 41:200, 1977 (1 page, RDB5915)

R-21 and R-142b, health effects, toxicity

H. J. Trochimowicz, B. L. Moore, and T. Chiu (E. I. duPont de Nemours and Company, Incorporated), **Subacute Inhalation Toxicity Studies on Eight Fluorocarbons**, *Toxicology and Applied Pharmacology* (TAP), abstract 161, 41:198-199, 1977 (2 pages, RDB5A13)

R-21, R-32, R-124, and others, health effects, toxicity

H. J. Trochimowicz, C. F. Reinhardt, L. S. Mullin, A. Azar, and B. W. Karrh (E. I. duPont de Nemours and Company, Incorporated), **The Effect of Myocardial Sensitization Potential of Certain Halocarbons**, *Journal of Occupational Medicine*, 18(1):26-30, January 1976 (5 pages with 3 figures and 3 tables, RDB65E7)

R-11, R-13B1 (halon 1301), R-140a (methyl chloroform), toxicity, cardiac sensitization NOEL and LOEL: summarizes tests on beagle dogs; "results showed no greater potential for cardiac sensitization among dogs having recovered from [induced] myocardial infarction as compared to normal healthy animals"

H. J. Trochimowicz, A. Azar, J. B. Terrill, and L. S. Mullin (E. I. duPont de Nemours and Company, Incorporated), **Blood Levels of Fluorocarbons Related to Cardiac Sensitization: Part II**, *AIHA Journal*, 35(10):632-639, October 1974 (8 pages with 7 figures and 7 tables, RDB5361)

R-11, R-12, R-113, R-114, and R-115; health effects, toxicity

H. J. Trochimowicz (E. I. duPont de Nemours and Company, Incorporated), **Blood Levels of Fluorocarbon During and After Acute Inhalation**, paper 11, *Proceedings of the Fourth Annual Conference on Environmental Toxicology* (Fairborn, OH, 16-18 October 1973), report AMRL-TR-73-125, Aerospace Medical Research Laboratory, U.S. Air Force, Wright-Patterson Air Force Base, OH, 137-149, December 1973 (13 pages with 7 figures and 7 tables including discussion, available from NTIS as document AD-781031, RDB65H2)

blood concentrations of R-11, R-12, R-113, R-114, and R-115 in unanesthetized beagle dogs based on tests using implanted catheters; no challenge epinephrine was administered; toxicity

S. Tsukamoto, S. Chiba, T. Muto, T. Ishikawa, and M. Shimamura, **Study on the Metabolism of Volatile Hydrocarbons in Mice**, *Journal of Toxicological Science*, Japan, 10(4):323-332, 1985 (10 pages, RDB6116)

R-290, R-600a, and others; metabolism in mice, toxicity

H. Uehleke, T. Werner, H. Greim, and M. Kramer, **Metabolic Activation of Haloalkanes and Tests in Vitro for Mutagenicity**, *Xenobiotica*, 7(7):393-400, 1977 (8 pages, RDB8182)

fluorochemical refrigerants, mutagenicity, toxicity

F. Valic and D. Beritic-Stahuljak (University of Zagreb, Croatia), **Are Chlorine-Free Compounds a Solution for Health Problems Caused by Ozone-Depleting Substances?**, *Acta Medica Croatica*, 50(2):61-63, 1996 (3 pages, RDB6A97)

reviews the environmental consequences of chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and hydrofluorocarbons (HFCs); concludes that CFCs and HCFCs are not acceptable based on their potentials for ozone depletion; examines the toxicity of HFC candidates; of those found to be nonflammable, the paper suggests that the toxicity of R-125, R-134a, and R-227ea appear to be low, but have not been fully evaluated

F. Valic and D. Beritic-Stahuljak (University of Zagreb, Croatia), **Substitutes for Dangerous Chlorofluorocarbons, A Challenge**, *Croatian Medical Journal*, 34(2):108-114, 1992 (7 pages, RDB5967)

R-125 and others, toxicity

V. Valic, Z. Skuric, and E. Zuskin, **Experimental Exposures to Fluorochemicals 12, 22, and 502,**

Rad Jazu, Yugoslavia, 402(18):229-243, 1982 (15 pages in Croatian with English summary, RDB-8183)

R-12, R-22, R-502, health effects, toxicity

V. Valic, Z. Skuric, M. Bantic, M. Rudar, and M. Hecej, **Effects of Fluorocarbon Propellants on Respiratory Flow and ECG**, *British Journal of Industrial Medicine*, 34(2):130-136, 1977 (7 pages, RDB7245)

fluorochemical aerosol propellants (also used as refrigerants), health effects, toxicity

V. Valic, E. Zuskin, Z. Skuric, and M. Denich, **Effects of Common Aerosols on the Ventilatory Lung Capacity, I. Change in $FEV_{1.0}$ in Exposure to Hair Sprays**, *Acta Medica Yugoslavia*, 28:231-246, 1974 (16 pages in Croatian with English summary, RDB8184)

fluorochemical aerosol propellants (also used as refrigerants), health effects, toxicity

O. W. Van Auken and R. H. Wilson, **Halogenated Hydrocarbon Induced Reduction in Coupling Parameters of Rabbit Liver and Mung Bean Mitochondria**, *Naturwissenschaften* [Natural Science], 60:259 ff, 1973 (RDB8191)

fluorochemical refrigerants, health effects, toxicity

A. Van Poznak and J. F. Artusio, Jr. (New York Hospital and Cornell University Medical College), **Anesthetic Properties of a Series of Fluorinated Compounds I. Fluorinated Hydrocarbons**, *Toxicology and Applied Pharmacology* (TAP), 2(4):363-373, July 1960 (11 pages with 1 table, RDB5828)

R-12, R-22, R-22B1, R-23, R-114, R-124, R-124B1, R-125, R-133aB1, R-152a, R-226da, R-243db, R-1233B1, and others; health effects, acute toxicity, and anesthetic effects in dogs; offers several generalizations, among them that completely halogenated hydrocarbons are likely to be convulsants or without anesthetic activity; based on findings by others and the new data, notes that anesthetic potency increases with halogenation or increases in the chain length (number of carbons for alkanes), either of which usually raises the boiling point as well as the molecular weight

A. Van Poznak and J. F. Artusio, Jr. (New York Hospital and Cornell University Medical College), **Anesthetic Properties of a Series of Fluorinated Compounds II. Fluorinated Ethers**, *Toxicology and Applied Pharmacology* (TAP), 2(4):374-378, July 1960 (5 pages with 1 table, RDB5872)

health effects, acute toxicity, anesthetic effects and cardiac sensitization in dogs

K. Verschueren, **Handbook of Environmental Data on Organic Chemicals** (second edition), Van Nostrand Reinhold Company, New York, NY, 1983 (3 pages, Rdb6211)

R-601a, R-717, and others, toxicity: cites RD_{50} mouse = 303 ppm for R-717

A. Vinegar (ManTech Environmental Technology, Incorporated), R. Cook (U.S. Air Force, USAF), J. D. McCafferty (USAF), M. C. Caracci (Geocenters Incorporated), and G. W. Jepson (ManTech), **Human Inhalation of Halon 1301, HFC-134a, and HFC-227ea for Collection of Pharmacokinetic Data**, posted on the Internet (http://voyager.wpafb.af.mil, since removed), Armstrong Laboratory, U.S. Air Force, Wright-Patterson Air Force Base, OH, 19 August 1997 (18 pages with 4 figures, RDB7C80)

inhalation toxicity of R-13B1, R-134a, and R-227ea: describes tests in human volunteers to validate a physiologically-based pharmacokinetic (PBPK) model for estimating chemical biodistribution; seven male subjects were exposed in a medical facility via face masks for up to 30 minutes; inhaled and end alveolar expired concentrations were measured and periodic blood samples were drawn through an inserted venous cannula; subjects were monitored via ECG, blood pressure, and pulse-rate measurements; although the tests were conducted at concentrations well below published lowest observable adverse effect levels (LOAELs), the tests with R-134a and R-227ea had to be terminated following unexpected responses; one volunteer exposed to 4,000 ppm v/v R-134a in air displayed a rapid increase in blood concentration at 2½ minutes into the exposure; he lost consciousness and both his pulse and blood pressure dropped to zero at 4 min, upon which the test was terminated and medical personnel intervened; a second subject exposed to 4,000 ppm v/v R-134a in air experienced a rapid rise in blood pressure and pulse before he signalled for termination; he was exposed again after recovery, to 2,000 ppm v/v, but his blood pressure and pulse again rose rapidly after 2½ min; both subjects recovered rapidly but reported dizziness and balance problems 6 wk post exposure; a third subject exposed to 6,400 ppm v/v R-227ea in air suffered rapid rise in pulse 3 min into exposure; report documents the details

of these and additional tests as well as blood concentrations versus time during and following exposures; it discusses the unexpected results and anomalous finding of R-134a in the blood 1 hr post exposure; report concludes that no plausible mechanism is apparent for the adverse effects [Subsequent investigation of the results indicates that the reported responses probably were not due to the chemical exposures. No adverse effects were seen in other human exposures to R-134a and R-227ea at lower or higher concentrations. See RDB7C81 - RDB7C82 for further information.]

A. Vinegar, G. W. Jepson (ManTech Environmental Technology, Incorporated), and J. H. Overton (U.S. Environmental Protection Agency, EPA), **PBPK Modeling of Short-Term (0-5 min) Human Inhalation Exposures to Halogenated Hydrocarbons**, *Inhalation Toxicology*, 10:411-429, 1998 (19 pages, RDB9950)

toxicity of fluorochemicals and other candidate fire suppressants also used as refrigerants); physiologically-based pharmacokinetic (PBPK) modeling

A. Vinegar and G. W. Jepson (ManTech Environmental Technology, Incorporated), **Cardiac Sensitization Thresholds of Halon Replacement Chemicals Predicted in Humans by Physiologically-Based Pharmacokinetic Modelling**, *Risk Analysis*, 16(4)571-579, 1996 (9 pages, RDB8194)

toxicity of fluorochemicals and other candidate fire suppressants also used as refrigerants); physiologically-based pharmacokinetic (PBPK) modeling

W. F. von Oettingen, **The Halogenated Hydrocarbons: Their Toxicity and Potential Dangers**, *Journal of Industrial Hygiene and Toxicology*, 19:422 ff, 1937; republished as publication 414, Public Health Service, U.S. Department of Health and Human Services, Washington, DC, 1955 (RDB5933)

refrigerants, health effects, toxicity: asserts that phosgene is formed when R-1120 (trichloroethylene) passes through burning tobacco in smoking

H. Wada (Daikin Industries, Limited), **Anesthetic Activity and Fatality (F-123, 123a, 124, and 11)**, attachment to 19 May 1977 correspondence to M. B. Berenbaum (Allied Chemical Corporation), Daikin Kogyu Company Limited Chemical Division, Settsu-shi, Osaka, Japan, 16 May 1977 (3 pages with 2 tables, RDBA309)

inhalation toxicity tests on adult male rats; provides results of tests for anesthesia for animals unable to maintain an upright position for 15 seconds in a bottle rotating at 14 rpm for 10 min; indicates calculated "approximate anesthetic concentration (AAC)" that appear to be EC_{50} values of 54,000 ppm for R-11, 130,000 ppm for R-123, 190,000 ppm for R-123a, and 150,000 for R-124; also provides approximate lethal concentration (ALC) and estimated LC_{50} (incorrectly identified as ALC in the document based on comparison to tabulated fatality counts) concentrations for 10 min exposures; 10 min ALC followed by (number of fatalities / sample size) and LC_{50} rat, respectively, were 120,300 (3/4) and 120,000 ppm for R-11, 72,500 (1/4) and 90,000 ppm for R-123, 106,000 (3/4) and 100,000 ppm for R-123a, 425,000 (1/4) and 440,000 ppm for R-124; concludes that R-123 and R-123a were more toxic than R-11 while R-124 was less toxic; transmittal letter raises questions about unidentified positive results of mutagenicity tests with R-152a in Europe [Note: This document is referenced in the 1994 ECETOC JACC assessment report for R-124, see RDB4C02.]

Y. Wang, M. J. Olson (General Motors Research Laboratories), and M. T. Baker, **Interaction of Fluoroethane Chlorofluorocarbon (CFC) Substitutes with Microsomal Cytochrome P450 — Stimulation of P450 Activity and Chlorodifluoroethene Metabolism**, *Biochemical Pharmacology*, UK, 46(1):87-94, 6 July 1993 (6 pages, RDB6545)

R-123, R-123B1, R-133a, R-124, R-134a and R-125 metabolism and toxicity: ability to stimulate cytochrome P450 activities; R-1122a (CDE) defluorination in hepatic microsomes from phenobarbital-treated rabbits; 10,000 ppm v/v R-123 doubled oxygen consumption; R-124, R-134a, and R-125 were successively less effective, increasing oxygen consumption by 50-100%

R. S. Waritz (E. I. duPont de Nemours and Company, Incorporated), **The Toxicology of Some Commercial Fluorocarbons**, paper 7, *Proceedings of the 2nd Annual Conference on Environmental Toxicology* (31 August - 2 September 1971), report AMRL-TR-71-120, Aerospace Medical Research Laboratory, U.S. Air Force, Wright-Patterson Air Force Base, OH, 85-99, December 1971 (15 pages with 11 tables, available from NTIS as document AD-751426, RDB65H1)

R-11, R-12, R-22, R-113, R-114, R-115, R-116, R-152a: ALC, clinical signs from inhalation, ALD, acute eye toxicity, chronic inhalation toxicity, chronic oral toxicity, chronic skin and eye toxicity, human studies; acute inhalation toxicity data for R-C318 and comparisons to the isolog hexafluorocyclobutene; acute inhalation toxicity comparison of octafluorobutene and octafluoroisobutene

S. Wason, W. B. Gibler, and M. Hassan, **Ventricular Tachycardia Associated with Non-Freon Aerosol Propellants**, *Journal of the American Medical Association* (JAMA), 256(1):78-80, July 1986 (3 pages, RDB6198)

case history of a nonfatal accident, involving cardiac sensitization and ventricular tachycardia in a 2-yr-old female patient, from inhalation of a commercial deodorant containing the aerosol propellants (also used as refrigerants) R-290 (propane), R-600 (n-butane), and R-600a (isobutane): describes the incident and treatment, noting resolution of the arrythmia within 48 hr; health effects and toxicity of human exposures

T. Watanabe, H. Ratcliffe, G. E. Thompson, and D. M. Aviado (University of Pennsylvania School of Medicine), **Bronchopulmonary Lesions Following Subacute Inhalation of Fluorocarbons**, *Propellant Supplement: Journal of Clinical Pharmacology*, 67 ff, 1977 (RDB7246)

fluorocarbon refrigerants, health effects, toxicity

T. Watanabe, H. Ratcliffe, G. E. Thompson, and D. M. Aviado (University of Pennsylvania School of Medicine), **Fluorinated Propellants for Aerosols**, CRC Press, Cleveland, OH, 1977 (RDB7293)

fluorochemical propellants (many also used as refrigerants), health effects, toxicity

T. Watanabe and D. M. Aviado (University of Pennsylvania School of Medicine), **Toxicity of Aerosol Propellants in the Respiratory and Circulatory Systems, VII. Influence of Pulmonary Emphysema and Anesthesia in the Rat**, *Toxicology*, 3:225-240, 1975 (16 pages, RDB5C64)

R-11, R-12, R-152a, and others; cardiac sensitization, health effects, toxicity

T. Watanabe, and D. M. Aviado (University of Pennsylvania School of Medicine), **Toxicity of Aerosol Propellants on the Respiratory and Circulatory Systems, IV. Influence of Pulmonary Emphysema and Anesthesia in the Rat**, *Toxicology*, 3:225-236, 1975 (12 pages, RDB8188)

cardiac sensitization, health effects, toxicity

T. Watanabe and D. M. Aviado (University of Pennsylvania School of Medicine), **Subacute Inhalational Toxicity of Aerosol Propellants**, abstract 097, *Pharmacologist*, 17(2):192, 1975 (1 page, RDB5A74)

R-12, R-114, and others; reduced pulmonary compliance in rats with 30 minute exposures to 40,000 ppm R-114 in air for 6 d/wk for 3 weeks as reported in RDB5141 and RDB5855

W. Weigand (Farbwerke Hoechst AG, Germany), **Untersuchungen über die Inhalationstoxizität von Fluoroderivaten des Methan, Äthan, und Cyclobutan** [Studies of the Inhalation Toxicity of Fluorinated Derivatives of Methane, Ethane and Cyclobutane], *Zentralblatt für Arbeitsmedizin und Arbeitsschutz* [Occupational Medicine and Safety], 21(5):149-156, 1971 (8 pages with 5 tables, in German, RDB5365)

R-12B1, R-13, R-21, R-22, R-115, R-C318, and others, toxicity: 2-hr acute inhalation toxicity tests in rats and guinea pigs; subchronic inhalation toxicity tests in rats, guinea pigs, dogs, and cats; anesthetic effect tests in rats; 4 rats and 2 guinea pigs exposed to 600,000 ppm R-C318 for 2 hr showed normal behavior during and for the subsequent 7-day observation period; 5 rats, 2 guinea pigs, 2 dogs, and 2 cats exposed to 200,000 ppm for 3½ hr/d, 5 d/wk for 4 weeks showed no adverse effects by observation or pathological examination

M. Wilkenfeld, **Simple Asphyxiants,** *Environmental and Occupational Medicine* (second edition), edited by W. N. Rom, Little, Brown and Company, Boston, MA, 535-538, 1992 (4 pages, RDB8423)

reviews simple asphyxiants including R-50 (methane), R-170 (ethane), R-702 (hydrogen), R-704 (helium), R-728 (nitrogen), R-740 (argon), R-744 (carbon dioxide), and R-744A (nitrous oxide): describes simple asphyxiants as gases that cause asphyxiation when present in concentrations high enough to lower oxygen levels, resulting in inadequate delivery of oxygen to tissues, but that are physiologically inert and do not suppress cardiac output or alter the function of hemoglobin; summarizes the physical and chemical characteristics of these substances; presents the concentrations known to produce asphyxiation and the occupational environments in which incidents and even fatali-

ties have been reported; discusses case histories to illustrate the need for safety checks when simple asphyxiants are present and the use of a self-contained breathing apparatus (SCBA) as a protective measure

J. H. Wills, **Sensitization of the Heart to Catecholamine-Induced Arrhythmia**, *Proceedings of the 3rd Annual Conference on Environmental Toxicology* (Fairborn, OH, 25-27 October 1972), National Technical Information Service (NTIS), Springfield, VA, 249 ff, 1972 (available from NTIS as document AD-773766, RDB8187)

cardiac sensitization, toxicity

J. H. Wills, P. Bradley, H. Kao, H. Grace, W. Hull, T. B. Griffin, F. Coulston, and E. S. Harris (Albany Medical College and NASA Manned-Spacecraft Center), **Sensitization of the Heart to Catecholamine-Induced Arrhythmia by Haloalkanes**, abstract 82 (11th Annual Meeting of the Society of Toxicology, SOT), *Toxicology and Applied Pharmacology* (TAP), 22:305-306, 1972 (2 pages, RDB6118)

R-11, R13B1, R-114B2 or R-114aB2, R-116, R-C318, cardiac sensitization via tracheal cannulae in anesthetized guinea pigs, cats, and dogs at concentrations of up to 200,000 ppm, all resulted in sensitization with R-11 the most potent followed by R-114B2 or R-114aB2

C. R. Wolf, D. Mansuy, W. Nastainczyk, G. Deutschmann, and V. Ullrich, **The Reduction of Polyhalogenated Methanes by Liver Microsomal Cytochrome P-450**, *Mol. Pharmacol.*, 13(4):698-705, 1977 (8 pages, RDB8186)

R-11, R-12, and others: biochemistry, health effects, metabolism, pharmacokinetics, toxicity

W. P. Yant (U.S. Bureau of Mines), **Toxicity Of Organic Fluorides**, *American Journal of Public Health*, 23:930-934, 1933 (5 pages, RDB5A73)

R-114 and others, health effects, toxicity

D. S. Young et al., *Journal of the American Chemical Society*, 62:1171-1173, 1940 (3 pages, RDB-5944)

R-125 and others

W. Young and J. Parker, **Effect of Freons on Acetylcholinesterase Activity and Some Counter Measures**, *Proceedings of the 3rd Annual Conference on Environmental Toxicology* (Fairborn, OH, 25-27 October 1972), National Technical Information Service (NTIS), Springfield, VA, 259 ff, 1972 (available from NTIS as document AD-773766); republished in *Combustion Toxicology*, 2:286-297, 1975 (?/12 pages, RDB-8190)

biochemistry, toxicity

J. A. Zapp, Jr., **Fluorocarbons**, *Encyclopedia of Occupational Health and Safety* (third revised edition), 1:895-897, 1983 (3 pages, RDB5951)

R-125 and others, health effects, toxicity

S. Zakhari, **Cardiovascular Toxicology of Halogenated Hydrocarbons and Other Solvents**, *Cardiovascular Toxicology* (second edition), Raven Press Limited, New York, NY, 1992 (RDB-6685)

addresses possible mechanisms responsible for cardiac sensitization of refrigerants and other chemicals

S. Zakhari and D. M. Aviado, **Cardiovascular Toxicology of Aerosol Propellants, Refrigerants, and Related Solvents, III. Toxicodynamics**, *Target Organ Toxicology Series, Cardiovascular Toxicology*, edited by E. W. Van Stee, Raven Press, New York, NY, 281-326, 1982 (46 pages, RDB6132)

R-10B4, R-12B1, R-31, R-40B2, R-41, R-113a, R-114, R-114a, R-114B2, R-130a, R-150, R-150B2, R-151a, R-152a, R-260da, R-280fa, R-280faB1, R-C318, R-31-10, R-1110, R-1114, R-1130c, R-1130t, R-1140B1, and others; toxicity

E. Zeiserl, **Hydrocarbon Ingestion and Poisoning**, *Compr. Ther.*, 5:35-42, 1979 (8 pages, RDB-8122)

hydrocarbons, health effects, toxicity in humans: direct aspiration into the tracheobronchial system, rather than gastrointestinal absorption, is the major toxic mechanism — as reported in RDB7B43

C. Zenz, **Fluorides**, *Occupational Medicine, Principles and Practical Applications* (second edition), Year Book Medical Publishers, Incorporated, Chicago, IL, chapter 35, 540-544, 1987 (5 pages, RDB5945)

R-125 and others, personal protective equipment, skin contact

P. S. Zurer, **Liver Damage Tied to CFC Substitute**, *Chemical and Engineering News*, 25 August 1997 (5 pages with 2 figures, limited copies available from JMC as RDB7C72)

provides further information on the underlying incident and subsequent investigations in re-

sponse to an article in *The Lancet* (see RDB-7C70) on exposures of workers to R-124/123 [actually R-290/124/123]: quotes R. Rubenstein (a senior staff toxicologist with the U.S. Environmental Protection Agency, EPA), on the hepatotoxicity mechanisms for R-123 and that it has "always been considered very safe when used properly"; quotes P. Hoet (one of the coauthors of the cited article) that the chronic concentrations involved were not determined but must have been high since "the workers said they were always refilling the air-conditioning system"; quotes L. R. Pohl (another coauthor of the cited article) on the metabolic processes for R-123 and R-124 on the possibility of further liver damage through an autoimmune reaction; quotes G. R. Rusch (director of toxicology for AlliedSignal Incorporated) that no "chemical has ever been more extensively evaluated than HCFC-123" and W. J. Brock (staff toxicologist for DuPont Chemicals) that tested primates (monkeys) developed liver damage, which was reversible, only when exposed to doses 20 times higher than recommended exposure limits; quotes D. Hufford (acting director of the EPA Stratospheric Ozone Protection Division) that R-123 and R-124 are well studied and can be safe if industry standards are followed, but also can be misused

E. Zuskin, Z. Skuric, and V. Valic, **Effects of Common Aerosols on the Ventilatory Lung Capacity, II**, *Acta Medica Yugoslavia*, 28:247-259, 1974 (13 pages in Croatian with English summary, RDB8185)

fluorochemical aerosol propellants (also used as refrigerants), health effects, toxicity

2000 Threshold Limit Values for Chemical Substances in the Work Environment, *2000 TLVs® and BEIs®: Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*, publication 0100, American Conference of Governmental Industrial Hygienists (ACGIH), Cincinnati, OH, 2000 (105 pages with 2 tables, available from ACGIH for $27.95, RDB-A936)

This book provides data for use as guidelines or recommendations in the control of potential health hazards. Threshold limit values (TLVs) are tabulated for airborne concentrations of chemical substances to which workers may be exposed. These chemicals include some commonly or historically used as refrigerants, based on their chronic and/or acute toxicity. The TLV data refer to concentrations under which it is believed that nearly all workers may be repeatedly exposed without adverse health effects subject to identified considerations. The TLVs are categorized as time-weighted average (TWA or TLV-TWA), short-term exposure limit (STEL or TLV-STEL), and ceiling (TLV-C). The document indicates the molecular weights and bases or critical effects underlying the adopted TLV concentrations. Notes are provided for interpretation, but the information is not intended for use without training in industrial hygiene. The document flags TLVs and other data for compounds included in the Notice of Intended Changes (NIC), to flag data for which future revision has been proposed. It also provides appendices addressing carcinogens, substances of variable composition, mixtures, and sampling criteria for airborne particulate matter. The refrigerants addressed include R-11, R-12, R-13B1, R-20, R-21, R-22, R-30, R-40, R-113, R-114, R-115, R-160, R-160B1, R-170 (ethane), R-290 (propane), R-600 (butane), R-601 (pentane), R-610, R-611, R-630, R-631, R-717 (ammonia), R-744 (carbon dioxide), R-764 (sulfur dioxide), R-1130, R-1150, R-1270, R-7146 (sulfur hexafluoride), and others. R-20B1, R-20B3, R-30, R-30B1, R-160B1, R-600a (isobutane), R-602 (n-heptane), R-1216, R-1250, and others are identified as chemical substances under study.

An Investigation of Possible Cardiotoxic Effects of the Aerosol Propellants Arctons 11 and 12, Allen and Hanburys Limited, UK, 1971 (RDB8127)

cardiac sensitization of fluorochemical aerosols 11 and 12 (also used as refrigerants): toxicity of R-11 and R-12

C. F. Reinhardt, **Cardiac Arrhythmias Induced by Epinephrine During Inhalation of Certain Halogenated Hydrocarbons: Cardiac Sensitization**, report 14-69, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 14 January 1969 (35 pages with 7 figures and 4 tables, RDB6A04)

toxicity tests to determine the cardiac sensitization potential in male beagle dogs with intravenous injection of epinephrine five minutes before and, with a challenge injection, midway into a 10 minute exposure of R-11, R-13B1, R-113, and R-1120; for R-11 and R-113, LOEL at 5,000 ppm v/v as reported in RDB6467; for R-13B1, LOEL at 75,000 ppm v/v as reported in RDB6527; R-C318 and others

Compendium of Abstracts from Long-Term Cancer Studies Reported by the National Toxicology Program from 1976-1992, *Environmental Health Perspectives* (EHP), publication NIH93-218, National Institute of Health, U.S. Department of Health and Human Services (DHHS), Research Triangle Park, NC, 101(supplement 1), April 1993 (220 pages, RDB7744)

abstracts of toxicity studies from long-term cancer studies by the NTP from 1976-1992 for R-10B2, R-11, R-20B1, R-20B2, R-20B3, R-20I3, R-30, R-40B1, R-110, R-120, R-130, R-130a, R-140, R-140a, R-150, R-150a, R-160, R-160B1, R-260da, R-260dab2, R-270da, R-1110, R-1120, R-1130a, R-1270, and others

Compendium of Abstracts from Long-Term Cancer Studies Reported by the National Toxicology Program, Addendum to EHP Supplements, Vol. 101, National Institute of Health, U.S. Department of Health and Human Services (DHHS), Research Triangle Park, NC, November 1996 (116 pages with no figures or tables, RDB-7745)

abstracts of toxicity studies

Criteria for a Recommended Standard — Occupational Exposure to Alkanes (C1-C8), publication 77-151, National Institute of Occupational Safety and Health (NIOSH), U.S. Department of Health and Human Services (DHS, then the U.S. Department of Health, Education, Welfare, DHEW), Cincinnati, OH, March 1977 (RDBA539)

toxicity of hydrocarbons (HC)

Documentation of the Threshold Limit Values and Biological Exposure Indices (sixth edition), publication 0206, American Conference of Governmental Industrial Hygienists (ACGIH), Cincinnati, OH, 1991 (RDB5141)

This book documents the bases for threshold limit values (TLVs) for airborne concentrations of chemical substances to which workers may be exposed. These chemicals include some commonly or historically used as refrigerants, based on their chronic and/or acute toxicity. The TLV data refer to concentrations under which it is believed that nearly all workers may be repeatedly exposed without adverse health effects subject to identified considerations. The TLVs are categorized as time-weighted average (TWA or TLV-TWA), short-term exposure limit (STEL or TLV-STEL), and ceiling (TLV-C). The refrigerants addressed include R-11, R-12, R-12B2, R-21, R-22, R-30, R-40, R-113, R-114, R-115, R-170 (ethane), R-290 (propane), R-600 (butane), R-611, R-630, R-631, R-717 (ammonia), R-744 (carbon dioxide), R-764 (sulfur dioxide), R-1130, R-7146 (sulfur hexafluoride), and others.

Encyclopedia of Occupational Health and Safety, International Labour Office, Geneva, Switzerland, 1983 (RDB5140)

toxicity, flammability

Guide to Occupational Exposure Values — 1999, publication 0377, American Conference of Governmental Industrial Hygienists (ACGIH), Cincinnati, OH, 1999 (145 pages, RDB9505)

This reference document compares the most recent concentrations for widely cited toxicity exposure limits. It includes Threshold Limit Values (TLV) from the American Conference of Governmental Industrial Hygienists (ACGIH), Permissible Exposure Limits (PEL) from the Occupational Safety and Health Administration (OSHA), the Recommended Exposure Limits (REL) from the National Institute for Occupational Safety and Health (NIOSH), and the 1989 maximale Arbeitsplatz Konzentration [maximum workplace concentration] (MAK) and biologischer Arbeitsstoff-Toleranz-Wert [biological tolerance value] (BAT) from the Deutsche Forschungsgemeinschaft [German Research Association] (DFG) Commission for the Investigation of Health Hazards of Chemical Compounds in the Workplace. It also identifies carcinogens found in the workplace that are identified by the above organizations, the International Agency for Research on Cancer (IARC), the U.S. National Toxicology Program (NTP), and the U.S. Environmental Protection Agency (EPA). The refrigerants addressed include R-11, R-12, R-12B2, R-21, R-22, R-30, R-40, R-114, R-115, R-170 (ethane), R-290 (propane), R-600 (butane), R-611, R-630, R-631, R-717 (ammonia), R-744 (carbon dioxide), R-764 (sulfur dioxide), R-1130, R-7146 (sulfur hexafluoride), and others.

Hydrofluorocarbons and Hydrochlorofluorocarbons — Interim Report, external review draft, U.S. Environmental Protection Agency (EPA), Washington, DC, 15 November 1990 (84 pages with 20 tables, RDB7234)

draft support document to assess the toxicity of chlorofluorocarbon (CFC) replacements; summarizes toxicity studies for R-22, R-123, R-124, R-125, R-134a, R-141b, R-142b, and R-152a; discusses the potential for occupational and consumer exposures to these chemicals as re-

frigerants and in other uses; briefly addresses their environmental fate and potential impacts on the general population; concludes as an interim finding based incomplete information and preliminary analyses that HCFCs and HFCs can be used in a manner safe to workers, consumers, and the general public given appropriate safeguards [Note: EPA staff indicate that this report has not been finalized (it remains a draft) as of February 1997, and there are no plans to publish a final version.]

IARC Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Humans, International Agency for Research on Cancer (IARC), Lyon, France, 1972-present (list of monographs as of 17 July 1998: 14 pages with no figures or tables, available from JMC as RDB8802)

The International Agency for Research on Cancer (IARC) / Centre International de Recherche sur le Cancer (CIRC) was established in 1965 by the United Nations (UN) World Health Organization (WHO). Its mission is to coordinate and conduct research on the causes of human cancer and to develop strategies for cancer control. The agency is involved in both epidemiological and laboratory research. IARC publishes a series of monographs summarizing evaluations of chemicals. IARC classifications indicated in the Refrigerant Database as from RDB8802 are as of 15 August 1998.

Inhalation Toxicity of Chlorotrifluoromethane (Freon 13) and Perfluorocyclobutane (Freon C318), report 38-56, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 31 August 1956 (RDB7634)

subchronic toxicity tests for R-13 and R-C318

Kälteanlagen — Sicherheitstechnische Grundsätze für Gestaltung, Ausrüstung, Aufstellung, und Betrieben [Refrigerating Plants — Safety Principles for their Construction, Equipment, Installation, and Operation], DIN Standard 8975, Deutsches Institut für Normung e.V., Berlin, Germany (RDB4680)

Merck Index (eleventh edition), edited by S. Budavari, M. J. O'Neil, A. Smith, and P. E. Heckelman, Merck Company, Rahway, NJ, 1989 (RDB6A05)

widely cited reference for toxicity and other safety data

NEHC Recommends Submarine Atmosphere Limits for New Ozone-Friendly Refrigerants, *CFC-Halon News*, Navy CFC & Halon Clearinghouse, Arlington, VA, 5(3):6, September 1995 (1 page with 1 table, copies available from JMC as RDB5A11)

preliminary limits for submarine atmospheres, recommended by the Navy Environmental Health Center (NEHC), based on toxicity and potential decomposition by and/or corrosive effects on catalytic oxygen replenishment systems; recommended limits for 1 hr, 24 hr, and 90 days are 5,000, 1,000, and 900 ppm for R-134a and 2,000, 1,000, and 100 ppm for R-236fa; article indicates that Naval Sea Systems Command (NAVSEA) plans to reduce the R-134a limits to 2,000, 1,000, and 100 ppm, respectively, based on the concentrations used to test the atmosphere control system

NIOSH Pocket Guide to Chemical Hazards, publication 95-115, National Institute for Occupational Safety and Health (NIOSH), U.S. Department of Health and Human Services, Cincinnati, OH, 1994 (available from GPO or NTIS, RDBA670)

This document lists safety information in tabular form for 677 chemicals found in the work environment. Many of them are regulated by the U.S. Occupational Safety and Health Administration (OSHA). Each entry identifies the chemical by name, synonym(s), trade name(s), structural or empirical chemical formula, Chemical Abstract Service (CAS) and Registry of Toxic Effects of Chemical Substances (RTECS) numbers, and assigned U.S. Department of Transportation identification and guide numbers. It then gives the National Institute for Occupational Safety and Health (NIOSH) Recommended Exposure Limit (REL), Short Term Exposure Limit (STEL), ceiling REL (REL-C), carcinogenic identification or cautions, and/or Immediately Dangerous to Life or Health (IDLH) value. It also indicates the OSHA Permissible Exposure Limit (PEL) or PEL ceiling value (PEL-C). The entries also provide physical descriptions and summary chemical and physical properties, as available. They include concentration conversion factors, molecular weight, normal boiling point, solubility in water, flash point, ionization potential, representative vapor pressure, melting or freezing point temperature, flammability limits, minimum explosive concentration, representative specific gravity, and relative density of gases referenced to air. Entries list incompatibilities, reactivities, and measurement methods for the chemicals along with recommendations for personal protection, sanitation, and respirators. The entries conclude with health hazard summaries that identify body en-

try routes, symptoms, first aid measures, and impacted target organs. An introduction briefly describes these data and the codes used in the listings. Appendices provide recommendations on potential occupation carcinogens, identify 13 regulated carcinogens, discuss supplementary exposure limits, discuss exposure limits for certain substances without established RELs, discuss respirator recommendations for selected chemicals, and provide miscellaneous notes. They also list more protective OSHA PELs that were vacated by a court decision and provide indices by synonym and trade names, by CAS registry numbers, and by DOT identification numbers. A number of historical, current, and candidate refrigerants are covered. They include R-10, R-11, R-12, R-12B2, R-13B1, R-21, R-22, R-30, R-30B1, R-40, R-112, R-113, R-114, R-115, R-290 (propane), R-600 (butane), R-600a (isobutane), R-601 (pentane), R-610, R-630, R-631, R-717 (ammonia), R-744 (carbon dioxide), R-764 (sulfur dioxide), R-1120, R-1130, R-7146 (sulfur hexafluoride), and others.

PAFT Member Companies Respond to Lancet Report, press release, Programme for Alternative Fluorocarbon Toxicity Testing (PAFT), Washington, DC, 27 August 1997 (3 pages with no figures or tables, limited copies available from JMC as RDB7C73)

provides further information on the underlying incident and subsequent investigations in response to an article in *The Lancet* (see RDB-7C70) on exposures of workers to R-124/123 [actually R-290/124/123]: describes the article as "incomplete and unsubstantiated"; quotes G. R. Rusch (director of toxicology and risk assessment for AlliedSignal Incorporated and chairman of the PAFT Toxicology Committee) that overexposure to any chemical can cause a toxic response; notes that R-123 and R-124 have undergone extensive toxicity testing and "have been found to not pose any adverse health effects, including acute liver toxicity, when used properly in their intended applications"; notes that the cited article attempted to correlate clinical evidence of hepatitis with exposure to refrigerants, but that exposure duration and concentration were never addressed; quotes W. J. Brock (staff toxicologist for DuPont Chemicals) that linkage of liver injury to exposure to R-123 or R-124 is premature since the authors made no attempt to assess exposure concentrations or to rule out other chemicals in the smelting plant; quotes R. Rubenstein (a toxicologist with the U.S. Environmental Protection Agency, EPA) that all of the alternative refrigerants can be used safely when industry standards are followed, but that they were not adhered to in this incident

PAFT Statement on Wright Patterson/Armstrong Laboratory Study Involving HFC-134a and HFC-227ea, press release, Programme for Alternative Fluorocarbon Toxicity Testing (PAFT), Washington, DC, 24 September 1997; posted on the Internet (http://thor.he.net/~paft), 3 October 1997 (2 pages with no figures or tables, RDB7C81)

provides further information on inhalation toxicity test responses reported in an Air-Force study (see RDB7C80) for exposures with R-13B1, R-134a, and R-227ea: notes that the wealth of experience from use of R-134a and R-227ea contradicts the results initially reported in that study; describes tests by the International Pharmaceutical Aerosol Consortium for Toxicology Testing (IPACT) and independent pharmaceutical companies at lower and higher concentrations in which no effect on blood pressure or pulse were seen; also notes animal tests relevant to human cardiovascular responses at concentrations at least 12 times higher with no adverse effects; concludes that the effects "were most likely not a direct result of the chemical exposure"; describes a planned clinical study, with independent oversight, to investigate the effects of prolonged exposures to R-134a and R-227ea

PAFT Update, document H-45950, DuPont Chemicals, Wilmington, DE, November 1992 (4 pages with 2 tables, available from JMC as RDB-3909)

This bulletin outlines the Programme for Alternative Fluorocarbons Toxicity Testing (PAFT), a cooperative research effort sponsored by chlorofluorocarbon producers. PAFT is designed to expedite the development of toxicology data for possible substitute fluorocarbons. The programs integrate past and present toxicological information to perform a careful risk assessment. The bulletin outlines the six main types of studies conducted by PAFT. They include acute toxicity primarily by inhalation, genotoxicity, subchronic toxicity by inhalation, developmental toxicity by teratology and inhalation, chronic toxicity and carcinogenicity by inhalation, and environmental toxicity. PAFT has initiated more than 100 individual toxicology studies. A table gives the schedule for

testing, broken into phases the longest of which requires four years. Five programs are identified: PAFT I, which began in 1987, covers R-123 and R-134a. PAFT II, initiated in 1988, addresses R-141b. PAFT III, begun in late 1989, is studying R-124 and R-125. PAFT IV, established in May 1990, will examine R-225ca and R-225cb for solvent cleaning. PAFT V, established in early 1992, will examine R-32. A table summarizes key results as of November 1992 for the fluids names as well as for R-11 and R-12 for comparison. The data include ALC/LC_{50}, oral LD_{50}, cardiac sensitization thresholds, Ames assay, in vivo mutagenicity, subchronic no observed effect level (NOEL), teratogenic, chronic inhalation, and flammability data. The completion schedule and recommended exposure limits are included.

Patty's Industrial Hygiene and Toxicology (fourth edition), edited by G. D. Clayton and F. E. Clayton, John Wiley and Sons, Incorporated, New York, NY, 1993-1995 (11 books totalling more than 9000 pages, RDB5704)

detailed reference for toxicity and other safety data; comprises volumes on "General Principles", "Toxicology", and "The Theory and Rationale of Industrial Hygiene Practice"

Permissible Levels of Toxic Substances in the Working Environment, Proceedings of the 6th Session of the Joint ILO/WHO Committee on Occupational Health (Geneva, Switzerland, 4-10 June 1968), International Labour Office (ILO) of the World Health Organization (WHO), Geneva, Switzerland, 1970 (405 pages, RDB8409)

R-717 and others, health effects, toxicity

Preliminary Environmental Hazard Assessment of Chlorinated Naphthalenes, Silicones, Fluorocarbons, Benzenepolycarboxylates, and Chlorophenols, U.S. Environmental Protection Agency (EPA), Washington, DC, 1973 (96 pages, available from NTIS as document PB-238074, RDB7241)

chlorinated refrigerants, BCFC, BHCFC, CFC, HCFC

Programme for Alternative Fluorocarbon Toxicity Testing (PAFT) Toxicology Summaries, PAFT, Washington, DC, September 1995 (16 pages, available from JMC as RDB5C39)

Eight data sheets summarize the status and findings of the Programme for Alternative Fluorocarbon Toxicity Testing (PAFT). They outline studies of acute toxicity (short-term exposures to high concentrations, such as accidental leakages), genotoxicity (effects on genetic material, an early screen for possible carcinogenic activity), sub-chronic toxicity (repeated exposure to determine any overall toxicological effect), reproductive and developmental toxicity (teratology, assessment of the effects on the reproductive system and of the potential for causing birth defects), chronic toxicity/carcinogenicity (lifetime testing to assess late-in-life toxicity or increased evidence of cancer), and ecotoxicity (assessment of potential to affect living organisms in the environment). Toxicology summaries for R-32, R-123, R-124, R-125, R-134a, and R-141b as well as a combined summary for R-225ca and R-225cb indicate that all have low or very low toxicity. Test results show them not to be genotoxic and, except for the R-225 isomers, also not developmental toxicants. The findings show that R-225ca produced effects on the liver of rodents and a minor effect in a primate at 650-1,000 ppm. Exposures to R-225cb in the range of 1,000 to 5,000 ppm resulted in only marginal effects in rodents or a primate. Additionally, R-123 was found to have low acute dermal and inhalation toxicity, but caused an increased incidence of benign — but not life threatening — tumors in animals following long-term exposures. R-134a and R-141b also caused an increased incidence of benign — but not life threatening — tumors in animals following long-term exposure to high concentrations. A *Glossary of Terms* is provided.

Registry of Toxic Effects of Chemical Substances (RTECS®), computerized database, National Institute of Occupational Safety and Health (NIOSH), U.S. Department of Health and Human Services, Cincinnati, OH, updated quarterly since June 1971 (see synopsis below for availability, RDB4450)

The Registry of Toxic Effects of Chemical Substances, more widely known by the trademarked acronym RTECS®, is a database of toxicologic information originally identified as the "Toxic Substances List" (TSL). RTECS is compiled, maintained, and updated by NIOSH pursuant to the Occupational Safety and Health Act of 1970. The database is a compendium of data extracted from the open scientific literature on more than 120,000 substances. They include most chemicals previously and currently used as refrigerants. Six types of toxicity data are included, namely primary irritation, mutagenic effects, reproductive effects, tumorigenic effects, acute toxicity, and other multiple-dose

toxicity. Specific numeric toxicity values such as LC_{50}, LD_{50}, TC_{Lo}, are noted with the species studied, exposure duration, and route of administration. A coded bibliographic source is included for most data to enable access to the cited studies. The actual data have not been evaluated by NIOSH. RTECS also includes chemical identification data and special reviews, including exposure limits and carcinogenicity assessments. It also includes information on regulatory requirements, NIOSH-generated data, and notations on U.S. Government program data tracking and sources. The database records consist of coded data that can be expanded, by the accessing software, to readable form. Quarterly updates to the database can be leased from the National Technical Information Service (NTIS). RTECS is more commonly accessed through a number of on-line services, among them the National Library of Medicine (NLM) TOXNET System, the Canadian Centre for Occupational Health and Safety (CCOHS) CCINFOLine system, and the European Space Agency (ESA) Informational Retrieval Service (IRS), and commercial sources. They include the Chemical Information Service (CIS), DIALOG, Science and Technology Network (STN, available in North America through the Chemical Abstract Service, CAS), and others. It also is available on the CHEM-BANK™ compact disk from SilverPlatter Information Limited (Norwood, MA, USA, and London, UK) and TOMES-PLUS™ from Micromedex Incorporated (Denver, CO, USA).

Registry of Toxic Effects of Chemical Substances (RTECS®) — Comprehensive Guide to the RTECS®, publication 93-1330, edited by D. V. Sweet, National Institute of Occupational Safety and Health (NIOSH), U.S. Department of Health and Human Services, Cincinnati, OH, September 1993 (80 pages with 1 figure, 19 tables, and a microfiche with the bibliographic citations, available from GPO, RDB4449)

This guide provides a detailed description of the format of the RTECS® database and tabulates the codes used and their meanings. The code tables and text define the measures, abbreviations, and qualitative descriptors contained in RTECS. The guide also summarizes data sources and record formats. It also reviews sources to obtain or access RTECS.

Report of Safety Concerns, press release, The Trane Company, La Crosse, WI, 25 August 1997 (3 pages with no figures or tables, limited copies available from JMC as RDB7C71)

provides further information on the underlying incident and subsequent investigations in response to an article in *The Lancet* (see RDB-7C70) on exposures of workers to R-124/123 [actually R-290/124/123]: notes that all of the workers fully recovered; quotes R. Rubenstein, a toxicologist with the U.S. Environmental Protection Agency (EPA), that the alternative refrigerants involved can be used safely and suggestion that incorrect handling practices resulted in hazardous conditions is "outlandish"; quotes W. R. Brock, manager of fluorochemical toxicology for DuPont Chemicals, that the recommended exposure limits were exceeded for a long period of time and that any chemical can be "dangerous" if not handled properly; quotes J. M. Calm, and independent engineering consultant, that numerous violations of accepted safety practices were involved and that the conditions were not typical; documents further details from these individuals; concludes that all refrigerants can be used safely and that all pose risks without regard to appropriate practices, as appears to have been the case in the reported exposures

Safety, Toxicity, and Biological Importance of Organofluorine Compounds, *Organic Fluorine Chemistry*, edited by W. A. Sheppard and C. M. Sharts, W. A. Benjamin Incorporated, New York, NY, 447-461, 1969 (25 pages, RDB7255)

reference for toxicity and other safety data for fluorinated refrigerants and other chemicals

Standard Test Method for Estimating Sensory Irritancy of Airborne Chemicals, standard E981-84, American Society of Testing and Materials (ASTM), West Conshoshocken, PA, May 1994, reapproved in 1992 (10 pages with 9 figures, RDB-6567)

This standard prescribes a laboratory test method for rapid determination of the sensory irritant potential for a wide range of airborne chemicals, including refrigerants and refrigerant blends. The procedure quantifies the concentration of airborne irritant that produces a 50% decrease in the respiratory rate (RD_{50}) in mice, based on a dose-response curve constructed from tests conducted for a range of concentrations. The RD_{50} may be used to estimate the threshold limit value (TLV) for man, but does not address discomfort from odors. The standard outlines the significance and use of the method; details the required apparatus, rea-

gents, and test animals; and identifies associated hazards and limitations. It outlines and schematically illustrates the procedure, including required steps for sample preparation, calibration, pretest conditioning, and selection of test parameters. It then presents the actual test procedure and methods to interpret the results. It also identifies the minimum information to be recorded and concludes with a nonmandatory list of accepted apparatus and suppliers.

Submarine Atmosphere Habitability Data Book, report AVSHIPS 250-649-1 revision 1, U.S. Bureau of Ships and U.S. Department of the Navy, Washington, DC, 1962 (RDB72A4)

maximum allowable concentration (MAC) for R-717 (25 ppm v/v for 60 days continuous exposure and 400 ppm for 1 hour) and others as reported in RDB5340

Tabulae Biologicae Per., 3:231-296, 1933 (65 pages in German, RDB6283)

LCLo human of 5,000 ppm v/v for R-717 (ammonia); LC_{Lo} human of 90,000 ppm v/v for R-744 (carbon dioxide) — as reported in RDB-4450 and RDB5340

The AIHA 2000 Emergency Response Planning Guidelines and Workplace Environmental Exposure Level Guides Handbook, document 358-EA-00, American Industrial Hygiene Association (AIHA), Fairfax, VA, 2000 (RDBA948)

summarizes development and intended uses for Emergency Response Planning Guideline (ERPG) concentrations, to "assist emergency response personnel planning for catastrophic chemical releases to the community;" discuses other occupational and emergency exposure guides; summarizes the rationales for ERPG values based on "the maximum airborne concentration below which it is believed nearly all individuals could be exposed for 1 hour" without specified responses; identifies three levels, namely the ERPG-1 ("without experiencing more than mild transient adverse health effects or without perceiving a clearly defined objectionable odor"), ERPG-2 ("without experiencing or developing irreversible or other serious health effects or symptoms that could impair an individual's ability to take protective action"), and ERPG-3 ("without experiencing or developing life-threatening health effects"); tabulates ERPGs for R-10, R-20, R-30, R-40, R-40B1, R-40I1, R-140a, R-142b, R-630, R-631a, R-717 (ammonia), R-764 (sulfur dioxide), R-1110, R-1113, R-1114, R-1120, R-1216, and others; describes Workplace Environmental Exposure Level (WEEL) Guides as "the workplace exposure levels to which it is believed that nearly all employees could be exposed repeatedly without adverse health effects;" tabulates WEELs for R-32, R-123, R-124, R-125, R-134a, R-141b, R-142b, R-143a, R-152a, R-E170, R-236fa, R-1113, and others; provides related definitions to assist users of ERPG and WEEL values in applying them

Two-Week Inhalation Toxicity Study of FC-132b and FC-124 in Rats, TSCAT report OTS-0530590, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 8 October 1976 (RDB7266)

R-124, R-132b, health effects, toxicity

report 23-45, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1945 (RDB6511)

R-12, R-23, and others, acute inhalation toxicity: guinea pigs were exposed to 30,000 ppm R-23 for 6 hr and no signs toxicity or gross or microscopic pathological changes were noted as reported in RDB5604

R-10

E. M. Adams, H. C. Spencer, V. K. Rowe, D D. McCollister, and D. D. Irish, **Vapor Toxicity of Carbon Tetrachloride Determined by Experiments on Laboratory Animals**, *Archives of Industrial Hygiene and Occupational Medicine*, 6:50-66, 1952 (7 pages, RDB6509)

R-10, health effects, toxicity, LC_{50}

Emergency Response Planning Guidelines — Carbon Tetrachloride, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1995 (RDB-4B82)

R-10, tetrachloromethane, ERPG-1, ERPG-2, ERPG-3, toxicology data, toxicity, safety classification

R-11

J. Adir et al., *Journal of Clinical Pharmacology*, 15:116-128, 1975 (13 pages, RDB6552)

R-11, health effects, toxicity

J. Adir et al., *Toxicology and Applied Pharmacology* (TAP), 29(1):142-143, 1974 (2 pages, RDB6553)

R-11, health effects, toxicity

Y. M. Amin, E. B. Thompson, And W. L. Chiou, **Fluorocarbon Aerosol Propellants. XIII. Correlation of Blood Levels of Trichloromonofluoromethane to Cardiovascular and Respiratory Responses in Anesthetized Dogs**, *Journal of Pharmaceutical Sciences*, 68(2):160-163, 1979 (4 pages, RDB6554)

R-11, cardiac sensitization, health effects, toxicity

J. Angerer, B. Schroder, and R. Heinrich, **Exposure to Fluorotrichloromethane (R-11)**, *International Archives of Occupational and Environmental Health*, Germany, 56(1):67-72, 1985 (6 pages, RDB6493)

R-11, health effects, toxicity

D. M. Aviado (University of Pennsylvania School of Medicine), **Toxicity of Aerosol Propellants in the Respiratory and Circulatory Systems, IX. Summary of the Most Toxic: Trichlorofluoromethane (FC 11)**, *Toxicology*, 3:311-319, 1975 (9 pages, RDB5C69)

R-11, cardiac sensitization, circulatory abnormalities, health effects, toxicity

C. E. Barras, **Acute Inhalation Test** [of Trichloromonofluoromethane (Freon® 11)], report 648-74, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 29 October 1974 (2 pages with 1 table, RDB5C53)

tests of the acute inhalation toxicity of R-11 in groups of 6 albino ChR-CD rats at concentrations of 5,100, 7,700, 9,600, 24,900, 30,000, 31,700, and 35,300 ppm v/v in air determined by gas chromatography of samples as time-weighted averages; no fatalities at µ9,600 ppm; 3 of 6 animals died during exposures or recovery at 24,900 ppm; calculated 4-hr LC_{50} rat = 26,200 ppm; at concentrations µ9,600 ppm, mild hyperactivity for the first 2 hr of exposure and rapid respiration throughout exposure; occasional weight loss for 1 day following exposure; at concentrations of ·24,900 ppm, initial mild hyperactivity followed by tremors, inactivity, irregular respiration, and death in 1-4 hr; surviving animals showed mild to moderate initial weight loss for 1 day post exposure

D. A. Blake and G. W. Mergner, **Inhalation Studies on the Biotransformation and Elimination of [^{14}C]-Trichlorofluoromethane (FC-11) and [^{14}C]-Dichlorodifluoromethane (FC-12) in Beagles**, *Toxicology and Applied Pharmacology* (TAP), 30(3):396-407, 1974 (12 pages, RDB5C70)

toxicity tests of R-11 and R-12 biochemistry and metabolism in dogs: very little of the inhaled dose appeared to be metabolized as reported in RDB5C72

P. J. Cox, L. J. King, and D. V. Parke, **A Study of the Possible Metabolism of Trichlorofluoromethane**, *Biochemical Journal*, 130(1):13P-14P, 1972 (2 pages, RDB8134)

R-11, biochemistry, health effects, metabolism, pharmacokinetics, toxicity

C. W. Eddy, **Eye Irritation in Rabbits** [of Trichloromonofluoromethane (Freon® 11)], report 423-70, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1 October 1970 (RDB-5C54)

R-11, dermal contact toxicity, irritation as reported in RDB5141

M. Haj, Z. Burstein, E. Horn, and B. Stamler, **Perforation of the Stomach Due to Trichlorofluoromethane (Freon 11) Ingestion**, *Israeli Journal of Medical Science*, 16(5):392-394, 1980 (3 pages, RDB7422)

R-11, health effects, toxicity: nonfatal accident involving human exposure; healthy man mistook a bottle of R-11 in a refrigerator for water and drank it, resulting in freezing, tissue necrosis, and multiple perforations of the stomach — as reported in RDB7414

D. B. Hood, **Eye Irritation**, report 107-64, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 4 September 1964 (RDB5C55)

R-11, dermal contact toxicity, irritation as reported in RDB5141

L. J. Jenkins, Jr., R. A. Jones, R. A. Coon, and J. Siegel, **Repeated and Continuous Exposures of Laboratory Animals to Trichlorofluoromethane**, *Toxicology and Applied Pharmacology* (TAP), 16:133-142, 1970 (RDB5C60)

R-11, chronic inhalation toxicity as reported in RDB5141

A. Koops, **Mutagenicity Activity of Methane, Trichlorofluoro- in the Salmonella/Microsome**

Assay, report 568-77, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 5 August 1977 (RDB5C58)

R-11, mutagenicity, Ames Assay, toxicity as reported in RDB5141

D. M. Krentz, P. J. Lardear, and R. C. Graham, untitled toxicity review for Freon® 11 (methane, trichlorofluoro-), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 17 February 1992 (RDB5873)

R-11, summary of published and unpublished toxicity literature

S. D. Morrison, **Inhalation Toxicity of "Freon 11" and of "Freon 11" + 0.3% Nitromethane**, report 53-61, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 25 October 1961 (5 pages with 2 tables, RDB65H3)

acute inhalation toxicity tests of R-11 and of mixtures for possible aerosol propellant use of R-11 with nitromethane: 0 of 4, 1 of 4, and 4 of 4 animals died in exposures to 35,600, 65,680, and 118,370 ppm R-11 in air; found the 4-hr ALC rat to be 66,000 ppm v/v probably by interference with the central nervous control of respiration; also summarizes repeat exposure tests at 12,000 ppm in groups of 4 male ChR-CD rats; exposed animals exhibited increased rate and depth of respiration, slight twitching, marked licking, and chewing movements, but apparent recovery was complete within a few minutes following exposures; no body weight gain or changes in gross appearance were observed, though one animal killed after the last R-11 exposure had kidney and liver weights slightly below those of a control group

National Cancer Institute (NCI), **Bioassay of Trichlorofluoromethane for Possible Carcinogenicity**, report 78-1356 (also identified as NCI-CG-TR-106), National Institute of Health (NIH), U.S. Department of Health, Education, and Welfare, Bethesda, MD, 1978 (84 pages, RDB7427)

R-11, toxicity: bioassays in mice and rats found R-11 to not be carcinogenic when administered orally as reported in RDB7414

S. Niazi and W. L. Chiou, **Fluorocarbon Aerosol Propellants IV: Pharmacokinetics of Trichloromonofluoromethane Following Single and Multiple Dosing in Dogs**, *Journal of Pharmaceutical Sciences*, 64(5):763-769, 1975 (7 pages, RDB-8167)

R-11, biochemistry, elimination, health effects, toxicity

S. Nick, **Inhalation Toxicity of Freon® 11**, report 71-64, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 17 June 1964 (RDB5C56)

R-11, inhalation toxicity as reported in RDB5141

R. Panson, J. Galvin, J. Figard, and S. Cragg, **Nine Light Petroleum Hydrocarbons: Toxicology, Environmental Fate, Ecological Effects**, Phillips Petroleum Company, Bartlesville, OK, 1996 (RDB7621)

summary of toxicity, ecotoxicity, and environmental fate, and ecological effects of R-600a (isobutane), R-601 (n-pentane), R-601a (isopentane), R-601b (neopentane), cyclopentane, 2-methylpentane, 2,2-dimethylbutane, and 2,3-methylbutane based on a review of published and unpublished studies

J. W. Sarver and D. A. Snee, **Washout Time of Freon® 11**, report 349-70, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 11 August 1970 (RDB5C59)

R-11, inhalation toxicity as reported in RDB5141

H. Sherman, **90-Day Feeding in Rats and Dogs with Freon® 11**, report 63-72, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 18 February 1972 (RDB5C57)

R-11, ingestion toxicity by ingastric administration: no abnormality in results of tests of hematologic, hepatic, or renal values; a slight increase in urinary fluorides was statistically not significant — as reported in RDB5141 and RDB5C72

R. D. Stewart et al. (Medical College of Wisconsin), **Acute and Repetitive Human Exposure to Fluorotrichloromethane** [trichlorofluoromethane], report PB-279203/LLC, National Technical Information Service (NTIS), Springfield, VA, 1 December 1975 (available from NTIS, RDB6598)

reports an inhalation toxicity test of R-11 in male volunteers; notes that acute exposures to 250, 500, or 1000 ppm v/v for 1 min to 8 hr "did not

produce any untoward physiological effects"; also reports that groups of male volunteers repetitively exposed to 1,000 ppm v/v for 1-10 hr/d, 5 d/wk, for 2-4 wk showed minor decrements in several cognitive tests, but no change in pulmonary function or alteration of in cardiac rhythm — as reported in RDB6115

G. J. Taylor and R. T. Drew, *Toxicology and Applied Pharmacology* (TAP), 32:177 ff, 1975 (RDB-5C67)

R-11, cardiac sensitization, circulatory abnormalities, health effects, toxicity

G. J. Taylor, *Archives of Environmental Health*, 30:349 ff, 1975 (RDB5C68)

R-11, cardiac sensitization, circulatory abnormalities, health effects, toxicity

G. Thomas, **Narcotic Effects of Acute Exposures to Trichloromonofluoromethane (Freon 11),** *Transactions of the Association of Indian Medical Officers*, 15(3):105-106, 1965 (2 pages, RDB8178)

R-11, anesthesia, narcosis, health effects, toxicity

F. M. Williams, G. H. Draffan, C. T. Dollery, J. C. Clark, A. J. Palmer, and P. Vernon, **Use of ^{18}F-Labelled Fluorocarbon-11 to Investigate the Fate of Inhaled Fluorocarbons in Man and in the Rat**, *Thorax*, 29:99-103, 1974 (5 pages, RDB-7429)

R-11, health effects, toxicity: inhaled R-11 is eliminated from the body rapidly as reported in RDB7414

C. R. Wolf, L. J. King, and D. V. Parke, **The Anaerobic Dechlorination of Trichlorofluoromethane by Rat Liver Preparations in Vitro**, *Chemical-Biological Interactions*, 21(2-3):277-288, 1978 (12 pages, RDB8189)

R-11: biochemistry, health effects, metabolism, pharmacokinetics, toxicity

NCI Carcinogenesis Bioassay Experimental Design Status Report, Contract Number 723278, Agent Number CO4637, National Cancer Institute (NCI), Bethesda, MD, 53, 22 February 1978 (RDB-5C61)

R-11, tumor incidence, toxicity as reported in RDB5141

Toxicity Summary — Genetron® 11 (Trichloromonofluoromethane), Acute Toxicity and Cardiotoxicity, AlliedSignal Incorporated (then Allied Corporation), Morristown, NJ, March 1978 (RDB-5144)

R-11

Trichlorofluoromethane (CFC 11) Health Effects Information, CAS# 75-69-4, Elf Atochem North America, Incorporated, Philadelphia, PA, undated circa 1995 (3 pages, RDB5B47)

R-11, summary of toxicological and ecological information

R-12

T. Astrom et al., **Exposure to Fluorocarbons During the Filling and Repair of Air-Conditioning Systems in Cars — A Case Report**, *Scandinavian Journal of Work Environment and Health*, 13(6):527-528, 1987 (2 pages, RDB-7529)

R-12, health effects, toxicity: human occupational exposures involving R-12

A. Azar, C. F. Reinhardt, M. E. Maxfield, P. E. Smith, Jr., and L. S. Mullin (E. I. duPont de Nemours and Company, Incorporated), **Experimental Human Exposure to Fluorocardon** [sic, Fluorocarbon] **12 (Dichlorodifluoromethane)**, presented at the AIHA Conference (Toronto, Canada, May 1971); republished in *AIHA Journal*, 33(4):207-216, April 1972 (10 pages with 4 figures and 7 tables, RDB5358)

tests in humans of the acute toxicity of R-12 by inhalation to determine safe hygienic standards for single, brief exposures; two volunteers were exposed whole body to concentrations of 0 (control), 1,000 and 10,000 ppm v/v (mean actual 1000 and 1027, 9855 and 10173 ppm v/v) R-12 in air for 2½ hr; no adverse effects were found at 1,000 ppm by clinical observations, laboratory tests, subjective impressions, electrocardiogram monitoring, and tests of psychomotor skills; exposures to 10,000 ppm v/v evoked a 7% reduction in standardized psychomotor test scores; paper note that this finding is not indicative of a serious health threat; breath samples showed that R-12 is quickly eliminated from the lungs

A. Azar, J. A. Zapp, C. F. Reinhardt, and G. J. Stopps (E. I. duPont de Nemours and Company, Incorporated), **Cardiac Toxicity of Aerosol Propellants**, *Journal of the American Medical Association* (JAMA), 215(9):1501-1502, 1971 (2 pages, RDB8128)

cardiac sensitization of fluorochemicals used as aerosol propellants and also as refrigerants, toxicity

M. Bass, **Sudden Sniffing Death**, *Journal of the American Medical Association* (JAMA), 212(12):-2075-2079, 1970 (5 pages, RDB6722)

fatal human exposure involving R-12 from abusive use of aerosol products

C. Brenner, **Note on the Action of Dichlorodifluoromethane on the Nervous System of the Cat**, *Journal of Pharmacology and Experimental Therapeutics* (JPET), 59:176-181, 1937 (6 pages, RDB7532)

R-12, health effects, acute inhalation toxicity, and anesthetic effect; examines the convulsant effects of R-12 in cats and concludes that the tremors see were the result of release phenomena, indicating a type of depressant with low toxicity rather than a true convulsant — as reported in RDB5828

R. F. Carlton, **Fluorocarbon Toxicity: Aerosol Deaths and Anesthetic Reactions**, *Annals of Clinical and Laboratory Science*, 6:411-414, 1976 (4 pages, RDB6723)

fatal human exposure involving R-12, sudden sniffing death from abusive use of aerosol products

I. K. Chernen'kii and V. A. Shugaev, **Toxicity of Freon 12 with Consideration of Its Decomposition Products**, *Gigiena Truda i Professional'nye Zabolevaniya* [Labor Hygiene and Occupational Diseases], Russia (then USSR), (7):52 ff, 1974 (in Russian, RDB7528)

R-12, health effects, toxicity

J. Cheymol, **Un réfrigérant industriel récent: le dichlorodifluorométhane** [A New Industrial Refrigerant: Dichlorodifluoromethane], *Presse Med.*, 44:1123 ff, 1936 (in French, RDB7219)

R-12, toxicity, historical perspective

R. Culik and H. Sherman, **Teratogenic Study in Rats with Dichlorodifluoromethane (Freon 12)**, report 206-73, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1973 (RDB8135)

R-12, teratogenicity, toxicity — as reported in RDB5367

C. W. Eddy and F. D. Griffith (E. I. duPont de Nemours and Company, Incorporated), **Metabolism of Dichlorodifluoromethane C^{14} (Freon® 12 C^{14}) by Rats**, presented at the AIHA Conference (Toronto, Canada, May 1971), American Industrial Hygiene Association (AIHA), Fairfax, VA, 1971 (RDB65H9)

R-12, metabolism, toxicity: radio-labeled R-12 study; approximately 2% of oral dose metabolized to carbon dioxide and ½% excreted in urine; R-12 and its matabolites were eliminated within 30 minutes — as reported in RDB65H1

I. G. Jefferson, **Accidental Death of Child Playing with Deodorant Aerosol**, *Lancet*, UK, 1:779, 1978 (1 page, RDB6727)

fatal human exposure involving R-12 from abusive use of aerosol products, sudden sniffing death

Joint FAO/WHO Expert Committee on Food Additives, **WHO Food Additive Series**, Report 8, World Health Organization (WHO), Geneva, Switzerland, 1975 (RDB7533)

R-12 and others, health effects, oral toxicity: dietary level of R-12 that causes no toxicological effect in rats is estimated to be 0.3% as reported in RDB5141

R. A. Kehoe, **Report on Human Exposure to Dichlorodifluoromethane in Air**, The Kettering Laboratory, University of Cincinnati, OH, June 1943 (RDB5C45)

R-12, toxicity: acute exposures of humans, for 11-80 minutes to concentrations of 40,000-110,000 ppm as reported (with summary) in RDB5906 and RDB7414

S. M. Kilen and W. S. Harris, **Effect of Hypoxia and Freon 12 on the Mechanics of Cardiac Contractions**, *American Journal of Physiology*, 230(6):1701-1707, 1976 (7 pages, RDB8154)

cardiac effects of R-12 aerosol propellant (also used as a refrigerant), health effects, toxicity

S. M. Kilen and W. S. Harris, **Direct Depression of Myocardial Contractility by the Aerosol Gas Dichlorodifluoromethane**, *Journal of Pharmacology and Experimental Therapeutics* (JPET), 183(2):245-255, 1972 (11 pages, RDB8155)

cardiac effects of R-12 aerosol propellant (also used as a refrigerant), health effects, toxicity

M. A. Lee and R. C. Graham, untitled toxicity review for Freon® 12 (methane, dichlorodifluoro-), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company,

Incorporated, Newark, DE, 19 February 1992 (RDB7525)

R-12, summary of published and unpublished toxicity literature

Y. Lessard and G. Paulet, **A Proposed Mechanism for Cardiac Sensitization: Electrophysiological Study of Effects of Dichlorodifluoromethane and Adrenaline on Different Types of Cardiac Preparations Isolated from Sheep Hearts**, *Cardiovascular Research*, 20:807-815, 1986 (9 pages, RDB8156)

R-12, cardiac sensitization

Y. Lessard and G. Paulet, **Mechanism of Liposoluble Drugs and General Anesthetic's Membrane Action: Action of Dichlorodifluoromethane (FC 12) on Different Types of Cardiac Fibers Isolated from Sheep Hearts**, *Cardiovascular Research*, 19(8):465-473, 1985 (8 pages, RDB8157)

R-12, cardiac sensitization

Y. Lessard, S. Desbrousses, and G. Paulet, **Action du dichlorodifluorométhane (FC 12) sur l'activité électrique cardiaque du mammifère au niveau cellulaire** [Effect of R-12 on the cardiac electrical activity in the cellular system of mammals], *Compte Rendu des Séances de la Société Biol.* [Proceedings of the Meeting of the Biological Society], Paris, France, 174(1):52-57, 1980 (6 pages in French, RDB8160)

R-12, cardiac sensitization, toxicity as reported in RDB5367

Y. Lessard, S. Desbrousses, and G. Paulet, **Rôle de l'adrénaline endogène dans le déclenchment de l'arythmie cardiaque par le dichlorodifluorométhane (FC 12) chez les mammifères** [Role of Endogenous Adrenaline in Initiating Cardiac Arrhythmia by R-12 in Mammals], *Compte Rendu des Séances de la Société Biol.* [Proceedings of the Meeting of the Biological Society], Paris, France, 172(2):337-347, 1978 (11 pages in French, RDB7432)

R-12, cardiac sensitization with endogenous adrenaline, toxicity as reported in RDB7414

Y. Lessard, S. Desbrousses, and G. Paulet, **Arythmie cardiaque chez le chien sous l'action de l'adrénaline et du dichlorodifluorométhane (FC 12)** [Cardiac Arrhythmia in the Dog by the Action of Adrenaline and R-12], *Compte Rendu des Séances de la Société Biol.* [Proceedings of the Meeting of the Biological Society], Paris, France, 171(6):1270-1282, 1977 (13 pages in French, RDB8158)

R-12, cardiac sensitization with adrenaline, toxicity as reported in RDB5367

Y. Lessard, S. Desbrousses, and G. Paulet, **Arythmie cardiaque chez le lapin sous l'action de l'adrénaline et du dichlorodifluorométhane (FC 12)** [Cardiac Arrhythmia in the Rabbit by the Action of Adrenaline and R-12], *Compte Rendu des Séances de la Société Biol.* [Proceedings of the Meeting of the Biological Society], Paris, France, 171(4):883-895, 1977 (13 pages in French, RDB8159)

R-12, cardiac sensitization with adrenaline, toxicity as reported in RDB5367

T. Midgley, Jr., and A. L. Henne (Ohio State University), **Decomposition of Difluoro-Dichloromethane by Flames**, presentation at the 83rd Meeting (New Orleans, LA, 28 March - 1 April 1932), American Chemical Society (ACS), Columbus, OH; republished in *Industrial and Engineering Chemistry*, ACS, 24:641-645, June 1932 (5 pages with 11 figures and 6 tables, RDB2530)

R-12, toxicity resulting from decomposition in open flames; presents analytical and experimental data for the acid concentration generation as an indication of decomposition in a room, patterned after a kitchen; concludes that "even under the worst possible circumstances [of decomposition] life is not endangered"

S. Niazi and W. L. Chiou, **Fluorocarbon Aerosol Propellants XI: Pharmacokinetics of Dichlorodifluoromethane in Dog Following Single and Multiple Dosing**, *Journal of Pharmaceutical Sciences*, 66:49-53, 1977 (5 pages, RDB8166)

R-12, biochemistry, elimination, health effects, toxicity

G. M. Rusch, **Literature Review: An Interpretive Review of the Toxicity and Human Exposure Data on Dichlorodifluoromethane**, Department of Toxicology report MA-250-82-2, AlliedSignal Incorporated (then Allied Corporation), Morristown, NJ, 11 February 1983 (11 pages with no figures or tables, RDB6138)

review of published literature on the health effects and toxicity of R-12: 30-min LC_{50} is 760,000-800,000 ppm in guinea pigs, mice, rabbits, and rats; one study with anesthetized rats exposed at 360,000 or 390,000 (conflict in document) ppm resulted in apnea for exposures of 15.6 min and death for exposures of 30 min; this study is discussed with indication

that the death may have been due to the anesthetic; cardiac sensitization level with exogenous epinephrine is 70,000-80,000 ppm in dogs and 370,000 ppm in cats; arrhythmias were not seen in mice even at 400,000 ppm; reviews subchronic, chronic, reproductive, and biochemistry studies in animals as well as studies with humans; concludes that R-12 "has shown a low level of toxicity," "has a long, satisfactory history of use in consumer products and immersion freezing of food," and "its presence as a low-level contaminant in food-grade hydrochloric acid should not represent a health hazard"

R. R. Sayers, W. P. Yant, J. Chornyak, and H. W. Shoaf, **Toxicity of Dichlorodifluoromethane: A New Refrigerant**, Report of Investigations 3013, U.S. Bureau of Mines, Washington, DC, May 1930 (18 pages with 1 figure and 3 tables, available from JMC as RDB5356)

Dogs, monkeys, and guinea pigs were exposed to air containing 200,000 ppm R-12 by volume for 7-8 hr/d, 5 d/wk and 4 hr/d, 1 d/wk for a 12-week period. No fatalities occurred among the dogs and monkeys; two of 16 treated guinea pigs and one of 16 controls died, from which the report concludes that there was "no effect of exposure on fatality." The document identifies symptoms observed during exposure, which included generalized tremor in dogs and mild to moderate tremor in monkeys. The maximum severity was reached in the first 10-20 minutes, suggesting development of tolerance during and for subsequent exposures. The report documents the test methods and observed responses, including slight to moderate inhibition of weight and growth in the first 2-3 weeks, which were subsequently regained and maintained similar to control animals. Like patterns were identified in red blood cell increases. Autopsies showed no treatment-related gross pathology. No differences were observed in the pregnancies and offspring of the guinea pigs. The report concludes that "the possibility of public health and accident hazards resulting from exposure to [R-12] when used as a refrigerant are remote."

E. H. Schjötz, **Freezing Agent Dichlorodifluoromethane from Point of View of Industrial Hygiene**, *Nordisk Hygienisk Tidskrift*, 27:230 ff, 1946; republished in French as **L'agent frigorifique freon 12 (dichlorodifluorométhane) du point de vue de l'hygiene industrielle**, *Chimie Ind.*, 52:459 ff, 1947 (RDB7220)

R-12, health effects, toxicity

H. S. Sherman, **Long-Term Feeding Studies in Rats and Dogs with Dichlorodifluoromethane (Freon®-12 Food Freezant)**, report 24-74, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1974 (21 pages, RDB7433)

R-12, ingestion toxicity: as reported in RDB7414

H. S. Sherman, J. R. Barnes, and E. F. Stula (E. I. duPont de Nemours and Company, Incorporated), **The Oral Toxicology of Dichlorodifluoromethane**, *Toxicology and Applied Pharmacology* (TAP), Academic Press, Incorporated, UK, 29:152, 1974 (1 page, RDB6711)

R-12, chronic and reproductive toxicity: not teratogenic to rats, did not interfere with reproduction and lactation, did not effect survival or clinical laboratory parameters (hematology, urinalysis, and liver function; no evidence of toxicity in dogs after administered in feed at 10 mg/kg and 3,000 mg/kg for two years — as reported in RDB5143

H. S. Sherman and J. R. Barnes, **Feeding Studies with Dichlorodifluoromethane (Freon®-12 Food Freezant)**, report 12-66, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1966 (18 pages, RDB65H8)

R-12, ingestion toxicity: 90-day feeding study in rats and dogs; no clinical or histopathologic signs of toxicity; urinary fluoride and plasma alkaline phosphatase levels were higher than for controls but within normal ranges; blood and urine analytical results were comparable between treated animals and controls in dogs — as reported in RDB65H1 and RDB7414

V. A. Shugaev, **The Toxicology of Freon-12**, *Gigiena i Sanitariya*, Russia (then USSR), 28(6):95-97, 1963 (3 pages with no figures or tables, in Russian); translation included in *U.S.S.R. Literature on Air Pollution and Related Occupational Diseases, A Survey*, edited by B. S. Levine, 12:161-163, 1966 (3 pages, available from NTIS as document TT 66-61429, Rdb7434)

R-12, health effects, toxicity: 3-hr ALC rat = 620,000 ppm v/v as reported in RDB7414

R. D. Stewart, A. A. Herrmann, E. D. Baretta, H. V. Forster, J. H. Crespo, P. E. Newton, and R. J. Soto (Medical College of Wisconsin), **Acute and Repetitive Human Exposure to Difluorodichlo-**

romethane [dichlorodifluoromethane], report PB-279204/LLC, National Technical Information Service (NTIS), Springfield, VA, April 1976 (available from NTIS, RDB6486)

R-12, health effects, toxicity

Acute Oral Toxicity Of Freon® 12, Dichlorodifluoromethane, report on project MR-312-7, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1955 (RDB7527)

toxicity tests of R-12 in rats for determine ingestion toxicity: oral ALD rat >1,000 mg/kg (based on the maximum feasible dose dissolved in peanut oil) as reported in RDB7414 and RDB7525

Dichlorodifluoromethane (CFC 12) Health Effects Information, CAS# 75-71-8, Elf Atochem North America, Incorporated, Philadelphia, PA, undated circa 1995 (3 pages, RDB5B48)

R-12, summary of toxicological and ecological information

Report on Dichlorodifluoromethane, Miscellaneous Hazard Report Number 2256, Underwriters Laboratories Incorporated, Northbrook, IL (then Chicago, IL), 10 October 1931 (RDB6671)

R-12, flammability, toxicity, decomposition

R-12B1

P. S. Beck, D. G. Clark, and D. J. Tinston (Imperial Chemical Industries Limited, ICI, UK), **The Pharmacologic Actions of Bromochlorodifluoromethane (BCF)**, *Toxicology and Applied Pharmacology* (TAP), 24:20-29, 1973 (10 pages, RDB-5A26)

R-12B1, health effects, toxicity

J. A. Styles et al. (ICI Chemicals and Polymers, UK), **Activity of Bromochlorodifluoromethane (BCF) in Three Mutation Tests**, *Mutation Research*, The Netherlands, 142:187-192, 1985 (6 pages, RDB65G7)

R-12B1, mutagenicity, toxicity: mixed positive and negative results depending on test as reported in RDB65G1

R-13B1

L. S. Mullin, C. F. Reinhardt, and R. E. Hemingway (E. I. duPont de Nemours and Company, Incorporated), **Cardiac Arrhythmias and Blood Levels Associated with Inhalation of Halon 1301**, *AIHA Journal*, 40:653-658, 1979 (6 pages, RDB6B47)

R-13B1, cardiac sensitization, health effects, toxicity

G. Paulet, *Archives des Maladies Professionelles de Médecine du Travail et de Securité Sociale*, France, 23:341 ff, 1962 (in French, RDB6588)

R-13B1, toxicity

C. F. Reinhardt and R. Reinke (E. I. duPont de Nemours and Company, Incorporated), **Toxicity of Halogenated Fire Extinguishing Agents: Halon 1301 (Bromotrifluoromethane)**, *An Appraisal of Halogenated Fire Extinguishing Agents*, National Academy of Sciences (NAS), Washington, DC, 67-78, 1972 (12 pages, RDB5A69)

R-13B1, health effects, toxicity

E. W. Van Stee and K. C. Back (U.S. Air Force Aerospace Medical Research Laboratory, AMRL), **The Hypotensive Response in Dogs Exposed to Bromotrifluoromethane**, abstract 85 (11th Annual Meeting of the Society of Toxicology, SOT), *Toxicology and Applied Pharmacology* (TAP), 22:306-307, 1972 (2 pages, RDB6559)

R-13B1, cardiac sensitization, toxicity

E. W. Van Stee and K. C. Back (U.S. Air Force Aerospace Medical Research Laboratory, AMRL), **Brain and Heart Accumulation of Bromotrifluoromethane**, report AMRL-TR-70-139, Aerospace Medical Research Laboratory, U.S. Air Force, Wright-Patterson Air Force Base, OH, February 1971 (RDB7244)

R-13B1, health effects, toxicity

report 45-71, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1971 (RDB7261)

toxicity tests to determine the cardiac sensitization potential in male beagle dogs with intravenous injection of epinephrine five minutes before and, with a challenge injection, midway into a 10 minute exposure; LOEL at 75,200 ppm v/v R-13B1 in air as reported in RDB6527

R-13I1

D. E. Dodd (ManTech Environmental Technology, Incorporated), R. E. Kinkead, R. E. Wolfe, H. F. Leahy (ManTech), J. H. English (U.S. Army Medical Research Unit), and A. Vinegar (ManTech), **Acute and Subchronic Inhalation Studies on**

Trifluoroiodomethane Vapor in Fischer 344 Rats, *Fundamental and Applied Toxicology*, 35:64-77, 1997 (14 pages, RDB8417)

toxicity of R-13I1

D. E. Dodd (ManTech Environmental Technology, Incorporated), **Trifluoroiodomethane — Subchronic Toxicity and Genotoxicity in Mice and Bacteria**, *Food and Chemical Toxicology* (FCT), 35(5):30, May 1997 (1 page, RDBA625)

summarizes genotoxicity and mutagenicity studies of R-13I1; mice exposed to concentrations of 50,000 or 75,000 ppm v/v for 6 hr/d for 3 days showed slight, dose-related increases in chromosome damage (micronuclei) in the blood; mutagenicity was seen in bacteria in an Ames test; it was not evident in mouse cells in culture with or without metabolic activation when tested up to cytotoxic concentrations

D. E. Dodd (ManTech Environmental Technology, Incorporated), **Trifluoroiodomethane — Subchronic Toxicity and Genotoxicity in Rats**, *Food and Chemical Toxicology* (FCT), 35(5):30, May 1997 (1 page, RDBA626)

13-week, subchronic inhalation toxicity and genotoxicity studies of R-13I1 in rats did not establish a no observable adverse effect level (NOAEL); the lowest exposure concentration tested, 20,000 ppm v/v, resulted in increased follicular colloid content in the thyroid, altered thyroid hormone levels, and degeneration of the testes; this concentration also produced chromosome damage in bone marrow; exposures to 40,000 and 80,000 ppm v/v resulted in impaired growth and nasal inflammation

E. R. Kinkead et al. (ManTech Environmental Technology, Incorporated), **90-Day Nose Only Inhalation Toxicity Study of Trifluoroiodomethane (CF_3I) in Male and Female Fischer Rats**, report AL/OE-TR-1996-0024, Armstrong Laboratory, U.S. Air Force, Wright-Patterson Air Force Base, OH, March 1996 (RDB65G8)

R-13I1, subchronic inhalation toxicity: exposures at 20,000, 40,000, and 80,000 ppm for 2 hr/d, 5 d/wk, for 90 days: found alteration in thyroid hormone levels indicated as specific to rats; no precancerous cell changes were noted — as reported in RDB65G1

A. D. Mitchell, **Genetic Toxicity Evaluation of Iodotrifluoromethane (CF_3I), Results of In Vivo Mouse Bone Marrow Erythrocyte Micronucleus Testing**, Genesys Research Incorporated, Research Triangle Park, NC, 1995 (RDB65H0)

R-13I1, trifluoroiodomethane, mutagenicity, toxicity: no significant changes were seen in the male's premature red blood cells (PRBCs) at 25,000, 50,000, or 75,000 ppm; significant changes were observed in the results were seen in the female's PRBCs exposed to 25,000 ppm and above — as reported in RDB65G9

A. D. Mitchell, **In Vitro Forward Mutation Assay of Iodotrifluoromethane (CF_3I) Using the L5178Y/tk+/- Mouse Lymphoma Cell Mutagenesis Assay (MLA) With Colony Sizing, With and Without Metabolic Activation**, report on project 94036, Genesys Research Incorporated, Research Triangle Park, NC, July 1994 (RDB65G4)

R-13I1, trifluoroiodomethane, mutagenicity, toxicity: mixed positive and negative results for potential for changes in genetic material depending on test as reported in RDB65G1

A. D. Mitchell, **In Vivo Bone Marrow Erythrocyte Micronucleus Testing of Iodotrifluoromethane (CF_3I)**, report on project 94037, Genesys Research Incorporated, Research Triangle Park, NC, July 1994 (RDB65G5)

R-13I1, trifluoroiodomethane, mutagenicity, toxicity: mixed positive and negative results for potential for changes in genetic material depending on test as reported in RDB65G1

A. D. Mitchell, **Mutagenesis Testing of Iodotrifluoromethane (CF_3I) Using the Ames Salmonella Typhimurium Histidine Reversion Assay for Volatile Chemicals, With and Without Metabolic Activation**, report on project 94036, Genesys Research Incorporated, Research Triangle Park, NC, July 1994 (RDB65G6)

R-13I1, trifluoroiodomethane, mutagenicity, toxicity: mixed positive and negative results for potential for changes in genetic material depending on test as reported in RDB65G1

D. E. Dodd (ManTech Environmental Technology, Incorporated), H. F. Leahy (ManTech), M. L. Feldman, J. H. English (U.S. Army Medical Research Unit), and A. Vinegar (ManTech), **Reproductive Toxicity Screen of Trifluoroiodomethane (CF_3I) in Sprague-Dawley Rats**, *Inhalation Toxicology*, 11(11):1041-1055, 1999 (15 pages, RDBA564)

reproductive toxicity tests in groups of 16 female rats exposed by whole body exposures at target concentrations of 0 (control), 2,000, 7,000, and 20,000 ppm v/v R-13I1 in air for 5 d/wk before mating and then 7 d/wk for 8 wk during mating, gestation, and lactation; pups were not exposed; indicates that there were no

clinical signs of toxicity except a minimal decrease in mean body weight in female rats at 20,000 ppm v/v; indicates no statistically significant, treatment-related findings by observation or examination at necropsy in the dams or pups; concludes that the no observed adverse effect level (NOAEL) was 20,000 ppm v/v on the basis of reproductive indices and parameters

A. Vinegar (ManTech Environmental Technology, Incorporated), G. W. Jepson (ManTech), S. J. Hammann (McDonnell Douglas Corporation), G. Harper (McDonnell Douglas), D. S. Dierdorf (Universal Technical Services), and J. H. Overton (U.S. Environmental Protection Agency, EPA), **Simulated Blood Levels of CF_3I in Personnel Exposed During Its Release from an F-15 Jet Engine Nacelle and During Intentional Inhalation**, *AIHA Journal*, 60:403-408, May-June 1999 (6 pages with 5 figures, RDB9935)

summarizes tests of R-13I1 use as a fire suppressant for aircraft engine fires to assess potential hazards to ground crews during discharges; presents concentration measurements at locations near the discharge and physiologically-based pharmacokinetic (PBPK) modeling to simulate blood levels in exposed individuals; compares blood levels reached in three exposures to the lowest observed adverse affect level (LOAEL) for cardiac sensitization; simulations showed that the highest blood concentrations were twice the cardiac sensitization level, but that the simulated blood concentration for one individual peaked at 100 times the target level without adverse effect; suggests that actual human data may supersede findings of animal tests; discusses findings in context of anecdotal accounts of voluntary but unmonitored human exposures [note that no mention is made of experimental verification of adrenaline levels in exposed individuals, and tests did not include epinephrine challenges]

A. Vinegar, D. E. Dodd, G. W. Jepson, and E. R. Kinkead (ManTech Environmental Technology, Incorporated), **Acute Toxicity, Genotoxicity, and Cardiac Sensitization Potential of CF_3I (Trifluoroiodomethane)**, *The Toxicologist*, 15(1):190 ff, 1995 (RDB7C86)

toxicity of R-13I1

Acute Inhalation Toxicity Study of Iodotrifluoromethane in Rats, report on project 1530-001 study 2, ManTech Environmental Technology, Incorporated, March 1994 (RDB65G2)

R-13I1, trifluoroiodomethane, toxicity: 15-min LC_{50} rat 274,000 ppm; animals showed drowsiness, drooling, and heavy breathing at concentrations >100,000 ppm — as reported in RDB-6208 and RDB65G1

Comparing the Toxicology of Triodide™ and Halon 1211, HTL/KIN-Tech Division, Pacific Scientific, Duarte, CA, May 1996 (6 pages with 4 tables, RDB65G9)

R-12B1, R-13I1, toxicity: acute inhalation toxicity, cardiac sensitization, mutagenicity, decomposition product toxicity in fires with comparisons of R-13I1 to R-12B1, R-13B1, R-23, R-227ea, R-31-10, and R-51-14

Toxicology of DuPont FE1301 Fire Extinguishing Agent, bulletin S-35A, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, 1971 (RDB7563)

toxicity of R-13B1 and its decomposition products in fires; safety

Toxicology of Triodide™, HTL/KIN-Tech Division, Pacific Scientific, Duarte, CA, April 1996 (3 pages with no figures or tables, RDB65G1)

R-13I1, toxicity: 15-min LC_{50} rat 274,000 ppm; cardiac sensitization NOAEL at 2,000 ppm and LOAEL at 4,000 ppm; mixed positive and negative results for potential for changes in genetic material depending on test; alteration in thyroid hormone levels, but no pre-cancerous cell changes were noted in subchronic inhalations tests

unpublished data, Huntingdon Research Centre Limited (HRC), Cambridgeshire, UK, July 1994 (RDB65G3)

R-13I1, cardiac sensitization study, toxicity: NOAEL at 2,000 ppm; LOAEL at 4,000 ppm — as reported in RDB65G1

R-14

R-20

A. G. Levy, **The Exciting Causes of Ventricular Fibrillation in Animals Under Chloroform Anesthesia**, *Heart*, 4:319-378, 14 June 1913 (60 pages, RDB6560)

discusses the evidence for and mechanisms of cardiac sensitization resulting from inhalation of R-20 (chloroform); discusses inducement of ventricular fibrillation (very rapid and irregular contractions of the ventricles of the heart re-

sulting in loss of synchronization between the heartbeat and pulse beat)

A. G. Levy and T. Lewis, **Heart Irregularities, Resulting from the Inhalation of Low Percentages of Chloroform Vapor, and their Relationship to Ventricular Fibrillation**, *Heart*, 3:99-112, 1911-1912 (14 pages, RDB6561)

presents findings of cardiac sensitization resulting from inhalation of R-20 (chloroform); discusses inducement of ventricular fibrillation (very rapid and irregular contractions of the ventricles of the heart resulting in loss of synchronization between the heartbeat and pulse beat) [this paper is cited in toxicity literature as the initial, historic identification of cardiac sensitization by halocarbon inhalation]

R-20B3

Occupational Safety and Health Guideline for Bromoform; National Institute of Occupational Safety and Health (NIOSH), U.S. Department of Health and Human Services, Cincinnati, OH; Occupational Safety and Health Administration (OSHA), U.S. Department of Labor, Washington, DC, 1992 (6 pages with no figures or tables, available from GPO, also available from JMC as RDB-5C47)

R-20B3, toxicity; chemical and physical properties, reactivity, flammability, exposure limits, health hazard information, exposure sources and control methods, medical monitoring, workplace monitoring and measurement, personal hygiene, storage, spills and leaks, special requirements, respiratory protection, personal protective equipment, references

R-21

L. S. Mullin, **Cardiac Sensitization with Freon-21**, report 707-75, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1975 (2 pages, RDB7435)

toxicity tests to determine the cardiac sensitization potential of R-21 in beagle dogs with intravenous injection of epinephrine five minutes before and, with a challenge injection, midway into a 10 minute exposure; marked response in 2 of 12 dogs at 10,000 ppm v/v in air [deemed a LOEL] as reported RDB7414

C. H. Tappan and R. S. Waritz, **Acute Inhalation Toxicity of Freon®-21 (Fluorodichloromethane)**, report 128-64, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1964 (2 pages, RDB7436)

R-21, dichlorofluoromethane, health effects, toxicity: 4-hr ALC rat = 49,900 ppm v/v as reported in RDB7414

R-22

D. Anderson and C. R. Richardson, **Arcton 22: A Second Cytogenetic Study in the Rat**, report CTL/P/445, Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, UK, 3 May 1979 (RDB5924)

R-22, health effects, toxicity

D. Anderson, C. R. Richardson, C. Howard, R. A. Riley, and T. M. Weight, **Arcton 22: Cytogenetic Study in the Rat**, report CTL/R/429, Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, UK, 6 December 1977 (RDB5925)

R-22, health effects, toxicity

D. Anderson, E. C. M. Hodge, T. M. Weight, and R. A. Riley, **Arcton 22: Dominant Lethal Study in the Mouse**, report CTL/R/430, Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, UK, 6 December 1977 (RDB-5926)

R-22, health effects, toxicity

B. E. Butterworth, **In Vitro Microbiol Mutagenicity Studies of Methane, Chlorodifluoro**, report 398-76, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1976 (RDB-6478)

R-22, health effects, toxicity, mutagenicity, positive Ames assay as reported in RDB5923

I. F. Carney, **Arcton 22 (Chlorodifluoromethane). Relationship Between Blood Levels and Inhaled Concentrations in Anesthetized, Artificially-Ventilated Rats**, report CTL/R/422, Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, UK, 1977 (RDB6479)

R-22, health effects, toxicity, uptake and metabolism studies

B. Checket-Hanks, **R-22 Leak at Ice Rink Kills One, Injures 34**, *Air Conditioning, Heating, and*

Refrigeration News, 1-2, 27 May 1991 (2 pages with 1 figure, RDB5118)

accident from escape of 0.9-1.8 tonnes (2,000-4,000 lb) R-22 resulted in death to a 24 year old male by cardiac arrest; victim was the assistant manager for a skating rink located in the 150-store, Dimond Center Shopping Mall in Anchorage, Alaska; victim was wearing a respirator that was ineffective; two coworkers also were hospitalized, one in critical condition, for oxygen deprivation; a total of 34 people were taken to the hospital for treatment; they included a number of swimmers rescued from a pool in the mall, where the refrigerant cloud "hovered close to the pool water" and reportedly looked like steam; responding personnel found refrigerant escaping from a 9.5 mm (3/8") high pressure line; article includes an annotated floor plan of the accident site

R. Culik and C. D. Crowe, **Embryotoxic and Teratogenic Studies in Rats with Inhaled Chlorodifluoromethane (FC-22) — Third Study**, report 314-78, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1976 (RDB6580)

developmental and reproductive toxicity of R-22

R. Culik, D. P. Kelly, and B. A. Burgess, **Embryotoxic and Teratogenic Studies in Rats with Inhaled Chlorodifluoromethane (FC-22)**, report 970-76, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1976 (RDB-5B67)

developmental and reproductive toxicity of R-22

P. W. Grube and R. C. Graham, untitled toxicity review for chlorodifluoromethane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 26 March 1990 (28 pages, RDB5856)

R-22, summary of published and unpublished toxicity literature

E. C. M. Hodge, D. Anderson, I. P. Bennett, and T. M. Weight, **Arcton 22: Second Dominant Lethal Study in the Mouse**, report CTL/R/450 (revised), Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, UK, 9 November 1979 (RDB5927)

R-22, health effects, toxicity

B. C. Karpov, **The Chronic Toxicity of 'Freon' 22**, *Tr. Leningrad Sanit. Gigien. Med. Inst.*, 75:231-240, 1963 (10 pages in Russian, RDB6166)

R-22, health effects, toxicity

D. F. Krahn (possibly A. Koops), **Mutagenic Activity of Methane, Chlorodifluoro- in the Salmonella Microsome Assay**, report 577-77, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1977 (RDB6481)

R-22, health effects, toxicity, mutagenicity, positive Ames assay as reported in RDB5923

I. P. Lee and K. Suzuki, **Studies on the Male Reproductive Toxicity of Freon 22**, *Fundamental and Applied Toxicology*, 1(3):266-270, 1981 (5 pages, RDB6482)

outlines a reproductive study of R-22; toxicity

M. A. Lee, P. W. Grube, and R. C. Graham, untitled toxicity review for chlorodifluoromethane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 15 February 1996 (35 pages, RDB6940)

summarizes published and unpublished toxicity information on R-22

M. H. Litchfield and E. Longstaff (Imperial Chemical Industries (ICI) plc, UK), **The Toxicological Evaluation of Chlorofluorocarbon 22 (CFC 22)** [sic, HCFC-22], *Fundamentals of Chemical Toxicology*, 22(6):465-475, 1984 (11 pages with 1 figure and 7 tables, RDB5923)

R-22, detailed review of acute, subchronic, and chronic toxicity studies: inhalation, mortality, uptake and metabolism, mutagenicity (R-22 "can be assessed as a bacteria-specific mutagen on the evidence of the Ames test, but it did not exhibit any consistent mutagenic activity in other assay systems"), reproductive toxicity, carcinogenicity

E. Longstaff and D. B. McGregor (Imperial Chemical Industries (ICI) plc, UK), **Mutagenicity of the Halocarbon Refrigerant Monochlorodifluoromethane (R-22) in Salmonella Typhimurium**, *Toxicology Letters*, 2(1):1-4, 1978 (4 pages, RDB-6275)

R-22, health effects, toxicity, positive Ames assay as reported in RDB5923

R. L. McCarthy, **Ecology and Toxicity of Fluorocarbons**, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1973 (RDB8150)

fluorochemical refrigerants, safety, impacts

K. T. McCooey, **Methane, Chlorodifluoro-, Chinese Hamster Ovary Cell Assay for Mutagenicity**, report 149-80, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1980 (RDB6483)

R-12 and R-22, health effects, toxicity, mutagenicity in both the presence and absence of metabolic activation at 330,000, 670,000, and 1,000,000 ppm R-22, no mutagenic activity was found as reported in RDB5923

A. K. Palmer, D. D. Cozens, R. Clark, and G. C. Clark, **Effect of Arcton 22 on Pregnancy of the New Zealand White Rabbit**, report ICI 177/78505, Huntingdon Research Centre Limited (HRC), Cambridgeshire, UK, 1 August 1978 (RDB5928)

R-22, health effects, toxicity

A. K. Palmer, D. D. Cozens, R. Clark, and G. C. Clark, **Effect of Arcton 22 on Pregnant Rats: Relationship to Anophthalmia and Microphthalmia**, report ICI 174/78208, Huntingdon Research Centre Limited (HRC), Cambridgeshire, UK, 12 June 1978 (RDB5929)

R-22, health effects, toxicity

M. Sakata, H. Kazama, A. Miki, A. Yoshida, M. Haga, and M. Morita, **Acute Toxicity of Fluorocarbon-22: Toxic Symptoms, Lethal Concentration, and Its Fate in Rabbit and Mouse**, *Toxicology and Applied Pharmacology* (TAP), 59(1):64-70, 1981 (7 pages, RDB5739)

R-22, inhalation toxicity, uptake and metabolism studies in the rabbit: 30-min MLC (ALC) rabbit = 300,000 ppm, 30-min LC_{50} mouse = 280,000 ppm as reported in RDB5923

A. G. Salmon, S. K. Basu, M. Fitzpatrick, and J. A. Nash, **Arcton 22: Metabolism Study in Vivo in Rats and in Vitro**, report CTL/P/438, Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, UK, 1979 (RDB6484)

R-22, health effects, toxicity

M. Smidt, O. Axelson, and C. Edling, **Kohortstudie av Freonexponerade**, *Acta Soc. Med. Suec. Hung.*, 90:77 ff, 1981 (RDB6485)

R-22, health effects, toxicity, epidemiological study of workers exposed to chlorofluorochemicals including R-22 found no increase in mortality due to heart, circulatory, or tumor disorders as reported in RDB5923

D. J. Tinston, I. S. Chart, M. J. Godley, C. W. Gore, B. A. Gaskell, and M. H. Litchfield, **Chlorodifluoromethane (CFC 22): Long-Term Inhalation Study in the Mouse** [HCFC-22], report CTL/P/547, Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, UK, 1981 (RDB6487)

R-22, chronic health effects, toxicity as reported in RDB5923

D. J. Tinston, I. S. Chart, M. J. Godley, C. W. Gore, M. H. Litchfield, and M. Robinson, **Chlorodifluoromethane (CFC 22): Long-Term Inhalation Study in the Rat** [HCFC-22], report CTL/P/548, Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, UK, 1981 (RDB6488)

R-22, chronic health effects, toxicity as reported in RDB5923

D. J. Tinston, unpublished data, Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, UK, 1976 (RDB6127)

R-22, acute toxicity as reported in RDB5856 and RDB5923

E. W. Van Stee and E. E. McConnell, **Studies of the Effects of Chronic Inhalation Exposure of Rabbits to Chlorodifluoromethane**, *Environmental Health Perspectives* (EHP), 20:246-247, 1977 (2 pages, RDB6490)

R-22, health effects, toxicity

Assistant Manager at Ice Rink Asphyxiated by an Oxygen-Deficient Atmosphere, Alaska, May 20, 1991, Fatal Accident Circumstances and Epidemiology (FACE) Report, 1991 (available from NTIS as PB92-193697, RDB6A95)

This report summarizes an accident from an R-22 leak in which a 24 year old male was killed by asphyxiation. The victim was the assistant manager for a skating rink located in the 170-store, Dimond Center Shopping Mall in Anchorage, Alaska. The refrigeration system had a long history of leaks, one of which had been plugged in a "makeshift fashion." While performing a routine check, a maintenance worker noticed oil oozing from under the doors of the compressor room. He entered the machinery room with a maintenance supervisor and the victim to stop the leak. The victim was wearing a cartridge type respirator, which was inadequate in an oxygen deficient atmosphere. Also, the machinery room had self-closing doors. A coworker saw the maintenance worker and supervisor lying on the floor and called 911, the

emergency assistance number in most of the USA, for help. They were rescued by the responding paramedics. The victim was not seen immediately and was not removed from the room until later, by which time he had suffocated. Two swimmers in a pool, located in the mall, and rescue personnel also were affected by the R-22 vapor, which spread into adjacent areas. The accident investigation found that there was no safety policy or program in place and identified a number of safety deficiencies, including an absence of leak detectors.

Chlorodifluoromethane (CAS No. 75-45-6), Joint Assessment of Commodity Chemicals (JACC) report 9, European Chemical Industry Ecology and Toxicology Centre (ECETOC), Brussels, Belgium, 19 October 1989 (80 pages with 1 figure and 11 tables, RDB3718)

This assessment reviews the environmental impacts and toxicity of R-22, described as a nonflammable, colorless, and nearly odorless gas under normal conditions. It notes that a large amount is used as a chemical intermediate, and not emitted to the atmosphere, whereas that used for air conditioning and refrigeration will eventually be released under current practices. Most released R-22 is destroyed by reaction with OH- radicals in the troposphere or OH- and excited oxygen atoms in the stratosphere, but not to any major extent by photodecomposition. The calculated ozone depletion potential (ODP) for R-22 is 0.05, described as low compared to fully halogenated chlorofluorocarbons. The report indicates that R-22 has a negligible bioaccumulation potential, based on its moderate water solubility and low octanol-water partition coefficient. Contamination of food or water should not be expected, and has not been reported. R-22 is rapidly equilibrated in tissues after inhalation, and is eliminated from the blood in expired air, with a half life of only a few minutes. Blood concentrations are linearly correlated with inhalation concentrations over a wide range, but metabolism occurs in only minor amounts if at all. The report indicates that R-22 has an extremely low order of acute toxicity, and that concentrations exceeding 200,000 ppm v/v are required to produce a lethal effect. The report reviews cardiovascular studies and cites a cardiac sensitization NOEL (0/12) to adrenaline for male beagles of 24,700 ppm and a LOEL (2/12) of 50,000 ppm with. R-22 showed no adverse effects on fertility in animal studies and was not teratogenic in rabbits at doses up to 50,000 ppm. A low incidence of anophthalmia (congenital absence of eyes) and microphthalmia (abnormally small eyes) combined (10 fetuses in 383 litters) was found when groups of 400 pregnant rats were exposed to 50,000 ppm. Although statistically significant, these findings and those of subsequent studies were deemed to not threaten the health of human beings occupationally exposed at or below recommended exposure limits. Most in vitro tests of R-22 are negative and a positive response in the Ames test is consistent with occurrence of bacteria-specific metabolic pathways. Only minimal or no effects were observed chronic exposures of rats and mice for 4-131 weeks. A slight decrease in body weight gain and a small increase in liver and kidney weight occurred with an exposure level of 50,000 ppm. The only exception was a limited study in rats, mice and rabbits which reported changes in the blood, liver, lung and nervous system in animals exposed to 14,000 ppm over a ten month period; these findings were not confirmed in subsequent studies. R-22 did not produce neoplastic changes in female rats and male and female mice exposed to concentrations as high as 50,000 ppm. In one study in male rats, a concentration of 50,000 ppm was associated with an increase in the number of fibrosarcomas and Zymbal gland tumors; they occurred late in the study and were not considered relevant to humans. Lower concentrations (10,000 ppm and below) did not increase tumor rates in any study. The assessment concludes that R-22 does not constitutes a carcinogenic hazard to man. The toxicological activities described are unlikely to be due to the formation of reactive intermediates. Although not a skin sensitizer, liquid R-22 in contact with skin causes local freezing. Reports on adverse health effects from R-22 are rare and are consistent with findings in experimental animals. Permissible occupational exposure limits vary between 500-1000 ppm (8 hr TWA) by country; the assessment judged these limits to provide adequate health protection.

Chlorodifluoromethane (Group 3), *IARC Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Humans*, International Agency for Research on Cancer (IARC), (supplement 7):149-150, 1987 (2 pages, RDB8420)

concludes that the evidence for carcinogenicity of R-22 to humans is inadequate based on a study of 539 refrigeration workers exposed to various refrigerants, including R-22, for at least

six months with follow up for up to 30 years: six deaths occurred from cancer and two of them from lung cancer, compared to statistical expectation of 5.7 and 2, respectively; summarizes tests for carcinogenicity in rats by oral administration and in mice and rats by inhalation of R-22; one rat study yielded no increase in tumor incidence while a mouse study gave inconclusive results for males and negative results for females; a third study in rats was deemed inadequate; a fourth found that males exposed to the highest concentration had a marginal increase in the incidence of subcutaneous fibrosarcomas and Zymbal-gland tumors, but obtained negative results for females; data examined on the genetic and related effects of R-22 found insufficient indications in humans; R-22 did not induce dominant lethal mutations in rats, chromosomal aberrations in bone-marrow cells of mice treated in vivo, unscheduled DNA synthesis in human cells in vitro, mutation in cultured Chinese hamster V79 cells, or mutation or mitotic gene conversion in yeast, either after direct exposure or in a host-mediated assay; R-22 was found to be mutagenic to plants and bacteria

Chlorodifluoromethane, *IARC Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Humans*, International Agency for Research on Cancer (IARC), 41:237-252, 1986 (15 pages, RDB8421)

identifies potential routes of exposure to R-22 from use in refrigeration and air conditioning as releases into the atmosphere, resulting in widespread, low-level human exposures, and from occupational exposure during its production and use; summarizes R-22 tests for carcinogenicity; no increase in tumor incidence was observed in rats after oral administration by gavage; results were inconclusive for males and negative for females for mice exposed in an inhalation study; male rats receiving the highest dose in an inhalation study showed increase incidence of fibrosarcomas and Zymbal-gland tumors; negative results were obtained for female rats; R-22 causes malformations of the eyes of fetal rats, but has no reproductive effect in male rats and does not cause prenatal toxicity in rabbits following exposure by inhalation; R-22 was found to be mutagenic to salmonella typhimurium in the presence and absence metabolic activation; it does not induce mutation or gene conversion in yeast, DNA damage or mutation in cultured mammalian cells, or chromosomal damage in bone marrow; R-22 does not induce dominant lethal mutations in mice or rats treated in vivo; no data were available to evaluate the reproductive effects or prenatal toxicity of R-22 to humans; a study of workers exposed to R-22 and other fluorochemicals was deemed to be uninformative with regard to the carcinogenic hazard of this chemical; report concludes that there is limited evidence of the carcinogenicity of R-22 to experimental animals, but inadequate evidence of carcinogenicity to humans

Health Hazard Report for Chlorodifluoromethane CAS 75-45-6: Refrigeration Workers, Salt Lake City, Utah, Hazard Evaluation Technical Assistance report HETA-81-043-1207, National Institute for Occupational Safety and Health (NIOSH), U.S. Department of Health and Human Services, Cincinnati, OH, 1982 (13 pages, available from NTIS as document PB-84-172998, RDB7236)

R-22, safety, toxicity

Occupational Safety and Health Guideline for Chlorodifluoromethane, U.S. Department of Health and Human Services and U.S. Department of Labor, Washington, DC, 1995 (7 pages, available from JMC as RDB6286)

R-22, Occupational Health Guideline (OHG), Occupational Safety and Health Guideline (OSHG), physical data, reactivity, flammability, exposure limits, health hazard information, toxicity, emergency procedures, medical monitoring, workplace monitoring and measurement, personal hygiene, storage, spills and leaks, emergency planning and community right-to-know requirements, hazardous waste management requirements, respiratory protection, personal protective equipment, references

R-23

R. Atkinson, *Chem. Review*, 85:69-201, 1985 (133 pages, RDB5B61)

R-23, toxicity

R. Atkinson and W. P. L. Carter, *Chem. Review*, 84:437-470, 1984 (34 pages, RDB5825)

R-23, toxicity

C. A. Branch, D. A. Goldberg, J. R. Ewing, S. C. Fagan, S. S. Butt, and J. Gayner (Henry Ford Hospital), **Evaluation of the Acute Cardiac and Central Nervous System Effects of the Fluorocarbon Trifluoromethane in Baboons**, *Journal of*

Toxicology and Environmental Health, 43(1):25-35, September 1994 (11 pages, RDB5158)

This study reports tests of R-23 for acute cardiotoxic, anesthetic, and central nervous system effects in primates (papio anubis). A dose-response effect was established for respiratory rate, electroencephalogram, and cardiac sinus rate, which exhibited a stepwise decrease from 10% R-23. No spontaneous arrhythmias were noted, and arterial blood pressure remained unchanged at any inspired level. Intravenous epinephrine infusions (1 µg/kg) induced transient cardiac arrhythmia in one animal with 70% R-23 by volume. R-23 appears to induce mild dose-related physiological changes at inspired levels of 30% or more, indicative of an anesthetic effect. These data suggest that R-23 may be safe to use in humans, without significant adverse acute effects, at an inspired level of 30%.

C. A. Branch, J. R. Ewing, S. C. Fagan, D. A. Goldberg, and K. M. A. Welch (Henry Ford Hospital), **Acute Toxicity of a Nuclear Magnetic Resonance Cerebral Blood Flow Indicator in Cats**, *Stroke*, 21(8):1172-1177, 1990 (6 pages, RDB5818)

R-23, acute inhalation toxicity: tests of blood flow, cardiac sensitization with epinephrine, and cerebral electrical activity tests in cats at 600,000 and 700,000 ppm R-23 as reported in RDB5604

J. C. Edwards, **Arcton 23 — Documentation for Hygiene Standard**, ICI Chemicals and Polymers Limited, Cheshire, UK, 17 June 1985 (1 page, RDB5A75)

R-23, toxicity, rationale for recommended hygiene standard (occupational exposure limit, OEL) of 1,000 ppm, 8-hr TWA

J. R. Ewing, C. A. Branch, S. C. Fagan, J. A. Helpern, R. T. Simkins, S. M. Butt, and K. M. A. Welch (Henry Ford Hospital), **Fluorocarbon-23 Measure of Cat Cerebral Blood Flow by Nuclear Magnetic Resonance**, *Stroke*, 21:100-106, 1990 (7 pages, RDB5736)

R-23, toxicity

S. C. Fagan, A. A. Rahill, G. Balakrishnan, J. R. Ewing, C. A. Branch, and G. G. Brown (Henry Ford Hospital), **Neurobehavioral and Physiological Effects of Trifluoromethane in Humans**, *Journal of Toxicology and Environmental Health*, 44:101-109, 1995 (9 pages with 1 table, RDB-5737)

R-23, toxicity: investigation of R-23 as a nuclear magnetic resonance indicator in human subjects, discontinued based on slight anesthetic effects, light headedness, tingling and numbness of the extremities, and hyperacusis (increased hearing) at 300,000 ppm; heart rate and rhythm as well as blood pressure not affected at concentrations studied

D. M. Krentz, M. A. Lee, and R. C. Graham, untitled toxicity review for trifluoromethane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 3 August 1992 (RDB5604)

R-23, summary of published and unpublished toxicity literature

S. M. Munley, **An Inhalation Developmental Toxicity Study in Rats**, report 995-96, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 27 February 1997 (142 pages with 1 figure and 8 tables, Rdb7631)

tests of maternal and developmental toxicity of R-23 by inhalation in groups of 25 mated Crl:CD(SD)BR rats on days 7-21 of gestation at whole-body exposure levels of 0 (control), 5,000, 20,000, or 50,000 (0, 5,600 ±45, 21,000 ±48, or 51,000 ±72 actual) ppm v/v in air for 6 hr/d: no evidence of maternal or developmental toxicity was found at any exposure concentration tested; no compound-related effects were observed for clinical signs, food consumption, maternal body weights, weight changes, or postmortem findings; concludes that R-23 "was not uniquely toxic to the rat conceptus" and that "the maternal and developmental no-observed-effect level (NOEL) was 50,000 ppm"

S. D. Nash, **Inhalation Approximate Lethal Concentration (ALC) of Trifluoromethane**, report 641-80, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 30 September 1980 (2 pages with 1 table, RDB6513)

4 hr acute inhalation toxicity tests of R-23 in groups of six male Charles River CD albino rats by whole body exposures: mortality ratios and corresponding concentrations were 0/6 at 18,900, 0/6 at 186,000, and 0/6 at 663,000 ppm v/v in air with oxygen enrichment (to maintain 19.7-21% levels); rats showed slight weight loss 24-48 hr after exposure at 18,900 ppm followed by normal weight gain in a 14-day recovery period; an unspecified number of rats showed reduced response to sound at 186,000

ppm; an unspecified number of rats showed no response to sound, gasping, labored breathing, sluggishness, and — for 1 of 6 rats — compulsive gnawing on basket at 663,000 ppm; an unspecified number exhibited slight weight loss 24 hr after exposure at 663,000 ppm, but normal weight gain thereafter; report concludes that the 4-hr ALC rat for R-23 exceeds 663,000 ppm v/v

O. Schaumann, *Archiv für Experimentelle Pathologie und Pharmakologie*, 181:144-145, 1936 (2 pages, RDB5606)

R-23, inhalation toxicity: exposure (species not indicated) at 900,000 ppm resulted in moderate, but not complete narcosis

Hazardous Substance Fact Sheet — Trifluoromethane, New Jersey Department of Health, Trenton, NJ, August 1988 (RDB5138)

R-23, toxicity

Toxicology Summary for FC 23 (Trifluoromethane), ICI Chemicals and Polymers Limited, Runcorn, UK, 21 September 1994 (1 page, RDB5168)

R-23, toxicity: references a 2-hr ALC rat >200,000 ppm, cardiac sensitization EC_{50} >500,000 ppm, and Ames test (not mutagenic); cites an ICI recommended exposure limit of 1,000 ppm, 8 hr TWA

Trifluoromethane (HFC 23) Health Effects Information, CAS# 75-46-7, Elf Atochem North America, Incorporated, Philadelphia, PA, undated circa 1995 (3 pages, RDB5B49)

R-23, summary of toxicological and ecological information

report 25-60, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1945 (RDB6512)

R-23, acute inhalation toxicity: 12 guinea pigs were exposed to 200,000 ppm R-23 for 2 hr; no animals died and neither clinical signs of toxicity nor pathological changes were noted — as reported in RDB5604

R-30

M. E. Andersen, H. J. Clewell III, M. L. Gargas, F. A. Smith, and R. H. Reitz, **Physiologically Based Pharmacokinetics and the Risk Assessment Process for Methylene Chloride**, *Toxicology and Applied Pharmacology* (TAP), 87:185-205, 1987 (21 pages, RDB65E5)

toxicity of R-30; pharmacokinetics; uptake, metabolism and elimination; health effects

G. D. Di Vincenzo and C. J. Kaplan, **Uptake, Metabolism and Elimination of Methylene Chloride Vapor by Humans**, *Toxicology and Applied Pharmacology* (TAP), 59:130-140, 1989 (11 pages, RDBA529)

toxicity of R-30; pharmacokinetics; uptake, metabolism and elimination; health effects

E. C. Riley, D. W. Fassett, and W. L. Sutton, **Methylene Chloride Vapor in Expired Air of Human Subjects**, *AIHA Journal*, 27:341 ff, 1966 (RDBA630)

toxicity of R-30

Methylene Chloride (Dichloromethane): An Overview of Experimental Work Investigating Species, Differences in Carcinogenicity, and their Relevance to Man, technical report 34, European Chemical Industry Ecotoxicology and Toxicology Centre (ECETOC), Brussels, Belgium, March 1989 (RDBA530)

toxicity of R-30; acute, subchronic, and chronic studies; carcinogenicity; mutagenicity; health effects

Methylene Chloride (Dichloromethane): Human Risk Assessment Using Experimental Animal Data, technical report 32, European Chemical Industry Ecotoxicology and Toxicology Centre (ECETOC), Brussels, Belgium, May 1988 (RDBA531)

toxicity of R-30; acute, subchronic, and chronic studies; carcinogenicity; mutagenicity; health effects

The Assessment of Carcinogenic Hazard for Human Beings Exposed to Methylene Chloride, technical report 26, European Chemical Industry Ecotoxicology and Toxicology Centre (ECETOC), Brussels, Belgium, January 1987 (RDBA532)

toxicity of R-30; carcinogenicity; mutagenicity; health effects

R-30B1

T. R. Torkelson, F. Oyen, and V. K. Rowe, **The Toxicity of Bromochloromethane as Determined on Laboratory Animals**, *AIHA Journal*, 21:275-286, 1960 (12 pages, RDB6510)

toxicity of R-30B1, health effects, LC_{50}

R-31

W. B. Coate, R. W. Zapp, J. Anderson, and J. Charm, **Inhalation Toxicity of Monochloromonofluoromethane** *Toxicology and Applied Pharmacology* (TAP), 48(A109):79 ff, 1979 (RDB-5563)

R-31, toxicity

R. C. Graham and C. D. VerNooy, untitled review of toxicity literature for methane, chlorofluoro- (R-31), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 6 April 1992 (10 pages with no figures or tables, RDB6778)

summary of published and unpublished information on the toxicity of R-31

R-32

M. Asakura (Japan Bioassay Laboratory, JBL, Japan), **Report on a Chromosomal Aberration Test of Difluoromethane on Cultured Mammalian Cells (CHL)**, report 5918 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Japan Industrial Safety and Health Association, Kanagawa, Japan, 1993 (RDB5750)

R-32, toxicity

R. L. Bornschein, L. Hastings, and J. M. Manson, **Behavioral Toxicity in the Offspring of Rats Following Maternal Exposure to Dichloromethane**, *Toxicology and Applied Pharmacology* (TAP), 52:29-37, 1980 (9 pages, RDBA527)

toxicity of R-32; teratogenicity

R. D. Callander, **HFC 32: An Evaluation of Mutagenic Potential Using S. Typhimurium and E. Coli**, report CTL/P/3351 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Zeneca Central Toxicology Laboratory (then part of ICI Chemicals and Polymers Limited), Cheshire, UK, 10 June 1992 (RDB5745)

R-32, toxicity: negative result for mutagenicity as reported in RDB6686

M. K. Ellis, R. Trebicock, J. L. Naylor, K. Tseung, et al. (Zeneca Central Toxicology Laboratory, UK), **The Inhalation Toxicology, Genetic Toxicology and Metabolism of Difluoromethane in the Rat**, *Fundamental and Applied Toxicology*, 31(2):243-251, 1996 (9 pages, RDB6A98)

R-32: toxicity, developmental toxicity, and genotoxicity; metabolism and disposition; physiologically-based pharmacokinetic (PB-PK) model; approximately 2.1% of inhaled R-32 is absorbed; steady-state blood levels are achieved within 2 hr and are proportional to dose; carbon dioxide is the major metabolite at all exposure levels; carbon monoxide was not detected; approximately 63% (1.4% of the R-32 entering the airways) was metabolized at all doses; inhalation of R-32 (up to 50,000 ppm) caused no organ-specific effects, but resulted in slight maternal toxicity in pregnant rats and rabbits and some fetotoxicity in rats; 50,000 ppm did not sensitize the heart to adrenaline; the overall results indicate that R-32 is of very low toxicity

M. K. Ellis, R. Trebicock, and T. Green, **Hydrofluorocarbon 32: Pharmacokinetics and Metabolism in the Rat**, report CTL/R/1220 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Zeneca Central Toxicology Laboratory (then part of ICI Chemicals and Polymers Limited), Cheshire, UK, 1994 (RDB5979)

R-32, toxicity

M. K. Ellis, J. L. Naylor, and T. Green, **Hydrofluorocarbon 32: Pharmacokinetics and Metabolism in Male Rats and Mice Following a Single Exposure by Inhalation**, report CTL/R/1137 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Zeneca Central Toxicology Laboratory (then part of ICI Chemicals and Polymers Limited), Cheshire, UK, 23 December 1992 (RDB5749)

R-32, toxicity

J. Ferguson-Smith, **HFC 32 Hygiene Standard Documentation**, ICI Chemicals and Polymers Limited, Cheshire, UK, 3 June 1996 (6 pages, RDB6686)

R-32, toxicity, literature review, rationale for recommended hygiene standard (occupational exposure limit, OEL) of 1,000 ppm, 8-hr TWA; cites a 10-min CNS EC_{50} rat of 370,000 ppm v/v, but this information could not be verified from the references provided

C. J. Hardy and P. C. Kieran, **Hydrofluorocarbon 32: Assessment of Cardiac Sensitization Potential in Beagle Dogs**, report ISN 276/920493 (also identified as ICI report CTL/C/2723) for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Huntingdon Research Centre Limited (HRC), Cambridgeshire, UK, 18 September 1992 (RDB5748)

R-32, health effects, toxicity: exposures as high as 350,000 ppm v/v did not produce a cardiac sensitization response in beagle dogs with

an intravenous epinephrine challenge as reported in RDB5C14 and RDB6686

K. Kawahara, **Test on 1-Octanol/Water Partition Coefficient of HFC-32**, report 80678, Kurume Research Laboratories (KRL), Fukuoka, Japan, 1992 (RDB5C29)

ecotoxicity of R-32; environmental impacts and fate; groundwater and soil

D. M. Krentz, M. A. Lee, and R. C. Graham, untitled toxicity review for difluoromethane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 15 July 1992 (RDB5862)

R-32, summary of published and unpublished toxicity literature

J. M. Mackay and C. A. Howard, **HFC 32: An Evaluation in the In Vitro Cytogenetic Assay in Human Lymphocytes**, report CTL/P/3465 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Zeneca Central Toxicology Laboratory (then part of ICI Chemicals and Polymers Limited), Cheshire, UK, 5 June 1992 (RDB5744)

R-32, toxicity, mutagenicity: no evidence of genotoxicity at 50,000-1,000,000 ppm as reported in RDB6686

B. L. Moore, **Acute Inhalation Toxicity (FC-32)**, report 698-75, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 18 November 1975 (2 pages with 1 table, RDB6171)

reports an acute inhalation toxicity study of R-32 in groups of six rats; indicates that no mortality resulted from 4-hr exposures to 111,000, 235,000, 270,000, 315,000, 432,000, 455,000, 482,000, or 760,000 ppm v/v; exposures at 315,000 ppm v/v and higher were oxygen enriched to maintain ~20% levels; notes that rats exhibited lethargy and loss of mobility in hind legs at all exposure concentrations; also notes that they also exhibited spasms and gnawing at the bottom of the cage at 315,000 ppm v/v and higher; notes quick recoveries, with no abnormal post-exposure signs, and no gross pathological changes in autopsies 14 days after exposures; concludes that the 4-hr ALC exceeds 760,000 ppm v/v

M. E. Moxon, **HFC-32: Developmental Toxicity Study in the Rat**, report CTL/P/3835 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Zeneca Central Toxicology Laboratory (then part of ICI Chemicals and Polymers Limited), Cheshire, UK, 20 May 1992 (RDB5747)

R-32, toxicity: not teratogenic to the rat at 5,000-50,000 ppm for 6 hr/d; maternal food consumption was slightly decreased at 50,000 ppm; minimal fetal toxicity at 50,000 ppm — as reported in RDB6686

M. E. Moxon, **HFC-32: Modified Chernoff-Kavlock Assay in the Rat**, report CTL/P/3695 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), ICI Central Toxicology Laboratory, ICI Chemicals and Polymers Limited, Cheshire, UK, 29 June 1992 (45 pages with 3 figures and 14 tables, RDB5C31)

modified Chernoff-Kavlock assay by whole-body exposure of groups of 10 female, Wistar derived rats to concentrations of 0 (control), 10,000, or 50,000 (0, 9,930, and 49,600 actual) ppm v/v R-32 in air for 6 hr/d on days 7-16 of gestation: exposures produced no clinical effects or changes in bodyweight gain and did not reduce litter size at birth or pup survival; a slight reduction in pup weight gain was observed at 50,000 ppm; report concludes that R-32 is neither potentially teratogenic or fetotoxic at the concentrations tested

L. S. Mullin and H. J. Trochimowicz, **Cardiac Sensitization Potential of Difluoromethane**, report 257-73, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 8 June 1973 (3 pages with 1 table, RDB6170)

toxicity tests to determine the cardiac sensitization potential of R-32 in male beagle dogs with intravenous injection of epinephrine five minutes before and, with a challenge injection, midway into a 10 minute exposure: marked response in 1 of 12 dogs at 250,000 ppm v/v in air [deemed a LOEL]; no sensitization was found in the dog that reacted at 250,000 ppm when tested several days later at 200,000 ppm; two dogs tested at 400,000 ppm showed no response; concludes that R-32 is "a very weak cardiac sensitizer"

D. P. Myres (Huntingdon Research Centre Limited HRC, UK), **HFC-32: A Study of the Effect on Pregnancy of the Rabbit**, report ALS 19/942190 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), AlliedSignal Incorporated, Morristown, NJ, 12 August 1994 (RDB5743)

R-32, toxicity: not teratogenic to the rabbit at concentrations of 5,000-50,000 ppm for 6 hr/d; animals exposed to 50,000 ppm had slight loss

of body weight during days 8-10 of pregnancy; no evidence of fetal or embryo toxicity — as reported in RDB6686

R. J. Parr-Dobrzanski, **HFC 32: 90-Day Inhalation Toxicity Study in the Rat**, report CTL/P/4064, Zeneca Central Toxicology Laboratory (then part of ICI Chemicals and Polymers Limited), Cheshire, UK, 4 October 1993 (RDB-5742)

R-32, toxicity

R. J. Parr-Dobrzanski, **HFC-32: 28-Day Subacute Inhalation Toxicity Study in the Rat**, report CTL/P/3746, ICI Central Toxicology Laboratory, ICI Chemicals and Polymers Limited, Cheshire, UK, 24 August 1992 (290 pages, RDB5741)

toxicity tests of groups of 5 female and 5 male Wistar-derived rats by whole body exposures for 6 hr/d, 5 d/wk, for 4 wk to concentrations of 0 (control), 2,000, 10,000, or 50,000 (0, 2,010, 9,870, or 49,500 actual) ppm v/v R-32 in air: no deaths or treatment-related effects on clinical condition, bodyweights, food consumption, organ weights, liver biochemistry, or pathology were observed; small changes in clinical chemistry and hematological parameters were noted; report concludes that the NOEL for this study was 49,500 ppm v/v

R. J. Parr-Dobrzanski, **HFC 32: 4-Hour Acute Inhalation Toxicity Study in the Rat**, report CTL/P/3456 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Central Toxicology Laboratory, ICI Chemicals and Polymers Limited, Cheshire, UK, 5 June 1992 (50 pages with 1 figure and 27 tables, RDB5740)

nose-only inhalation tests with four groups of 5 female and 5 male albino rats exposed to 0, 7,510, 85,900, and 520,000 ppm v/v R-32 in air (oxygen-enriched for the highest concentration) for 4 hr: no deaths or severe toxicity resulted; minor clinical signs were observed during and immediately after exposures at the two highest concentrations, but the affected animals showed a rapid reversal of effects; no significant effects on body or lung weights resulted; no toxicologically significant effects were found at necropsy; report concludes the 4-hr LC_{50} rat exceeds 520,000 ppm v/v, but indicates a reduced response to sound in 10/10 rats at 85,900 ppm that was not observed at 7,510 ppm

V. M. Randall and J. M. Mackay, **HFC 32: An Evaluation of the Mouse Micronucleus Test**, report CTL/P/3927, Zeneca Central Toxicology Laboratory (then part of ICI Chemicals and Polymers Limited), Cheshire, UK, 23 December 1992 (RDB5746)

R-32, toxicity, mutagenicity: no evidence for clastogenicity as reported in RDB6686

Y. Tobeta, **Test on Biodegradability of HFC-32 by Microorganisms (Closed-Bottle Method)**, report 12121, Kurume Research Laboratories (KRL), Fukuoka, Japan, 1992 (RDB5C33)

ecotoxicity of R-32; environmental impacts and fate; groundwater and soil

Difluoromethane (HFC-32, CAS No. 75-10-5), Joint Assessment of Commodity Chemicals (JACC) report 32, European Chemical Industry Ecotoxicology and Toxicology Centre (ECETOC), Brussels, Belgium, May 1995 (32 pages, RDB-5C13)

This assessment reviews the environmental impacts and toxicity of R-32, described as a flammable, colorless, and odorless gas under normal conditions.

It notes that a large amount is used as a chemical intermediate, and not emitted to the atmosphere, whereas that used for air conditioning and refrigeration will eventually be released under current practices. Most released R-22 is destroyed by reaction with OH- radicals in the troposphere or OH- and excited oxygen atoms in the stratosphere, but not to any major extent by photodecomposition. The calculated ozone depletion potential (ODP) for R-22 is 0.05, described as low compared to fully halogenated chlorofluorocarbons. The report indicates that R-22 has a negligible bioaccumulation potential, based on its moderate water solubility and low octanol-water partition coefficient. Contamination of food or water should not be expected, and has not been reported. R-22 is rapidly equilibrated in tissues after inhalation, and is eliminated from the blood in expired air, with a half life of only a few minutes. Blood concentrations are linearly correlated with inhalation concentrations over a wide range, but metabolism occurs in only minor amounts if at all. The report indicates that R-22 has an extremely low order of acute toxicity, and that concentrations exceeding 200,000 ppm v/v are required to produce a lethal effect. The report reviews cardiovascular studies and cites a cardiac sensitization NOEL (0/12) to adrenaline for male beagles of 24,700 ppm and a LOEL (2/12) of 50,000 ppm with. R-22

showed no adverse effects on fertility in animal studies and was not teratogenic in rabbits at doses up to 50,000 ppm. A low incidence of anophthalmia (congenital absence of eyes) and microphthalmia (abnormally small eyes) combined (10 fetuses in 383 litters) was found when groups of 400 pregnant rats were exposed to 50,000 ppm. Although statistically significant, these findings and those of subsequent studies were deemed to not threaten the health of human beings occupationally exposed at or below recommended exposure limits. Most in vitro tests of R-22 are negative and a positive response in the Ames test is consistent with occurrence of bacteria-specific metabolic pathways. Only minimal or no effects were observed chronic exposures of rats and mice for 4-131 weeks. A slight decrease in body weight gain and a small increase in liver and kidney weight occurred with an exposure level of 50,000 ppm. The only exception was a limited study in rats, mice and rabbits which reported changes in the blood, liver, lung and nervous system in animals exposed to 14,000 ppm over a ten month period; these findings were not confirmed in subsequent studies. R-22 did not produce neoplastic changes in female rats and male and female mice exposed to concentrations as high as 50,000 ppm. In one study in male rats, a concentration of 50,000 ppm was associated with an increase in the number of fibrosarcomas and Zymbal gland tumors; they occurred late in the study and were not considered relevant to humans. Lower concentrations (10,000 ppm and below) did not increase tumor rates in any study. The assessment concludes that R-22 does not constitutes a carcinogenic hazard to man. The toxicological activities described are unlikely to be due to the formation of reactive intermediates. Although not a skin sensitizer, liquid R-22 in contact with skin causes local freezing. Reports on adverse health effects from R-22 are rare and are consistent with findings in experimental animals. Permissible occupational exposure limits vary between 500-1000 ppm (8 hr TWA) by country; the assessment judged these limits to provide adequate health protection.

Difluoromethane (HFC 32) Health Effects Information, CAS# 75-10-5, Elf Atochem North America, Incorporated, Philadelphia, PA, undated circa 1995 (3 pages, RDB5B50)

R-32, summary of toxicological and ecological information

Hydrofluorocarbon 32: Physiologically Based Pharmacokinetic Modelling to Predict Uptake and Metabolism in the Rat, report CTL/R/1137, Zeneca Central Toxicology Laboratory (then part of ICI Chemicals and Polymers Limited), Cheshire, UK, 1992 (RDB6689)

R-32, biochemistry, health effects, toxicity

Workplace Environmental Exposure Level Guide — Difluoromethane, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1997 (3 pages with no figures or tables, RDB5C14)

R-32: identification, summary chemical and physical properties, uses, animal toxicology data, toxicity, human uses and experience (no reports of adverse effects), recommended WEEL guide (1,000 ppm, 2,200 mg/m^3, for 8-hr TWA) and rationale, references

report 57-15, Jackson Laboratory / Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, date unknown (RDB6169)

R-32, toxicity, subchronic exposure of guinea pigs as reported in RDB5862

report 159-76, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1976 (RDB6172)

R-32, toxicity, subchronic exposures in rats as reported in RDB5862

R-40

Emergency Response Planning Guidelines — Methyl Chloride, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1995 (RDB4B83)

R-40, chloromethane, ERPG-1, ERPG-2, ERPG-3, toxicology data, toxicity, safety classification

R-40I1

Emergency Response Planning Guidelines — Methyl Iodide, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1991 (RDB4B80)

R-40I1, iodomethane, ERPG-1, ERPG-2, ERPG-3, toxicology data, toxicity, safety classification

R-50 (METHANE)

F. G. Carpenter, **Anesthetic Action of Inert and Unreactive Gases on Intact Animals and Isolated Tissues**, *American Journal of Physiology*, 178:505-509, 1954 (5 pages, RDB7421)

anesthetic effect of R-50 (methane) and others in mice, toxicity

Toxicity Study Summary: Methane, Pure Grade, Phillips Petroleum Company, Bartlesville, OK, February 1990 (1 page with no figures or tables, RDB7622)

tests of the acute inhalation toxicity in 5 female and 5 male albino, Sprague-Dawley rats by 4 hr, whole body exposures to 34,149 ppm v/v R-50 (methane) in air: no deaths resulted and animals appeared normal throughout the exposures and subsequent 14-day observation period; no gross signs or symptoms of intoxication were noted; treated females showed a slight reduction in mean body weight on days 2-7 following exposures; animals appeared normal at necropsy, with the exception of 1 female; an enlarged mandibular lymph node and scattered white foci on the lung surface were found in pathological examination of this animal; concludes that the 4-hr LC_{50} rat is >34,149 ppm v/v; respiratory tract irritancy studies in male mice by head-only exposures to 34,276 ppm v/v R-50 in air for 1 min, repeated 10 minutes later, while monitored by a plethysmograph: no patterns of respiratory pause were evident; concludes that R-50 failed to produce upper respiratory irritancy in mice at 34,276 ppm v/v

R-112 AND R-112a

J. W. Clayton, Jr., H. Sherman, S. D. Morrison, J. R. Barnes, and D. B. Hood (E. I. duPont de Nemours and Company, Incorporated), **Toxicity Studies on 1,2-Difluorotetrafluoroethane (Freon 112) and 1,1-Difluorotetrafluoroethane (Freon 112a)**, *Toxicology and Applied Pharmacology* (TAP), 6:342 ff, 1964 (RDB5562)

R-112 and R-112a, health effects, toxicity

L. A. Greenberg and D. Lester (Yale University), **The Toxicity of the Tetrachlorodifluoroethanes**, *Archives of Industrial Hygiene and Occupational Medicine*, 2:345-347, 1950 (3 pages, RDB8145)

R-112 and R-112a, health effects, toxicity

R-113

T. K. Bodganowicz, **Acute Inhalation Toxicity**, report 179-73, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1973 (1 page, RDB7437)

R-113, health effects, toxicity: 4-hr ALC rat as reported in RDB7414

V. L. Carter, P. M. Chikos, J. D. MacEwen, and K. C. Back, **Effects of Inhalation of Freon 113 on Laboratory Animals**, paper 20, *Proceedings of the 1st Annual Conference on Environmental Toxicology*, report AMRL-TR-70-102, Aerospace Medical Research Laboratory, U.S. Air Force, Wright-Patterson Air Force Base, OH, 309-314, 1970 (6 pages, available from NTIS as document AD-727524, RDB7438)

R-113, health effects, toxicity

R. Carchman and M. M. Greenberg, **Summary Review of Health Effects Associated with 1,1,2-Trichloro-1,2,2-trifluoroethane (Chlorofluorocarbon 113): Health Issue Assessment**, report EPA 600/8-82-002F, Office of Health and Environmental Assessment, U.S. Environmental Protection Agency (EPA), Washington, DC, January 1983 (available from NTIS as document PB84-118843, RDB6494)

R-113, health effects, toxicity

E. E. Christofano, J. B. Bryant, J. M. Trowell, **Human Exposures to 1,1,2-Trichloro-1,2,2-trifluoroethane**, abstract 91, proceedings of the AIHA conference (Denver, CO, 10-16 May 1969), American Industrial Hygiene Association (AIHA), Fairfax, VA, 30:134, 1969 (1 page, RDB5C02)

R-113, health effects, toxicity

O. L. Dashiell, **1,1,2-Trifluoro-1,2,2-trichloroethane: Acute Inhalation Toxicity**, report 46-71, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1971 (2 pages, RDB-7439)

R-113, 1,1,2-trichloro-1,2,2-trifluoroethane, toxicity, health effects: 4-hr ALC rat as reported in RDB7414

H. Desoille, L. Truffert, A. Bourguignon, P. Delavierre, M. Philbert, and C. Girard-Wallon, **Experimental Study on the Toxicity of Trichlorotrifluoroethane (Freon 113)**, *Archives des Maladies Professionelles de Médecine du Travail et de Se-*

curité Sociale, France, 29(7-8):381-388, 1968 (8 pages, in French, RDB6B56)

R-113, toxicity: 2-hr ALC rat 110,000 ppm as reported in RDB65H1

G. T. Hall, P. W. Grube, and R. C. Graham, untitled toxicity review for CFC-113 (ethane, 1,1,2-trichloro-1,2,2-trifluoro-), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 4 April 1993 (38 pages, RDB5874)

R-113, summary of published and unpublished toxicity literature

Industrial Test Laboratory (ITL), **Toxicity Tests of Non-Inflammable Solvent Cleaner for Insulated Electrical Motor Parts**, report ITL 2335/NS 041 001, Philadelphia Naval Shipyard, U.S. Navy, Philadelphia, PA, 1952 (8 pages, RDB7456)

R-113, health effects, toxicity

H. R. Imbus and C. Adkins, **Physical Examinations of Workers Exposed to Trichlorotrifluoroethane**, *Archives of Environmental Health*, 24(4):257-261, 1972 (5 pages, RDB6733)

R-113, 1,1,2-trichloro-1,2,2-trifluoroethane, human exposures, toxicity

T. Kawakami, T. Takano, and R. Araki (Japan Bioassay Laboratory, JBL, Japan), **Enhanced Arrhythmogenicity of Freon 113 by Hypoxia in the Perfused Rat Heart**, *Toxicology Ind. Health*, 6:493-506, 1990 (8 pages, RDB6B45)

R-113, cardiac sensitization, health effects, toxicity

G. Limperos, **Inhalation Toxicity of 'Freon 113' (1,1,2-Trichlorotrifluoroethane)**, report 3-54, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1954 (9 pages, RDB-7440)

R-113, 1,1,2-trichloro-1,2,2-trifluoroethane, toxicity, health effects: rats exposed to an average of 2,520 ppm v/v for 7 hr/d, 5 d/wk for 6 weeks showed no signs of toxicity as reported in RDB7414

D. C. May and M. J. Blotzer, **A Report of Occupational Deaths Attributed to Fluorocarbon-113**, *Archives of Environmental Health*, 39(5):352-354, 1984 (3 pages, RDB6734)

R-113, human exposures, toxicity

J. E. McKnight and J. L. McGraw, **Ultrastructural Study of the Effects of Trichlorotrifluoroethane on the Liver of Hairless Mice**, *Journal of Submicroscopic Cytology*, 15(2):447-451, 1983 (5 pages, RDB8165)

R-113, mutagenicity, toxicity

J. B. Michaelson and D. J. Huntsman, **Oral Toxicity Study of 1,2,2-Trichloro-1,1,2-trifluoroethane**, *Journal of Med. Pharm. Chem.*, 7:378-379, 1964 (2 pages, RDB7441)

R-113, 1,1,2-trichloro-1,2,2-trifluoroethane, toxicity, health effects: LD_{50} rat = 43 g/kg as reported in RDB7414

G. B. Raffi and F. S. Violante, **Is Freon 113 Neurotoxic? A Case Report**, *International Archives of Occupational and Environmental Health*, 49:125-127, 1981 (RDB6735)

case history of human exposures to R-113; toxicity

C. F. Reinhardt, M. E. McLaughlin, M. E. Maxfield, L. S. Mullin, and P. E. Smith, **Human Exposures to Fluorocarbon 113 (1,1,2-trichloro-1,2,2-trifluoroethane)**, *AIHA Journal*, 32:143-152, March 1971 (10 pages, RDB6496)

examination of human exposures to R-113; toxicity

C. F. Reinhardt and L. R. Schultze, **Human Skin Absorption Studies with Trichlorotrifluoroethane, F-113**, report 84-68, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1968 (7 pages, RDB7443)

R-113, dermal contact toxicity, health effects: skin exposures result in local numbness followed by transient erythema after exposure stopped as reported in RDB7414

R. E. Reinke, **Freon 113 (1,1,2-trichlorotrifluoroethane). Eye Irritation Experiment**, report 39-62, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1962 (1 page, RDB-6B57)

dermal contact toxicity and eye irritation in rabbits of R-113 (1,1,2-trichloro-1,2,2-trifluoroethane); results in mild conjunctivitis (inflammation of the mucous membrane inside the eyelids) and corneal dullness — as reported in RDB65H1

H. Savolainen and P. Pfaffli, **Dose Dependent Neurochemical Effects of 1,1,2-Trichloro-1,2,2-trifluoroethane Inhalation Exposure in Rats**, *Toxicology Letters*, 6:43-49, 1980 (RDB6497)

inhalation toxicity of R-113

J. W. Sarver, **1,1,2-Trifluoro-1,2,2-trichloroethane: Four-Hour Inhalation Toxicity**, report 104-71, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 7 April 1971 (2 pages with 1 table, RDB6804)

toxicity tests by acute inhalation of R-113 in male, Manor Farm rats at 32,000, 40,500, 45,000, and 53,000 ppm v/v and for 10 repeated, subacute exposures at 1,000 ppm; record of clinical signs shows anesthetic/central nervous system (CNS) effects as well as slight weight loss, followed by normal weight gain, at 32,000 ppm; 4-hr LC_{50} rat = 52,500 ppm; pathologic examination of exposed animals revealed no compound-related changes in the respiratory tract; comparison to prior test results with Charles River rats, which showed the 4-hr LC_{50} to be 56,000 ppm, concludes that "there are basically no differences ... in the two strains of rats" within 95% confidence limits

M. B. Steinberg, R. E. Boldt, R. A. Renne, and M. H. Weeks, **Inhalation Toxicity of 1,1,2-Trifluoro-1,2,2-trichloroethane (TCTFE)**, report on study 33-18-68/69, Environmental Hygiene Agency, U.S. Army, Edgewood Arsenal, MD, 1969 (20 pages, available from NTIS as document AD-854705, RDB7444)

inhalation toxicity of R-113 (1,1,2-trichloro-1,2,2-trifluoroethane)

G. J. Stopps and M. McLaughlin, **Psychophysiological Testing of Human Subjects Exposed to Solvent Vapors**, *AIHA Journal*, 28:43-50, 1967 (8 pages, RDB7445)

toxicity tests of R-113 and others to humans

G. Triebig and K. Burkhardt, **Occupational Medicine Investigations into Occupational Exposure to FC113**, *International Archives of Occupational and Environmental Health*, Germany, 42:129-135, 1978 (7 pages, RDB6498)

toxicity of R-113

H. J. Trochimowicz (E. I. duPont de Nemours and Company), G. M. Rusch (AlliedSignal Incorporated), T. Chiu, and C. K. Wood, **Chronic Inhalation Toxicity/Carcinogenicity Study in Rats Exposed to Fluorocarbon 113 (FC-113)**, *Fundamental and Applied Toxicology*, 11:68-75, 1988 (8 pages, RDB8179)

toxicity of R-113

H. J. Trochimowicz, **The Toxicology of Fluorocarbon 113**, presentation to the Swedish Board of Occupational Safety and Health (Stockholm, Sweden), E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 19 January 1984 (RDB-8180)

toxicity of R-113

H. Vainio, J. Nickels, and T. Heinonen, **Dose Related Hepatotoxicity of 1,1,2-Trichloro-1,2,2-trifluoroethane in Short-Term Intermittent Inhalation Exposures in Rats**, *Toxicology*, 18(1):17-35, 1980 (19 pages, RDB6499)

R-113, health effects, toxicity

C. K. Wood, **Two-Year Inhalation Toxicity Study with 1,1,2-Trichloro-1,2,2-trifluoroethane in Rats**, report 488-84, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 5 March 1985 (63 pages, RDB6730)

R-113, two year inhalation study in rats, as reported in RDB5143

B. H. Woollen, E. A. Guest, W. Howe, J. R. Marsh (ICI Central Toxicology Laboratory, UK), H. K. Wilson (Occupational Medicine and Hygiene Laboratories, UK), T. R. Auton, and P. G. Blain (ICI Central Toxicology Laboratory, UK), **Human Inhalation Pharmacokinetics of 1,1,2-Trichloro-1,2,2-trifluoroethane (FC113)**, *International Archives of Occupational and Environmental Health*, Germany, 62:73-78, 1990 (6 pages with 5 figures and 3 tables, RDB6492)

R-113, health effects, toxicity: tests of absorption and elimination in experimental human exposures by seven male volunteers at concentrations of 254, 526, or 980 ppm v/v for 4 hr

NIOSH Alert: Preventing Death from Excessive Exposure to Chlorofluorocarbon 113, publication 89-109, National Institute for Occupational Safety and Health (NIOSH), U.S. Department of Health and Human Services, Cincinnati, OH, 1989 (available from GPO; RDB6B48)

R-113, health effects, toxicity

Occupational Health Guideline for 1,1,2-Trichloro-1,2,2-trifluoroethane, U.S. Department of Health and Human Services and U.S. Department of Labor, Washington, DC, September 1978 (4 pages, available from JMC a RDB6291)

R-113, Occupational Health Guideline (OHG), exposure limits, health hazard information, toxicity, chemical and physical data, reactivity, flammability, monitoring and measurement, res-

pirators, personal protective equipment, emergency first aid procedures, spills and leaks, references

Teratogenicity Study of 1,1,2-Trichloro-1,2,2-trifluoroethane in Rats, report CTL/P/731, ICI Central Toxicology Laboratory, Cheshire, UK, 19 November 1982 (RDB6732)

R-113, teratogenicity study in rats, as reported in RDB5143 and RDB5367

Toxicity Studies with 1,1,2-Trichloro-1,2,2-trifluoroethane, bulletin S-24, E. I. duPont de Nemours and Company, Incorporated, Wilmington, DE, 1980 (RDB8139)

R-113, health effects, safety, toxicity

1,1,2-Trichloro-1,2,2-trifluoroethane (Freon 113), chemical infogram 22, Canadian Centre for Occupational Health and Safety (CCOHS), Hamilton, ON, Canada, December 1989 (1 page with no figures or tables, RDB7457)

R-113, safety, toxicity, flammability, occupational exposure guidance

report 3-54, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1954 (RDB7541)

toxicity tests to determine the acute dermal toxicity of R-113 applied to the clipped skin of rabbits at >11,000 mg/kg: no signs indicating systemic toxicity were found, though the treatment caused local irritation, as reported in RDB5874

report 724-81, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 11 December 1981 (RDB6731)

R-113, 90-day inhalation study in rats, as reported in RDB5143

R-114

D. W. D. Collure et al., *Journal of the American College of Emergency Physicians*, 5(10):814 ff, 1976 (RDB7544)

R-114, dermal effects and toxicity: experiments on human volunteers

H. Desoille et al., *Archives des Maladies Professionelles de Médecine du Travail et de Securité Sociale*, France, 36(12):697-706, 1975 (10 pages, in French, RDB7545)

R-114, health effects, toxicity

H. Desoille, L. Truffert, C. Gierard-Wallon, J. Ripault, and M. Philbert, **Recherche Expérimentale de la Toxicité Chronique Éventuelle du Dichlorotetrafluoroethane** [Experimental Research on the Long-Term Chronic Toxicity of Dichlorotetrafluoroethane], *Archives des Maladies Professionelles de Médecine du Travail et de Securité Sociale*, France, 34(3):117-125, 1973 (9 pages, in French, RDB5362)

R-114, health effects, toxicity

Z. Durakovic, L. Stilinovic, and I. Bakran, Jr., **Electrocardiographic Changes in Rats After Inhalation in Dichlorotetrafluoroethane, Arcton 114, $C_2Cl_2C_4$**, *Japan Heart Journal*, 17(6):753-759, 1976 (7 pages, RDB6738)

R-114, toxicity

F. D. Griffith and H. Sherman, **The Effect of Freon® 114 (Ethane-1,2-dichlorotetrafluoro) on Growth Rate, Urinary Fluoride, and Bone Fluoride in Rats**, report 381-69, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, December 1969 (RDB5A70)

R-114, toxicity, three-week intubation exposure study with rats, possibility of some metabolism as reported in RDB5141 and RDB7414

D. B. Hood, **Skin Tests with Rexall Facial Cleanser Containing 'Freon-114'**, report 110-67, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1967 (RDB65H6)

R-114, dermal toxicity: no irritation observed when sprayed on shaved backs of guinea pigs as reported in RDB65H1

D. B. Hood and M. Ward, **Acute Oral Toxicity Of Freon® 114, Dichlorotetrafluoroethane**, report on project MR-312-7, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1955 (RDB65H5)

toxicity tests of R-114 in rats for determine ingestion toxicity: oral ALD rat >2,250 mg/kg (based on the maximum feasible dose dissolved in corn oil); comparison to R-12 ALD rat >1,000 mg/kg (maximum feasible dose dissolved in corn oil) as reported in RDB65H1

D. B. Hood and M. Ward, **Eye Irritation of Freon® 114 in Rabbits**, report on project MR-312-7, Haskell Laboratory for Toxicology and Industrial

Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1955 (RDB7447)

toxicity tests of R-114 in rabbits: mild conjunctivitis (inflammation of the mucous membrane inside the eyelids), persisting less than 48 hr, resulted from acute eye exposure tests with a mineral oil solution — as reported in RDB65H1

H. Kuebler, *Aerosol Age*, 9:44 ff., 1964 (RDB6870)

indicates an anesthetic effect in rats exposed to 500,000 ppm v/v R-114 for 2 hr — as reported in RDB5855

R. R. Montgomery, M. A. Lee, R. C. Graham, and P. J. Lardear, untitled toxicity review for 1,2-Dichloro-1,1,2,2-tetrafluoroethane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 11 June 1992 (RDB5855)

R-114, summary of published and unpublished toxicity literature

S. Niazi and W. L. Chiou, **Fluorocarbon Aerosol Propellants X: Pharmacokinetics of Dichlorotetrafluoroethane in Dogs**, *Journal of Pharmaceutical Sciences*, 65:60-64, 1976 (5 pages, RDB7253)

R-114, biochemistry, elimination, health effects, toxicity

G. Paulet and S. Desbrousses, **Le Dichlorotetrafluoroethane: Toxicité Aiguë et Chronique à Moyen Terme** [Dichlorotetrafluoroethane: Acute and Mid-Test Chronic Toxicity], *Archives des Maladies Professionelles de Médecine du Travail et de Securité Sociale*, France, 30(9):477-492, 1969 (16 pages in French, RDB5172)

R-114, toxicity

J. F. Russell, report 19-78, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, January 1978 (RDB7446)

toxicity tests to determine the mutagenicity of R-114 in Salmonella typhimurium bacteria (Ames assay) both in the presence and absence of a metabolic activation system (S-9) derived from rat livers: finding was negative as reported in RDB5141 and RDB5855

H. Sherman, **Ninety-Day Feeding Study in Rats and Dogs with Dichlorotetrafluoroethane (Freon® 114)**, report 5-72, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, January 1972 (RDB5A71)

R-114, toxicity, 90-day intubation exposure study with dogs and rats as reported in RDB5141

W. P. Yant, H. H. Schrenk, and F. A. Patty, **The Toxicity of Dichlorotetrafluoroethane**, Report of Investigations 3185, U.S. Bureau of Mines, Washington, DC, October 1932 (12 pages with 1 table, available from JMC as RDB5359)

R-114; 12-week exposures of dogs, guinea pigs, and monkeys to 200,000 ppm v/v, reduced to 150,000 ppm v/v and then 141,600 ppm v/v (equivalent fluorine content on a weight basis to 200,000 ppm v/v R-12) following observation of effects; documents observed symptoms including tremors and convulsions, changes in weight, changes in blood picture, fatality, and pathology; report concludes that "the toxicity of [R-114] on a vapor-volume basis is somewhat greater than [R-12], but on a weight basis is of the same order as the latter, and is an organic vapor of remarkably low toxicity"

1,2-Dichloro-1,1,2,2-tetrafluoroethane (CFC 114) Health Effects Information, CAS# 76-14-2, Elf Atochem North America, Incorporated, Philadelphia, PA, undated circa 1995 (8 pages, RDB5B51)

R-114, summary of toxicological and ecological information

Bioassay Report — Acute Toxicity — Fish, TSCAT report OTS-0520348, Bionomics Incorporated, 12 June 1989 (11 pages, RDB7252)

ecotoxicity of R-114; toxicological and ecological information; environmental impacts; toxicity

Occupational Health Guideline for Dichlorotetrafluoroethane (Refrigerant 114), U.S. Department of Health and Human Services and U.S. Department of Labor, Washington, DC, September 1978 (4 pages, available from JMC as RDB6287)

R-114, Occupational Health Guideline (OHG), exposure limits, health hazard information, toxicity, physical data, reactivity, flammability, monitoring and measurement, respirators, personal protective equipment, emergency first aid procedures, spills and leaks, references

R-115

R. F. Bopp et al., *Organic Geochemistry*, 3:9-14, 1981 (6 pages, RDB7613)

R-115, aquatic and environmental toxicity, ecotoxicity: most R-115 will volatize and bioconcentration in aquatic organisms is not expected to be important — as reported in RDB6776

J. F. Breen and J. E. Wallis, **Report on Refrigerant**, Miscellaneous Hazard Report Number 2256, Underwriters Laboratories Incorporated, Northbrook, IL (then Chicago, IL), 20 August 1963 (RDB7614)

toxicity tests of R-115 to guinea pigs by inhalation exposures at concentrations of 200,000 ppm for up to 2 hr: no signs of toxicity, weight change, or gross or microscopic pathological abnormalities were found — as reported in RDB6776

J. W. Clayton, Jr., D. B. Hood, M. S. Nick, and R. S. Waritz (E. I. duPont de Nemours and Company, Incorporated), **Inhalation Studies of Chloropentafluoroethane**, *AIHA Journal*, 27(3):234-238, May-June 1966 (5 pages, RDB65H4)

R-115, toxicity: 4-hr ALC rat >800,000 ppm v/v as reported in RDB65H1

G. T. Hall, P. W. Grube, M. A. Lee, and R. C. Graham, untitled toxicity review for chloropentafluoroethane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 16 March 1993 (14 pages with no figures or tables, RDB-6776)

R-115, summary of published and unpublished toxicity literature

H. S. Sherman, report 146-64, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1964 (RDB65H7)

R-115, ingestion toxicity: intragastric intubation of R-115 in cottonseed oil to rats on a daily level of 140-172 mg/kg for 10 days produced no clinical or histopathologic changes related to R-115 as reported in RDB65H1

J. B. Terrill (E. I. duPont de Nemours and Company, Incorporated), **Arterial Venous Blood Levels from Chlorofluoroethane Inhalation versus Oral Exposure**, *AIHA Journal*, 35(5):269-275, May 1974 (7 pages, RDB7239)

R-115, health effects, toxicity: no deaths resulted in dogs that consumed up to 1,200 mg/kg of R-115 in a food topping, suggesting an LD_{50} oral dog of >1,200 mg/kg

J. B. Terrill (E. I. duPont de Nemours and Company, Incorporated), paper 12, *Proceedings of the Fourth Annual Conference on Environmental Toxicology* (Fairborn, OH, 16-18 October 1973), report AMRL-TR-73-125, Aerospace Medical Research Laboratory, U.S. Air Force, Wright-Patterson Air Force Base, OH, 151-174, December 1973 (24 pages, available from NTIS as document AD-781031, RDB7615)

R-115 and others, health effects, toxicity

Chloropentafluoroethane (CFC 115) Health Effects Information, CAS# 76-15-3, Elf Atochem North America, Incorporated, Philadelphia, PA, undated circa 1995 (4 pages, RDB5B52)

R-115, summary of toxicological and ecological information

Occupational Safety and Health Guideline for Chloropentafluoroethane, U.S. Department of Health and Human Services and U.S. Department of Labor, Washington, DC, 1995 (7 pages, available from JMC as RDB6288)

R-115, Occupational Health Guideline (OHG), Occupational Safety and Health Guideline (OSHG), physical data, reactivity, flammability, exposure limits, health hazard information, toxicity, emergency procedures, medical monitoring, workplace monitoring and measurement, personal hygiene, storage, leaks, emergency planning and community right-to-know requirements, hazardous waste management requirements, respiratory protection, personal protective equipment, references

report 143-64, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1964 (RDB7618)

R-115, acute inhalation toxicity

R-116

J. Carson et al., abstract 133, *Veterinary and Human Toxicology*, 31(4):363 ff, 1989 (RDB6575)

accidents resulting in injection of R-116 into the fingers of workers, treatment and result

J. Ferguson-Smith, **Hygiene Standard Documentation: Perfluoroethane** document ESC/PFC 116, ICI Chemicals and Polymers Limited, Cheshire, UK, 22 January 1996 (5 pages, RDB6687)

R-116, toxicity, literature review, rationale for recommended hygiene standard (Health Based Standard) of 1,000 ppm, 8-hr TWA

T. B. Griffin et al., *Toxicology and Applied Pharmacology* (TAP), 29:92 ff, 1974 (RDB6577)

R-116, toxicity

M. A. Lee and R. C. Graham, untitled toxicity review for hexafluoroethane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 26 July 1991 (RDB5605)

R-116, summary of published and unpublished toxicity literature

M. Hughes, unpublished data, Atlantic Research Corporation, 1973 (RDB6119)

R-116, cardiac sensitization, toxicity: indicates a cardiac sensitization NOEL dog at 600,000 ppm, but the test protocol (e.g., whether an epinephrine challenge was used, whether the test mixture was oxygen enriched, and the duration of exposure) is not clear — as reported in RDB5605

S. D. Morrison, report 41-62, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1962 (RDB6580)

R-116, inhalation, acute toxicity: 2-hr ALC rat >200,000 ppm, 4-hr ALC rat >800,000 ppm as reported in RDB5605 and RDB65H1

report CTL/L/6119, ICI Central Toxicology Laboratory, Cheshire, UK, 22 November 1994 (RDB6691)

R-116, toxicity, mutagenicity: Ames test with and without metabolic activation to *Salmonella typhimurium* and *Escherichia coli*: not mutagenic as reported in RDB6687

report CTL/L/6908, ICI Central Toxicology Laboratory, Cheshire, UK, 31 October 1995 (RDB6690)

R-116, toxicity, mutagenicity: not clastogenic to human lymphocytes with and without metabolic activation as reported in RDB6687

R-123

F. C. Barsky, **In Vitro Microbial Mutagenicity Studies of 2,2-Dichloro-1,1,1-Trifluoroethane**, report 581-76, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1989 (RDB6164)

R-123, toxicity

W. E. Brewer and S. Smith (Industrial Bio-Test Laboratories, Incorporated), **Teratogenic Study via Inhalation with Genetron 123 in Albino Rats**, report IBT 8562-09344, AlliedSignal Incorporated (then Allied Chemical Corporation), Morristown, NJ, 8 November 1977 (32 pages with 10 tables, RDB6143) [included in RDB6142 as appendix C]

toxicity test of the teratogenicity of R-123 in groups of 20 female (16 pregnant) Charles River albino rats by inhalation exposures at 0 (control) or 5,000 ppm for 5 hr/d on gestation days 6-15: bodyweight gains were lower in the treated animals; both treated and control animals had red nasal discharges; no grossly apparent uterine anomalies attributed to exposures were noted; pathological findings of the sacrificed dams and fetuses were essentially the same for the test and control groups; report concludes that R-123 was not teratogenic as tested

W. E. Brewer and S. Smith (Industrial Bio-Test Laboratories, Incorporated), **90-Day Subacute Inhalation Toxicity Study with Genetron 123 in Albino Rats**, report IBT 8562-09344, AlliedSignal Incorporated (then Allied Chemical Corporation), Morristown, NJ, 2 September 1977 (19 pages with 2 tables, Rdb6144) [included in RDB6142 as appendix A]

R-123, subchronic inhalation toxicity: groups of 35 male and 25 female rats were exposed to concentrations of 0 (control), 500 (actual 487), 1000 (actual 1009), and 5000 (actual 4836) ppm for 6 hr/d for 5 d/wk; lower body weight gains were noted at 5000 ppm in both sexes and at 1000 ppm in females with full recovery post exposure; no remarkable effects were seen in hematology, clinical chemistry, or urinalysis parameters; increases were seen in liver weight to body weight ratios in males in the 5000 ppm group and in the females in all three exposure groups; kidney and heart weight decreases were noted, but may have been related to depressed body weight; only the liver showed treatment-related microscopic changes, namely focal necrosis and multifocal atrophy of hepatocytes, but these findings also were seen in the control groups and neither their incidence nor severity followed a treatment-related pattern; summarized and discussed in RDB6142 and, as study A-77, in RDB65D8 [prepared from partial report with missing pages]

M. R. Brittelli, **Eye Irritation Test in Rabbits**, report 747-75 (FYI-OTS-0889-0695), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1975 (RDB6160)

R-123, health effects, toxicity

W. J. Brock, **Acute Dermal Toxicity Study of HCFC-123 in Rabbits**, report 578-88 (FYI-OTS-0889-0695), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1988 (RDB-6148)

R-123, health effects, toxicity, 24-hr ALD skin rabbit 0/10 >2,000 mg/kg as reported in RDB5861

W. J. Brock, **Acute Dermal Toxicity Study of HCFC-123 in Rats**, report 577-88, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1988 (RDB6147)

R-123, health effects, toxicity, 24-hr ALD skin rat 0/5 >2,000 mg/kg as reported in RDB5861

W. J. Brock, **Primary Dermal Irritation Study with HCFC-123 in Rabbits**, report 535-88 (FYI-OTS-0889-0695), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1988 (RDB6149)

R-123, health effects, toxicity

D. Brusick (Litton Bionetics Incorporated, LBI), **Mutagenicity Evaluation of Genetron 123**, report on LBI project 2547, AlliedSignal Incorporated (then Allied Chemical Company), Morristown, NJ, 30 July 1976 (RDB6135)

R-123, health effects, toxicity

R. D. Callander, **HCFC 123: An Evaluation Using the Salmonella Mutagenicity Assay**, report CTL/P/2421 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT) #88-01, ICI Central Toxicology Laboratory, Cheshire, UK, 15 December 1989 (RDB6136)

R-123, mutagenicity, toxicity

C. P. Chengelis (WIL Research Laboratories, Incorporated), **Acute Pharmacokinetic Study of HCFC-123 in Dogs by Inhalation**, Great Lakes Chemical Corporation, West Lafayette, IN, 5 July 1994 (82 pages with 5 figures and 18 tables, RDB-8114)

R-123, biochemistry, health effects, toxicity; a copy of this report is appended to RDB6573

J. W. Clayton, **Preliminary Studies on the Inhalation Toxicity of Technical (70.9 per cent) 1,1-Dichloro-2,2,2-Trifluoroethane** [2,2-dichloro-1,1,1-trifluoroethane], report 151-64, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1966 (RDB6151)

R-123, toxicity

W. B. Coate (Hazleton Laboratories America, Incorporated), **LC_{50} of G123 in Rats**, report M165-162 (FYI report OTS-06890695), AlliedSignal Incorporated (then Allied Chemical Company), Morristown, NJ, 4 October 1976 (RDB6137)

R-123, acute inhalation toxicity, LC_{50} rat, 6 hr = 52,640 ppm as reported in RDB3719, RDB5371, RDB5861, and RDB65E8

D. W. Coombs (Huntingdon Research Centre Limited, HRC, UK), **HCFC-123: 13-Week Inhalation Neurotoxicity Study in the Rat**, report ALS 3/931038 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), AlliedSignal Incorporated, Morristown, NJ, 21 June 1994 (RDB-6217)

R-123, health effects, subchronic toxicity

C. A. Dance, **In Vitro Assessment of the Clastogenic Activity of HCFC-123 in Cultured Human Lymphocytes**, report 91/PFE 003/0093 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Life Science Research Limited (LSR), Suffolk, UK, 1991 (RDB6219)

R-123, toxicity, mutagenicity

R. W. Darr, **An Acute Inhalation Toxicity Study of Fluorocarbon 123 in the Chinese Hamster**, Corporate Medical Affairs report MA-25-78-15, AlliedSignal Incorporated (then Allied Corporation), Morristown, NJ, 10 June 1981 (25 pages with 1 figure and 1 table, RDB5149)

test of the acute inhalation toxicity of R-123 in groups of 5 male Chinese hamsters exposed to 10,000, 14,000, 22,000, 26,000, or 31,000 ppm v/v R-123 in air: 4-hr LC_{50} = 28,400 ppm v/v

W. Dekant, **Metabolism of 1,1-Dichloro-2,2,2-trifluoroethane (HCFC-123)**, report MA-RR-93-1972a, Universität Würzburg, Germany, 1994 (RDB65C2)

toxicity of R-123 (2,2-Dichloro-1,1,1-trifluoroethane

C. Doleba-Crowe, **Ninety-Day Inhalation Exposure of Rats and Dogs to Vapors of 2,2-Dichloro-1,1,1-trifluoroethane (FC-123)**, report

229-78, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 19 May 1978 (RDB6155)

R-123, subchronic inhalation toxicity: groups of 27 male and 27 female rats and 4 male beagle dogs were exposed to concentrations of 0 (control), 1000 (actual 900), and 10,000 (9800 ppm) for 6 hr/d, 5 d/wk for 4 weeks; narcosis was seen at 10,000, but not at 1000 ppm and was reversible upon cessation of exposures; decreased rates of body weight gain and increased absolute and relative liver weight gains were seen in the rats; higher relative adrenal and testes weights were seen in the male rats and in the kidney and stomachs of the female rats at both exposure levels, while lower absolute heart and kidney weights were seen at 10,000 ppm; no remarkable hematology findings were reported, though sporadic increases in serum total protein levels were noted in both the males and females; there were no noteworthy histopathological findings from evaluation of tissues from rats; dogs exposed to 10,000 ppm had lower erythrocyte counts, hemoglobin concentrations, and hematotcrits; dogs exposed to 10,000 ppm also exhibited degenerative changes in the liver; overall, 1000 ppm was a NOAEL for the dogs — as reported in RDB65D8 which summarizes this (identified as D-78) and three related studies

C. N. Edwards, **HCFC-123 (Vapour Phase): In Vitro Assessment of Clastogenic Activity in Cultured Human Lymphocytes**, report 91/PFE 002/0125 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Life Science Research Limited (LSR), Suffolk, UK, 1991 (RDB-6220)

R-123, toxicity, mutagenicity

J. Ferguson-Smith, **Hygiene Standard Documentation — 1,1-Dichloro-2,2,2-trifluoroethane** [2,2-dichloro-1,1,1-trifluoroethane], document HSP/-92/14, ICI Chemicals and Polymers Limited, Cheshire, UK, 1992 (14 pages with 3 tables, RDB-5A77)

R-123, toxicity, literature review, rationale for recommended hygiene standard (occupational exposure limit, OEL) of 10 ppm, 8-hr TWA, provisional

R. Ferrara (University of Padova Medical School, Italy), R. Tolando (University of Surrey, UK), L. J. King (Surrey), and M. Manno (Padova), **Cytochrome P450 Inactivation During Reductive Metabolism of 1,1-Dichloro-2,2,2-trifluoroethane (HCFC-123) by Phenobarbital- and Pyridine-Induced Rat Liver Microsomes**, *Toxicology and Applied Pharmacology* (TAP), 143(2):420-428, April 1997 (9 pages with 9 figures and 1 table, RDB7C67)

toxicity of R-123 by *in vitro* tests in rats of the reductive metabolic activation of R-123; dose- and time-dependent depletion of added exogenous glutathione was observed during incubation of liver microsomes under anaerobic conditions; R-133a and R-142 were detected as products of reductive metabolism of HCFC-123 under similar incubation conditions except for the absence of glutathione; results indicate that R-123, like hepatoxic R-123B1 (halothane) which is a close structural analog, is activated reductively to reactive metabolites by at least two P450 isoforms, namely P4502E1 and P4502B1/2; these metabolites, probably free radicals and/or carbene species, may attack the enzyme resulting in modification of the microsomal heme group and subsequent loss of catalytic activity

R. Ferrara, R. Tolando, L. J. King, and M. Manno (University of Padova Medical School, Italy), **Reductive Activation of 2,2-Dichloro-1,1,1-trifluoroethane (HCFC-123) by Rat Liver Microsomal Cytochrome P-450**, *Proceeding of the Fifth International Symposium on Biological Reactive Intermediates*, Munich, Germany, 4-8 January 1995 (RDB65C5)

toxicity of R-123

K. M. Gerber, M. A. Lee, R. C. Graham, and S. W. Snyder, untitled review of toxicity literature for ethane, 2,2-dichloro-1,1,1-trifluoro- (HCFC-123), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 28 February 1996 (25 pages, RDB6941)

summary of published and unpublished information on the toxicity of R-123

C. S. Godin, J. M. Drerup, and A. Vinegar, **Conditions Influencing the Rat Liver Microsomal Metabolism of 2,2-Dichloro-1,1,1-Trifluoroethane (HCFC-123)**, *Drug Metabolism and Disposition*, 21(3):551-553, May 1993 (3 pages, RDB6213)

R-123, toxicity

N. C. Goodman, **Primary Skin Irritation and Sensitization Tests on Guinea Pigs**, report 678-75, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company,

Incorporated, Newark, DE, 31 December 1975 (RDB6161)

R-123, health effects, toxicity: produced no irritation or sensitization on shaved skin of albino guinea pigs in 10 and 50% solutions in propylene glycol as reported in RDB6941

G. T. Hall and B. L. Moore, **1,1-Dichloro-2,2,2-trifluoroethane: Acute Inhalation Toxicity**, report 426-75, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 16 July 1975 (2 pages with 1 table, RDB6139)

4 hr acute inhalation toxicity tests of R-123 in groups of six male Charles River CD rats: mortality ratios and corresponding concentrations were 0/6 at 20,700, 3/6 at 32,000, 3/6 at 33,700, 4/6 at 42,100, and 6/6 at 52,500 and 55,000 ppm v/v in air; rats showed loss of mobility, lethargy, prostration, unresponsiveness to sound, and dyspnea (difficult or labored breathing) within 5 minutes at all concentrations; rats that survived showed no noticeable clinical signs 30 minutes following exposures; no pathologic examinations were performed; concludes that the 4-hr LC_{50} rat for R-123 is approximately 32,000 ppm v/v, confirming an earlier study, and therefore "practically non-toxic on an acute inhalation basis," but that R-123 does cause an adverse central" nervous system (CNS) effect at 20,700 ppm

J. W. Harris, L. R. Pohl, J. L. Martin, and M. W. Anders, **Tissue Acylation by the Chlorofluorocarbon Substitute 2,2-Dichloro-1,1,1-Trifluoroethane**, *Proceedings of the National Academy of Science* (NAS), Washington, DC, 88(4):1407-1410 or 1407-1416, 15 February 1991 (4 or 10 pages, RDB6222)

toxicity of R-123; biochemistry

J. E. Henry and A. M. Kaplan, **Acute Oral Test on FC-123**, report 638-75 (FYI-OTS-0889-0695), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 30 October 1975 (RDB6140)

toxicity of R-123; ALD as reported in RDB5861

E. W. Hughes (Huntingdon Research Centre Limited, HRC, Cambridgeshire, UK), **A Study of the Effect on the Reproductive Function of Two Generations in the Rat**, report ALS 5/932336 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), AlliedSignal Incorporated, Morristown, NJ, 1994 (RDB6218)

toxicity of R-123; health effects

E. W. Hughes, D. P. Myers, and D. W. Coombs (Huntingdon Research Centre Limited, HRC, UK), **Range Finding Study in Mature Male and Female Rats and their Offspring**, report ALS 4/920200 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), AlliedSignal Incorporated, Morristown, NJ, 28 February 1992 (RDB6574)

reproductive toxicity of R-123

J. Huwyler, D. Aeschlimann, U. Christen, and J. Gut, **The Kidney as Novel Target Tissue for Protein Adduct Formation Associated with Metabolism of Halothane and the Candidate Chlorofluorocarbon Replacement 2,2-Dichloro-1,1,1-trifluoroethane**, *European Journal of Biochemistry*, 207(1):229-238, 1 July 1992 (10 pages, RDB65C7)

toxicity of R-123 and R-123B1 (halothane); metabolism; health effects

J. Huwyler and J. Gut, **Exposure to the Chlorofluorocarbon Substitute 2,2-Dichloro-1,1,1-trifluoroethane and the Anesthetic Agent Halothane is Associated with Transient Protein Adduct Formation in the Heart**, *Biochemical and Biophysical Research Communications*, 184(3):-1344-1349, 15 May 1992 (6 pages, RDB65C8)

R-123, R-123B1 (halothane), health effects, toxicity

A. M. Jarabek (U.S. Environmental Protection Agency, EPA), J. W. Fisher (U.S. Air Force Armstrong Laboratory, USAF-AL), R. Rubenstein (EPA), J. C. Lipscomb (USAF-AL), R. J. Williams (USAF-AL), A. Vinegar (ManTech Environmental Technology, Incorporated), and J. N. McDougal (USAF), **Mechanistic Insights Aid the Search for CFC Substitutes: Risk Assessment of HCFC-123 as an Example**, *Risk Analysis*, 14(3):231-250, June 1994 (20 pages with 9 figures and 14 tables, RDB6B52)

brief review of stratospheric ozone depletion and the Montreal Protocol; discussion and table of ODP and GWP values; use of the former in setting production quotas; phaseout schedules; search for substitutes and structural similarities in candidates; summary of the Programme for Alternative Fluorocarbon Toxicity Testing (PAFT) and study sequences; risk characterization under the Significant New Alternatives Program (SNAP); use of the Workplace Guidance Level (WGL, described as essentially analogous to the Permissible Exposure Level, PEL)

gous to the Permissible Exposure Level, PEL) and Emergency Guidance Level (EGL, described as similar in intent to the Immediately Dangerous to Life and Health concentration, IDLH) as screening tools; EGL is based on the no-observed-adverse-effect-level (NOAEL) or lowest-observed-adverse effect level (LOAEL) for cardiotoxicity in the dog; assessment by comparison of the WGL and EGL to a reference concentration (RfC) with tabular data for R-22, R-123, R-124, R-134a, R-141b, R-142b, and R-152a; review of R-123 toxicity and dose-response analyses; risk assessment by physiologically-based, pharmacokinetic (PBPK) modeling for R-123 by analogy to R-123B1 (halothane) data, to decrease the need for extensive laboratory animal testing

C. A. Jenkins, **HCFC 123: Acute Toxicity to Daphnia Magna**, report 91/PFE006/0972 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Life Science Research Limited (LSR), Suffolk, UK, 1992 (RDB65C9)

R-123, effects on organisms in the environment, aquatic toxicity, mutagenicity

C. A. Jenkins, **HCFC 123: Acute Toxicity to Rainbow Trout**, report 91/PFE004/0939 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Life Science Research Limited (LSR), Suffolk, UK, 1992 (RDB65D0)

R-123, effects on organisms in the environment, aquatic toxicity, mutagenicity

C. A. Jenkins, **HCFC 123 (Liquid): Biotic Degradation Closed Bottle Test**, report 91/PFE008/-0477 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Life Science Research Limited (LSR), Suffolk, UK, 1992 (RDB65D1)

R-123, effects on organisms in the environment, aquatic toxicity, mutagenicity

C. A. Jenkins, **HCFC 123: Determination of its EC_{50} to Selenastrum Capricornutum**, report 91/-PFE007/0935 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Life Science Research Limited (LSR), Suffolk, UK, 1992 (RDB-65D2)

R-123, effects on organisms in the environment, aquatic toxicity, mutagenicity

D. A. Keller, P. H. Lieder, W. J. Brock, and J. C. Cook (E. I. duPont de Nemours and Company), **1,1,1-Trifluoro-2,2-dichloroethane (HCFC-123) and 1,1,1-Trifluoro-2-bromo-2-chloroethane (Halothane) Cause Similar Biochemical Effects in Rats Exposed by Inhalation for Five Days**, *Drug and Chemical Toxicology*, 21(4):405-415, November 1998 (11 pages, RDBA654)

summarizes comparative toxicity tests in groups of male rats by exposure to air (control) or to 5,000 ppm v/v R-123 or R-123B1 (halothane) for 6 hr/d for 5 consecutive days; indicates that rats exposed to either compound gained little or no weight during the study, their liver weights were slightly lower, serum triglycerides were decreased to approximately 20% of control level, and serum cholesterol was decreased to less than 80% of control; both compounds increased hepatic beta-oxidation by approximately a factor of three over the control animals, and R-123 caused a significant increase in hepatic cytochrome P450 content; results indicate that R-123 and halothane share not only common metabolic pathways, but also several common biological effects, specifically those associated with peroxisome proliferation; these data indicate that human experience with halothane may be useful in the risk assessment of R-123

D. P. Kelly, **Four-Week Inhalation Study with HCFC-123 in Rats**, report 229-89 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1989 (RDB-6157)

R-123, subchronic inhalation toxicity: groups of 10 male and 10 female rats were exposed to concentrations of 0 (control), 1000, 5000, and 10,000 ppm for 6 hr/d, 5 d/wk for 4 weeks; rats exposed to 5000 ppm and higher showed exposure-related narcosis that was reversible upon cessation of exposures; decreased rates of body weight gain were seen in females at 1000 ppm and higher and in males at 10,000 and 20,000 ppm; this effect was not exposure related in females, but was in males; an exposure-related increase in relative liver weights was seen in the females, but only at 20,000 ppm in the males; no hematological effects were observed and the only noteworthy clinical chemistry effects were increases in SGOT and SGPT in the male rats at 20,000 ppm; a dose-related increase in cytochrome P-450 was seen in the female rats at 1000 ppm and higher and in males at 10,000 ppm and higher; urinary fluoride and volume increased with complimentary decrease in osmolarity, reported to be statistically significant only at the high concentrations; no treatment-related effects were seen

in histopathological examination of the livers for either the male or female rats — as reported in RDB65D8 which summarizes this (identified as P-89) and three related studies

J. C. Kennelly, **HCFC 123: Assessment for the Induction of Unscheduled DNA Synthesis in Rat Liver after Inhalation Exposure**, report CTL/P/3807 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Zeneca Central Toxicology Laboratory (then part of ICI Chemicals and Polymers Limited), Cheshire, UK, 4 October 1993 (RDB6215)

R-123, toxicity

M. A. Lee, R. C. Graham, and S. W. Snyder, untitled toxicity review for ethane, 2,2-dichloro-1,1,1-trifluoro- (HCFC-123), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 12 August 1991 (16 pages, RDB5861)

R-123, summary of published and unpublished toxicity literature

R. W. Lewis, **HCFC 123: 28-Day Inhalation Study to Assess Changes in Rat Liver and Plasma**, report CTL/T/2706, ICI Central Toxicology Laboratory, Cheshire, UK, 1990 (RDB6214)

R-123, toxicity

P. H. Lieder, J. C. Cook, and D. A. Keller (E. I. duPont de Nemours and Company), **Similarities in Peroxisome Proliferation and Biochemical Effects between HCFC-123 and Halothane (HCFC-123B1)** [sic HBCFC-123B1] **in Rats**, abstract 1552, *The Toxicologist*, 13(1):396 ff, 1993 (RDB6224)

toxicity of R-123; mechanistic studies based on structural similarity to R-123B1

G. D. Loizou (University of Rochester), G. Urban, W. Dekant (Universität Würzburg), and M. W. Anders (University of Rochester), **Gas-Uptake Pharmacokinetics of 2,2-Dichloro-1,1,1-Trifluoroethane (HCFC-123)**, *Drug Metabolism and Disposition*, 22(4):511-517, July 1994 (7 pages with 5 figures and 3 tables, RDB6223)

in vivo rate constants for metabolism of R-123 in rats, by physiologically-based, pharmacokinetic (PBPK) modeling with validation based on 6-hr inhalation exposures at 500-5,000 ppm v/v; toxicity of R-123; concludes that uptake involves a single, saturable process, with no differences in rate constants between male and female rats; the model fails to simulate the reduction in R-123 uptake at 2,000-5,000 ppm; inhibition of uptake and a decrease in trifluoroacetic acid (TFA, the primary urinary metabolite of R-123) excretion by a selective, mechanism-based inhibitor (diallyl sulfide) indicate that cytochrome P450 2E1 catalyzes the biotransformation of R-123

J. M. Mackay, **HCFC 123: An Evaluation in the In Vitro Cytogenetic Assay Using Human Lymphocytes**, report CTL/P/2978 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Zeneca Central Toxicology Laboratory (then part of ICI Chemicals and Polymers Limited), Cheshire, UK, January 1992 (RDB6572)

R-123, mutagenicity, toxicity

G. Malinverno (Ausimont S.p.A., Italy), **HCFC-123 and Reproductive Toxicity**, *Food and Chemical Toxicology* (FCT), 35(2):305, February, 1997 (1 page, RDBA624)

summarizes a study of the reproductive toxicity of R-123 in rabbits; animals exposed to 5,000 ppm v/v in air for 6 hr/d on days 6-18 of pregnancy did not exhibit fetal malformations; mild maternal toxicity was evidenced by slight decreases in body weight gain and food consumption; also summarizes one- and two-generation rat studies; exposures to 5,000 and 1,000 ppm v/v, respectively, for 6 hr/d, 7 d/wk did not adversely affect reproduction; the offspring in the two-generation study showed reduced body weight gain during lactation in all treatment groups, the lowest of which was 30 ppm v/v

G. Malinverno (Ausimont S.p.A., Italy), G. M. Rusch (AlliedSignal Incorporated, USA), R-J. Millischer (Elf Atochem S.A., France), E. W. Hughes (Huntingdon Research Centre, HRC, UK), R. E. Schroeder (Pharmaco-LSR, Incorporated, USA), and D. W. Coombs (HRC), **Inhalation Teratology and Reproduction Studies with 1,1-Dichloro-2,2,2-trifluoroethane (HCFC-123)**, article 0197, *Fundamental and Applied Toxicology*, 34(2):276-287, December 1996 (12 pages with 10 figures and 2 tables, RDB7233)

R-123, health effects, toxicity: summarizes an inhalation teratology study in rabbits; pregnant specimens were exposed to 0 (control), 500, 1500, and 5000 ppm v/v for 6 hr/d on days 6-18 of gestation; reduced food consumption and slight body weight losses were observed at 500 ppm and higher in an exposure-related pattern, but there were no other signs of maternal toxicity or treatment-related effects on the kits; a one-generation reproduction study in rats is

summarized; four groups of 24 male and female rats were exposed to concentrations of 0 (control), 300, 1000, and 5000 ppm R-123 for 6 hr/d, 7 d/wk for 4 weeks prior to mating and through weaning of the pups; no effects on mating, fertility, pub survival, or birth weight were found; a two-generation study also is summarized; five groups of 32 male and female rats were exposed to R-123 from the age of 6 weeks through weaning; groups of their offspring were exposed from weaning (4 weeks of age) through weaning of the following generation for 6 hr/d, 7 d/wk; exposures were at 0 (control), 30, 100, 300, and 1000 ppm v/v; no treatment-related effects were found on fertility or reproduction, but decreases were measured in serum triglyceride levels; pup survival and birth weight were not affected, but body-weight gain was lower in all treatment groups during nursing in an exposure-related pattern; liver weights of adult rats exposed at 100 ppm and above were higher than in the controls; histopathologic examination found hepatic enlargement and vacuolation; the study concluded that exposure to R-123 at concentrations as high as 5000 ppm did not cause reproductive, survival, or viability effects, but did affect the body weight gain of offspring during lactation and liver weights

L. A. Malley (E. I. duPont de Nemours and Company, Incorporated), M. C. Carakostas (SmithKline Beecham Animal Health), J. F. Hansen (DuPont), G. M. Rusch (AlliedSignal Incorporated), D. P. Kelly (DuPont), and H. J. Trochimowicz (DuPont), **Two-Year Inhalation Toxicity Study in Rats with Hydrochlorofluorocarbon 123**, *Fundamental and Applied Toxicology*, 25(1):101-114, April 1995 (14 pages with 3 figures and 10 tables, RDB65D4)

R-123, combined chronic toxicity and oncogenicity study: four groups of 80 male and 80 female rats were exposed to 0 (control), 300, 1000, and 5,000 ppm R-23 in air for 6 hr/d, 5 d/wk, for up to two years (10 males and 10 females were subjected to clinical pathological examination at 6, 12, 18, and 24 months); males and females exposed to 5000 ppm and females exposed to 300 and 1000 ppm had lower body weights and body weight gains; serum triglyceride and cholesterol were lower in both sexes at 300 ppm except the latter was only seen in males at 5000 ppm; serum protein concentrations were altered at 300 ppm and higher, but survival was notably higher in both sexes, and dramatically so in females, at 1000 and 5000 ppm; relative liver weight increases and absolute kidney weight decreases were observed at the high concentrations; benign hepatocellular adenomas increased in males at 5000 ppm and in females at 300 ppm and higher; hepatic cholangiofibromas also increased in females exposed to 5000 ppm; pancreatic acinar cell adenomas increased for all male test groups and acinar cell hyperplasia was increased in the 1000 ppm and 5000 ppm males and females; benign testicular interstitial adenomas and focal interstitial cell hyperplasia were higher in exposed males, and diffused retinal atrophy was increased in all male and female test groups, though found to be an indirect compound-related effect; hepatic peroxisome proliferation (beta oxidation activity) was higher at 300 ppm and above in males and at 1000 ppm and above in females; statistical differences in hepatic cell proliferation were not observed, and decreased incidences of age-related lesions occurred with exposures at 1000 and 5000 ppm; a NOAEL was not achieved in this study, and recommendations are made for further mechanistic studies particularly with respect to relevance to humans

L. A. Malley, **Combined Chronic Toxicity/Oncogenicity Study with HCFC-123: Two-Year Inhalation Toxicity Study in Rats**, report 669-91 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1992 (RDB6152)

R-123, toxicity — see RDB65D4 for summary

L. A. Malley (E. I. duPont de Nemours and Company, Incorporated), M. C. Carakostas (SmithKline Beecham Animal Health), J. F. Hansen (DuPont), H. J. Trochimowicz (DuPont), and G. M. Rusch (AlliedSignal Incorporated), **Chronic Toxicity of Hydrochlorofluorocarbon HCFC-123**, *The Toxicologist*, 11:103 ff, 1991 (RDB65F0)

R-123, health effects, toxicity

L. A. Malley, **Combined Chronic Toxicity/Oncogenicity Study with HCFC-123: Two-Year Inhalation Toxicity Study in Rats (One-Year Interim Report)**, report 260-90 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1990 (RDB5B62)

R-123, toxicity — see RDB65D4 for summary

L. A. Malley, **Subchronic Inhalation Toxicity Study: 90-Day Study with HCFC-123 in Rats**, report 594-89 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, January 1990 (RDB6154)

R-123, subchronic inhalation toxicity: groups of 10 male and 10 female rats were exposed to concentrations of 0 (control), 300, 1000, and 5000 ppm for 6 hr/d, 5 d/wk for 13 weeks; rats exposed to 5000 ppm showed what might have been slight narcosis that disappeared upon cessation of exposures; no changes were seen in body weights compared to controls; serum triglyceride levels were lower in both males and females at 300 ppm and higher; serum cholesterol levels were significantly lower in females exposed at 1000 and 5000 ppm; the mean lymphocyte count for females in the 5000 ppm group decreased; exposure related increases in urinary fluoride was seen in males exposed to 5000 ppm and in females at 300 ppm and higher, but these increases were described as minimal; absolute liver weights for males were significantly higher in the 5000 ppm group and relative liver weights were higher in males and females at 1000 ppm and higher; no morphological changes were found in tissues with microscopic examination, but hepatic peroxisomal activity increased in treated males and females; this increase was nearly double in high-dose males and females, suggesting a conclusion of very mild peroxisome proliferation — as reported in RDB65D8 which summarizes this (identified as P-90) and three related studies

G. B. Marit (U.S. Air Force Armstrong Laboratory, USAF-AL), D. E. Dodd (ManTech Environmental Technology, Incorporated), M. E. George (USAF-AL), and A. Vinegar (ManTech), **Hepatotoxicity in Guinea Pigs Following Acute Exposure to 1,1-Dichloro-2,2,2-Trifluoroethane**, *Toxicologic Pathology*, 22(4):404-414, July-August 1994 (11 pages with 5 figures and 4 tables, RDB6216)

acute inhalation toxicity tests of R-123 (2,2-dichloro-1,1,1-trifluoroethane) for concentrations of 0, 1,000, 10,000, 20,000, and 30,000 ppm v/v and of 10,000 ppm v/v R-123B1 (halothane) in groups of 10 male Hartley guinea pigs for 4 hr: gross and histopathologic examination of the liver, heart, and kidney as well as routine hematology and clinical chemistry analyses were performed after sacrifice of the animals 48 hr after the exposures; lesions were observed in the livers of 90-100% of the exposed animals, but were absent in the controls; the lesions included centrolobular vacuolar (fatty) change, multifocal random degeneration and necrosis, and centrolobular degeneration and necrosis; significant variation in susceptibility was observed, but there was similarity in the response between R-123 and halothane; the paper concludes that humans susceptible to halothane-induced hepatitis may be susceptible to R-123 by a common mechanism; the paper also notes that all guinea pigs exposed to 10,000 ppm v/v R-123B1 or 20,000-30,000 ppm v/v were rendered unconscious within 10-15 minutes of exposure and that some animals exposed to lower concentrations were uncoordinated or lethargic

R. R. Marshall, **Evaluation of Chromosomal Aberrations Frequencies in Cultured Peripheral Blood Lymphocytes from Rats Treated with HCFC-123**, report ALS/4-R (also identified as ASU 1/RLC or 1RLRE ASU.001) for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Hazleton Microtest, Harrogate, North Yorkshire, UK, 1992 (RDB6221)

R-123, health effects, toxicity

J. L. Martin, J. W. Harris, M. W. Anders, and L. R. Pohl (Johns Hopkins Medical Institute), **Trifluoroacetylated Proteins in Livers of Rats Treated with the Potential Chlorofluorocarbon Replacement 1,1,1-Trifluoro-2,2-dichloroethane (HCFC-123)**, abstract A348, *Anesthesiology*, 73(3A), September 1990 (1 page with no figures or tables, RDB7232)

inhalation toxicity tests for metabolism of R-123 (2,2-dichloro-1,1,1-trifluoroethane) in groups of male, Fischer 344 rats exposed for 2 hr to 0 (control), 7,000, or 11,000 ppm v/v and, for comparison, another group to 13,000 ppm v/v R-123B1: both compounds were found to produce identical patterns of trifluoroacetyl (TFA) labeled proteins; concludes that further metabolic and toxicologic studies of R-123 are needed based on the possibility (not established) of sensitization and increased risk for hepatic damage from repeated exposures or following anesthesia with enflurane or halothane (R-123B1) [see RDB6213, RDB6223, RDB65C2, RDB6A99, RDB65C7, RDB65E1, RDB65E2, and others for further investigations of this topic]

Meridian Research, Incorporated, **Results of Employee Exposure Monitoring for HCFC-123 at Centrifugal Chiller Installations**, U.S. Environ-

mental Protection Agency (EPA), Washington, DC, 26 November 1991 (82 pages, RDB2529)

R-123, toxicity, machine room concentrations, *occupational exposures*

MPI Research, **HCFC-123: Inhalation Study in Pregnant Monkeys to Assess Milk Transfer and Composition Following Postpartum Exposures**, report HLO-197-00152 (also identified as MPI study 125-042), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1997 (RDB7611)

mechanistic toxicity tests in Rhesus monkeys to investigate the transfer of R-123 and its major metabolite, trifluoroacetic acid (TFA), in milk from exposed mothers to nursing infants: groups of 4 mothers and infants were exposed to 0 (control) or 1,000 ppm v/v in air by inhalation for 6 hr/d, 7 d/wk for 3 wk beginning 6-8 days following birth; no changes were observed in maternal weight gain, clinical signs deemed adverse, or blood chemistry (including triglyceride, cholesterol, and glucose levels); no effect was found on milk production or milk fat and protein content, but both R-123 and TFA were detected in the milk and TFA was found in maternal blood; slight, microscopic evidence of liver toxicity (focal cytotoxicity) was found in the mothers at study termination, but was deemed to be reversible; no increases were found in ß-oxidation activity; infants showed neither adverse clinical signs nor body weight changes compared to control animals; TFA measurements in the blood of infants were three times higher than in the mothers; study concluded that there was no adverse consequence to the infant monkeys because of lactation exposure to either R-123 or its metabolite — as reported in RDB8611 [WEEL documentation notes that the absence of changes in infant weight gains with monkeys is significant; this finding supports the hypothesis that decreases in rat pup weight gains, previously observed in other studies, is due to peroxisome proliferation, to which primates do not respond]

L. S. Mullin, **Fluorocarbon 123 (2,2-Dichloro-1,1,1-trifluoroethane): Behavioral Toxicity Testing**, report 941-76, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 10 December 1976 (4 pages with 2 tables, RDB6153)

toxicity tests to determine the concentrations at which behavioral effects occur for whole-body exposures of groups of 6 male Charles River CD rats to 0 (control), 1,000, 2,500, 5,000, or 10,000 (0, 975, 2,697, 5,237, and 9,950 actual) ppm v/v R-123 in air for 1 hr: effects were measured on a pass-fail basis for a suite of tests to evaluate unconditioned reflexes, simple behavioral patterns, locomotor activity, and observation of unusual signs or symptoms; effects were measured before exposures, at 15, 30, and 60 min during exposures, and at 15 min, 60 min, and 24 hr after exposures; EC_{50} values were calculated by probit analysis; results for the most sensitive tests — grip, lift, vertical bar, ataxia (inability to coordinate voluntary muscular movements), and pinna tactile (response to touching of an ear) were >10,000 ppm before exposures, 7,080-9,710 ppm at 15 min, 5,790-8,660 at 30 min, 3,930-8,830 at 60 min, and >10,000 after exposures; report notes that ataxia and catatonia (decrease in spontaneous activity) were evident 15 min into exposures and loss of exploratory activity was evident at 30 min for exposures at 9,950 ppm; mean body temperature of rats exposed to 5,237 and 9,950 ppm were lower than controls (by approximately 1 °C, 1.8 °F, at 9,950 ppm at 60 min of exposure); study concluded that behavioral test failures were produced consistently at and above 5,237 ppm during exposure, that occasional failures were seen 15 min after exposure at 9,950 ppm, and that recovery was rapid and complete in all cases

W. Müller and T. Hofmann (Pharma Research Toxicology and Pathology Laboratory), **HCFC 123 — Micronucleus Test in Male and Female NMRI Mice After Inhalation**, report 88.1340 (on study 88.0372) for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Hoechst Aktiengesellschaft, Frankfurt am Main, Germany, 1988 (RDB6141)

R-123, mutagenicity, toxicity

J. D. Obourn (E. I. duPont de Nemours and Company, Incorporated), S. R. Frame (DuPont), R. H. Bell, Jr. (University of Washington School of Medicine, Seattle Veterans Affairs Medical Center), D. S. Longnecker (Dartmouth Medical School), G. S. Elliott (DuPont), J. C. Cook (DuPont), **Mechanisms for the Pancreatic Oncogenic Effects of the Peroxisome Proliferator Wyeth-14,643**, *Toxicology and Applied Pharmacology* (TAP), 145(2):425-436, August 1997 (12 pages, RDB-A649)

toxicity of R-123; examines the role of peroxisome proliferation in producing pancreatic aci-

nar cell hyperplasia and adenocarcinomas in rats as detected in 2-yr bioassays; summarizes *in vitro* and *in vivo* approaches used to investigate mechanisms of pancreatic tumorigenesis by peroxisome proliferating compounds

T. L. Pravecek (U.S. Air Force, USAF) and S. R. Channel (Tri-Service Toxicology Consortium), **A Volatile Exposure Method for Precision Cut Tissue Slices: HCFC-123 Study**, *In Vitro Toxicology*, 8(3):283-289, 1995 (7 pages with 5 figures and 1 table, RDB6A99)

R-123 toxicity: application of precision-cut tissue slice cultures to study the metabolic fate and toxicologic effects of chemicals; data describe a saturable metabolic pathway for R-123 in Sragues-Dawley rats; analyses of R-123 metabolism in rat livers suggest significant strain differences and that R-123 may inhibit its own metabolism at higher concentrations

G. M. Rusch (AlliedSignal Incorporated), H. J. Trochimowicz (E. I. duPont de Nemours and Company, Incorporated), L. A. Malley (DuPont), D. P. Kelly (DuPont), J. Peckham (Experimental Pathology Laboratory), J. Hansen (DuPont), and J. B. Charm (AlliedSignal), **Subchronic Inhalation Toxicity Studies with Hydrochlorofluorocarbon 123 (HCFC 123)**, *Fundamental and Applied Toxicology*, 23(2):169-178, August 1994 (10 pages with 11 tables, RDB65D8)

summarizes four subchronic inhalation toxicity studies in rats and dogs for R-123: increases in liver weight were seen at concentrations of 1000 ppm and higher; one study showed this effect at 500 ppm; histopathological findings are described as minimal and include focal necrosis (death of a portion of tissue) in the liver of dogs, induction of peroxisomal activity, lowering of serum cholesterol and triglyceride levels, and an increase in urinary fluoride levels; paper observes that while the 4-hr LC_{50} rat is 35,000 ppm, repeated exposures at 20,000 ppm (almost the same daily dose for the product of concentration and time) for 6 hr/d in a 4-week study yielded no mortality or marked signs of toxicity; concludes that R-123 "appears to have a low level of toxicity by the inhalation route" and that there is "no evidence for cumulative toxicity from multiple exposures in these studies"

G. M. Rusch, **A Ninety-Day Inhalation Toxicology Study and an Inhalation Teratology Study of Genetron 123 in the Rat**, report MA-127-80-1 (also identified as MA-RR-85-993), AlliedSignal Incorporated (then Allied Corporation), Morristown, NJ, 19 September 1985 (>61 pages with ·12 tables, Rdb6142) [includes RDB6143 and RDB6144 as appendices A and C]

examination and summary of the findings of two R-123 toxicity studies (IBT reports 8562-09344 dated 2 September 1977 and 8 November 1977, see RDB6143 and RDB6144) conducted by Industrial Bio-Test Laboratories, Incorporated: outlines the earlier findings, describes a review of the raw data, and compares earlier interpretations with those from reexamination of the original tissue specimen slides by a pathologist; report concludes that 500 (487 ppm actual) ppm v/v is a no-effect level (NOEL) for rat exposures to R-123 by inhalation for 6 hr/d, 5 d/wk, for 3 months while 1,000 (1,009 actual) ppm represents a minimal biological effect level; notes that hepatic alterations identified in the earlier reports did not follow an exposure-related pattern by either severity or frequency and that they probably were not related to the exposures; also concludes that primary effect was depression of body weight gain in the female rats; addressing the teratology study, the report concludes that exposure of pregnant rats for 6 hr/d for days 6-15 of gestation to a concentration of 5,000 (4,495-6,065 actual) ppm v/v produced a response of depressed weight gain in the dams, but did not result in a teratogenic response [prepared from partial report with missing pages]

J. Sandow, W. von Rechenberg, and G. Jerabek-Sandow (Hoechst AG Pharma Research), **HCFC-123: Effect of HCFC-123 and Androgen Biosynthesis and Gonadotropin Secretion in Rats**, report MA-RR-95-2196 (also identified as Hoechst report 1/94 and as "Hoechst study Exp. 8-210 as part of Huntingdon Toxicology Study ALS/5") for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), AlliedSignal Incorporated, Morristown, NJ, 30 April 1995 (34 pages with 4 figures and 2 tables, RDB65D9)

toxicity tests to investigate the mechanism of testicular changes (Leydig cell hyperplasia) found in adult male Wistar rats after long-term (22-week) exposures to R-123: tests examined the serum luteinising hormone (LH) response, testosterone secretion, and testosterone biosynthesis ex vivo to develop understanding of the endocrine mechanism, which if deemed to be reversible in rodents would be of no concern for human safety; report concludes that there was no qualitative change in androgen biosynthesis and "the small decrease in testosterone

secretion observed at 1000 ppm was not of concern for further compound development because Leydig cell hyperplasia is a rodent-specific finding in rats and mice rarely observed in humans;" report also notes that R-123 poses "a low risk for human exposure in industrial application"

R. Schroeder (Bio/dynamics Incorporated), **An Inhalation Developmental Toxicity Study in Rabbits with HCFC-123**, report 88-3304 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, September 1989 (RDB6162)

study of the potential for R-123 to produce developmental and reproductive toxicity in New Zealand rabbits by exposure of pregnant dams to 0 (control), 500, 1,500, or 5,000 ppm on gestation days 6-18; maternal toxicity was evident at all concentrations with decreased food consumption and bodyweight gain — as reported in RDB6B52

R. Schroeder (Bio/dynamics Incorporated), **An Inhalation Range-Finding Study to Evaluate the Toxicity of HCFC-123 in the Pregnant Rabbit**, report 88-3303, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1989 (RDB6163)

study of the potential for R-123 to produce developmental and reproductive toxicity in New Zealand rabbits by exposure of pregnant dams

H. W. Sibley, **A Study for Determining Refrigerant Exposure Levels While Servicing an HCFC-123 Centrifugal Chiller**, publication 819-061, Carrier Corporation, Syracuse, NY, April 1992 (8 pages with 4 figures and 1 table, RDB2916)

This report summarizes an investigation to determine the exposure levels encountered while working around or on chillers using R-123. It also addresses whether there are reliable instruments to measure that low, and whether a machine room can be adequately monitored and ventilation controlled to stay below a recommended exposure limit of 10 ppm [subsequently raised by some refrigerant manufacturers]. The single test involved a 700 kW (200 ton) hermetic centrifugal chiller at the manufacturer's plant. The report outlines steps to select and qualify refrigerant sensors, develop a decision model for the test, prepare a team for use of the refrigerant monitors and safety equipment, develop service practices, and execute the plan. It was based on removal of R-123 from the machine and recharge with R-11. Additional steps were scheduled between charge removal and recharging, to determine the effects on components exposed to R-123 in a year of operation. For purposes of this test, the exhaust fans in the machinery room were reset from 10 ppm to operation when concentrations exceeded 500 ppm. A table lists the R-123 monitors used, and a figure outlines the safety decision model developed. A figures shows measured exposure concentrations, with two excursions to approximately 500 ppm, and time-weighted average (TWA) exposures of 2-5 ppm. The report notes that once R-123 was released, "it tended to drop to floor level, hang together, and move as an invisible cloud." One part of the plan included a deliberate spill of 1 litre (¼ gallon), deemed the maximum that would be lost during a typical accident. A plot shows the resulting concentrations. The report concludes that new methods and procedures will have to be employed to minimize exposures. A brief addendum to the report notes concentrations in field restoration of three other chillers from R-123 back to R-11 use.

E. Sullivan, **Refrigerant Safety, Worker Health, and HCFC-123**, *Building Operating Management*, 46-48, August 1997 (3 pages with no figures or tables, RDB7B47)

reviews new occupational exposure limits recommended by the American Industrial Hygiene Association (AIHA) and DuPont Chemicals for R-123 in layman's terms; a sidebar summarizes the mechanistic tests that led to the AIHA Workplace Environmental Exposure Limit (WEEL) and DuPont Acceptable Exposure Limit (AEL) of 50 ppm v/v on a time-weighted-average basis; quotes a number of toxicologists and manufacturers representatives on the safety implications and recommended procedures for use of refrigerants and R-123 in particular; contrasts the new limits to concentrations normally encountered; compares the safety of R-123 to R-11 which it replaces; concludes that all refrigerants can be used safely if recommended procedures are followed

T. Takebayashi (Keio University School of Medicine, Japan), I. Kabe, Y. Endo, S. Tanaka (Kitasato University, Japan), H. Miyauchi, K. Nozi, S. Imamiya, K. Takahashi, and K. Omae, **Exposure to 2,2-Dichloro-1,1,1-trifluoroethane (HCFC-123) and Acute Liver Dysfunction: A Causal**

Inference, *Journal of Occupational Health*, Japanese Society of Occupational Health, Tokyo, Japan, 40(4):334-338, October 1998 (2 pages, RDB-A927)

describes an investigation of reversible liver toxicity from chronic occupational exposures by inhalation in an industrial setting; reports acute liver dysfunction among workers repeatedly exposed to R-123; estimates levels of exposure by reproducing working conditions and by a job record survey; describes health surveillance, including liver function and subjective symptoms, initiated when two workers first complained of ill health; indicates that the mean R-123 concentration in air exceeded 200 ppm v/v with a peak of approximately 1,000 ppm v/v; notes that concentrations of 18-24 ppm v/v were detected in the adjacent areas; describes classification of workers into groups according to their estimated exposure levels, confirmed by determination of urinary trifluoroacetic acid (TFA, a metabolite of R-123), to examine causality; notes that some workers also reported symptoms involving the central nervous system, digestive organs, and mucous membranes; indicates that the degree and prevalence of these health effects were higher in the high-exposure group suggesting an exposure-effect and exposure-response relationship; discusses the consistency and temporality of observed health effects in relation to R-123 exposure levels; concludes that repeated exposure to high concentrations of R-123 for no more than five weeks causes acute liver dysfunction in humans that can be severe and manifest itself in various symptoms; recommends that biological plausibility should be clarified to confirm the causality; case report of hepatotoxicity

T. Takebayashi (Keio University School of Medicine, Japan) I. Kabe, Y. Endo, S. Tanaka (Kitasato University, Japan), H. Miyauchi, K. Nozi, K. Takahashi, and K. Omae, **Acute Liver Dysfunction among Workers Exposed to 2,2-Dichloro-1,1,1-trifluoroethane (HCFC-123): A Case Report**, *Journal of Occupational Health*, Japanese Society of Occupational Health, Tokyo, Japan, 40(3):169-170, July 1998 (2 pages, RDBA928)

case report of reversible liver toxicity from chronic occupational exposures by inhalation of R-123 in an industrial setting; hepatotoxicity

S. Tanaka (Kitasato University, Japan), I. Kabe, T. Takebayashi (Keio University School of Medicine, Japan), Y. Endo, H. Miyauchi, K. Nozi, K. Takahashi, Y. Seki, and K. Omae, **Environmental and Biological Monitoring of 2,2-Dichloro-1,1,1-trifluoroethane (HCFC-123)**, *Journal of Occupational Health*, Japanese Society of Occupational Health, Tokyo, Japan, 40(4):348-349, October 1998 (2 pages, RDBA929)

case report of reversible liver toxicity from chronic occupational exposures by inhalation of R-123 in an industrial setting; investigation of exposure levels; hepatotoxicity

H. J. Trochimowicz (E. I. duPont de Nemours and Company, Incorporated), **The Toxicology of HCFC-123 (2,2-Dichloro-1,1,1-Trifluoroethane)**, *Proceedings of the European Meeting of the Toxicology Forum* (Toulouse, France, 18-22 September 1989), Société Française de Toxicologie, France, 182-190, 1989; republished in the *Journal of the American College of Toxicology* (JACT), 8(6):1220 ff, 1989 (9 pages comprising an abstract and presentation outline, RDB6145)

R-123, toxicity: ALD oral rat = 9,000 mg/kg; LD_{50} rat = 2,000 mg/kg; 4-hr LC_{50} rat = 32,000 ppm; cardiac sensitization EC_{50} dog = 19,000 ppm; dose-related, anesthetic effects observed in rats at 5,000 ppm during 15-minute inhalation exposures in a glove box, NOEL at 2,500 ppm; not mutagenic, embryotoxic, fetotoxic, or teratogenic; low in toxicity on a subchronic basis; chronic inhalation toxicity study underway

H. J. Trochimowicz and L. S. Mullin, **Cardiac Sensitization Potential (EC_{50}) of Trifluorodichloroethane**, report 132-73 (FYI-OTS-0889-0695), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 30 March 1973 (8 pages with 1 table, RDB6146)

summarizes tests of the cardiac sensitization potential of R-123 in healthy, male, beagle dogs with control injection of adrenalin before exposure and a challenge injection after inhalation for five minutes; target concentrations of 5,000, 10,000, 20,000 and 80,000 ppm v/v bracketed the estimated median effective concentration (EC_{50}) of 40,000 ppm v/v using a "staircase method," by which tests at 80,000 ppm v/v were eliminated based on results from the lower concentrations; actual concentrations were determined using by gas chromatography (GC) by samples taken at 75 sec intervals; 7 of the 12 dogs tested exhibited marked responses, 6 of which resulted in ventricular fibrillation (very rapid and irregular contractions of the ventricles of the heart resulting in loss of synchronization between the heartbeat and pulse beat); and death; notes that obvious cen-

tral nervous system depression (decreased motor reflexes and lassitude) as well as tachycardia were observed prior to adrenalin injection in the 6 dogs that died; reports marked responses in 0 of 3 dogs tested at 10,300 ppm v/v, 4 of 6 = 20,900 ppm v/v, and 3 of 3 at 40,600 ppm v/v; reports NOEL 0/3 as 10,300 ppm v/v, LOEL 4/6 as 20,900 ppm v/v, and a calculated EC_{50} as 19,000 ppm; notes an estimated cardiac sensitization EC_{50} for R-11 of 12,400 ppm v/v; toxicity data

G. Urban and W. Dekant (Universität Würzburg), **Metabolism of 1,1-Dichloro-2,2,2-trifluoroethane in Rats**, *Xenobiotica*, 24(9):881-892, September 1994 (12 pages, RDB8404)

toxicity of R-123: metabolism tests with two male rats individually exposed to radiolabeled R-123 in air for 6 hr; 14% was recovered in urine within 48 hr; trifluoroacetic acid (TFA) was the major metabolite and N-trifluoroacetyl-2-aminoethanol and N-acetyl-S-(2,2-dichloro-1,1-difluoroethyl)-L-cysteine were identified as minor urinary metabolites; urinary excretion of these metabolites was very slow; examination of the sacrificed animals showed covalent binding of the metabolites to protein to be highest in the liver followed by the kidneys and lungs; no covalent binding above background levels was observed in the pancreas or testis, noted as the target organs of R-123 tumorigenicity; results suggest that the biotransformation of R-123 in rodents follows a pathway identical to that of R-123B1 (halothane), an extensively studied structural analog

G. Urban, P. Speerschneider, and W. Dekant (Universität Würzburg), **Metabolism of the Chlorofluorocarbon Substitute 1,1-Dichloro-2,2,2-trifluoroethane by Rat and Human Liver Microsomes: The Role of Cytochrome P450 2E1**, *Chemical Research in Toxicology*, 7(2):170-176, March 1994 (7 pages with 8 figures and 3 tables, RDB65E1)

toxicity of R-123 (2,2-dichloro-1,1,1-trifluoroethane; shows that trifluoroacetic acid (TFA) is a major metabolite of R-123; also indicates that chlorodifluoroacetic acid and inorganic fluoride also are products of the enzymatic oxidation of R-123 in rat and human liver microsomes; concludes that cytochrome P450 2E1 plays a major role in metabolism of R-123 and its analog R-123B1 (halothane) in vitro

G. Urban and W. Dekant (Universität Würzburg), **The CFC Substitute 2,2-Dichloro-1,1,1-Trifluoroethane Is Primarily Oxidized by Cytochrome P450 2E1**, abstract 1704, *The Toxicologist*, 13:431, 1993 (1 page, RDB65E4)

R-123, toxicity

A. Vinegar, D. E. Dodd, D. L. Pollard (ManTech Environmental Technology, Incorporated), R. J. Williams, and J. N. McDougal (Armstrong Laboratory, U.S. Air Force), **Pharmacokinetics of HCFC-123 in Dogs**, report AL/OE-TR-1995-0025, Armstrong Laboratory, U.S. Air Force (USAF), Wright-Patterson Air Force Base, OH, 1995 (104 pages with 8 figures and 20 tables, available from JMC as RDB6573)

R-123, biochemistry, health effects, toxicity

A. Vinegar, R. J. Williams, J. W. Fisher (ManTech Environmental Technology, Incorporated), and J. N. McDougal (Armstrong Laboratory, U.S. Air Force), **Dose-Dependent Metabolism of 2,2-Dichloro-1,1,1-trifluoroethane: A Physiologically Based Pharmacokinetic Model in the Male Fischer 344 Rat**, *Toxicology and Applied Pharmacology* (TAP), 129(1):103-113, November 1994 (11 pages, RDB65E2)

R-123, toxicity

D. B. Warheit, **Mechanistic Studies with HCFC-123**, report 828-92, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1993 (RDB6159)

R-123, toxicity

R. S. Waritz and J. W. Clayton, **Acute Inhalation Toxicity on 1,1-Dichloro-2,2,2-trifluoroethane (FC-123, Commercial Grade)**, report 16-66, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 4 February 1966 with correction dated 12 May 1966 (two pages with no figures or tables, RDB6150)

acute inhalation toxicity tests of R-123 (2,2-dichloro-1,1,1-trifluoroethane) in six male Charles River CD rats by 4 hr, whole body exposures; actual concentrations were determined by gas chromatography; notes that rats showed immediate unresponsiveness followed by loss of balance, unconsciousness, hyperemia, irregular breathing, and lacrimation before death, but that surviving rats regained consciousness within 5 min of the exposures; also notes slight weight loss on the day following exposures, but normal growth and behavior thereafter; also notes that rats exposed to sublethal concentrations of 16,480-18,900 ppm v/v

showed the same clinical signs seen at lethal levels, but coordination returned within 10 min following exposures; gross examinations at necropsy revealed no treatment-related effects; microscopic examination showed marked congestion in the lungs, kidney, and liver as well as edema in the lungs of the rats that died during an exposure suggesting respiratory irritation at high concentrations; none of the survivors had microscopically observable tissue effects that were attributed to the exposures; indicates a 4 hr LC_{50} rat of 35,000 ppm; warns that the LC_{50} is less than the saturated vapor concentration and that anesthetic effects make self rescue doubtful at high concentrations

R. J. Williams (U.S. Air Force Armstrong Laboratory, USAF-AL), A. Vinegar (ManTech Environmental Technology, Incorporated), J. N. McDougal (USAF), A. M. Jarabek (U.S. Environmental Protection Agency, EPA), and J. W. Fisher (USAF-AL), **Rat to Human Extrapolation of HCFC-123 Kinetics Deduced from Halothane Kinetics: A Corollary Approach to Physiologically Based Pharmacokinetic Modeling**, *Fundamental and Applied Toxicology*, 30(1):55-66, March 1996 (12 pages, RDB7C68)

development and of a human, physiologically based pharmacokinetic (PBPK) model for R-123 and its major metabolite, trifluoroacetic acid (TFA): corollary approach was developed in the absence of available human kinetic data for R-123, noted as a structural analog of the common anesthetic agent R-123B1 (halothane); both follow a common pathway of oxidative biotransformation, resulting in formation of TFA; models were developed and validated for halothane for rats and humans; a corollary approach then was used to develop the human R-123 model; this strategy was implemented by using a previously validated PBPK model for R-123 and TFA in the Fisher 344 rat as a template; metabolic constants for halothane in the rat were used in the human model, and specific parameters describing the kinetics of TFA were estimated by optimization; the model was validated against published human-exposure data for halothane; a similar approach was then used to derive the R-123 model; use of this PBPK model is proposed for deriving dose-response estimates of health risks in the absence of human kinetic data

Crossover Study with HCFC-123 in Lactating Sprague-Dawley Rats Including Additional Studies on Milk Production and Metabolites in Offspring Urine, report 95/9 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Fraunhofer Institute of Toxicology and Aerosol Research, Hannover, Germany, 1996 (RDB7610)

tests of R-123 developmental and reproductive toxicity by exposure of pregnant and/or lactating rats to 0 (control) or 1,000 ppm v/v for 6 hr/d on days 6-19 of gestation and 5-21 post partum, to evaluate the effects on offspring with cross fostering: control pups (from mothers in the control group) nursed by treated mothers showed reduction in body weight gain during the nursing period; pups from treated mothers nursed by control mothers did not; no effect was found on milk production or the nutritional composition of the milk from exposed mothers, but the milk contained the major metabolite of R-123, trifluoroacetic acid (TFA); report concludes that the adverse effects occurred by transfer of the TFA in maternal milk, and were not attributable to developmental toxicity — as reported in RDB8611

1,1-Dichloro-2,2,2-trifluoromethane (HCFC-123, CAS No. 306-83-2), Joint Assessment of Commodity Chemicals (JACC) report 33, European Chemical Industry Ecotoxicology and Toxicology Centre (ECETOC), Brussels, Belgium, February 1996 (68 pages with 2 figures and 11 tables, RDB-65E8)

R-123, 2,2-dichloro-1,1,1-trifluoroethane, environmental impacts, toxicity

1,1-Dichloro-2,2,2-trifluoroethane (HCFC 123) Health Effects Information, CAS# 306-83-2, Elf Atochem North America, Incorporated, Philadelphia, PA, undated circa 1995 (5 pages, RDB5B53)

R-123, 2,2-dichloro-1,1,1-trifluoroethane, summary of toxicological and ecological information

2,2-Dichlor-1,1,1-trifluorethan Toxikologisch-arbeitsmedizinische Begrundung von MAK-Werten (Maximale Arbeitsplatz Konzentrationen) [Toxicological and Occupational Medical Basis for the 2,2-Dichloro-1,1,1-trifluoroethane MAK Values (Maximum Workplace Concentrations), Deutsche Forschungsgemeinschaft [German Research Association] (DFG), Bonn, Germany, 1994 (18 pages, RDB6AA0)

R-123, documentation for listing as a III B compound [substances suspected of having carcinogenic potential and subject to reevaluation, for assignment to category III A (unequivocally carcinogenic substances) or dismissal from the category] in the German occupational exposure limits for chemicals

2,2-Dichloro-1,1,1-trifluoroethane (HCFC-123) — Priority Existing Chemical 4, full public report, National Industrial Chemicals Notification and Assessment Scheme (NICNAS), Worksafe Australia, Sidney Australia, March 1996 (134 pages, available from the Australian Government Publishing Service, RDBA403)

toxicity and environmental risk assessment of R-123

2,2-Dichloro-1,1,1-trifluoroethane (HCFC-123) — Priority Existing Chemical 4 Secondary Notification Assessment, full public report, National Industrial Chemicals Notification and Assessment Scheme (NICNAS), Worksafe Australia, Sidney Australia, July 1999 (142 pages, RDBA404)

toxicity and environmental risk assessment of R-123

Report on Testing and Analysis of the Concentration of HCFC-123 in Field Installations with General Machinery Rooms Containing Hermetic Centrifugal Chillers, report CFC-1, The Trane Company, La Crosse, WI, October 1991 (34 pages with 14 figures and 15 tables, limited copies available from JMC as RDB2246)

This report provides measured data on R-123 concentrations in equipment rooms housing hermetic centrifugal chillers. Twelve sites, representing a broad range of applications, were tested during normal operation. Additional data were taken at two sites during refrigerant transfers. Measurements were made by gas chromatography, both on site and using activated charcoal tubes (subsequently analyzed in laboratories). All of the sites except one were determined to have concentrations substantially less than 1 ppm, if any. Concentrations above minimum quantifiable levels, 0.33-0.56 ppm, were detected in only two cases. Leakage from empty, but improperly sealed, refrigerant drums was identified as the probable cause for one site. The sources in the other were improperly sealed drums and a leak from the purge vent line. The latter was ascribed to improper field installation and use of incompatible piping materials. A retest of this site, after corrections, found concentrations in line with the others. Reports on the individual sites and summary discussion describe the tests and safety considerations for refrigerants. The findings emphasize the importance of following proper refrigerant handling and storage procedures as well as installation recommendations.

Report of Worker Exposure to HCFC-123 During Servicing of Hermetic Centrifugal Chillers, report CFC-2, The Trane Company, La Crosse, WI, May 1992 (16 pages with 3 figures and 9 tables, limited copies available from JMC as RDB-2908)

This report addresses the safety aspects of exposure of service personnel to R-123 during the full range of service procedures for centrifugal chiller applications. Earlier toxicity findings and implications are reviewed as background. The report then documents the measured concentrations during refrigerant transfer, routine maintenance, and major service from three different installations. Chronic (long-term), acute (short-term intermittent), and emergency acute exposure considerations are outlined. The measurement procedures are described; they used activated charcoal tubes subsequently analyzed by gas chromatography in laboratories, and on-site infrared vapor analyzers. Time-weighted average (TWA) exposures are tabulated for the chronic exposures, ranging from less than the limit of quantification (LOQ) to 1.9 ppm. Peak concentrations and durations are tabulated for the intermittent, acute exposures. Test reports are included to describe each site and provide detailed measured data. The report concludes that the long-term concentrations observed were more than five times below the allowable exposure limit (AEL) of 10 ppm [subsequently raised by some refrigerant manufacturers]. The instantaneous concentrations were well within the 30-50 ppm limits based on guidelines developed by the American Conference of Governmental Industrial Hygienists (ACGIH). The findings emphasize the importance of following proper handling and storage procedures for refrigerants and installation recommendations of ASHRAE Standard 15R [now 15-1992].

Workplace Environmental Exposure Level Guide — 1,1,1-Trifluoro-2,2-dichloroethane, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1998 (11 pages with 2 tables, RDB-8611)

documents determination of a Workplace Environmental Exposure Level (WEEL) Guide for R-123; summarizes identifiers, chemical and physical properties, uses, production quantities, toxicology tests conducted in animals (acute, subchronic, chronic, carcinogenicity, reproductive, developmental, genotoxicity, mutagenicity, metabolism, pharmacokinetics, and mechanistic); reviews human uses and exposures expe-

rience; discusses a rationale for setting the occupational exposure limit; indicates that R-123 induces a slight anesthetic effect at 5000 ppm v/v; notes that increased incidence of microscopic tumors in rats, found to be both benign (nonmalignant) and not life threatening, were due to induction of peroxisome proliferation and thus of little relevance to humans; discusses reversible hepatic lesions observed in monkeys, dogs, and guinea pigs at 1,000, 10,000, and 5,000 ppm v/v, respectively; allowing an inter- and intraspecies safety factor, recommends a WEEL guide of 50 ppm (310 mg/m^3) for 8-hr on a time-weighted average (TWA) basis; includes 64 references

Workplace Guidelines for Suva Centri-LP (HCFC-123) in Refrigeration and Air Conditioning Applications, document AS-5 (H-53018), DuPont Chemicals, Wilmington, DE, November 1993 (4 pages with 2 tables, RDB4C50)

This bulletin presents recommended workplace guidelines for use of R-123 in air-conditioning and refrigeration applications. It notes that DuPont has concluded that R-123 poses no acute (short-term, single exposure) or chronic (long-term, repeated exposure) hazard when handled in accordance with recommendations and when exposures are maintained at or below its recommended Acceptable Exposure Limit (AEL). The bulletin indicates that the AEL for R-123 has been set at 30 ppm for exposures of 8 or 12 hours daily or 40 hours weekly on a time-weighted average (TWA) basis. It also notes that DuPont has set an Emergency Exposure Limit (EEL) of 1000 ppm for up to 1 hour, with a 1 minute ceiling of 2500 ppm. The bulletin recommends that users read and understand the Material Safety Data Sheet (MSDS) and presents guidance for storage, handling, and use of R-123. It notes that ASHRAE Standard 15 requires area monitors to detect refrigerant concentrations and additional guidance on system and machinery room design. A table recommends alarm levels and appropriate actions for increasing detection levels. A second table outlines minimum respirator protection for concentrations exceeding the cited AEL. The bulletin identifies prohibited uses for R-123, personal protective equipment, and storage and handling procedures. It also recommends safety measures for system charging, maintenance, and sampling as well as responses to leaks or spills. DuPont's product names for R-123 are Suva® Centri-LP and Suva® 123.

report 57-95, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1995 (RDB7235)

presents a subchronic inhalation toxicity studyo f in male rats; examines biochemical changes and peroxisome proliferation for exposures to 5,000 ppm v/v for 6 hr/d for 5 days

R-123B1

K. D. Hall and F. H. Norris, Jr., **Fluothane Sensitization of Dog Heart to Epinephrine**, *Anesthesiology*, 19:631-641, September-October 1958 (11 pages, RDB6565)

identifies R-123B1 as a cardiac sensitizer — as reported in RDB5644

J. Raventós, **The Action of Fluothane — A New Volatile Anaesthetic**, *British Journal of Pharmacology*, 11:394-410, 1956 (17 pages, RDB7365)

toxicity tests of R-123B1 with focus on its anesthetic effects

R-124

F. C. Barsky, **In Vitro Microbial Mutagenicity Studies of 1-Chloro-1,2,2,2-tetrafluoroethane**, report 349-76 (TSCAT report OTS-0530589), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 4 May 1976 (RDB-6178)

R-124, genotoxicity, health effects, mutagenic potential, toxicity as reported in RDB5863 and RDB5B54

Bio/dynamics Incorporated, report 89-3513, Allied-Signal Incorporated, Morristown, NJ, 1991 (RDB-6177)

R-124, health effects, toxicity as reported in RDB5863

W. E. Brewer and S. Smith (Industrial Bio-Test Laboratories, Incorporated), **Teratogenic Study via Inhalation with Genetron 124 in Albino Rats**, report MA-RR-89-1493 (also identified as IBT 8562-09345 and as TSCAT report OTS-0000695-2), AlliedSignal Incorporated (then Allied Chemical Corporation), Morristown, NJ, 8 November 1977 (32 pages with 10 tables, RDB6173)

toxicity test of the teratogenicity of R-124 in groups of 20 female Charles River albino rats by inhalation exposures at 0 (control) or 5,000

(4,424-5,527 actual) ppm for 5 hr/d on gestation days 6-15: no difference was found in the maternal body weights and body weight gains between the test and control groups; some animals in both groups had red nasal discharges; the number of resorption sites were slightly higher and the number of pregnancies was 20 in the test group versus 16 in the control group; no other reaction or grossly apparent uterine anomalies attributed to exposures were noted; pathological findings of the sacrificed dams and fetuses were essentially the same for the test and control groups; report concludes that R-124 was not teratogenic as tested [a letter from the study sponsor indicates that the quality of the R-124 used in this study was not certain and that further studies (see RDB5A22, RDB-65F5, RDB7268, RDB7270, and others) were performed]

W. E. Brewer and S. Smith (Industrial Bio-Test Laboratories, Incorporated), **90-Day Subacute Inhalation Toxicity Study with Genetron 124 in Albino Rats**, report IBT 8562-09345, AlliedSignal Incorporated (then Allied Chemical Corporation), Morristown, NJ, 2 September 1977 (RDB6174)

R-124, health effects, subchronic toxicity [detailed summary provided in RDB3720 and discussed in RDB4C02; a letter from the study sponsor indicates that the quality of the R-124 used in this study was not certain and that further studies (see RDB65F5 and others) were performed]

D. J. Brusick (Litton Bionetics Incorporated, LBI), **Mutagenicity Evaluation of Genetron 124**, report MA-RR-89-1451 (also identified as LBI project 2547), AlliedSignal Incorporated (then Allied Chemical Company), Morristown, NJ, 30 July 1976 (42 pages with 1 figure and 18 tables, RDB5807)

R-124, health effects, toxicity: concluded that R-124 did not exhibit genetic activity in any of the in vitro assays evaluated: tests were performed with *Saccharomyces cerevisiae* (yeast) and *Salmonella typhimurium* (bacteria) with and without metabolic activation

C. N. Edwards and G. Hodson-Walker (Life Science Research Limited, LSR, UK), **In Vitro Assessment of the Clastogenic Activity of HCFC 124 in Cultured Chinese Hamster Ovary (CHO-K1) Cells**, report MA-RR-92-1788a (also identified as LSR report 91/PAR002/0885a and 91/0885a, also identified as TSCAT report OTS-0535094, Japanese version identified as 91/PAR002/0885b) for the Program the Alternative Fluorocarbon Toxicity Testing (PAFT), AlliedSignal Incorporated, Morristown, NJ, 20 December 1991 (52 pages with 1 figure and 11 tables, RDB6176)

toxicity tests of R-124 to assess mutagenic potential in cultured Chinese hamster ovary cells at concentrations of 150,000, 300,000, and 600,000 ppm v/v; concludes that R-124 showed no evidence of clastogenic (chromosome-damaging) activity either in the presence or absence of a metabolic activation system, derived from rat livers, under the conditions tested

Gleason and W. B. Coate (Hazleton Laboratories America, Incorporated), **LC_{50} of G124 in Rats**, report MA-RR-89-1450 (also identified as project 165-163), AlliedSignal Incorporated (then Allied Chemical Company), Morristown, NJ, 4 October 1976 (6 pages with 2 tables, RDB5806)

R-124, acute inhalation toxicity: tests of 10 male albino rats at 0 (control), 100,000, and 360,000 ppm R-124 nominal concentrations (actual concentrations not indicated) in air: no deaths occurred, leading to the conclusion that the 6-hr LC_{50} rat exceeds 360,000 ppm; hyperactivity was observed for the first 30 min during exposures at 100,000 ppm followed by inactivity; compound awareness also was observed at 360,000 ppm, at which animals appeared inactive and anesthetized after 1 hr; animals appeared normal during the post-exposure observation period; animals exposed to 360,000 ppm showed a lower rate of weight gain on days 1-8 following exposures, but the report suggests that it may have been due to their higher initial weight; one animal had no gross pathology, but discoloration was found in the cervical lymph nodes, lungs, liver, kidneys of one or more animals and one had unusually dark medullas while another had enlarged cervical lymph nodes; the report describes these pharmacotoxic effects as not serious

D. P. Kelly, **Four-Hour Inhalation Approximate Lethal Concentration (ALC) of HCFC-124 in Rats**, report 71-90 (possibly TSCAT report OTS-0530585), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 19 June 1990 (11 pages with 1 table, RDB6180)

tests of the acute inhalation toxicity of R-124 in groups of 6 male rats by 4-hr, nose-only exposures at mean concentrations based on measurements by gas chromatography (GC) of 48,000, 160,000, 230,000, and 300,000 ppm v/v: no rats died at concentrations of 230,000 ppm and lower, but all six died at 300,000 ppm

leading to a conclusion that the 4-hr ALC rat = 230,000-300,000 ppm; no clinical effects were observed at 48,000 ppm; animals exposed to 160,000 and 230,000 ppm and higher showed weight loss the day after exposure followed by normal weight gain; animals exposed to 160,000 and 230,000 ppm exhibited decreased response to startle and tail pinches, prostration, lethargy, and incoordination; report indicates Good Laboratory Practice (GLP) compliance

D. M. Krentz, R. C. Graham, and M. A. Lee, untitled toxicity review for 2-chloro-1,1,1,2-tetrafluoroethane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 8 June 1992 (RDB5863)

R-124, summary of published and unpublished toxicity literature

Life Science Research Limited (LSR, UK), report 91/PAR001/0925 for the Program the Alternative Fluorocarbon Toxicity Testing (PAFT), AlliedSignal Incorporated, Morristown, NJ, 20 December 1991 (RDB6175)

in vitro toxicity tests with Salmonella typhimurium and Escherichia coli to assess the mutagenicity of R-124

G. D. Loizou and M. W. Anders (University of Rochester), **Gas-Uptake Pharmacokinetics and Metabolism of 2-Chloro-1,1,1,2-tetrafluoroethane (HCFC-124) in the Rat, Mouse, and Hamster**, *Drug Metabolism and Disposition*, 23(8):875-880, 1995 (6 pages, RDB-A934)

reports on an investigation of the gas-uptake pharmacokinetics and metabolism of R-124 in rats, mice, and hamsters; notes that species differences were observed in the rate of R-124 uptake and in urinary trifluoroacetic acid (TFA, the major urinary metabolite of R-124) excretion; the uptake of R-124 was described by both saturable and first-order components in rats and mice whereas only first-order uptake was observed in hamsters; presents *in vivo* metabolic rate constants determined from computer simulation of the gas-uptake data; also presents simulations of the production and excretion of TFA in rats and mice, but not in hamsters, by a physiologically based pharmacokinetic (PBPK) model using the new metabolic rate constants; notes that the blood to air partition coefficient of R-124 in hamsters was lower than in mice or rats; indicates that a low coefficient may limit the pulmonary uptake of volatile chemicals, so species that show coefficients much lower than in humans may not be suitable for chemical hazard evaluation and human risk assessment

L. A. Malley (E. I. duPont de Nemours and Company, Incorporated), S. R. Frame (DuPont), G. S. Elliott (DuPont), K. S. Bentley (DuPont), W. J. Brock (DuPont), H. J. Trochimowicz (DuPont), and G. M. Rusch (AlliedSignal Incorporated), **Chronic Toxicity, Oncogenicity, and Mutagenicity Studies with Chlorotetrafluoroethane (HCFC-124)**, *Drug and Chemical Toxicology*, 21(4):417-447, November 1998 (31 pages, RDBA665)

summarizes studies of the chronic toxicity, oncogenicity, and mutagenicity of R-124; in the chronic toxicity and oncogenicity study, groups of male and female rats were exposed whole body to target concentrations of 0 (control), 2,000, 10,000, or 50,000 ppm v/v R-124 in air for 6 hr/d, 5 d/wk, for 2 yr; no compound-related, adverse effects were observed on body weight, food consumption, survival, clinical signs of toxicity, ophthalmoscopically observable ocular lesions, serum hormone concentrations, or clinical pathology parameters at any exposure concentration; compared to controls, urine fluoride was increased in both males and females at all exposure concentrations, and plasma fluoride was increased in females at all exposure concentrations; excretion of fluoride represents conversion of the R-124 parent molecule and was not considered an adverse effect; there were no toxicologically significant, compound-related organ weight changes or gross or microscopic findings at any of the exposure concentrations; R-124 was deemed not toxic or carcinogenic in rats of either sex after inhalation exposure at concentrations of up to 50,000 ppm; this concentration was deemed a no-observed-adverse-effect level (NOAEL); paper also summarizes a series of mutagenicity studies; R-124 was considered not mutagenic in *Salmonella typhimurium* with and without activation at concentrations up to 600,000 ppm v/v for 48 hr; no evidence of clastogenic activity was observed in cultured human lymphocytes at concentrations up to 1,000,000 ppm v/v R-124 for 3 hr, with and without metabolic activation; no micronuclei were induced *in vivo* in mouse bone marrow cells following exposure of mice to concentrations of 99,000 ppm R-124 for 6 hr/d for 2 days; overall, R-124 was found to be nontoxic for chronic exposures up to 50,000 ppm v/v, not mutagenic, and not oncogenic as tested

L. A. Malley (E. I. duPont de Nemours and Company, Incorporated), M. C. Carakostas (DuPont), G. S. Elliott (DuPont), L. Alvarez (DuPont), R. E. Schroeder (Pharmaco-LSR, Incorporated), S. R. Frame (DuPont), C. Van Pelt (DuPont), H. J. Trochimowicz (DuPont), and G. M. Rusch (Allied-Signal Incorporated), **Subchronic Toxicity and Teratogenicity of 2-Chloro-1,1,1,2-tetrafluoroethane (HCFC-124)**, article 0102, *Fundamental and Applied Toxicology*, 32(1):11-22, 1996 (12 pages with 1 figure and 8 tables, RDB65F5)

tests of subchronic toxicity of R-124 in groups of rats and mice by inhalation exposures for 6 hr/d, 5 d/wk, for 13 weeks at 0 (control), 5,000, 15,000, or 50,000 ppm v/v; R-124 caused minimal compound-related effects; hepatic beta-oxidation activity was significantly higher in male mice exposed at 5,000, 15,000, or 50,000 ppm, but there were no compound related effects on beta-oxidation activity in rats; rats, mice, and rabbits exposed to 50,000 ppm were less responsive to auditory stimuli or less active compared to controls; male rats exposed to 15,000 or 50,000 ppm for 13-weeks had decreased arousal; no compound-related effects on mortality, clinical signs, ocular tissues, hematology parameters, organ weights, or tissue morphology were found at any concentration in rats or mice; female rats showed a significant decrease in weight gain and food consumption at 50,000 ppm; pregnant rabbits also consumed less food at 50,000 ppm; no evidence of fetal toxicity was found at any concentration

L. A. Malley, **Subchronic Inhalation Toxicity: 90-Day Study with HCFC-124 in Mice**, report 695-91 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 21 October 1992 (459 pages, RDB-7B41)

R-124, health effects, toxicity

L. A. Malley, L. Alvarez, S. R. Frame, M. C. Carakostas, H. J. Trochimowicz (E. I. duPont de Nemours and Company, Incorporated), and G. M. Rusch (AlliedSignal Incorporated), **Subchronic Toxicity and Teratogenicity of HCFC-124 in Rats**, abstract 1388 (SOT 31st Annual Meeting, February 1992) for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), *The Toxicologist*, 12(1):355, 1992 (1 page with no figures or tables, RDB7268)

90-day inhalation toxicity study for R-124 in rats exposed to 0 (control), 5,000, 15,0000, or 50,000 ppm v/v for 6 hr/day, 5 d/wk: anesthetic effect observed at 50,000 ppm based on reduced response to sound; slight differences observed in clinical chemistry parameters and decreased arousal in males at 15,000 and 50,000 ppm; no compound-related morphological changes were observed; in a related inhalation teratology study, groups of 24 pregnant rats were exposed to 50,000 ppm; no compound-related morphological changes were observed in the dams and no teratogenic changes were observed in the fetuses

L. A. Malley, **Subchronic Inhalation Toxicity: 90-Day Study with HCFC-124 in Rats**, report 79-91 (TSCAT report OTS-0529977) for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 8 August 1991 (602 pages, Rdb5C06)

subchronic inhalation study in groups of 20 male and 20 female Crl:CD-BR rats exposed to R-124 for 6 hr/d, 5 d/wk, for 13 wk at target concentrations of 0 (control), 5,000, 15,000, and 50,000 (0, 5,033, 15,143, 49,987 actual) ppm v/v; males exposed to 15,000 and 50,000 ppm had lower serum triglyceride concentrations at the 45-day clinical evaluation; females exposed to 50,000 ppm had higher alkaline phosphatase activity; plasma fluoride, urinary fluoride, and fractional clearance of free fluoride were increased compared to controls in both sexes at all exposure concentrations; plasma fluoride levels remained higher at the end of the recovery period following exposures for males exposed to 15,000 and 50,000 ppm as did urinary fluoride in males and females at all exposure levels; these differences are described as expected and not considered adverse; males exposed to 15,000 and 50,000 ppm also exhibited mild diuresis attributed to osmotic activity from excreted fluoride ions; rats exposed to 50,000 ppm showed anesthetic effects during exposures based on reduced response to sound; males had decreased arousal on the day after the final exposures 4/10 at 15,000 ppm and 6/10 at 50,000 ppm; there were no treatment-related effects on body weight, food consumption, mortality, clinical signs, ocular tissues, hematology parameters, organ weights, or tissue morphology at any tested concentration; study deemed the NOEL to be 5,000 ppm for males and 15,000 ppm for females

L. A. Malley, **Subchronic Inhalation Toxicity: Four-Week Study with HCFC-124, Inhalation Study in Rats**, report 257-90 (TSCAT report OTS-0000695-9) for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 24 October 1990 (340 pages, Rdb-5A14)

tests of the subchronic inhalation toxicity of R-124 in five groups of ten male and five groups of ten female rats exposed to target concentrations of 0 (control), 500, 2,000, 10,000, or 50,000 ppm v/v; six additional female rats per group were exposed concurrently for a probe teratology study: anesthetic LOEC rat = 50,000 ppm; NOEL rat = 10,000 ppm

K. May, D. Watson, and G. Hodson-Walker (Life Science Research Limited, LSR, UK), **HCFC 124 in Gaseous Phase: Assessment of Mutagenic Potential in Amino-Acid Auxotrophs of Salmonella Typhimurium and Escherichia Coli (The Ames Test)**, report MA-RR-92-1787a (also identified as LSR report 91/PAR001/0842 and 91/0842 and as TSCAT report OTS-0535123) for the Program the Alternative Fluorocarbon Toxicity Testing (PAFT), AlliedSignal Incorporated, Morristown, NJ, 20 December 1991 (51 pages with 1 figure and 23 tables, RDB5809)

toxicity tests to assess the mutagenicity of R-124 in bacteria, both with and without an activating system derived from rat livers, at 31,250, 62,500, 125,000, 250,000, and 500,000 ppm v/v; concludes that R-124 "was devoid of mutagenic activity under the conditions of the tests"

L. S. Mullin, **Fluorocarbon 124 (1-Chloro-1,2,2,2-tetrafluoroethane): Cardiac Sensitization**, report 220-76 (TSCAT report OTS-0530588), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 12 March 1976 (2 pages with 1 table, RDB5808)

toxicity tests to determine the cardiac sensitization potential of R-124 in male beagle dogs with intravenous injection of epinephrine five minutes before and, with a challenge injection, midway into a 10 minute exposure; no marked response in 10 dogs at 10,100 ppm v/v in air [deemed a NOEL]; marked response in 4 of 10 dogs at 25,000 ppm [deemed a LOEL] with 1 death; marked response in 2 of 2 dogs at 50,000 ppm

M. J. Olson, J. T. Johnson, J. F. O'Gara, and S. E. Surbrook, Jr. (General Motors Research Laboratories), **Metabolism In Vivo and In Vitro of the Refrigerant Substitute 1,1,1,2-Tetrafluoro-2-chloroethane**, *Drug Metabolism and Disposition*, 19(5):1004-1011, 1991 (8 pages, RDB6183)

R-124, 2-chloro-1,1,1,2-tetrafluoroethane, toxicity, metabolism in rats

L. B. Rickard, **Mouse Bone Marrow Micronucleus Assay of HCFC-124**, report 52-90 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 26 February 1990 (24 pages, RDB5A21)

R-124, genotoxicity, health effects, mutagenic potential, toxicity as reported in RDB4B88 and RDB5B54

An Inhalation Developmental Toxicity Study in Rabbits with HCFC-124, report 89-3514 (OTS-0535094) for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Bio/dynamics Incorporated, East Millstone, NJ, 19 December 1991 (RDB5A12)

R-124, health effects, toxicity as reported in RDB4B88

1-Chloro-1,2,2,2-tetrafluoroethane (HCFC 124, CAS No. 2837-89-0), Joint Assessment of Commodity Chemicals (JACC) report 25, European Chemical Industry Ecotoxicology and Toxicology Centre (ECETOC), Brussels, Belgium, July 1994 (34 pages, RDB4C02)

summarizes toxicity and environmental data for R-124 (2-chloro-1,1,1,2-tetrafluoroethane)

2-Chloro-1,1,1,2-Tetrafluoroethane (HCFC 124) Health Effects Information, CAS# 2837-89-0, Elf Atochem North America, Incorporated, Philadelphia, PA, undated circa 1995 (5 pages, RDB5B54)

summarizes toxicological and ecotoxicological information for R-124

Biodegradability of HCFC-124 by Microorganisms, report for the Program the Alternative Fluorocarbon Toxicity Testing (PAFT), Kurume Research Laboratories (KRL), Fukuoka, Japan, 1992 (RDB7B38)

documents an ecotoxicity study of R-124; environmental impacts and fate; groundwater and soil

Dissociation Constant of Flon 124, report for the Program the Alternative Fluorocarbon Toxicity

Testing (PAFT), Kurume Research Laboratories (KRL), Fukuoka, Japan, 1991 (RDB7B39)

documents an ecotoxicity study of R-124; environmental impacts and fate; groundwater and soil

Octanol-Water Partition Coefficient of Flon 124, report for the Program the Alternative Fluorocarbon Toxicity Testing (PAFT), Kurume Research Laboratories (KRL), Fukuoka, Japan, 1992 (RDB-7B40)

documents an ecotoxicity study of R-124; environmental impacts and fate; groundwater and soil

In Vitro Evaluation of HCFC-124 for Chromosome Aberrations in Human Lymphocytes, report 367-90 for the Program the Alternative Fluorocarbon Toxicity Testing (PAFT), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 24 October 1990 (RDB5A20)

R-124, mutagenicity, toxicity, potential clastogenic (chromosome-damaging) activity as reported in RDB4B88 and RDB5863

Mutagenicity Testing of HCFC-124 in the Salmonella Typhimurium Plate Incorporation Assay, report 191-90 (TSCAT report OTS-0530587), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 14 September 1990 (RDB6182)

R-124, health effects, genotoxicity, mutagenic potential, toxicity as reported in RDB5863 and RDB5B54

Pilot Teratogenicity Study of HCFC-124 in the Rat, TSCAT report OTS-0530407, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 9 March 1991 (RDB7270)

R-124, health effects, toxicity as reported in RDB5B54

Subchronic Inhalation Toxicity: 90-Day Study with 2-Chloro-1,1,1,2-Tetrafluoroethane in Mice, TSCAT report OTS-0543411, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, volumes I and II, 21 October 1992 (RDB7267)

R-124, health effects, toxicity

Teratogenicity Study of HCFC-124 in Rats, report 482-90 (TSCAT report OTS-0535088) for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 25 October 1991 (RDB5A22)

R-124, health effects, toxicity as reported in RDB4B88 and RDB5B54

Workplace Environmental Exposure Level Guide — 2-chloro-1,1,1,2-tetrafluoroethane, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1992 (2 pages with no figures or tables, RDB4B88)

R-124: identification, summary chemical and physical properties, uses, animal toxicology data, toxicity, human uses and experience (no reports of adverse effects), recommended WEEL (1,000 ppm for 8-hr TWA) guide and rationale, references

report 108-90, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1990 (RDB6181)

R-124, health effects, toxicity, developmental and reproductive toxicity, teratogenicity as reported in RDB5863

R-125

M. W. Anders, **Pharmacokinetics of HFC-125 (Pentafluoroethane) in Rats**, report for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), University of Rochester Medical Center, Rochester, NY, 16 December 1993 (RDB5751)

R-125, toxicity

R. Atkinson et al., *Advances in Photochemistry*, 11:375-488, 1979 (114 pages, RDB5936)

R-125

A. J. Brooker, P. J. Brown, D. M. John, and D. W. Coombs (Huntingdon Research Center Limited HRC, UK), **A Study of The Effect of HFC-125 on Pregnancy of the Rabbit**, report ALS 10/920856 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), AlliedSignal Incorporated, Morristown, NJ, 14 or 24 November 1992 (RDB-5752)

R-125, developmental toxicity, teratogenicity: neither embryotoxic nor teratogenic in the rabbit at exposures up to 50,000 ppm v/v as reported in 5B55 and 65E6

C. A. Dance and G. Hodson-Walker, **In Vitro Assessment of the Clastogenic Activity of HFC-125 in Cultured Chinese Hamster Ovary (CHO) Cells**, report 91/PAR006/1015a for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Life Science Research Limited (LSR), Suffolk, UK, 18 May 1992 (RDB5759)

R-125, toxicity, mutagenicity: no evidence of clastogenic activity as reported in RDB65E6

C. A. Dance, K. E. Beach, and G. Hodson-Walker, **In Vitro Assessment of the Clastogenic Activity of HFC-125 in Cultured Human Lymphocytes**, report 91/PAR005/1014a for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Life Science Research Limited (LSR), Suffolk, UK, 18 May 1992 (RDB5760)

R-125, toxicity, mutagenicity: no evidence of clastogenic activity as reported in RDB65E6

C. N. Edwards, G. Hodson-Walker, and S. Cracknell, **HFC-125: In Vitro Assessment of Clastogenic Action on Bone Marrow Erthrocytes in the Micronucleus Test**, report 92/PAR004/0148 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Life Science Research Limited (LSR), Suffolk, UK, 7 July 1992 (RDB5758)

R-125, toxicity, mutagenicity: no evidence of clastogenic activity in the mouse micronucleus assay as reported in RDB65E6

J. Ferguson-Smith, **Hygiene Standard Documentation — HFC 125**, document HSP/92/20, ICI Chemicals and Polymers Limited, Cheshire, UK, 27 January 1993 (4 pages, RDB5A78)

R-125, toxicity, literature review, rationale for recommended hygiene standard (occupational exposure limit, OEL) of 1,000 ppm, 8-hr TWA, provisional

T. Kawano (Daikin Industries, Limited, Japan), H. J. Trochimowicz (E. I. duPont de Nemours and Company, Incorporated, USA), G. Malinverno (Ausimont S.p.A., Italy), and G. M. Rusch (AlliedSignal Incorporated, USA), **Toxicological Evaluation of 1,1,1,2,2-Pentafluoroethane (HFC-125)**, *Fundamental and Applied Toxicology*, 28(2):223-231, 1995 (9 pages with 7 tables, RDB65E6)

summarizes the Program for Alternative Fluorocarbon Toxicity Testing (PAFT) studies of R-125; indicates that the 4-hr ALC and LC_{50} rat is >800,000 ppm v/v, the 5-min cardiac sensitization NOEL dog is 75,000 ppm v/v, the LOEL is 100,000 ppm, and the EC_{50} is 100,000-150,000 ppm; reports that subchronic exposures of rats for 6 hr/d, 5 d/wk for 4 and 13 weeks showed no evidence of toxicity at 50,000 ppm v/v, the highest concentration tested; indicates that the developmental tests found slight, reversible toxicity in the rabbit and rat dams, but no convincing evidence of embryotoxicity or teratogenicity; also indicates that *in vitro* tests in *Salmonella typhimurium* and *Escherichia coli* bacteria (Ames Assay) found no clear evidence of clastogenic activity in Chinese hamster ovary (CHO) cells or human lymphocytes; similarly indicates that *in vivo* tests found R-125 not mutagenic in the mouse micronucleus test, even at concentrations as high as 600,000 ppm v/v for 6 hr; concludes that R-125 is "very low in biological reactivity," "is not acutely toxic, not a cumulative toxin, not a developmental toxin, not a mutagen," and is "low or lower in toxicity than any of the CFCs it will eventually replace"

R. E. Masters, R. J. Brown, D. M. John, and D. W. Coombs (Huntingdon Research Center Limited HRC, UK), **A Study of the Effect of HFC-125 on Pregnancy of the Rat (Inhalation Exposure)**, report ALS 9/920434 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), AlliedSignal Incorporated, Morristown, NJ, 6 November 1992 (RDB5753)

R-125, developmental toxicity: neither embryotoxic nor teratogenic in the rat at exposures up to 50,000 ppm v/v as reported in 65E6

K. May, D. Watson, and G. Hodson-Walker, **HFC-125 in Gaseous Phase: Assessment of Mutagenic Potential in Amino-Acid Auxotrophs of Salmonella Typhimurium and Escherichia Coli (The Ames Test)**, report 91/PAR003/1152a for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Life Science Research Limited (LSR), Suffolk, UK, 12 or 28 May 1992 (RDB5757)

R-125, toxicity, mutagenicity, Ames assay: R-125 deemed not mutagenic as reported in RDB5B55 and RDB65E6

E. Nakayama, K. Nagano, M. Chrishi, S. Katagiri, and O. Motegi (Japan Bioassay Laboratory, JBL, Japan), **Acute Inhalation Toxicity Study of 1,1,1,2,2-Pentafluoroethane (HFC-125) in Rats**, report on study 0184 (also identified as MA-RR-92-1801) for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Japan Industrial Safety and Health Association, Kanagawa, Japan, 18 March 1992 (84 pages with 11 figures and 22 tables, RDB5754)

tests of the acute inhalation toxicity in groups of 5 female and 5 male Crj:CD(SD) rats exposed (whole body) to concentrations of 0 and

800,000 (769,000 actual with a brief excursion to 398,000) ppm v/v R-125 in oxygen: no deaths resulted, but "almost all" animals exhibited ataxic (uncoordinated) gait, decreases in locomotor movement and sound response [suggesting an anesthetic LOEC at 769,000 ppm v/v], abnormal respiration, prone or lateral, up and down movement of the neck during exposures; mean body weight gain of the treated male rats was 3-5% lower postexposure than the controls; no other clinical signs were noted during a 14 day observation period and no toxic effects were found at necropsy; concludes that R-125 has very low toxicity by acute inhalation and that the 4-hr ALC rat is >800,000 ppm v/v as tested

E. Nakayama, K. Nagano, M. Ohnishi, S. Katagiri, and O. Motegi (Japan Bioassay Laboratory, JBL, Japan), **Four-Week Inhalation Toxicity Study of 1,1,1,2,2-Pentafluoroethane (HFC-125) in Rats**, report 0182 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Japan Industrial Safety and Health Association, Kanagawa, Japan, 23 October 1992 (RDB5756)

R-125, inhalation toxicity: 13-wk NOAEL rat at 0, 5,000, 15,000, or 50,000 ppm v/v as reported in RDB65E6

E. Nakayama, K. Nagano, M. Ohnishi, and O. Motegi (Japan Bioassay Laboratory, JBL, Japan), **Thirteen-Week Inhalation Toxicity Study of 1,1,1,2,2-Pentafluoroethane (HFC-125) in Rats**, report 0197 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Japan Industrial Safety and Health Association, Kanagawa, Japan, 31 August 1993 (918 pages, RDB5761)

documents a study to determine the inhalation toxicity of R-125; 20 male and 20 female rats were exposed for 6 hr/d, 5 d/wk, for 13 wk to target concentrations of 0, 5,000, 15,000, or 50,000 ppm v/v in air; actual mean concentrations determined from measurements by an automatic gas chromatograph (GC) were 0, 4995, 14,891, and 50,113 ppm v/v; half were then sacrificed for necropsy and the remainder were necropsied after an a 4 wk recovery period; all rats survived to the sacrifice and there were no treatment-related effects on body weight, food consumption, clinical signs, hematological parameters, blood biochemical parameters, urinalysis parameters, organ weights, gross findings, pathological findings, plasma fluoride concentrations, or urinary fluoride excretion at any exposure level; there also were no signs of peroxisomal ß-oxidation activity of the livers and ophthalmoscopic findings; concludes that the no observable effect level (NOEL) is 50,000 ppm v/v

S. Nick, **Pentafluoroethane (FC-125): Acute Inhalation Toxicity**, report 54-64, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 28 May 1964 (1 page with 1 table, RDB6456)

tests of the acute inhalation toxicity in groups of 4 male ChR-CD rats exposed whole body to concentrations of 50,000 and 100,000 ppm v/v R-125 in air for 4 hr: no deaths resulted; exposed animals exhibited slightly deep respiration and inactivity during exposure, but recovered immediately thereafter; rats showed a weight gain within one day following exposures but appeared normal throughout the remainder of the 14-day observation period; gross examination of the lungs at necropsy revealed slight pulmonary changes; concludes that the 4-hr ALC rat exceeds 100,000 ppm v/v and that R-125 appears to have no deleterious effect as a contaminant of R-115 food propellant (also used as a refrigerant) if present in the expected concentration of approximately 50 ppm

A. S. Panepinto, **Four-Hour Inhalation Approximate Lethal Concentration (ALC) of HFC-125 in Rats**, report 582-90 (TSCAT report 0530584), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 4 December 1990 (12 pages with 1 table, RDB6457)

tests of the acute inhalation toxicity in groups of 6 male Crj:CD(BR) rats exposed nose only to concentrations of 503,000 and 709,000 ppm v/v R-125 in air, with oxygen added to maintain concentrations of 20-22%, for 4 hr: no deaths resulted and no clinical signs of toxicity were observed during exposures or immediately thereafter; animals showed transient weight losses of 1-9% on the first day following exposures, but gained weight during the 14-day recovery period; two rats exposed at the higher concentration also exhibited transient weight loss later in the recovery period; concludes that the 4-hr ALC exceeds 709,000 ppm and that R-125 is considered to have a very low toxicity

R. L. Swann et al., **Research Review**, 85:17-28, 1983 (12 pages, RDB5943)

R-125, toxicity

V. Thompson and R. C. Graham, untitled toxicity review for pentafluoroethane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 10 December 1993 (16 pages, RDB-5871)

R-125, summary of published and unpublished toxicity literature

Pentafluoroethane (HFC-125, CAS No. 354-33-6), Joint Assessment of Commodity Chemicals (JACC) report 24, European Chemical Industry Ecotoxicology and Toxicology Centre (ECETOC), Brussels, Belgium, May 1994 (36 pages with 2 tables, RDB4C01)

R-125, environmental impacts, toxicity

Pentafluoroethane (HFC 125) Health Effects Information, CAS# 354-33-6, Elf Atochem North America, Incorporated, Philadelphia, PA, undated circa 1995 (3 pages, RDB5B55)

R-125, summary of toxicological and ecological information

Test on Biodegradability of HFC-125 (1,1,1,2,2-Pentafluoroethane) by Microorganisms (closed-Bottle Method), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 19 January 1993 (RDB7271)

ecotoxicity of R-125; environmental impacts and fate; groundwater and soil

Test on 1-Octanol/Water Partition Coefficient of HFC-125, Kurume Research Laboratories (KRL), Fukuoka, Japan, 28 April 1992 (RDB7273)

ecotoxicity of R-125; environmental impacts and fate; groundwater and soil

Test Report HFC 125 Dissociation Constant, Kurume Research Laboratories (KRL), Fukuoka, Japan, 28 April 1992 (RDB7272)

ecotoxicity of R-125; environmental impacts and fate; groundwater and soil

Workplace Environmental Exposure Level Guide — 1,1,1,2,2-pentafluoroethane, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1996 (4 pages, RDB5C15)

occupational exposure limit for R-125; WEEL; toxicology data; toxicity; safety

report 726-90, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1990 (RDB6455)

R-125, health effects, toxicity, mutagenicity

R-132b

M. R. Brittelli, **Eye Irritation Test in Rabbits**, report 13-76, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1976 (RDB-5373)

R-132b, health effects, toxicity as reported in RDB5371

N. C. Goodman, **Primary Skin Irritation and Sensitization Tests on Guinea Pigs**, report 14-76, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1976 (RDB5374)

R-132b, health effects, toxicity as reported in RDB5371

J. W. Harris and M. W. Anders, **Metabolism of the Hydrochlorofluorocarbon 1,2-Dichloro-1,1-difluoroethane**, *Chemical Research in Toxicology*, 4:180-186, 1991 (7 pages, RDB5375)

R-132b, health effects, metabolism, toxicity

P. J. M. Janssen and T. E. Pot (Duphar B.V., The Netherlands), **Acute Dermal Toxicity Study with FC 132b in Rats**, report S.8807, Solvay et Cie S.A., Brussels, Belgium, 1989 (RDB5379)

toxicity tests for acute dermal toxicity of R-132b in rats as reported in RDB5371

P. J. M. Janssen (Duphar B.V., The Netherlands), **Acute Inhalation Toxicity Studies on FC 132b in Rats**, report S.8811, Solvay et Cie S.A., Brussels, Belgium, 1989 (RDB5380)

tests for acute inhalation toxicity of R-132b in rats as reported in RDB5371

P. J. M. Janssen (Duphar B.V., The Netherlands), **Acute Inhalation Study to Investigate the Respiratory Irritancy Properties of FC 132b in Male Rats**, report S.8907, Solvay et Cie S.A., Brussels, Belgium, 1989 (RDB-5381)

toxicity tests for acute inhalation toxicity of R-132b in rats as reported in RDB5371

P. J. M. Janssen and T. E. Pot (Duphar B.V., The Netherlands), **Acute Oral Toxicity Study with FC 132b in Rats**, report S.8816, Solvay et Cie S.A., Brussels, Belgium, 1988 (RDB5382)

toxicity tests for acute ingestion toxicity of R-132b in rats as reported in RDB5371

E. M. Johnson, B. E. G. Gabel, P. H. Lieder, and R. E. Staples, **An In Vitro Evaluation of the Developmental Hazard Potential of DuPont compound H16469**, report 643-86, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1986 (RDB5383)

R-132b, health effects, toxicity, mutagenicity, teratogenicity as reported in RDB5371

D. P. Kelly, **HFA 132b: 90-Day Inhalation Toxicity Study in Rats**, report 20-88, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1976 (RDB5384)

R-132b, health effects, toxicity as reported in RDB5371

R-133a

B. R. Brown, Jr., I. G. Sipes, and R. K. Baker, **Halothane Hepatoxicity and the Reduced Derivative, 1,1,1-Trifluoro-2-chloroethane**, *Environmental Health Perspectives* (EHP), 21:185-188, 1977 (4 pages, RDB8813)

toxicity of R-133a; health effects

R. Culik and D. P. Kelly, **Embryotoxic and Teratogenic Studies in Rats with Chlorotrifluoroethane (FC 133a)**, report 127-79, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1979 (RDB5376)

R-133a, health effects, developmental and reproductive toxicity as reported in RDB5371

E. C. M. Hodge, D. Anderson, I. P. Bennett, and T. M. Weight, **Arcton 133a: Dominant Lethal Study in the Mouse**, report CTL/P/467, Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, UK, 1979 (RDB5377)

R-133a, health effects, toxicity

E. C. M. Hodge, D. Anderson, I. P. Bennett, T. M. Weight, and J. Wilson, **Arcton 133a: First Combined Dominant Lethal and Fertility Study in the Mouse**, report CTL/P/461, Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, UK, 1979 (RDB5378)

R-133a, health effects, toxicity

M. Kilmartin, D. Anderson, I. P. Bennett, D. Richards, T. M. Weight, and J. Wilson, **Arcton 133a: Second Combined Dominant Lethal and Fertility Study in the Mouse**, report CTL/P/544, Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, UK, 1980 (RDB5875)

R-133a, health effects, toxicity as reported in RDB5137

M. Shulman and M. S. Sadove (University of Illinois Research and Education Hospitals), **Safety Evaluation and Anesthetic Properties of 1,1,1-Trifluoroethyl Chloride**, *Toxicology and Applied Pharmacology* (TAP), 7:473-477, 1965 (5 pages, RDB8812)

toxicity of R-133a; 10 minute AD_{50} = approximately 80,000 ppm as reported in RDB8811

Summary of Toxicity Information: HCFC-133a, AlliedSignal Incorporated, Morristown, NJ, undated (after 1984) (5 pages, RDB8811)

toxicity of R-133a; health effects

R-134

M. A Collins, **Toxicology Summary for 1,1,2,2-Tetrafluoroethane (HFC 134)**, ICI Chemicals and Polymers Limited, Runcorn, UK, 9 June 1993 (2 pages, RDB6688)

R-134, summary of published and unpublished toxicity literature; ICI Hygiene Standard = 10 ppm Occupational Exposure Band; no metabolism data available, but absorption is expected to be poor; reported to be of low acute inhalation toxicity, but no data are available; no chronic exposure data, but R-134 was administered to rats at 7 ppm for 1 yr, as an impurity in refrigerant 134a, with no effect; mutagenicity tests (Ames test in human lymphocyte in vitro cytogenetics study) negative for genotoxic effects; concludes that R-134 is probably of low overall toxicity

Huntingdon Research Centre Limited (HRC), **HFC 134: Assessment of Cardiac Sensitization Potential in Dogs**, report DPT 300/932252, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 21 February 1994 (29 pages, RDB6802)

R-134, cardiac sensitization in beagle dogs for exposures with epinephrine challenge; NOEL at 50,000 and 75,000 ppm v/v, LOEL 33% at 100,000 ppm

D. M. Krentz, M. A. Lee, and R. C. Graham, untitled toxicity review for 1,1,2,2-tetrafluoroethane, Haskell Laboratory for Toxicology and Industrial

Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 6 October 1992 (RDB-5864)

R-134, summary of published and unpublished toxicity literature

D. B. Warheit, **Four-Hour Inhalation Approximate Lethal Concentration (ALC) of HFC-134 in Rats**, report 452-91, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 22 July 1991 revised 7 August 1991 (12 pages with 2 tables, RDB6188)

4 hr acute inhalation toxicity tests in groups of six male Charles River Crl:CD BR rats by nose-only exposures to R-134: no mortalities resulted at concentrations of 120,000, 200,000, 380,000, and 460,000 ppm v/v in air with oxygen enrichment (to maintain 20-22% levels); no clinical signs were observed at 120,000 ppm; rats exposed to 200,000 ppm showed no response to tapping on the chamber; rats exposed to 380,000 and 460,000 ppm showed rapid breathing, but no response to a tail pinch or tapping on the chamber; all rats lost 1-6% body weight 1 day following exposures but resumed weight gain thereafter; report concludes that the 4-hr ALC rat for R-134 exceeds 460,000 ppm v/v and that R-134 is "considered to have very low toxicity" on an acute inhalation basis

report 725-90, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1990 (RDB6186)

R-134, health effects, toxicity, mutagenicity, potential clastogenic (chromosome-damaging) activity as reported in RDB5864

report 729-90, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1990 (RDB6187)

R-134, health effects, toxicity, mutagenic potential, Ames Assay negative as reported in RDB-5864

R-134a

D. J. Alexander (Glaxo Research and Development Limited, UK), S. E. Libretto, M. J. Adams, E. W. Hughes, and M. Bannerman, **HFA-134a (1,1,1,2-Tetrafluoroethane): Effects of Inhalation Exposure upon Reproductive Performance, Development and Maturation of Rats**, *Human and Experimental Toxicology*, 15(6):508-517, 1996 (10 pages, RDB8416)

two series of toxicity tests of rats to R-134a: chronic exposures at 2,500, 10,000, or 50,000 ppm to assess effects on reproduction and development; exposures from days 17 to 20 of pregnancy and days 1 to 21 post partum to atmospheres of 1,800, 9,900, or 64,400 ppm; the only treatment-related effect was a slight reduction in body weight gain of males of the treated parental generation at 50,000 ppm; no adverse effects were observed in either study on the reproductive performance of treated animals or on the development, maturation, or reproductive performance of up to two successive generations

D. J. Alexander and S. E. Libretto (Glaxo Research and Development Limited, UK), **An Overview of the Toxicology of HFA-134a (1,1,1,2-Tetrafluoroethane)**, *Human and Experimental Toxicology*, 14(9):715-720, 1995 (6 pages, RDB-A931)

reviews the results of preclinical toxicology studies of R-134a for use as a pharmaceutical propellant for metered-dose inhaler (MDI) use [and also used as refrigerant]; outlines a comprehensive range of studies conducted in animal models selected for the individual investigations; indicates that exposures were by inhalation route in all *in vivo* studies except those for local tolerance and sensitization; reports that there were no incidences of mortality in rodents or dogs at extremely high vapor concentrations of 810,000 ppm v/v; also reports that R-134a was deemed not toxic or oncogenic and be safe for use as an MDI propellant

D. J. Alexander (Glaxo Research and Development Limited, UK), S. E. Libretto, H. J. Chevalier, T. Imamura, et al., **HFA-134a (1,1,1,2-Tetrafluoroethane): Lack of Oncogenicity in Rodents after Inhalation**, *Human and Experimental Toxicology*, 14(9):706-714, 1995 (6 pages, RDBA932)

reviews chronic toxicity studies of R-134a for use as a pharmaceutical propellant for metered-dose inhaler (MDI) use [and also used as refrigerant]; groups of 60 male and 60 female mice or Wistar rats were exposed snout-only to R-134a for 1 hr/d for at least 104 weeks at concentrations of 2,500, 15,000, and 75,000 ppm v/v for mice and at 2,500, 10,000, and 50,000 ppm v/v for rats; absorption was evident at each exposure and was dose related; no treat-

ment-related effects on survival, clinical signs, body weights, hematology, or on the type, incidence, site, or severity of gross lesions was observed in either species; there was no effect of treatment on the type, incidence, site or severity of neoplasms in mice or rats; there were no non-neoplastic findings related to treatment in mice; concludes that R-134a is considered not to be oncogenic and to be safe for use in pharmaceutical MDIs

D. J. Alexander (Glaxo Research and Development Limited, UK), **Safety of Propellants**, *Journal of Aerosol Medicine*, 8(supplement 1):S29-S34, 1995 (6 pages with 1 table, RDB8111)

summarizes a toxicological assessment of fluorochemical 134a for use as an aerosol propellant in metered-dose inhalers (MDIs, compound also is used as a refrigerant identified as R-134a): test samples were prepared by adding "essentially all the manufacturing impurities" to a stock that was in excess of 99.9% pure; results showed that R-134a has exceptionally low acute toxicity and is devoid of genotoxicity and, in rats and mice, oncogenic potential; tests showed no toxicity in rabbits, rats, mice, or dogs exposed to maximum concentrations of 40,000, 50,000, 75,000, or 120,000 ppm v/v, respectively, for up to one year; no fetotoxicity, effects on reproductive performance, peri- or post-natal development, sensitization or local irritation to the eyes or skin was found; mice and rats exposed to concentrations of 810,000 ppm v/v with oxygen supplementation for 1 hr showed no evidence of clinical reactions or acute toxicity; dogs were essentially unaffected by R-134a during acute inhalation exposures of up to 80,000 ppm but showed intolerance and minor motor disturbances at concentrations of 160,000 and 320,000 ppm v/v without oxygen enrichment; all species tested demonstrated high systemic concentrations with half-lives of 4-7 minutes following a 1-hr exposure; metabolism was very limited in rats with the main metabolites being carbon dioxide and trifluoroacetic acid (TFA) in the urine, amounting to less than 0.67% of the administered dose; TFA was detected at trace levels in the urine of humans exposed to high doses of R-134a; article concludes that R-134a is suitable for MDI use

P. Graepel and D. J. Alexander (Glaxo Research and Development Limited, UK), **CFC Replacements: Safety Testing, Approval for Use in Metered Dose Inhalers**, *Journal of Aerosol Medicine*, 4(3):193-200, 1991 (8 pages, RDB8193)

toxicity of R-134a and others tested as metered-dose inhaler (MDI) propellants

D. Anderson and C. R. Richardson, **Arcton 134a: A Cytogenetic Study in the Rat**, report CTL/P/-444 (SR0002, FYI-OTS-0689-0698), Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, UK, 17 May 1979 (RDB-5B33)

R-134a, mutagenicity, toxicity: no chromosomal damage in rat bone marrow cells as reported in RDB5150, RDB5870, and RDB6533

A. Araki (Japan Bioassay Laboratory, JBL, Japan), **Report on Reverse Mutation Assay in Bacteria on Tetrafluoroethane**, report 5292/5312, Japan Industrial Safety and Health Association, Kanagawa, Japan, 11 October 1990 (RDB6534)

mutagenicity test of R-134a; health effects; toxicity

M. Asakura (Japan Bioassay Laboratory, JBL, Japan), **Report on a Chromosomal Aberration Test of 1,1,1,2-Tetrafluoroethane in Cultured Mammalian Cells**, report 5879 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Japan Industrial Safety and Health Association, Kanagawa, Japan, 14 June 1990 (RDB6535)

mutagenicity test of R-134a; health effects; toxicity

R. D. Callander and K. P. Priestley, **HFC 134a: An Evaluation Using the Salmonella Mutagenicity Assay**, report CTL/P/2422 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, UK, 16 March 1990 (RDB5B37)

R-134a, toxicity

C. A. Coleman and R. S. Thompson, **HFC 134a: Determination of the Acute Toxicity to Pseudomonas Putida**, report CTL/BL3980/B, Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, UK, 1990 (RDB65B0)

R-134a, toxicity as reported in RDB6533

M. A. Collins (ICI Chemicals and Polymers Limited, UK), G. M. Rusch (AlliedSignal Incorporated, USA), F. Sato (Showa Denko K.K., Japan), P. M. Hext (Zeneca Central Toxicology Laboratory, UK), and R-J. Millischer (Elf Atochem S.A., France), **1,1,1,2-Tetrafluoroethane: Repeat Exposure Inhalation Toxicity in the Rat, Developmental Toxicity in the Rabbit, and Genotoxicity in Vitro and in Vivo**, *Fundamental and Applied Toxicol-*

ogy, 25(2):271-280, May 1995 (10 pages with 1 figure and 6 tables, RDB5610)

This paper summarizes toxicity studies for animal exposures to R-134a by inhalation. It presents the findings for subchronic and chronic rat exposures to 0, 2,500, 10,000, and 50,000 ppm for 13, 52, and 104 weeks. No statistically significant effects were observed on clinical condition, growth, and survival or on hematological, clinical chemistry, and urinary parameters. The only treatment-related pathological changes seen were increased incidence of Leydig cell hyperplasia (abnormal or unusual increase) and adenoma (benign tumor of glandular structure or origin) in male rats exposed to 50,000 ppm. The tumors, which also were found in control animals, were benign and not life threatening. The survival rates are plotted and key data are tabulated for these chronic inhalation studies. The paper also summarizes a battery of "in vivo" and "in vitro" tests for genotoxic activity. They include mouse micronucleus, unscheduled DNA synthesis assays, Ames assay, cytogenic assay in cultured mammalian cells, and cytogenic assay in human lymphocytes. Pregnant rabbits exposed to R-134a showed minimal maternal toxicity at high concentrations, but there were no effects on fetal development. The paper presents the test methods and conditions, statistical analysis approaches, and results. Data are tabulated for the developmental toxicity and in vivo genotoxicity studies. The paper concludes that R-134a is of very low toxicity.

M. A. Collins, **HFC 134a: Acute Toxicity in Rats to Tetrafluoroethane**, report CTL, Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, UK, 1984 (RDB65A9)

R-134a, inhalation toxicity as reported in RDB-6533

K. M. Cooper, S. F. Chang, and L. I. Harrison, **Determination of the Chlorofluorocarbon Substitute 1,1,1,2-Tetrafluoroethane (HFA-134a) in Human and Animal Blood Using Gas Chromatography with Headspace Analysis**, *Journal of Chromatography*, 667:85-93, 1995 (9 pages, RDB8118)

R-134a: biochemistry, pharmacokinetics, toxicity

D. Donnell, L. I. Harrison, S. Ward, N. M. Klinger, B. P. Ekholm, K. M. Cooper, I. Porietis, and J. McEwen, **Acute Safety of the CFC-Free Propellant HFA-134a from a Pressurized Metered-Dose Inhaler**, *European Journal of Clinical Pharmacology*, 48:473-477, 1995 (5 pages, RDB8117)

acute inhalation toxicity tests of R-134a for use as a metered-dose inhaler (MDI) aerosol propellant (compound also is used as a refrigerant identified as R-134a): health effects

M. K. Ellis, L. A. Gowans, T. Green, and R. J. N. Tanner (Zeneca Central Toxicology Laboratory, then part of ICI Chemicals and Polymers Limited, UK), **Metabolic Fate and Disposition of 1,1,1,2-Tetrafluoroethane (HFC-134a) in Rat Following a Single Exposure by Inhalation**, *Xenobiotica*, 23(7):719-729, July 1993 (11 pages, RDB6531)

R-134a, metabolism, toxicity: tests in rats following single 1-hr inhalation exposures at 10,000 ppm; approximately 1% was recovered in urine, feces, and expired air after exposures, indicating low absorption of R-134a by the lungs; of the 1%, approximately two-thirds were exhaled within 1 hr of the cessation of exposure as unchanged R-134a; remainder was exhaled as carbon dioxide and excreted in urine and feces as trifluoroacetic acid; carbon dioxide was the major metabolite accounting for 0.22 and 0.27% of the inhaled dose in male and female rats, respectively; urinary excretion accounted for 0.09% of the dose and fecal excretion 0.04% of the dose by both sexes; total metabolism in urine, feces and as carbon dioxide amounted to 0.34 and 0.40% of the inhaled dose in males and females, respectively; no evidence for a specific uptake of R-134a or metabolites into any organ or tissue analyzed, including fat

M. K. Ellis, L. A. Gowans, and T. Green, **Hydrofluorocarbon 134a: Pharmacokinetics and Metabolism in Rats Following a Single Exposure by Inhalation**, report CTL/R/1090 (TSCAT report OTS-0536297), Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, UK, circa 1985 (RDB6581)

R-134a, biochemical study, toxicity

H. H. Emmens and E. M. G. Hoogendijk, **Report on an Ascending Dose Safety Study Comparing HFA-134a with CFC-12 and Air, Administered by Whole-Body Exposure to Healthy Volunteers**, report V98.754 - volume 1 (also identified as Honeywell, the AlliedSignal, report MA-RR-99-2539 and MA-250B-82-306) for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT) and the International Pharmaceutical Aerosol Consortium for Toxicology Testing OF HFA-134a (IPACT-I), TNO Nutrition and Food Research In-

stitute, Zeist, The Netherlands, 23 February 1999 (154 pages, RDBA535)

documents a study to investigate the effect of R-134a on electrocardiogram (ECG), pulse rate, blood pressure, lung function, and pharmacokinetic data in relation to exposure levels in 8 (4 male and 4 female) healthy human volunteers; exposures were for 1 hr each to ascending (subject to termination if lower concentrations indicated adverse affect) target concentrations of 1000, 2000, 4000, and 8000 ppm v/v in air; comparative exposures were administered to air and to 1000 and 4000 ppm v/v R-12 in air as controls; introduction notes that the study was designed to evaluate responses associated with inhalation of R-134a at levels achieved in industrial, medical (pharmaceutical propellant in metered-dose inhalers, MDI), or emergency (fire suppression) uses; it cites motivation to respond to questions arising from an earlier pharmacokinetic study (see RDB7C80) halted based on observed effects, subsequently deemed to have been caused by factors other than R-134a exposure such as physical or psychological factors; concludes that there were no treatment-related effects of inhalation exposure to R-134a on ECG, pulse rate, systolic and diastolic blood pressure, or lung function for maximum concentrations of 8000 ppm v/v target (7600 ppm v/v mean actual) R-134a compared to air or up to 4000 ppm v/v target (3913 ppm v/v mean actual) R-12

H. H. Emmens and E. M. G. Hoogendijk, **Report on an Ascending Dose Safety Study Comparing HFA-134a with CFC-12 and Air, Administered by Whole-Body Exposure to Healthy Volunteers**, report V98.754 - volume 2 (also identified as Honeywell, the AlliedSignal, report MA-RR-99-2539 and MA-250B-82-306) for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT) and the International Pharmaceutical Aerosol Consortium for Toxicology Testing OF HFA-134a (IPACT-I), TNO Nutrition and Food Research Institute, Zeist, The Netherlands, 23 February 1999 (99 pages, RDBA536)

documents the protocol including safety precautions for a study to investigate the effect of R-134a on electrocardiogram (ECG), pulse rate, blood pressure, lung function, and pharmacokinetic data in relation to exposure levels in 8 (4 male and 4 female) healthy human volunteers (see RDBA535); exposures were for 1 hr each to ascending (subject to termination if lower concentrations indicated adverse affect) target concentrations of 1000, 2000, 4000, and 8000 ppm v/v in air; comparative exposures were administered to air and to 1000 and 4000 ppm v/v R-12 in air as controls

J. Ferguson-Smith, **Hygiene Standard Documentation — HFC 134a**, document HSP/93/02, ICI Chemicals and Polymers Limited, Cheshire, UK, 1993 (9 pages with 2 tables, RDB5A79)

R-134a, toxicity, literature review, rationale for recommended hygiene standard (occupational exposure limit, OEL) of 1,000 ppm, 8-hr TWA

E. L. Frederickson and C. Nielson, *Progr. Anaesthesiology* (proceedings of the 4th World Congress of Anaesthesiology, 1968), 723-729, 1970 (7 pages, RDB6532)

R-134a, cardiac study, health effects, toxicity

P. W. Grube, D. M. Krentz, M. A. Lee, and R. C. Graham, untitled toxicity review for ethane, 1,1,1,2-tetrafluoro-, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 14 February 1994 (18 pages, RDB5870)

R-134a, summary of published and unpublished toxicity literature

C. J. Hardy (Huntingdon Research Centre Limited, HRC, UK), **HFC-134a: Cardiac Sensitization Study in Dogs**, report ISN 250/91169, Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, UK, 1991 (RDB6B44)

R-134a, toxicity

L. I. Harrison (3M Pharmaceuticals), **Pharmacokinetics of HFA-134a: A Preliminary Report**, *American Journal of Therapeutics*, 3(11):763-766, November 1996 (3 pages with 1 figure and 2 tables, RDB7537)

combines the accumulated data from four clinical studies to provide a preliminary description of the pharmacokinetics of R-134a: notes that R-134a is absorbed and eliminated quickly, with an estimated half-life 5.1 minutes based on a population pharmacokinetics approach; subjects were healthy humans and, in one study, mild asthmatic patients; a total of 34 subjects were exposed and there were 24 controls

P. M. Hext and J. R. Parr-Dobrzanski, **HFC 134a: 2-Year Inhalation Toxicity Study in the Rat**, report CTL/P/3841, Zeneca Central Toxicology Laboratory (then part of ICI Chemicals and Polymers Limited), Cheshire, UK, 19 March 1993 (RDB6546)

R-134a, health effects, 2-yr inhalation toxicity study in rats exposed to 0, 2,500, 10,000, and 50,000 ppm for 6 hr/d, 5 d/wk: no significant differences in survival, body weight, clinical chemistry (except occasional small increases in urinary fluoride levels at 10,000 and 50,000 ppm), hematology, or organ weight (with exception of testes); mean testicular weight was higher at 50,000 ppm; tumor incidence comparable between control and exposed groups except at 50,000 ppm, at which the incidence of Leydig cell hyperplasia and benign Leydig cell tumors was statistically higher; low incidence of generalized large granular lymphocyte leukemia was seen across all groups, and while slightly higher in the control group and at 50,000 ppm; NOEL = 10,000 ppm — as reported in RDB5870; see RDB 6A01 for discussion, which notes that "Leydig-cell tumors are not considered indicative of adverse effects in humans because they are not applicable to humans"

P. M. Hext, **HFC 134a: 90-day Inhalation Toxicity Study in the Rat**, report CTL/P/2466 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, UK, 15 November 1989 (RDB5B38)

R-134a, toxicity study in rats exposed to 2,000, 10,000, and 50,000 ppm for 6 hr/d, 5 d/wk: NOEL = 49,500 ppm as reported in RDB5870

M. C. Hodge, M. Kilmartin, R. A. Riley, T. M. Weight, and J. Wilson, **Arcton 134a: Teratogenicity Study in the Rat**, report CTL/P/417 (FYI-OTS-0689-0698), Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, UK, 9 January 1980 (RDB5B31)

R-134a, developmental and reproductive toxicity based on tests at 0 (control), 1,000, 10,000, and 50,000 ppm; concludes that R-134a is neither teratogenic nor embryotoxic at the levels tested as reported in RDB5150

M. C. E. Hodge, D. Anderson, I. P. Bennett, and T. M. Weight, **Arcton 134a: Dominant Lethal Study in the Mouse**, report CTL/R/437 (FYI-OTS-0689-0698), Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, UK, 8 January 1979 (RDB5B32)

R-134a, mutagenicity (negative), toxicity as reported in RDB5150 and RDB5870

IPACT Data Review Committee, **Interpretation of Brain Weight Data from the Study 'HFC 134a: 90-day Inhalation Toxicity Study in the Rat (ICI Report Number CTL/P/2466, November 15, 1989)'**, International Pharmaceutical Aerosol Consortium for Toxicology Testing (IPACT), 1990 (RDB7B42)

R-134a, interpretation of findings from a prior toxicity study (see RDB5B38) in rats exposed to 2,000, 10,000, and 50,000 ppm for 6 hr/d, 5 d/wk

Litton Bionetics Incorporated (LBI), Kensington, MD, 1976 (RDB6536)

R-134a, health effects, extended oral toxicity study in rats administered 300 mg/kg/d, 5 d/wk, for 52 weeks: no significant increase in the incidence of neoplasms was observed in any organ a reported in RDB5870

M. Lu and R. Staples, **1,1,1,2-Tetrafluoroethane (FC 134a): Embryo-Fetal Toxicity and Teratogenicity Study by Inhalation in the Rat**, report 317-81 (TSCAT report OTS-0530569 and OTS-0535914), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1981 (RDB-6530)

R-134a, developmental and reproductive toxicity

J. M. Mackay, **HFA 134a: An Evaluation in the In Vitro Cytogenetic Assay in Human Lymphocytes**, report CTL/P/2977 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, UK, 10 July 1990 (RDB5B41)

R-134a, mutagenicity, toxicity

T. A. Mahoney, **Test Subject Faints After Inhaling HFC-134a in Botched Air Force Exposure Experiments**, *The Air Conditioning, Heating, and Refrigeration News*, 202(8):1-2, 20 October 1997 (2 pages with no figures or tables, RDB7C82)

provides further information on the inhalation toxicity test responses reported in an Air-Force study (see RDB7C80) on exposures with R-13B1, R-134a, and R-227ea: describes the tests in which "one subject lost consciousness and had to be revived" following exposure to R-134a at 4,000 ppm v/v as "conducted somewhat haphazardly"; quotes D. Hufford (director of the U.S. Environmental Protection Agency, EPA, Stratospheric Ozone Protection Division) that the EPA believes "R-134a is safe and we are not urging any changes to its use"; quotes A. Vinegar (ManTech Environmental Technol-

ogy, Incorporated, and coauthor of the original report) that the reported results were not a direct effect based on newer evidence; quotes a Program for Alternative Fluorocarbon Toxicity Testing (PAFT) statement (see RDB7C81) that the responses were "likely not a direct result of the chemical exposure"; quotes R. Rubenstein (an EPA toxicologist) that the first test subject reacted to a stress reaction from the manner of blood sampling and that similar causes are suspected in the other anomalous reactions

R-J. Millischer (Elf Atochem S.A., France), **The Toxicology of HFC 134a**, *Journal of the American College of Toxicology* (JACT), 8(6):1220 ff, 1989 (RDB6549)

summarizes toxicity assays of the acute, subacute, subchronic, and chronic toxicity as well as genotoxicity, teratogenicity and carcinogenicity of R-134a; notes that some tests are still in progress or planning, but the findings thus far point to a low order of toxicity; indicates a 4-hr LC_{50} in the rat of >500,000 ppm v/v with acute exposure symptoms indicative of central nervous system (CNS) depression and anesthetic effects induced at sub-lethal levels; describes the cardiac sensitization potential as very low with a LOEL of 75,000 ppm in dogs; indicates a NOEL at 50,000 ppm v/v in subacute and subchronic inhalation studies in rats exposed for 6 ht/d 5 d/wk; describes a 90-day study, inhalation teratogenicity assays in the rat and rabbit; notes that no teratogenic effect was found at any of the exposure levels, although minimal maternal toxicity occurred at 40,000 ppm v/v in rabbits and maternal and embryofoetal toxicity was observed at 100,000 ppm v/v in rats; indicates that R-134a was not genotoxic in a battery of short term tests *in vitro* studies including by Ames and human lymphocyte assays; notes that no carcinogenic potential was found *in vivo* in a micronucleus, dominant lethal, and similar studies as well as in a limited *in vivo* bioassay in rats receiving daily oral doses of 300 mg/kg in corn oil for 1 yr; notes that a 2-yr inhalation combined chronic toxicity and carcinogenicity bioassay in rats is in progress; describes a metabolic study in rats with radiolabelled material that found that R-134a is virtually not transformed in the body, is quickly eliminated via the respiratory route, and does not accumulated in any particular organ

L. S. Mullin, **Ethane, 1,1,1,2-tetrafluoro-: Cardiac Sensitization**, report 42-79, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 26 January 1979 (3 pages with 1 table, RDB6527)

toxicity tests to determine the cardiac sensitization potential of R-134a in male beagle dogs with intravenous injection of epinephrine five minutes before and, with a challenge injection, midway into a 10 minute exposure: no marked response in 10 dogs at 49,800 ppm v/v R-134a in air [deemed a NOEL]; marked response in 2 of 10 dogs at 75,200 ppm [deemed a LOEL] and in 2 of 4 dogs with one death at 101,900 ppm; concludes that R-134a is "a weak cardiac sensitizer similar to Halon 1301"

W. Müller and T. Hofmann (Pharma Research Toxicology and Pathology Laboratory), report 89.0115 (on study 88.1244), **CFC 134a Micronucleus Test in Male and Female NMRI Mice After Inhalation**, Hoechst Aktiengesellschaft, Frankfurt am Main, Germany, 16 March 1989 (36 pages, RDB6584)

R-134a, mutagenicity, toxicity

M. J. Olson and S. E. Surbrook, Jr. (General Motors Research Laboratories), **Human Metabolism of the CFC-Substitute HFC-134a: Role of Cytochrome P450IIE1**, abstract 148, *The Toxicologist*, 12:62, 1992 (1 page with no figures or tables, RDB7538)

toxicity of R-134a: concludes that R-134a is "essentially nontoxic" based on rates of defluorination in human microsomes, with focus on the role of P450IIE1; defluorination rates were similar in humans, rabbits, and rats; suggests that potentiation of toxicity may be possible by P450IIE1 induction for more-readily metabolized fluorochemicals, such as R-123

M. J. Olson (General Motors Research Laboratories), C. A. Reidy, J. T. Johnson, and T. C. Pederson, **Oxidation of 1,1,1,2-Tetrafluoroethane in Rat Liver Microsomes is Catalyzed Primarily by Cytochrome P450IIE1**, *Drug Metabolism and Disposition*, 19(2):298-303, 1991 (6 pages, RDB6537)

R-134a, health effects, metabolism, toxicity

M. J. Olson and S. E. Surbrook, Jr. (General Motors Research Laboratories), **Defluorination of the CFC-Substitute 1,1,1,2-Tetrafluoroethane: Comparison in Human, Rat and Rabbit Hepatic Microsomes**, *Toxicology Letters*, 59(1-3):89-99, December 1991 (11 pages, RDB6538)

R-134a, toxicity: compares metabolism by hepatic microsomes in human tissue to that from rats and rabbits; defluorination of R-134a in a

cytochrome-P450 catalyzed reaction was similar; maximal rate of R-134a metabolism was very low and showed little interindividual variation; findings indicate that laboratory animals are an adequate surrogate for humans to characterize R-134a toxicity, especially that which may be mediated by products of halocarbon metabolism

M. J. Olson (General Motors Research Laboratories), C. A. Reidy, J. T. Johnson, and T. C. Pederson, **Oxidative Defluorination of 1,1,1,2-Tetrafluoroethane by Rat Liver Microsomes**, *Drug Metabolism and Disposition*, 18(6):992-998, 1990 (7 pages, RDB6539)

R-134a, health effects, metabolism, toxicity

M. J. Olson (General Motors Research Laboratories) C. A. Reidy, and J. T. Johnson, **Defluorination of 1,1,1,2-Tetrafluoroethane (R-134a) by Rat Hepatocytes**, *Biochemical and Biophysical Research Communications*, 166(3):1390-1397, 1990 (8 pages, RDB6540)

R-134a, health effects, toxicity

M. J. Olson (General Motors Research Laboratories), C. A. Reidy, and J. T. Johnson, **Modulation of Glucose Metabolism in Isolated Rat Hepatocytes by 1,1,1,2-Tetrafluoroethane**, *Fundamental and Applied Toxicology*, 15(2):270-280, August 1990 (11 pages, RDB6541)

R-134a, toxicity: effects on cell viability and functional competence at concentrations of µ750,000 ppm by glucose metabolism measurements in cultures of hepatocytes derived from fed or fasted rats; R-134a did not produce evidence of cytolethality following a 2-hr exposure; by contrast, R-123B1 caused cell death at 1250 ppm; 125,000-750,000 ppm R-134a increased glycolysis (production of lactate and pyruvate) in a concentration-dependent manner in hepatocytes from fed rats; no effect was observed at 50,000 ppm; R-12, R-114, and R-134a were equal in potency to stimulate glycolysis at 250,000 ppm; R-115 depressed glycolysis slightly; R-123B1 markedly increased glycolysis rates at concentrations as low as 300 ppm; glucose production by hepatocytes of fed rats was decreased by R-12, R-114, and R-134a only at concentrations of ·250,000 ppm; R-123B1 potently decreased glucose production by hepatocytes at ·300 ppm; R-134a exposure inhibited gluconeogenesis in a concentration-dependent manner in cells isolated from livers of fasted rats, although this effect was not significant until concentrations reached 125,000 ppm; comparative potency studies showed that R-12, R-114, and R-134a inhibited gluconeogenesis about equally at 250,000 ppm while R-123B1 was effective at 300 ppm and R-115 was without effect at 250,000 ppm; paper concludes that toxicologically significant alteration of glucose-linked bioenergetics is unlikely at anticipated levels of R-134a exposure in the workplace or environment

M. J. Olson (General Motors Research Laboratories) et al., abstract 202, *The Toxicologist*, 10(1):51 ff, 1990 (RDB6542)

R-134a, health effects, toxicity

V. W. Pike, F. I. Aigbirhio, C. A. J. Freemantle, B. C. Page, C. G. Rhodes, S. L. Waters, T. Jones, P. Olsson, G. P. Ventresca (Glaxo Research and Development Limited, UK), R. J. N. Tanner, M. Hayes, and M. B. Hughes, **Deposition of Inhaled 1,1,1,2-Tetrafluoroethane (HFA-134a) in Healthy Subjects and in Patients with Chronic Airflow Limitation**, *Drug Metabolism and Disposition*, 23:832-839, 1995 (8 pages, RDB8116)

R-134a health effects, pharmacokinetics, toxicity

C. A. Reidy, J. T. Johnson, and M. J. Olson (General Motors Research Laboratories), **Metabolism In Vitro of Fluorocarbon R-134a**, abstract 1295, *The Toxicologist*, 10(1):324 ff, 1990 (RDB6543)

R-134a, biochemical study, health effects, toxicity

R. A. Riley, I. P. Bennett, I. S. Chart, C. W. Gore, M. Robinson, and T. M. Weight, **Arcton 134a: Subacute Toxicity to the Rat by Inhalation**, report CTL/P/463 (FYI-OTS-0689-0698), Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, UK, 6 December 1979 (RDB5B34)

inhalation toxicity study in rats exposed to 1,000, 10,000, or 50,000 ppm v/v R-134a in air for 6 hr/d, 5 d/wk, for 4 weeks: gas was absorbed into the blood; liver weights and plasma potassium levels were higher for 10,000 and 50,000 ppm exposures; changes were noted in liver, kidney, and gonad weights of males at 50,000 ppm, but there were no pathology changes in these tissues; pathological change was observed in the lungs of several male rats at the 50,000 ppm dose as reported in RDB5150 and RDB5870

S. B. Rissolo, **1,1,1,2-Tetrafluoroethane (Freon® 134a): Acute Inhalation Toxicity**, report 190-67,

Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 2 November 1967 (2 pages with no figures or tables, RDB6525)

tests of the acute inhalation toxicity of R-134a in Charles River CD rats exposed to 750,000 ppm v/v in oxygen-enriched air for 30 min; 2 of 4 rats died, one each at 20 and 29 minutes; rats showed incoordination, pumping respiration, darkening of the eyes, unresponsiveness, cyanosis (blue or purple discoloration of the skin or mucous membranes due to blood-oxygen deficiency), and convulsions; survivors were limp, but still showed a righting reflex after exposure and appeared to recover within 5 min; one had a moderate weight loss the first day, but growth was normal for the remainder of the 14-day observation period; both rats that died had discolored and hyperinflated lungs with some areas of edema; the survivors were found in microscopic pathology to have pulmonary vascular congestion and edema, but no other compound related effects; recommends that R-134a be handled with care and in well-ventilated areas in light of the findings and apparent lack of preliminary warning signs; findings imply a 30-min ALC 2/4 of 750,000 ppm v/v

G. M. Rusch, **Review of the ICI Toxicology Studies on Fluorocarbon 134a**, report MA-141-80-1 (also identified as MA-RR-83-428), AlliedSignal Incorporated (then Allied Corporation), Morristown, NJ, 3 March 1983 (2 pages with no figures or tables, RDB5150)

review of teratogenicity; excretion, tissue distribution, and metabolism; subchronic toxicity; cytogenetic; and dominant lethal toxicity studies [see RDB5B31, RDB5B35, RDB5B34, RDB5B33, and RDB5B32, respectively]; concludes that R-134a has a low order of toxicity showing only slight effects at an exposure level of 50,000 ppm; notes that R-134a is not teratogenic, embryotoxic, or mutagenic and is rapidly eliminated and poorly metabolized

A. G. Salmon, J. A. Nash, M. F. S. Oliver, and A. Reeve, **Arcton 134: Excretion, Tissue Distribution, and Metabolism in the Rat**, report CTL/P/-513 (FYI-OTS-0689-0698), Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, UK, 6 March 1980 (RDB5B35)

R-134a, biochemical study, toxicity: concludes that R-134a is rapidly eliminated and only poorly metabolized in the rat as reported in RDB5150

M. Shulman and M. S. Sadove (University of Illinois Research and Education Hospitals), **1,1,1,2-Tetrafluoroethane. An Inhalation Anesthetic Agent of Intermediate Potency**, *Anesthesia and Analgesia*, 46(5):629-635, September-October 1967 (7 pages with 3 figures and 3 tables, RDB-7274)

examination of R-134a as an anesthetic: discusses effect levels in the mouse, (EC_{50} 270,000 ppm v/v), dog, cat, and rhesus monkey; notes cardiac sensitization, and specifically ventricular fibrillation (very rapid and irregular contractions of the ventricles of the heart resulting in loss of synchronization between the heartbeat and pulse beat), by R-134a to catecholamines and infusions of epinephrine or isoproterenol; includes discussion by J. F. Artusio, Jr. (New York Hospital, Cornell University Medical Center)

L. S. Silber, **Acute Inhalation Toxicity Study of Tetrafluoroethane**, report 422-79, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 3 August 1979 (3 pages with 1 table, RDB6529)

4 hr acute inhalation toxicity tests of R-134a in groups of six male Charles River CD rats by whole body exposures: mortality ratios and corresponding concentrations were 0/6 at 81,100, 0/6 at 205,000, 0/6 at 359,300, 5/6 at 566,700, 0/6 at 646,700, and 2/6 at 652,700 ppm v/v in air with oxygen enrichment; rats showed lethargy and rapid respiration at 205,200 ppm and additionally trembling and tearing at 359,300 ppm; 4 of 6 showed weight loss within 24 hr of exposures at 359,300 ppm followed by weight gain; the report does not comment on the high fatality occurrence at 566,700 ppm compared to the two higher concentrations tested, but the range of measured concentrations for this group is reported as 494,400-668,800 ppm, the high end of which is similar (664,300-685,300) for the three highest concentrations tested

L. S. Silber and G. L. Kennedy, **Subacute Inhalation Toxicity of Tetrafluoroethane (FC 134a)**, report 228-79, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, August 1979 (RDB6528)

R-134a, toxicity study in rats: no exposure-related hematological, chemical analysis, or pathologic changes were observed; significant in-

crease in fluoride excretion indicates metabolism of R-134a as reported in RDB5870

S. E. Surbrook, Jr., and M. J. Olson (General Motors Research Laboratories), **Dominant Role of Cytochrome P450 2E1 in Human Hepatic Microsomal Oxidation of the CFC-Substitute 1,1,1,2-Tetrafluoroethane**, *Drug Metabolism and Disposition*, 20(4):518-524, 1992 (7 pages, RDB6544)

R-134a, health effects, metabolism, toxicity

J. D. Taylor, **1,1,1,2-Tetrafluoroethane: Mutagenic Activity in the Salmonella/Microsome Assay**, report 534-78, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1978 (RDB6526)

summarizes a mutagenicity study of R-134a by Ames assay; indicates that the results were negative; toxicity — as reported in RDB5870

R. W. Trueman, **HFC 134a: Assessment for the Induction of Unscheduled DNA Synthesis in Rat Hepatocytes In Vivo**, report CTL/P/2550 (SR0337) for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, UK, June 1990 (RDB5B40)

summarizes a mutagenicity study of R-134a; toxicity

G. P. Ventresca (Glaxo Research and Development Limited, UK), **Clinical Pharmacology of HFA134a**, *Journal of Aerosol Medicine*, 8(supplement 1):S35-S39, 1995 (5 pages with 4 figures and 1 table, RDB8112)

summarizes an assessment in healthy human males of the safety, tolerability, and pharmacokinetics of fluorochemical 134a for use as an aerosol propellant in metered-dose inhalers (MDIs, compound also is used as a refrigerant identified as R-134a): absorption and disposition also were investigated in both healthy subjects and patients with severe chronic obstructive pulmonary disease (COPD) using radiolabeled R-134a; no serious adverse events were reported and there were no clinically significant changes in vital signs, electrocardiogram (ECG), pulmonary function tests, and laboratory parameters; R-134a was mainly eliminated by exhalation within several minutes; it was rapidly absorbed into the blood after inhalation, reaching maximum concentrations in 30-60 seconds, and distributed throughout the body with no obvious accumulation in any region; peak blood concentrations were highly variable, but generally dose dependent; blood concentrations declined rapidly after dosing, with an apparent half-life of 31 minutes; metabolism was not found to be significant; article concludes that inhalation grade R-134a is safe and well tolerated in healthy subjects and that it is rapidly eliminated by exhalation without significant metabolism in by healthy subjects and COPD patients; no accumulation was found with repeat dosing

G. A. Wickramratne (possibly Wickramaratne), **Fluorocarbon 134a: Embryotoxicity Inhalation Study in the Rabbit**, report CTL/P/2380 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, UK, 23 November 1989 (RDB5B36)

R-134a, developmental and reproductive toxicity

G. A. Wickramratne (possibly Wickramaratne), **HFC 134a: Teratogenicity Inhalation Study in the Rabbit**, report CTL/P/2504 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, UK, 23 November 1989 (RDB5B39)

R-134a, developmental and reproductive toxicity

A. Woodcock (Wythenshawe Hospital, UK), **Continuing Patient Care with Metered-Dose Inhalers**, *Journal of Aerosol Medicine*, 8(supplement 2):S5-S10, 1995 (6 pages with 1 figure, RDB8113)

outlines clinical tests of fluorochemical 134a as an aerosol propellant in metered-dose inhalers (MDIs, compound also is used as a refrigerant identified as R-134a): notes very few adverse affects from the R-134a inhalers, generally comparable to those from R-12/11 inhalers; paper discusses replacement of R-12/11 blends and the transition from to alternatives for MDI use

A Seven Day Multiple Dose Tolerability and Pharmacokinetic Study of HFA-134a in Healthy Volunteers at Two Dose Levels (4x 100 µL and 8x 100 µL) Given Four Times Daily, report 7928, ICR, 1993 (RDBA537)

toxicity of R-134a; tests in humans

Criteria Group for Occupational Standards: Consensus Report for 1,1,1,2-Tetrafluoroethane, *Arbete och Hlsa*, 19:86-88, 1995 (3 pages, RDB8422)

toxicological review of R-134a: concludes that the critical toxicity of R-134a is its effect on heart rhythm based on limited data from animal studies

HFC 134a: 2-Year Inhalation Toxicity Study in the Rat. Interim Report after 52 Weeks, TSCATS report 421398 (FYI-OTS-1091-0695) for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, UK, 30 September 1991 (RDB7C78)

R-134a, chronic toxicity study [also see RDB-6582]

HFC 134a: 2-Year Inhalation Toxicity Study in the Rat. Interim Report after 52 Weeks, report CTL/P/3317 for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Central Toxicology Laboratory, Imperial Chemical Industries Limited (ICI), Cheshire, UK, 21 August 1991 (RDB6582)

R-134a, chronic toxicity study

Measurement of Dissociation Constant in Water of 1,1,1,2-Tetrafluoroethane, Kurume Research Laboratories (KRL), Fukuoka, Japan, 28 August 1990 (RDB7276)

ecotoxicity of R-134a; environmental impacts and fate; groundwater and soil

Measurement of 1-Octanol/Water Partition Coefficient of 1,1,1,2-Tetrafluoroethane, report 80678, Kurume Research Laboratories (KRL), Fukuoka, Japan, 22 August 1992 (RDB7277)

ecotoxicity of R-134a; environmental impacts and fate; groundwater and soil

Test on Biodegradability of HFC-134a by Microorganisms (Closed-Bottle Method), report 11598, Kurume Research Laboratories (KRL), Fukuoka, Japan, 22 August 1990 (RDB7275)

ecotoxicity of R-134a; environmental impacts and fate; groundwater and soil

1,1,1,2-Tetrafluoroethane (HFC-134a, CAS No. 811-97-2), Joint Assessment of Commodity Chemicals (JACC) report 31, European Chemical Industry Ecology and Toxicology Centre (ECETOC), Brussels, Belgium, February 1995 (42 pages with 1 figure and 3 tables, RDB6533)

R-134a, environmental impacts, toxicity

1,1,1,2-Tetrafluoroethane (HFC 134a) Health Effects Information, CAS# 811-97-2, Elf Atochem North America, Incorporated, Philadelphia, PA, undated circa 1995 (6 pages, RDB5B56)

R-134a, summary of toxicological and ecological information

Workplace Environmental Exposure Level Guide — 1,1,1,2-Tetrafluoroethane, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1991 (4 pages, RDB4B86)

R-134a, WEEL, toxicology data, toxicity, safety classification

R-E134

R. C. Graham and P. J. Lardear, untitled review of toxicity literature for bis(difluoromethyl) ether, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 15 April 1994 (5 pages, RDB6206)

summary of published and unpublished information on the toxicity of R-E134

D. A. Keller et al., **HFOC-134E**, report for project MR-9563-1, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 25 March 1994 (1 page with no figures or tables, RDB6207)

summarizes acute inhalation toxicity tests of R-E134 in rats; indicates that rats exposed to approximately 100,000 ppm v/v for 4 hr showed narcosis, but no other effects; notes that they recovered quickly and that no adverse effects were apparent three days later; indicates that rats exposed to approximately 45,000 ppm v/v for 4 hr showed light narcosis, but no other effects, and also recovered quickly; indicates that rats exposed to 18,000 ppm v/v for 4 hr showed no effects; concludes that the 4-hr ALC exceeds 100,000 ppm v/v [a Haskell summary of this study elaborates that the tests were conducted in groups of 3 rats, cites the high exposure concentration as 95,000 ppm v/v; indicates the resulting 4-hr ALC rat as >95,000 ppm, and describes the behavior as incoordination and loss of response to sound — as reported in RDB6206]

C. W. Simons, G. J. O'Neill, and J. A. Gribens, **New Aerosol Propellants for Personal Products**, U.S. patent 4,041,148, 9 August 1977 (4 pages, RDBA944)

claims invention of dimethyl ethers, and specifically bis(difluoromethyl) ether [R-E134] and perfluorodimethyl ether [R-E116], as aerosol

propellants for cosmetic, hygienic, pharmaceutical, and other personal products; provides limited toxicity data on them of potential relevance for their use as refrigerants; indicates no deaths or recognizable biological effects during or after exposures in six mice exposed to concentrations as high as 750,000 ppm v/v R-E116 for 1 hr; indicates no deaths but anesthetic effects in ten mice exposed to slightly more than 200,000 ppm v/v R-E134 for 2 hr; also indicates no deaths or signs of convulsions in an unspecified quantity of rats exposed to 50,000 ppm v/v R-E134 for 3 hr/d for 5 days

R-141b

M. Bazzon and G. Hervouet (Institut National de Recherche Chimique Appliquée, IRCHA, France), **Determination of Acute Toxicity of HCFC 141b to Brachydanio Rerio**, report B.7073 (FYI report OTS-5900695) for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Levallois-Perret, France, 7 September 1989 (29 pages with 3 figures and 8 tables, RDB6475)

tests for acute aquatic toxicity to brachydanio rerio (zebra fish) exposed for 96 hr to concentrations of 60-444 mg/l R-141b in water; based on observed mortalities, the 96-hr LC_0 and LC_{50} were found to be <60 and 126 mg/l, respectively

J. Bootman, G. Hodson-Walker, and J. M. Lloyd, **CFC 141b: Investigation of Mutagenic Activity at the HGPRT Locus in a Chinese Hamster V79 Cell Mutation System**, report 88/PSV005/257, Life Science Research Limited (LSR), Suffolk, UK, July 1988 (RDB59A1)

mutagenicity of R-141b (HCFC-141b); genotoxicity; genotoxic and mutagenic potential; toxicity

J. Bootman, G. Hodson-Walker, S. Cracknell, and C. A. Dance, **HCFC 141b: Assessment of Clastogenic Action on Bone Marrow Erythrocytes in the Micronucleus Test**, report 88/PSV029, Life Science Research Limited (LSR), Suffolk, UK, 1988 (RDB7746)

mutagenicity of R-141b; genotoxicity; genotoxic and mutagenic potential; toxicity

J. Bootman and G. Hodson-Walker, **In Vitro Assessment of Clastogenic Activity of CFC 141 in Cultured Chinese Hamster Ovary (CHO-K1) Cells**, report 88/PSV007/214, Life Science Research Limited (LSR), Suffolk, UK, 1988 (RDB7286)

mutagenicity of R-141b (HCFC-141b); genotoxicity; genotoxic and mutagenic potential; toxicity — as reported in RDB5B57

D. Briand and G. Hervouet (Institut National de Recherche Chimique Appliquée, IRCHA, France), **Determination of Acute Toxicity of HCFC 141b to Daphnia Magna**, report B.7072 (FYI report OTS-5900695) for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Elf Atochem S.A., Levallois-Perret, France, 7 September 1989 (31 pages with 3 figures and 9 tables, RDB6474)

tests for acute aquatic toxicity to daphnia magna exposed for 48 hr to concentrations of 25.4-114.3 mg/l R-141b in water; based on observed immobilizations, the 24- and 48-hr $EC(I)_{50}$ (median effective inhibiting concentrations) were found to be 33.3 and 31.2 mg/l, respectively

W. J. Brock (E. I. duPont de Nemours and Company, USA), H. J. Trochimowicz (DuPont), R-J. Millischer (Elf Atochem S.A., France), C. H. Farr (Elf Atochem North America, USA), T. Kawano (Daikin Industries, Japan), and G. M. Rusch (AlliedSignal Incorporated, USA), **Acute and Subchronic Toxicity of 1,1-Dichloro-1-fluoroethane (HCFC-141b)**, *Food and Chemical Toxicology* (FCT), 33(6):483-490, June 1995 (8 pages with 3 tables, RDB65A4)

This paper summarizes acute and subchronic toxicity test methods and findings for R-141b, to assist in establishing proper handling guides. It describes the sample material used, acute oral toxicity tests in rats administered in corn oil, dermal toxicity tests in rats and rabbits, occular and dermal irritation tests in rabbits, and dermal sensitization studies in guinea pigs. It also outlines acute, two-week, four-week, and 90-day inhalation tests in rats, cardiac sensitization tests in beagle dogs and monkeys, and neurobehavioral toxicity tests in rats. The paper summarizes results including an oral LD_{50} rat of >5,000 mg/kg and oral LD_{50} rat of >2,000 mg/kg, since none of the specimens died in these tests. It also provides inhalation lethality data by sex, concluding that the 4-hr and 6-hr LC_{50} rat is 61,647 and 56,700 ppm, respectively. It notes that reduced motor activity, rapid breathing, and anesthesia were observed at all concentrations above 29,000 ppm. The cardiac sensitization study showed a LOEL at 5,000 and 9,000 ppm in the dog and monkey, respectively, the lowest concentrations tested; reference is made to earlier tests that showed

an LOEL of 5,000 ppm in dogs exposed for 5 minutes, also with epinephrine challenges. The NOAEL for subchronic inhalation studies was considered to be 8,000 ppm. No changes were found to indicate neurotoxicity. The data indicate that R-141b has low acute oral and inhalation toxicity potential, but is a mild skin and eye irritant.

W. J. Brock, **Acute Dermal Toxicity Study of FC-141b in Rabbits**, report 501-88, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1988 (RDB6471)

toxicity of R-141b by skin contact; LD_{50} dermal rabbit > 2,000 mg/kg — as reported in RDB5868 and RDB5B57

W. J. Brock, **Primary Eye Irritation Study with FC-141b in Rabbits**, report 318-88, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1988 (RDB6470)

toxicity of R-141b; health effects; eye irritation in rabbits as reported in RDB5868 and RDB5B57

W. J. Brock, **Skin Irritation Test in Rabbits of FC-141b**, report 312-88, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1988 (RDB6469)

R-141b, health effects, toxicity, dermal irritation in rabbits, not a skin irritant as reported in RDB-5868 and RDB5B57

CIVO, report V89.214, Netherlands Organization for Applied Scientific Research (TNO), Apeldoorn, The Netherlands, 1989 (RDB5973)

R-141b, toxicity

CIVO Institute, report V88.156/271236, Netherlands Organization for Applied Scientific Research (TNO), Apeldoorn, The Netherlands, 1988 (RDB-5974)

R-141b, health effects, toxicity

CIVO Institute, **Chromosome Analysis of Chinese Hamster Ovary Cells Treated in Vitro with FC 141b**, report 56645/50/88, Netherlands Organization for Applied Scientific Research (TNO), Apeldoorn, The Netherlands, 1988 (RDB7281)

R-141b, HCFC-141b, genotoxicity, health effects, toxicity

D. W. Coombs et al., **Potential Neuropathological Effects of Exposure of Rats to the Vapour (6 Hours a day, 5 Days a Week Over a 16-Week Period) of HCFC-141b**, report for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), Huntingdon Research Center Limited (HRC), Cambridgeshire, UK, 9 January 1992 (RDB7279)

R-141b, health effects, subchronic toxicity as reported in 5B57

D. E. Coombs, C. J. Hardy, D. Crook, P. A. Mullins, and C. Gopinath (Huntingdon Research Centre Limited, HRC, UK), **FC-141b: Two-Week Inhalation Study in the Rat**, report PWT 76/8893, Elf Atochem North America (then Pennwalt Corporation), King of Prussia, PA, December 1988 (RDB5996)

R-141b, health effects, subchronic toxicity

C. H. de Rooij (Solvay et Cie S.A., Belgium), **The Toxicology of HFA-141b**, *Proceedings of the European Meeting of the Toxicology Forum* (Toulouse, France, 18-22 September 1989), Société Française de Toxicologie, France, 204-216, 1989 (13 pages, RDB65A7)

R-141b, health effects, toxicity

C. Doleba-Crowe, **Acute Inhalation Toxicity — 6 Hours (FC 141b)**, report 61-77, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 17 February 1977 (2 pages with 1 table, RDB6465)

reports acute inhalation toxicity tests for groups of six male rats exposed to R-141b; indicates 0, 0, 1, 2, 6, and 6 deaths at 31,730, 42,800, 50,200, 55,270, 72,400, and 95,900 ppm v/v, respectively; concludes that the 6-hr ALC rat is 50,200 ppm v/v, described as "practically nontoxic"; notes shallow, rapid respiration and mild anesthesia in the test animals within the first hour of exposures at all levels; further notes tremors, incoordination, and some convulsions, indicative of a central nervous system response, at concentrations of 50,200 ppm v/v and higher; also notes that animals seemed to develop a tolerance to the compound at 31,730 and 42,800 ppm after 4 hr; indicates that mild weight loss occurred one day post exposure followed by normal weight gain at all exposure levels; also indicates that no histopathologic examinations were conducted

F. J. Dwyer et al., **CFC Alternatives in Thermoset Foam Production**, *Proceedings of the 33rd Annual Polyurethane Technical/Marketing Confer-*

ence (20 September - 3 October 1990), 400-406, 1990 (7 pages, RDB59A5)

R-141b, toxicity

ENVIRON Corporation, **Evaluation Of Potential Risks Associated with Substitution of HCFC 141b for CFCs Used in the Manufacture of Insulating Foam**, Elf Atochem North America, Incorporated, Philadelphia, PA, April 1992 (94 pages with 20 tables, RDB7288)

review of toxicity data for R-141b and its primary degradation products (R-151a, R-1131a, R-142b, and R-143a), toxicity criteria and dose-duration responses, exposure assessment, and risk characterization; concludes that "the potential health hazard ... of exposure is negligible for workers manufacturing the foam insulation and for residents (both adults and children) living in homes insulated with foam boards"

J. W. Gardner (Huntingdon Research Centre Limited, HRC, UK), **Acute Dermal Toxicity to Rats of 4874-89**, report 881114D/PWT 91/AC, Elf Atochem North America (then Pennwalt Corporation), King of Prussia, PA, 12 October 1988 (16 pages with 4 tables, RDB5991)

test to assess the dermal toxicity of R-141b (identified in the study as 4874-89) by a single exposure to the skin of five male and five female CFY (Sprague-Dawley) rats: no signs of systemic reaction were observed and deaths resulted; rats achieved normal bodyweight gains and terminal autopsy findings were normal; concluded that the ALD dermal rat > 2000 mg/kg (1.63 mL/kg)

C. J. Hardy, G. C. Jackson, R. S. Rao, D. J. Lewis, and C. Gopinath (Huntingdon Research Centre Limited, HRC, UK), **HCFC 141b Acute Inhalation Toxicity Study in Rats 4-Hour Exposure**, report PWT 95/881676, Elf Atochem North America (then Pennwalt Corporation), King of Prussia, PA, 17 July 1989 (69 pages with 2 figures and 8 tables including 1 page sponsor summary, RDB5995)

tests of acute inhalation toxicity to groups of five male and five female Sprague-Dawley, albino rats by whole-body exposures at 0 (control), 29,674, 45,347, 67,499, or 76,485 ppm v/v R-141b in air for 4 hr: 5 of 10 and 10 of 10 animals died at the two highest concentrations, leading to findings of 4-hr LC_{50} rat of 58,931 for the males, 64,991 for the females, and 61,647 ppm v/v overall; treated animals showed increased respiration rates, wetness around the mouth, reduced motor activity, restless behavior, and abnormal body carriage at all concentrations except the control group; rats showed reduced bodyweight or bodyweight gain for one day following exposure; the lung to body weight ratios were high for those that died, but no treatment-related macroscopic or microscopic abnormalities were found in pathological examinations

J. H. Harris and M. W. Anders, **In Vivo Metabolism of the Hydrochlorofluorocarbon 1,1-Dichloro-1-fluoroethane (HCFC-141b)**, *Biochemical Pharmacology*, UK, 41(9):R13-R16, 1991 (4 pages, RDB5975)

R-141b, toxicity

Y. Hino, K. Yamasaki, and K. Shiraishi, **Twenty-Eight Day Repeated Dose Inhalation Toxicity Study of HCFC-141b in Rats**, report T-2966, Hita Research Laboratories Chemical Biotesting Center, Chemicals Inspection and Testing Institute, Japan, February 1992 (RDB5984)

R-141b, toxicity

G. Hodson-Walker, **HCFC-141b: Lymphocyte Cytogenetic Study Using the Methodology Recommended by the OECD (1983)**, report 89/-PFG002/1029 (FYI report OTS-006900695), Life Science Research Limited (LSR), Suffolk, UK, 1990 (RDB5998)

R-141b, genotoxicity, health effects, mutagenic potential, toxicity

G. Hodson-Walker, **In Vitro Assessment of Clastogenic Activity of HCFC-141b in Cultured Chinese Hamster Ovary (CHO-K1) Cells**, report 89/PFG001/0971a (FYI report OTS-0690-0695), Life Science Research Limited, Suffolk, UK, 1990 (Rdb5997)

R-141b, genotoxicity, health effects, mutagenic potential, toxicity

G. Hodson-Walker and K. May, **CFC 141b: Assessment of Mutagenic Potential in Histidine Auxotrophs of Salmonella Typhimurium (The Ames Test)**, report 88/PSV004/237, Life Science Research Limited (LSR), Suffolk, UK, 1988 (RDB-59A0)

R-141b, HCFC-141b, genotoxicity, health effects, mutagenic potential, toxicity

G. Hodson-Walker and K. May, **CFC 141b: Assessment of Its Ability to Cause Lethal DNA Damage in Strains of Escherichia Coli**, report 88/PSV008/258, Life Science Research Limited (LSR), Suffolk, UK, June 1988 (RDB59A2)

R-141b, HCFC-141b, genotoxicity, health effects, toxicity

W. Howe, **Hygiene Standard Documentation — HCFC 141b**, document MC001, ICI Chemicals and Polymers Limited, Cheshire, UK, 14 October 1991 (3 pages, RDB5A80)

R-141b, toxicity, rationale for recommended hygiene standard (occupational exposure limit, OEL) of 500 ppm, 8-hr TWA, and for a short-term exposure limit of 1,250 ppm for 10 minutes

E. W. Hughes, B. A. Homan, D. M. John, T. J. Kenney, D. W. Coombs, and C. J. Hardy (Huntingdon Research Centre Limited (HRC, UK), **Study of the Effect of PWC 4874-89 on the Pregnancy of the Rabbit**, report PWT 82/89243, October 1989 (RDB5986)

R-141b, health effects, reproduction and developmental study, toxicity

E. W. Hughes, B. A. Homan, T. J. Kenney, D. W. Coombs, C. J. Hardy, and S. A. Tesh (Huntingdon Research Centre Limited, HRC, UK), **Effects of HCFC-141b on Pregnancy of the Rabbit**, report PWT 77/88952, Elf Atochem North America (then Pennwalt Corporation), King of Prussia, PA, November 1988 (RDB5985)

R-141b, developmental study, health effects, reproduction, toxicity

E. W. Hughes, B. A. Homan, T. J. Kenney, D. W. Coombs, and C. J. Hardy, **The Effect of HCFC-141b on Pregnancy of the Rat**, Huntingdon Research Centre Limited (HRC), Cambridgeshire, UK, 1988 (RDB5A82)

R-141b, developmental study, health effects, reproduction, toxicity

Huntingdon Research Centre Limited (HRC, UK), **HCFC-141b: Potential Tumorigenic and Toxicological Effects During Prolonged Inhalation Administration in Rats**, report ALS 1/911274, AlliedSignal Incorporated, Morristown, NJ, 1992 (RDB7285)

R-141b, health effects, chronic toxicity

Huntingdon Research Centre Limited (HRC, UK), **HCFC-141b: Potential Tumorigenic and Toxicological Effects During Prolonged Inhalation Administration in Rats**, report ALS 1/921032, AlliedSignal Incorporated, Morristown, NJ, volumes 1-8, 1993 (RDB5989)

R-141b, health effects, chronic toxicity

P. J. M. Janssen (Duphar B.V., The Netherlands), **Acute Inhalation Toxicity Studies on FC 141b in Rats**, report S.8820 (also identified as 55645/61/88), Solvay et Cie S.A., Brussels, Belgium, October 1988 with June 1989 supplement (76 pages with 3 figures and 37 tables, RDB6463)

toxicity tests for acute inhalation toxicity of R-141b in groups of 5 male and 5 female Wistar-derived rats by nose-only exposures to 0 (control), 3,000, 6,000, or 10,000 ppm v/v averages of 0, 2,946, 5,992, or 11,096 ppm by analysis) R-141b in air for 6 hr: tests included observation of clinical signs, analysis of post-exposure blood and urine, and macroscopic and histopathologic examinations at necropsy; no irritation, anesthesia, or other clinical signs were observed during or after exposures; slight decreases were observed in body-weight gain for males exposed to 3,000 and 11,000 ppm and females exposed to 6,000 and 11,000 ppm; slight effects were observed in the inorganic phosphate levels in blood plasma and in the and kidney function of treated animals; absolute increases were found in the lung weights of animals exposed to 3,000 ppm and relative increases in kidney weights were observed in males exposed to 6,000 ppm; kidney is suggested as a possible target organ with prolonged exposure; no deaths resulted leading to interpretation that the 6-hr ALC rat exceeds 11,096 ppm; R-141b used is identified as 95.5-97.1% pure with 2.6-3.8% R-365 as the major impurity; supplement documents compliance with Good Laboratory Practice regulations

P. J. M. Janssen (Duphar B.V., The Netherlands), **Acute Inhalation Study to Investigate the Respiratory Irritancy Properties of FC 141b in Male Rats**, report 56645/41/89, Solvay et Cie S.A., Brussels, Belgium, 1989 (RDB7749)

tests for acute inhalation toxicity of R-141b in rats as reported in RDB5371

P. J. M. Janssen (Duphar B.V., The Netherlands), **Acute Oral Toxicity Study with FC 141b in Rats**, report S.8812 (also identified as 55645/36/88), Solvay et Cie S.A., Brussels, Belgium, January 1989 with June 1989 supplement (Rdb6461)

toxicity tests for acute ingestion toxicity of R-141b in groups of 5 male and 5 female rats by ingastric intubation of 0 (control) or 2000 mg/kg bodyweight R-141b in corn oil: no deaths resulted and the report concludes that the LD_{50} oral rat exceeds 2000 mg/kg as tested; clinical signs were mainly indicative of an effect on the autonomic nervous system, on the central ner-

vous system, on motor coordination, an motor activity, and on muscle tone; macroscopic examination at necropsy found a higher incidence of liver changes (swollen hydropic degeneration of the hepatocytes and cloudy swelling of the renal tubular epithelium) in treated animals compared to no males and 2 females in the control groups

P. J. M. Janssen and T. E. Pot (Duphar B.V., The Netherlands), **Acute Dermal Toxicity Study with FC 141b in Rats**, report S.8801 (also identified as 56645/23/88), Solvay et Cie S.A., Brussels, Belgium, May 1988 (13 pages with 5 tables, RDB-6460)

toxicity tests for acute dermal toxicity of R-141b in groups of 5 male and 5 female Wistar rats by application under an occlusive dressing to the shaved, intact skin of 0 (control) or 2,000 mg/kg bodyweight R-141b: no deaths resulted and the report concludes that the LD_{50} dermal rat exceeds 2,000 mg/kg as tested; slight vocalization was observed in 3 females of the treated group for the first 30 minutes of application; the treated males and 1 male from the control group were somewhat quiet for the corresponding period; macroscopic examination of the animals at necropsy revealed 5 males and 3 females with swollen or slightly swollen livers

R. J. Kenny (Huntingdon Research Centre Limited, HRC, UK), **HCFC-1717: Assessment of Cardiac Sensitization Potential in Dogs**, report ALS 57/942811 (also identified as MA-RR-95-2156), AlliedSignal Incorporated, Morristown, NJ, USA, 22 December 1994 (38 pages with 4 figures and 7 tables; 3 page cover and summary available from JMC as RDB7206)

toxicity tests of R-141b [identified with a truncated CAS number as a "blind control study"], to determine the cardiac sensitization level in male beagle dogs: 6 animals were exposed snout-only for 10 minutes following adrenaline administration, by intravenous injection, and with a second, challenge injection midway through the exposure; tests were repeated, on separate days, at concentrations of 0 (control), 10,000, and 20,000 ppm v/v R-141b in air: results were negative and no abnormal clinical signs were observed at 10,000 ppm; 1 dog (17%) responded positively, resulting in fatal ventricular fibrillation (very rapid and irregular contractions of the ventricles of the heart resulting in loss of synchronization between the heartbeat and pulse beat), at 20,000 ppm; report concludes that "HCFC-1717" [R-141b] has cardiac sensitization potential at a concentration in air of "up to 20,000 ppm"

J. C. Koorn (Duphar B.V., The Netherlands), **Study to Examine the Possible Mutagenic Activity of the Volatile Liquid FC 141b in the Salmonella/Microsome Assay**, report S.8819 (also identified as 55645/60/88 and 56645/41/89), Solvay et Cie S.A., Brussels, Belgium, 1988 (RDB-6462)

R-141b, genotoxicity, mutagenic potential, toxicity

S. R. Kynoch and B. I. Parcell (Huntingdon Research Centre Limited, HRC, UK), **Delayed Contact Hypersensitivity in the Guinea Pig with 4874-89**, report PWT 94/881236D/SS, Elf Atochem North America (then Pennwalt Corporation), King of Prussia, PA, 1989 (RDB5994)

R-141b, health effects, toxicity as reported in RDB5371 and RDB5B57

T. D. Landry, F. S. Cieszlak, J. R. Szabo, and B. L. Yano, **1,1-Dichloro-1-fluoroethane: 13-Week Toxicity Study with Fischer 344 Rats**, report DR-0006-8553-002B, Dow Chemical Company, Midland, MI, July 1989 (RDB5983)

summarizes a subchronic toxicity study of R-141b

J. P. Lavelle and T. Doyle (Elf Atochem North America), **Safety, Storage, and Handling Recommendations for HCFC-141b**, *Proceedings of the 33rd Annual Polyurethane Technical/Marketing Conference* (20 September - 3 October 1990), 407-412, 1990 (6 pages, RDB6583)

R-141b, safety, toxicity

M. A. Lee, D. M. Krentz, and R. C. Graham, untitled toxicity review for ethane, 1,1-dichloro-1-fluoro-, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 24 November 1993 (18 pages, RDB5868)

R-141b, summary of published and unpublished toxicity literature

M. P. Liggett, S. Allan, and I. S. Dawe (Huntingdon Research Centre Limited, HRC, UK), **Acute Oral Toxicity to Rats of PWC 4874-89**, report 8913D/PWT 90/AC, Elf Atochem North America (then Pennwalt Corporation), King of Prussia, PA, 5 October 1989 (20 pages with 9 tables, RDB-5988)

toxicity tests for acute toxicity by a single oral dose of PWC 4874-89 [subsequently identified

by the study sponsor as R-141b] dissolved 50% w/v (sic) in corn oil administered to groups of 5 male and 5 female CD rats by a syringe and plastic catheter: no deaths resulted and the report concludes that the LD_{50} oral rat exceeds 5,000 mg/kg bodyweight as tested; piloerection was observed in all rats within 5 min of dosing and throughout the remainder of the day; no other clinical signs were observed and recovery, as judged by external appearance and behavior, was complete by the next day; bodyweight gains were slightly lower for 1 male and 2 females during the second week of observation, but all animals achieved anticipated bodyweight gains during the 14-day observation period; terminal autopsy findings were normal

M. P. Liggett (Huntingdon Research Centre Limited, HRC, UK), **Irritant Effects on Rabbit Skin of 4874-89**, report PWT 92/881066D/SE, Elf Atochem North America (then Pennwalt Corporation), King of Prussia, PA, 1988 or 1989 (RDB5992)

R-141b, toxicity as reported in RDB5B57

M. P. Liggett (Huntingdon Research Centre Limited, HRC, UK), **Irritant Effects on the Rabbit Eye of 4874-89**, report PWT 93/881067D/SE, Elf Atochem North America (then Pennwalt Corporation), King of Prussia, PA, 1988 or 1989 (RDB-5993)

R-141b, toxicity as reported in RDB5B57

G. D. Loizou and M. W. Anders (University of Rochester), **Gas-Uptake Pharmacokinetics and Biotransformation of 1,1-Dichloro-1-fluoroethane (HCFC-141b)**, *Drug Metabolism and Disposition*, 21:634-639, 1993 (6 pages, RDB-65E3)

R-141b, biochemistry, metabolism, toxicity

K. May, **HCFC 141b: Assessment of Mutagenic Potential in Amino Acid Auxotrophs of Salmonella Typhimurium and Escherichia Coli (The Ames Test)**, report 89/PFG003/0600, Life Science Research Limited, Suffolk, UK, 1989 (RDB5999)

mutagenicity of R-141b; genotoxicity; genotoxic and mutagenic potential; toxicity; deemed R-141b not mutagenic in 5 histidine-dependent auxotrophs of Salmonella typhimurium and 1 strain of tryptophan dependent auxotroph of Escherichia coli using modified pour-plate assays with and without metabolic activation — as reported in RDB5868

K. May, **HCFC 141b: Assessment of Mutagenic Potential in Amino Acid Auxotrophs of Salmonella Typhimurium and Escherichia Coli (The Ames Test)**, report 88/PFG003/0823, Life Science Research Limited (LSR), Suffolk, UK, 1989 (RDB-7287)

R-141b, genotoxicity, health effects, mutagenic potential, toxicity as reported in RDB5B57

R-J. Millischer (Elf Atochem S.A., France), C. H. de Rooij (Solvay S.A., Belgium), G. M. Rusch (misspelled "Rush" in the paper, AlliedSignal Incorporated), C. H. Farr (Elf Atochem North America, USA), R. Ben-Dyke (Ben-Dyke Associates Incorporated, USA), C. J. Hardy (Huntingdon Research Centre Limited, HRC, UK), D. J. Lewis (HRC), and G. Hudson-Walker (Pharmaco:LSR, UK), **Evaluation of the Genotoxicity and Chronic Inhalation Toxicity of 1,1-Dichloro-1-Fluoroethane (HCFC-141b)**, *Food and Chemical Toxicology* (FCT), 33(6):491-500, June 1995 (10 pages with 2 figures and 3 tables, RDB65A8)

summarizes a series of *in vitro* and *in vivo* tests of R-141b for genotoxicity; based on the data presented and prior testing, deems R-141b to be non-genotoxic; reports a no-observable adverse effect level (NOAEL) of 1500 ppm v/v for a two-year chronic exposure study in rats

L. S. Mullin, **Fluorocarbon 141b (Ethane, 1,1-dichloro-1-fluoro): Cardiac Sensitization**, report 957-77, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 23 November 1977 (3 pages with 1 table, RDB6467)

R-141b, toxicity tests to determine the cardiac sensitization potential in male beagle dogs with intravenous injection of epinephrine five minutes before and, with a challenge injection, midway into a 10 minute exposure; NOEL (0/10) at 2,600 ppm v/v; LOEL (1/10) at 5,200 ppm; lethal to 1 of 10 dogs at 10,200 ppm and to 2 of 2 at 21,600 ppm; concludes that R-141b is a strong cardiac sensitizer

T. K. Nikijenko, *Toksikologiya Novykh Promyshlennykh Khimicheskikh Veshchestva* [Toxicology of New Industrial Chemical Substances], 8:83-97, 1966 (11 pages in Russian, RDB5978)

toxicity of R-141b

G. M. Rusch (AlliedSignal Incorporated), R-J. Millischer (Elf Atochem S.A., France), C. H. de Rooij (Solvay & Cie S.A., Belgium), A. J. Brooker (Huntingdon Research Centre, HRC, UK), E. W. Hughes (HRC), and D. W. Coombs (HRC), **Inhalation Teratology and Two-Generation Reproduction Studies with 1,1-Dichloro-1-fluoroethane**

(HCFC-141b), *Food and Chemical Toxicology* (FCT), 33(4):285-300, April 1995 (16 pages with 1 figure and 17 tables, RDB7283)

teratology studies in rabbits and rats and a two generation reproductive toxicity in rats of R-141b; notes significant effects in pups as low as 8,000 ppm v/v, but deems 2,000 ppm v/v to be a NOEL

J. F. Russell, **Mutagenic Activity of Ethane, 1,1-Dichloro-1-fluoroethane) in the Salmonella/Microsome Assay)**, report 988-77, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1977 (RDB6468)

mutagenicity of R-141b; toxicity; not mutagenic by Ames Assay — as reported in RDB5868

J. W. Sarver, **Acute Oral Toxicity Study of FC-141b in Male Rats**, report 363-88, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1988 (RDB5977)

toxicity of R-141b; LD_{50} oral rat >5,000 mg/kg — as reported in RDB5868 and RDB5B57

J. A. Seckar (Pennwalt Corporation), **The Toxicology of HCFC-141b (1,1-Dichloro-1-fluoroethane)**, *Journal of the American College of Toxicology* (JACT), 8(6):1221, 1989 (1 page, RDB7278)

briefly summarizes toxicity studies of R-141b; indicates that it is a very slight skin and eye irritant in rabbits, but not a dermal sensitizer in the guinea pig, with an LD_{50} dermal rabbit exceeding 5,000 mg/kg; indicates that the LD_{50} oral rat exceeds 2,000 mg/kg and the 4-hr LC_{50} rat exceeds 62,000 ppm v/v; notes central nervous system (CNS) depression above 30,000 ppm v/v, rapidly reversible upon termination of exposure; reports tests of cardiac sensitization to epinephrine in dogs with an effect at 10,000 ppm v/v; discusses reproductive, teratogenic, and subchronic toxicity tests that found an unequivocal no-observed-effect level (NOEL) of 8,000 ppm v/v; notes that mutagenicity, a combined chronic toxicity and oncogenicity, and ecotoxicity studies are planned

R. Tolando (University of Surrey, UK), R. Ferrara (University of Padova Medical School, Italy), N. I. Eldirdiri, A. Albores, L. J. King (Surrey), and M. Manno (Padova), **Reductive Activation of 1,1-Dichloro-1-fluoroethane (HCFC-141b) by Phenobarbital- and Pyridine-Induced Rat Liver Microsomal Cytochrome P450**, *Xenobiotica*, 26:425-435, 1996 (11 pages, RDBA565)

toxicity of R-141b; health effects

D. A. Viachos (possibly Vlachos), **Mouse Bone Marrow Micronucleus Assay of FC-141b**, report 746-88, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1988 (RDB-6472)

sumarizes a mutagenicity study of R-141b; toxicity — as reported in RDB5868 and RDB5B57

B. L. Yano, F. S. Cieszlak, and T. D. Landry, **1,1-Dichloro-1-fluoroethane: 4-Week Toxicity Study with Fischer 344 Rats**, report DR-0006-8553-002A, Dow Chemical Company, 1989 (RDB-5982)

subchronic toxicity of R-141b; health effects

4874-89: Assessment of Clastogenic Action on Bone Marrow Erythrocytes in the Micronucleus Test, report 88/0504, Life Science Research Limited (LSR), Suffolk, UK, 1989 or 1990 (RDB59A3)

toxicity of R-141b; genotoxicity; health effects; mutagenic potential — as reported in RDB5B57

CFC 141b: Investigation of Mutagenic Activity at the HGPRT Locus in a Chinese Hamster V79 Cell Mutation System, report 88/PSV005/257, Life Science Research Limited (LSR), Suffolk, UK, July 1988 (RDB59A1)

mutagenicity of R-141b; genotoxicity; toxicity

1,1-Dichloro-1-fluoroethane (HCFC-141b, CAS No 1717-00-6), Joint Assessment of Commodity Chemicals (JACC) report 29, European Chemical Industry Ecology and Toxicology Centre (ECETOC), Brussels, Belgium, December 1994 (RDB-6585)

toxicity and environmental impacts of R-141b

1,1-Dichloro-1-fluoroethane (HCFC 141b) Health Effects Information, CAS# 1717-00-6, Elf Atochem North America, Incorporated, Philadelphia, PA, undated circa 1995 (6 pages, RDB5B57)

summary of toxicological and ecological information for R-141b; toxicity; environmental impacts

1,1-Dichloro-1-fluoroethane (HCFC-141b): Probe Study to Assess the Neuropharmacologic Effects of Acute Inhalation Exposure in Rats, Dow Chemical Company, 1989 (RDB7280)

toxicity of R-141b; health effects

Prehl. Prumysolve Toxikol. Org. Latky, 134 ff, 1986 (RDB5981)

toxicity of R-141b

Workplace Environmental Exposure Level Guide — 1,1-dichloro-1-fluoroethane, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1992 (RDB4B87)

Workplace Environmental Exposure Level (WEEL) Guide for R-141b; recommended occupational exposure limit; summary of toxicology data; toxicity

report 55635/49/90 [possibly 55645/49/90], Duphar B.V., The Netherlands, 1991 (RDB6464)

ecological toxicity of R-141b; aquatic environmental study,

report 715-77, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1977 (RDB6466)

subchronic inhalation toxicity tests of R-141b — as reported in RDB5868

report ALS 1/901565, Huntingdon Research Centre (HRC), Cambridgeshire, UK, 17 December 1990 (RDB6473)

neurologic toxicity study of R-141b in rats; found no changes indicative of neurotoxic effect — as reported in RDB5868

report ALS 2/920766, Huntingdon Research Centre Limited (HRC), Cambridgeshire, UK, 1988 (RDB5990)

toxicity of R-141b

study of the metabolic and biochemical effect of R-141b in rats, AlliedSignal Incorporated, Morristown, NJ, 6 May 1992 (RDB6476)

toxicity of R-141b

R-142b

F. C. Barsky and B. E. Butterworth, **In Vitro Microbial Mutagenicity Studies of Ethane, Chlorodifluoro**, report 322-76, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1976 (RDB6517)

R-142b, health effects, toxicity as reported in RDB3721 and RDB5869

Bio/dynamics Incorporated, **A Dominant-Lethal Inhalation Study with Fluorocarbon 142b in Rats**, report 79-7288, Elf Atochem North America (then Pennwalt Corporation), King of Prussia, PA, 1980 (RDB5916)

R-142b, toxicity

Bio/dynamics Incorporated, **A Study in the Rat of the Cytogenetic Effect of Inhalation of Fluorocarbon 142b for 13 Weeks**, report 79-7289, Elf Atochem North America (then Pennwalt Corporation), King of Prussia, PA, 1980 revised 16 June 1983 (RDB5917)

R-142b, health effects, toxicity

Bio/dynamics Incorporated, **A Two-Year Inhalation Study of Fluorocarbon 142b in the Rat**, report 79-7287, Elf Atochem North America (then Pennwalt Corporation), King of Prussia, PA, 1983 (RDB5918)

R-142b, health effects, toxicity

M. R. Brittelli, **Eye Irritation Test in Rabbits**, report 752-75, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1976 (RDB6521)

R-142b, health effects, toxicity as reported in RDB5869

R. Culik and D. P. Kelly, **Embryotoxic and Teratogenic Studies in Rats with Inhaled Chlorodifluoroethane (FC 142b)**, report 700-76, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1976 (RDB6520)

R-142b, health effects, developmental and reproductive toxicity as reported in RDB3721, RDB5371, and RDB5869

D. R. Damske, F. J. Mecler, and R. P. Beliles, **Teratology Study in Rats — Isotron 142b — Monochlorodifluoroethane**, report for project 20980 or 29890, Litton Bionetics Incorporated (LBI), Kensington, MD, 1978 (RDB5914)

R-142b, health effects, toxicity

A. P. Filicheva, **Changes in the Nervous System Following the Chronic Action of Fluorinated Aliphatic Carbohydrates**, *Gigiena Truda i Professional'nye Zabolevaniya* [Labor Hygiene and Occupational Diseases], Moscow, Russia (then USSR), 10:14-16, 1975 (3 pages in Russian, RDB6523)

R-142b, health effects, toxicity

A. H. C. Groeneveld and L. A. M. Kuijpers, **The Acute Toxicity of 1-Chloro-1,1-difluoroethane**

(HCFC-142b) to Daphnia Magna, report 56635/32/90, Duphar B.V., The Netherlands, 1990 (RDB7747)

R-142b, aquatic environmental study, ecological toxicity

A. H. C. Groeneveld and L. A. M. Kuijpers, **The Acute Toxicity of 1-Chloro-1,1-difluoroethane (HCFC-142b) to the Guppy Poecilia Reticulata**, report 56635/33/90, Duphar B.V., The Netherlands, 1990 (RDB7748)

R-142b, aquatic environmental study, ecological toxicity

P. W. Grube, M. A. Lee, G. T. Hall, R. C. Graham, and L. J. Ver Nooy, untitled toxicity review for ethane, 1-chloro-1,1-difluoro-, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 17 January 1990 (12 pages, RDB5869)

R-142b, summary of published and unpublished toxicity literature

D. G. Hutton, **Flow-Through Acute 96-Hour EC_{50} of Chlorodifluoroethane to Rainbow Trout (Oncorhynchus Mykiss)**, report 543-89, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1989 (RDB7752)

ecotoxicity of R-42b; environmental impacts and fate; aquatic impacts -- as reported in RDB5371

D. G. Hutton and P. H. Lieder, **Static Acute 48-Hour EC_{50} of Chlorodifluoroethane to Daphnia Magna**, report 542-89, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1989 (RDB7751)

ecotoxicity of R-42b; environmental impacts and fate; aquatic impacts -- as reported in RDB5371

D. R. Jagannath and D. J. Brusick, **Mutagenicity Evaluation of Isotron 142b**, report for project 20838, Litton Bionetics Incorporated (LBI), Kensington, MD, 1977 (RDB5912)

R-142b, health effects, toxicity

D. P. Kelly and H. J. Trochimowicz, **Ninety Day Inhalation Exposure of Rats and Dogs to Vapors of 1-Chloro-1,1-difluoroethane**, report 469-76, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1976 (RDB6518)

R-142b, health effects, toxicity: no adverse clinical hematological, blood chemical, urine analytical, or histopathologic evidence of effects attributable to exposures at 1,000 or 10,000 ppm v/v as reported in RDB3721 and RDB5869

A. Koops and D. F. Krahn, **Mutagenic Activity of Ethane, Chlorodifluoro- in the Salmonella/Microsome Assay**, report 578-77, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1977 (RDB6519)

R-142b, health effects, toxicity as reported in RDB2721, RDB5371, and RDB5869

D. W. Matheson and D. Brusick, **Mutagenicity Evaluation of Isotron 142b in the In Vitro Transformation of BALB/3T3 Cells Assay**, report for project 20840, Litton Bionetics Incorporated (LBI), Kensington, MD, 1978 (RDB5913)

R-142b, toxicity

F. J. Mecler and P. J. Knapinsky, **Acute Inhalation Toxicity Study in Rats. Isotron 142b**, report for project 20888, Litton Bionetics Incorporated (LBI), Kensington, MD, 1978 (RDB59A8)

6 hr acute inhalation toxicity tests of R-142b in Charles River CD rats: mortality ratios and corresponding concentrations were 0% at 200,000 ppm in air and 20% at 400,000 ppm [deemed an ALC]; rats showed rapid and labored breathing, lethargy, and discharges from the eyes and nose at 400,000 ppm; necropsy of the surviving rats after a 14 day observation period revealed dark red mottling of the lungs and kidneys, especially at the higher concentration — as reported in RDB3721

B. L. Moore and H. J. Trochimowicz, **Subacute (Two-Week) Inhalation Toxicity of 1-Chloro-1,1-difluoroethane**, report 145-76, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1976 (RDB6516)

R-142b, health effects, toxicity, inhalation study in the rat: no clinical hematological, blood chemical, urine analytical, or histopathologic evidence of effects attributable to exposures at 20,000 ppm as reported in RDB3721 and RDB-5869

J. A. Seckar (Pennwalt Corporation), H. J. Trochimowicz (E. I. duPont de Nemours and Company, Incorporated), and G. K. Hogan, **Toxicological Evaluation of Hydrochlorofluorocarbon 142b**,

Fundamentals of Chemical Toxicology, 24(3):237-240, 1986 (RDB5919)

R-142b, health effects, toxicity

J. D. Sterling, *Aerosol Age*, 12:48-52, 1982 (5 pages, RDB6524)

R-142b, health effects, toxicity

Acute Toxicity Study in Rats — Isotron 142b, Monochlorodifluoroethane, report for project 20795, Litton Bionetics Incorporated (LBI), Kensington, MD, 1978 (RDB5911)

R-142b, health effects, toxicity

Chlorodifluoroethane (1-Chloro-1,1-difluoroethane; HFA-142b, CAS: 75-68-3), Joint Assessment of Commodity Chemicals (JACC) report 17, European Chemical Industry Ecology and Toxicology Centre (ECETOC), Brussels, Belgium, February 1991 (36 pages with 1 table, RDB3721)

R-142b, environmental impacts, toxicity

Workplace Environmental Exposure Level Guide — 1-chloro-1,1-difluoroethane, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1994 (RDB4B89)

R-142b, toxicity, safety classification: 4-hr ALC rat = 128,000 ppm, WEEL = 1,000 ppm

R-143

L. J. Sibinski, **Two-Year Oral (Diet) Toxicity-Carcinogenicity Study of the Fluorochemical FC 143 in Rats**, Riker Laboratories, Incorporated, 3M Company, Minneapolis, MN, 1987 (RDB65E0)

R-143 (possibly R-143a), toxicity

R-143a

W. J. Brock, H. J. Trochimowicz (E. I. duPont de Nemours and Company, USA), C. H. Farr (Elf Atochem North America, USA), R-J. Millischer (Elf Atochem S.A., France), and G. M. Rusch (Allied-Signal Incorporated, USA), article 0092, **Acute, Subchronic, and Developmental Toxicity and Genotoxicity of 1,1,1-Trifluoroethane (HFC-143a)**, *Fundamental and Applied Toxicology*, 31(2):200-209, June 1996 (10 pages with 7 tables, RDB6597)

acute, subchronic, and developmental inhalation toxicity and genotoxicity studies for R-143a: no mortalities resulted in groups of 6 Crl:CDBR male rats exposed nose-only for 4 hours to 97,000 and 540,000 ppm v/v R-134a in air with added oxygen to maintain 20% levels; animals showed body weight loss after exposures, but recovered by the second day; concludes that the 4-hr LC_{50} rat exceeds 540,000 ppm; groups of 5-6 male beagle dogs were exposed to 50,000, 100,000, 150,000 200,000, 250,000, and 300,000 ppm with intravenous injection of epinephrine five minutes before and, with a challenge injection, midway into a 10 minute exposure; 1 of 6 dogs exhibited an equivocal response at 200,000 ppm, but none (including the same dog) did so at 250,000 ppm [deemed a NOEL]; 2 of 5 dogs showed marked responses at 300,000 ppm considered to be the cardiac sensitization LOEL; four groups of 10 male and 10 female rats were exposed nose-only to concentrations of 0 (control), 2,000, 10,000, and 40,000 ppm v/v R-143a in air for 6 hr/d, 5 d/wk for 4 weeks; 3 premature deaths were determined not to be treatment-related; decreases were observed in male, but not female body weights, but no toxicologically significant clinical signs or pathology measurements were observed during or after the exposures; microscopic degenerative changes were found in the testes of male rats in each exposure group, ranging in severity from slight at 2000 ppm to minimal or mild at 10,000 ppm and 40,000 ppm; based on problems encountered with the restraining devices, excessive temperatures, and prior documentation of related stress effects, the study was repeated without restraints (whole-body exposures); no adverse testicular effects or adverse clinical signs were seen at any exposure level; based on these results, 40,000 ppm was determined to be the 4-wk NOAEL rat for R-143a; 20 male and 20 female rats were exposed (whole body) to 0 (control), 2,000, 10,000, and 40,1000 ppm v/v for 6 hr/day, 5 d/wk for 90 days; sporadic changes in body weight were observed, but did not follow a dose-response relationship and were not considered to be treatment-related; no clinical signs of toxicity were observed during or after the exposures, and no pathology changes were found; no ß-oxidation activity (peroxisome proliferation), organ weight, adverse gross, or microscopic changes were observed; 90-day NOAEL rat was considered to be 40,000 ppm; developmental studies conducted in both rats and rabbits by whole-body exposures at 2,000, 10,000, and 40,000 ppm for 6 hr/d on days 6 through 15 (rats) or 18 (rabbits) of gestation; no adverse clinical signs or biologically significant effects were identified; reproductive parameters

and developmental variations were unaffected in rats, but visceral variations due to retarded development were observed; incidence of skeletal malformations was higher in exposed rabbits than in controls, but did not follow a dose-response relation; genotoxicity studies included the Ames Assay, in vitro tests with human lymphocytes, and in vivo micronucleus tests in mouse bone marrow; no increases in revertants were found in bacteria with 5 strains of Salmonella typhimurium and 2 strains of Esche-richia coli; no aberrations in clastogenic activity were found in human lymphocytes; no clinical signs of toxicity or statistically significant effects were found in the micronucleus study using male and female mice; paper concludes that R-143a is "able to induce a cardiac sensitization response at very high exposure levels," "has a low acute and subchronic toxicity potential," is not a developmental toxicant, and is not genotoxic

S. Cracknell (Life Science Research Limited, LSR, UK), **Forane 143a: Acute Inhalation Toxicity in the Rat**, report 91/ATH007/1159 (also identified as 91/1159), Elf Atochem S.A., Paris - La Défense, France, 4 February 1992 (72 pages with 3 figures and 5 tables, Rdb7450)

toxicity tests for acute inhalation toxicity of R-143a in groups of 5 male and 5 female Sprague-Dawley rats by nose-only exposures to 0 (control), 300,000, or 600,000 ppm v/v (averages of 0, 305,000, or 591,000 ppm v/v by analysis) R-143a in air for 4 hours: tests included observation of clinical signs, analysis of post-exposure blood and urine, and macroscopic and histopathologic examinations at necropsy; no deaths resulted and report concludes that the 4-hr LC_{50} rat exceeds 591,000 ppm as tested; minor changes were observed in the respiratory pattern of 3 treated animals; peripheral vasodilation was seen for 4 females and 1 male exposed to 591,000 ppm; no other clinical signs, changes in bodyweight, effects on organ weight, or macroscopic changes attributed to treatment were found

S. R. Frame, M. C. Carakostas, and D. B. Warheit (E. I. duPont de Nemours and Company, Incorporated), **Two Four-Week Inhalation Toxicity Studies with HFC-143a in Rats**, abstract 1391 (SOT 31st Annual Meeting, February 1992) for the Program for Alternative Fluorocarbon Toxicity Testing (PAFT), *The Toxicologist*, 12(1):355, 1992 (1 page, RDB8120)

inhalation toxicity tests in four groups of ten male and ten female CD rats exposed nose-only to 0 (control), 2,000, 10,000, and 39,000 ppm v/v R-143a in air for 31 days: males showed a trend toward decreased absolute testicular weight and microscopic degenerative changes in the testes in all exposure groups; the validity of these findings was suspect and the effects noted could have been due to excessive stress and heat; a second 4-wk study was initiated with four groups of ten male rats exposed whole body to the same concentrations; no testicular or other differences (body weights, gross and microscopic pathology, or clinical signs) were noted compared to the control group; abstract concludes that 4-wk exposures to R-143a produced no significant pathological effects in rats at the concentrations tested

C. J. Hardy and I. J. Sharman (Huntingdon Research Centre Limited, HRC, UK), **HFC 143a: Assessment of Cardiac Sensitization Potential in Dogs**, report DPT 281/930477, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 3 June 1993 (30 pages with 7 figures and 8 tables, RDB5C26)

toxicity tests to determine the cardiac sensitization potential of R-143a in male beagle dogs with intravenous injection of adrenaline five minutes before and, with a challenge injection, midway into a 10 minute exposure; no marked response in 6 dogs at 50,000, 100,000, 150,000, 200,000, and 250,000 ppm v/v in air [deemed a NOEL]; marked response in 2 of 5 dogs at 300,000 ppm v/v [deemed a LOEL] with test interrupted in a sixth dog due to severe clinical signs

D. P. Kelly, **Four-Hour Acute Inhalation Toxicity Study with FC-143a in Rats**, report 283-90, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 6 August 1990 (11 pages with 2 tables, RDB5C17)

4 hr acute inhalation toxicity tests in groups of six male Charles River Crl:CD BR rats by nose-only exposures to R-143a: no mortalities resulted at concentrations of 97,000 and 540,000 ppm v/v in air with oxygen enrichment (to maintain 19.8-20.2% levels); rats responded normally to a tail pinch during exposures; clinical signs observed at both concentrations were noted as common to rats held in restrainers plus wet perineums following exposures at

540,000 ppm; rats exposed to 97,000 and 540,000 ppm showed slight and moderate to severe, respectively, weight loss on the day following exposure, but returned to normal weight gain in the 14-day recovery period; report concludes that the 4-hr ALC rat for R-143a exceeds 540,000 and that this compound "is considered to have low acute toxicity on an acute inhalation basis"

M. A. Lee, P. J. Lardear, and R. C. Graham, untitled toxicity review for 1,1,1-trifluoroethane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 10 February 1994 (RDB5867)

R-143a, summary of published and unpublished toxicity literature

Pharmaco-LSR Limited (UK), **Forane® 143a in Vapour Phase: Assessment of Mutagenic Potential in Amino-Acid Auxotrophs of Salmonella Typhimurium and Escherichia Coli (the Ames Test)**, report 93/ATH008/0209, Elf Atochem S.A., Paris - La Défense, France, 1993 (RDB-5C27)

R-143a, health effects, toxicity as reported in RDB5C16

An Inhalation Developmental Toxicity Study of HFC-143a in Rabbits, report WIL-189005, WIL Research Laboratories, Incorporated, volumes I and II, 27 August 1993 (RDB5C28)

R-143a, health effects, toxicity as reported in RDB5C16

Bacterial Mutagenicity Testing of HFC-143a in the Salmonella Typhimurium and Escherichia Coli: Plate Incorporation Assay, report 787-93, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1993 (21 pages, RDB-5C18)

R-143a, health effects, toxicity as reported in RDB5B58 and RDB5C16

Developmental Toxicity Study of HFC-143a in Rats, report 700-92, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1992 (RDB5C19)

R-143a, health effects, toxicity as reported in RDB5C16

Forane® 143a - Assessment of Peroxisome Proliferation in Vitro in Rat Hepatocyte Primary Cultures Assay of Palmitoyl-CoA-Oxidase Activity, report RS0006931126/03 (PN), Elf Atochem S.A., Paris - La Défense, France, 1994 (RDB7282)

R-143a, health effects, toxicity as reported in RDB5B58

Four-Week Inhalation Toxicity Study with HFC-143a in Rats, report 6-92 (TSCAT report OTS-0529920-2), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1992 (RDB-5C20)

four groups of 10 male rats were exposed (whole body) to concentrations of 0 (control), 2,000, 10,000, and 40,000 ppm v/v R-143a in air for 6 hr/d, 5 d/wk for 4 weeks; no adverse clinical signs or testicular effects were observed at any exposure level; 40,000 ppm was determined to be the 4-wk NOAEL rat as reported in RDB5B58, RDB5C16, and RDB6597

Four-Week Inhalation Toxicity Study with HFC-143a in Rats, report 99-91 (TSCAT reports OTS-0529920 and OTS-0529920-1), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1991 (RDB5C21)

four groups of 10 male and 10 female rats were exposed nose-only to concentrations of 0 (control), 2,000, 10,000, and 40,000 ppm v/v R-143a in air for 6 hr/d, 5 d/wk for 4 weeks; 3 premature deaths were determined to not be treatment-related; decreases were observed in male, but not female body weights, but no toxicologically significant clinical signs or pathology measurements were observed during or after the exposures; microscopic degenerative changes were found in the testes of male rats in each exposure group, ranging in severity from slight at 2000 ppm to minimal or mild at 10,000 ppm and 40,000 ppm, but might have stemmed from stress due to the restraining devices and excessive temperatures — as reported in RDB5B58, RDB6597, and RDB5C16; study was repeated (see RDB5C20) with whole-body exposures based on the suspect findings as reported in RDB6597

In Vitro Evaluation of HFC-143a for Chromosome Aberrations in Human Lymphocytes, report 788-93, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1994 (23 pages, RDB5C22)

R-143a, health effects, toxicity as reported in RDB5B58 and RDB5C16

Metabolism of HFC-143a in the Rat, report 3-94, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1994 (RDB5C23)

R-143a, health effects, toxicity as reported in RDB5C16

Mouse Bone Marrow Micronucleus Assay of HFC-143a by Inhalation, report 770-92, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1993 (30 pages, RDB5C24)

R-143a, health effects, toxicity as reported in RDB5B58 and RDB5C16

Summary — Mutagenicity Testing with Salmonella Typhimurium Strains on Plates of Gases, Liquids, and Solids, TSCAT report OTS-0520485, ICI Central Toxicology Laboratory, Cheshire, UK, 1 August 1976 (RDB7284)

R-143a, genotoxicity, mutagenicity, toxicity as reported in RDB5B58

Static Acute 48-Hour EC_{50}[a] to Daphnia Magna, report 541-89, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1989 (RDB5C93)

ecotoxicity of R-143a; ecological toxicity; aquatic impacts: 48-hr EC_{50} daphnia magna = 300 mg/l (practically nontoxic) as reported in RDB-5B58 and RDB5867

Subchronic Inhalation Toxicity: 90-Day Study with HFC-143a in Rats, report 690-92, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1992 (498 pages, RDB5C25)

20 male and 20 female rats were exposed (whole body) to 0 (control), 2,000, 10,000, and 40,1000 ppm v/v for 6 hr/d, 5 d/wk for 90 days; sporadic changes in body weight were observed, but did not follow a dose-response relationship and were not considered to be treatment-related; no clinical signs of toxicity were observed during or after the exposures, and no pathology changes were found; no ß-oxidation activity (peroxisome proliferation), organ weight, adverse gross, or microscopic changes were observed; 90-day NOAEL rat was considered to be 40,000 ppm — as reported in RDB5C16 and RDB6597

1,1,1-Trifluoroethane (HFC 143a) Health Effects Information, CAS# 420-46-2, Elf Atochem North America, Incorporated, Philadelphia, PA, undated circa 1995 (4 pages, RDB5B58)

R-143a, summary of toxicological and ecological information

Workplace Environmental Exposure Level Guide — 1,1,1-trifluoroethane, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1996 (2 pages, RDB5C16)

R-143a, WEEL, toxicology data, toxicity, safety classification

report 540-89, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1989 (RDB5C92)

R-143a, toxicity, aquatic effects, 96-hr LC_{50} rainbow trout as reported in RDB5867

R-152a

R. H. Bruner (Pathology Associates, Incorporated), **Pathology Peer Review of a Two-Year Inhalation Study of FC-152a in CD Rats**, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 19 May 1992 (RDB5C90)

summarizes chronic inhalation toxicity tests of R-152a in rats — as reported in RDB4B90

R. Culik and D. P. Kelly, **Embryotoxicity and Teratogenicity Studies in Rats with 1,1-Difluoroethane (FC-152a)**, report 437-79, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 10 March 1980 (RDB5C88)

summarizes reproductive and teratology toxicity tests of R-152a in rats — as reported in RDB4B90

J. C. Edwards, **Arcton 152a — Documentation for Hygiene Standard**, ICI Chemicals and Polymers Limited, Cheshire, UK, 17 June 1985 (2 pages, RDB5A81)

outlines the rationale for an occupational exposure limit (OEL) for R-152a; recommends a hygiene standard of 1,000 ppm on an 8-hr TWA basis; toxicity

A. Koops, **Mutagenic Activity of Ethane, 1,1-Difluoro in the Salmonella/Microsome Assay**, report 731-77, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and

Company, Incorporated, Newark, DE, 16 September 1977 (RDB5C86)

mutagenicity test of R-152a; toxicity — as reported in RDB4B90

M. A. Lee, P. W. Grube, and R. C. Graham, untitled toxicity review for 1,1-difluoroethane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 4 May 1990 (10 pages, RDB-5857)

summarizes published and unpublished information on the toxicity of R-152a

D. E. Malek, **Approximate Lethal Dose (ALD) of HFC-152a in Rats**, report 524-90, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 26 September 1990 (RDB5C84)

summarizes an ingestion toxicity study of R-152a in rats — as reported in RDB4B90

J. W. McAlack and P. W. Schneider, **Two-Year Inhalation Study with Ethane, 1,1-Difluoro (FC-152a) in Rats**, report 8-82 (OTS-0520320), Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 30 November 1982 (RDB5C87)

summarizes chronic inhalation toxicity tests of R-152a in rats — as reported in RDB4B90

B. L. Moore, **Difluoroethane: Acute Inhalation Toxicity**, report 699-75, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 18 November 1975 (2 pages with 1 table, RDB5C85)

tests of the acute inhalation toxicity in groups of 6 male Charles River CD rats exposed whole body to concentrations of 66,400, 175,200, 319,000, 383,000, and 437,500 ppm v/v in air for 4 hr: except for the 66,400 ppm exposures, oxygen was added to maintain a level of approximately 20%; mortality ratios for the cited concentrations were 0/6, 0/6, 0/6, 1/6, and 2/6 respectively; shallow breathing and hyperemia (excess of blood in a body part) were observed at 66,400 ppm and higher; lethargy and reduced, or no, response to sound were observed at concentrations of 175,200 and higher; labored breathing resulted as the concentrations increased above 66,400 ppm; no abnormal signs were noted post exposure; gross pathology was performed on surviving animals after a 14-day recovery period, but no compound-related changes were found; concludes that the 4-hr ALC rat for R-152a is 383,000 ppm v/v

B. L. Moore, **Subacute Two-Week Inhalation Toxicity**, report 158-76, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 2 March 1976 (RDB5C89)

summarizes a 2-wk inhalation toxicity study of R-152a in rats — as reported in RDB4B90

1,1-Difluoroethane (HFC 152a) Health Effects Information, CAS# 75-37-6, Elf Atochem North America, Incorporated, Philadelphia, PA, undated circa 1995 (4 pages, RDB5B59)

R-152a, summary of toxicological and ecological information

Workplace Environmental Exposure Level Guide — 1,1-Difluoroethane, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1994 (4 pages, RDB4B90)

R-152a, WEEL, toxicology data, toxicity, safety classification

R-160

H. Hermann and J. Vial, **Syncopes Adrénalino-Monochloroéthanique** [Sensitization by Adrenaline and Chloroethane], *Compte Rendu Société de Biol.*, France, 117:439-440, October 1934 (2 pages, RDB6566)

R-160, cardiac sensitization, toxicity

R-170 (ETHANE)

Toxicity Study Summary: Ethane, Phillips Petroleum Company, Bartlesville, OK, February 1990 (1 page with no figures or tables, RDB7623)

tests of the acute inhalation toxicity in 5 female and 5 male albino, Sprague-Dawley rats by 4 hr, whole body exposures to 24,838 ppm v/v R-170 (ethane) in air: no deaths resulted and animals appeared normal throughout the exposures and 14-day observation period; treated females showed a slight reduction in mean body weight on day 3 following exposures; gross pathological signs found at necropsy included irregularly shaped pituitary with two clear cysts on the surface, scattered red foci on the surface of the lung, and — in two animals — dilation of the "right pelvis of the kidney" (probably intended as "pelvis of the right kidney"); concludes that the 4-hr LC_{50} rat is

>24,838 ppm v/v; respiratory tract irritancy studies in male mice by head-only exposures to 23,985 ppm v/v R-170 in air for 1 min, repeated 10 minutes later, while monitored by a plethysmograph: no patterns of respiratory pause were evident; concludes that R-170 failed to produce upper respiratory irritancy in mice at 23,985 ppm v/v

R-E170

Workplace Environmental Exposure Level Guide — Dimethyl Ether, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1980 (RDB4B84)

R-E170, E-170, DME, WEEL, toxicology data, toxicity, safety classification

R-217I1

Acute Inhalation Toxicity Study of Iodoheptafluoropropane in Rats report on project 1530-001 study 3, ManTech Environmental Technology, Incorporated, 1994 (RDB6693)

R-217I1 (either R-217bal1 or R-217cal1), heptafluoroiodopropane, toxicity: 15-min LC_{50} rat 62,000 ppm (also see RTECS) as reported in RDB6208

R-218

Huntingdon Research Centre Limited (HRC, UK), report MIN 68/930457, 3M, St. Paul, MN, May 1993 (RDB65F8)

R-218 (3M PF-5030), acute inhalation (whole body exposure) toxicity study in rats: 4-hr LC_{50} rat >110,000 ppm; no deaths or clinical signs; body weight gain of female rats was slightly less than in the control group; macroscopic pathological examination after a 15-day observation period following exposures revealed some lung congestion in 1 of 10 exposed rats — as reported in RDB5703

Huntingdon Research Centre Limited (HRC, UK), report MIN 101/930623, 3M, St. Paul, MN, 23 June 1993 (RDB65F9)

R-218 (3M PF-5030), cardiac sensitization study in dogs, toxicity: tests at 50,000, 100,000, 200,000, 300,000, and 400,000 ppm in air (oxygen enriched above 100,000 ppm to maintain oxygen concentration at approximately 22%; sensitization NOEL 0/6 at 300,000 ppm, LOEL 2/8 (one of them a questionable response) at 400,000 ppm — as reported in RDB5703

Huntingdon Research Centre Limited (HRC, UK), report MIN 67/920961, 3M, St. Paul, MN, 24 August 1992 (RDB65G0)

R-218 (3M PF-5030), mutagenicity, toxicity: in vitro assay in Salmonella typhimurium bacteria at 800,000 ppm v/v; concluded not mutagenic — as reported in RDB5703

Huntingdon Research Centre Limited (HRC, UK), **Perfluoropropane: Mouse Micronucleus Test**, Rhône-Poulenc Chemicals, Bristol, UK, 1992 (RDB6556)

R-218, health effects, mutagenicity for 6 hr exposure of mice (negative at necropsy), toxicity

M. A. Lee and R. C. Graham, untitled toxicity review for 1,1,1,2,2,3,3,3-octafluoropropane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 8 January 1986 (5 pages, RDB5858)

summarizes published and unpublished information on the toxicity of R-218

Product Toxicity Summary Sheet: PF-5030 3M Brand Performance Fluid, summary 25937, 3M, St. Paul, MN, 22 October 1993 (2 pages, RDB-5703)

R-218, toxicity: 4-hr LC_{50} rat >110,000 ppm; cardiac sensitization NOEL 0/6 dogs at 300,000 ppm and LOEL 2/8 at 400,000 ppm; not mutagenic by in vitro assay in Salmonella typhimurium bacteria at 800,000 ppm v/v

R-225ca AND R-225cb

Y. Kurata, Takechi, N. Toyatas, M. Tsuchitani, M. Katoh (Asahi Glass, Japan), G. M. Rusch (Allied-Signal Incorporated, USA), H. J. Trochimowicz (E. I. duPont de Nemours and Company, USA), and S. Shin-ya, **Four-Week Repeated Inhalation Study of HCFC-225ca and HCFC-225cb in the Common Marmoset**, *Toxicology Letters*, 92:209-219, 1997 (11 pages, RDBA528)

subchronic toxicity of R-225ca and R-225cb

Four-Week Repeated Inhalation Study of HCFC-225ca and HCFC-225cb in the Common Marmoset, report 3L029, Mitsubishi-Kasei Institute of Toxicological and Environmental Sciences (MITES), Japan, 1993 (RDB65D6)

subchronic toxicity of R-225ca and R-225cb

R-227ea

Dr. Bury, **ARW-Begründung für HFA-227** [Documentation for Exposure Limit for HFA-227], Hoechst Aktiengesellschaft, Frankfurt am Main, Germany, 26 August 1992 (3 pages in German, RDB7116)

summary of unreferenced toxicity data: R-227ea resulted in no mortalities at 110,000 ppm v/v, but higher concentrations were not tested because the rats [animals are not identified for this test, identification is based on corroborating information in a Hoechst Material Safety Data Sheet] breathed irregularly and became uncoordinated; Wistar rats and mice exposed head and nose only to concentrations of 0, 150,000, 300,000 and 500,000 ppm for 1 hr found the maximum tolerable concentration to exceed 500,000 ppm subject to effects of sedation, trembling, increased blood-concentrations of carbon dioxide, all reversible following exposures; 2 male and 2 female beagle dogs exposed to concentrations of 50,000, 150,000, 200,000 250,000, 300,000, and 500,000 ppm R-227ea by face masks for 1 hr showed lethargy, sedation, and listlessness at 150,000 ppm and difficulty in breathing, spasms, and vomiting at higher concentrations, all fully reversible; concludes that the maximum tolerance in dogs is 300,000 ppm; summaries of subchronic and chronic exposures in rats and mice suggest NOEL concentrations of 300,000 ppm and in beagle dogs at 150,000 ppm (the highest concentration tested); an incomplete 90-day study on six beagle dogs found strongly narcotic effects, reversible following exposures, in two dogs at 300,000 ppm study; Ames tests in salmonella typhimurium and Escherichia coli with and without metabolic activation found R-227ea to not be mutagenic; negative findings also were found in a "HGPRT" test and a mouse micronucleus test; a cardiac sensitization test in dogs [use of epinephrine is typical but not mentioned] resulted in a response in one dog at 300,000 ppm and a NOEL at 50,000 ppm; recommends an ARW [Hoechst exposure limit] of 1000 ppm [CAUTION: Users should examine the source documentation carefully before use of this summary, which was prepared without a translation.]

C. P. Chengelis (WIL Research Laboratories, Incorporated), **Toxicological Evaluation of HFC-227ea (FM-200™) — Background Document**, Great Lakes Chemical Corporation, West Lafayette, IN, 20 June 1994 (RDB65F1)

toxicity of R-227ea

Japan Bioassay Laboratory (JBL, Japan), **Reverse Mutation Assay of HFC-227ea (Fron 227ea) by Using Bacteria** (English translation), report 5542, Japan Industrial Safety and Health Association, Kanagawa, Japan, 1993 (RDBA618)

test of the mutagenicity of R-227ea of *Salmonella typhimurium* and *Escherichia coli* with and without metabolic activation; health effects; toxicity; results indicate that R-227ea is not mutagenic as tested — as reported in RDBA612

M. A. Lee and R. C. Graham, untitled toxicity review for 1,1,1,2,3,3,3-heptafluoropropane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 8 January 1986 (5 pages, RDB5860)

R-227ea, summary of published and unpublished toxicity literature

D. J. Naas (WIL Research Laboratories, Incorporated), **A 90-Day Inhalation Toxicity Screen of FM-200™ in Rabbits**, report on project WIL-12318, Great Lakes Chemical Corporation, West Lafayette, IN, 1994 (RDBA619)

toxicity of R-227ea

M. D. Nemec (WIL Research Laboratories, Incorporated), **An Inhalation Developmental Toxicity Study of FM-200™ in Rabbits**, report on project WIL-12317, Great Lakes Chemical Corporation, West Lafayette, IN, 1993 (RDBA620)

tests of the developmental toxicity of R-227ea in rabbits at concentrations of 0 (control), 20,000, 50,000, and 105,000 ppm v/v in air with enrichment to maintain 19% oxygen at the highest concentration; indicates a no observable adverse effect level (NOAEL) for both maternal dn developmental toxicity of 731.60 mg/L [105,000 ppm v/v] for 6 h/d — as reported in RDBA612

M. D. Nemec (WIL Research Laboratories, Incorporated), **An Inhalation Developmental Toxicity Study of FM-200™ in Rats**, report on project WIL-12314, Great Lakes Chemical Corporation, West Lafayette, IN, 1993 (RDBA667)

tests of the developmental toxicity of R-227ea in groups of 24 rats at concentrations of 0 (control), 20,000, 50,000, and 105,000 ppm v/v in air with enrichment to maintain 19% oxygen at the highest concentration; indicates a no observable adverse effect level (NOAEL) for both

maternal and developmental toxicity of 731.60 mg/L [105,000 ppm v/v] for 6 h/d — as reported in RDBA612

WIL Research Laboratories, Incorporated, **Acute Cardiac Sensitization Study in Dogs with FM-200™ by Inhalation**, report on project WIL-12265, Great Lakes Chemical Corporation, West Lafayette, IN, 1993 (RDBA615)

tests in 10 beagle dogs of the potential of R-227ea to sensitize the heart to adrenaline; animals were exposed to 0, 35,000, 70,000, 90,000, 105,000, and 140,000 ppm v/v R-227ea in air for a minimum of 30 min at each concentration with at least 36 hr between exposures; animals were challenged with intravenous injections of adrenaline both before and immediately after each induction; positive responses were determined by the occurrence of one or more premature ventricular contractions; they were observed in 1, 5, and 6 of 10 animals after exposures to 90,000, 105,000, and 140,000 ppm v/v, respectively, indicating a treatment-dependent effect; there were no treatment-related clinical findings; indicates that concentrations of 90,000 ppm v/v and higher cause cardiac sensitization as tested — as reported in RDBA612 [also see RDB65F2 for a summary of what probably was the same test with a different interpretation of the results]

WIL Research Laboratories, Incorporated, **An Acute Inhalational Toxicity Screen of FM-200™ in Rats**, report on project WIL-12248, Great Lakes Chemical Corporation, West Lafayette, IN, 1992 (RDBA616)

tests of the acute inhalation toxicity of R-227ea in 5 female and 5 male Charles River rats by whole-body exposures to concentrations of 788,696 ppm v/v in oxygen for 4 hr; no deaths occurred; females showed a 1.4% decrease in mean body weight and males showed a reduction in body weight gain during the 14 day observation period following exposures; all animals showed signs of anesthesia including decreased motor activity, decreased respiration, ataxia (inability to coordinate voluntary muscular movements), and prostration during exposures; one animal exhibited lacrimation and another tail chewing; necropsy revealed red foci in the lung of one animal and a mottled lung in another; no significant lung-weight differences were found; concluded that the 4-hr LC_{50} rat was >788,696 ppm v/v — as reported in RDBA612

WIL Research Laboratories, Incorporated, **Acute Inhalational Toxicity Screen in Albino Rats with FM-200™**, report on project WIL-12226, Great Lakes Chemical Corporation, West Lafayette, IN, 1991 (RDBA617)

tests of the acute inhalation toxicity of R-227ea in groups of 3 female and 3 male Charles River rats by whole-body exposures to concentrations of 0 and 121,267 ppm v/v for 4 hr or 241,188 ppm v/v for 4.5 hr, the latter with a 19 min break during the exposure period; no deaths occurred; no significant body weight changes, exposure-related findings at necropsy, or lung-weight differences were found; all animals exhibited anesthesia, hypoactivity (less than normal activity), bradypnea (slow breathing), and/or ataxia (inability to coordinate voluntary muscular movements) during the treatment, but signs of anesthesia diminished after exposures; two animals showed signs of salivation for one day; concluded that the LC_{50} rat was >241,188 ppm v/v — as reported in RDBA612

FM-200™ Toxicological Study Summaries, Great Lakes Chemical Corporation, West Lafayette, IN, circa 1995 (RDB65F2)

R-227ea, toxicity: 4-hr LC_{50} rat = >788,698 ppm, anesthetic LOEL rat = 800,000 ppm, not mutagenic by reverse mutation assay with *Salmonella typhimurium* or *Escherichia coli*, no induction of chromosomal aberrations in cultured Chinese hamster lung, NOAEL = 100,000 ppm in both a 10-day range-finding inhalation study in the rabbit and in a 14-day inhalation screening study in the rat, NOEL rat = 105,000 ppm in a 90-day inhalation study, NOAEL rat = 105,000 ppm in a developmental toxicity study, 30-min cardiac sensitization in 10 male beagle dogs with pre-exposure and 30-minute challenge injections of epinephrine showed NOAEL (effects described as "minimal or mild in nature (single or few monofocal premature ventricular contractions)") = 90,000 ppm v/v, LOAEL for an unspecified number of dogs = 105,000 ppm v/v, and EC_{50} = 140,000 ppm v/v

Heptafluoropropane (HFC-227ea) — Priority Existing Chemical 4 Secondary Notification Assessment, full public report, file EX/5 (NA/64), National Industrial Chemicals Notification and Assessment Scheme (NICNAS), Worksafe Australia, Sidney Australia, 30 July 1999 (30 pages with 4 tables, RDBA612)

toxicity and environmental risk assessment of R-227ea

Test on Biodegradability of HFC-227ea by Microorganisms (Closed-Bottle Method), report 12419, Kurume Research Laboratories (KRL), Fukuoka, Japan, December 1993 (RDBA613)

ecotoxicity of R-227ea; environmental impacts and fate; groundwater and soil

R-236fa

C. J. Hardy, P. C. Kieran, and I. J. Sharman (Huntingdon Research Centre Limited, HRC, UK), **HFC 236fa: Assessment of Cardiac Sensitization Potential in Dogs**, report DPT 293/931308, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 3 February 1994 (34 pages with 5 figures and 4 tables, RDB65A5)

cardiac sensitization tests for R-236fa in male beagle dogs for 10-minute exposures with adrenaline challenge by intravenous injection at 0 (control with adrenaline), 50,000, 100,000, 150,000, 200,000, 250,000, and 300,000 ppm v/v; positive responses were found in 0/6, 0/6, 0/6, 2/6, and 2/5 dogs at 0, 50,000, 100,000, 150,000, and 200,000 ppm v/v; the investigators interpreted the result at 200,000 ppm v/v as 3/6 positive based on the eliminated animal's responses at lower concentrations; 0/3 tested animals showed positive responses at 250,000 ppm, but 3 dogs that had shown positive responses at lower concentrations were eliminated; tests at 300,000 ppm v/v were not completed due to animal struggling at 250,000 ppm and observed anesthesia in 3 dogs at 300,000 ppm v/v; concludes that R-236fa has the potential to cause cardiac sensitization in dogs at 150,000 ppm v/v (2/6 positive) increasing to 3/6 positive at 200,000 ppm v/v; toxicity [findings imply a NOEL 0/6 at 100,000 ppm v/v and a LOEL 2/6 at 150,000 ppm v/v]

R. J. Hilarski (International Research and Development Corporation, IR&D), **Nose Only Acute Inhalation Toxicity Evaluation on T-6195 in Rats**, report 137-178, 3M Company, St. Paul, MN, 27 September 1995 (41 pages with 1 figure and 26 tables, RDB6692)

tests of the acute toxicity of R-236fa by nose-only, 4 hr inhalation in 5 male and 5 female albino rats; exposures at mean vapor concentrations of 1,960 and 148,600 ppm v/v; no mortalities at either concentration [4-hr ALC rat >148,600 ppm]; post exposure weight gain was normal, at 7 and 14 days, and no significant macroscopic abnormalities were noted at necropsy; no significant pharmacotoxic signs were observed at 1,960 ppm; animals exposed to 148,600 ppm exhibited rapid respiration; no anesthetic effect indicated at either concentration

N. D. Smith, **Summary of HFC-236fa Toxicity Studies**, fax to D. Minday (3M Company), U.S. Environmental Protection Agency (EPA), Research Triangle Park, NC, 22 February 1996 (5 pages, RDB65A6)

R-236fa, toxicity: mutagenicity tests in the Salmonella typhimurium and Escherichia coli (negative); clastogenic (chromosome damaging) test in human lymphocytes (negative); mouse bone-marrow micronucleus test (negative); two-week inhalation study in the rat at 0, 5,000, 20,000, and 50,000 ppm (NOAEL at 5,000 ppm and anesthetic effect at 20,000 ppm); 90-day inhalation study in the rat for 6 hr/d, 5 d/wk, for 14 weeks (NOAEL at 20,000 ppm); inhalation developmental study in the rat at 0, 5,000, 20,000, and 50,000 ppm (maternal NOAEL at 5,000 ppm, developmental NOAEL at 50,000, anesthetic effect at 20,000 ppm); 5-day extended inhalation study in the rat at 50,000 ppm (slight respiratory tract irritation, concluded that R-236fa has low acute inhalation toxicity at 50,000 ppm)

R. Valentine, D. A. Keller, J. C. Cook, L. B. Biegel, G. S. Elliott, T. W. Slone, S. M. Munley, K. S. Bentley, W. J. Brock (E. I. duPont de Nemours and Company, Incorporated), and G. B. Briggs (GeoCenters, Incorporated), **Toxicologic Profile of the Alternative Refrigerant HFC-236fa**, abstract 1489 (35th Annual Meeting, 1996), *The Toxicologist*; republished in *Fundamental and Applied Toxicology*, 30(1/2):291, March 1996 (1 page, RDB6A96)

R-236fa, HFC-236fa: acute, subchronic, developmental, and genetic toxicity; cardiac sensitization; 4-hr ALC rat >195,000 ppm; narcosis was the predominant clinical sign observed during exposure; cardiac sensitization LOEL in beagle dogs was ·150,000 ppm with a NOEL of 100,000 ppm; no evidence of mutagenic or genotoxic activity was found in vitro in Ames or human lymphocyte assays or in vivo in the mouse micronucleus assay; subchronic inhalation studies with exposures of rats for 6 hr/d, 5 d/wk, for 2 and 13 weeks at 5,000, 20,000 and 50,000 ppm yielded no evidence of body or organ weight effects, clinical pathology, organ pathology, or induction of hepatic peroxisomes; rats exposed to 20,000 or 50,000 ppm had a

transiently diminished acoustic startle response during exposures; rats exposed to 5,000 ppm were unaffected and some adaptation to narcosis was noted as the study progressed for the higher concentrations; maternal weight gain was evident at ·20,000 ppm in a rat developmental toxicity study; fetal toxicity was found at ·5,000 ppm; the overall NOEL was 5,000 ppm, based on narcosis noted at concentrations of ·20,000 ppm

R. Valentine, **Two-Week Inhalation Toxicity Study with HFC-236fa in Rats**, report 596-94, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 20 June 1995 (211 pages with 3 figures and 21 tables, Rdb6A93)

R-236fa, health effects, toxicity: four groups of 5 female and 5 male rats were exposed by inhalation to target concentrations of 0, 5,000, 20,000, or 50,000 ppm v/v R-236fa in air for 6 hr/d, 5 d/wk, for two weeks; actual concentrations determined by gas chromatography (GC) were 0, 5,020±10, 20,000±35, and 50,000±60 ppm v/v and daily means were within ±10% of the targets; no body weight effects or abnormal clinical observations to exposed rats; NOAEL rat = 5,000 ppm; anesthetic NOEL at 5,000 ppm and LOEC rat at 20,000 ppm; slight decrease in hepatic ß-oxidation activity at 50,000 ppm in rats killed after the tenth exposure, but this effect was deemed not biologically adverse since the change was not accompanied by relevant clinical, pathologic, organ weight, or liver histopathologic changes

A. Vinegar (ManTech Environmental Technology, Incorporated), G. W. Butler, M. C. Caracci (Geocenters Incorporated), and J. D. McCafferty (U.S. Air Force, USAF), **Gas Uptake Kinetics of 1,1,1,3,3,3-Hexafluoropropane (HFC-236fa) and Identification of its Potential Metabolites** report AL/OE-TR-1995-0177, Armstrong Laboratory, U.S. Air Force, Wright-Patterson Air Force Base, OH, 1995 (RDB7C85)

pharmacokinetic toxicity test of R-236fa in rats exposed to concentrations up to 20,000 ppm v/v for 6 hr; indicates that R-236fa was readily absorbed with inhalation, but analyses of blood, urine, and feces showed that it was not metabolized and was excreted as the parent compound — as reported in RDB8612

90-Day Inhalation Toxicity: 90-Day Study with HFC-236fa in Rats, report 211-95, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 12 February 1996 (332 pages with 4 figures and 28 tables, RDbA306)

subchronic toxicity tests of R-236fa in groups of 10 male and 10 female Charles River CD rats by inhalation for whole-body exposures at target concentrations of 0 (control), 5,000, 20,000, or 50,000 ppm v/v for 6 hr/d, 5 d/wk; actual mean concentrations were 0, 4,980, 20,000, or 50,300 ppm v/v; indicates that there were no compound-related effects except reduced alerting response at the highest concentration; notes that this anesthetic effect was observed in 6-8 of 10 rats in the first day and in 1-3 of 10 rats for the first two weeks, but primarily in the last two hours of the exposures; further notes that the number of rats exhibiting diminished response decreased with successive exposures and that all rats exhibited normal alerting response by study day 18; concludes that the no observed adverse effect level (NOAEL) was 20,000 ppm v/v based on the anesthetic effect; report indicates Good Laboratory Practice (GLP) compliance

Acute Inhalation Toxicity Study of HFC-236fa in Albino Rats, report WIL-189022, WIL Research Laboratories, Incorporated, circa 1996 (Rdb6A94)

tests of the acute inhalation toxicity of R-236fa by whole-body exposures of 5 female and 5 male rats at 457,000 ppm v/v; since no deaths occurred, reports the 4-hr ALC rat as >457,000 ppm; all of the animals exhibited hyperactivity and then prostration during exposures, but recovered in 1 day; 2 females exhibited slight body weight loss, but appeared normal by the end of the 14-day observation period; 4 animals had dark red lungs at necropsy; 2 females had cysts on the kidneys and 1 female had an enlarged pituitary gland

In Vitro Assay of HFC-236fa for Chromosome Aberrations in Human Lymphocytes, report 604-94, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1994 (RDBA303)

mutagenicity toxicity study of R-236fa for target exposures of 200,000, 300,000, 400,000, 600,000, 800,000, or 1,000,000 ppm v/v; indicates R-236fa was not genotoxic in this *in vitro* test — as reported in RDB8612

Inhalation Developmental Toxicity Study of HFC-236fa in Rabbits, report 417-96, Haskell Laboratory for Toxicology and Industrial Medicine,

E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1996 (RDBA307)

developmental toxicity of R-236fa in 20 white rabbits exposed by inhalation to target concentrations of 0 (control), 5,000, 20,000, or 50,000 ppm v/v in air for 6 hr/d on days 7-19 of gestation; indicates no evidence of maternal or developmental effects at any concentration — as reported in RDB8612

Inhalation Developmental Toxicity Study of HFC-236fa in Rats, report 66-95, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1996 (RDBA308)

developmental toxicity of R-236fa in 25 pregnant rats exposed by inhalation to target concentrations of 0 (control), 5,000, 20,000, or 50,000 ppm v/v for 6 hr/d on days 6-15 of gestation; indicates a decrease in maternal body weight gain for the first two days of exposure at 20,000 and 50,000 ppm v/v, with accompanying reduction in food consumption and occasional diminished alerting response at the higher exposure level; indicates no evidence of maternal toxicity at 5,000 ppm v/v or of reproductive toxicity at any concentration — as reported in RDB8612

Mouse Bone Marrow Micronucleus Assay of HFC-236fa by Inhalation, report 602-94, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1994 (RDBA304)

mutagenicity toxicity study of R-236fa by a mouse bone marrow micronucleus test for target exposures of 5,000, 20,000, or 50,000 ppm v/v for 6 hr/d for 2 consecutive days; indicates R-236fa was inactive in this *in vivo* test — as reported in RDB8612

Mutagenicity Testing of HFC-236fa in the Salmonella Typhimurium and Escherichia Coli: Plate Incorporation Assay, report 647-94, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1994 (RDBA305)

mutagenicity toxicity test of R-236fa by an Ames assay; indicates R-236fa was found to not be mutagenic with or without metabolic activation — as reported in RDB8612

Workplace Environmental Exposure Level Guide — 1,1,1,3,3,3-Hexafluoropropane, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1998 (3 pages with no figures or tables, RDB-8612)

documents determination of a Workplace Environmental Exposure Level (WEEL) Guide for R-236fa; summarizes identifiers, chemical and physical properties, uses, production quantities, toxicology tests conducted in animals (acute, subchronic, chronic, carcinogenicity, reproductive, developmental, genotoxicity, mutagenicity, metabolism, and pharmacokinetics); indicates no human use and exposures experience; discusses a rationale for setting the occupational exposure limit; indicates that R-236fa is low in acute toxicity with a 4-hr LC_{50} rat of >450,000 ppm v/v and cardiac sensitization LOEL in dogs at 150,000 ppm v/v; notes a subchronic NOAEL of 5,000 or 20,000 ppm v/v in rats based on a transient anesthetic effect; also notes absence of developmental toxicity up to 50,000 ppm v/v and genotoxicity as tested; recommends a WEEL guide of 1,000 ppm for 8-hr on a time-weighted average (TWA) basis; includes 12 references

R-245ca

R. D. Bagnall, W. Bell, and K. Pearson (Imperial Chemical Industries Limited, UK), **New Inhalation Anaesthetics: IV — Fluorinated Propanes**, *Journal of Fluorine Chemistry*, 13(3):209-223, 1979 (15 pages with 6 figures and 4 tables, RDB-5C76)

summarizes acute inhalation toxicity tests in mice of R-245ca and others for 30 min exposures of mixtures of the tested gases with oxygen; for R-245ca, indicates a 30-min ALC of 240,000 ppm v/v with minimal, unspecified side effects as well as an anesthetic LOEL at 100,000 ppm v/v

P. W. Grube, untitled toxicity review for 1,1,2,2,3-pentafluoropropane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 24 July 1991 (5 pages, RDB5859)

summarizes published and unpublished toxicity information on R-245ca

report 33-60, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1960 (RDB5C77)

summarizes tests of the anesthetic capabilities of R-245ca in mice; animals were exposed to concentrations of 50,000, 100,000, 120,000,

and 150,000 ppm v/v for 5 or 10 min in a rotating apparatus; inability to maintain an upright position for a minimum of 15 consecutive seconds was deemed an anesthetic effect; the LOEC for an unspecified number of mice and unspecified number tested was 100,000 ppm v/v; indicates no clinical evidence of permanent injury, but exposures at 120,000 and 150,000 ppm v/v caused severe, transient effects on respiration; toxicity — as reported in RDB5859

R-245fa

D. W. Coombs (Huntingdon Life Sciences Limited, HLS, UK), **HFC-245fa (515-96A): A Study for Effects on Embryofoetal Development of the Rat (Inhalation Administration)**, report MA-RR-97-2374 (also identified as ALS 132/963712), AlliedSignal Incorporated, Morristown, NJ, USA, 20 June 1997 (137 pages with 2 figures and 12 tables, Rdb7556)

toxicity tests by whole-body exposures of pregnant rats to nominal concentrations of 0 (control), 500, 2,000, 10,000, and 50,000 ppm R-245fa for 6 hr/d on days 6-19 post coitum: food consumption and bodyweight gain were reduced on days 6-19 and 6-12, respectively, for animals exposed to 10,000 ppm and on days 6-19 and 6-20, respectively, for animals exposed to 50,000 ppm; animals were sacrificed on day 20 for post mortem determination of litter values and examination for visceral and skeletal changes; no effects were found on fetal parameters; study concluded that the NOEL for maternal effects was 2,000 ppm and for fetal effects was 50,000 ppm [full report not obtained — prepared from report summary]

D. W. Coombs (Huntingdon Life Sciences Limited, HLS, UK), **HFC-245fa (507-96A and 515-96A): 13-Week Repeat Dose Inhalation Toxicity Study in Rats**, report MA-RR-97-2376 (also identified as ALS 131/963272), AlliedSignal Incorporated, Morristown, NJ, USA, 18 June 1997 (379 pages with 6 figures and 12 tables, Rdb7558)

subchronic inhalation toxicity tests of R-245a in rats exposed to concentrations of 0 (control), 500, 2,000, 10,000, or 50,000 (0, 508, 2,038, 10,152, and 50,555 actual) ppm v/v in air for 6 hr/d, 5 d/wk, for 13 weeks: exposures were reduced to approximately 3 hr for exposure 40 due to apparatus failure; no treatment-related effects were seen in clinical signs, food consumption, bodyweight gains, macroscopically at necropsy, or in organ weight data; dose related increases were seen in urinary fluoride levels, water consumption, and urine volumes, suggesting some metabolism of R-245fa; some changes, possibly related to the increased urine volume, were observed in clinical chemistry parameters; they included increases in blood urea nitrogen and serum level enzyme activity, but they did not follow an exposure-related pattern; trace to moderate inflammation of the myocardium (heart muscle) were found at necropsy in both the males and females; study suggests that this response resulted from long-term exposures, since myocarditis (inflammation of the heart muscle) was not observed in rats exposed for 28 days [full report not obtained — prepared from report summary and additional information from RDB7612]

D. W. Coombs (Huntingdon Life Sciences Limited, HLS, UK), **HFC-245fa (507-96A): 28-Day Repeat Dose Inhalation Toxicity Study in Rats**, report MA-RR-97-2346 (also identified as ALS 105/-962523), AlliedSignal Incorporated, Morristown, NJ, USA, 3 March 1997 (350 pages with 6 figures and 20 tables, Rdb7557)

subchronic inhalation toxicity tests in groups of rats by whole-body exposures to concentrations of 0 (control), 500, 2,000, 10,000, or 50,000 (0, 516, 1,998, 10,102, and 49,600 actual) ppm v/v R-245fa in air for 6 hr/d for 28 consecutive days [RDB7612 indicates 5 d/wk]: 2 female rats exposed to 49,600 ppm died during the study; absence of marked effects in other animals suggests that these deaths, considered to be agonal in origin, were not treatment related, but report notes that this possibility cannot be excluded; 4 females exposed to 49,600 ppm exhibited lethargy and unsteady gait following overnight collection of urine samples at week 4, but animals recovered when given access to water; increases were seen in urinary fluoride levels, water consumption, and urine volumes, suggesting some metabolism of R-245fa; increases in blood urea nitrogen and serum level enzyme activity also were seen, but did not follow an exposure-related pattern; report concludes that the NOEL was 500 ppm v/v; the no adverse effect level (NOAEL) is indicated as 50,000 ppm v/v based on lack of histopathological effects and significant recovery following withdrawal; study also concluded that the observed effects of treatment were considered of biological but not necessarily toxicological significance [full report not obtained — prepared from report summary and additional information from RDB7612]

C. A. Dance (Pharmaco-LSR Limited, UK), **HFC-245fa (Vapour Phase): In-Vitro Assessment of Clastogenic Activity in Cultured Human Lymphocytes**, report MA-RR-94-2014 (also identified as 93/ADL010/0986 and as 93/09086), AlliedSignal Incorporated, Morristown, NJ, USA, 18 February 1994 (53 pages with 10 tables, Rdb7551)

test for mutagenic potential of R-245fa by an in vitro mammalian cytogenetic study using cultured human lymphocytes with a metabolic activation system, derived from rat livers (S-9 mix), at nominal concentrations of 300,000, 500,000, and 700,000 ppm v/v and without activation at 100,000, 200,000, and 300,000 ppm v/v: no biologically or statistically significant increases in aberrant cell frequencies were found with activation, but there was evidence of toxicity, based on a 25% reduction in mitotic activity, at 300,000 ppm without it; mean aberrant cell frequencies were 7.0, 7.5, and 12% at the three concentrations tested, respectively, without activation; study concluded that R-245fa showed weak clastogenic (chromosome-damaging) activity in the absence of metabolic activation [full report not obtained — prepared from report summary]

C. N. Edwards (Pharmaco-LSR Limited, UK), **HFC-245fa: Mouse Micronucleus Test**, report MA-RR-94-2016 (also identified as 93/ADL013/1219 and as 93/1219), AlliedSignal Incorporated, Morristown, NJ, USA, 18 February 1994 (40 pages with 1 figure and 2 tables, Rdb-7552)

test for mutagenic potential of R-245fa by an in vivo mouse micronucleus study in bone marrow following a 4-hr acute inhalation exposure at 101,300 ppm: exposed animals were underactive in their restraint tubes during the exposures, but no depression of bone marrow proliferation that would indicate toxicity was found 24 or 48 hr after exposure; report concludes that there was no evidence of induced chromosomal or other damage [full report not obtained — prepared from report summary and additional information from RDB7612]

Huntingdon Life Sciences Limited (HLS, UK), **A Two-Week Dose Range-Finding Inhalation Toxicity Study with HFC-245fa in Dogs**, report ALS 174/982608, AlliedSignal Incorporated, Morristown, NJ, USA, 1998 (RDBA474)

toxicity tests of R-245fa

Huntingdon Life Sciences Limited (HLS, UK), **HFC-245fa (Vapour Phase): In-Vitro Assessment of Clastogenic Activity in Cultured Human Lymphocytes**, report 96/ADL040/0605, AlliedSignal Incorporated, Morristown, NJ, USA, 19 November 1996 (RDB7554)

test for mutagenic potential of R-245fa

G. C. Jackson (Huntingdon Life Sciences Limited, HLS, UK), **HFC 245fa (513-96A): Acute Inhalation Toxicity in Rats (4-Hour Exposure)**, report ALS 125/961468 (also identified as MA-RR-97-2342), AlliedSignal Incorporated, Morristown, NJ, USA, 27 January 1997 (46 pages with 2 figures and 12 tables; 4 page cover and summary available from JMC as RDB7115)

acute inhalation toxicity tests with two groups of 5 male and 5 female albino rats exposed (snout only) to 0 and 116,000 ppm v/v R-245fa in air for 4 hours: no deaths resulted; animals exhibited irregular respiration, restless behavior, and intermittent muscular contractions during exposure at 116,000 ppm as well as piloerection (involuntary erection or bristling of fur) immediately following the exposure; no reported clinical signs indicate anesthesia or central nervous system (CNS) response, suggesting an anesthetic effect NOEL in rats of 116,000 ppm; no effects were noted on the rate of bodyweight gain, lung weight to bodyweight ratio, and food and water consumption; appearance and behavior were normal from the day following exposure; slight congestion was observed in the lungs of one male test rat, but deemed to be unrelated to the test treatment; no other macroscopic pathology abnormalities were found; report concludes that the 4-hr LC_{50} rat exceeds 116,000 ppm v/v

G. C. Jackson (Huntingdon Life Sciences Limited, HLS, UK), **HFC 245fa (493-95A): Acute Inhalation Toxicity in Rats 4-Hour Exposure**, report ALS 104/951746 (also identified as MA-RR-96-2270), AlliedSignal Incorporated, Morristown, NJ, USA, 22 February 1996 (47 pages; 4 page cover and summary available from JMC as RDB7111)

acute inhalation toxicity tests with three groups of 5 male and 5 female Sprague-Dawley CD rats exposed to 0 (control), 143,000, and 203,000 ppm v/v R-245fa in air for 4 hours: no deaths resulted; all animals exposed to 143,000 and 203,000 ppm v/v exhibited exaggerated respiratory movements, adoption of an abnormal posture, and reduced response to external stimuli during exposures; 3 female rats experienced occasional clonic (spasms of alternating contractions and partial relaxations) convulsions at 143,000 ppm; no clinical signs

were observed during a subsequent 14-day observation period; food consumption was reduced for 1 day following exposures, but water consumption and the rate of bodyweight gain were the same for treated animals and controls; no macroscopic abnormalities were found; report concludes that the 4-hr LC_{50} rat is >203,000 ppm v/v and that there was evidence of an anesthetic effect at both 143,000 and 203,000 ppm v/v [full report not obtained - prepared from summary]

I. R. Johnson (Pharmaco-LSR Limited, UK), **HFC-245fa: Acute Percutaneous Toxicity Study in the Rabbit**, report 93/ADL011/1086 (also identified as MA-RR-94-2015), AlliedSignal Incorporated, Morristown, NJ, USA, 21 February 1994 (37 pages; 3 page cover and summary available from JMC as RDB7113)

dermal toxicity of R-245fa to 5 male and 5 female New Zealand White rabbits at a dosage of 2 mL/kg (0.031 oz/lb) bodyweight for 24 hr: there were no deaths or signs of reaction to treatment; animals achieved expected bodyweight gains; organ weights were unremarkable and there was no sign of macroscopic lesion at necropsy; report concludes that the LD_{50} dermal was >2 mL/kg (>2,600 mg/kg) [full report not obtained - prepared from summary]

T. J. Kenny (Huntingdon Research Centre Limited, HRC, UK), **HFC 245fa: Assessment of Cardiac Sensitization Potential in Dogs**, report ALS 52/942695 (also identified as MA-RR-94-2151), AlliedSignal Incorporated, Morristown, NJ, USA, 29 November 1994 (30 pages; 3 page cover and summary available from JMC as RDB7112)

toxicity for cardiac sensitization in 6 beagle dogs with intravenous injection of adrenaline before and during inhalation of 10,000 and 20,000 ppm v/v R-245fa in air: no dogs responded positively at either concentration, leading to a finding that 20,000 ppm is a cardiac sensitization NOEL [full report not obtained - prepared from summary]

K. May (Pharmaco-LSR Limited, UK), **HFC-245fa: Assessment of Mutagenic Potential in Amino-Acid Auxotrophs of Salmonella Typhimurium and Escherichia Coli (the Ames Test)**, report MA-RR-95-2205 (also identified as 95/ADL035/0004 and as 95/0004), AlliedSignal Incorporated, Morristown, NJ, USA, 30 June 1995 (49 pages with 6 tables, Rdb7553)

test for mutagenic potential of R-245fa by an Ames assay using five histidine-dependent strains of Salmonella typhimurium and one tryptophen-dependent auxotroph of E. coli exposed to R-245fa vapor, both with and without a metabolic activation system derived from rat livers (S-9 mix), at nominal concentrations of 0 (control), 25,000, 50,000, 100,000, 200,000, and 400,000 ppm v/v: no increases in reversion to prototrophy were found; study concluded that R-245fa vapor is not mutagenic as tested [full report not obtained — prepared from report summary]

D. P. Meyers (Huntingdon Life Sciences Limited, HLS, UK), **HFC-245fa: A Dose Range Finding Study by Inhalation Administration in the Pregnant Rat**, report MA-RR-97-2339 (also identified as ALS 130/961798), AlliedSignal Incorporated, Morristown, NJ, USA, 15 January 1997 (87 pages with 2 figures and 4 tables, Rdb7555)

pilot developmental toxicity study in groups of 12 pregnant rats by whole body exposures to nominal concentrations of 0 (control), 500, 2,000, 10,000, and 50,000 ppm R-245fa: no effects were observed at concentrations as high as 10,000 ppm; food intake was lower on days 9-10 and body weight gains were reduced on days 9-13 of pregnancy for animals exposed to 50,000 ppm, but there were no treatment-related effects on litter parameters or macroscopic external fetal structure; concluded that the tested concentrations would be appropriate for a future embryotoxicity study in the rat [full report not obtained — prepared from report summary]

G. M. Rusch (AlliedSignal Incorporated, USA), D. W. Coombs, and C. J. Hardy (Huntingdon Life Sciences Limited, HLS, UK), **The Acute, Genetic, Developmental, and Inhalation Toxicity of 1,1,1,3,3-Pentafluoropropane**, *Toxicological Sciences*, 52(2):289-301, December 1999 (13 pages with 14 tables, RDB9707)

summary of toxicity tests of R-245fa: there were no effects on body weight or observable changes at necropsy in screening inhalation tests with five male and five female mice at 101,300 ±12,900 ppm v/v by snout-only exposures for 4 hr; subsequent tests in groups of five male and five female Sprague Dawley CD rats at 143,000 ±1,800 and 203,000 ±1,000 ppm for 4 hr yielded no mortalities or effects on body weight; food consumption was slightly reduced for the day following exposures, but rebounded; exposed animals showed signs of central nervous system (CNS) depression including irregular respiration, restless behavior,

intermittent muscular contractions, abnormal posture, and reduced response to external stimuli, but these symptoms disappeared following exposures; tests of cardiac sensitization in six beagle dogs led to a fatal ventricular fibrillation (very rapid and irregular contractions of the ventricles of the heart resulting in loss of synchronization between the heartbeat and pulse beat) in one dog at 73,000 ppm v/v and disqualification of a second because it did not accept the procedure; concludes that the no-observed-effect level (NOEL) and the lowest-observed-effect level (LOEL) for cardiac sensitization were 34,100 and 44,000 ppm, respectively; tests of acute dermal toxicity of R-245fa with 5 male and 5 female rabbits yielded no adverse reactions at a dose of 2 ml/kg for 24 hr; no developmental effects were found in a rat study at 10,000 and 50,000 ppm, though there was a slight reduction in pup weight at the higher concentration; subchronic and chronic inhalation exposures of rats yielded no treatment related effects on survival, clinical signs, food consumption, or body weight gain at 50,000 ppm v/v by snout-only exposures for 6 hr/d for two weeks, by whole-body exposures for four weeks, or by whole-body exposures for 5 d/wk for 13 weeks; urine volumes increased, urinary fluorides were elevated, and small changes were seen in red blood counts and blood chemistry, but histopathological examination showed no effects on the kidneys, liver, or lungs; there was an increased incidence of mild myocarditis (inflammation of the heart muscle) in all animals exposed at 50,000 ppm and in the majority exposed at 10,000 ppm; the authors suggest a NOEL level of 2,000 ppm v/v; R-245fa was found to be inactive in reverse mutation genetic assays (Ames tests) with five strains of Salmonella typhimurium and one strain of Escherichia coli with and without S-9 metabolic activation at concentrations up to 400,000 ppm v/v in air and at 1,000,000 ppm v/v (no air); weak evidence of clastinogenic activity was seen in an *in vitro* cytogenetics study with cultured human lymphocytes in the absence of metabolic activation for exposures of 300,000 and 400,000 ppm v/v, but not at 200,000 ppm v/v or for 6 hr exposures; no evidence of clastogenicity was found with S-9 activation; tests for chromosomal damage in polychromatic erythrocytes of mice at 100,000 ppm for 4 hr were negative; paper concludes that R-245fa appears to show only minimal toxicity, that exposures up to 5,000 ppm v/v yielded no clear signs of toxicity, and exposures up to 10,000 ppm v/v resulted in only mild effects

G. M. Rusch, **Toxicology Testing of a New Hydrofluorocarbon**, FYI notification to the U.S. Environmental Protection Agency (EPA), AlliedSignal Incorporated, Morristown, NJ, 16 December 1996 (4 pages with no figures or tables, RDB7612)

summary of toxicity test data for R-245fa: mutagenicity tests include Ames (negative), human lymphocyte chromosome aberration (slight response, but only at high concentrations in the absence of metabolic activation), and mouse micronucleus genetic assays (negative); concludes that the weight of evidence indicates that R-245fa is not a mutagen; screening tests in beagle dogs with adrenaline injections show no potential for cardiac sensitization up to 20,000 ppm v/v in air; tests in female rabbits indicate an acute dermal LD_{50} of >2 mL/kg; preliminary data from a developmental toxicity study in rats indicate that concentrations as high as 50,000 ppm v/v did not cause adverse effects on the development of pups; acute inhalation studies in mice and rats result in 4-hr LC_{50} determinations of >101,300 in mice and >203,000 in rats; treated mice showed underactivity and treated rats exhibited abnormal posture, exaggerated respiratory movements, reduced response to external stimuli, and — at high concentrations — evidence of an anesthetic effect; these effects were transient and all of the animals recovered rapidly following exposures; rats exposed for 6 hr/d, 5 d/wk, for 2 wk at concentrations up to 50,000 ppm showed no evidence of treatment related effects, but were found to have increased levels of blood urea nitrogen and serum liver enzyme activities; the latter are described as not representing an adverse finding, since there was no marked dose response and since no histopathological changes were found in the kidneys, liver, or other organs; the finding leading to this "for your information" (FYI) notification was an increased frequency of slight to minimal myocarditis (inflammation of the heart muscle) in both male and female rats exposed to 10,000 and 50,000 ppm in a 13-week inhalation study; dose related increases were seen in urinary fluoride levels, water consumption, and urine volumes after 4 weeks, suggesting some metabolism of R-245fa; increases in blood urea nitrogen and serum level enzyme activity also were seen; the document describes R-245fa as of low toxicity based on the preliminary findings

G. M. Rusch, **Preliminary Results of an Acute Inhalation Study of Propane, 1,1,1,3,3-Pentafluoro- In Mice**, submission to the U.S. Environmental Protection Agency (EPA/OTS 88-940000354S, TSCATS 441482), AlliedSignal Incorporated, Morristown, NJ, 13 July 1994 (RDB-8364)

acute inhalation toxicity of R-245fa

R-C270

H. L. Price, A. A. Lurie, R. E. Jones, M. L. Price, and H. W. Linde, **Cyclopropane Anesthesia. II. Epinephrine and Nonepinephrine in Initiation of Ventricular Arrhythmias by Carbon Dioxide Inhalation**, *Anesthesiology*, 19:619-630, September-October 1958 (12 pages, RDB5575)

toxicity tests for cardiac sensitization by R-C270 (cyclopropane) with inhalation of R-744 (carbon dioxide)

J. W. Stutzman, Q. Murphy, C. R. Allen, and W. J. Meek, **Further Studies on Production of Cyclopropane-Epinephrine Tachycardia**, *Anesthesiology*, 8:579 ff, November 1947 (RDB65B8)

cardiac sensitization of R-C270 (cyclopropane); toxicity

R. M. Waters, **Present Status of Cyclopropane**, *British Medical Journal*, UK, 2:1013-1017, 21 November 1936 (5 pages, RDBA673)

cardiac sensitization of R-C270 (cyclopropane); toxicity

R-290 (PROPANE)

L. Ambrosio, A. Inserra, and C. Sfogliano, **Cases of Occupational Poisoning among Workers Engaged in Bottling Commercial Liquid Gas (Butane-Propane)**, *Folia Med.*, Italy, 51:14 ff, 1968 (RDB7409)

R-290, R-600, R-290/600, toxicity, accidents involving human exposure as reported in RDB-6569

L. L. Anderson and R. C. Graham, untitled toxicity review for propane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 6 March 1990 (RDB6107)

R-290, summary of published and unpublished toxicity literature

O. Ishikawa, S. Warita, M. Shimaoka, and Y. Miyachi, **Atypical Scleroderma with Centrifugal Skin Sclerosis**, *European Journal of Dermatology*, 4(8):618-620, 1994 (3 pages, RDBA930)

presents a case history in which R-290 (propane) exposures were suggested as the eliciting factor in skin sclerosis (hardening from overgrowth of fibrous or interstitial tissue); case involved a 53 yr old male who had worked in a liquid propane company for 8 yr and who responded to therapy with oral prednisone; dermal contact toxicity

F. A. Patty and W. P. Yant, **The Toxicity of Propane** or **Odor Intensity and Symptoms Produced by Commercial Propane, Butane, Pentane, Hexane, and Hexane Vapor**, Report of Investigations 2979, U.S. Bureau of Mines, Washington, DC, 1929 (RDB6114)

R-290; human exposures

S. Tsukamoto et al., *Nippon Hoijaku Zasshi*, Japan, 39(2):124-130, 1985 (7 pages, RDB6117)

R-290, metabolism, toxicity

Occupational Health Guideline for Propane, U.S. Department of Health and Human Services and U.S. Department of Labor, Washington, DC, September 1978 (4 pages with 1 table, RDB5608)

R-290, safety, toxicity, flammability, OHG, occupational exposure guidance

Propane, chemical infogram 87, Canadian Centre for Occupational Health and Safety (CCOHS), Hamilton, ON, Canada, October 1990 (1 page, RDB5609)

R-290, safety, toxicity, flammability, occupational exposure guidance

Toxicity Study Summary: Propane (Hydrocarbon Propellant A-108), Phillips Petroleum Company, Bartlesville, OK, February 1990 (1 page with no figures or tables, RDB7624)

tests of the acute inhalation toxicity in 5 female and 5 male albino, Sprague-Dawley rats by 4 hr, whole body exposures to 12,190 ppm v/v R-290 (propane) in air: no deaths resulted and animals appeared normal throughout the exposures and subsequent 14-day observation period; no gross signs or symptoms of intoxication were noted; no exposure-related trend was evident in body weights following exposures; no mention is made of pathological examinations following the observation period; concludes that the 4-hr LC_{50} rat is >12,190 ppm v/v; respiratory tract irritancy studies in male mice by head-only exposures to 11,472 ppm v/v R-290 in air for 1 min, repeated 10 minutes later, while

monitored by a plethysmograph: no patterns of respiratory pause were evident; concludes that R-290 failed to produce upper respiratory irritancy in mice at 11,472 ppm v/v

R-C318

S. Brubaker, G. A. Peyman, and C. Vygantas (University of Illinois Eye and Ear Infirmary), **Toxicity of Octafluorocyclobutane After Intracameral Injection**, *Archives of Ophthalmology*, 92:324-328, October 1974 (5 pages with 9 figures and 2 tables, RDB7223)

R-C318, comparisons to R-7146, toxicity: use for surgical injection to treat retinal detachment

J. W. Clayton, Jr., M. A. Delaplane, and D. B. Hood (E. I. duPont de Nemours and Company, Incorporated), **Toxicity Studies with Octafluorocyclobutane**, presented at the 21st Annual Meeting of the American Industrial Hygiene Association (AIHA, Rochester, NY 27 April 1960); republished in the *American Industrial Hygiene Journal*, 21:382-388, 1960 (7 pages with 5 figures and 2 tables, RDB5A25)

R-C318 (identified as OFCB), health effects, toxicity: 4-hr ALC rat >800,000 ppm v/v and 4-hr anesthetic NOEL rat = 800,000 ppm; 10-min EC_{50} mouse for anesthesia >800,000; exposures of 10 male and 10 female rats, 10 female mice, 2 male and 2 female rabbits, and 4 male dogs for 6 hr/d, 5 d/wk for 90 days to 100,000 ppm revealed no harmful effects; paper concludes that R-C318 "is a material possessing an extremely low order of acute toxicity"

J. W. Clayton, Jr., M. A. Delaplane, E. E. Hurlbrink, G. L. Lescanec, L. B. Roemer, L. Wells, J. Zerbe, A. R. Borgmann, and D. M. Gay, **Toxicity Studies with Octafluorocyclobutane (OFCB)**, report 15-59, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 17 June 1959 (128 pages with 8 figures and 10 tables, RDB7736)

toxicity studies and literature review for R-C318, then a candidate food propellant; 4-hr acute inhalation toxicity test of R-C318 in 2 rats by exposures to 800,000 (792,000-804,000 actual, 798,000 midpoint) ppm v/v in oxygen; rats showed red ears, mild lacrimation (secretion of tears), and hyperpnea (abnormally rapid or deep breathing) during exposure and mild mydriasis (dilation of the pupil of the eye) afterward, but appeared normal 15 minutes after exposure; 4-hr ALC 0/2 rat >798,000 ppm; tests for anesthetic properties at 800,000 ppm v/v in oxygen in a jar rotated at 14 rpm for 10 minutes found that 6 rats were able to maintain their balance; describes subchronic and chronic toxicity tests in rats, mice, dogs, and rabbits; concludes that animals showed no harmful effects at 100,000 ppm v/v

S. W. D'Amico and R. C. Graham, untitled toxicity review for octafluorocyclobutane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 31 October 1997 (17 pages with 1 table, RDBA302)

R-C318, summary of published and unpublished toxicity literature

A. I. Evdokimov and V. V. Kerekesha, *Tr. Leningrad Sanit. Gigien. Med. Inst.*, (III):39-41, 1975 (3 pages in Russian, RDB7217)

R-C318, health effects, toxicity: chronic exposure test at 100,000 ppm found no differences compared to a control group as reported in RDB7215

R. C. Graham, untitled toxicity review for octafluorocyclobutane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 27 April 1982 (13 pages with 1 table, RDB7215)

R-C318, summary of published and unpublished toxicity literature

C. H. Tappan, **Freon-C318® - JLNB-8580-70: Inhalation Toxicity**, report 98-65, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 9 July 1965 (1 page with 1 table, RDB7216)

4-hr acute inhalation toxicity test of R-C318, with approximately 40 ppm of an identified impurity, in six rats by whole-body exposures to 800,000 ppm v/v in oxygen: rats showed red ears, mild lacrimation (secretion of tears, 2/6), and hyperpnea (abnormally rapid or deep breathing, 2/6) during exposure and mild mydriasis (dilation of the pupil of the eye, 6/6) afterward, but appeared normal 15 minutes after exposure; no examination was performed for pathology; 4-hr ALC rat >800,000 ppm

R-401A, R-401B, R-401C

Safety of Suva MP Refrigerants, document AS-3 (H-35814-1), DuPont Chemicals, Wilmington, DE, May 1994 (4 pages with 1 table, RDB4C49)

This bulletin reviews considerations for safe use of R-401A, R-401B, and R-401C — ternary blends of R-22, R-152a, and R-124 — by providing answers to common questions. It outlines the uses of these as replacements for R-12 in medium-temperature stationary refrigeration, stationary refrigeration with evaporator temperatures below -23 °C (-10 °F) and some transport refrigeration, and retrofit of mobile air-conditioning systems, respectively. It briefly reviews the collaborative Programme for Alternative Fluorocarbon Toxicity Testing (PAFT) and partial findings for R-124. The document discusses the flammability of R-22/152a/124 blends, noting that they are neither flammable nor will become so with leakage, but can become flammable when mixed with gases that are. The document notes that mixtures of R-134a with more than 60% air (by volume) can become flammable at raised pressures and temperatures. It counsels that R-22/152a/124 blends may behave similarly and counsels against use of refrigerant-air mixtures for leak testing. The document then addresses inhalation toxicity. It explains the DuPont Acceptable Exposure Limit (AEL), a time-weighted average (TWA) concentration for an 8 or 12 hour day or 40 hour week, to which nearly all workers may be repeatedly exposed without adverse effects. The compositions, average boiling points, and AELs are tabulated for R-401A, R-401B, and R-401C. The document discusses symptoms of exposure to high refrigerant concentrations, cardiac sensitization, and special charging procedures these near-azeotropic blends. It also discusses suffocation, safety measures for enclosed areas, guidance when a large spill or leak occurs, dangers of deliberate inhalation, and detection by odor. The bulletin provides general advice on skin and eye contact with refrigerants, frostbite, pressure hazards, handling and disposal of cylinders, brazing or welding of pipes in air-conditioning and refrigeration systems, and decomposition. It concludes with specific cautions. The document recommends familiarization with the Material Safety Data Sheet (MSDS) available for these refrigerants. DuPont's product names R-401A, R-401B, and R-401C are Suva® MP39, Suva® MP66, and Suva® MP52, respectively.

R-416A

T. J. Kenny and C. J. Hardy (Huntingdon Research Centre Limited, HRC, UK), **FRIGC™ FR-12™: Assessment of Cardiac Sensitization Potential in Dogs**, report HZL 6/942384, Hazleton Washington, Incorporated, Vienna, VA, 31 May 1994 (33 pages with 7 figures and 9 tables, RDB-7407)

toxicity tests to determine the cardiac sensitization potential of R-416A (R-134a/124/600 (59/37/4) by analysis) in male beagle dogs with intravenous injection of adrenaline five minutes before and, with a challenge injection, midway into a 10 minute exposure in 6 dogs at 50,000 and 70,000 ppm v/v, 5 dogs at 85,000 ppm v/v, and 2 dogs at 100,000 ppm v/v in air; no positive responses were observed at 50,000 ppm v/v [deemed a NOEL], but two of the dogs were reported to be struggling; one dog died during testing at 70,000 ppm v/v before adrenaline administration and 1 (a replacement animal) of 6 dogs showed a positive response at 70,000 ppm v/v; 1 of 5 and 2 of showed positive responses at 85,000 and 100,000 ppm v/v, respectively; the LOEL and EC_{50} were determined to be 70,000 and 90,000 ppm v/v, respectively; comparative tests with 2 dogs for R-11 indicate a LOEL at 20,000 ppm v/v (lowest tested concentration); report cites prior studies that determined the EC_{50} for R-124 and R-134a as 40,000 and 205,000 ppm v/v, respectively [Note: the referenced study could not be obtained, but a draft from the referenced source does not mention these data]; concludes that the cardiac sensitization level of the R-134a/124/600 blend is predictable from the R-124 content and that there is little evidence of a synergistic effect from the other components; the report indicates Good Laboratory Practice (GLP) compliance [Note: The cardiac sensitization level for R-416A may be slightly lower than indicated here; the fraction of R-124 in the tested sample was below that of the nominal formulation and outside the tolerance for this blend.]

R-502

J. F. Breen and J. E. Wallis, **Report on Refrigerant**, Miscellaneous Hazard Report, Underwriters Laboratories Incorporated, Northbrook, IL (then Chicago, IL), 19 November 1963 (RDB7654)

summarizes acute inhalation toxicity tests of R-502 at 100,000 and 200,000 ppm v/v in groups

of three guinea pigs; indicates no clinical signs after five min at 100,000 ppm v/v, but all three treated animals breathed more rapidly after 30 min; also indicates that all three showed occasional chewing movements and slight shaking of their heads at 90 min, but appeared normal and gained weight during a subsequent 10-day observation period; describes more pronounced responses at 200,000 ppm v/v at which the animals appeared uneasy and showed occasional chewing movements and rapid breathing at 30 min; indicates that one animal showed tremors and rubbed its nose while all three showed reduced activity at 60 min; notes that all had difficulty standing and their rear limbs were weak at 90 min progressing to loss of equilibrium and difficulty walking at 2 hr; reports that no gross abnormalities were found in autopsies after a ten-day observation period during which animals appeared normal and gained weight, but that microscopic examination revealed some focal, acute inflammation in the lungs — as reported in RDB5866

J. W. Clayton, Jr., **Freon-502 Refrigerant (Azeotrope of F-22, 48.8% and F-115, 51.2%): Acute Testing**, report 156-63, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 27 December 1963 (1 page with 1 table, RDB-6273)

2-hr acute inhalation toxicity tests of R-502 in four male Charles River CD rats by whole-body exposure to 200,000 ppm v/v in air: this report expands on an earlier one [see RDB6272] with addition of pathology findings from histology studies; no deaths occurred, but animals showed discomfort, tremors, and rapid respiration during exposures; two rats showed slight weight loss during the 14-day observation period following exposures; gross examination of the sacrificed animals revealed some pulmonary congestion at necropsy; no compound-related changes were found in the brain, lung trachea, liver, kidneys, alimentary tract, spleen, thymus, pancreas, testes, or bone marrow; concludes that the 2-hr ALC rat for R-502 exceeds 200,000 ppm v/v, which indicates a low order of toxicity by acute inhalation

J. W. Clayton, Jr., **Freon-502 Refrigerant (Azeotrope of F-22, 48.8% and F-115, 51.2%): Acute Testing**, report 91-62, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 13 December 1962 (1 page with 1 table, RDB-6272)

2-hr acute inhalation toxicity tests of R-502 in four male Charles River CD rats by whole-body exposure to 200,000 ppm v/v in air: no deaths occurred, but animals showed discomfort, tremors, and rapid respiration during exposures; two rats showed slight weight loss during the 14-day observation period following exposures; gross examination of the sacrificed animals revealed some pulmonary congestion at necropsy; histological examination had not been completed at report issuance [see RDB6273]; concludes that the 2-hr ALC rat for R-502 exceeds 200,000 ppm v/v, which indicates a low order of toxicity by acute inhalation

M. A. Lee, untitled toxicity review for Freon® 502, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 22 May 1992 (RDB-5866)

summarizes published and unpublished toxicity information for R-502

R-600 (n-BUTANE)

T. Berzins, **Health Effects of Selected Chemicals 3. Butane**, *NORD*, 28:10-26, 1995 (17 pages, RDBA933)

summarizes toxicity data for R-600 (n-butane) based on a literature search; indicates that the 4-hr LC_{50} rat was 272,000 ppm v/v [based on conversion from 658 mg/l, [see RDB5363] and the 2-hr LC_{50} mouse was 281,000 ppm v/v (680 mg/l) [see RDB5363] by inhalation exposures; indicates that the lethal concentrations in dogs ranged from 196,000-245,000 (474 to 592 mg/l) [200,000-250,000, see RDB6197]; notes that a concentration of 127,000 ppm v/v (308 mg/l) caused light anesthesia in mice in an average of 25 minutes [see RDB6197], and an exposure to 215,000 ppm v/v (521 mg/l) had similar effect within one minute [see RDB6197]; indicates that n-butane induced cardiac sensitization to epinephrine in dogs after inhalation; explains that no reports addressing the acute toxicity of R-600 by administration routes other than inhalation were located; summarizes a 21-day inhalation toxicity study in Sprague-Dawley rats exposed 6 hr/d for a total of 15 exposures over 3 wk to a mixture of R-600 (n-butane), R-600a (isobutane), R-601 (n-pentane), R-601a (isopentane) containing 25% of each, namely R-600a/600/601a/601 (25.0/25.0/25.0/25.0); in-

dicates that no toxicity was evident up to 4,880 ppm v/v (11.8 mg/l), which was the highest concentration tested; reports that no studies of long-term toxicity, carcinogenicity, reproduction toxicity, teratogenicity, immunotoxicity, or allergic sensitivity were found for pure n-butane; indicates that no mutagenic activity was observed in several tests in *Salmonella typhimurium* with or without metabolic activation; summarizes several reports of injuries and deaths from human exposures to R-600, among them accounts suggesting increasing abuse of volatile substances ["sniffing"], including of R-600; notes that use of an oven cleaner containing n-butane as propellant caused transient myoclonus in one patient; cites an incident in which an aerosol spray contained n-butane caused deep frostbite when sprayed directly on skin; cites a study of truck drivers and terminal operators from different loading facilities and service stations were examined for exposure to gasoline vapors containing 90-92% n-butane, isobutane, n-pentane, and isopentane; reports that the concentrations were substantially lower than the established ACGIH TLV-TWA of 300 ppm v/v for gasoline and 800 ppm v/v for n-butane; also reports that 53 male workers exposed to n-butane for an average of 11 years in a refinery to concentrations of 0.17-7.4 ppm v/v (0.0004 mg/l to 0.0178 mg/l) without observed symptoms; notes that some case reports indicate central nervous system (CNS) effects in n-butane abusers including visual hallucinations, increasing irritability and tendency to become easily provoked; also indicates incidence of rapid and severe liver damage potentially attributable to long-term, heavy n-butane abuse by a 17-year-old male; concludes that exposures to low concentrations of R-600 has not been reported to cause adverse effects in humans, but that it causes anesthetic effects and sudden death if inhaled at high concentrations; notes that the safety margin between anesthetic and lethal concentrations appears to be very narrow

T. R. Cartwright, E. D. Brown, and R. E. Brashear (Indiana University School of Medicine), **Pulmonary Infiltrates Following Butane 'Fire-Breathing'**, *Archives of Internal Medicine*, 143:2007-2008, October 1983 (2 pages with 3 figures, RDB7B43)

deliberate inhalation of ordinary R-600 (butane) for a stage trick identified as 'fire-breathing' resulted in rapidly progressive pulmonary infiltrates in a 19-yr old male leading to weakness, malaise, a nonproductive cough, and mild dyspnea (difficult or labored breathing); article concludes that this misuse of chemicals can have a serious or even fatal outcome due to the pulmonary toxic reaction in humans

A. C. Evans and D. Raistrick, *British Journal of Psychiatry*, 150:769-773, June 1987 (5 pages, RDB6A84)

R-600, health effects, toxicity; study of the effects of misuse by direct inhalation; compared effects for 12 youths to 31 inhaling toluene and resultant marked changes of mental state; most users reported elevation of mood and hallucinations; nearly one-fourth believed they were able to fly or swim — as reported in RDB6A83

F. Fernandez, A. Perez-Higueras, R. Hernandez et al., **Hydraencephaly After Maternal Butane Gas Intoxication During Pregnancy**, *Dev. Med. child. Neurology*, 28:361-363, 1986 (3 pages, RDB7B49)

health effects of R-600 (n-butane); toxicity

R. Fytizas-Danielidou, *Ann. Inst. Phytopathol. Benaki*, 10(4):327-332, 1973 (6 pages, RDB6A85)

R-600, health effects, toxicity; liquified butane causes burns or frostbite to the eyes upon direct contact as reported in RDB6A83

M. Y. Gray and J. H. Lazarus (Llandough Hospital, UK), **Butane Inhalation and Hemiparesis**, *Clinical Toxicology*, 31(3):483-485, 1993 (3 pages with no figures or tables, RDB7406)

reports a case of hemiparesis (muscular weakness or paralysis on one side of the body) following inhalation of an unknown concentration of R-600 (butane) in a human; acute inhalation toxicity; health effects, substance abuse

T. J. Hughes et al., report EPA 600/S1-84-005, Office of Health and Environmental Assessment, U.S. Environmental Protection Agency (EPA), Washington, DC, 1984 (RDB6A86)

R-600, health effects, mutagenicity, toxicity: not mutagenic in Salmonella typhimurium or Escherichia coli in the absence and presence of rat microsomal activation as reported in RDB6A83

M. A. Lee and R. C. Graham, untitled toxicity review for butane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 29 January 1990 (RDB6A83)

R-600, summary of published and unpublished toxicity literature

W. W. Marsh, **Butane Firebreathing in Adolescents: A Potentially Dangerous Practice**, *Journal of Adolescent Health Care*, 5(1):59-60, 1984 (2 pages, RDB7408)

R-600, abuse, health effects in humans, toxicity

B. Mathew, E. Kapp, and T. R. Jones, **Commercial Butane Abuse: A Disturbing Case**, *British Journal of Addiction*, 84(5):563-564, 1989 (2 pages, RDB6A91)

health effects from "sniffing" R-600 (n-butane); abuse; toxicity in humans

A. S. McIntyre and R. G. Long, **Fatal Fulminant Hepatic Failure in a 'Solvent Abuser'**, *Postgraduate Medical Journal*, 68:29-30, 1992 (2 pages, RDB7B46)

health effects from "sniffing" R-600 (n-butane); abuse; toxicity in humans

H. Shimizu et al., *Sangyo Igaku*, 27(6):400-419, 1985 (20 pages, RDB6A88)

R-600, health effects, toxicity; not mutagenic in Salmonella typhimurium or in Escherichia coli in the absence or presence of rat microsomal activation as reported RDB6A83

M. Vr'cevi'c and R. Stani'c, **Butane Gas Poisoning — Current Problems in Emergency Internal Medicine**, *Med. Pregl.*, 26(5):173-179, 1973 (7 pages, RDB6A92)

R-600, health effects, toxicity

Occupational Safety and Health Guideline for n-Butane; National Institute of Occupational Safety and Health (NIOSH), U.S. Department of Health and Human Services, Cincinnati, OH; Occupational Safety and Health Administration (OSHA), U.S. Department of Labor, Washington, DC, 1992 (5 pages with no figures or tables, available from GPO, also available from JMC as RDB-5C48)

R-600, toxicity; chemical and physical properties, reactivity, flammability, exposure limits, health hazard information, exposure sources and control methods, medical monitoring, workplace monitoring and measurement, personal hygiene, storage, leaks, special requirements, respiratory protection, personal protective equipment, references

R-600a (ISOBUTANE)

M. A. Lee and R. C. Graham, untitled toxicity review for isobutane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 22 February 1990 (RDB5865)

R-600a, summary of published and unpublished toxicity literature

T. Litovitz, *Occupational Medicine - State of the Art Review*, 3(3):567-568, 1988 (2 pages, RDB6193)

R-600, R-600a, cardiac sensitization, health effects, toxicity

R. D. Stewart (Medical College of Wisconsin), A. A. Herrmann (S. C. Johnson & Son, Incorporated), E. D. Baretta (Johnson), H. V. Forster (Medical College of Wisconsin), J. J. Sikora (Johnson), P. E. Newton (Medical College of Wisconsin), and R. J. Soto (Johnson), **Acute and Repetitive Human Exposure to Isobutane**, *Scandinavian Journal of Work Environment and Health*, 1977(3):234-243, 1977 (10 pages with 4 tables, RDB5364)

summarizes acute and subchronic toxicity tests in healthy human volunteers by whole-body exposures; indicates that acute exposures to 250, 500, or 1000 ppm v/v for 1 min to 8 hr "did not produce any untoward physiological effects" as determined by observation, routine hematology, clinical chemistry, EKG, and pulmonary function as well as by cognitive skill and other neurological measurements; further notes that repetitive exposures to 500 ppm v/v for 1, 2, or 8 hr/d, 5 d/wk, for 2 wk also showed no adverse effects

Industrial Hygiene and Toxicology Bulletin, Phillips Petroleum Company, Bartlesville, OK, November 1976 (RDB6196)

R-600a, health effects, toxicity

Toxicity Study Summary: Isobutane (A-31 Hydrocarbon Propellant), Phillips Petroleum Company, Bartlesville, OK, February 1990 (1 page with no figures or tables, RDB7625)

tests of the acute inhalation toxicity in 5 female and 5 male albino, Sprague-Dawley rats by 4 hr, whole body exposures to 13,023 ppm v/v R-600a (isobutane) in air: no deaths resulted and no symptoms of intoxication were noted; animals appeared normal throughout the exposures and 14-day observation period; treated males showed a slight reduction in mean body weight on days 2-3 following exposures and in females for the entire period; animals appeared normal in pathological examination at necropsy with the exception of 2 animals; one male exhibited dilation of the pelvis of the left kidney and 1 female had a dilated pelvis of the left kid-

ney that was white and hard; concludes that the gross pathological findings did not appear related to treatment and that the 4-hr LC_{50} rat is >13,023 ppm v/v; respiratory tract irritancy studies in male mice by head-only exposures to 12,640 ppm v/v R-600a in air for 1 min, repeated 10 minutes later, while monitored by a plethysmograph: no patterns of respiratory pause were evident; concludes that R-600a failed to produce upper respiratory irritancy in mice at 12,640 ppm v/v

R-601 (n-PENTANE)

Toxicity Study Summary: n-Pentane, Commercial, Phillips Petroleum Company, Bartlesville, OK, February 1990 (1 page with no figures or tables, RDB7626)

tests of the acute inhalation toxicity in 5 female and 5 male albino, Sprague-Dawley rats by 4 hr, whole body exposures to 6,107 ppm v/v R-601 (n-pentane) in air: while no deaths resulted during exposures or a subsequent 14-day observation period; one female was observed to be wheezing with a bloody crust around the nose on days 10-11 following exposures; 3 females were found to have a grey depressed area on the left lung lobe, a pinpoint red spot on the left lobe surface of the liver, a tan area at the cleft of the medium lobe of the liver, a dilated kidney pelvis filled with white fluid, and enlarged peribronchial lymph nodes; concludes that the gross pathological findings were not consistent and that the 4-hr LC_{50} rat is >6,107 ppm v/v; respiratory tract irritancy studies in male mice by head-only exposures to 5,559 ppm v/v pentane in air for 1 min, repeated 10 minutes later, while monitored by a plethysmograph: no patterns of respiratory pause were evident; concludes that pentane failed to produce upper respiratory irritancy in mice at 5,559 ppm v/v

R-601a (IOSPENTANE)

M. A. Lee and R. C. Graham, untitled review of toxicity literature for isopentane, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 19 August 1986 (6 pages with no figures or tables, RDB6777)

summary of published and unpublished information on the toxicity of R-601a (isopentane)

CYCLOPENTANE

Toxicity Study Summary: Cyclopentane (70%), Phillips Petroleum Company, Bartlesville, OK, February 1990 (3 pages with no figures or tables, RDB7627)

cyclopentane, summary of acute oral toxicity, acute inhalation toxicity, respiratory tract irritancy, eye irritancy, and primary dermal irritancy studies

R-602 (n-HEXANE)

Toxicity Study Summary: n-Hexane, Phillips Petroleum Company, Bartlesville, OK, February 1990 (5 pages with no figures or tables, RDB7629)

R-602 (n-hexane), summary of acute oral toxicity, acute dermal toxicity, acute inhalation toxicity, respiratory tract irritancy, eye irritancy, primary dermal irritancy, and mutagenicity tests (Ames, mouse lymphoma forward mutational assay, and *in vitro* sister chromoid exchange) studies

R-630

Emergency Response Planning Guidelines — Monomethylamine, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1990 (RDB4B77)

R-630, ERPG-1, ERPG-2, ERPG-3, toxicology data, toxicity, safety classification

R-717 (AMMONIA)

J. S. Alabaster and D. W. M. Herbert, **Influence of Carbon Dioxide on the Toxicity of Ammonia**, *Nature*, UK, 174(4426):404 ff, 1954 (RDB8405)

R-717, toxicity

I. M. Alpatov, **A Study of Gaseous Ammonia Toxicity**, *Gigiena Truda i Professional'nye Zabolevaniya* [Labor Hygiene and Occupational Diseases], Russia (then USSR), 2:14-18, 1964 (5 pages in Russian, RDB6232)

R-717, toxicity

I. M. Alpatov and V. I. Mikhailov, **Inquiries into Gaseous Ammonia Toxicity**, *Gigiena Truda i Professional'nye Zabolevaniya* [Labor Hygiene and Occupational Diseases], Moscow, Russia (then USSR), 12:51-53, 1963 (3 pages in Russian, RDB6233)

R-717, toxicity

J. Andanson, J. Berenger, R. Castela, J. Catoir, P. Delmon, M. Graille, B. Guidoni, J. P. d'Ortoli, H. Raulot-Lapointe, and J. J. Vigneau, **L'Intoxication Chronique par l'Ammoniaque: Est-Elle Observable en Service Médical Interentreprises?** [Chronic Ammonia Poisoning: Is it Detectable in Joint Plant Medical Services?], *Revue de Médecine du Travail*, France, 4(4):293-300, 1976 (in French, RDB6A36)

R-717, health effects, toxicity: workers exposed to low levels of ammonia for prolonged periods have reported symptoms of headache, drowsiness, asthma, laryngitis, and skin irritation as reported in RDB6270

L. M. Appelman (TNO-CIVO Toxicology and Nutrition Institute, The Netherlands), W. F. ten Berge (DSM, The Netherlands), and P. G. J. Reuzel (TNO-CIVO), **Acute Inhalation Toxicology Study of Ammonia in Rats with Variable Exposure Periods**, *AIHA Journal*, 43(9):662-665, September 1982 (4 pages with 4 tables, RDB5152)

presents acute inhalation toxicity data and a correlation between exposure concentrations and duration for R-717 (ammonia): summarizes lethality tests in male and female rats for varied concentrations and durations of 10, 20, 40, and 60 min; presents a probit relationship for concentrations, exposure periods, and mortality rates; indicates LC_{50} values in rats for 10, 20, 40, and 60 min of 40,300, 28,595, 20,300, and 16,600 ppm, respectively; demonstrates a higher mortality rate for male rats compared to females for tested concentrations as illustrated by 1-hr LC_{50} values of 14,071 and 19,671 ppm v/v respectively

R. Arwood, J. Hammond, and G. G. Ward, **Ammonia Inhalation**, *Journal of Trauma*, 25:444-447, 1985 (4 pages, RDB6257)

R-717, health effects, toxicity

C. S. Barrow and W. H. Steinhagen (University of Pittsburgh), **NH_3 Concentrations in the Expired Air of the Rat: Importance to Inhalation Toxicology**, *Toxicology and Applied Pharmacology* (TAP), 53:116-121, 1980 (6 pages, RDB6A45)

R-717, health effects, toxicity

C. S. Barrow, Y. Alarie, and M. F. Stock (University of Pittsburgh), **Sensory Irritation and Incapacitation Evoked by Thermal Decomposition Products of Polymers and Comparisons with Known Sensory Irritants**, *Archives of Environmental Health*, 33(2):79-88, March-April 1978 (10 pages with 6 figures and 1 table, RDB6231)

R-717 (ammonia), health effects, toxicity, source-study for widely cited RD_{50} mouse of 303 ppm; the maximal response was achieved within the first two minutes of exposure for tested concentrations of R-717

S. P. Bessman and N. Pal, **Ammonia Intoxication: Energy Metabolism and Brain Protein Synthesis**, *Israeli Journal of Medical Science*, 18(1):171-175, 1982 (5 pages, RDB5762)

R-717, health effects, toxicity

G. A. Birken, P. J. Fabri, and L. C. Carey, **Acute Ammonia Intoxication Complicating Multiple Trauma**, *Journal of Trauma*, 21(9):820-822, 1981 (3 pages, RDB6258)

R-717, health effects, toxicity

G. Bittersohl and H. Heberer, **Toxicity of Aliphatic Amines**, *Zeitschrift für die gesamte Hygiene und Ihre Grenzgebiete*, 24(7):529-534, 1978 (6 pages, RDB6A39)

R-717 and others, health effects, toxicity

G. Bittersohl, presentation at the XVIth International Congress of Occupational Health (Tokyo, Japan, 1969), Japanese Industrial Health Association, 250-251, 1971 (RDB6A57)

R-717, carcinogenic potential, health effects, toxicity: evaluation of neoplasms (new benign or malignant growths resembling the tissues from which they arise, but serving no physiologic functions) in East German manufacturing facilities; workers in ammonia plants exhibited a 500-600% higher rate of tumors than others; 80% of the workers were exposed for more than 10 years to exposures of 60-100 ppm as reported in RDB1106

G. Bittersohl, **Epidemiologische Untersuchungen über Krebserkrankungen in der chemischen Industrie** [Epidemiological Study of Cancer Incidence in the Chemical Industry], *Archiv für Geschwulstforschung*, 38:198-209, 1971 (9 pages in German, RDB6A58)

R-717, carcinogenic potential, health effects, toxicity: expands on study in RDB6A57, noting that known carcinogens were present; reports a 200% increase in cancers for workers exposed to ammonia and asbestos compared to asbestos alone — as reported in RDB1106 which discusses limitations to the study and concludes that the influence of ammonia on the formation of tumors by other agents, such as asbestos, cannot be determined

E. M. Boyd, M. L. McLachlan, and W. F. Perry, **Experimental Ammonia Gas Poisoning in Rabbits and Cats**, *Journal of Industrial Hygiene and Toxicology*, 26:29-34, 1944 (6 pages, RDB6245)

R-717, toxicity: 1-hr LC_{50} cat and rabbit = 9,859 ppm v/v as reported in RDB5151 (with summary) and RDB5340

L. A. Buckley, X. Z. Jiang, R. A. James, K. T. Morgan, and C. S. Barrow (Chemical Industry Institute of Toxicology, CIIT), **Respiratory Tract Lesions Induced by Sensory Irritants at the RD_{50} Concentration**, *Toxicology and Applied Pharmacology* (TAP), 74(3):417-429, 1984 (13 pages with 8 figures and 2 tables, RDB6227)

toxicity; health effects; study to determine if pathologic changes occur in the respiratory tracts of mice after inhalation exposure at their RD_{50} concentration for 10 sensory irritants including R-717 (ammonia, RD_{50} mouse = 303 ppm) and R-764 (sulfur dioxide, RD_{50} mouse = 117 ppm); found no or slight changes of doubtful significance in the squamous epithelium for all 10; found slight to minimal changes but moderate inflammation to the respiratory epithelium and no change to the olfactory epithelium or lungs for R-717; found moderate to severe changes and moderate inflammation to the respiratory epithelium and minimal to severe changes to the olfactory epithelium for R-764; comments that ionization of R-717 in water is comparatively limited resulting in less damage than for hydrogen chloride, for which the RD_{50} and water solubility are similar; concludes that "the value of the mouse sensory irritant model for setting occupational guidelines to sensory irritants is strengthened in that these studies demonstrate the RD_{50} concentration is associated with respiratory tract damage and is not an acceptable concentration for occupational exposures"; safe levels are predicted at 0.01-0.1 times the RD_{50} concentration

T. R. Burns, M. L. Mace, S. D. Greenberg, et al., **Ultrastructure of Acute Ammonia Toxicity in the Human Lung**, *American Journal of Forensic Medical Pathologists*, 6:204-210, 1985 (RDB6A41)

R-717, health effects, toxicity

T. R. Burns, S. D. Greenberg, M. L. Mace, and J. A. Jachimczyk, **Pulmonary Ultrastructure in Acute Ammonia Toxicity in Humans**, *Environmental and Occupational Health*, 127:180 ff, 1983 (RDB6259)

R-717, health effects, toxicity

M. Caplin, **Ammonia Gas Poisoning — Forty-Seven Cases in a London Shelter**, *Lancet*, UK, 235(2):95-96, 1941 (2 pages, RDB6A06)

R-717, accident involving human exposure, health effects, toxicity: 13 of 47 people exposed to ammonia in an air raid shelter died within 48 hr of initial exposure; paper documents affects including symptoms similar to pulmonary edema and bronchopneumonia

B. L. Carson, C. M. Beall, H. V. Ellis III, and L. H. Baker, **Ammonia Health Effects**, report EPA 460/3-81/027, Office of Mobile Source Air Pollution Control, U.S. Environmental Protection Agency (EPA), Ann Arbor, MI, 1981 (available from NTIS as document PB82-116047, RDB6260)

R-717, health effects, toxicity

E. Chico et al., **Ammonia Overloading in Hepatocytes Isolated from Liver of Fetal and Adult Rats**, *Biochim. Biophys. Acta.*, 586(3):481-491, 1979 (11 pages, RDB6A40)

R-717, health effects, toxicity

Clement Associates, Incorporated, **Health Effects Assessment for Ammonia**, The Fertilizer Institute, Washington, DC, February 1990 (148 pages, RDB1106)

This document reviews data relevant to assessing the health effects of inhalation exposure to ammonia. The focus is on chronic exposures; information on subchronic and acute exposures also is reviewed to acquire a complete picture of the toxicity of ammonia. Physical and chemical properties, sources, environmental fate, environmental effects, and other related topics are discussed to provide context and perspective.

L. G. Close, F. I. Catlin, and A. M. Cohn, **Acute and Chronic Effects of Ammonia Burns of the Respiratory Tract**, *Archives of Otolaryngology*, 106(3):151-158, 1980 (8 pages, RDB5763)

R-717, health effects, toxicity

T. J. Cole, J. E. Cotes, G. R. Johnson, et al., **Ventilation, Cardiac Frequency and Pattern of Breathing During Exercise in Men Exposed to o-Chlorobenzylidene Malonitrile and (CS) and Ammonia Gas in Low Concentrations**, *Quarterly Journal of Experimental Physiol. Cogn. Medical Science*, 62:341-351, 1977 (11 pages, RDB6A07)

R-717, health effects, toxicity

R. A. Coon, R. A. Jones, L. J. Jenkins, Jr., and J. Siegel, **Animal Inhalation Studies on Ammonia,**

Ethylene Glycol, Formaldehyde, Dimethylamine, and Ethanol, *Toxicology and Applied Pharmacology* (TAP), 646-655, 1970 (10 pages, RDB6234)

R-717 (ammonia) and five other gases, health effects, toxicity as reported in RDB5151 (with summary)

L. V. Cralley, **The Effect of Irritant Gases Upon the Rate of Ciliary Activity**, *Journal of Industrial Hygiene and Toxicology*, 24:193-198, 1942 (6 pages, RDB6235)

R-717, toxicity

T. A. Czuppon, S. A. Knez, and J. M. Rovner, **Ammonia**, *Kirk-Othmer Encyclopedia of Chemical Technology*, John Wiley and Sons, Incorporated, New York, 2:638-691, 1982 (54 pages, RDB9514)

R-717, properties, applications, safety (flammability and toxicity)

T. Dalhamn, **Effect of Ammonia Alone and Combined with Carbon Particles on Ciliary Activity in the Rabbit Trachea in Vivo with Studies of the Absorption Capacity of the Nasal Cavity**, *International Journal of Air and Water Pollution*, 7:531-539, 1963 (9 pages, RDB6A42)

R-717, health effects, toxicity

M. L. Dalton, Jr., and D. L. Bricker, **Anhydrous Ammonia Burn of the Respiratory Tract**, *Tex. Med.*, 74(9):51-54, 1978 (4 pages, RDB5764)

R-717, corrosivity, health effects, toxicity

K. T. Dodd and D. R. Gross, **Ammonia Inhalation Toxicity in Cats: A Study of Acute and Chronic Respiratory Dysfunction**, *Archives of Environmental Health*, 35:6-14, 1980 (RDB6236)

R-717, toxicity

G. D. Duda and P. Handler, **Kinetics of Ammonia Metabolism in Vivo**, *Journal of Biol. Chem.*, 232:303-314, 1958 (12 pages, RDB8406)

toxicity of R-717: biochemistry, metabolism, pharmacokinetics

J. A. Duke, **Phytotoxin Tables**, *Critical Reviews in Toxicology*, 5:191 ff, 1977 (RDB5153)

R-717, health effects, toxicity

J. L. Egle, Jr., **Retention of Inhaled Acetone and Ammonia in the Dog**, *AIHA Journal*, 34:533-539, 1974 (7 pages, RDB6A09)

R-717, health effects, toxicity

H. B. Elkins, **Ammonia, NH_3**, *The Chemistry of Industrial Toxicology* (second edition), John Wiley and Sons, Incorporated, New York, NY, 1959 (86 pages, RDB8407)

toxicity of R-717

A. Z. El-Sewefy and S. Awad, **Chronic Bronchitis in an Egyptian Ice Factory**, *Journal of the Egyptian Medical Association*, 54:304-310, 1971 (7 pages, RDB7452)

R-717, health effects, toxicity: effects on workers exposed to R-717, frost, and dampness in an ice-manufacturing plant; observed that 20% of the exposed workers had chronic bronchitis compared to 14% in a control group, but concludes that the difference is not statistically significant as reported in RDB7419

W. S. Ferguson, W. C. Koch, L. B. Webster, and J. R. Gould, **Human Physiological Response and Adaptation to Ammonia**, *Journal of Occupational Medicine* (JOM), 19:319-326, 1977 (RDB6237)

R-717, health effects, toxicity: people regularly exposed to ammonia may develop tolerance to its effects, as demonstrated in exposures of 6 male and female volunteers exposed to 25, 50, and 100 ppm for 6 weeks; acclimatized subjects experienced eye tearing and some discomfort at 150-200 ppm, but no lasting health effects were observed as reported in RDB6270

A. J. Finkel, **Ammonia**, *Hamilton and Hardy's Industrial Toxicology of Commercial Products* (fourth edition), John Wright PSG Incorporated, 150-152, 1983 (3 pages, RDB6A35)

R-717, health effects, toxicity: anecdotal report of long-term exposure effect on humans; man working in a walk-in refrigerator developed a persistent cough and dyspnea (difficult or labored breathing); test showed lung damage even 3 yr later — as reported in RDB6270 and RDB6A37

K. E. Flury, D. E. Dines, J. R. Rodarte, and R. Rogers, **Airway Obstruction Due to Inhalation of Ammonia**, *Mayo Clinic Proceedings*, 58:389-393, 1983 (5 pages, RDB6238)

R-717, health effects, toxicity

M. J. Gerald And M. D. Slot, **Ammonia Gas Burns (An Account of Six Cases)**, *Lancet*, UK, 1356-1357, 1938 (2 pages, RDB6A48)

R-717, health effects, toxicity, accident involving human exposure

R. E. Gosselin, R. P. Smith, and H. C. Hodge, **Ammonia**, *Clinical Toxicology of Commercial Products* (fifth edition), Williams and Wilkins, Baltimore, MD, III-21 - III-26, 1984 (6 pages, RDB-6A34)

R-717, health effects, toxicity

R. F. Griffiths and L. C. Megson, **The Effect of Uncertainties in Human Toxic Response on Hazard Range Estimation of Ammonia and Chlorine**, *Atmospheric Environment*, 18(6):1195-1206, 1984 (12 pages, RDB6261)

R-717, health effects, toxicity

H. W. Haggard, **Action of Irritant Gases upon the Respiratory Tract**, *Journal of Industrial Hygiene*, 5:390-398, 1924 (9 pages, RDB8408)

toxicity of R-717 (ammonia) and others

D. V. Hatton and C. S. Leach, **Collagen Breakdown and Ammonia Inhalation**, *Archives of Environmental Health*, 34:83-87, 1979 (5 pages, RDB6A10)

R-717, health effects, toxicity

R. A. Hawkins, A. L. Miller, R. C. Nielson, and R. L. Veech, **The Acute Action of Ammonia on Rat Brain Metabolism In Vivo**, *Biochemical Journal*, 134(4):1001-1008, 1973 (8 pages, RDB5765)

R-717, health effects, toxicity

Y. Henderson and H. W. Haggard, **Noxious Gases and the Principles of Respiration Influencing their Action**, American Chemical Society Monograph 35 (second edition), Reinhold Publishing Corporation, New York, NY, 1943 (RDB-72A0)

reports that the maximum short exposure tolerance for R-717 (ammonia) is 300-500 ppm v/v for 30-60 minutes — as reported in RDB5340

C. Heymans and J. J. Es, **Blood Changes Due to Ammonia Inhalation**, *Science*, 109:121-122, 1949 (2 pages, RDB6A50)

R-717, health effects, toxicity

C. J. Hilado, H. G. Cumming, A. M. Machado, C. J. Casey, and A. Furst, **Effect of Individual Gaseous Toxicants on Mice**, *Proceedings of the Western Pharmacology Society*, 21:159-160, 1978 (2 pages, RDB6A11)

R-717, health effects, toxicity

C. J. Hilado, C. J. Casey, and A. Furst, **Effect of Ammonia on Swiss Albino Mice**, *Journal of Combustion Toxicology*, 41:385-388, 1977 (4 pages, RDB6251)

R-717, health effects, toxicity: 30-min LC_{50} mouse = 21,000 ppm as reported in RDB5151 (with summary)

H. B. Hoeffler, H. I. Schweppe, and S. D. Greenberg, **Bronchiectasis Following Pulmonary Ammonia Burn**, *Archives of Pathology and Laboratory Medicine*, 106(13):686-687, 1982 (2 pages, RDB5766)

R-717, health effects, toxicity; accident in Houston involving a tanker truck, carrying 17.2 tonnes (38,000 lb) of anhydrous ammonia, resulted in dispersion 1500 m (5000') downwind and 550 m (1800') wide; resulted in 5 deaths and 178 injuries; the fatalities and most disabling injuries occurred within approximately 70 m (230') of the accident; bronchiectasis is a a late-stage from of chronic bronchitis in which permanent dilation of bronchi due to destruction of the elastic and muscular components of the airway walls

H. Hofer, E. Reindle, and E. Hruby, **Acute Inhalation Toxicity of Ammonia — Evaluation of an Apparatus**, publication unknown, Austria, 1981 (RDB6246)

R-717, toxicity: LC_{50} mouse, 30 min = 9,085 ppm as reported in RDB5151 (with summary)

D. L. Holness, J. T. Purdham, and J. R. Nethercott, **Acute and Chronic Respiratory Effects of Occupational Exposure to Ammonia**, *AIHA Journal*, 50(12):646-650, December 1989 (4 pages with 7 tables, RDB3238)

R-717, health effects, toxicity

International Programme on Chemical Safety (IPCS), **Ammonia**, Environmental Health Criteria (EHC) report 54, World Health Organization (WHO), Geneva, Switzerland, 1986 (214 pages with 21 tables, Rdb6241)

R-717, health effects, toxicity

N. I. Jarudi and B. Golden, **Ammonia Eye Injuries**, *Journal of the Iowa Medical Society*, 63(6):260-263, 1973 (4 pages, RDB5767)

R-717, health effects

J. Johnston, L. Legters, and R. Dailey (Enviro Control, Incorporated), **Biological Effects of Short, High-Level Exposure to Gases: Ammonia**, draft final report under contract DMD 17-79-C-9086, U.S. Army Medical Research and Develop-

ment Command, Fort Detrick, MD, 1979 (RDB-6262)

R-717, health effects, toxicity: This draft report is widely cited in the literature, though no reference has been found to the final version. subjects experienced decreased respiratory tidal volume in exposures to 205-335 ppm v/v for 30 min and temporary changes in respiratory physiology at 500 ppm v/v for 30 min

S. R. Jones, **Ammonia and the Nervous System**, *Journal of the American Medical Association* (JAMA), 620 ff, 1945 (RDB6A51)

R-717, health effects, toxicity

L. E. Kane, C. S. Barrow, and Y. Alarie (University of Pittsburgh), **A Short-Term Test to Predict Acceptable Levels of Exposure to Airborne Sensory Irritants**, *AIHA Journal*, 40:207-229, March 1979 (23 pages with 2 figures and 16 tables, RDB-6249)

presents a model to predict human sensory irritation responses based on sensory irritation data from animal tests; provides RD_{50} data and TLV comparisons for 11 chemicals including 303 ppm for R-717 (ammonia) and 117 ppm for R-764 (sulfur dioxide); compares predicted responses to published effects; proposes use of the RD_{50} measure to set guidelines for exposure limits; concludes that the threshold limit value (TLV) should be set at 1-10% of the RD_{50}, the short-term exposure limit (STEL) at 20% of the RD_{50}, and the emergency exposure limit (EEL) at 30% of the RD_{50}

J. C. Kapeghian, A. B. Jones, and I. W. Waters (Mississippi University), **Effects of Ammonia on Selected Hepatic Microsomal Enzyme Activity in Mice**, *Bulletin of Environmental Contamination and Toxicology*, 35:15-22, 1985 (8 pages, RDB-6A14)

R-717, health effects, toxicity

J. C. Kapeghian, H. H. Mincer, A. B. Jones, A. J. Verlangieri, and I. W. Waters (Mississippi University), **Acute Inhalation Toxicity of Ammonia in Mice**, *Bulletin of Environmental Contamination and Toxicology*, 29(3):371-378, 1982 (8 pages, RDB-5768)

R-717, toxicity: 30-min LC_{50} mouse = 4,230 and 60-min LC_{50} mouse = 5,981 ppm, depending on calculation method as reported in RDB5151 (with summary) RDB5155

J. C. Kapeghian, A. B. Jones, H. H. Mincer, A. J. Verlangieri, and I. W. Waters (Mississippi University), **The Toxicity of Ammonia Gas in the Mouse**, abstract 7586, *Federation Proceedings*, Federation of the American Society of Experimental Biologists, 41:1568, 1982 (1 page, RDB72A1)

1-hr LC_{50} mouse = 4,230 ppm v/v for R-717 (ammonia) as reported in RDB5340

I. Kass, N. Zamel, C. A. Bobry, and M. Holzer, **Bronchiectasis Following Ammonia Burns of the Respiratory Tract**, *Chest*, 62:282-285, 1972 (4 pages, RDB6A13)

R-717, health effects, toxicity: high concentrations of ammonia dissolve in moisture on the skin, leading to skin corrosion as reported in RDB6270

A. Kimmerle, *JFF/Combustion Technology*, 1:4-51, 1974 (48 pages, RDB6250)

reviews toxicity parameters and data, from other sources, on the inhalation toxicity of R-717 (ammonia) in animals; characterizes concentrations of 480-570 ppm and 800-1070 ppm as "irritation" for 4-hr exposures and "strong irritation" for 7-hr exposures, respectively; the latter overlaps with dyspnea (difficult or labored breathing) and traechitis from 820-1430 ppm; indicates that a 4-hr exposures of rats to 2,000 ppm v/v was not fatal while another at 4,000 ppm v/v was, but does not indicate the quantities of animals involved; notes reports of 2-hr LC_{50}s of 3,420, 4,760, and 10,930 ppm v/v in mice, mice, and rats respectively — as reported (with summary) in RDB5151

V. Kirhov, **Neuroautonomic Response of Workers in the Ammonia Industry**, *Suvrem Med*, Bulgaria, 28(10):10-13, 1977 (in Bulgarian, RDB6A55)

R-717, health effects, toxicity: anecdotal study of extended occupational exposures; compares beginning and end-of-day symptoms for 45 male and 28 female workers, exposed to 13-51 ppm, for 5-10 years in an ammonia production plant; subjects reported increases in headaches, vertigo, staggering, and tremors to interviewers; findings were dismissed by others as "not meaningful due to major methodological flaws" as reported in RDB1106

V. Kondrasuov, *Gigiena Truda i Professional'nye Zabolevaniya* [Labor Hygiene and Occupational Diseases], Russia (then USSR), 2:34-38, 1978 (5 pages in Russian, RDB6252)

R-717, toxicity: LC_{50} rat comparison between inhalation and skin absorption as reported (with summary) in RDB5151

Kujawska, **Analysis of Lung Function in Workers Exposed to Irritating Dusts and Gases**, *Med. Pr.*, Poland, 28(5):419-426, 1977 (in Polish, RDB6A56)

R-717, health effects, toxicity: anecdotal study of extended occupational exposures; 143 workers exposed to 7-41 ppm of ammonia, as well as other irritants, had lowered forced expiratory volume than workers from the same facility not exposed to ammonia; critiqued for methodological flaws and other confounding factors as reported in RDB1106

D. Leduc, P. Gris, P. Lheureux, et al., **Acute and Long Term Respiratory Damage Following Inhalation of Ammonia**, *Thorax*, 47:755-757, 1992 (3 pages, RDB6A15)

R-717, health effects, toxicity

K. B. Lehmann (Universität Würzburg), **Experimental Studies on the Acquisition of Tolerance to Technically and Hygienically Important Gases and Vapors: Ammonia**, *Archiv für Hygiene*, 6, 1889 (126 pages in German, RDB6247)

R-717, toxicity: early toxicity testing with cats, dogs, guinea pigs, rabbits, and rats; distinctions among species as reported in RDB5151 (with summary)

K. B. Lehmann (Universität Würzburg), **Experimental Studies on the Effect of Technically and Hygienically Important Gases and Vapors on the Organism (Part I, Ammonia)**, *Archiv für Hygiene*, 5:1-126, 1886 (126 pages in German, RDB6248)

R-717, toxicity: early toxicity testing with cats, dogs, guinea pigs, rabbits, and rats; distinctions among species — as reported in RDB5151 (with summary)

G. Leonardos, D. Kendall, and N. Barnard, **Odour Threshold Determination of 52 Oderant Chemicals**, *Journal of the Air Pollution Control Association*, 19:91-95, 1969 (5 pages, RDB8410)

odor detection threshold of R-717 (ammonia)

D. M. Levy, M. B. Divertie, T. J. Litzow, and J. W. Henderson, **Ammonia Burns of the Face and Respiratory Tract**, *Journal of the American Medical Association* (JAMA), 190:95-98 (possibly 190:873-876), 1964 (4 pages, RDB6243)

R-717, health effects, toxicity: accidental exposure to high concentrations may cause severe eye injury, including fluid accumulation in the eyelids, scarring of the cornea, and even loss of vision as reported in RDB6270

H. Lonsdale, **Ammonia Tank Failure — South Africa**, *Ammonia Plant Safety*, American Institute of Chemical Engineers (AIChE), New York, NY, 17:126-131, 1975 (6 pages, RDB6A16)

R-717, health effects, toxicity, accident involving human exposure: failure of a pressurized ammonia tank in Potchefstroom, South Africa, released 38 tonnes (42 tons) of anhydrous ammonia resulting in 18 deaths and multiple injuries

J. D. MacEwen and E. H. Vernot (University of California, Irvine, UCI), **Annual Technical Report**, report NTIS AD 3555 358, Toxic Hazards Research Unit Technical, National Technical Information Service (NTIS), Springfield, VA, 1972 (RDB6230)

R-717, toxicity, 1-hr LC_{50} rat, = 7,338 ppm as reported in RDB1106 and (with summary) RDB5151

C. A. Mangold (U.S. Navy Industrial Hygiene Division of Investigation), **Investigation of Occupational Exposure to Ammonia**, Puget Sound Naval Shipyard, U.S. Navy, Puget Sound, WA, 1971 (RDB8412)

R-717 (ammonia), health effects, toxicity

A. Manninen, S. Antilla, and H. Savolainen, **Rat Metabolic Adaptation to Ammonia Inhalation**, *Proceedings of the Society of Experimental Biol. Medicine*, 187:278-281, 1988 (4 pages, RDB6263)

R-717, health effects, toxicity

R. S. Marknam, **A Review of Damage from Ammonia Spills**, *Proceedings of the Ammonia Symposium* (Boston, MA, August 1986), American Institute of Chemical Engineers (AIChE), New York, NY, 1986 (RDB6A17)

R-717, health effects, toxicity, accident involving human exposure

J. L. Martin, **Review of Literature on the Toxicity of Ammonia**, The Fertilizer Institute, Washington, DC, 1979 (RDB6A54)

R-717, health effects, toxicity; anecdotal report of the potential effects of long-term, human occupational exposure to ammonia; physician reviewed the results of physical examinations of employees of a fertilizer manufacturer prior to employment and every two years thereafter for up to 15 years; concludes that there is no long-term toxicity due to ammonia exposure as reported in RDB1106

M. H. Mayan and C. P. Merilan, **Effects of Ammonia Inhalation on Young Cattle**, *New Zealand Veterinary Journal*, 24:221-224, 1976 (4 pages, RDB6A18)

R-717, health effects, toxicity

M. H. Mayan and C. P. Merilan, **Effects of Ammonia Inhalation on Respiration Rate of Rabbits**, *Journal of Animal Science*, 34:448-452, 1972 (RDB6A19)

R-717, health effects, toxicity

S. E. A. McCallan and C. Setterstrom, **Toxicity of Ammonia, Chlorine, Hydrogen Cyanide, Hydrogen Sulfide, and Sulfur Dioxide. I. General Methods and Correlations**, *Contrib. Boyce Thompson Institute*, 11:325-330, 1940 (6 pages, RDB8411)

R-717, health effects, toxicity

J. A. McLean, K. P. Mathews, W. R. Solomon, P. R. Brayton, and N. K. Bayne, **Effect of Ammonia on Nasal Resistance in Atopic and Nonatopic Subjects**, *Annals of Otol. Rhinol. Laryngol.*, 88:228-234, 1979 (7 pages, RDB7453)

R-717, health effects, toxicity

R. A. Michaels, **Acute Inhalation Risk Potentially Posed by Anhydrous Ammonia**, RAM TRAC Corporation, Schenectady, NY, 1996 (99 pages, RDB6A25)

R-717, health effects, toxicity

W. Moeller, **Zur chronischen Ammoniak-Exposition aus Opthalmologischer Sicht** [Chronic Ammonia Exposure from an Ophthalmologic Point of View], *Zeitschrift für die gesamte Hygiene und Ihre Grenzgebiete*, 20(9):579-581, 1974 (3 pages, RDB5769)

R-717, health effects, toxicity

T. J. Montague and A. R. Macneil, **Mass Ammonia Inhalation**, *Chest*, 77(4):496-498, 1980 (3 pages, RDB5770)

R-717, health effects, toxicity

K. Mudan and K. Mitchell, **Report on the Potchefsroom, South Africa Ammonia Incident**, Four Elements, Incorporated, Columbus, OH, 1996 (14 pages, RDB6A20)

R-717, health effects, toxicity, accident involving human exposure

J. S. Mulder and H. O. Van der Zalm, **Een gavel van dodelijke ammoniakvergiftiging** [A Fatal Case of Ammonia Poisoning], Tijdschrift Voor Sociale Geneeskunde, Rotterdam, The Netherlands, 45:458-460, 1967 (3 pages in Dutch, RDB6A21)

describes a fatal accident involving human exposure to R-717 (ammonia); indicates that a worker exposed to a very high, but unknown concentration of ammonia vapor immediately experienced coughing, dyspnea (difficult or labored breathing), and vomiting; notes that the victim developed conjunctivitis (inflammation of the mucous membrane inside the eyelids) 3 hr after exposure, and died of cardiac arrest 6 hr after exposure; indicates that the autopsy revealed marked respiratory irritation, denudation of the tracheal epithelium (surface layer of tissue lining the air passages connecting the nose and mouth to the lungs), and pulmonary edema

H. Musehenborn, **The Physiological Action of Ammonia on Man and Means of Protection Against It**, *Dräger Hefte*, Germany, 190:3503 ff, 1937 (RDBA947)

toxicity study of R-717 (ammonia) in humans

National Research Council (NRC) Committee on Medical and Biological Effects of Environmental Pollutants, **Ammonia**, University Park Press, Baltimore, MD, 1979 (RDB5771)

R-717, health effects, toxicity

National Research Council (NRC) Committee on Toxicology, **Guideline for Short Term Exposures of the Public to Air Pollutants, IV, Guide for Ammonia**, National Academy of Sciences (NAS), National Academy Press, Washington, DC, 1987 (RDB5154)

R-717, health effects, toxicity

F. Navazio, T. Gerritsen, and G. J. Wright, **Relationship of Ammonia Intoxication to Convulsions an Coma in Rats**, *Journal of Neurochemistry*, 8:146-151, 1961 (6 pages, RDB8413)

R-717, health effects, toxicity

A. Niden, **Effect of Ammonia Inhalation on the Terminal Airways**, *Proceedings of the 11th Aspen Emphysema Conference*, II:41-44, 1968 (4 pages, RDB6253)

R-717, health effects, toxicity: histological changes of the lung after acute exposure to ammonia, dose-dependent effects in mice as reported in RDB5151 (with summary)

G. J. O'Kane, **Inhalation of Ammonia Vapour: A Report of Eight Patients During the Acute Stages**, *Anesthesia*, 38:1208-1213, 1983 (6 pages, RDB6A22)

R-717, health effects, toxicity, accident involving human exposure

F. Pedersen and R. S. Selig, **Predicting the Consequences of Short-Term Exposure to High Concentrations of Gaseous Ammonia**, *Journal of Hazardous Materials*, 21:143-159, 1989 (17 pages, RDB6A23)

R-717, health effects, toxicity

J. O. Pierce, **Ammonia**, *Patty's Industrial Hygiene and Toxicology* (fourth edition), edited by G. D. Clayton and F. E. Clayton, John Wiley and Sons, Incorporated, New York, NY, 2A:756-782, 1994 (27 pages, RDB6A24)

R-717, health effects, toxicity

A. S. Propkop'eva and G. C. Yushkov, **Toxicology of Ammonia in Animals Repeatedly Exposed for Short Lengths of Time**, *Gigiena Truda i Professional'nye Zabolevaniya* [Labor Hygiene and Occupational Diseases], Russia (then USSR), 9:54-55, 1975 (2 pages in Russian, RDB6228)

R-717, health effects, toxicity: subchronic exposures of rats as reported in RDB5151 (with summary)

A. S. Propkop'eva, G. C. Yushkov, and I. O. Ubasheev, **Materials for a Toxicological Characteristic of the Long-Term Effect of Ammonia on the Organisms of Animals After Brief Exposure**, *Gigiena Truda i Professional'nye Zabolevaniya* [Labor Hygiene and Occupational Diseases], Russia (then USSR), 6:56-57, 1973 (2 pages in Russian, RDB6229)

R-717, toxicity, LC_{50} rat = 26,704 ppm for 5 min, 17,371 ppm for 15 min, 10,050 ppm for 30 min, and 11,341 ppm for 60 min as reported in RDB1106, RDB5106, and (with summary) RDB5151

P. K. Raj, J. H. Hagopian, A. S. Kalelkar, and J. Cece, **Predicting Health Hazards from Ammonia Spills**, *Ammonia Plant Safety*, 17:102-108, 1975 (7 pages, RDB6A52)

R-717, health effects, toxicity

D. Richard, J. Jouany, and C. L. Bondène, **Acute Toxicity of Ammonia in Rabbits by Inhalation**, *Compte Rendu de l'Académie de Science* [Proceedings of the Academy of Science], France, series D, 287(4):375-378, 1978 (4 pages, RDB5772)

R-717, health effects, toxicity: acute exposures of rabbits at 1000-2000 ppm as reported in RDB5151 (with summary)

D. Richard, G. Bouley, and C. L. Bondène, **Effets de l'Inhalation Continué d'Ammoniac Chez le Rat et la Souris** [Effect of Continuous Inhalation of Ammonia in the Rat and Mouse], *Bulletin of the European Physiopathol. Respir.*, 14(5):573-582, 1978 (10 pages in French, RDB6244)

R-717, health effects, toxicity: chronic exposures of rats at 250-300 ppm, without general toxic effect, and 500 ppm as reported RDB5151 (with summary)

K. J. Schadeberg, J. W. Goode, M. L. Keplinger, and J. C. Calandra (Industrial Bio-Test Laboratories, Incorporated), **Irritation Threshold Evaluation Study with Ammonia**, report IBT 663-03161, International Institute of Ammonia Refrigeration (IIAR), Washington, DC, 23 March 1973 (12 pages with 2 tables, RDB6A12)

R-717, health effects, toxicity; study to determine the threshold for irritation by R-717 in humans: irritation was taken to be any annoyance to eyes, nose, mouth, throat, or chest that persisted throughout a five-minute, head-only exposure for a panel of ten subjects; 1 of 10 reported dryness of the nose (deemed not an uncomfortable irritation in the report) at 32 ppm and 2 of 10 did so at 50 ppm; irritation was reported by 3 or more of 10 subjects at 72 and 134 ppm; effects were greater with increasing concentrations; report concludes that concentrations of 50 ppm or less did not cause irritation or discomfort

M. M. Saifutdinov, **Maximum Permissible Concentration of Ammonia in the Atmosphere**, *Hyg. Sanitariya*, 31:171-176, 1966 (6 pages in Russian, RDB6A53)

R-717, health effects, exposure limit, toxicity

A. D. Schaerdel, W. J. White, C. M. Lang, et al., **Localized and Systemic Effects of Environmental Ammonia in Rats**, *Laboratory Animal Science*, 33:40-45, 1983 (16 pages, RDB6A26)

R-717, health effects, toxicity

M. B. Shimkin, A. A. de Lorimier, J. R. Mitchell, and T. P. Burroughs, **Appearance of Carcinoma Following Single Exposure to a Refrigeration Ammonia-Oil Mixture: Report of a Case and Discussion of the Role of Co-Carcinoginesis**, *Archives of Industrial Hygiene and Occupational Medicine*, 9:186-193, 1954 (8 pages, RDB6264)

R-717, carcinogenic potential, health effects, toxicity: technician splattered with R-717 and lubricant on his nose and lip developed a small blister, which became a persistent, chronically

inflamed lump; biopsy confirmed presence of epidermoid carcinoma 6 months later as reported in RDB1106; RDB1106 discusses confounding factors and concludes that it is impossible to draw conclusions concerning the role of R-717 in the observed response

S. D. Silver and F. P. McGrath, **A Comparison of Acute Toxicities of Ethylene Amine and Ammonia to Mice**, *Journal of Industrial Hygiene and Toxicology*, 30:7-9, 1948 (3 pages, RDB6254)

R-717, health effects, toxicity: acute exposures of mice at high concentrations, 10-min LC_{50} mouse = 10,152 ppm as reported in RDB5151 (with summary)

L. Silverman, J. L. Whittenberger, and J. Muller (Harvard School of Public Health), **Physiological Response of Man to Ammonia in Low Concentrations**, *American Public Health Association Meeting* (session of the Industrial Hygiene Section, Boston MA, 10 November 1948), 1948; republished in the *Journal of Industrial Hygiene and Toxicology*, 31(2):74-78, March 1949 (5 pages with 1 figure and 1 table, RDB6226)

summarizes an inhalation toxicity study of R-717 (ammonia) in human volunteers to determine the physiological effects; describes controlled exposures of six male subjects at rest to 500 ppm v/v for 30 min and a seventh for 15 min; reports that subjects exhibited hyperventilation (abnormally high breathing rate) with cyclic variation during exposures and transient hypoventilation (abnormally low breathing rate) during recovery following the exposures; notes that one subject showed a slight increase in blood pressure and pulse rate; also reports that the subjects exhibited irritation of the nose and throat, hypo-esthesia (reduced capacity for sensation and feeling) of the exposed skin, and lacrimation (abnormal or excessive secretion of tears); notes that subjects reported respiratory irritation with some effects persisting for 24 hr after exposures; notes that the subjective reactions varied considerably, but were present in all subjects and severe in two

H. F. Smyth, Jr., **Improved Communication: Hygienic Standards for Daily Inhalation**, *AIHA Quarterly*, 17(2):129-185, 1956 (RDB72A2)

exposures to R-717 (ammonia) of 2,500-6,000 ppm v/v for 30 min are considered dangerous to life as reported in RDB5340

H. F. Smyth, Jr., J. Seaton, and L. Fischer (Carnegie-Mellon Institute, then the Mellon Institute), **The Single Dose Toxicity of Some Glycols and Derivatives**, *Journal of Industrial Hygiene and Occupational Medicine*, 23(6):259-268, June 1941 (10 pages with 3 tables, RDB6267)

R-717 and others, health effects, toxicity: widely referenced LD_{50} oral, rat = 350 mg/kg based on tests using ammonium hydroxide (ammonia-water solution, NH_4OH) with calculated result for ammonia

R. Sobonya, **Fatal Anhydrous Ammonia Inhalation**, *Human Pathology*, 8(3):293-299, 1977 (7 pages, RDB5773)

R-717, health effects, toxicity, accident involving human exposure: 4 fatalities following exposure to ammonia in a farming accident; 3 workers died immediately; the fourth, a 25-yr old man, died from secondary effects 60 days later

S. Stroud, **Ammonia Inhalation - A Case Report**, *Critical Care Nurse*, 1(2):23-26, 1981 (4 pages, RDB5774)

R-717, health effects, toxicity

M. Stupfel et al., *Compte Rendu Société Biol.*, France, 165:1869-1872, 1971 (4 pages, RDB-6255)

R-717, health effects, toxicity: acute exposures of mice at 12,000 ppm for 20 min and at 11,000 ppm for 40 min; males mortality found to be higher as reported in RDB5151 (with summary)

R. B. Swotinsky and K. H. Chase, **Health Effects of Exposure to Ammonia: Scant Information**, *American Journal of Industrial Medicine*, 17:515-521, 1990 (7 pages, RDB6A27)

R-717, health effects, toxicity

Syracuse Research Corporation, **Toxicological Profile for Ammonia**, report TP-90-03, Agency for Toxic Substances and Disease Registry (ATSDR), Public Health Service, U.S. Department of Health and Human Services, Washington, DC, December 1990 (available from NTIS as document PB91-180315, RDB5156)

R-717, health effects, toxicity

S. P. Targowski W. Klucinski, S. Babiker, et al., **Effect of Ammonia on in Vivo and in Vitro Immune Responses**, *Infect. Immunology*, 43:289-293, 1984 (5 pages, RDB6A43)

R-717, health effects, toxicity

J. S. Tepper, B. Weiss, and R. W. Wood, **Alterations in Behavior Produced by Inhaled Ozone**

or Ammonia, *Fundamental and Applied Toxicology*, 5:1110-1118, 1985 (7 pages, RDB6A28)

R-717, health effects, toxicity

Y. C. Ting, **The Toxicity of Ammonia**, *Science*, American Association for the Advancement of Science (AAAS), Washington, DC, 112:91 ff, 1950 (RDB6265)

R-717, health effects, toxicity

M. M. Verberk, **Effect of Ammonia in Volunteers**, *International Archives of Occupational and Environmental Health*, Germany, 39:73-81, 1977 (9 pages, RDB6A29)

reports exposures of 16 volunteers to 50-140 ppm v/v R-717 (ammonia) for 2 hr; indicates that subjects experienced nasal irritation, but no changes to their ventilation capacity; notes that eight of the subjects found 140 ppm v/v to be intolerable; toxicity — as reported in RDB4B76.

E. H. Vernot, J. D. MacEwen, C. C. Haun, and E. R. Kinkead (University of California, Irvine, UCI), **Acute Toxicity and Skin Corrosion Data for Some Organic and Inorganic Compounds and Aqueous Solutions**, *Toxicology and Applied Pharmacology* (TAP), 42:417-423, 1977; republished in report AMRL-TR-77-9, Aerospace Medical Research Laboratory, U.S. Air Force, Wright-Patterson Air Force Base, OH, 1977 (7 pages with 1 table, RDB5157)

R-717 (ammonia), health effects, toxicity: LC_{50} rat, 1 hr = 7338 ppm; LC_{50} and/or LD_{50} data for 110 organic compounds and aqueous solutions thereof (except for ammonia, the others are not commonly used as refrigerants)

D. P. Wallace, **Atmospheric Emissions and Control**, *Ammonia Plant Safety*, 21:51-56, 1979 (6 pages, RDBA672)

summarizes subjective observations by seven human volunteers accustomed to working with R-717 (ammonia) to informal exposures for 1-3 min; indicates that concentrations of 150-200 ppm v/v affected their eyes to a limited extent after approximately 1 min, but their vision was not seriously impaired and breathing was not affected; 440 ppm v/v affected their eyes more quickly, but not sufficiently to impair vision; 600 ppm v/v caused their eyes to stream after 30 seconds, but was still breathable; at 1,000 ppm v/v, their eyes streamed instantly and vision was impaired but not lost, breathing was deemed intolerable to most of those exposed, and skin irritation followed several minutes of exposure; and 1,500 ppm v/v resulted in an instant reaction to get out of the area — as rreported in RDB4236

M. Walton, **Industrial Ammonia Gassing**, *British Journal of Industrial Medicine*, 30:78-86, 1973 (9 pages, RDB6A30)

R-717, health effects, toxicity: 1 of 7 workers exposed to ammonia in an industrial accident died; autopsy showed marked laryngeal edema, acute congestion, pulmonary edema (evidence of damage to alveolar region), and denudation of the bronchial epithelium

R. C. Wands, **Alkaline Materials**, *Patty's Industrial Hygiene and Toxicology* (third revised edition), edited by G. D. Clayton and F. E. Clayton, John Wiley and Sons, Incorporated, New York, NY, chapter 42, 2B(Toxicology):3045-3052, 1981 (8 pages, RDB6A38)

R-717 and others, health effects, toxicity

K. Ward, B. Murray, and G. P. Costello, **Acute and Long Term Pulmonary Sequelae of Acute Ammonia Inhalation**, *Irish Medical Journal*, 76:279-281, 1983 (3 pages, RDB6A44)

R-717, health effects, toxicity

J. H. Weatherby, **Chronic Toxicity of Ammonia Fumes by Inhalation**, *Proceedings of the Society of Experimental Biol. Medicine*, 81:300-301, 1952 (2 pages, RDB6239)

R-717, health effects, toxicity

F. R. Weedon, A. Hartzell, and C. Setterstrom, **Toxicity of Ammonia, Chlorine, Hydrogen Cyanide, Hydrogen Sulfide, and Sulfur Dioxide. V. Animals**, *Contrib. Boyce Thompson Institute*, 11:475-482, 1940 (8 pages, RDB6256)

R-717, health effects, toxicity: acute exposures of rats, mice, and flies at 1,000 ppm for 16 hr as reported in RDB5151 (with summary)

E. S. White, **Case Report — A Case of Near Fatal Ammonia Gas Poisoning**, *Journal of Occupational Medicine*, 13:549-550, 1971 (2 pages, RDB-7454)

R-717, toxicity: accident involving human exposure, health effects, treatment

J. Withers (LUT, UK), W. F. ten Berge (DSM, The Netherlands), J. Gordon (ICI), C. Harris (Technica), I. Hymes (HSE), and J. Jolley (HSE), **The Lethal Toxicity of Ammonia — A Report to the MHAP** [Major Hazards Advisory Panel], North Western Branch Papers, Institution of Chemical

Engineers, UK, 1986(1):6.1-6.27, 1985 (27 pages with 3 figures and 9 tables, RDB6A31)

R-717, health effects, toxicity

K. L. Wong, **Ammonia**, *Maximum Allowable Concentrations for Selected Airborne Contaminants in Spacecraft*, National Research Council (NRC), Committee on Toxicology, 39-59, 1995 (21 pages, RDB6A32)

R-717, health effects, toxicity

R. W. Wood, **Determinants of Irritant Termination Behavior**, *Toxicology and Applied Pharmacology* (TAP), 61:260-268, 1981 (9 pages, RDB6266)

R-717 (ammonia), health effects, toxicity

R. W. Wood, **Behavioral Evaluation of Sensory Irritation Evoked by Ammonia**, *Toxicology and Applied Pharmacology* (TAP), 50:157-162, 1979 (6 pages, RDB6240)

R-717 (ammonia), health effects: tolerance and respiratory depression (5% and 500 ppm) as reported in RDB5151 (with summary)

D. Zissu (Institut National de Recherche et de Sécurité, France), **Histopathological Changes in the Respiratory Tract of Mice Exposed to Ten Families of Airborne Chemicals**, *Journal of Applied Toxicology*, 15(3):207-213, 1995 (7 pages with 3 figures and 3 tables, RDB6A33)

study to identify and compare the histopathological changes induced in the respiratory tract of mice by repeated exposures at targets of 0.3, 1.0, and 3.0 times the RD_{50} concentrations of airborne chemicals, among them R-717 (ammonia); toxicity; health effects: only 11 of the 15 tested irritants induced lesions, among them R-717 which injured the respiratory epithelium; no pathological changes were observed from R-717 at 257 ppm (RD_{50} x 0.85), but lesions were found following exposures at 711 ppm (RD_{50} x 2.35); injuries from R-717 progressed from moderate for 4 days to severe for 9 days to very severe for 14 days based on exposures of 6 hr/d for 5 d/wk; the authors suggest that a repair mechanism may moderate further injury for the majority of tested chemicals, for which the most severe injuries occurred within the first 4 days, but the intensity of lesions induced by R-717 became more severe with further exposures

Ammonia, chemical infogram 73, Canadian Centre for Occupational Health and Safety (CCOHS), Hamilton, ON, Canada, October 1990 (1 page, RDB6269)

R-717, safety, toxicity, flammability, occupational exposure guidance

Ammonia, *Industrial Exposure and Control Technologies for OSHA Regulated Hazardous Substances*, Occupational Safety and Health Administration (OSHA), U.S. Department of Labor, Washington, DC, 104-111, March 1989 (8 pages, available from GPO, RDB6A37)

R-717, health effects, toxicity, exposure and use statistics, controls and protective equipment

Ammonia (CAS 7664-41-7), chemical hazard summary 37, report C88-1E, Canadian Centre for Occupational Health and Safety (CCOHS), Hamilton, ON, Canada, 1988 (18 pages with 1 table, RDB6270)

occupational exposure guidance for R-717 (ammonia); safety; toxicity; flammability

Ammonia: Environmental and Technical Information for Problem Spills, Environment Canada, Ottawa, Ontario, Canada, 1984 (RDB6271)

occupational exposure guidance for R-717 (ammonia); safety; toxicity; flammability; environmental impact

Ammonia Health Effects Information, CAS# 7664-41-7, Elf Atochem North America, Incorporated, Philadelphia, PA, undated circa 1995 (2 pages, RDB5B60)

occupational exposure guidance for R-717 (ammonia); safety; toxicity; flammability; environmental impact; ecological information

Ammonia Toxicity Monograph, The Institution of Chemical Engineers, Warwickshire, UK, 1988 (RDB5151)

R-717, health effects: review and statistical analysis of LC_{50} studies, regression for LC_{50} for the rat by time (30 min = 11,502 ppm, 1 hr = 8,133 ppm, 4 hr = 4,067 ppm)

Criteria for a Recommended Standard — Occupational Exposure to Ammonia, publication 74-136, National Institute of Occupational Safety and Health (NIOSH), U.S. Department of Health and Human Services, Cincinnati, OH, 1974 (RDB5369)

R-717, toxicity

Critical Reviews in Toxicology, Chemical Rubber Company (CRC), Cleveland, OH, 5:189 ff, 1977 (RDB6591)

R-717, toxicity

Emergency First Aid Treatment Guide for Ammonia (7664-41-7), U.S. Environmental Protection Agency (EPA), Washington, DC, undated circa 1990 (RDB6268)

R-717, health effects, toxicity

Emergency Response Planning Guidelines — Ammonia, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1988 (4 pages, RDB-4B76)

R-717, ERPG-1, ERPG-2, ERPG-3, toxicology data, toxicity, safety classification

Hygienic Guide Series — Anhydrous Ammonia, American Industrial Hygiene Association (AIHA), *AIHA Journal*, 32:139-142, 1971 (3 pages, RDB-5775)

R-717, health effects, toxicity: maximum short-exposure tolerance is 300-500 ppm v/v for 30-60 minutes, 2,500-6000 ppm are considered dangerous to life, and 5,000-10,000 ppm are reported to be fatal — as reported in RDB5340

Occupational Safety and Health Guideline for Ammonia; National Institute of Occupational Safety and Health (NIOSH), U.S. Department of Health and Human Services, Cincinnati, OH; Occupational Safety and Health Administration (OSHA), U.S. Department of Labor, Washington, DC; 1992 (7 pages with no figures or tables, available from GPO, also available from JMC as RDB-5C46)

R-717, toxicity; chemical and physical properties, reactivity, flammability, exposure limits, health hazard information, exposure sources and control methods, medical monitoring, workplace monitoring and measurement, personal hygiene, storage, spills and leaks, special requirements, personal protective equipment, references

Summary Review of Health Effects Associated with Ammonia: Health Issue Assessment, report EPA 600/8-89/052F, Office of Health and Environmental Assessment, U.S. Environmental Protection Agency (EPA), Washington, DC, June 1989 (72 pages with 1 figure and 5 tables, RDB-5155)

assesses the toxicity R-717 (ammonia); provides an extensive list of references

R-744 (CARBON DIOXIDE)

M. R. Banerjee, *International Journal of Biometeorology*, 16(3):259-267, 1972 (9 pages, RDB6454)

effects on rats of acute exposure to increased R-744 (carbon dioxide) in the air; toxicity

P. Brighten, **A Case of Industrial Carbon Dioxide Poisoning**, *Anaesthesia*, UK, 31(3):406-407, 1976 (2 pages, RDB5788)

toxicity of R-744 (carbon dioxide)

E. B. Brown Jr. and F. Miller, **Ventricular Fibrillation Following a Rapid Fall in Alveolar Carbon Dioxide Concentration**, *American Journal of Physiology*, 169:56-60, 1952 (5 pages, RDBA936)

indicates that 15 of 17 dogs exposed to 400,000 ppm v/v R-744 (carbon dioxide) for 2 hr or more died upon sudden reexposure to air; toxicity — as reported in RDB5787

E. W. Brown (Edgewood Arsenal, Medical Corps), **The Physiological Effects of High Concentrations of Carbon Dioxide**, *U.S. Navy Medical Bulletin*, 28:721-734, 1930 (15 pages with foldout and 1 figure and 1 table, RDBA655)

reports an inhalation toxicity study in human volunteers to determine the physiological effects of inhalation of R-744 (carbon dioxide); indicates that seven male subjects were exposed via face masks to concentrations of 55,000-124,000 ppm v/v with oxygen maintained between 14.4 and 39.7%; the concentrations tested were deemed tolerable for only short periods of time, ranging from 22 min for 60,000 ppm v/v to 30 sec for 124,000 ppm v/v; notes that exposed subjects showed negligible to slight increases in respiratory rate, moderate increases in pulse rate, and dose-dependent increases in both diastolic and systolic blood pressure; notes that subjects showed varying degrees of increase in minute-expiration volume and the severity of subjective symptoms including dyspnea (difficult or labored breathing), dizziness, flushing and sweating of the face, feeling of stupefaction (reduced sensation, perception, and understanding), apprehension of impending collapse, and limited to moderately severe headache; indicates that despite marked differences in individual tolerance to the exposures, the author did not think any of the subjects could have withstood 100,000 ppm v/v for more than 10 min without loss of consciousness; notes that increasing the oxygen concentration did not alleviate the

toxic effects of high carbon dioxide concentrations

E. S. Cooper et al., **The Relation Between Cardiac Function and Cerebral Blood Flow in Stroke Patients 1: Effect of CO_2 Inhalation**, *Stroke*, 1(5):330-347, 1970 (18 pages, RDB5789)

toxicity of R-744 (carbon dioxide)

Council on Pharmacy and Chemistry of the American Medical Association (AMA), **Reports of the Council: Oxygen-Carbon Dioxide Mixtures**, *Journal of the American Medical Association* (JAMA), 114(12):1077-1079, 23 March 1940 (3 pages with no figures or tables, RDBA657)

toxicity of R-744 (carbon dioxide) in humans; cautions those administering oxygen-carbon dioxide therapy at 50,000 ppm v/v carbon dioxide for longer than 30 min to look for signs of intoxication; further recommends careful observation from the start for concentrations of 100,000 ppm v/v; notes that carbon dioxide toxicity must be kept in mind after 10-15 min [by inference, the AMA cautions must have been predicated on incidents in which the anesthetic and toxic affects suggested were observed — see RDB72A5 for related information]

D. J. Cullen and E. L. Eger, **Cardiovascular Effects of Carbon Dioxide in Man**, *Anesthesiology*, 41:345-349, 1974 (5 pages, RDB5790)

R-744, health effects, toxicity

R. D. Dripps and J. H. Comroe, Jr. (University of Pennsylvania and the Hospital of the University of Pennsylvania), **The Respiratory and Circulatory Response of Normal Man to Inhalation of 7.6 and 10.4 Per Cent CO_2 with a Comparison to the Maximal Ventilation Produced by Severe Muscular Exercise, Inhalation of CO_2, and Maximal Voluntary Hyperventilation**, *American Journal of Physiology*, 149:43-51, 1947 (9 pages with 1 figure and 4 tables, RDBA658)

toxicity of R-744 (carbon dioxide) in humans: 1 of 42 subjects who breathed 76,000 ppm v/v for an average of 7.4 min lost consciousness while 9 of the subjects indicated dizziness; 3 of 31 subjects who breathed 104,000 ppm v/v for an average of 3.8 min lost consciousness while 7 indicated faintness and 13 indicated dizziness [each subject may have reported more than one symptom]

F. Flury and F. Zernik, **Schädliche gase, dämpfe, nebel, rauch- und staubarten** [Dangerous Gases, Fumes, Mists, Smokes, and Dusts], Springer-Verlag (then Verlag von Julius Springer), Berlin, Germany, 1931 (in German, RDB72A6)

exposure at 70,000-100,000 ppm v/v R-744 (carbon dioxide) produces unconsciousness in humans — as reported in RDB5340

W. J. Friedlander and T. Hill, **EEG Changes During Administration of Carbon Dioxide**, *Diseases of the Nervous System*, 15:71-75, 1954 (5 pages, RDBA663)

inhalation tests in humans exposed to 300,000 ppm v/v R-744 (carbon dioxide) in oxygen via a face mask for 50-52 sec; average patient lost consciousness within 24-28 sec, but regained it in 110 seconds after exposures; toxicity — as reported in RDB5787; subjects also had abnormal electroencephalograms (EEGs) suggesting cardiac irritability — as reported in RDB5787

P. M. Gramenitskii et al., **Long Term Exposure of Rats to High Concentration of Carbon Dioxide**, *Biull. Eksp. Biol. Med.*, 86(9):285-287, 1978 (3 pages, RDB5791)

R-744, health effects, toxicity

E. Griez and M. A. Van den Hout, **Carbon Dioxide and Anxiety: Cardiovascular Effects of a Single Inhalation**, *Journal of Behavioral Therapy and Experimental Psychiatry*; 14(4):297-304, 1983 (8 pages, RDB8419)

toxicity of R-744 (carbon dioxide): effects of acute exposures on the cardiovascular system; notes that inhalation of carbon dioxide produces sensations usually associated with anxiety; investigation concluded that anxiety-like responses are largely sympathomimetic

J. Haldane and J. L. Smith, **The Physiological Effects of Air Vitiated by Respiration**, *Journal of Pathology and Bacteriology*, 1:168-186, 1893 (19 pages with 6 figures and 7 tables, RDBA659)

toxicity of R-744 (carbon dioxide) in humans: reports an observation from 1892 that breathing 186,000 ppm v/v for 94-110 seconds caused "confusion of the mind" in two subjects — as reported in RDB72A5

A. Hendrik and F. Muller, **Hyperglycemic Effect of Acute Carbon Dioxide Intoxication**, *Zeitschrift für die gesamte Innre Medizin*, Germany, 28(7):209-211, 1973 (3 pages, RDB5792)

R-744, health effects, toxicity

F. Herles et al., **Influence of Acute Respiratory Acidosis, Induced by Carbon Dioxide Inhalation, on Pulmonary Circulation**, *Vnitr. Lek.*, 13(7):692-699, 1967 (8 pages, RDB5793)

R-744, health effects, toxicity

D. Hunter, **The Diseases of Occupations** (fifth edition), Hodder and Stoughton, London, UK, 618 ff, 1975 (RDB72A7)

exposure to 100,000 ppm v/v R-744 (carbon dioxide) for only a few minutes can cause loss of consciousness in humans as reported in RDB5340

I. Juzwiak and K. Brodziak-Krzesiek, **Clinical Studies on Persons Subjected to the Effect of Carbon Dioxide in Comparison to the Environmental Studies in Cellulose and Plastic Industry**, *Postepy Hig. Med. Dosw.*, 22(2):353-356, 1968 (4 pages, RDB5794)

toxicity of R-744 (carbon dioxide)

B. G. King (Medical Service, Civil Aeronautics Administration), **High Concentration—Short Time Exposures and Toxicity**, presented to the Greater New York Safety Council, 1 April 1949; republished in the *Journal of Industrial Hygiene and Occupational Medicine*, 31(6):365-375, November 1949 (11 pages with 3 figures and 3 tables, RDBA660)

examines the toxicity dependence on time and concentration for R-10 (carbon tetrachloride), R-40B1 (methyl bromide), and R-744 (carbon dioxide) in humans

S. Kwiatowski et al., **Permanent Sequelae of Acute Carbon Dioxide Poisoning**, *Pol. Tyg Lek.*, 36(31):1165-1168, 1981 (4 pages, RDB5795)

toxicity of R-744 (carbon dioxide)

A. A. LaVerne et al., **Occupational, Accidental, Explorational Carbon Dioxide Inhalation Poisonings and Prevention**, *Behavioral Neuropsychiatry*, 4(12):33-48, 1973 (16 pages, RDB5796)

toxicity of R-744 (carbon dioxide)

C. D. Leake, A. E. Guedal, and M. E. Botsford, **The Stimulating Effect of Carbon Dioxide Inhalations in Dementia Praecox Catatonia**, *California West. Med.*, 31:20-23, 1929 (4 pages, RDBA662)

use of R-744 (carbon dioxide) as an anesthetic for animal surgery; toxicity — as reported in RDB5787

F. M. MacDonald and E. Simonson, **Human Electrocardiogram During and After Inhalation of Thirty Percent Carbon Dioxide**, Journal of Applied *Physiology*, 6:304-310, 1953 (7 pages, RDBA940)

toxicity of R-744 (carbon dioxide); indicates that 17 male volunteers exposed to 300,000 ppm v/v carbon dioxide for 38 sec experienced narcosis and electrocardiogram (ECG) abnormalities in a broader tests — as reported in RDB5787

H. Mitsuda et al., **Effects of Carbon Dioxide on Serum Biochemical Patterns and on Histopathological Changes of Organ in Rats**, *Journal of Nutritional Science and Vitaminology*, 28(2):105-115, 1982 (11 pages, RDB5797)

R-744, health effects, toxicity based on studies of male rats anesthetized with a 40/60 mixture of carbon dioxide and oxygen for 3 hr

R. R. Montgomery, untitled toxicity review for carbon dioxide, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 9 August 1983 (RDB6453)

R-744, summary of published and unpublished toxicity literature

D. P. Mukherjee and S. P. Singh, **Effect of Increased Carbon Dioxide in Inspired Air on the Morphology of Spermatozoa and Fertility of Mice**, *Journal of Reproduction and Fertility*, 13:165-167, 1967 (3 pages, RDBA938)

toxicity of R-744 (carbon dioxide); indicates that 10 male mice exposed to 350,000 ppm v/v for 6 hr experienced changes in their sperm development resulting in smaller litters — as reported in RDB5787

W. C. Petty and T. S. Sulkowski, **Narcosis in the Rat — II. Effects on the ECG**, *Aerospace Medicine*, 42:553-558, 1971 (6 pages, RDBA937)

toxicity of R-744 (carbon dioxide); indicates that rats exposed to concentrations of carbon dioxide exceeding 400,000 ppm v/v for 20 min experienced arrhythmias 10-55 sec after sudden withdrawal — as reported in RDB5787

K. E. Schaefer, **Studies of Carbon Dioxide Toxicity**, report 181, Submarine Medical Research Laboratory, Bureau of Medicine and Surgery, U.S. Department of the Navy, New London, CT, 10:156-189, 1951 (34 pages, RDB72A8)

submarine personnel continuously exposed to 30,000 ppm R-744 were only slightly affected

provided the oxygen content of the air was maintained at normal concentrations as reported in RDB5340

K. E. Schaefer, **The Effects of CO_2 and Electrolyte Shifts on the Central Nervous System**, *Selective Vulnerability of the Brain in Hypoxemia*, edited by J. P. Schade and W. H. McMehemy, Blackwell Scientific Publications, Oxford, UK, 101-123, 1963 (23 pages, RDBA939)

toxicity of R-744 (carbon dioxide); indicates that 8 rhesus monkeys exposed to 300,000 ppm v/v for 30 min showed increases in cortical and hypothalamic activities as well as increased tolerance for carbon dioxide after exposures; reports a range of central nervous system (CNS) effects in 42 human volunteers exposed to 75,000 ppm v/v carbon dioxide for 15 minutes including restlessness for ten subjects, loss of balance in seven, loss of limb control for four, and mental disorientation for two; indicates that exposure to 33,000 v/v and higher depressed the autonomic nervous system — as reported in RDB5787

P. H. Sechzer, L. D. Egbert, H. W. Linde, D. Y. Cooper, R. D. Dripps, and H. L. Price, **Effect of CO_2 Inhalation on Arterial Pressure, ECG and Plasma Catecholamines and 17-OH Corticosteroids in Normal Man**, *Journal of Applied Physiology*, 13:454-458, 1960 (5 pages, RDBA941)

toxicity of R-744 (carbon dioxide); indicates that 12 human male volunteers exposed to concentrations of carbon dioxide of 70,000-140,000 ppm v/v for 10-20 min experienced physiological effects, among them loss of consciousness at concentrations above 100,000 ppm v/v and headaches and sweating above 70,000 ppm v/v — as reported in RDB5787

D. Sevel and A. Freedman, **Cerebro-Retinal Degeneration Due to Carbon Dioxide Poisoning**, *British Journal of Opthalmology*, 51(7):475-482, 1967 (8 pages, RDB5798)

toxicity of R-744 (carbon dioxide)

J. M. Stinson and J. L. Mattsson, **Cardiac Depression in the Detection of the High Environmental CO_2: A Comparative Study in Rhesus Monkeys and Chimpanzees**, *Aerospace Medicine*, 42(1):78-80, 1971 (3 pages, RDB5815)

toxicity of R-744 (carbon dioxide): indicates that three chimpanzees exposed to concentrations up to 510,000 ppm v/v survived if the concentration was increased and decreased slowly — as reported in RDB5787

J. M. Stinson and J. L. Mattsson, **Tolerance of Rhesus Monkeys to Graded Increase in Environmental CO_2: Serial Changes in Heart Rate and Cardiac Rhythm**, *Aerospace Medicine*, 41(4):415-418, 1970 (4 pages, RDB5816)

toxicity of R-744 (carbon dioxide)

W. Storm and C. L. Giannetta, **Effects of Hypercapnia and Bedrest on Psychomotor Performance**, *Aerospace Medicine*, 45:431-433, 1974 (3 pages, RDBA943)

toxicity of R-744 (carbon dioxide); describes tests psychomotor impairment in six healthy male volunteers exposed to 40,000 ppm v/v for 2 wk; notes that the test series measured complex tracking performance, eye-hand coordination, and problem-solving ability; concludes that performance was not impaired — as reported in RDB5787

C. J. S. Thompson, **Henry Hill Hickman — A Forgotten Pioneer of Anaesthesia**, *British Medical Journal*, 1:843-845, 1912 (3 pages, RDBA661)

use of R-744 (carbon dioxide) as an anesthetic for animal surgery; toxicity — as reported in RDB5787

N. L. Vandemark, B. D. Schanbacher, and W. R. Gomes, **Alterations in Testes of Rats Exposed to Elevated Atmospheric Carbon Dioxide**, *Journal of Reproduction and Fertility*, 28(3):457-459, 1972 (3 pages, RDB5826)

toxicity of R-744 (carbon dioxide); indicates that 8 rhesus monkeys exposed to 300,000 ppm v/v for 30 min showed increases in cortical and hypothalamic activities as well as increased tolerance for carbon dioxide after exposures; reports a range of central nervous system (CNS) effects in 42 human volunteers exposed to 75,000 ppm v/v carbon dioxide for 15 minutes including restlessness for ten subjects, loss of balance in seven, loss of limb control for four, and mental disorientation for two — as reported in RDB5787

E. B. Weybrew, **An Exploratory Study of the Psychological Effects of Intermittent Exposure to Elevated Carbon Dioxide Levels**, report 647, Submarine Medical Research Laboratory, Bureau of Medicine and Surgery, U.S. Navy, Groton, CT, 1970 (9 pages, RDBA942)

describes a test of human exposure to R-744 (carbon dioxide) to investigate its effects of on

psychological function; indicates that a 24-yr-old male was exposed to a concentration that increased from 300 to 30,000 ppm v/v during 15-hr periods for 6 days in a 30 m^3 (1000 cf) recompression chamber; summarizes tests of psychologic efficiency including addition of single-digit numbers, cancellation of letters, response analysis testing (RATER), and selection of adjectives from a list to describe mood and interests; indicates that the tests did not show any remarkable changes related to the carbon dioxide exposure; concludes that the experiment produced emotional changes in the subject based on the adjective-choice test, but attributes these changes to the confinement; toxicity — as reported in RDB5787

H. I. Williams, **Carbon Dioxide Poisoning — Report of Eight Cases, with Two Deaths**, *British Medical Journal*, 2:1012-1014, 1958 (3 pages, RDB6281)

toxicity of R-744 (carbon dioxide)

J. Winter, *Arbeitsschutz* [Occupational Safety], 104-105, 1937 (RDB6282)

toxicity of R-744 (carbon dioxide); fatalities

Criteria for a Recommended Standard — Occupational Exposure to Carbon Dioxide, publication 76-194, National Institute of Occupational Safety and Health (NIOSH), U.S. Department of Health and Human Services, Cincinnati, OH, August 1976 (184 pages with 1 figure and 11 tables, available from NTIS as publication PB266-597, RDB5787)

review of toxicity data for R-744 (carbon dioxide) to recommend an occupational exposure limit; recommends that occupational exposures not exceed 10,000 ppm v/v as a time-weighted average (TWA) for up to a 10-hr work shift in a 40-hr work week with a ceiling concentration of 30,000 ppm v/v; notes that carbon dioxide is a normally present in air at approximately 300 ppm v/v, is widely used in direct-contact food refrigeration and preservation, is common in beverages for carbonation, and was used as an anesthetic for animal surgery in the early 1800s

Hygienic Guide Series — Carbon Dioxide, *AIHA Journal*, 25:519-521, 1964 (3 pages, RDB5783)

toxicity of R-744 (carbon dioxide)

Occupational Health Guideline for Carbon Dioxide; National Institute of Occupational Safety and Health (NIOSH), U.S. Department of Health and Human Services, Cincinnati, OH; Occupational Safety and Health Administration (OSHA), U.S. Department of Labor, Washington, DC; September 1978 (available from GPO as part of publication PB83-154609; RDB6280)

R-744, toxicity; identification, exposure limits, health hazard information, chemical and physical properties, monitoring and measuring procedures, respirators and respiratory protection, personal protective equipment, common operations and controls, emergency first aid procedures, leak procedures, references

R-744A

B. D. Greenberg, R. Moore, R. Letz, and E. L. Baker, **Computerized Assessment of Human Neurotoxicity: Sensitivity to Nitrous Oxide Exposure**, *Clinical Pharmacology and Therapeutics*, 38:656-660, 1985 (6 pages, RDB5738)

R-744a

R-764

H. Salem and D. M. Aviado (University of Pennsylvania School of Medicine), **Inhalation of Sulfur Dioxide**, *Archives of Environmental Health*, 2:656-662, 1961 (RDB6939)

R-764, health effects, toxicity

Emergency Response Planning Guidelines — Sulfur Dioxide, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1990 (RDB4B78)

R-764, ERPG-1, ERPG-2, ERPG-3, toxicology data, toxicity, safety classification

R-7146

G. Kimmerle, **Vergleichende Untersuchungen der inhalations Toxicität von Schwefelselen- und Tellurhexafluorid**, *Archiv. für Toxik.*, 18:140-144, 1960 (5 pages, RDB7367)

R-7146 and others, toxicity

D. Lester and L. A. Greenberg (Yale University), **The Toxicity of Sulfur Hexafluoride**, *Archives of Industrial Hygiene and Occupational Medicine*, 2:348-349, 1950 (2 pages, RDB5A39)

R-7146, toxicity

H. Specht and H. F. Brubach, **Inhalation of Sulfur Hexafluoride**, *Science*, 114:662-663, 1951 (2 pages, RDB7368)

R-7146, toxicity

R-1110

E. Guberan and J. Fernandez, **Control of Exposure to Tetrachloroethylene by Measuring Alveolar Concentrations: Theoretical Approach Using a Mathematical Model,** *British Journal of Industrial Medicine*, 31:159-167, 1974 (9 pages, RDB6495)

R-1110, health effects, toxicity

V. K. Rowe, D D. McCollister, H. C. Spencer, E. M. Adams, and D. D. Irish, **Vapor Toxicity of Tetrachloroethylene for Laboratory Animals and Human Subjects**, *Archives of Industrial Hygiene and Occupational Medicine*, 5:566-579, 1952 (14 pages, RDB6507)

R-1110, health effects, toxicity, LC_{50}

R-1113

Emergency Response Planning Guidelines — Chlorotrifluoroethylene, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1992 (RDB-4B81)

R-1113, 1-chloro-1,2,2-trifluoroethene, ERPG-1, ERPG-2, ERPG-3, toxicology data, toxicity, safety classification

Workplace Environmental Exposure Level Guide — Chlorotrifluoroethylene, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1986 (RDB4B85)

R-1113, 1-chloro-1,2,2-trifluoroethene, WEEL, toxicology data, toxicity, safety classification

R-1114

R. Lafaux, *Practical Toxicology of Plastics*, CRC Press, Incorporated, Cleveland, OH, 205 ff, 1968 (RDB8124)

R-1114 toxicity: small amounts of fluorochemicals R-C318, R-1216, and R-1318 (perfluoroisobutylene, PFIB) are formed by thermal decomposition of R-1114 above 400 °C (752 °F) when air is present

Emergency Response Planning Guidelines — Tetrafluoroethylene, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1991 (RDB4B79)

R-1114, tetrafluoroethene, ERPG-1, ERPG-2, ERPG-3, toxicology data, toxicity, safety classification

R-1120

E. M. Adams, H. C. Spencer, V. K. Rowe, D D. McCollister, and D. D. Irish, **Vapor Toxicity of Trichloroethylene Determined by Experiments on Laboratory Animals**, *Archives of Industrial Hygiene and Occupational Medicine*, 4:469-481, 1951 (13 pages, RDB6508)

R-1120, health effects, toxicity, LC_{50}

C. R. Elcombe, **Species Differences in Carcinogenicity and Peroxisome Proliferation Due to Trichloroethylene: A Biochemical Human Hazard Assessment. Receptors and Other Targets for Toxic Substances**, *Archives of Toxicology Supplement*, 8:6-17, 1985 (12 pages, RDB65C4)

R-1120, health effects, toxicity

C. Maltoni, G. Lefermine, and G. Cotti, **Experimental Research on Trichloroethylene Carcinogenesis**, *Archives of Research on Industrial Carcinogenesis*, edited by C. Maltoni and M. A. Mohlman, Princeton Scientific Publishing Company, Princeton, NJ, 5:1-393, 1986 (393 pages, RDB-65C0)

R-1120, health effects, toxicity

J. H. Mennear, **Toxicology and Carcinogenensis Studies of Trichloroethylene (CAS No. 79-01-6) in Four Strains of Rats (ACI, August, Marshall, Osborne-Mendel) (Gavage Studies)**, report TR-273 (also identified as NIH publication 88-2529) for the National Toxicology Program (NTP), U.S. Department of Health and Human Services, research Triangle Park, NC, April 1988 (available from NTIS as publication PB88-218896/AS, RDB65D5)

R-1120, carcinogenicity, health effects, toxicity

R. M. Waters, O. S. Orth, and N. A. Gillespie, **Trichloroethylene Anesthesia and Cardiac Rhythym**, *Anesthesiology*, 4:1 ff, 1943 (RDB65A1)

R-1120, cardiac sensitization, health effects, toxicity

J. F. White and G. P. Carlson, **Epinephrine-Induced Cardiac Arrhythmias in Rabbits Exposed to Trichloroethylene: Role of Trichloroethylene Metabolites**, *Toxicology and Applied Pharmacology* (TAP), 60:458-465, 1981 (8 pages, RDB6B49)

R-1120, cardiac sensitization, health effects, toxicity: chemically-induced arrhythmias did not occur when epinephrine was administered 15-30 minutes after exposure to a sensitizing level of chemical

R-1140

Occupational Safety and Health Guideline for Vinyl Chloride — Potential Human Carcinogen, National Institute of Occupational Safety and Health (NIOSH), U.S. Department of Health and Human Services, Cincinnati, OH, 1988 (available from GPO as document 1993-750-004/80503, RDB4A73)

R-1140, toxicity; properties, exposure limits, health hazard information, recommended medical practices, monitoring and measurement procedures, personal protective equipment, sanitation, common operations and controls, emergency first aid procedures, spills and leaks, waste removal and disposal, respiratory protection, references

R-1150 (ETHYLENE)

A. B. Luckhardt and J. B. Carter (University of Chicago), *Journal of the American Medical Association* (JAMA), 80:765-770, 1923 (6 pages, RDB-7740)

toxicity tests of the anesthetic effects of R-1150

R-1216

Acute Inhalation Toxicity, report EPA/OTS-878220382 TSCATS 019448, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, circa 1987 (RDB8431)

acute inhalation toxicity of R-1216, hexafluoropropene oxide (HFPO), and others

Hexafluoropropylene, Evaluation in the In Vitro Assay for Chromosome Aberrations in Chinese Hamster Ovary (CHO) Cells, report EPA/OTS-09860510, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 1986 (RDB-8126)

toxicity tests of R-1216 mutagenicity in both the presence and absence of metabolic activation: significant increases were observed in the number of aberrations, percent abnormal cells, and percentage of cells with more than one aberration compared to controls in both activated and nonactivated cultures at 2900 ppm, 5500 ppm, and above; positive dose-related trends were observed

R-1270 (PROPYLENE)

A. P. Altshuller et al., *Preprints*, American Chemical Society (ACS), Washington, DC, 5(1):183-184, 1965 (2 pages, RDB6A60)

R-1270, health effects, toxicity: irradiated (to induce decomposition) mixture of 1 ppm R-1270 and nitric oxide produced slight eye irritation, increased to moderate with 2-3 ppm R-1270 as reported in RDB6A59

B. Beije (Nordic Expert Group), **Propene**, report 117, *Arbete och Hlsa*, 1995 (36 pages, RDB8427)

toxicity of R-1270: metabolizes to propylene oxide, which binds to hemoglobin and DNA; chronic inhalation of R-1270 on a long-term causes non-neoplastic toxic changes in the nasal cavity of rats, but not of mice; increases the incidence of chronic focal renal inflammation in male mice and of uterine endometrial stromal polyps and, to a lesser extent, hemangiosarcoma and combined hemangioma in female mice; data on the potential health hazard to humans are limited; because the metabolite, propylene oxide, is carcinogenic to experimental animals, it is not possible at the present time to rule out R-1270 as a human carcinogen

A. M. Caine and C. Reynolds (Tulane University of Louisiana), **Electrocardiographic Studies of the Action of Propylene and Some Other Anesthetic Gases**, *Proceedings of the Society of Experimental Biology and Medicine*, New York, 23:488, 1925-1926 (1 page, RDB7739)

R-1270, and others, health effects, toxicity: examination of propylene as a general anesthetic agent

A. Ciliberti, C. Maltoni, and G. Perino (Institute of Oncology F. Addarii, Italy), **Long-Term Carcinogenicity Bioassays on Propylene Administered by Inhalation to Sprague-Dawley Rats and Swiss Mice**, *Annals of the New York Academy of Science*, 534:235-245, 1988 (11 pages, RDB8425)

toxicity of R-1270: tests with Sprague-Dawley rats and Swiss mice by inhalation of 0, 200, 1000 or 5,000 ppm v/v R-1270 in air for 7 hr/d, 5 d/wk; groups of 120 male and 120 female rats (high-dose and controls) or 100 male and 100 female rats (mid- and low-dose) were treated for 104 weeks, and groups of 100 male and 100 female mice (each dose and controls) for 78 weeks; animals were kept under observation until spontaneous death; concludes that R-1270 was not carcinogenic as tested

R. B. Conolly and T. G. Osimitz, **Mixed Function Oxidase System Inducers and Propylene Hepatoxicity**, *The Toxicologist*, 1:406 ff, 1981 (RDB-7741)

acute toxicity tests of R-1270 in rats with concentrations up to 65,000 ppm for 4 hr produced no observable toxic effects, but only the liver was examined — as reported in RDB6A72

E. F. Darley, J. T. Middleton, and M. J. Garber (University of California at Riverside), **Plant Damage and Eye Irritation from Ozone-Hydrocarbon Reactions**, *Journal of Agriculture and Food Chemistry*, 8(6):483-485, 1960 (3 pages with 1 table, RDB6A63)

toxicity tests of R-1270 and others used as fumigants: no appreciable plant damage or eye irritation from propylene-ozone reaction

B. M. Davidson (University of Aberdeen), **Study of Intoxication IV. The Action of Propylene**, *Journal of Pharmacology and Experimental Therapeutics* (JPET), 26:33-36, 1925 (4 pages with 1 figure and 1 table, RDB6A64)

toxicity tests of R-1270 in humans by acute inhalation exposures: inhalation of 64,000 ppm v/v with 26% oxygen for 2¼ minutes yields mild intoxication, parasthesia, and inability to concentrate; the same symptoms are accentuated at 128,000 ppm in 1 minute; unconsciousness results at 240,000 ppm in 3 minutes; concludes that R-1270 is more potent as an anesthetic than acetylene or R-1150 (ethylene) and appears more promising for intended use as an anesthetic

K. Golka, H. Peter, B. Denk, and J. G. Filser (Universität Dortmund, Germany), **Pharmacokinetics of Propylene and its Reactive Metabolite Propylene Oxide in Sprague-Dawley Rats**, *Archives of Toxicology*, 13(supplement):240-242, 1989 (3 pages, RDB8426)

R-1270, health effects, metabolism, toxicity

J. T. Halsey, C. Reynolds, and W. A. Prout (Tulane University of Louisiana), **A Study of the Narcotic Action of Propylene**, *Journal of Pharmacology and Experimental Therapeutics* (JPET), 26:479-490, 1926 (12 pages with 3 tables, RDB-6A65)

toxicity tests of anesthetic and central nervous system (CNS) effects in cats, dogs, mice, and humans: minimal anesthetic dose (MAD) or minimal narcotic dose (MND) is defined as loss of righting reflex; for R-1150, MAD mouse = 850,000-900,000 ppm v/v and the 1-hr approximate lethal concentration (ALC) is inexplicably indicated as 1,400,000-1,460,000 ppm v/v; for a commercial (E. R. Squibb and Sons) preparation of R-1270, indicated as containing an unidentified impurity, MAD = 400,000 ppm v/v and 1-hr ALC = 600,000-650,000 ppm v/v in mice; anesthetic LOEL = 400,000-500,000 ppm v/v and 1-hr ALC = 750,000-800,000 ppm in dogs; effects are similar in cats and dogs; anesthetic effect to the point of unconsciousness in humans at 350,000-400,000 ppm

J. T. Halsey, C. Reynolds, and W. A. Prout (Tulane University of Louisiana), **Anesthetic Properties of Propylene**, *Anesthesia and Analgesia*, 4:195-198, 1925 (4 pages, RDB6A78)

R-1270, anesthetic and central nervous system (CNS) effects, health effects, toxicity

J. T. Halsey, C. Reynolds, and H. B. Cook (Tulane University of Louisiana), **Some Observations on a New Anesthetic Gas**, *New Orleans Medical and Surgical Journal*, 77:29-30, 1924-1925 (2 pages, RDB6A79)

R-1270 and others, anesthetic and central nervous system (CNS) effects, health effects, toxicity

T. J. Hughes, *Environ. Mutagen.*, 6:411-412, 1984 (2 pages, RDB6A66)

R-1270, mutagenic potential, health effects, toxicity: not mutagenic in Salmonella typhimurium as reported in RDB6A59

M. H. Kahn and L. K. Riggs, **Electrocardiographic Studies of the Effects of Propylene as a General Anesthetic in Man**, *Annals of Internal Medicine*, 5:651-658, 1931 (2 pages with 1 figure and 9 tables, RDB6A67)

R-1270, health effects, toxicity: experimental human exposures at 400,000-750,000 ppm v/v caused reddening of the eyelids, flushing of the face, lacrimation, coughing, and sometimes flexing of the legs in a few minutes when used as a general anesthetic; progress of the anesthesia was otherwise gradual and complete in an average of ten breaths

M. A. Lee, R. C. Graham, R. R. Montgomery, G. T. Hall, and L. J. Ver Nooy, untitled toxicity review for propylene, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, 5 January August 1993 (RDB6A59)

R-1270, summary of published and unpublished toxicity literature

D. B. McGregor et al., *Environmental and Molecular Mutagenicity*, 17(2):122-129, 1991 (8 pages, RDB6A69)

R-1270, health effects, mutagenicity, toxicity

K. H. Meyer and H. Hopff, **Theorie der Narkose durch Inhalationsanästhetika. II. Mitteilung. Narkose durch indifferente Gase under Druck** [Theory of Narcosis by Inhaled Anesthetics. II. Announcement. Narcosis by Pressurized Inert Gases] *Zeitschrift für Physiologische Chemie* [Journal of Physiological Chemistry], Germany, 126:280-298, 1923 (19 pages with 1 figure and 8 tables, in German, RDB6A70)

toxicity of R-20 (chloroform), R-40 (methyl chloride), R-50 (methane), R-160B1 (ethyl bromide), R-E170 (dimethyl ether), R-601 (pentane), R-610 (diethyl ether), R-728 (nitrogen), R-744A (nitrous oxide), R-1130 (dichloroethylene, specific isomer not indicated), R-1150 (ethylene), R-1270, acetylene, benzene, carbon disulphide, ether, ethylene oxide, and others

T. G. Osimitz and R. B. Conolly, **Mixed-Function Oxidase System Induction and Propylene Hepatotoxicity**, *Journal of Toxicology and Environmental Health*, 15(1):39-49, 1985 (11 pages, RDB-8424)

toxicity tests of R-1270 in male rats: concludes that R-1270 is hepatoxic to rats based on 4-hr inhalation exposures at 50,000 ppm v/v; liver weight to body weight ratios increased and serum enzyme activities were elevated in rats pretreated with polychlorinated biphenyls (PCB); concludes that PCB pretreatment is a prerequisite for R-1270 hepatotoxicity; cytochrome P-450-dependent bioactivation of R-1270 is associated with this hepatotoxicity, but further studies are needed to characterize the mechanism of the PCB-propene interaction

K. Pernov, *Suvrem Med*, Bulgaria, 30(1):27-31, 1979 (5 pages, in Bulgarian, RDB6A71)

R-1270, health effects, toxicity: irritation as a component of smog

J. A. Quest, J. E. Tomaszewski, J. K. Haseman, G. A. Boorman, J. F. Douglas (National Institute of Environmental Health Sciences), and W. J. Clarke (Battelle Pacific Northwest Laboratories), **Two-Year Inhalation Toxicity Study of Propylene in F344/N Rats and B6C3F$_1$ Mice**, *Toxicology and Applied Pharmacology* (TAP), 76(2):288-295, 1984 (8 pages with 2 tables, Rdb6A72)

chronic inhalation toxicity tests of R-1270 in groups of 50 male and 50 female Charles River F344/N rats and 50 male and 50 female Charles River B6C3F$_1$ mice by whole-body exposures to 0 (control), 5,000, and 10,000 (4,985 and 9,891 actual for rats and 4,999 and 9,957 actual for mice) ppm v/v for 6 h/d, 5 d/wk, for 103 wk: no compound-related clinical signs were observed in rats or mice, though the latter showed 6% reduced body weights during exposures to 10,000 ppm; survival among all groups was similar; increased incidences of nonneoplastic lesions in the nasal cavity; they consisted of epithelial hyperplasia in female rats exposed to 10,000 ppm, squamous metaplasia in female rats exposed to both treatment concentrations, and squamous metaplasia in male rats exposed to 5,000 ppm; inflammatory changes including an influx of lymphocytes, macrophages, and granulocytes into the submucosa and granulocytes into the lumen in male rats at both treatment concentrations; no signs of lesions were found in the mice; no treatment-related increases or decreases in tumor incidence was detected in either the rats or mice or rats; study concludes that chronic inhalation of R-1270 induces nasal cavity toxicity in rats but not mice, but that the chemical is not carcinogenic to either species as tested

L. K. Riggs (E. R. Squibb and Sons), **Further Studies on the Physiologic Action of Propylene**, *Journal of the American Pharmaceutical Association*, 16:635-639, 1925 (5 pages, RDB6A81)

R-1270 and others, anesthetic and central nervous system (CNS) effects, health effects, toxicity: anesthetic effect in white rats at 40,000 ppm v/v as reported in RDB6A59

L. K. Riggs and H. D. Goulden (E. R. Squibb and Sons), **Studies of Physiologic Action of Propylene**, *Anesthesia and Analgesia*, 4:299-307, 1925 (9 pages, RDB6A75)

R-1270, health effects, inhalation toxicity in humans as reported in RDB6A59 and RDB6A67

L. I. Sof'ina, *Tr. Ufim. Nauch.-Issled. Inst. Gigiena i Professional'nye Zabolevaniya*, 5:64-68, 1969 (5 pages in Russian, RDB6A76)

R-1270, health effects, chronic inhalation toxicity in rats

T. S. Sunargulov and E. T. Akhmetova, *Vopr. Reakt. Org. Norme Patol. Mater. Nauchn. Konf.*, 118-120, 1974 (3 pages, RDB6A77)

R-1270, health effects, inhalation toxicity in humans

Properties and Essential Information for Safe Handling and Use of Propylene Chemical Safety Data Sheet SD-59, Manufacturing Chemists Association (MCA), Washington, DC, 1974 (RDB6A68)

R-1270

Propylene, *IARC Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Humans*, International Agency for Research on Cancer (IARC), 60:161-180, 1994 (20 pages, RDB8428)

toxicity of R-1270: data on occupational exposures are limited; no relevant human carcinogenicity data were found; R-1270 was tested by inhalation in two studies each in mice and rats, but two of them were inconclusive; a slight increase in the incidence of vascular tumors was observed in female mice in one study; no treatment-related increase in tumor incidence was observed in a rat study; a metabolism study in rats exposed to 50 ppm, approximately one-sixth of the inhaled material was absorbed of which nearly half was later exhaled unchanged; the remainder was eliminated metabolically, through oxidation to propylene oxide; alkylation products of this metabolite were found in hemoglobin and in DNA from mice exposed to propylene by inhalation; although insufficient data are available to evaluate the genetic and related effects of propylene, the metabolite propylene oxide is genotoxic in a broad range of assays; concludes that R-1270 is not classifiable as to its carcinogenicity to humans (Group 3)

Propylene Toxicity Profile, *BIBRA Toxicology International*, British Industrial Biological Research Association (BIBRA), 1993 (5 pages, RDB8429)

R-1270 vapor is not irritating to the skin, but may be an irritant to the eyes and mucous membranes; the liquified form causes skin and eye burns; inhalation induces rapid anesthesia and other central nervous system (CNS) effects; nasal inflammation and mild kidney injury were observed in chronic inhalation studies in rats and mice, respectively; shorter exposures yielded liver effects in rodents; evidence of carcinogenicity was insufficient in rats or mice, but DNA binding was detected in mice; the results of mutagenicity assays were inconclusive

Toxicity Study Summary: Propylene, Phillips Petroleum Company, Bartlesville, OK, February 1990 (1 page with no figures or tables, RDB7630)

tests of the acute inhalation toxicity in 5 female and 5 male albino, Sprague-Dawley rats by 4 hr, whole body exposures to 7,217 ppm v/v R-1270 (propylene) in air: no deaths resulted, but animals were hyperactive for 5 min after exposure initiation; all animals showed a body weight increase after exposures, but females showed a slight weight decline on days 2-7 postexposure; no other gross signs or symptoms of intoxication are noted, and no gross pathological changes were found at necropsy; concludes that the 4-hr LC_{50} rat is >7,217 ppm v/v; respiratory tract irritancy studies in male mice by head-only exposures to 7,228 ppm v/v R-1270 in air for 1 min, repeated 10 minutes later, while monitored by a plethysmograph: half of the test animals showed decreases in respiratory rates up to 25%; concludes that R-1270 failed to produce upper airway irritancy in mice at 7,228 ppm v/v [implies that RD_{50} exceeds 7,200 ppm]

National Toxicology Program (NTP), **Toxicology and Carcinogenesis Studies of Propylene (CAS No. 115-07-1) in F344/N Rats and B6C3F$_1$ Mice (Inhalation Studies)**, report TR-272 (also identified as NIH publication 88-2528), U.S. Department of Health and Human Services (DHHS), Research Triangle Park, NC, November 1985 (146 pages with 11 figures and 16 tables available from NTIS as document PB86-145521/AS, also available from JMC as RDB7534)

2-yr chronic inhalation toxicity tests of R-1270 in groups of 50 male and 50 female Charles River F344/N rats and 50 male and 50 female Charles River B6C3F$_1$ mice by whole-body exposures to 0 (control), 5,000, or 10,000 (4,985 and 9,891 actual for rats and 4,999 and 9,957 actual for mice) ppm v/v for 6 h/d, 5 d/wk, for 103 wk: report also summarizes 2 wk and 14-wk pilot studies in groups of male and female rats exposed to concentrations of 0 (control), 625, 1,250, 2,500, 5,000, or 10,000 ppm v/v for 6 hr d, 5 d/wk, for 2 or 14 wk; no compound-related clinical signs were observed in rats or mice in the 2-yr study, though the mice showed 6% reduced body weights during exposures to 10,000 ppm; survival among all groups was similar; increased incidences of nonneoplastic lesions in the nasal cavity; they consisted of epithelial hyperplasia in female rats exposed to 10,000 ppm, squamous metaplasia in female rats exposed to both treatment concentrations, and squamous metaplasia in male rats exposed to 5,000 ppm; inflammatory changes including an influx of lymphocytes, macrophages, and granulocytes into the submucosa and granulocytes into the lumen in male rats at both treatment concentrations; no signs of lesions

were found in the mice; no treatment-related increases or decreases in tumor incidence was detected in either the rats or mice or rats; study concludes that chronic inhalation of R-1270 induces nasal cavity toxicity in rats but not mice, but that the chemical is not carcinogenic to either species as tested

R-1316

R. Truhaut, C. Boudene, J. M. Jouany, A. Bouant, **Experimental Study of the Toxicity of a Fluoroalkene Derivative, Hexafluorodichlorobutene (HFCB)**, *Fluoride*, 5:4 ff, 1972 (RDB8181)

R-1316, health effects, toxicity

HEXAFLUOROPROPENE OXIDE (HFPO)

Acute Inhalation Exposure (Six-Hours) of a Dog To Hexafluoropropylene Epoxide (HFPO), Preliminary Report, report EPA/OTS-878220383 TSCATS 019449, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, circa 1987 (RDB8432)

test of the acute inhalation toxicity of hexafluoropropene oxide (HFPO) in a single male beagle dog exposed to 897 ppm v/v (1000 ppm nominal) for 6 hr: animal died within 24 hr following exposure; no irritation was observed during the exposure, but convulsions were noted 10 min post-exposure; gross necropsy revealed severe pulmonary edema, dark red fluid in the pericardial sac, numerous subepicardial and subendocardial petechial and ecchymotic hemorrhages in the heart, scattered subserosal ecchymotic hemorrhages, and dark red kidneys

Acute Inhalation Studies On Hexafluoropropylene Epoxide (CAS 428-59-1), report EPA/OTS-878220381 TSCATS 019447, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, circa 1987 (RDB8430)

tests of the acute inhalation toxicity of hexafluoropropene oxide (HFPO) in groups of 2 male ChR-CH albino rats by exposures to 500 ppm v/v for 4 hr, 1000 ppm for 4 hr, 2,000 ppm for 2½-3 hr, or 4,000 ppm for 1 hr: exposure was lethal to all animals in the 2,000 and 4000 ppm groups; clinical signs were normal; gross necropsy revealed acute pulmonary edema and congestion in decedents, but no treatment-related effects in the survivors; concludes that the 4-hr ALC rat = 2000 ppm v/v

Subacute Inhalation Toxicity (CAS 428-59-1), report EPA/OTS-878220386 TSCATS 019452, Haskell Laboratory for Toxicology and Industrial Medicine, E. I. duPont de Nemours and Company, Incorporated, Newark, DE, circa 1987 (RDB8433)

test of the subchronic inhalation toxicity of hexafluoropropene oxide (HFPO) in 4 male ChR-CD rats exposed to 400 ppm v/v nominal for 4 hr/d for 10 exposures: there were no mortalities; clinical observations included deep respiration and inactivity; necropsy revealed no gross or microscopic effects

APPENDIX 5: BACKGROUND PAPER

J. M. Calm (Engineering Consultant), **The Toxicity of Refrigerants**, *Proceedings of the 1996 International Refrigeration Conference at Purdue* (23-26 July 1996), edited by J. E. Braun and E. A. Groll, Purdue University, West Lafayette, IN, 157-162, July 1996; republished as report DOE/CE/23810-72E, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, 1996 (RDB6832)

This paper presents toxicity data and exposure limits for refrigerants. The data address both acute (short-term, single exposure) and chronic (long-term, repeated exposure) effects, with emphasis on the former. The refrigerants covered include those in common use for the last decade, those used as components in alternatives, and selected candidates for future replacements. Specifically addressed are R-11, R-12, R-22, R-23, R-32, R-113, R-114, R-115, R-116, R-123, R-124, R-125, R-134a, R-141b, R-142b, R-143a, R-152a, R-218, R-290, R-C318, R-600, R-600a, R-717, R-744, and R-1270. The paper also reviews the toxicity indicators used in both safety standards and building, mechanical, and fire codes. Data are tabulated for the LC_{50}, cardiac sensitization NOEL and LOEL, anesthetic/CNS EC_{50}, respiratory RD_{50}, IDLH (both from the Standards Completion Program and from the 1994 revisions), PEL, UL group, and Standard 34 safety classifications. The paper outlines current classification methods for refrigerant safety and relates them to standard and code usage.

THE TOXICITY OF REFRIGERANTS

James M. Calm, P.E.
Engineering Consultant
10887 Woodleaf Lane
Great Falls, VA 22066-3003 USA

This paper presents toxicity data and exposure limits for refrigerants. The data address both acute (short-term, single exposure) and chronic (long-term, repeated exposure) effects, with emphasis on the former. The refrigerants covered include those in common use for the last decade, those used as components in alternatives, and selected candidates for future replacements. The paper also reviews the toxicity indicators used in both safety standards and building, mechanical, and fire codes. It then outlines current classification methods for refrigerant safety and relates them to standard and code usage.

INTRODUCTION

Most of the dominant refrigerants for the past fifty years have been or are being replaced, to protect the stratospheric ozone layer or as a precaution to address global warming. Much to the credit of the air-conditioning and refrigeration industry, both chemical and equipment manufacturers have resisted compromise to either safety or performance in developing replacements. None of the alternative refrigerants that have been commercialized are highly toxic or even toxic, as classified by federal regulations.[1] Scrutiny of the new refrigerants shows them to be as safe or safer than those they replace.[2] Still, safety concerns have surfaced as significant factors in regulations for the new refrigerants. These concerns do not arise from increased hazard levels, but from lack of familiarity and necessary information. The rapid phaseout schedule for chlorofluorocarbon refrigerants required introduction of new chemicals before complete data were available.

Most of the early refrigerants — before the 1930s — were flammable, toxic, or both. The advent of fluorochemicals ushered in a new era of safety, as illustrated by the dramatic demonstration by Thomas Midgley in April 1930.[3] In announcing the development of fluorochemicals to the American Chemical Society, he inhaled R-12 and blew out a candle with it. Although this dramatic performance suggested that the new refrigerant was neither toxic nor flammable, it would clearly violate current safety practices.

As subsequent testing established the low toxicity of the new refrigerants, recognition evolved that the primary safety risks were the pressure hazards inherent to any compressed gas, asphyxiation from possible displacement of air, and frostbite with skin contact at low temperatures. These concerns were, however, common to the volatile compounds used before fluorochemicals. As the level of safety improved, so did expectations. Rules evolved to also address acute exposure hazards under emergency conditions, for example potential decomposition in fires into carbonyl halides as well as hydrochloric and hydrofluoric acids. Likewise, safety provisions also addressed the potential for cardiac sensitization and the effects of chronic exposures for both technicians and building occupants. The resulting regulations restricted the use of refrigerants, set quantity limits in occupied areas, imposed isolation requirements for refrigerant-containing components and machinery rooms, and prescribed a range of detection, ventilation, pressure relief, emergency discharge, and other safety provisions.

More recent focus on the effects of refrigerants on the environment spawned two significant safety measures, namely system tightening and modification of service practices to reduce venting. While their motivation was environmental protection, to curtail avoidable emissions, the result also lowers the likelihood and concentrations of refrigerant exposures.

CODE ACCEPTANCE OF ALTERNATIVE REFRIGERANTS

International treaties, most noticeably the Montreal Protocol and Framework Convention on Climate Change, have focused on the global issues of environmental protection, information sharing, and assistance to developing countries. These treaties, and revisions to them, have fostered scientific assessments and set phaseout schedules for substances of concern. While federal laws govern the production and trade of alternative chemicals, most ordinances for application of refrigerants are adopted and enforced at the local level. They are included in building, mechanical, and fire safety codes, which govern building construction, system installation, equipment operation and maintenance, system modification including refrigerant conversion, and ultimate demolition. Although most are based on national or regional model codes, the introduction of alternative refrigerants occurred so rapidly that the cautious process of regulatory revision has not caught up yet. One cause of delay has been the time needed to complete toxicity tests, publish the findings, modify impacted standards, develop and adopt code revisions, and prepare design professionals, contractors, technicians, and building and fire prevention officials.

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Toxicity Testing

Facing unprecedented testing and phaseout requirements, the chemical industry formed an international consortium to accelerate the development of toxicology data for substitute fluorocarbons, both for refrigerant and other uses. The cooperative effort, named the Programme for Alternative Fluorocarbon Toxicity Testing (PAFT), was sponsored by the major producers of chlorofluorocarbons (CFCs). The PAFT research entailed more than 200 individual toxicology tests, by more than a dozen laboratories in Europe, Japan, and the United States. The first tests were launched in 1987, to address R-123 and R-134a (PAFT I). Subsequent programs were initiated for R-141b (PAFT II), R-124 and R-125 (PAFT III), R-225ca and R-225cb (PAFT IV), R-32 (PAFT V), and — still underway — the mechanistic, metabolic, and pharmacokinetic aspects of the toxicology of fluorocarbons.[4,5] Extensive additional data were developed, or contributed from prior tests, by individual chemical manufacturers.

The tasks of assembling and interpreting the resultant data were expanded by the need, in some cases, to collect comparative information for the refrigerants being replaced. Whereas their introduction largely preceded the more rigorous, current testing and classification requirements of the codes, the amount of information needed was significant.

Safety Standards

Most code provisions for refrigerant and refrigeration-system safety can be traced to either ASHRAE Standard 15, *Safety Code for Mechanical Refrigeration*,[6] or to general code provisions developed for occupancies where more hazardous materials are used. Standard 15 prescribes safeguards for design, construction, installation, and operation of refrigerating systems.[7,8] Many of the specific requirements are based on safety classifications from Standard 34, *Designation and Safety Classification of Refrigerants*.[9,10] This standard is the definitive source for assignment of refrigerant number designations. It also provides a safety classification system and assigned classifications.

An effort is underway, by the committees responsible for the two standards, to move determination of data needed for Standard 15 into Standard 34, and to rewrite the application requirements in Standard 15 parametrically, based on the referenced data. In doing so, the committees are refining the methods to determine refrigerant quantity limits for occupied areas, both to increase consistency and to take advantage of the new data and understanding. They also are addressing the toxicity, flammability, and fractionation concerns arising from use of zeotropic and azeotropic refrigerant blends.

Parameters

Building, fire, and mechanical codes vary throughout the United States. They are based on state or local amendments to regional model codes or, in a few locations, locally-developed codes. Nevertheless, the data needed for compliance are fairly consistent. They include:

LC_{50}: The "lethal concentration for 50% of tested animals," sometimes referred to as the *median lethal concentration*, is a primary measure of acute toxicity by inhalation of gases. It most commonly is measured with rats for exposures of four hours. A number of federal regulations (e.g., reference 1) and most building, fire, and mechanical codes deem substances to be toxic for one-hour LC_{50} concentrations of 200 - 2 000 ppm and highly toxic for less than 200 ppm.* Typical LC_{50} concentrations for one hour are double those for four hours.[11,12] Multipliers of 1.6-4 have been suggested,[13,14] and one study found a range of 1.5-5.7 for 20 tested chemicals.[15] None of the refrigerants identified in table 1, or blends of them, qualify as toxic or highly toxic based on the LC_{50} data and the stated criteria.

IDLH: The concentration deemed to be "immediately dangerous to life and health," set by the National Institute for Occupational Safety and Health (NIOSH). This measure was initially developed as a criterion for respirator selection in the 1970s as part of the Standards Completion Program (SCP). The SCP definition for IDLH was "the maximum concentration from which, in the event of a respirator failure, one could escape within 30 minutes without a respirator and without experiencing any escape-impairing (e.g., severe eye irritation) or irreversible health effects." The 1994 revision defines an IDLH condition as one "that poses a threat of exposure to airborne contaminants when that exposure is likely to cause death or immediate or delayed permanent adverse health effects or prevent escape from such an environment." The revised and added IDLHs in 1994 are based on additional toxicity criteria and data. Whereas the IDLHs derived for the SCP were set at

* The definitions for *toxic* and *highly toxic* also include LD_{50} (median lethal dosage) criteria for mortality by ingestion and contact. LD_{50} values generally are not determined for or applicable to gases and volatile substances, such as refrigerants, since the standard test methods are not suited for them. Similarly, the likelihood of ingestion of or prolonged contact with the quantities involved is remote. Some LD_{50} data, mostly based on solutions of refrigerants in liquids, are provided in reference 20.

100% of the lower-flammability limit (LFL), if there were no known health hazards below those concentrations, the 1994 IDLHs are reduced to 10% of the LFL. Most fire codes use the IDLH, based on the SCP definition, as a criterion for ventilation rates and emergency discharge treatment. Standard 15 also uses the SCP IDLH as one of several criteria to determine refrigerant quantity limits for occupied areas. Use of the IDLH concentrations for these purposes has been challenged as inconsistent with their definition.

PEL: The "permissible exposure limit" is the concentration level established by the Occupational Safety and Health Administration (OSHA). Without qualification, the PEL implies a time weighted average (TWA) for an 8-hour work shift in a 40-hour work week. Consistent data include similarly-defined occupational exposure limits set by manufacturers (such as the Allowable Exposure Limit, AEL), the Threshold Limit Value (TLV) adopted by the American Conference of Governmental Industrial Hygienists (ACGIH),[16] and the Workplace Environmental Exposure Level (WEEL) guides developed by the American Industrial Hygiene Association (AIHA).[17] Where designated as a PEL-C (e.g., for R-11), the PEL is a ceiling concentration that shall not be exceeded. Most codes use either PEL or TLV-TWA values as the maximum activation levels for leak-detector alarms; Standard 15 and the new International Mechanical Code (IMC) use the TLV-TWA. While the PEL and TLV-TWA are similarly defined, and the original PELs were based on TLVs, the PEL values have not been revised since 1971. More protective limits published in 1989 were vacated by a court order in 1992. ACGIH publishes annual TLV updates. Still, neither PELs nor TLVs have been set for most alternative refrigerants, for which the primary recourse is use of WEELs or other consistent measures.

UL group: The Underwriters Laboratories classification reflects the comparative life hazard of refrigerants in the absence of flames or surfaces at high temperatures. Group 1 is the most toxic (e.g., R-764) and group 6 the least.[18] This measure is used to classify refrigerants in older codes, still in effect in some jurisdictions.

Standard 34 safety group: This classification consists of a letter (A or B), which indicates the toxicity class, followed by a number (1, 2, or 3), which indicates the flammability class. Toxicity classes A and B signify refrigerants with *lower toxicity* and *higher toxicity*, respectively, based on prescribed measures of chronic (long-term, repeated exposures) toxicity. Flammability class 1 indicates refrigerants that do not show flame propagation in air when tested by prescribed methods at specified conditions. Classes 2 and 3 signify refrigerants with *lower flammability* and *higher flammability*, respectively; the distinction depends on both the LFL and heat of combustion (HOC). Some of the mechanical codes written before 1993 used an older safety classification system from earlier editions of Standard 34. They included groups 1 (no flame propagation and low degree of toxicity), 2 (TLV-TWA less than 400 ppm), 3a (flammable with low LFL or high HOC), 3b (flammable with high LFL and low HOC), 4a (mixtures of groups 1 and 3a that are nonflammable as formulated, but could become flammable upon fractionation), and 4b (mixtures of groups 1 and 3b that are nonflammable as formulated, but could become flammable upon fractionation). Excluding the group 2 refrigerants, the ranked order from the lowest to highest flammability hazard was 1, 4b, 4a, 3b, and 3a. One motive for the current classification system, introduced in 1992, was to provide a more rational system. Based on current understanding and usage, however, the author questions whether two toxicity classes provide sufficient distinction and whether the classification criterion should be a measure of acute, rather than chronic, toxicity or a combination of acute and chronic toxicity.

quantity limits for occupied areas: The primary criterion to determine whether refrigeration systems, or refrigerant-containing components, are allowed in occupied areas of buildings are quantity limits set by the codes or Standard 15. Nearly all limits set in the codes were transcribed from Standard 15, though a few intended and unintended revisions were made in the process.

As discussed above, efforts are underway to develop consensus quantity limits for new refrigerants, including blends. The following additional data are likely to be needed:

cardiac sensitization: An acute effect in which the heart is rendered more sensitive to the body's own catecholamine compounds or administered drugs, such as epinephrine, possibly resulting in irregular heart beat (cardiac arrhythmia), which could be fatal.[10] *LOEL* is the "lowest-observed effect level," the lowest concentration at which sensitization occurs in tests, normally to beagle dogs treated with epinephrine to simulate the effects of stress. *NOEL* is the "no-observed effect level," the highest exposure concentration at which no sensitization is observed.

anesthetic EC_{50}: The concentration of a substance that caused the temporary loss of ability to perceive pain and other sensory stimulation to 50% of test animals, normally measured for 10 minute exposures. EC_{50} refers to the "effective concentration for 50% of specimens."

RD_{50}: The concentration that resulted in 50% decrease in respiratory rate, normally measured in mice. A maximal effect generally occurs in less than 30 minutes; the response to R-717 (ammonia), as an example, is reported to take approximately two minutes.

Table 1: Refrigerant Toxicity Data, Exposure Limits, and Classifications [a] (data and limits in ppm v/v)

refrigerant [b]	LC_{50} [c]	cardiac sensitization [d] LOEL	cardiac sensitization [d] NOEL	anesthetic EC_{50} [e]	RD_{50} [f]	IDLH [g] SCP	IDLH [g] 1994	PEL [h]	UL [i] group	safety group [b]
11	26 200	5 000	1 100	35 000	--	5 000 [j]	2 000	C1 000 [j]	5(a)	A1
12	>800 000	50 000	25 000	250 000	--	50 000	15 000	1 000	6	A1
22	220 000	50 000	25 000	140 000	--	50 000 [k]	--	1 000 [l]	5(a)	A1
23	>663 000	>800 000	300 000	186 000 [m]	--	--	--	1 000 [k]	6 [k]	A1
32	>760 000 [n]	250 000	200 000	86 000 [m]	--	--	--	1 000 [p]	--	A2
113	52 000 [n]	5 000	2 500	28 000	--	4 500	2 000	1 000	4-5	A1
114	>600 000 [o]	25 000	--	250 000	--	50 000	15 000	1 000	6	A1
115	>800 000 [n]	150 000	--	28 000 [m]	--	--	--	1 000 [l]	6	A1
116	>800 000 [n]	[q]	200 000	800 000 [m]	--	--	--	1 000 [k]	6 [k]	A1
123	32 000	20 000	10 300	40 000	--	4 000 [k]	--	10-30 [k]	--	B1
124	262 500	25 000	10 000	140 000	--	--	--	1 000 [p]	6	A1
125	>800 000 [n]	100 000	75 000	>10 000 [m]	--	--	--	1 000 [p]	--	A1
134a	567 000 [n]	75 000	50 000	205 000 [m]	--	50 000 [k]	--	1 000 [p]	--	A1
141b	61 647	5 000	2 500	25 000	--	--	--	500 [p]	--	--
142b	128 000 [n]	50 000	25 000	250 000	--	--	--	1 000 [p]	--	A2
143a	>540 000 [n]	300 000	250 000	>540 000 [m]	--	--	--	1 000 [p]	--	A2
152a	383 000 [n]	150 000	50 000	200 000	--	--	--	1 000 [p]	--	A2
218	>800 000 [o]	400 000	300 000	>113 000 [m]	--	--	--	1 000 [p]	--	A1
290	>800 000 [o]	100 000	50 000	280 000	--	20 000 [r]	2 100	1 000	5(b)	A3
C318	>800 000	100 000	--	>600 000 [m]	--	--	--	--	6 [k]	A1
600	280 000	5 000	--	130 000	--	--	--	800 [l]	5(b)	A3
600a	570 000 [o]	50 000	25 000	200 000 [s]	--	--	--	600 [k]	5(b)	A3
717	2 000 [t]	--	--	--	303	500	300	50 [u]	2	B2
744	[v]	--	--	--	--	50 000	40 000	5 000	5(a)	A1
1270	650 000 [w]	100 000	--	400 000	--	--	--	1 000 [k]	--	A3

[a] Please see the source publications (identified in reference 20) to verify these data and examine their limitations.[9,10]

[b] from ANSI/ASHRAE Standard 34-1992 and addenda thereto

[c] 4-hr LC_{50} rat; federal and fire code toxicity classifications are based on a 1-hr LC_{50} rat

[d] dog with epinephrine challenge

[e] 10-min EC_{50} mouse or rat

[f] 30-min RD_{50} mouse

[g] NIOSH IDLH values from the Standards Completion Program (SCP) and 1994 revision[13]

[h] time-weighted average (TWA) for 8 hr/day and 40 hr/wk

[i] comparative life hazard where group 1 is the most toxic and group 6 the least

[j] The SCP IDLH and OSHA PEL are 10 000 and 1 000 ppm, respectively; ARI recommends 5 000 and C1 000 ppm based on the cardiac sensitization potential.[19]

[k] industry or manufacturer recommendation

[l] ACGIH Threshold Limit Value - Time-Weighted Average (TLV-TWA)[16]

[m] anesthetic effects observed in rats at this concentration during ALC, LC_{50}, or other studies

[n] 4-hr Approximate Lethal Concentration (ALC) rat

[o] 2-hr LC_{50} rat for R-114; 1-hr ALC rat for R-218; and 15-min LC_{50} rat for R-290 and R-600a

[p] AIHA Workplace Environmental Exposure Limit (WEEL)[17]

[q] response observed at 200 000 ppm in anesthetized dogs using tracheal cannulae (intubation); no effect found at 600 000 ppm, in a separate study, by simple inhalation

[r] based on the lower flammability limit (LFL)

[s] 17-min EC_{50} mouse

[t] wide dispersion found in the literature: 6 586 - 19 671 for 1 hr and 2 000 - 4 067 for 4 hr

[u] ACGIH Threshold Limit Value - Time-Weighted Average (TLV-TWA) = 25 ppm

[v] 5-min LC_{L0} human = 90 000 ppm

[w] 2-hr ALC rat (4-hr ALC rat ≈ 460,000 ppm using the conversion from reference 11)

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Working drafts of the proposed method to determine quantity limits, identified as Recommended Quantity Limits (RQLs), use the preceding acute-toxicity data to determine an intermediate limit, identified as the Acute Toxicity Exposure Limit (ATEL). The RQL is then set at the lowest of the ATEL, the oxygen deprivation level (ODL, the calculated concentration that will reduce the oxygen concentration in normal air to below 19½% by volume) of 69 100 ppm, and 25% of the LFL. One proposal to establish RQLs for blends uses the same calculation method as for single compounds, after determining a mole-weighted average for each parameter based on the values for the blend components.

Findings

Table 1 summarizes data for common, single-compound refrigerants. The quantity limits for occupied areas are not included, since the calculation method still is being revised. Those limits and corresponding data and limits for blends will be presented in a subsequent paper.

Multiple values were located for approximately half of the data in the table. In general, those shown are the most conservative found in the published literature, except that the highest published concentrations are included for no-effect levels and where a study found a lower bound to, but did not actually establish, an end point. Space limitations in this paper prevent inclusion of the more than 200 pertinent references from which the data in table 1 were obtained. Specific or multiple corroborating sources and additional data are identified in reference 20.

Comparison of the acute-toxicity data for R-123 to those for R-11 show it to be as safe, or safer, with respect to acute toxicity. The same conclusion results from comparison of the data for R-134a to those for R-12. An earlier paper showed that chronic exposures can be maintained well below recommended limits.[2]

Another point that is evident with the assembled data is that the hydrocarbons proposed as replacements for fluorochemicals are generally more toxic. The LC_{50} values for R-32, R-125, R-134a, R-290 (propane), R-600 (butane), R-600a (isobutane), and R-1270 (propene) all indicate very low acute toxicity. The cardiac sensitization and anesthetic effect indicators, however, suggest that R-600 and R-600a pose higher risks than R-134a and that the inhalation lethality of R-1270, while very low, is higher than for either R-32 or R-125. Although not addressed herein, these hydrocarbons also introduce much higher explosivity, flammability, and heat release concerns.

The compiled data result from a fairly extensive data search. Two caveats accompany the data presented. First, the table constitutes a work in progress, to provide data for interim use. Some of the values may be superseded as further information is located or new data become available. Second, users must satisfy themselves with the suitability and appropriateness of the data for specific uses. The data or resultant determinations also must be approved by the code official having jurisdiction where required. While care has been taken in assembly of the data, the effort cannot be viewed as exhaustive and no attempt was made to verify the data. They are intended for use by knowledgeable professionals, and offered without warranty of any kind.

Additional Data Sources

Other sources for the data include the PAFT summaries[5] published scientific literature, manufacturers, and material safety data sheets. A number of databases are available to assist in finding the data, among them the Chemical Abstract Service (CAS), Hazardous Substances Data Base (HSDB), and Registry of Toxic Effects of Chemical Substances (RTECS). Additional sources, including a number of compilations, are identified in reference 20.

CONCLUSIONS

The toxicity data presented herein provide an interim means to address code requirements for use of alternative refrigerants, subject to the caveats indicated. These data also may be useful to evaluate proposed changes to safety standards for refrigerants and refrigeration. While the data show the alternative refrigerants to be of comparable or lower toxicity than those they replace, and especially so for acute effects, safe use depends on adherence to proper application, handling, and service procedures.

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REFERENCES

1 Occupational Safety and Health Administration (OSHA), U.S. Department of Labor, *Health Hazard Definitions* in **Air Contaminants**, 29 CFR §1910.1200, Appendix A, Government Printing Office, Washington, DC, 1 July 1995

2 J. M. Calm, *Refrigerant Safety*, **ASHRAE Journal**, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, **36**(7):17-26, July 1994

3 R. C. Downing, *Fluorocarbon Refrigerants Handbook*, Prentice Hall, Englewood Cliffs, NJ, 1988

4 *Programme for Alternative Fluorocarbon Toxicity Testing (PAFT)*, program description, PAFT, Washington, DC, September 1995

5 *Programme for Alternative Fluorocarbon Toxicity Testing (PAFT) Toxicology Summaries*, PAFT, Washington, DC, September 1995: The full texts of these summaries are included in reference 20.

6 *Safety Code for Mechanical Refrigeration*, ASHRAE Standard 15-1994, ASHRAE, August 1994

7 L. W. Burgett, *Revised Standards for Mechanical Refrigeration*, **ASHRAE Journal**, ASHRAE, **35**(8):31-35, August 1993

8 T. E. Watson, *ASHRAE Standards and Alternative Refrigerants*, paper 7.4, **Proceedings of the International Symposium on R22 & R502 Alternative Refrigerants**, Japan Refrigeration and Air-Conditioning Industry Association (JRAIA), Tokyo, Japan, 187-192, December 1994

9 *Number Designation and Safety Classification of Refrigerants*, ANSI/ASHRAE Standard 34-1992, ASHRAE, February 1992

10 *Addenda to Number Designation and Safety Classification of Refrigerants*, ANSI/ASHRAE 34a-o and 34q-s, ASHRAE, 1995. Additional addenda are in publication or under review.

11 *Uniform Fire Code*, International Fire Code Institute (IFCI), Whittier, CA, appendix VI-A, table A-VI-A-1, page 460, 1994, as amended by the *Accumulative Supplement to the Uniform Fire Code*, International Conference of Building Officials (ICBO), Whittier, CA, page 291, 1996

12 *Class 6.1 — Poisons*, **International Maritime Dangerous Goods Code**, International Maritime Organization, London, §2.1.5.2.2, page 6007, 1986

13 H. R. Ludwig, S. G. Cairelli, and J. J. Whalen, *Documentation for Immediately Dangerous to Life or Health Concentrations (IDLHs)*, National Institute for Occupational Safety and Health (NIOSH), U.S. Department of Health and Human Services, Cincinnati, OH, pages 5-6, May 1994

14 Haber's law, a tenet of toxicology, states that different concentrations have the same lethal effect when the product of the exposure concentration and duration — for small differences in time — is constant. Application to the example discussed yields a factor of four (see references 13, 15, and 17).

15 W. F. ten Berge, A. Zwart, and L. M. Appelman, *Concentration-Time Mortality Response Relationship of Irritant and Systematically Acting Vapours and Gases, Journal of Hazardous Materials*, Elsevier Science Publishers B.V., Amsterdam, The Netherlands, volume 13, pages 301-309, 1986: The range cited herein was calculated with correlations from this reference.

16 *1995-1996 Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*, American Conference of Governmental Industrial Hygienists (ACGIH), Cincinnati, OH, 1995

17 *The AIHA 1996 Emergency Response Planning Guidelines and Workplace Environmental Exposure Level Guides Handbook*, American Industrial Hygiene Association (AIHA), Fairfax, VA, 1996

18 A. H. Nuckolls, *The Comparative Life, Fire, and Explosion Hazards of Common Refrigerants*, Miscellaneous Hazard Report Number 2375, Underwriters' Laboratories Incorporated, Chicago, IL, pages 106-107, 13 November 1933

19 *Refrigerant Safety Data — Recommendations of the Air-Conditioning and Refrigeration Industry*, Air-Conditioning and Refrigeration Institute (ARI), Arlington, VA, October 1993

20 J. M. Calm, *ARTI Refrigerant Data*base, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, April 1996 (updated quarterly, see http://www.ari.org on the Internet for database information)