International Journal of Toxicology
2024, Vol. 43(Supplement 2) 70S–131S

DOI: 10.1177/10915818231224234
journals.sagepub.com/home/ijt
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Safety Assessment of Alkane Diols as Used in Cosmetics

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Abstract

The Expert Panel for Cosmetic Ingredient Safety (Panel) assessed the safety of 10 alkane diol ingredients as used in cosmetics. The alkane diols are structurally related to each other as small diols, and most are reported to function in cosmetics as solvents. The Panel reviewed the relevant data for these ingredients, and concluded that seven alkane diols are safe in cosmetics in the present practices of use and concentration described in this safety assessment, but that the available data are insufficient to make a determination of safety for three ingredients, namely 1,4-Butanediol, 2,3-Butanediol, and Octanediol.

Keywords

Cosmetics, Safety, Propanediol (1,3-propanediol), 1,4-Butanediol, 2,3-Butanediol, 1,5-Pentanediol, Hexanediol (1,6-hexanediol), Octanediol (1,8-octanediol), 1,10-Decanediol, Methylpropanediol (2-methyl-1,3-propanediol), Butyl Ethyl Propanediol (2-butyl-2-ethyl-1,3-propanediol), Isopentyldiol (3-methyl-1,3-butanediol)

Introduction

This assessment is a review of the safety of the 10 alkane diols listed below (with systematic nomenclature in parenthesis when different from the ingredient name) as used in cosmetic formulations:

Propanediol (1,3-propanediol)	Octanediol (1,8-octanediol)
1,4-Butanediol	1,10-Decanediol
2,3-Butanediol	Methylpropanediol (2-methyl-1,3-propanediol)
1,5-Pentanediol	Butyl Ethyl Propanediol (2-butyl-2-ethyl-1,3-propanediol)
Hexanediol (1,6-hexanediol)	Isopentyldiol (3-methyl-1,3-butanediol)

The alkane diols reviewed in this safety assessment have various reported functions in cosmetics (Table 1), as indicated in the web-based *International Cosmetic Ingredient Dictionary and Handbook* (wINCI; *Dictionary*). Most of the alkane diols are reported to function in cosmetics as solvents, but other reported functions include humectants, skin conditioning agents, plasticizers, fragrance ingredients, and viscosity decreasing agents.[1,2] Propanediol, for example, is used as a solvent and viscosity decreasing agent; Butyl Ethyl Propanediol is used as a skin-conditioning agent and humectant.

The alkane diol ingredients in this report are structurally related to each other as small diols. Diols with 1,2-substitution regiochemistry (e.g., 1,2-Butanediol) have been reviewed previously by the Panel, and the conclusion for each is summarized in Table 2.[3-11] Almost all of these previously-reviewed diols were assessed to be safe as used; Propylene Glycol (aka 1,2-propanediol) was deemed to be safe as used when formulated to be non-irritating. Please see the original reports for further details (https://www.cir-safety.org/ingredients).

This safety assessment includes relevant published and unpublished data that are available for each endpoint that is evaluated. Published data are identified by conducting an

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Table 1. Definitions, Structures, and Functions of the Ingredients in This Safety Assessment.[1;CIR Staff]

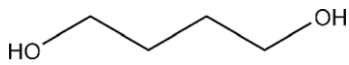
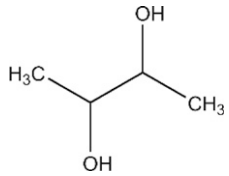
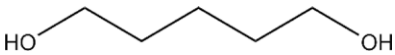
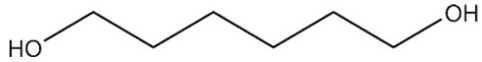
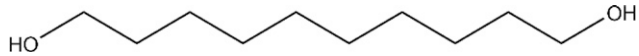
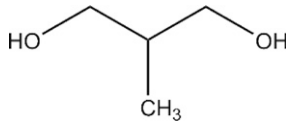
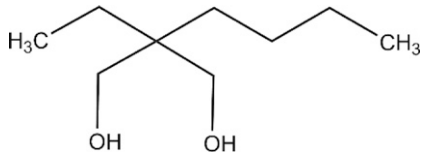
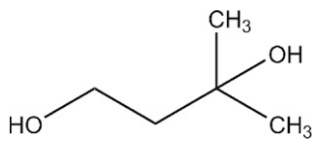
Ingredient Name & CAS No.	Definition & Structure	Function
Propanediol 504-63-2	Propanediol is the organic compound that conforms to the structure: 	Solvent; Viscosity Decreasing Agent
1,4-Butanediol 110-63-4	1,4-Butanediol is the organic compound that conforms to the structure: 	Solvent
2,3-Butanediol 513-85-9	2,3-Butanediol is the organic compound that conforms to the structure: 	Fragrance Ingredient; Humectant; Skin-Conditioning Agent-Humectant; Solvent
1,5-Pentanediol 111-29-5	1,5-Pentanediol is the organic compound that conforms to the structure: 	Solvent
Hexanediol 629-11-8	Hexanediol is the organic compound that conforms to the structure: 	Solvent
Octanediol 629-41-4	Octanediol is the organic compound that conforms to the structure: 	Plasticizer
1,10-Decanediol 112-47-0	1,10-Decanediol is the organic compound that conforms to the structure: 	Solvent
Methylpropanediol 2163-42-0	Methylpropanediol is the organic compound that conforms to the structure: 	Solvent
Butyl Ethyl Propanediol 115-84-4	Butyl Ethyl Propanediol is the organic compound that conforms to the structure: 	Skin-Conditioning Agent; Humectant
Isopentyldiol 2568-33-4	Isopentyldiol is the diol that conforms to the structure: 	Solvent

Table 2. Aliphatic Diols and Constituent Acids Previously Reviewed by the Panel.

Ingredient	Conclusion (Year Issued)[a]	Reference
1,2-ALKANE DIOLS (aliphatic diols)		
Propylene Glycol (1,2-propanediol)	Safe as used when formulated to be non-irritating (2012)	1,3,5
1,2-Butanediol	Safe as used (2012)	4
Pentylene Glycol (1,2-pentanediol)	Safe as used (2012)	4
1,2-Hexanediol	Safe as used (2012)	4
Caprylyl Glycol (1,2-octanediol)	Safe as used (2012)	4
Decylene Glycol (1,2-decanediol)	Safe as used (2012)	3,4
OTHER ALIPHATIC DIOLS		
Butylene Glycol (1,3-butanediol)	Safe as used (1985); reaffirmed in 2006	8,9
Ethyl Hexanediol (2-ethyl-1,3-hexanediol)	Safe as used (1994); reaffirmed in 2011	7,8
Hexylene Glycol (2-methyl-2,4-pentanediol)	Safe as used (1985); reaffirmed in 2006	8,9
SYNTHETIC STARTING MATERIALS		
Maleic Acid (sometimes used in the synthesis of 1,4-Butanediol)	Safe for use in cosmetic formulations as a pH adjuster (2007)	10
Succinic Acid (sometimes used in the synthesis of 1,4-Butanediol)	Safe as used (2012)	11

[a]Please see the original reports for further details (www.cir-saftey.org/ingredients).

exhaustive search of the world's literature. A listing of the search engines and websites that are used and the sources that are typically explored, as well as the endpoints that the Panel typically evaluates, is provided on the Cosmetic Ingredient Review (CIR) website (https://www.cir-safety.org/supplementaldoc/preliminary-search-engines-and-websites; https://www.cir-safety.org/supplementaldoc/cir-report-format-outline). Unpublished data are provided by the cosmetics industry, as well as by other interested parties.

The European Chemicals Agency (ECHA)[12-17] website and the Australian Government Department of Health National Industrial Chemicals Notification and Assessment Scheme (NICNAS)[18-20] website provide summaries of data generated by industry, and ECHA and NICNAS are cited as the sources of the summary data in this safety assessment as appropriate. Also referenced in this safety assessment are summary data found in reports published by the World Health Organization (WHO),[21] the Organization for Economic Cooperation and Development Screening Information Data Sets (OECD SIDS),[22] and in reports made publicly available by the United States (US) Food and Drug Administration (FDA),[23-27] the US Environmental Protection Agency (EPA),[2,28-32] and through the National Technical Information Service (NTIS).[33-37]

Chemistry

Definition and Structure

All of the ingredients in this report are structurally related to each other as small diols (i.e., three to ten carbon alkyl diols). The ingredients in this report include regiochemistry other than 1,2-substitution. For example, 2,3-Butanediol is a vicinal diol with the first hydroxyl substitution at the 2-position and 1,4-Butanediol is a terminal diol with substitution at the 1- and 4-positions (Figure 1).

Variations in the regiochemistry of small alkane diols may lead to significant differences in toxicity. For example, 2,5-hexanediol, which is not a cosmetic ingredient, is known to be a neurotoxic metabolite of hexane.[38,39] However, the structurally similar cosmetic ingredient, Hexanediol (i.e., 1,6-hexanediol), is not a neurotoxin.

Physical and Chemical Properties

Alkane diols can be liquids or crystalline solids. Some are soluble in alcohol (Table 3). All of the terminal diols are soluble or somewhat soluble in water, except for the longest chain ingredient, 1,10-Decanediol, which is nearly insoluble in water. The branched alkane diols among these ingredients are very soluble in water, with the exception that Butyl Ethyl Propanediol (C9) is only slightly soluble.

Method of Manufacture

Propanediol. Propanediol may be prepared by fermentation from corn-derived glucose using a biocatalyst (non-pathogenic strain of *Escherichia coli* K-12).[40] Propanediol can also be manufactured by heating γ,γ-dihydroxydipropyl ether with hydrobromic acid, followed by hydrolysis with sodium hydroxide. It is also reported to be obtained from plants that produce glycerol.[37]

1,4-Butanediol. Some industrial chemical companies manufacture 1,4-Butanediol using cupric acetylide catalysts in the condensation reaction of acetylene with formaldehyde.[37] Some manufacturers convert propylene oxide to allyl

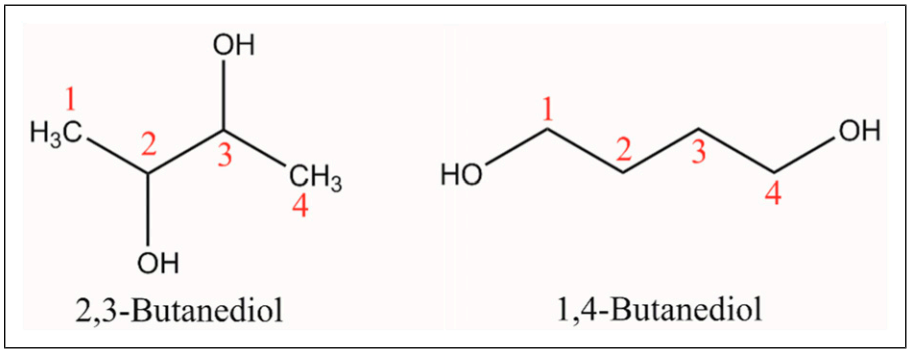


Figure 1. 2,3-Butanediol and 1,4-Butanediol.

alcohol, which is then hydroformylated to 4-hydroxybutyraldehyde, followed by reduction to the diol via hydrogenation.[21] Maleic acid and succinic acid can be used to manufacture 1,4-Butanediol via vapor phase hydrogenation of their corresponding esters and anhydrides. *E. coli* can be genetically engineered to metabolize sugar to 1,4-Butanediol.[41]

2,3-Butanediol. 2,3-Butanediol has been commercially produced by fermentation of molasses or sugar using *Mesentericus*, *Aerobacter*, *Klebsiella*, and *Serratia* bacteria; *Bacillus polymyxa*, *Lactobacilli* and *Staphylococci* strains and filamentous fungi (e.g., *Rhizopus nigricans*, *Penicillium expansum*) can also produce 2,3-Butanediol.[37] Fermentation of potatoes or wheat mash also yields 2,3-Butanediol. Mixtures of gases containing isobutylene and *n*-butenes, when combined with hydrogen peroxide and formic acid, yield a product containing 2,3-Butanediol, fractions of which are collected by distillation. The *meso*-form of 2,3-Butanediol can be prepared from *trans*-2,3-epoxybutane; the D-form can be prepared by fermenting carbohydrate solutions with *Bacillus subtilis*.[42]

1,5-Pentanediol. 1,5-Pentanediol can be prepared in the presence of copper chromite via hydrogenolysis of tetrahydrofurfuryl alcohol.[42]

1,10-Decanediol. 1,10-Decanediol may be prepared by reducing diethyl or dimethyl sebacate with sodium metal in ethyl alcohol. It may also be prepared by catalytic hydrogenation of sebacic esters.[42]

Methylpropanediol. On an industrial scale, carbon monoxide and hydrogen can be used to hydroformylate allyl alcohol to the intermediate, hydroxymethylpropionaldehyde, which is then hydrogenated to yield Methylpropanediol.[2]

Impurities

Propanediol. The following Food Chemicals Codex acceptance criteria apply for Propanediol in relation to food preparation: cobalt (≤1.0 mg/kg or 1 ppm); lead (≤1.0 mg/kg or 1 ppm); nickel (≤1.0 mg/kg or 1 ppm).[2,40] The purity of Propanediol should be ≥99.9% and water content should be ≤.1%. A manufacturer reported Propanediol to be 99.8% pure (impurities were not provided) and stated that the product did not contain added preservatives, animal by-products, or petroleum ingredients.[43] Propanediol was reported to be ≥99.98% pure; water was listed as an impurity, but no heavy metals, monomers, or amines were known to be present.[44]

1,4-Butanediol. Maleic acid and succinic acid may be potential residual impurities of 1,4-Butanediol because they are sometimes used as starting materials in the manufacture of this ingredient, as mentioned above.[21] 1,4-Butanediol has been reported to be 98% pure.[22]

1,5-Pentanediol. 1,5-Pentanediol was found to be 98.1% pure by gas chromatographic/mass-spectrometry analysis; a total of .28% unknown impurities (not diols, as stated by the study authors) were reported.[45] Contamination by water, 1,5-hexanediol, and 1,6-Hexanediol was found to be .02, 1.02, and .56%, respectively. Other diol impurities, including 1,4-Butanediol, 2,5-Hexanediol, and cyclic diols, were below the limit of detection (<.05%).

Hexanediol. Hexanediol has been reported to be >96% pure (impurities were not specified).[46]

Methylpropanediol. Methylpropanediol has been reported to be 98% pure (maximum 2% impurities; maximum .1% water content, maximum .05% carbonyl content) by a manufacturer.[47]

Isopentyldiol. Isopentyldiol has been reported to be 97% pure with 3% of impurities (no further details provided).[19] Isopentyldiol is >99% pure as reported by a cosmetics raw material supplier.[48]

Natural Occurrence

2,3-Butanediol. 2,3-Butanediol occurs naturally in certain foods, some examples include ".006 mg/kg in fish (lean), up to

Table 3. Physical and Chemical Properties.

Property	Value	Reference
Propanediol		
Physical Form	Hygroscopic liquid; viscid (sticky) liquid	40,42
Color	Colorless; Colorless to pale yellow	40,42
Odor	Mild, sweet	40,42
Molecular Weight (g/mol)	76.10	42
Density (g/mL)	1.0597	42
Melting Point (°C)	146-147	112
Boiling Point (°C)	210-212	42
Water Solubility	Slightly soluble	40
Other Solubility	Soluble in alcohols and acetone; miscible with many polar solvents	40
Log P @ 25°C	−1.093 ± .458 est.	113
1,4-Butanediol		
Physical Form	Viscous liquid	42
Color	Colorless	42
Molecular Weight (g/mol)	90.12	42
Density (g/mL @ 20°C)	1.069	112
Melting Point (°C)	19-19.5	42
Boiling Point (°C)	230	42
Water Solubility	Soluble	42
Other Solubility	Soluble in DMSO, acetone, 95% ethanol	42
Log P (@ 25°C)	−.767 ± .187 est.	113
2,3-Butanediol		
Physical Form	Hygroscopic crystals (*meso*-form)	42
Molecular Weight (g/mol)	90.12	42
Density (g/mL) @ 25°C	.9873	112
Melting Point (°C)	34.4 (*meso*-form)	42
Boiling Point (°C)	181.7	42
Water Solubility (g/L; @ 25°C & pH 6.90)	245 est.	113
Other Solubility	Moderately soluble in diisopropyl ether	42
Log P (@ 25°C)	−.655 ± .221 est.	113
1,5-Pentanediol		
Physical Form	Viscous, oily liquid; bitter taste	42
Odor	Odorless	64
Molecular Weight (g/mol)	104.15	42
Density (g/mL)	.9941	42
Melting Point (°C)	−18	42
Boiling Point (°C)	239	42
Water Solubility	Miscible with water	42
Other Solubility	Miscible with methanol, alcohol, acetone, ethyl acetate; Soluble in ether (25°C, 11% w/w); Limited solubility in benzene, trichloroethylene, methylene chloride, petroleum ether, heptane	42
Log P (@ 25°C)	−.559 ± .185 est.	113
Hexanediol		
Physical Form	Crystals	42
Molecular Weight (g/mol)	118.18	42
Density (g/mL @ 0°C)	.967	112
Melting Point (°C)	42.8	42
Boiling Point (°C @ 760 mmHg)	208	112
Water Solubility	Soluble	42
Other Solubility	Soluble in alcohol; Sparingly soluble in hot ether	42
Log P (@ 25°C)	−.049 ± .185 est.	113

(continued)

Table 3. (continued)

Property	Value	Reference
Octanediol		
Molecular Weight (g/mol)	146.23 est.	113
Density (g/mL)	.939 ± .06 est.	113
Melting Point (°C)	61 - 62	112
Boiling Point (°C)	140 - 150	112
Water Solubility (g/L @ 25°C & pH 7.00)	4.8 est.	113
Log P (@ 25°C)	.970 ± .186 est.	113
1,10-Decanediol		
Physical Form	Needles from water or diluted alcohol	42
Molecular Weight (g/mol)	174.28	42
Density (g/mL @ 20°C & 760 mmHg)	.923 ± .06 est.	113
Melting Point (°C)	74	42
Boiling Point (°C)	71.5	112
Water Solubility	Almost insoluble	42
Other Solubility	Freely soluble in alcohol, warm ether; almost insoluble in petroleum ether	42
Log P (@ 25°C)	1.989 ± .186 est.	113
Methylpropanediol		
Physical Form	Viscous liquid	100
Molecular Weight (g/mol)	90.12 est.	113
Density (g/mL @ 20°C)	1.020	112
Vapor Pressure (mmHg @ 25°C)	.021	100
Melting Point (°C)	−91	112
Boiling Point (°C)	195	112
Water Solubility (g/L @ 25°C & pH 6.88)	215 est.	113
Log P (@ 25°C)	−.740 ± .462 est.	113
Butyl Ethyl Propanediol		
Molecular Weight (g/mol)	160.25 est.	113
Density (g/mL @ 20°C & 760 mmHg)	.930 ± .06 est.	113
Melting Point (°C)	41.4 - 41.9	112
Boiling Point (°C)	262	112
Water Solubility (g/L @ 25°C & pH 7.00)	1.9 est.	113
Log P (@ 25°C)	1.709 ± .470 est.	113
Isopentyldiol		
Molecular Weight (g/mol)	104.15 est.	113
Density (g/mL @ 20°C)	.9867	112
Boiling Point (°C @ 760 mmHg)	202	112
Water Solubility (g/L @ 25°C & pH 6.96)	122 est.	113
Log P (@ 25°C)	−.329 ± .470 est.	113

90 mg/kg in cheddar cheese, up to 2.3 mg/kg in raspberries, up to 850 mg/kg in vinegar, 1.9 mg/kg in sherry, and up to 2900 mg/kg in various types of wine."[49]

Use

Cosmetic

The Panel evaluated the safety of the cosmetic ingredients included in this assessment based on the expected use of and potential exposure to the ingredients in cosmetics. The data received from the US FDA are collected from manufacturers through the FDA Voluntary Cosmetic Registration Program (VCRP), and include the use of individual ingredients in cosmetics by cosmetic product category. The data received from the cosmetic industry are collected by the Personal Care Products Council (Council) in response to a survey of the maximum reported use concentrations by product category.

VCRP data obtained from the FDA in 2018[50] indicated that eight of the alkane diols are being used in cosmetic formulations (Table 4). Propanediol has the highest number of reported uses (1528 uses), followed by Methylpropanediol (570 uses). Results from a concentration of use survey conducted in 2015[51] (Table 4) indicated that the ingredients with the highest maximum reported concentrations of use were Propanediol (39.9% in non-spray deodorants), Methylpropanediol (21.2% in body and hand products), and Isopentyldiol (15% in non-coloring hair formulations).

In some cases, uses of alkane diols were reported in the VCRP, but concentration of use data were not provided in the Council survey. For example, 1,4-Butanediol is reported to be used in 5 cosmetic formulations, but no use concentration data were reported.[50] Conversely, there was an instance in which no uses were reported in the VCRP, but use concentrations were provided in the industry survey; Butyl Ethyl Propanediol was not reported to be in use in the VCRP, but the Council survey indicated that it is used at concentrations of .29% in tonics, dressings and other hair grooming aids.[51] It should be presumed that there is at least one use in this category.

There are no frequency or concentration of use data reported for 2,3-Butanediol or 1,5-Pentanediol.[50,51]

Alkane diols were reported to be used in cosmetic sprays, including perfumes, hair sprays, and deodorants, and could potentially be incidentally inhaled. For example, Propanediol was reportedly used in aerosol and pump hair sprays at concentrations up to .12 and 1.5%, respectively, and it was used in face and neck sprays at concentrations up to 3%.[51] Isopentyldiol was reportedly used in perfumes and aerosol deodorants at concentrations up to 5% and up to 1%, respectively. In practice, 95% to 99% of the droplets/particles released from cosmetic sprays have aerodynamic equivalent diameters >10 μm, with propellant sprays yielding a greater fraction of droplets/particles below 10 μm compared with pump sprays.[52-55] Therefore, most droplets/particles incidentally inhaled from cosmetic sprays would be deposited in the nasopharyngeal and bronchial regions and would not be respirable (i.e., they would not enter the lungs) to any appreciable amount.[52,54] There is some evidence indicating that deodorant spray products can release substantially larger fractions of particulates having aerodynamic equivalent diameters in the range considered to be respirable.[54] However, the information is not sufficient to determine whether significantly greater lung exposures result from the use of deodorant sprays, compared to other cosmetic sprays. Isopentyldiol was reportedly used in face powders at concentrations up to .33%,[51] and could possibly be inhaled. Conservative estimates of inhalation exposures to respirable particles during the use of loose powder cosmetic products are 400-fold to 1000-fold less than protective regulatory and guidance limits for inert airborne respirable particles in the workplace.[56-58]

Some alkane diols were reported to be used in cosmetic formulations indicative of potential eye exposure (e.g., Propanediol is used at up to 10% in eye makeup removers) and possible mucous membrane exposure and ingestion (e.g., Propanediol at up to 10% in dentifrices). Propanediol was reported to be used in baby shampoos and baby lotions, oils, powders, and creams (concentrations of use were not reported).

None of the alkane diols named in this report are restricted from use in any way under the rules governing cosmetic products in the European Union.[59] In a NICNAS report, Isopentyldiol was determined not to be an unacceptable risk to public health in cosmetic products up to 10% (the highest use concentration reported in the NICNAS document).[19]

Non-Cosmetic

The non-cosmetic uses of 1,4-Butanediol, Hexanediol, and Methylpropanediol, as specified in the Code of Federal Regulations (CFR) Title 21, are described in Table 5. 1,4-Butanediol and Hexanediol are permitted as indirect food additives.

1,4-Butanediol. 1,4-Butanediol is known to be an illicit drug of abuse because of its conversion to gamma-hydroxybutyric acid (GHB) after oral administration.[60] GHB, occurring endogenously in mammals, is a neurotransmitter with a high affinity for pre- and postsynaptic neuron GHB-receptors.[60,61] In 1999, the FDA issued a warning about products (i.e., dietary supplements advertised as a sleep aid) containing 1,4-Butanediol and gamma-butyrolactone because of reports linking these compounds to adverse health effects (eg, decreased respiration) and 3 deaths. In this warning, the FDA noted 1,4-Butanediol to be a Class I Health Hazard (potentially life-threatening risk). GHB has been used in dietary supplements because it can reportedly increase physiological concentrations of growth hormone, leading to an increase in lean muscle mass; weight control and sedation were other effects of GHB ingestion advertised by health food stores.[28,61]

Table 4. Frequency and Concentration of Use of Alkane Diols.

	# of Uses[50]	*Max Conc Use (%)*[51]	*# of Uses*[50]	*Max Conc Use (%)*[51]	*# of Uses*[50]	*Max Conc Use (%)*[51]
	Propanediol		**1,4-Butanediol**		**Hexanediol**	
Totals*	**1528**	**0.0001-39.9**	**5**	**NR**	**3**	**0.011-0.5**
Duration of Use						
Leave-On	*688*	*0.0001-39.9*	*5*	*NR*	*3*	*0.011-0.5*
Rinse-Off	*840*	*0.005-12*	*NR*	*NR*	*NR*	*0.02-0.45*
Diluted for (Bath) Use	*NR*	*NR*	*NR*	*NR*	*NR*	*NR*
Exposure Type						
Eye Area	66	0.002-10	2	NR	1	0.011-0.08
Incidental Ingestion	6	3-10	NR	NR	NR	NR
Incidental Inhalation-Spray	spray: 21 possible: 266[a]; 211[b]	spray: 0.0001-3 possible: 2-38[a]	possible: 3[a]	NR	possible: 1[a]	NR
Incidental Inhalation-Powder	possible: 211[b]; 5[c]	possible: 0.0071-24[c]	NR	NR	NR	possible: 0.38[c]
Dermal Contact	1430	0.0001-39.9	5	NR	2	0.011-0.5
Deodorant (underarm)	12[a]	not spray: 5-39.9	NR	NR	NR	NR
Hair - Non-Coloring	74	0.005-38	NR	NR	NR	NR
Hair-Coloring	11	0.17-12	NR	NR	NR	NR
Nail	NR	5	NR	NR	1	NR
Mucous Membrane	680	0.5-10	NR	NR	NR	NR
Baby Products	8	NR	NR	NR	NR	NR
	Octanediol		**1,10-Decanediol**		**Methylpropanediol**	
Totals*	**3**	**NR**	**6**	**0.006**	**570**	**0.025-21.2**
Duration of Use						
Leave-On	*3*	*NR*	*5*	*0.006*	*360*	*0.025-21.2*
Rinse-Off	*NR*	*NR*	*1*	*NR*	*209*	*5-12*
Diluted for (Bath) Use	*NR*	*NR*	*NR*	*NR*	*1*	*NR*
Exposure Type						
Eye Area	NR	NR	NR	NR	45	0.71-5
Incidental Ingestion	NR	NR	NR	NR	2	NR
Incidental Inhalation-Spray	possible: 3[a]	NR	possible: 3[a]; 2[b]	NR	spray: 5 possible: 117[a]; 147[b]	NR
Incidental Inhalation-Powder	NR	NR	possible: 2[b]	possible: 0.006[c]	possible: 147[b]	possible: 0.8-21.2[c]
Dermal Contact	3	NR	6	0.006	534	0.025-21.2
Deodorant (underarm)	NR	NR	NR	NR	NR	not spray: 0.025
Hair - Non-Coloring	NR	NR	NR	NR	16	NR
Hair-Coloring	NR	NR	NR	NR	8	NR
Nail	NR	NR	NR	NR	1	0.04-12
Mucous Membrane	NR	NR	NR	NR	116	5
Baby Products	NR	NR	NR	NR	NR	NR
	Butyl Ethyl Propanediol		**Isopentyldiol**			
Totals*	**NR**	**0.29**	**160**	**0.13-15**		
Duration of Use						
Leave-On	*NR*	*0.29*	*155*	*0.13-15*		
Rinse-Off	*NR*	*NR*	*5*	*3-15*		
Diluted for (Bath) Use	*NR*	*NR*	*NR*	*NR*		
Exposure Type						
Eye Area	NR	NR	27	0.13-5		
Incidental Ingestion	NR	NR	NR	NR		
Incidental Inhalation-Spray	NR	possible: 0.29[a]	spray: 4 possible: 91[a]; 12[b]	spray: 3-5 possible: 2-5[a]		
Incidental Inhalation-Powder	NR	NR	powder: 3 possible: 12[b]	powder: 0.33 possible: 1-10[c]		
Dermal Contact	NR	NR	156	0.33-10		
Deodorant (underarm)	NR	NR	NR	spray: 1		
Hair - Non-Coloring	NR	0.29	3	3-15		
Hair-Coloring	NR	NR	NR	5		
Nail	NR	NR	NR	NR		
Mucous Membrane	NR	NR	NR	NR		
Baby Products	NR	NR	NR	NR		

*Because each ingredient may be used in cosmetics with multiple exposure types, the sum of all exposure types may not equal the sum of total uses

[a]Includes products that can be sprays, but it is not known whether the reported uses are sprays

[b]Not specified whether this product is a spray or a powder or neither, but it is possible it may be a spray or a powder, so this information is captured for both categories of incidental inhalation

[c]Includes products that can be powders, but it is not known whether the reported uses are powders

NR – no reported use

Table 5. U.S. Permitted Non-Cosmetic Uses.

Ingredient	Non-Cosmetic Use	References
1,4-Butanediol	Polymer component used in fabricating non-absorbable sutures for use in general and ophthalmic surgery Indirect food additive used as a component of adhesives Indirect food additive used as a component in polyurethane resins (no limit on amount used, but only to be used in closure gasket compositions in contact with certain food types), which are used in the manufacturing of closure-sealing gaskets for food containers Indirect food additive used in the formation of copolyester-graft-acrylate copolymer used as a nylon modifier in nylon resins, which are used as basic components of food contact surfaces Indirect food additive used as a reactant in the formation of polyester elastomers, which are used as basic components of food contact surfaces Indirect food additive used as a reactant to modify polyethylene phthalate polymers used as components of plastics in contact with food Indirect food additive used as a reactant in the formation of poly (tetramethylene terephthalate), which is used as a component in food contact surfaces Indirect food additive used as a reactant in the formation of polyurethane resins, which are used as components of food contact surfaces Indirect food additive used as a reactant in the formation of polyester elastomers (polybutadiene) and polyurethane resins (polyisoprene), which are rubber articles intended for repeat use in food packaging, processing, etc. FDA estimated exposure to 1,4-Butanediol as a migrant in polyurethane resins (indirect food additive-21CFR177) would be not more than 90 μg/person/day, which FDA concluded was safe based on available toxicological data and estimated dietary exposure	21CFR74.3045; 21CFR175.105; 21CFR177.1210; 21CFR177.1500; 21CFR177.1590; 21CFR177.1630; 21CFR177.1660; 21CFR177.1680; 21CFR177.2600; [23]
Hexanediol	Indirect food additive used as a component of adhesives Indirect food additive used as a reactant in the formation of polyester resins and polyesterpolyurethanediol resins in adhesives, which are used in high-temperature laminate structures for food contact surfaces Indirect food additive used as a reactant in the formation of polyurethane resins, which are used as components of food contact surfaces	21CFR175.105; 21CFR177.1390; 21CFR177.1680
Methylpropanediol	Exemption from requirement of a tolerance for 2-Methyl-Propanediol residues (40CFR180.940a) was established when "…used as an inert ingredient component of food contact sanitizing solutions applied to all food contact surfaces in public eating places, diary-processing equipment, and food-processing equipment and utensils."-Based on EPA's review of toxicity data, especially that which showed no systemic toxicity or adverse reproductive/developmental effects at doses up to 1,000 mg/kg/day in animals, and potential for aggregate exposure Exemption from requirement of a tolerance for 2-Methyl-Propanediol (40CFR180.910 and 40CFR180.930) when "…used as an inert ingredient in pesticide formulations applied to growing crops, raw agricultural commodities after harvest, and to animals (used for food)."	40CFR180.940(a); 40CFR180.910; 40CFR180.930; [29,31]

In 1997, the FDA re-issued a warning for GHB used recreationally and in body building because it caused serious adverse health effects.[28] As of 2000, the Drug Enforcement Agency (DEA) reported GHB to be a Schedule I Controlled Substance and 1,4-Butanediol and gamma-butyrolactone to be controlled substance analogs if they are intended for human consumption pursuant to 21 USC §§802(32)(A) and 813.[28,60] Sodium oxybate (the sodium salt form of GHB) is an FDA-approved prescription drug product (schedule III controlled substance)[60] used to treat attacks of muscle weakness and daytime sleepiness in narcolepsy patients.[24,25] The warnings and regulatory actions listed above pertain to oral administration.

Pentylene Glycol. Pentylene Glycol is listed as an ingredient in a prescription hydrogel wound dressing (medical device classified under 21CFR878.4022), which was cleared by the FDA (Section 510(k)).[27,30] Sources did not specify whether 1,2-Pentanediol or 1,5-Pentanediol was used or the concentration used.

1,5-Pentanediol. 1,5-Pentanediol has been reported to have antimicrobial and antifungal properties in pharmaceutical applications.[45,62-64] Additionally, 1,5-Pentanediol has reported uses in products for hair loss, cold sores, nail problems, dry and scaly feet, and eczema; it can be used as a moisturizing substance and solvent.[64] According to information submitted to CIR, 1-5 Pentanediol is used at concentrations of 5 - 25% in products used for baldness, dandruff, cold sores, nail fungus infections, and for the treatment of foot problems.[65]

Toxicokinetic Studies

Dermal Penetration

In vitro

Propanediol. A dermal penetration study conducted using human cadaver skin evaluated the penetration of Propanediol.[12] The stratum corneum (abdominal region of human cadaver skin, n = 6 representing 3 donors) was mounted on an in vitro static diffusion cell (skin surface area .64 cm^2). The experiment was conducted using Good Laboratory Practice (GLP) and in accordance with OECD Test Guideline (TG) 428 (Skin Absorption: in vitro Method). A solution containing 1.059 g/mL Propanediol (purity 99.953%) was applied to the skin (1200 $\mu L/cm^2$, infinite dose) in the donor chamber (opening to chamber was occluded). The receptor fluid (.9% saline) was maintained at 32°C in a recirculating water bath and was sampled at time zero and every 4 - 6 hours up to 48 hours post-application. The permeability coefficient was calculated to be 1.50×10^{-5} cm/h, based on the slope at steady state (15.9 $\mu g/cm^2/h$) and the concentration of Propanediol applied (test solution density 1,059,700 $\mu g/cm^3$). The percentage of the applied Propanediol recovered from the receptor chamber 48 hours post-application was .12%.

Penetration Enhancement

In vitro. Provided below is a summary of penetration experiments that are presented in greater detail in Table 6.

The ability of Propanediol, 1,4-Butanediol, and 1,5-Pentanediol to enhance the penetration of the drug estradiol in human skin was evaluated in an in vitro experiment using a Franz diffusion cell; (.05 M isotonic phosphate buffer, pH 7.4 with .01% mercury chloride was used as the receptor fluid).[66] The test substance (100 µL of .12% [^{3}H]-estradiol in 1:10 Propanediol, 1,4-Butanediol, or 1,5-Pentanediol/ethanol solution) was applied to the dermis, which faced the receptor side of the cell. Receptor fluid samples were collected at various time points. The steady-state flux of estradiol in Propanediol, 1,4-Butanediol, and 1,5-Pentanediol was determined to be .11, .017, and .005 $\mu g/cm^2/h$, respectively, indicating a decrease in steady-state flux with increasing alkyl chain length. After ~ 85 - 90 minutes the permeability of [^{3}H]-estradiol in human skin was ~ 5 - 6 $\mu g/cm^2$ with Propanediol and <1 $\mu g/cm^2$ with 1,4-Butanediol or 1,5-Pentanediol.

Penetration enhancement tests in vitro showed 1,5-Pentanediol to be a penetration enhancer for certain pharmaceutical drugs.[67,68] Test cream formulations containing .1% triiodothyroacetic acid (TRIAC; a thyroid hormone analog) and either 1,5-Pentanediol (10%) or propylene glycol (10%) showed 1,5-Pentanediol to be a more effective penetration enhancer than propylene glycol for TRIAC in a multilayer membrane system (MMS) experiment.[67] Results for 1,5-Pentanediol indicated that 33% of the TRIAC (pharmacologically active agent) was released from the carrier vehicle, or formulation (in MMS), to enable TRIAC to contact the skin at the epidermal surface by 30 minutes post-application; 62% TRIAC was released from the formulation by 300 minutes.[67] In a separate experiment, test cream formulations containing 1% hydrocortisone and either 1,5-Pentanediol (25%) or propylene glycol (25%) were evaluated using human breast skin.

Both 1,5-Pentanediol (increased drug absorption 4-fold, compared to controls) and propylene glycol (increased drug absorption 13-fold, compared to controls) were shown to be penetration enhancers.[67] However, propylene glycol enhanced the transfer of the drug through the skin more effectively and 1,5-Pentanediol increased retention of the drug in the skin more effectively (receptor fluid [ethanol/phosphate buffered saline (PBS)] collected up to 60 hours post-application). Another experiment evaluating test cream formulations containing .1% mometasone furoate and either 1,5-Pentanediol (25%) or Hexylene Glycol (12%) revealed that both formulations were percutaneous absorption enhancers in human breast skin (receptor fluid [ethanol/PBS] collected up to 60 hours post-application). The absorption of .1% mometasone furoate into the skin was 6% using 1,5-Pentanediol and 7% using Hexylene Glycol as penetration enhancers.

Table 6. Penetration Enhancement Studies.

Test Substance(s)	Species	Sample Type or Test Population-Sex	Concentration (Vehicle)	Exposure Route	Procedure	Results	Reference
				IN VITRO			
Propanediol; 1,4-Butanediol; 1,5-Pentanediol	human	Abdominal skin from cadavers (with subcutaneous fat removed)	.12% [^{3}H]-estradiol in 1: 10 test substance	1.8 cm^2 diffusion area in open glass Franz diffusion cell	Experiment performed with dermis facing receptor fluid (.05 M isotonic phosphate buffer, pH 7.4 with .01% mercury chloride), cells equilibrated for 1 h prior to addition of test substance; 100 μL of test substance was applied to skin sample and allowed to sit for a few minutes while ethanol evaporated (drug and vehicle remained on skin); diffusion cell incubated at 37 °C; receptor cell samples were collected at various time intervals (not specified) and fresh replacement fluid was added; steady-state flux was determined	Permeation of estradiol in skin after ~ 85 to 90 min was ~ 5 to 6 μg [^{3}H]estradiol/cm^2 for Propanediol and < 1 μg [^{3}H]estradiol/cm^2 for 1,4-Butanediol and 1,5-Pentanediol; steady-state flux of estradiol in Propanediol, 1,4-Butanediol, and 1,5-Pentanediol was .11, .017, and .005 μg/cm^2·h, respectively	[66]
1,5-Pentanediol; Propylene Glycol*	human	Cells of a MMS comprised 3 dodecanol collodion membranes functioning as acceptors	Test cream formulations (semisolid) containing: .1% TRIAC (a thyroid hormone analog) + 10% 1,5-Pentanediol or .1% TRIAC + 6% propylene glycol or .1% TRIAC + 10% propylene glycol	membrane area 4 cm^2; dodecanol membrane content was 2.5 mg/ 4 cm^2	10 mg test cream applied to membrane area; beaker @ 32°C used to perform experiments; penetration cells were removed from beaker at 30, 100, and 300 min; membranes separated and TRIAC extracted and analyzed by High Performance Liquid Chromatography (HPLC)	1,5-Pentanediol was a more effective penetration enhancer for TRIAC than propylene glycol; 33% TRIAC released from formulation @ 30 min, 57% released @ 100 min, 62% released @ 300 min Propylene Glycol (6%) was a penetration enhancer for TRIAC; 11% TRIAC released from formulation @ 30 min, 25% released @ 100 min, 37% released @ 300 min Propylene Glycol (10%) was a penetration enhancer for TRIAC; 14% TRIAC released from formulation @ 30 min, 37% released @ 100 min, 41% released @ 300 min	[67]

(continued)

Table 6. (continued)

Test Substance(s)	Species	Sample Type or Test Population-Sex	Concentration (Vehicle)	Exposure Route	Procedure	Results	Reference
1,5-Pentanediol; propylene glycol*	human	Breast skin; 3x6 cm; epidermal/dermal sample 400-500 μm thick; n=2 per formulation	Test cream formulations containing: 1% hydrocortisone + 25% 1,5-Pentanediol or 1% hydrocortisone + 25% propylene glycol or 1% hydrocortisone were prepared following Good Laboratory Practice (GLP)	Stratum corneum (1 cm^2) mounted on an in vitro continuous flow diffusion cell	50 mg test cream applied to top of skin in diffusion cell, receptor fluid (ethanol/phosphate buffered saline, 30:70 pumped through cell @ 2 mL/h) samples taken every 30 min between 0 and 60 h post-application; portion of test cream that was not absorbed was removed and weighed; fractions of test substance that diffused through skin were analyzed by HPLC; amount of test substance absorbed into skin was assayed separately; negative control (1% hydrocortisone) used in receptor fluid analysis	Absorption of hydrocortisone through skin increased by 4.4 times using 1,5-Pentanediol (has lipophilic characteristics) as compared to control (no penetration enhancer); hydrocortisone absorbed into skin was 58% (control not used in this part of experiment); the authors' speculated that 1,5-Pentanediol was potentially better absorbed into skin than propylene glycol (results below) because of the ability of 1,5-Pentanediol to bind to lipophilic structures in skin, slowing down drug transfer Absorption of hydrocortisone through skin increased by 12.6 times using propylene glycol (less lipophilic than 1,5-Pentanediol) compared to control; hydrocortisone absorbed into skin was 37% (control not used in this part of the experiments)	[67]
1,5-Pentanediol; 2-Methyl-Pentane-2,4-Diol (Hexylene Glycol)	human	Breast skin; 3x6 cm; epidermal/dermal sample 400-500 μm thick; n=5 per formulation	Test cream formulations containing: .1% mometasone furoate + 25% 1,5-Pentanediol or .1% mometasone furoate + 12% 2-Methyl-Pentane-2,4-Diol were prepared (GLP)	Stratum corneum (1 cm^2) mounted on an in vitro continuous flow diffusion cell	50 mg test cream applied to top of skin in donor chamber, receptor fluid (ethanol/phosphate buffered saline, 30:70 pumped through cell @ 2 mL/h) samples taken every 30 min between 0 and 60 h post-application; portion of test cream that was not absorbed was removed and weighed; fractions of test substance that diffused through skin were analyzed by HPLC; amount of test substance absorbed into skin was assayed separately	1,5-Pentanediol was a percutaneous absorption enhancer increasing the mometasone furoate absorbed through skin (4% mometasone furoate in receptor fluid) and into skin (6% mometasone furoate); 12 mg of cream remained on skin at completion of experiment 2-Methyl-Pentane-2,4-Diol was a percutaneous absorption enhancer increasing mometasone furoate absorbed through skin (5% in receptor fluid) and into skin (7%); 29 mg of cream remained on skin; the authors' speculated that the increase amount in remaining cream was possibly related to the greasiness of the formulation compared to cream containing 1,5-Pentanediol	[67]

(continued)

Table 6. (continued)

Test Substance(s)	Species	Sample Type or Test Population-Sex	Concentration (Vehicle)	Exposure Route	Procedure	Results	Reference
1,5-Pentanediol; propylene glycol*	human	Breast skin; 3x6 cm; epidermal/dermal sample 300-400 μm thick; n=5 per test condition	Test substance hydrogels (1.5% PEG-40 Hydrogenated Castor Oil and water, pH 6) containing: 1% terbinafine only (control); 1% terbinafine + 5% or 20% 1,5-Pentanediol; 1% terbinafine + 5% or 20% propylene glycol	Stratum corneum (1 cm^2) mounted on an in vitro continuous flow diffusion cell	50 mg test substance applied to top of skin in donor chamber, receptor fluid (ethanol/phosphate buffered saline, 30:70 pumped through cell @ 2 mL/h) samples taken every 30 min between 0 and 60 h post-application; portion of test substance that was not absorbed was removed and weighed; fractions of test substance that diffused through skin were analyzed by HPLC; amount of test substance absorbed into skin was assayed separately	1,5-Pentanediol and propylene glycol were percutaneous absorption enhancers for terbinafine (lipophilic drug); peak concentration of terbinafine in receptor fluid occurred at ~15 h for 5% 1,5-Pentanediol and at ~25 h for 5% propylene glycol with both curve profiles dropping off quickly after that; the 20% formulations had a more consistent profile at lower peak concentrations Control: 8% terbinafine absorbed into skin, .35% in receptor fluid, 11 μg gel not absorbed 20% propylene glycol + 1% terbinafine: 21% terbinafine absorbed into skin, 2% in receptor fluid, 19 μg gel not absorbed 20% 1,5-Pentanediol + 1% terbinafine: 11% terbinafine absorbed into skin, 3% in receptor fluid, 76 μg gel not absorbed 5% propylene glycol + 1% terbinafine: 19% terbinafine absorbed into skin, 2.5% in receptor fluid, 34 μg gel not absorbed 5% 1,5-Pentanediol + 1% terbinafine: 52% terbinafine absorbed into skin, 3% in receptor fluid, 14 μg gel not absorbed	[68]

GLP, Good Laboratory Practice; HPLC, High Performance Liquid Chromatography; MMS, multilayer membrane system; TRIAC, tri-iodothyroacetic acid; **Dictionary* name is Propylene Glycol.

1,5-Pentanediol (5% and 20%) and propylene glycol (5% and 20%) were also evaluated in an in vitro experiment investigating the penetration enhancement of 1% terbinafine, a lipophilic drug used to treat foot and nail fungus, in a hydrogel formulation.[68] Both alkane diols were found to be percutaneous absorption enhancers in human breast skin (receptor fluid [ethanol/PBS] collected up to 60 hours post-application). Results indicated that 21% and 11% terbinafine was absorbed into the skin with 20% propylene glycol or 20% 1,5-Pentanediol, respectively. The 5% propylene glycol or 5% 1,5-Pentanediol yielded 19 and 52% terbinafine absorption into skin, respectively. For comparison, the control (1% terbinafine in hydrogel without either alkane diol) resulted in 8% drug absorption into the skin.

Absorption, Distribution, Metabolism, Excretion

In mammals, 1,4-Butanediol is metabolized endogenously to gamma-hydroxybutyraldehyde by alcohol dehydrogenase and then by aldehyde dehydrogenase to GHB.[61] This metabolism has been reported to occur in rat brain and liver.[69] Ethanol, a competitive substrate for alcohol dehydrogenase, can inhibit 1,4-Butanediol metabolism.[61,70] GHB is metabolized to succinic semialdehyde by GHB dehydrogenase, and then to succinic acid by succinic semialdehyde dehydrogenase; succinic acid then enters the Krebs cycle.[61] Alternatively, succinic semialdehyde can be metabolized by gamma-aminobutyric acid (GABA) transaminase to produce the neurotransmitter GABA.

Absorption, distribution, metabolism, and excretion studies are summarized below; details are presented in Table 7.

In vitro. Competitive inhibition between 1,4-Butanediol (.5 mM) and ethanol (.5 mM) occurred in a test performed using horse liver alcohol dehydrogenase.[70] In rat liver homogenates, 10 nmol of diacetyl, acetoin, and 2,3-Butanediol were interconvertible with a molar equilibrium ratio of 0:3:7, respectively.[71] Methylpropanediol was a substrate for rat liver alcohol dehydrogenase.[2]

Animal. Metabolism experiments conducted using liver homogenates from rats that were fed 500 ppm Propanediol in the diet for 15 weeks and control rats (fed a plain diet) revealed that Propanediol was converted to malondialdehyde (5.6 nmol/h/100 mg tissue) in the liver homogenates of Propanediol-exposed rats and controls, but little-to-no conversion occurred in the testicular homogenates of treated or control rats.[72] Experiments in rabbits administered single doses of alkane diols via stomach tube revealed metabolites isolated from the urine 1 to 3 days post-dosing. Propanediol glucuronic acid conjugation accounted for up to 2% of the administered dose (4 mmol/kg); 1,4-Butanediol (9 g) was metabolized to succinic acid (7% of administered dose); 2,3-Butanediol glucuronic acid conjugation accounted for up to 26% of the administered dose (4 mmol/kg); phenacyl glutarate (.5% of dose) was identified after 1,5-Pentanediol (8.5 g) administration; Hexanediol glucuronic acid conjugation accounted for up to 9% of the administered dose (2 mmol/kg) and adipic acid was detected.[73]

Rats were intragastrically exposed to a single dose of 1 g/kg 1,4-Butanediol; 75 minutes post-dosing 96 µg/g were measured in the brain, 52 µg/g in the liver, and 58 µg/g in the kidney; endogenous levels of 1,4-Butanediol in rats dosed with ethanol were found to be .02 to .05 µg/g (type of tissue not specified), by comparison; 1,4-Butanediol levels in the liver peaked at 50 µg/g 1.5 to 3 hours post-dosing; sedation and ataxia were observed 30 minutes post-dosing and, by 60 minutes, catalepsy was noted (these effects were synergistically intensified when ethanol was concurrently administered).[70] In rats orally administered up to 400 mg/kg 1,4-Butanediol (radiolabels on C1 and C4), >75% of the radioactivity was excreted as [^{14}C]-CO_2 (by 24 hours post-administration), up to 6% of the radioactivity was excreted in urine (by 72 hours post-administration), and up to .6% of the radioactivity was excreted in feces (by 72 hours post-administration).[74] Endogenous concentrations of 1,4-Butanediol in rats were found to be 165 ng/g (stomach) and 30 ng/g (liver) in aqueous phase tissues (i.e., aqueous portion of supernatant of homogenized tissues) and in lipid phase tissues (i.e., lipid portion of supernatant of homogenized tissues) were 150 to 180 ng/g.[69]

Experiments in rats orally administered 1 M diacetyl, acetoin or 2,3-Butanediol showed that these compounds interconvert.[71] Methylpropanediol orally administered to rats (100 or 1000 mg/kg, [^{14}C]-labeled) was rapidly metabolized and eliminated in the urine as 3-hydroxybutyric acid (31% - 45% of dosed radioactivity), in the exhaled breath as CO_2 (42 - 57% of dosed radioactivity), and in the feces (<1% of dosed radioactivity).[32,75]

In liver perfusion experiments in rats (in vivo), perfusion with 1 mM 2,3-Butanediol resulted in the oxidation of 2,3-Butanediol to small amounts of diacetyl and acetoin; 33% of the perfused 2,3-Butanediol was metabolized or conjugated in the liver.[2,71]

Human. In human subjects dermally exposed to 25% 1,5-Pentanediol (2 applications, 12 hours apart), increasing levels of glutaric acid were detected in urine and serum (no concentrations were provided).[64] The study authors reported that the risk of 1,5-Pentanediol accumulation at the concentration tested (therapeutic dose) was low.

Human subjects orally exposed to 1,4-Butanediol (single 25 mg/kg dosage) in fruit juice exhibited measurable plasma concentrations of GHB between 5 and 30 minutes post-dosing, indicating rapid conversion of 1,4-Butanediol to GHB; 4 hours post-dosing plasma levels were below the limit of quantitation (1 mg/L).[76] Clearance of 1,4-Butanediol was rapid in some subjects and relatively slow in subjects who were confirmed to have a genetic mutation of variant alleles (G143 A single nucleotide-polymorphism of ADH-1B). Lightheadedness, headaches, and increased blood pressure were observed 15 minutes post-dosing, and reports of subjects feeling dizzy or less alert were expressed for up to 4 hours post-dosing. A study in which human subjects were injected intravenously with 1,4-Butanediol (15 or 30 mg/kg) showed rapid and nearly 100% conversion of 1,4-Butanediol to GHB; 1,4-Butanediol and GHB had essentially the same decay curves when equal doses of each were administered.[74] In another study, human subjects were orally administered GHB (single 25 mg/kg dosage) in water; absorption and elimination (linear kinetics) of GHB were rapid.[77] Terminal plasma elimination half-life was 17.4 to 42.5 min. The majority of subjects showed the highest concentrations in urine 60 minutes post-dosing; by 24 hours post-dosing, up to 2% of the administered dose was recovered in the urine. Confusion, sleepiness, and dizziness were observed, with substantial variation among the subjects.

Toxicological Studies

Acute Toxicity

Provided below is a summary of the acute toxicity studies; details are presented in Table 8.

Animal

Dermal. Dermal exposure animal studies evaluating the toxicity of the alkane diols indicated an LD_{50} > 20 g/kg in rats for Propanediol,[78] >20 mL/kg in rabbits for

Table 7. Toxicokinetics Studies-Absorption, Distribution, Metabolism, Excretion (ADME).

Test Substance(s)	Species/ Strain	Sample Type or Test Population-Sex	Concentration or Dosage (Vehicle)	Procedure	Results	Reference
			IN VITRO			
1,4-Butanediol	Horse	Horse liver alcohol dehydrogenase	.5 mM 1,4-Butanediol and .5 mM ethanol (no further details provided)	1,4-Butanediol and ethanol were combined with 80 mM potassium phosphate (pH 7.6), .5 mM NAD, and 10 μg crystalline horse liver alcohol dehydrogenase in a mixture (3 mL total volume) and incubated at 37°C	Competitive inhibition of the metabolism of 1,4-Butanediol occurred with ethanol; oxidation of 1,4-Butanediol was inhibited in the presence of .5 mM ethanol; oxidation of ethanol was inhibited in the presence of .5 mM 1,4-Butanediol	[70]
2,3-Butanediol	Rat, Wistar	Males, rat liver homogenates	10 nmol diacetyl, 10 nmol acetoin, or 10 nmol 2,3-Butanediol were added to homogenate mixture described in Procedure column	Rat liver was homogenized in sodium phosphate buffer, centrifuged, and a mixture of 10 nmol diacetyl, acetoin or 2,3-Butanediol plus NADH, nicotinamide, .1 mL homogenate supernatant, and buffer were incubated for 10 min @ 37°C; reaction stopped by adding $HClO_4$, sample centrifuged, and supernatant was assayed for diacetyl, acetoin, or 2,3-Butanediol	Diacetyl, acetoin, and 2,3-Butanediol were interconvertible; they became equilibrated at a molar ratio of 0:3:7, respectively (diacetyl and acetoin were used as substrates)	[71]
Methylpropanediol	Rat	Rat liver cells	Not specified	Not specified	Metabolism studies showed that Methylpropanediol is a substrate for rat liver alcohol dehydrogenase, no further details provided	[100]
			ANIMAL			
			Oral			
Propanediol	Rat, Sprague-Dawley	Rat liver and testicular homogenates	0 or 10 mM Propanediol in 100 mg of homogenized tissue mixture	For 15 weeks rats were dosed with 500 ppm Propanediol in the diet (control rats were fed a plain diet); rats were killed and livers and testes of 2 rats/group were homogenized; a reaction mixture of either liver or testes homogenates from treated or control rats, 0 or 10 mM Propanediol, buffer, sodium pyruvate, lactic dehydrogenase, and NAD (nicotinamide adenine dinucleotide) was prepared (in duplicate) and incubated at 37°C for 3 h; 2-thiobarbituric acid in buffer and trichloroacetic acid were added, mixture heated at 95°C for 1 h, and absorbance measured at 532 nm	Propanediol was converted to malondialdehyde (~5.6 nmol/h/100 mg of tissue) by rat liver homogenates from both the control (plain diet) and Propanediol-exposed rats; testicular homogenates from control and treated rats showed little to no ability to convert Propanediol to malondialdehyde This study focused on DNA cross-linking in liver and testes of rats orally administered Propanediol (data presented in the Genotoxicity Studies section of this safety assessment)	[72]
Propanediol; 1,4-Butanediol; 2,3-Butanediol; 1,5-Pentanediol; Hexanediol	Rabbit, Chinchilla	Variable n, see Procedure column	1.0-1.5 g/kg test substances in water is specified in the reference with the total g administered listed in the Procedure column	Single doses administered via stomach tube as follows (details regarding frequency of administration were not provided): 16 g total Propanediol fed to 4 rabbits; 9 g total 1,4-Butanediol fed to 4 rabbits; 1.2-1.5 g total 2,3-Butanediol fed to rabbits and 2 g total 2,3-Butanediol fed to 4 rabbits; 8.5 g total 1,5-Pentanediol fed to 4 rabbits; 2.8 g total Hexanediol fed to 1 rabbit; Rabbits were fed 60 g of rat cubes and 100 mL water/day; urine was treated, extracted, and assayed by various methods for metabolites 1-3 days post-dosing	Propanediol: neither malonic acid nor unchanged diol was isolated from urine 1,4-Butanediol: .81 g (7% of dose) of succinic acid was isolated 2,3-Butanediol: neither diacetyl nor acetoin were detected in urine or breath of rabbits (1.2-1.5 g dose); a glucuronide (triacetyl methyl ester) was isolated from urine of 2-g dosed rabbits 1,5-Pentanediol: phenacyl glutarate (.5% of dose) was isolated from the urine Hexanediol: unchanged diol was not isolated from urine, from the carboxylic acid fraction of urine adipic acid was isolated	[73]

(continued)

Table 7. (continued)

Test Substance(s)	Species/ Strain	Sample Type or Test Population-Sex	Concentration or Dosage (Vehicle)	Procedure	Results	Reference
Propanediol; 1,4-Butanediol; 2,3-Butanediol; 1,5-Pentanediol; Hexanediol	Rabbit, Chinchilla	n=3	4 mmol/kg Propanediol, 1,4-Butanediol, and 2,3-Butanediol 2 mmol/kg 1,5-Pentanediol	Single dose administered via stomach tube; rabbits were fed 60 g of rat cubes and 100 mL water/day; 1-3 days post-dosing urine was treated, extracted, and assayed by various methods for metabolites of glycols and glucuronic acid conjugation	Propanediol glucuronic acid conjugation was 0-2% of dose, no other urinary metabolites were reported; the authors' surmised that Propanediol is likely oxidized completely to CO_2 in body; 1,4-Butanediol glucuronic acid conjugation was 0-2% of dose, urinary metabolite identified was succinic acid; 2,3-Butanediol glucuronic acid conjugation was 20%-26% of dose, glucuronide of the glycol (triacetyl methyl ester) was the urinary metabolite identified; 1,5-Pentanediol had no glucuronic acid conjugation reported, urinary metabolite identified was glutaric acid (glutaric acid is metabolized to CO_2 in body); Hexanediol glucuronic acid conjugation was 4%-9% of dose, urinary metabolite identified was adipic acid	[73]
1,4-Butanediol	Rat	Not specified	1 g/kg (no further details specified)	Animals were dosed via stomach tube and the concentrations of 1,4-Butanediol in brain, liver, kidney, stomach, and pancreas were determined by Gas Chromatography/ Mass Spectrometry (GC/MS) analysis 75 min post-dosing; the same organ concentrations of 1,4-Butanediol in control rats (naïve) were determined similarly	In naïve rats concentrations were 165 ng/g (stomach) and 30 ng/g (liver) in aqueous phase tissues (aqueous portion of supernatant generated from homogenized tissues); in lipid phase tissues (lipid portion of supernatant generated from homogenized tissues) concentrations ranged from 150 to 180 ng/g in all organs tested; at 75 min post-dosing 1,4-Butanediol was distributed through all organ systems evenly (no further details regarding concentrations of 1,4-Butanediol in organs of naïve or treated animals were provided in the abstract that is referenced); 1,4-Butanediol is ubiquitous in lipid membranes and aqueous phase fractions of the organs analyzed, implying 1,4-Butanediol may be an extraneuronal source for GHB; 1,4-Butanediol is an endogenous hepatotoxin relevant to alcohol induced liver damage	[69,70]
1,4-Butanediol	Rat, F344/N	4 males/group	4, 40, 120, or 400 mg/kg ^{14}C-1,4-Butanediol (C1 and C4 labeled)	Single doses administered via gavage; rats housed individually in metabolism chambers; urine and feces collected @ 8, 24, 48, and 72 h post-dosing; breath samples were collected by various traps and analyzed 2, 4, 8, 12, 24, 32, 48, 56, and 72 h post-dosing; blood drawn by cardiac puncture from anesthetized rats at completion of experiment (72 h); adipose tissue, muscle, skin, liver, and brain were removed from rats dosed with 40 mg/kg ^{14}C-1,4-Butanediol and assayed for ^{14}C; the carcasses of 2 rats each dosed with 4 or 400 mg/kg ^{14}C-1,4-Butandiol were assayed for ^{14}C; no controls used	>75% of dosed radioactivity was excreted as $^{14}CO_2$ 24 h post-dosing; with 400 mg/kg capacity-limited metabolism observed at 26-30% lower $^{14}CO_2$ production 2 h post-dosing compared to other dose levels but differences decreased over time; by 72 h post-administration 3%-6% of dosed radioactivity was excreted in urine and .04%-.6% of dosed radioactivity excreted in feces; ≤1% of ^{14}C were recovered in volatile compounds in breath after 4 or 400 mg/kg exposures so volatile compounds were not collected at remaining dosages; accumulation of ^{14}C after the 40 mg/kg exposures was .9% of dosed radioactivity in muscle tissue, .5% of dosed radioactivity in liver tissue, .1% of dosed radioactivity in blood, .01% of dosed radioactivity in brain, .15% of dosed radioactivity in adipose tissue; ^{14}C in carcass was 2.2% of 4 mg/kg dosed radioactivity and 2.8% of 400 mg/kg dosed radioactivity	[74]

(continued)

Table 7. (continued)

Test Substance(s)	Species/ Strain	Sample Type or Test Population-Sex	Concentration or Dosage (Vehicle)	Procedure	Results	Reference
1,4-Butanediol	Rat, Sprague-Dawley	4/cage (no further details specified)	1 g/kg 1,4-Butanediol and/or 3 g/kg ethanol (in 38% v/v water)	Single doses of 1,4-Butanediol (intragastrically) and ethanol (intraperitoneally) administered; food and water available ad libitum; rats were killed 75 min after dosing with ethanol and/or 1,4-Butanediol (maximal behavioral effects of drugs were observed at this time)	Blood ethanol levels were no different between 1,4-Butanediol and ethanol administered together compared to ethanol administered alone; concentrations of 1,4-Butanediol in brain (338 μg/g), liver (315 μg/g), and kidney (347 μg/g) tissues of rats dosed with both 1,4-Butanediol and ethanol together were statistically significantly higher than in rats administered 1,4-Butanediol alone in brain (96 μg/g), liver (52 μg/g), and kidney tissues (58 μg/g); endogenous 1,4-Butanediol in animals dosed only with ethanol was .02-.05 μg/g of tissue (type of tissue not specified); liver 1,4-Butanediol concentrations were maximal 1.5-3 h post-administration of 1,4-Butanediol alone (50 μg/g) or when administered together with ethanol (>300 μg/g); by 30 min post-dosing with 1,4-Butanediol alone sedation and ataxia were observed and by 60 min catalepsy was noted, these types of effects were intensified with administration of 1,4-Butanediol and ethanol together	[70]
1,4-Butanediol	Rat, Sprague-Dawley	10	1 g/kg 1,4-Butanediol and 20% ethanol (v/v) in water	Ethanol administered intragastrically 6x/day for 4 days, then 10-11 h after last ethanol exposure 1,4-Butanediol was administered to 5 rats and 5 rats received saline	1,4-Butanediol had no effect on ethanol elimination	[70]
2,3-Butanediol	Rat, Wistar	Males	1 M diacetyl, acetoin, or 2,3-Butanediol dissolved in saline administered at 5 mmol/kg	Single dose administered orally (control rats administered saline); 1 h post-dosing rats were intraperitoneally injected with pentobarbital and liver, kidney, and brain were removed and perfused with ice-cold saline; organs homogenized @ 4°C, centrifuged, and supernatants analyzed for diacetyl, acetoin, and 2,3-Butanediol	Diacetyl, acetoin, and 2,3-Butanediol interconvert; reduced 2,3-Butanediol was found in liver, kidney, and brain at a total of 2.3% of the administered dose of diacetyl; reduced 2,3-Butanediol was found in liver, kidney, and brain at a total of 2.6% of the administered dose of acetoin; small amounts of 2,3-Butanediol were oxidized to diacetyl and acetoin (these accumulated in liver) and 2,3-Butanediol was located in liver, kidney, and brain tissues at a total of 3% of administered dose	[71]
Methylpropanediol	Rat	4/group	100 or 1000 mg/kg (each animal received ~ 10.5-13.0 μCi, ^{14}C-labeled)	Gavage administration (no further details provided)	Rapid metabolism and elimination in the urine as 3-hydroxybutyric acid and exhaled air as CO_2 (42%-57% of dosed radioactivity mostly recovered within 24 h post-dosing) were observed; 31%-45% of dosed radioactivity eliminated by renal excretion and cage wash; <1% of dose excreted in feces; dosed radioactivity remaining 7 days post-dosing was .1% in blood, .3% in liver and kidney, and 5% in carcass; >60% of dosed radioactivity eliminated in 6 h and 83% by 24 h; half-life was calculated to be 3.57 h (high dose) and 3.87 h (low dose); alcohol dehydrogenase catalyzed metabolism to S- and R- stereoisomers of 3-hydrobutyric acid and CO_2, R-stereoisomer of 3-hydrobutyric acid largely excreted in urine	[2,32,99]

(continued)

Table 7. (continued)

Test Substance(s)	Species/ Strain	Sample Type or Test Population-Sex	Concentration or Dosage (Vehicle)	Procedure	Results	Reference
				Other		
2,3-Butanediol	Rat, Wistar	Males	1 mM diacetyl, acetoin, or 2,3-Butanediol	Rats were administered pentobarbital, liver perfusion performed through portal vein to inferior vena cava @ 37°C; substrate added to buffer 30 min after perfusion began; perfusion was conducted without recirculation; perfusates collected every 10 min for 1 h, then liver was removed, homogenized, deproteinized, and assayed for diacetyl, acetoin, and 2,3-Butanediol	Diacetyl was reduced to acetoin and 2,3-Butanediol in liver (mole ratio diacetyl: acetoin: 2,3-Butanediol was 5: 39:100; perfusate showed 45, 15, and 10% of diacetyl dose, respectively); diacetyl in perfused liver was .1% of perfused diacetyl dose so ~30% was metabolized or underwent glucuronidation in liver Acetoin was reduced to 2,3-Butanediol and small amount oxidized to diacetyl in liver (mole ratio diacetyl: acetoin: 2,3-Butanediol was 1:38:100; perfusate showed 1:15:45 of acetoin dose, respectively); acetoin in perfused liver was .1% of perfused acetoin dose, therefore ~30% was metabolized or conjugated in liver 2,3-Butanediol was oxidized in small amounts to diacetyl and acetoin; ~33% of perfused 2,3-Butanediol was metabolized or conjugated in liver; when only buffer was perfused none of the test compounds were detected in the perfusate	[71]
2,3-Butanediol	Rat, Sprague-Dawley	Male Exp. 1, n=6 livers/ substrate Exp. 2, n=2 Exp. 3, n=1	Exp. 1: 2 mM 2R,3R-Butanediol or 2 mM 2S,3S-Butanediol or Racemic 2,3-Butanediol (.8 mM RR-,SS-forms and 1.2 mM *meso*-forms); 2 mM 2R,3R-[2-^{14}C]Butanediol or 1 mM *meso*-[2-^{14}C]2,3-Butanediol	Exp. 1-Rats were fed ad libitum. Livers were perfused with 150 mL of bicarbonate buffer containing bovine serum albumin and 15 mM glucose for 30 min, then various forms of labeled, unlabeled, or racemic 2,3-Butanediol were added to perfusate Exp. 2-To determine if isomer interconversion occurred, buffer (in deuterium oxide, 99.9% ^{2}H) solution containing 15 mM glucose and 2 mM 2R,3R-Butanediol or 2 mM 2S,3S-Butanediol was perfused through the liver Exp. 3-To examine whether the liver would convert ethanol to 2,3-Butanediol, 15 mM glucose and 20 mM ethanol were perfused through the liver for 2 h; 5 mM pyruvate was added to perfusate after 1 h (no exogenous 2,3-Butanediol was added) In a control experiment the livers of fed rats were perfused with 15 mM glucose	Exp. 1-In unlabeled 2,3-Butanediol experiments, the uptake rate (linear) of the RR- form was greater than for the SS- form; uptake rate for either labeled or unlabeled RR- form was double that of the labeled *meso*- form; rate of formation of *meso*- form from labeled RR- form was approx. double the rate of formation of labeled RR-, SS- forms produced from *meso*-form; uptake of labeled RR- and meso- forms resulted in formation of $^{14}CO_2$, acetate, ketone bodies, acetoin, and isomers of 2,3-Butanediol, which is attributed to approx. 1/3 of label uptake; results indicate the oxidation of 2,3-Butanediol to acetyl-CoA via acetoin Exp. 2-10 μM *meso*-[$^{2}H_1$]2,3-Butanediol and 3 μM of RR,SS-[$^{2}H_1$]2,3-Butanediol were produced 60 min after start of perfusion of RR-form; no *meso*-[$^{2}H_1$]2,3-Butanediol was detected and no RR,SS-2,3-Butanediol showed deuterium present in the perfusion of the SS-form Exp. 3-No 2,3-Butanediol or acetoin were produced from ethanol perfusion 1 h after the start of perfusion, but during the 2nd h 2,3-Butanediol and acetoin were reported to be 15 μM Controls did not show any detectable 2,3-Butanediol (<1 μM) after the start of the perfusion	[114]
				HUMAN		
				Dermal		
1,5-Pentanediol	Human	n=12	Therapeutic concentration of 25% (gel)	Test substance was applied 2x (12 h apart) to backs of subjects; plasma, serum, and urine samples were collected at varying times points (no further details provided)	Study authors reported a medium-long elimination time (no further details provided) of 1,5-Pentanediol, which was eliminated (after biotransformation) as glutaric acid in urine; glutaric acid was noted in subjects' urine prior to treatment (concentrations were not specified); by 24 h after first application of test substance, glutaric acid was detected in serum (concentrations not specified, increased over time in serum and urine); authors stated low risk of accumulation of 1,5-Pentanediol at concentration tested	[45,64]

(continued)

Table 7. (continued)

Test Substance(s)	Species/ Strain	Sample Type or Test Population-Sex	Concentration or Dosage (Vehicle)	Procedure	Results	Reference
				Oral		
1,4-Butanediol	Human	n=5 males, 3 females	25 mg/kg in orange or cranberry juice	Subjects were not GHB-naïve (GHB-naïve= not once ingested GHB, 1,4-Butanediol, or gamma-butyrolactone) or illicit drug or prescription drug (except for oral contraceptives) users; they were not heavy alcohol consumers (not >3 drinks/week) and consumed no alcohol 3 days prior to the study and only light users of GHB (no more than 2 x in 6 months); design of study was randomized double-blinded, placebo-controlled, two arm, crossover; subjects were orally administered a single dose of placebo (plain juice) or 1,4-Butanediol after fasting overnight; subjects allowed to eat 3 h post-dosing; 2 day washout period between treatments; heart rate, blood pressure, respiratory rate, and skin temperature were measured 30 and 15 min prior to and every 15 min for the first 2 h after dosing; blood samples collected prior to and at 5, 15, 30, 45, 60, and 90 min and 2, 3, 4, 5, 6, 12, and 24 h after dosing; blood sample analysis done by GC/MS; subjects completed a visual analog scale questionnaire and a computerized cognitive battery to evaluate drug effects prior to and 1, 2, and 4 h after dosing; subjects' DNA was tested for the G143A single-nucleotide polymorphism of ADH-IB (non-synonymous mutation of an amino acid 48 substitution from arginine to histidine, R48H, associated with 40-fold increase in ethanol metabolism)	Extensive conversion of 1,4-Butanediol to GHB was observed ; average C_{max} for GHB was 45.6 mg/L and for 1,4-Butanediol was 3.8 mg/L in blood plasma; 5 of 8 subjects had measurable plasma GHB levels 5 min post-dosing, the 3 other subjects did not, potentially because of slower gastrointestinal absorption; at 30 min post-dosing all subjects had measurable plasma GHB levels; elimination half-life for GHB was 32 min and for 1,4-Butanediol was 39 min; at 4 h post-dosing plasma levels were below the limit of quantitation (1 mg/L); 4 subjects showed rapid clearance and 4 showed relatively slower clearance (3 of 4 subjects with slower metabolism had variant alleles for G143A and 3 of 4 with faster metabolism had normal wild-type ADH-IB); 2 subjects experienced lightheadedness and 2 had headaches; blood pressure increased 15 min post-dosing compared to placebo; O_2 saturation was statistically significantly decreased compared to placebo, but only by 1%; heart rate or rhythm and body temperature were unaffected; some subjects reported feeling less awake and alert, less able to concentrate, more lightheaded or dizzy up to 4 h post-dosing with effects at a max 60-90 min post-dosing	[76]
GHB sodium salt (a metabolite of 1,4-Butanediol)	Human	n=4 males, 4 females; subjects were GHB naive	25 mg/kg in water	Single dose of freshly prepared solution administered orally through a drinking straw on an empty stomach; subjects not allowed to consume medication, alcohol, or drugs 48 h prior to and 24 h after study; blood samples were collected just before dosing and at 10, 15, 20, 25, 30, 45, 60, 69, 90, 120, 150, 180, 240, and 360 min post-dosing; urine samples were collected 10 min pre- and 120, 240, 360, 480, 720, and 1440 min post-dosing; oral fluid was collected up to 360 min post-dosing; above samples were assayed and quantitative analysis performed using GC/MS; blood pressure, heart rate, and hemoglobin oxygen saturation were measured when blood was drawn	GHB plasma levels ranged from < LOD to 76.3 μg/mL with C_{max} between 4.70 and 76.3 μg/mL occurring 20-45 min post-dosing; terminal plasma elimination half-lives were 17.4 to 42.5 min indicating oral absorption and elimination of GHB were rapid; mean residence time was 43.7 to 194 min; total clearance was 476 to 2520 mL/min; linear elimination kinetics were observed; GHB in oral fluid ranged from < LOD to 778 μg/mL (mean highest values of 203 to 101 μg/mL observed 10 to 15 min post-dosing, respectively); GHB in urine ranged from <LOD to 840 μg/mL (most subjects excreted highest GHB concentrations 60 min post-dosing, no GHB was detected in baseline urine or in urine samples collected 1440 min post-dosing; within 24 h, .2%-2.1% of administered dose was recovered in urine; no severe psychotropic side effects noted or vital functions substantially affected; confusion, sleepiness, and some dizziness were observed; substantial inter-individual variation noted	[77]
				Intravenous		
1,4-Butanediol	Human	Not specified	15 or 30 mg/kg (no further details specified)	Either dose level was administered by IV, additionally gamma-hydroxybutyric acid was administered for comparison (1,4-Butanediol converts to gamma-hydroxybutyric acid or GHB in the body); no further details provided	Within 2 min post-administration of 1,4-Butanediol, GHB blood levels peaked and began to decay; 1,4-Butanediol and GHB had nearly identical decay curves when equal doses of each were administered, showing a rapid and almost 100% conversion of 1,4-Butanediol to GHB (no further details provided)	[74]

C_{max}, maximum concentration; GC/MS, Gas Chromatography/Mass Spectrometry; GHB, gamma-hydroxybutyric acid or gamma-hydroxybutyrate; LOD, limit of detection; NAD, nicotinamide adenine dinucleotide.

Table 8. Acute Toxicity Studies.

Test Substance(s)	Species/Strain	Test Population	Concentration/Dosage (Vehicle)	Procedure	Results	Reference
				Dermal		
Propanediol	Rat, Wistar	n=2/sex/group	1.0, 2.0, or 4.0 mL/kg (undiluted, no vehicle)	Dorso-lumbar skin shaved free of hair; test substance applied to dorso-lumbar skin and occlusively covered for 24 h (rats fasted during exposure); at 24 h post-application covering removed and skin washed with detergent; rats observed for 9 days post-application	LD_{50} > 4 mL/kg (or 4.2 g/kg); no mortalities reported	12
Propanediol	Rabbit	Not specified	Not specified	No details provided	LD_{50} > 20 g/kg	78
1,4-Butanediol	Rat, Wistar Imp: DAK	12 females	5 g/kg (undiluted liquid)	Food and water were available ad libitum; sides and dorsum clipped free of hair; single application of test substance to dorsum and occlusively covered for 24 h, then covering was removed; rats were observed for 48 h (n=4) or daily for 14 days (n=8) post-application and then killed	No mortality; 48 h post-application dermal lesions (segmentary acanthosis, single microcrusts with granulocytes infiltrations, slight collagen edema, mononuclear cell infiltrations in hypodermis) were observed in 2 of 4 rats and in the liver of all 4 rats extensive vacuolar degeneration of hepatocyte cytoplasm was noted; 14 days post-application rats showed small, single desquamating crusts on skin and focal granulocyte infiltrations in epidermis and in the liver moderate periportal vacuolization of hepatocytes cytoplasm was noted; the pathological lesions observed were similar to those noted following acute oral doses	82
1,4-Butanediol	Rat, Sprague-Dawley	5/sex	2 g/kg (vehicle=water)	Test substance applied (whether skin was shaved or not was not specified) to a 50 cm^2 area and skin occlusively covered for 24 h post-dosing, at that time skin washed with warm water; animals observed for 14 days post-dosing	LD_{50} > 2 g/kg for males and females; no mortalities; animals gained weight; gross pathology revealed no abnormalities; clinical signs: dyspnea, poor general state within 2 h post-exposure, slight erythema after removing test substance	13
1,5-Pentanediol	Rabbit, New Zealand (albino)	4 males	20 mL/kg	Rabbit trunk was clipped free of hair; single application of test substance to hairless skin and covered with occlusive plastic film for 24 h, at which point plastic film was removed; rabbits were observed for 14 days; researchers noted that doses >20 mL/kg could not be "retained in contact with the skin"	LD_{50} > 20 mL/kg was reported	79
Hexanediol	Rabbit, New Zealand (albino)	4 males	10 g/kg in a "suitable vehicle"	Rabbit trunk was clipped free of hair; single application of test substance to hairless skin and covered with occlusive plastic film for 24 h, at which point plastic film was removed; rabbits were observed for 14 days	LD_{50}>10 g/kg was reported	79,80
Hexanediol	Rabbit, Vienna White	5/sex	2.5 g/kg (vehicle = .5% carboxymethyl cellulose)	Procedures followed were in accordance with OECD Test Guideline (TG) 402 (Acute Dermal Toxicity); rabbit dorsal and lateral back area and flanks were clipped free of hair; single application of test substance to hairless skin and occlusively covered for 24 h then skin was washed with warm water; animals observed for 8 days post-application; necropsy performed	LD_{50} > 2.5 g/kg for males and females; no mortalities; gross pathology revealed no abnormalities; clinical signs: within 20-30 min slight apathy in 1 male and 1 female, slight skin irritation in 1 male (resolved after 5 days) and in 1 female (cleared within 48 h)	15
Methylpropanediol	Rabbit, New Zealand	5/sex	2 g/kg	Procedure followed was in accordance with OECD TG for Testing Chemicals; single application of test substance (semi-occlusive) for 24 h; animals observed for 14 days post-application; necropsy performed	LD_{50} > 2 g/kg; 1 death on day 12 (deemed not treatment-related because there were no signs observed previously); no-to-slight dermal reaction in 2 rabbits on day 1, but cleared by day 7; 5 of 9 animals showed abnormal kidneys and gastrointestinal tract at necropsy; a tissue mass and hemorrhagic areas on dorsal abdominal cavity of 1 animal were noted; weight loss in 2 animals observed; clinical signs: slight erythema, diarrhea, yellow nasal discharge, few feces, bloated abdomen and soiling of anogenital area; abnormalities in lungs, pleural cavity, liver and gastrointestinal tract	20,100
Butyl Ethyl Propanediol	Rat, CD(SD) BR VAF/ Plus	5/sex	2 g/kg (no vehicle, test substance in powder form and moistened with distilled water before application)	Procedures followed (non-GLP) were in accordance with OECD TG 402 (Acute Dermal Toxicity); rat skin was clipped free of hair; a single application of test substance to hairless skin and occlusively covered for 24 h then skin was washed with water; animals were observed for 14 days post-application; necropsy performed	LD_{50} > 2 g/kg for males and females; no mortalities; no abnormal clinical signs; rats gained weight; gross pathology revealed no treatment-related observations	17
Butyl Ethyl Propanediol	Rabbit	Not specified	Not specified	Single application of test substance to skin (no further details provided)	LD_{50} was reported to be 3.81 mL/kg	81
				Oral		
Propanediol	Rat, Wistar (albino)	5/sex/dose	9.0, 10.8, 13.0, 15.6, 18.7 mL/kg (no vehicle was used)	Procedures followed were in accordance with OECD TG 401 (Acute Oral Toxicity) but no controls; animals were fasted overnight; single doses administered by gavage; animals observed for 14 days post-dosing, necropsy performed on survivors	LD_{50} was calculated (Weil method) to be 14.9 mL/kg; clinical signs within a few hours post-dosing were sluggishness, sedation, ataxia, and unconsciousness preceding death; animals that survived recovered to good health by 14 days post-dosing; no gross pathology changes in survivors were reported; mortality was as follows: 1 female (10.8 mL/kg), 2 males (13.0 mL/kg), 3 males and 2 females (15.6 mL/kg); 5 males and 5 females (18.7 mL/kg)	12

(continued)

Table 8. (continued)

Test Substance(s)	Species/Strain	Test Population	Concentration/Dosage (Vehicle)	Procedure	Results	Reference
Propanediol	Rat	at least 5/dose	1-9, 11, 12, 13, 14, 15, 16, 17, 18, 19 mL/kg (no vehicle specified)	Dose administered by gavage (no further details provided)	Mortality rates were as follows: 10%-18% (11-14 mL/kg); 64% (15 mL/kg); 50% (16 mL/kg); 40% (17 mL/kg); 100% (18-19 mL/kg) Authors speculated that the variable mortality was potentially related to gastrointestinal absorption variability No mortality observed with 1-9 mL/kg	12
Propanediol	Cat	n=3	3 mL/kg	Dose administered by gavage (no further details provided)	At 48 h post-dosing no effects observed; by 72 h post-dosing cats vomited after drinking water and would not eat; weight loss and death reported within 1 week post-dosing	12
Propanediol	Rat, Wistar	8/sex	10.5 g/kg (equivalent to 10 mL/kg; no vehicle used)	Dose administered by gavage (no further details provided)	LD_{50} reported to be 10 mL/kg; piloerection noted 24 h post-dosing in some animals; 4 of 16 animals died	12
Propanediol	Rat, ChR-CD	1 male/dose	2.25, 3.4, 5, 7.5, 11, 17, 25 g/kg; two different grades of Propanediol were evaluated undiluted at the above dosages (refined 99.8% and crude 70%)	Single dose administered by intragastric intubation; rats observed for 14 days post-dosing	ALD > 25 g/kg for 99.8% purity; no mortalities at any dosages; clinical signs observed at all dosages 1-2 days post-dosing included pallor, irregular respiration, belly-crawling, chewing motion, and salivation ALD of 17 g/kg for 70% purity; rats died within 24 h of dosing with 17 or 25 g/kg; no mortalities at remaining dosages; clinical signs at dosages below 17 g/kg observed on days 1-6 post-dosing were pallor, irregular respiration, salivation, chewing motions, belly-crawling, and diuresis	35
Propanediol	Rat	Preliminary Test: 1/sex/group Definitive Test: 4/sex	Preliminary Test: .63, 1.25, 2.5, 5, 10 mL/kg Definitive Test: 10 mL/kg	Preliminary Test: Single dose administered by gavage; animals observed through 9 days post-dosing (no further details provided) Definitive Test: Single dose administered by gavage (no further details provided)	Preliminary Test: 2 deaths (females) by 2 days post-dosing (no details as to which dose was lethal), other animals survived until 9 days post-dosing; piloerection noted 24 h post-dosing Definitive Test: LD_{50} of 10 mL/kg (or 10.5 g/kg)	26
1,4-Butanediol	Rat, Sprague-Dawley	No further details specified	1 g/kg 1,4-Butanediol or 3 g/kg ethanol or both together	A single dose of 1,4-Butanediol, ethanol, or both together were administered	Mortality rate 24 h post-administration of 1,4-Butanediol was 1 of 18 rats, for ethanol was 0 of 18 rats, and for both administered together was 9 of 18 rats; 1,4-Butandiol concentrations in liver tissues of 2 of 9 animals (dosed with both compounds) that died 1.5 to 2.5 h after dosing were 1450-1600 µg/g shortly after death; the remaining 7 of 9 died 12 to 24 h post-dosing when liver concentrations of 1,4-Butanediol were low	70
1,4-Butanediol	Rat, Sprague-Dawley	5/group	1 g/kg 1,4-Butanediol or 3 g/kg ethanol or both together	A single dose of 1,4-Butanediol (intragastrically), ethanol (intraperitoneally), or both together were administered; rats killed 24 h post-dosing; gross and microscopic studies of brain, liver and kidney were conducted	No histological changes were noted in kidney, liver, or brain 24 h post-dosing with ethanol only; 1,4-Butanediol dosed rats showed hyperemia in all organs examined; in rats dosed with ethanol and 1,4-Butanediol the following results were observed: ascites and liver congestion, microscopic liver changes (fatty infiltration and necrosis) and kidney changes (medullary necrosis)	70
1,4-Butanediol	Rat, Wistar Imp: DAK	4/sex/dose group; 5/sex/dose group	1.5 to 2.5 g/kg at increasing doses; 1.8 g/kg	Food and water were available ad libitum; animals fasted for 16 h prior to dosing; single doses of 1.5 to 2.5 g/kg were administered by gavage and rats observed daily for 14 days; single doses of 1.8 g/kg administered, rats killed 48 h (n=8) or 14 days (n=8) post-dosing and examined for pathological lesions	Estimated LD_{50} of 1.83 g/kg (1.7-1.98 g/kg range) for males and 2.00 g/kg (1.8-2.22 g/kg range) for females 48 h post-dosing: unspecified number of deaths were reported (pathological findings were fluid-filled gastrointestinal tract and congestion of internal organs); in both sexes irregular, decreased respiration and catalepsy were observed; histopathological changes in liver and kidneys were noted (1.8 g/kg dose); extensive vacuolar degeneration of hepatic parenchyma noted in liver of all rats; 1 male showed periportal fatty changes in liver; hyaline or granular casts/clusters of desquamated cells (renal tubule lumen of subcortical zone and outer medulla), tubules with regeneration, and interstitial infiltration of mononuclear cells in kidneys were noted 14 days post-dosing: periportal vacuolization of hepatocytes cytoplasm and cells in mitosis were observed in liver; in 3 of 3 males and 2 of 5 females hyaline casts, single tubules regenerations, and dispersed interstitial infiltration with lymphocytes were seen in kidneys; liver and kidney changes were reversible	82
1,4-Butanediol	Rat, Sprague-Dawley	5/sex/dose	1, 1.3, 1.5, 2, 2.5 g/kg (vehicle=water)	Procedures followed were comparable to OECD TG 401(Acute Oral Toxicity); single dose administered by gavage and animals observed for 14 days post-dosing; necropsy was performed	Combined LD_{50} estimated to be 1.5 g/kg, for males (1.35 g/kg) and females (1.67 g/kg); at 24 h post-dosing 27 animals dead (≥1.3 g/kg); deaths attributed to congestive hyperemia; animals killed after 14 days showed no abnormalities; clinical signs reported: dyspnea, apathy, abnormal position, staggering, atony, unusual pain reflex, unusual cornea reflex, narcotic-like state, tremor, spastic gait, scrubby fur, hair loss, exsiccosis, exophthalamus, poor general state; animals that survived to 14 days gained weight	13,34
1,4-Butanediol	Rat, albino	25/sex	Not specified	Not specified	LD_{50} of 1.55 g/kg	74
1,4-Butanediol	Rat	Not specified	Not specified	Not specified	LD_{50} of 1.78 g/kg	37

(continued)

Table 8. (continued)

Test Substance(s)	Species/Strain	Test Population	Concentration/Dosage (Vehicle)	Procedure	Results	Reference
1,4-Butanediol	Rat, Wistar	Not specified	Not specified	Not specified	LD_{50} of 1.5 g/kg; deaths on days 1-2; signs of poisoning 10 to 15 min post-dosing; lateral posture, hyperemia of mucosa, and lethargy observed; hyperemia in brain and internal organs noted during necropsy	22,37
1,4-Butanediol	Mouse	Not specified	Not specified	Not specified	LD_{50} of 2.1 g/kg; animal deaths occurred on days 1-2; signs of poisoning were noted 10 to 15 min post-dosing; lateral posture, hyperemia of mucosa, and lethargy were observed; hyperemia in brain and internal organs noted during necropsy	22,37
1,4-Butanediol	Mouse	Not specified	Not specified	Not specified	LD_{50} of 2.2 g/kg (24 h post-dosing)	37
1,4-Butanediol	Guinea Pig	Not specified	Not specified	Not specified	LD_{50} of 1.2 g/kg; animal deaths occurred on days 1-2; signs of poisoning were noted 10 to 15 min post-dosing; lateral posture, hyperemia of mucosa, and lethargy were observed; hyperemia in brain and internal organs noted during necropsy	22,37
1,4-Butanediol	Rabbit	Not specified	Not specified	Not specified	LD_{50} of 2.5 g/kg; animal deaths occurred on days 1-2; signs of poisoning were noted 10 to 15 min post-dosing; lateral posture, hyperemia of mucosa, and lethargy were observed; hyperemia in brain and internal organs noted during necropsy	22,37
2,3-Butanediol	Mouse	Not specified	Not specified	Oral administration, details were not provided	LD_{50} of 9 g/kg	49
2,3-Butanediol	Rat, Sprague-Dawley	5/sex	5 g/kg (vehicle=water)	Procedures followed were in accordance with OECD TG 401 (Acute Oral Toxicity)	LD_{50} > 5 g/kg for males and females; no mortality; clinical signs: dyspnea, apathy, staggering, piloerection, erythema, exophthalmos, poor general state	16
1,5-Pentanediol	Rat, Carworth-Wistar	n=5	Dose not specified, a "suitable vehicle" (e.g. water, corn oil, or semi-sold agar suspension) was used	Single dose administered by gastric intubation to non-fasted rats; rats observed for 14 days post-dosing	An estimated LD_{50} of 5.89 g/kg ±1.96 standard deviations was reported, LD_{50} range reported was 5.38 to 6.44 g/kg	79
1,5-Pentanediol	Rat, Sprague-Dawley	12 total (males and females)	1, 4.64, 6.81, 10 g/kg (vehicle=water)	Procedures followed were in accordance with OECD TG 401 (Acute Oral Toxicity); single dose administered by gavage; animals observed for 14 days post-dosing	LD_{50} of 10 g/kg for males and females; 1 death in 24 h (6.81 g/kg dose), 3 deaths in 24 h (10 g/kg dose), no deaths at two lower doses; reduced weight gain early in study; gross pathology with 10 g/kg revealed acute dilation of the heart and congestive hyperemia, bloody stomach ulcerations, diarrhetic and hematonic gut content, and abnormal bladder content; clinical signs: reduced state, staggering, paresis, spastic gait, salivation, exsiccosis	14
1,5-Pentanediol	Guinea Pig	Not Specified	Not Specified	Not Specified	LD_{50} of 4.6 g/kg; somnolence, excitement, and muscle weakness noted (no further details provided)	115
1,5-Pentanediol	Mouse	Not Specified	Not Specified	Not Specified	LD_{50} of 6.3 g/kg; somnolence, excitement, and muscle weakness noted (no further details provided)	115
1,5-Pentanediol	Rabbit	Not Specified	Not Specified	Not Specified	LD_{50} of 6.3 g/kg; somnolence, excitement, and muscle weakness noted (no further details provided)	115
Hexanediol	Rat, Carworth-Wistar	n=5	Dose not specified, a "suitable vehicle" (e.g. water, corn oil, or semi-sold agar suspension) was used	Single oral dose administered by gastric intubation to non-fasted rats; rats observed for 14 days post-dosing	An estimated $LD_{50}$of 3.73 g/kg was reported, LD_{50} range reported was 2.68 to 5.21 g/kg	79,80
Hexanediol	Rat	20 total (males and females)	2.5, 3.2, 6.4 g/kg (vehicle=water)	Procedures followed were in accordance with OECD TG 401 (Acute Oral Toxicity); dose administered by gavage; animals observed for 7 days (2.5 and 6.4 g/kg dose) or 14 days (3.2 g/kg dose); necropsy performed	LD_{50} of 3 g/kg for males and females; mortality as follows: none in 7 days (2.5 g/kg dose), 7 deaths in 24 h (3.2 g/kg dose), 4 deaths in 24 h and 5 deaths in 7 days (6.4 g/kg dose); gross pathology revealed no abnormalities; clinical signs: staggering (within 24 h of 2.5 g/kg dose); apathy (within 1 h of 3.2 g/kg dose), lateral position, narcotic state, and atonia, constant urination (within 3 h of 3.2 g/kg dose); apathy and atonia (within 1 h of 6.4 g/kg dose), lateral position, increased urination (within 3 h of 6.4 g/kg dose), piloerection (within 24 h of 6.4 g/kg dose)	15
1,10-Decanediol (supplier reported >98% pure); Propylene Glycol	Mice	10 males	Test mixture: 1.2% 1,10-Decanediol in a trade name mixture containing unspecified amount of Propylene Glycol; 20 mL/kg test mixture was used	Single dose was administered; animals were observed for 8 days post-exposure and then necropsies were performed	LD_{50} > .20 mL/kg (1.2% of a 20 mL/kg test mixture); clinical signs, behavior, and gross pathology were unaffected by test substance	84
1,10-Decanediol (supplier reported >98% pure); Butylene Glycol	Mice	10 males	Test mixture: 1.2% 1,10-Decanediol in a trade name mixture also containing unspecified amount of Butylene Glycol; 20 mL/kg of test mixture was used	Single dose was administered; animals were observed for 8 days and then necropsies were performed	Normal animal behavior observed; no clinical signs; no changes to main organs (no digestive tract necrosis or ulceration) seen at necropsy	84
Methylpropanediol	Rat, Wistar	5/sex	5 g/kg	Procedures followed were in accordance with OECD TG for Testing of Chemicals; dose administered orally by a syringe and animals observed for 14 days post-dosing; negative controls used; necropsy performed	LD_{50} > 5 g/kg; no mortality; body weight not different from controls; 1 male had pink fluid in bladder at necropsy; clinical signs: diarrhea and chromorhinorrhea observed in 3 animals	20
Methylpropanediol	Rat	Not specified	Not specified	Not specified	LD_{50} > 5g/kg	100

(continued)

Table 8. (continued)

Test Substance(s)	Species/Strain	Test Population	Concentration/Dosage (Vehicle)	Procedure	Results	Reference
Butyl Ethyl Propanediol	Rat, Sprague-Dawley	5/sex/dose	2, 3.2, and 5 g/kg (vehicle=aqueous methylcellulose 1% w/v)	Procedures followed were in accordance with (Good Laboratory Practice-GLP), and similar to European Union Method B.1 (Acute Toxicity Oral); single dose administered by gavage; animals observed for 15 days post-dosing; necropsy performed	LD_{50} calculated to be 2.9 g/kg for males and females; mortality as follows (most within 2 h post-dosing): 1 male (2 g/kg dose), 2 males and 5 females (3.2 g/kg dose), 5 males and 4 females (5 g/kg dose); gross pathology revealed no abnormalities; normal weight gain for rats except for 2 females with low weight gain; clinical signs (all dose levels): piloerection, hunched posture, waddling, lethargy, decreased respiration, ptosis, pallor-these resolved within 48 h post-dosing	17
Butyl Ethyl Propanediol	Rat	Not specified	Not specified	Single oral dose administered (no further details provided)	LD_{50} of 5.04 g/kg	81
Butyl Ethyl Propanediol	Mouse, NMRI	2/sex/dose	.313, .625, 1.25 g/kg (vehicle=PEG 400)	Single dose administered by gavage; animals were observed for toxicity 1, 2-4, 6, 24, 30, and 48 h post-dosing (this acute study was performed in conjunction with a genotoxicity study; summary data from the genotoxicity study is presented in the Genotoxicity Table 11)	No mortality below 1.25 g/kg; 2 male deaths (4 h post-dosing) with 1.25 g/kg dose; clinical signs at all dose levels included reduced activity, eyelid closure, ruffled fur-these resolved by 24 h post-dosing	17
Butyl Ethyl Propanediol	Mouse	2/sex/dose	1, 1.25, 1.5, 2 g/kg	Single dose administered by gavage; animals were observed for up to 48 h post-dosing for toxicity; this was a range-finding study used to determine dosages for a genotoxicity study (summary data is presented in Genotoxicity Table 11)	No mortality below 1.5 g/kg; 1 male death (4 h post-dosing) and 1 female death (6 h post-dosing) with 1.5 g/kg; 1 male death (6 h post-dosing) and 2 female deaths (4 h post-dosing) with 2 g/kg; clinical signs observed throughout all dosages included reduced activity, abdominal position, ruffled fur, closed eyelids (most signs resolved within 24 h or less post-dosing)	17
Isopentyldiol	Mouse, CD-1	5/sex/dose	2 g/kg and 5 g/kg (vehicle= water)	Procedures followed were in accordance with OECD TG 401 (Acute Oral Toxicity); necropsy performed	LD_{50} > 5 g/kg; no mortality; gross necropsy revealed no abnormalities; no signs of toxicity reported	19
				Inhalation		
Propanediol	Rat, Crl:CD (SD)BR	6 males	5 mg/L mean aerosol concentration (vehicle=air)	Animals were restrained in test chamber with conical nose pieces; airflow rate 15 L/min; mass median aerodynamic diameter/geometric standard deviation = 3.2 μm/ 2.1μm; animals exposed for 4 h and observed for 14 days post-exposure	Authors reported an ALC > 5.0 mg/L; no mortalities reported; after animals were removed from chamber all had wet fur/perineum and 1 animal had ocular discharge; 24 h post-exposure weight loss observed in all rats, but all rats gained weight by 14 days post-exposure	12
Propanediol	Rat	Not specified	2000 to 5000 mg/L	Animals were exposed to concentration for 4 hours (no further details provided)	Rats survived; slight-to-moderate weight loss observed the day following exposure	78
1,4-Butanediol	Rat, Crl:CD (SD) BR	10 males/group	4.6 (± .4), 9.4 (± 1.1), or 15.0 (± 4.2) mg/L; particle sizes were 3.0 to 3.6 μm mass median diameter	Food and water were available to rats ad libitum except during exposure; animal noses were positioned in a chamber where aerosolized liquid was present for inhalation of a single, 4 h duration; chamber samples were collected every 30 min; particle size (mass median diameter) was evaluated; rats were observed and weighed daily for 14 days post-exposure and then killed	1 rat died 1 day after exposure to 15.0 (±4.2) mg/L; lethargy and labored breathing were reported with 4.6 and 9.4 mg/L concentrations; red discharge was observed in perineal area with 15.0 mg/L concentration; slight (seen with 4.6 mg/L concentration) to severe (seen with 15.0 mg/L concentration) weight loss noted 24 h post-exposure, but then normal weight gain resumed; with 9.4 and 15.0 mg/L concentrations rats exhibited lung noise and dry, red nasal discharge 1 to 9 days post-exposure	85
1,4-Butanediol	Rat, Wistar	5/sex	5.1 mg/L (no vehicle)	GLP procedures were followed in accordance with OECD TG 403 (Acute Inhalation Toxicity); animals were restrained in test chamber with conical nose pieces; animals were exposed to a single concentration for 4 h; rate of air 1500 L/h; mass median aerodynamic diameter 1.9 μm; animals were observed for 14 days post-exposure; necropsy performed	LC_{50} > 5.1 mg/L (in air) for 4 h for males and females; no mortality; animals gained weight; gross pathology revealed no abnormalities; clinical signs: during exposure and on test day shallow breathing reported; on test day nasal discharge, ruffled fur, staggering gait, and deterioration observed; by 48 h post-exposure all animals were symptom free	13,22
2,3-Butanediol	Rat	12 total	Saturated atmosphere @ 20°C (up to .85 mg/L in air)	Animals exposed for 7 h (no further details specified)	LC_{50} > .85 mg/L (in air) for males and females; no mortality	16
diacetyl (potential metabolite of 2,3-Butanediol)	Rat	6 test animals/group; 18 controls	99.3 ppm, 198.4 ppm, 294.6 ppm	6-hour continuous exposures; animals were necropsied the following morning (18 to 20 hours after removal from the full body exposure chamber)	Scanning electron microscopy revealed consistent changes in the surface morphology of the tracheal bifurcation of rats in the high-exposure groups. These changes consisted of loss of microvilli, decreased numbers of ciliated and mucous cells, flattening and expansion of remaining epithelial cells, and foci of denuded basement membrane.	86
1,5-Pentanediol	Rat, albino	6/sex	Concentrated vapor (concentration in air not specified)	Rats were exposed to a stream of air containing the concentrated vapor; vapor was produced by passing dried air (2.5 liters/min) through a glass disc immersed in 1 inch of 50 mL 1,5-Pentanediol; duration of inhalation exposure was up to 8 h; rats observed for 14 days post-exposure	No deaths were reported for up to 8 h of inhalation exposure	79
1,5-Pentanediol	Rat, Sprague-Dawley	6/sex	.11 g (no vehicle)	Procedures followed were in accordance with OECD TG 403 (Acute Inhalation Toxicity); animals exposed for 7 h; animals observed for 14 days post-exposure; necropsy performed	LC_0 of .078 mg/L air for 7 h for males and females was reported; no mortality; gross pathology revealed no findings	14

(continued)

Table 8. (continued)

Test Substance(s)	Species/Strain	Test Population	Concentration/Dosage (Vehicle)	Procedure	Results	Reference
Hexanediol	Rat, albino	6/sex	Concentrated vapor (concentration in air not specified)	Rats were exposed to a stream of air containing the concentrated vapor; vapor was produced by passing dried air (2.5 liters/min) through a glass disc immersed in 1 inch of 50 mL Hexanediol; duration of inhalation exposure was up to 8 h; rats observed for 14 days post-exposure	No deaths were reported for up to 8 h of inhalation exposure	79,80
Hexanediol	Rat, Fischer 344	3/sex	3.3 mg/L (no vehicle used)	Procedures followed were in accordance with OECD TG 403 (Acute Inhalation Toxicity); animals exposed for 8 h; animals observed for 14 days post-exposure; necropsy performed	LC_0 of 3.3 mg/L (in air) for 8 h for males and females was reported; no mortality; gross pathology revealed no abnormalities; no clinical signs reported	15
Methylpropanediol	Rat	Not specified	Not specified	Not specified	LC_{50} > 5.1 g/L	100

ALC, Approximate Lethal Concentration; ALD, Approximate Lethal Dose; GLP, Good Laboratory Practice; NOAEL, No Observed Adverse Effect Level; OECD TG, Organization for Economic Co-operation and Development Test Guideline.

Table 9. Short-Term and Subchronic Toxicity Studies.

Test Substance(s)	Species/ Strain	Test Population	Concentration/ Dosage (Vehicle)	Exposure Duration	Procedure	Results	Reference
				Oral			
Propanediol	Rat, Crl: CD(SD) BR	5/sex/dose	0, 100, 250, 500, 1000 mg/kg (vehicle=deionized water)	14 days	Animals were dosed daily by gavage as indicated; necropsy performed at study termination	NOEL of 1000 mg/kg/day; no mortality; no clinical signs; body weight, food consumption, organ weights were no different than control group; neither gross necropsy nor microscopic examination revealed any treatment-related findings different from control group	[12]
Propanediol	Rat, Crl: CD(SD) BR	10/sex/group	0, 100, 300, 1000 mg/kg/day (control group received water)	90 days	Procedures followed (GLP) were in accordance with EPA Toxic Substances Control Act Health Effects Testing Guidelines (40CFR1989); single doses were administered daily by gastric intubation for 91-92 days; food and water were available ad libitum; blood samples (fasting) were collected for clinical pathology analysis (evaluated at 4 weeks post-dosing and at study termination); necropsy performed	NOEL of 1000 mg/kg/day for males and females; no mortality; no treatment-related clinical signs; no treatment-related hematology or chemistry parameter changes; neither microscopic nor gross pathology change related to treatment were observed (only incidental lesions typically seen in laboratory rats were noted)	[88]
Propanediol	Rat	5/group	5% or 12% in diet; 5 mL/kg or 10 mL/kg (by gavage); control diet; control diet + 10 mL water by gavage; control diet + 10 mL propylene glycol* by gavage	15 weeks	Animals were dosed by gavage or in the diet as indicated (no further details provided)	100% mortality prior to study termination for animals dosed with 10 mL/kg Propanediol (by gavage); 2 rats died (5 mL/kg group administered by gavage); reduced growth weights were noted in groups dosed in diet with 5% and 12% Propanediol and in rats dosed with 5 mL/kg Propanediol by gavage	[12]
1,4-Butanediol	Rat, Wistar Imp: DAK	8/sex/group	0, 5, 50, 500 mg/kg/ day (control group received distilled water)	28 days	Food and water were available ad libitum; dose administered by gavage 1 time per day for 28 consecutive days; blood samples (fasting) were collected just prior to necropsy	NOEL of 500 mg/kg/day (females) and NOEL of 50 mg/kg/day (males) for clinical chemistry parameters; NOEL of 50 mg/kg/day and LOEL of 500 mg/kg/day for histopathological changes; no mortality; unremarkable clinical observations; body weight, food consumption, and organ weights were unaffected; hematology parameters showed statistically significant differences compared to controls as follows: decrease in red blood cells and elevated hemoglobin (in various treatment groups, not dose dependent), lower hematocrit (males with 500 mg/kg dose), other parameters were statistically significantly different from controls (erythrocytic mean corpuscular volume, mean corpuscular hemoglobin, platelets, thrombocytes) but were not dose dependent; statistically significant increase in alanine aminotransferase and sorbitol dehydrogenase and decrease in total protein (males with 500 mg/kg dose); pronounced proliferation of bile ducts with 500 mg/kg dose (statistically significant compared to controls) and periportal infiltrations in the liver were noted in treated animals	[87]
1,4-Butanediol	Rat, Sprague-Dawley	13/sex/dose	200, 400, 800 mg/kg/day (vehicle=water); controls received water	42 days (males), from 14 days prior to mating until day 3 of lactation (females)	Food and water were available ad libitum; procedures followed were in accordance with OECD TG 422 (Combined Repeated Dose Toxicity Study with the Reproduction/Developmental Toxicity Screening Test); dose administered by gavage daily as indicated; hematology and clinical chemistry samples were collected at study termination; necropsy performed	NOAEL of 200 mg/kg/day for males and females; dose dependent toxic central nervous system signs observed in both sexes; hyperactivity immediately following administration (200 mg/kg/day); hyperactivity observed after a few 400 mg/kg/day doses; some animals exhibited hypoactivity or were recumbent prior to becoming comatose (800 mg/kg/day) but this resolved 5 h post-dosing and animals recovered to normal; lower body weight gains and food consumption earlier in study (at 400 and 800 mg/kg/day) that remained through study termination; statistically significant (dose-related) decrease of blood glucose in treated animals (males); gross pathology revealed no treatment-related lesions; diffuse transitional epithelial hyperplasia and fibrosis in lamina propria of bladder (400 and 800 mg/kg/day) were noted	[13]
1,4-Butanediol and Hexanediol	Rat, Sprague-Dawley	4 (1,4-Butanediol), n=6 (Hexanediol)	.5% 1,4-Butanediol or .5% Hexanediol (control animals received untreated water)	10 wk (1,4-Butanediol); 12 wk (Hexanediol)	Food and water were available ad libitum for test and control animals; each test substance was dissolved in the treated animals' drinking water; at study termination 2 to 4 animals/group were necropsied	1,4-Butanediol: animals lost weight 6 weeks into the study, but gradually resumed weight gain; histology results revealed no changes in tissues compared to controls Hexanediol: weight gain and clinical signs were unaffected; histology results revealed no changes in tissues compared to controls	[39]

(continued)

Table 9. (continued)

Test Substance(s)	Species/ Strain	Test Population	Concentration/ Dosage (Vehicle)	Exposure Duration	Procedure	Results	Reference
Hexanediol	Rat, Wistar	5/sex/dose	100, 400, 1000 mg/kg/day (controls were dosed with water vehicle only)	28 days	Procedures followed were in accordance with GLP and OECD TG 407 (Repeated Dose 28-Day Oral Toxicity in Rodents); animals were dosed daily by gavage as indicated; blood and urine samples were collected throughout study	NOEL of 1000 mg/kg/day for males and females was reported; statistically significant decrease in female body weights was not considered to be treatment-related because of the lack of dose-response relationship and was consistent with historical controls (food consumption was similarly affected); clinical observations, clinical chemistry, gross pathology, and histopathology were unaffected by treatment	15
Hexanediol	Rat, Wistar	10/sex/dose	100, 400, 1000 mg/kg/day (controls were dosed with water vehicle only)	91-92 days	Procedures followed were in accordance with GLP and OECD TG 408 (Repeated Dose 90-Day Oral Toxicity in Rodents); animals were dosed daily by gavage as indicated; blood and urine samples were collected	NOAEL of 400 mg/kg/day (males) and NOAEL of 1000 mg/kg/day (females); no mortality; treatment-related decrease with 1000 mg/kg/day (males only) in mean body weight (−10.5%) and mean body weight change (−18.7%); no treatment-related effects were reported for food/water consumption, ophthalmoscopic exam, hematology, clinical chemistry, histopathology, estrous cycle, sperm parameters, gross pathology; non-adverse treatment-related effects for urinalysis (decreased urine volume and pH and increased specific gravity in males with 1000 mg/kg/day); non-adverse treatment-related decrease in grip strength of hind limbs (males 1000 mg/kg/day); statistically significant increase (compared to controls) in absolute (males 400 mg/kg/day) and relative (males 400 and 1000 mg/kg/day) adrenal gland weight; statistically significant increase in relative brain, epididymides, and testes weights (males 1000 mg/kg/day); statistically significant decrease in absolute weights of heart, seminal vesicle, and spleen (males 1000 mg/kg/day) and absolute and relative spleen weight (females 1000 mg/kg/day)	15
Hexanediol	Rabbit	Not specified	50 to 2000 mg/kg	Not specified	Up to 25 doses were administered by gavage as indicated (no further details provided)	Hexanediol	36
Methylpropanediol	Rat, Wistar	5/sex/dose	0, 300, 600, 1000 mg/kg/day	14 days	Procedures followed were in accordance with OECD Guidelines for Testing Chemicals; doses administered daily by gavage as indicated	There were no treatment-related clinical signs and histopathology; clinical chemistry and hematology parameters were unaffected	20
Methylpropanediol	Rat, Wistar	10/sex/dose	0, 300, 600, 1000 mg/kg/day	90 days	Procedures followed were in accordance with OECD Guidelines for Testing Chemicals; doses administered daily by gavage as indicated	NOEL of 600 mg/kg/day; no treatment-related clinical signs or histopathology were reported; small increase in partial thromboplastin time (females with 1000 mg/kg/day); decrease (10%-14%) in ALT and aspartate aminotransferase AST in males with 1000 mg/kg/day; decrease in inorganic phosphate (males and females with 1000 mg/kg/day)	20
Butyl Ethyl Propanediol	Rat, Sprague-Dawley (CD)	5/sex/dose	15, 150, 1000 mg/kg/day (controls were dosed with methylcellulose vehicle only, 1% w/v aqueous)	28 days	Procedures followed were in accordance with OECD TG 407 (Repeated Dose 28-Day Oral Toxicity in Rodents); animals were dosed daily by gavage as indicated; blood samples collected; necropsy performed	NOAEL of 1000 mg/kg/day (males and females); NOEL of 15 mg/kg/day (males and females); no mortalities; no treatment-related effects were correlated with clinical signs, body weight and weight gain, food/water consumption, hematology, clinical chemistry, and organ weights; gross pathology revealed liver and kidney enlargement (males with 1000 mg/kg/day) and pale, mottled kidneys (males with 150 or 1000 mg/kg/day); an adaptive liver effect noted (males with 1000 mg/kg/day); dose-related increase in renal cortical tubular eosinophilic inclusions (males with 150 or 1000 mg/kg/day)	17

(continued)

Table 9. (continued)

Test Substance(s)	Species/ Strain	Test Population	Concentration/ Dosage (Vehicle)	Exposure Duration	Procedure	Results	Reference
Butyl Ethyl Propanediol	Rat, Wistar	10/sex/dose	15, 150, 1000 mg/kg/day (controls received hydroxypropyl methylcellulose vehicle only)	90 days	Procedures (GLP) followed were in accordance with OECD TG 408 (Repeated Dose 90-Day Oral Toxicity in Rodents); dose administered daily by gavage as indicated; blood and urine samples collected; necropsy performed	NOAEL of 15 mg/kg/day (males) and NOAEL of 150 mg/kg/day (females); treatment-related deaths of 3 males (1000 mg/kg/day) and 1 male (150 mg/kg/day); the following were unaffected by treatment: body weight and weight gain, food/water consumption, ophthalmoscopic exam, hematology, and gross pathology; clinical signs (with 1000 mg/kg/day) were reduced activity, abnormal locomotion and respiration up to 1-2 hours post-dosing after which animals returned to normal, piloerection, hunched body posture, and partially closed eyes were observed; compared to controls a statistically significant increase in urea (males with 150 or 1000 mg/kg/day) and protein and globulin levels (males with 1000 mg/kg/day); statistically significant decrease in urinary pH (males and females with 1000 mg/kg/day); statistically significant increase in urinary specific gravity (males with 1000 mg/kg/day); higher kidney weights (males with ≥ 150 mg/kg/day) and corresponding tubular dilation (males with ≥ 150 ng/kg/day) and nephropathy (males with ≥ 15 mg/kg/day)	[15]
				Inhalation			
Propanediol	Rat, Crl: CD(SD) BR	10 males/group	0, 41, 650, 1800 mg/L (analytical concentrations verified the nominal concentrations 0, 60, 600, 1800 mg/L)	6 h/day for 2 weeks (9 exposures total)	Rats were restrained and fitted with conical nose pieces extending into a chamber during exposure; mass median aerodynamic diameter 2.2-2.4 μm at 2 higher concentrations and vapor at lower concentration; concluding the 2- week exposure period urine and fasting blood samples were collected, 5 rats/group were killed and pathological exam performed; concluding the 2-week exposure an 18-day recovery was allowed for remainder of animals prior to urine and fasting blood analysis and pathological exams	No mortalities during exposure and/or recovery period; no treatment-related clinical signs or clinical chemistry or hematology changes were reported; no abnormalities during microscopic or gross pathological exam (other than incidental or typical of occurring in this strain); NOEL for body weights was 1800 mg/L; vapor phase concentration achieved at 41 mg/L	[2]
1,4-Butanediol	Rat, Crl:CD BR	10 males/group (4 groups total including a control group)	.2, 1.1, 5.2 mg/L (control group was exposed to air only); particle size was 2.5 to 3.6 μm (mass median diameter)	6 h/day, 5 days/wk for 2 weeks (10 exposures total)	Food and water were available to rats ad libitum except during exposure; animal noses were positioned in a chamber where aerosolized liquid was present for inhalation; chamber samples were collected every 30 min; particle size (mass median diameter) was evaluated; rats were observed and weighed daily for 14 days post-exposure; 5 rats/group were killed and necropsied at the end of the 2-week exposure period; the remainder were killed and necropsied concluding the 14-day post-exposure recovery period; clinical laboratory and urine analysis were performed on all rats (both after 2-wk exposure period and after 14-day post exposure period)	NOAEC reported for .2 and 1.1 mg/L; no mortality at any level; only clinical sign noted for some rats in all groups was slight, red nasal discharge during inhalation exposure; body weights (5.2 mg/L) were statistically significantly lower than controls; serum cholesterol concentrations (5.2 mg/L) were statistically significantly lower in rats killed after 10th exposure compared to controls (not seen in 14-day post-exposure rats at 5.2 mg/L); statistically significantly higher erythrocyte counts and hematocrits (5.2 mg/L) in rats killed after 10th exposure compared to controls (not seen in 14-day post-exposure rats at 5.2 mg/L); urine analysis and organ weights were unaffected by treatment; in lymphoid cells from thymus slight atrophy was noted (5.2 mg/L), but was not present in the 14-day post exposure rats with 5.2 mg/L	[85]
1,4-Butanediol	Rat	Males	1500 to 2000 mg/L	2 h/day each day for 4 months	Animals were exposed daily as indicated (no further details provided)	LOAEC of 1500 mg/L (or LOAEL 85 of mg/kg/day); around 3-4 weeks into the study a sleepy condition was induced 10-20 min post-exposure; noted on histopathological exam were pulmonary emphysema, mild lung edema, treatment-related inflammatory changes of single alveolar cell and weak hyperplasia of alveolar septum (lymphocytes and histiocytes were present)	[22]
1,4-Butanediol	Rat	Males	300 to 500 mg/L	2 h/day for 6 days/week for 4 months	Animals were exposed as indicated (no further details provided)	NOAEC of 500 mg/L (or 23 mg/kg/day); body weight, neuromuscular response, hemogenesis, liver and kidney function were unaffected	[22]

(continued)

Table 9. (continued)

Test Substance(s)	Species/ Strain	Test Population	Concentration/ Dosage (Vehicle)	Exposure Duration	Procedure	Results	Reference
diacetyl (potential metabolite of 2,3-Butanediol) (≥98.5%)	Mouse, B6C3F1/N	10/sex/dose	0, 6.25, 12.5, 25, 50, or 100 ppm	6 h + T_{90} (10 min)/ day, 5 days/wk for 14 wks	Whole body inhalation	Mean body weights of males exposed to 50 or 100 ppm and females exposed to ≥12.5 ppm were significantly less than controls. Significant increases in neutrophil counts occurred in 50 and 100 ppm males and 100 ppm females and were consistent with inflammation in the respiratory tract. Exposure-related significantly increased incidences of non-neoplastic lesions occurred in the respiratory tract of male and female mice, primarily in the 50 and 100 ppm groups, and the highest number of lesions occurred in the nose.	[89]
diacetyl (potential metabolite of 2,3-Butanediol) (≥98.5%)	Rat, Wistar Han [Crl: WI (Han)]	10/sex/dose for both main and subgroups	0, 6.25, 12.5, 25, 50, or 100 ppm	6 h + T_{90} (10 min)/ day, 5 days/wk for 14 wk	Whole body inhalation; a subgroup was exposed for 23 days for clinical pathology analysis	The mean body weights of 100 ppm males and females were significantly less than those of the controls. Clinical observations, noted only in the 50 and 100 ppm groups, included abnormal breathing, sneezing, and lethargy. On day 23 and at study termination, neutrophil counts were significantly increased in 100 ppm females and were consistent with the inflammation observed in the respiratory tract. Exposure-related significantly increased incidences of non-neoplastic lesions occurred in the respiratory tract of male and female rats, primarily in the 50 and 100 ppm groups, and the highest number of lesions occurred in the nose.	[89]

ALT, alanine transaminase; AST, aspartate aminotransferase; GLP, Good Laboratory Practice; LOAEC, Lowest Observed Adverse Effect Concentration; LOAEL, Lowest Observed Adverse Effect Level; LOEL, Lowest Observed Effect Level; NOAEC, No Observed Adverse Effect Concentration; NOAEL, No Observed Adverse Effect Level; NOEL, No Observed Effect Level; OECD TG, Organization for Economic Co-operation and Development Test Guideline.

1,5-Pentanediol,[79] >10 g/kg in rabbits for Hexanediol,[79,80] and >2 g/kg in rabbits for Butyl Ethyl Propanediol.[81] The LD_{50}s reported for 1,4-Butanediol and Methylpropanediol were >2 g/kg in dermally exposed rats[13] and rabbits.[20] After dermal exposure to 1,4-Butanediol (5 g/kg) in rats, findings included dermal lesions (48 h post-application) and abnormalities in the liver (14 days post-application), but no mortality.[82] Clinical signs observed in rats within 2 hours of exposure to 2 g/kg 1,4-Butanediol were dyspnea and poor general state; slight erythema was noted 24 hours post-exposure.[13] One source reported that 1,4-Butanediol was toxic on the skin, however the quality of the test material was questionable; the same source noted that there was no indication of absorption of acutely toxic quantities of 1,4-Butanediol in rabbit skin (no further details provided).[83] Clinical signs reported in rabbits following dermal exposure to 2 g/kg Methylpropanediol (time between exposure and appearance of signs not specified) were slight erythema, diarrhea, yellow nasal discharge, bloated abdomen, soiling of anogenital area, gastrointestinal tract abnormalities, and lung and liver abnormalities.[20] By 14 days post-application (2 g/kg Methylpropanediol), abnormalities in kidney and gastrointestinal tract of rabbits were reported at necropsy; there were no treatment-related mortalities.

Oral. Propanediol, 1,4-Butanediol, 2,3-Butanediol, 1,5-Pentanediol, Hexanediol, 1,10-Decanediol, Methylpropanediol, Butyl Ethyl Propanediol, and Isopentyldiol were evaluated for toxicity in acute oral exposure studies in animals. An approximate lethal dosage (ALD) of 17 g/kg (70% purity) and >25 g/kg (99.8% purity) and an LD_{50} of 14.9 mL/kg were reported in rats dosed with Propanediol; clinical effects noted were sluggishness, sedation, ataxia, irregular respiration, unconsciousness followed by the death of some of the animals.[12,35] Various animal studies reported an LD_{50} between 1.2 and 2.5 g/kg for 1,4-Butanediol.[13,22,34,37,74,82] Findings at necropsy in one rat study (animals killed 48 h post-dosing with 1.8 g/kg 1,4-Butanediol) were fluid-filled gastrointestinal tract and congestion of internal organs, histopathological changes in liver and kidneys, extensive vacuolar degeneration of hepatic parenchyma, granular clusters of desquamated cells, and interstitial infiltration of mononuclear kidney cells.[82] In another rat study, 14-days post dosing (1 to 2.5 g/kg 1,4-Butanediol), the animals that survived to necropsy showed no abnormal findings and an LD_{50} of 1.5 g/kg was reported.[13] Clinical signs observed after 1,4-Butanediol (1.35 to 2 g/kg dosage) administration in rats included irregular, decreased respiration and catalepsy, dyspnea, apathy, abnormal position, staggering, spastic gait, atony, and unusual pain reflex.[13,82] For the following alkane diols, LD_{50}s were reported as: >5 g/kg in rats[16,34] and 9 g/kg[49] in mice for 2,3-Butanediol; 10 g/kg 1,5-Pentanediol in rats;[14] 3 g/kg Hexanediol in rats[15]; >.20 mL/kg 1,10-Decanediol (1.2% in a 20 mL/kg trade name mixture also containing unspecified amounts of Propylene Glycol) in mice;[84] >5 g/kg Methylpropanediol in rats;[20] 2.9 g/kg[17] and 5 g/kg[81] Butyl Ethyl Propanediol in rats; and >5 g/kg Isopentyldiol in mice.[19] Clinical signs reported in rats included staggering, dyspnea, piloerection, and erythema after dosing with 2,3-Butanediol, staggering, spastic gait, salivation, exsiccosis, paresis, and dyspnea after dosing with 1,5-Pentanediol, staggering, apathy, narcotic state, constant urination, and piloerection after dosing with Hexanediol, diarrhea, chromorhinorrhea, piloerection, and pallor after dosing with Methylpropanediol, and piloerection and pallor and dosing with Butyl Ethyl Propanediol.[14-17,20] In rats dosed with 10 g/kg 1,5-Pentanediol, dilation of the heart and congestive hyperemia, bloody stomach ulcerations, and abnormal bladder content were observed at necropsy.[14] After dosing with Methylpropanediol (5 g/kg), 1 rat (n = 10) showed pink bladder fluid at necropsy.[20] There were no clinical signs reported in mice dosed with Isopentyldiol[19]; at necropsy, rats dosed with Hexanediol[15] or Butyl Ethyl Propanediol[17] and mice dosed with 1,10-Decanediol[84] or Isopentyldiol[19] showed no abnormalities. In mice (n = 2/sex/dosage) dosed with Butyl Ethyl Propanediol, 2 deaths were reported at 1.25 g/kg; 2 deaths at 1.5 g/kg; 3 deaths at 2 g/kg.[17]

Inhalation. Studies evaluating the toxicity of Propanediol, 1,4-Butanediol, 2,3-Butanediol, 1,5-Pentanediol, Hexanediol, and Methylpropanediol were conducted in rats exposed by inhalation. An approximate lethal concentration (ALC) was estimated by the authors to be >5 mg/L for Propanediol (4 h exposure time, 3.2 µm mass median aerodynamic diameter); clinical signs were wet fur/perineum and ocular discharge.[12] Rats survived a 4-hour exposure to 2000 to 5000 mg/L Propanediol.[78] Rats exposed to 1,4-Butanediol (4.6 to 15 mg/L) by inhalation showed lethargy, labored breathing, red discharge in perineal area, weight loss within 24 hours post-exposure, followed by resumption of normal weight gain, and lung noise/dry nasal discharge 1 to 9 days post-dosing; 1 death (15 mg/L) occurred 1 day post-dosing.[85] In a study in which groups of 6 rats were exposed for 6 hours to 99.3 ppm, 198.4 ppm, or 294.6 ppm diacetyl (potential metabolite of 2,3-Butanediol), and necropsied 18-20 hours after removal from the full body exposure chamber, consistent changes in the surface morphology of the tracheal bifurcation of rats in the high-exposure groups were observed.[86] In another rat study, an LC_{50} > 5.1 mg/L 1,4-Butanediol (4 hour exposure time) was reported; no mortality or abnormalities during gross pathology examination were reported and clinical signs, which resolved within 48 hours post-exposure, included shallow breathing, nasal discharge, ruffled fur, staggering gait, and deterioration.[13,22] The results for other alkane diols evaluated were: no deaths after 7 to 8 hours of exposure to 2,3-Butanediol (up to .85 mg/L in air)[16]; 1,5-Pentanediol (concentrated vapor),[79] Hexanediol (concentrated vapor),[79,80] or an LC_{50} > 5.1 g/L was reported for

inhalation of Methylpropanediol (duration of inhalation not specified).[2]

Short-Term Toxicity

Below is a summary of the short-term toxicity studies that are presented in detail in Table 9.

Animal

Oral. Short-term oral exposure studies were conducted in animals to investigate the toxicity of Propanediol, 1,4-Butanediol, Hexanediol, Methylpropanediol, and Butyl Ethyl Propanediol. A no-observed-effect-level (NOEL) of 1000 mg/kg/day was reported for Propanediol in a 14-day rat study.[12] A 28-day experiment in rats evaluating the toxicity of 1,4-Butanediol revealed liver abnormalities; NOELs of 500 mg/kg/day (females) and 50 mg/kg/day (males) were reported.[87] Another rat study (approximately 42 days exposure duration) examining 1,4-Butanediol, showed lower body weight gains and food consumption (400 and 800 mg/kg/day), a statistically significant dose-related decrease of blood glucose (male treated animals), and bladder abnormalities (400 and 800 mg/kg/day); a no-observed-adverse-effect-level (NOAEL) of 200 mg/kg/day was reported.[13] The results of testing Hexanediol in rats (up to 1000 mg/kg/day for 28 days)[15] and rabbits (up to 2000 mg/kg for 25 doses, duration unknown)[36] yielded a reported NOEL of 1000 mg/kg/day for the rats[15] and observations of thrombosis and treatment-related effects (unspecified) on the liver and kidneys in the rabbits.[36] Results of testing Methylpropanediol in rats up to 1000 mg/kg/day for 14 days were reported to be unremarkable.[20] A NOAEL of 1000 mg/kg/day was reported for Butyl Ethyl Propanediol in a 28-day rat experiment; rats exhibited abnormalities of the liver (in males at 1000 mg/kg/day) and kidney (in males at 150 or 1000 mg/kg/day).[17]

Inhalation. Short-term inhalation exposure studies were conducted in animals to evaluate the toxicity of Propanediol and 1,4-Butanediol. A rat study evaluating exposure to Propanediol, up to 1800 mg/L, 6 h/day for 2 weeks (9 exposures total), reported no remarkable results.[78] A study in which rats were exposed to 1,4-Butanediol (up to 5.2 mg/L), 6 h/day, 5 days/week for 2 weeks showed slight, red nasal discharge at all levels tested (.2, 1.1, 5.2 mg/L), lower body weights (at 5.2 mg/L only), and abnormal blood chemistry parameters (at 5.2 mg/L only); a no-observed-adverse-effect-concentration (NOAEC) of 1.1 mg/L was reported.[85]

Subchronic Toxicity

Below is a synopsis of the subchronic toxicity studies that are presented in detail in Table 9.

Animal

Oral. Propanediol, Hexanediol, Methylpropanediol, and Butyl Ethyl Propanediol were evaluated for toxicity in subchronic (approximately 3-month) studies in rats with oral exposure. A NOEL of 1000 mg/kg/day was reported for Propanediol[88]; another evaluation of 5 or 10 mL/kg of Propanediol resulted in 100% mortality (5 deaths) at 10 mL/kg and 2 deaths at 5 mL/kg.[12] NOAELs for Hexanediol were reported to be 400 mg/kg/day (males) and 1000 mg/kg/day (females); a treatment-related decrease (in males at 1000 mg/kg/day) in mean body weights and a statistically significant increase in relative adrenal gland weights (in males at 400 and 1000 mg/kg/day) and in relative weights of the brain, epididymides, and testes (in males at 1000 mg/kg/day) were observed.[15] A NOEL of 600 mg/kg/day was reported for Methylpropanediol; abnormalities seen were decreased liver enzymes and inorganic phosphate (at 1000 mg/kg/day).[20] NOAELs of 150 mg/kg/day (females) and 15 mg/kg/day (males) were reported for Butyl Ethyl Propanediol; there were 4 treatment-related deaths (males at 150 or 1000 mg/kg/day), abnormal locomotion and respiration 1 to 2 hours post-dosing (after which animals returned to normal), hunched body, and urinary (at 150 and 1000 mg/kg/day) and kidney abnormalities (at ≥15 mg/kg/day) reported.[17]

Inhalation. In rat studies of 4-month durations (2 h/day exposure time) evaluating 1,4-Butanediol, a NOAEC of 500 mg/L (or NOAEL of 23 mg/kg/day) and a lowest-observed-adverse-effect-concentration (LOAEC) of 1500 mg/L (or lowest-observed-adverse-effect-level, LOAEL, of 85 mg/kg/day) were reported; observations in the study reporting the LOAEC of 1500 mg/L included a sleepy condition 20 minutes post-exposure, and histopathological exam revealed pulmonary emphysema, mild lung edema, treatment-related inflammatory changes of single alveolar cell and weak hyperplasia of alveolar septum.[22] In 14-wk studies of diacetyl (potential metabolite of 2,3-Butanediol) in mice and rats, significant increases in neutrophil counts consistent with inflammation in the respiratory tract were observed at 50 and 100 ppm (mice), and at 100 ppm (rats).[89] Significantly increased incidences of exposure-related, non-neoplastic lesions occurred in the respiratory tract of male and female rats and mice, primarily in the 50 and 100 ppm groups; the highest number of lesions occurred in the nose.

Chronic Toxicity

Oral

1,4-Butanediol. Experimental details for one chronic toxicity study found in the literature were limited.[22,90] In this study male rats (n = 6/group) were orally exposed to .25, 3, or 30 mg/kg 1,4-Butanediol for 6 months. Controls were used (no further details). At the 30 mg/kg dosage, blood

Table 10. Developmental and Reproductive Toxicity (DART) Studies.

Test Substance(s)	Species/ Strain	Test Population	Dosage (Vehicle)	Procedure	Results	Reference
			Oral			
Propanediol	Rat, Crl: CD(SD) BR	10 males/ group	0, 100, 300, 1000 mg/kg/day (control group received water)	Procedures followed were in accordance with GLP and EPA Toxic Substances Control Act Health Effects Testing Guidelines (40CFR1989); single doses were administered daily by gastric intubation for about 90 days; food and water were available ad libitum; at study termination the animals were killed and epididymis excised and weighed; sperm motility was measured; sperm assessed for morphology; testis and epididymis were homogenized and examined for sperm production rates	Spermatogenic endpoints (mean testicular and epididymal sperm counts, sperm production rate, sperm motility and morphology) were unaffected by treatment at all dose rates	[88]
Propanediol	Rat, Sprague-Dawley	20 females/ group	0, 250 or 1000 mg/kg/day (vehicle=.8% aq. hydroxypropyl-methylcellulose gel)	Procedures followed (GLP) were in accordance with OECD TG 414 (Prenatal Developmental Toxicity Study); females were dosed by gavage on days 6 through 15 of gestation	Maternal and fetal toxicity NOAEL of 1000 mg/kg/day; no maternal toxic effects from treatment (fertility rate was 91% for all dose rates); no embryotoxic or teratogenic effects on fetuses from treatment	[12]
1,4-Butanediol	Mouse, Swiss (CD-1)	28-32/ group	0, 100, 300, 600 mg/kg/day	Pregnant mice were dosed by gavage during days 6 through 15 of gestation	Maternal and developmental NOAEL of 100 mg/kg/day; maternal and developmental LOAEL of 300 mg/kg/day ; no maternal mortality; maternal central nervous system intoxication was observed (300-600 mg/kg/day) 4 h after daily dosing; reduced food consumption and body weight/weight gain noted (maternal with 300-600 mg/kg/day); developmental toxicity observed was reduced fetal body weight (300-600 mg/kg/day maternal dose)	[91]
1,4-Butanediol	Rat, Sprague-Dawley	13/sex/ dose	200, 400, 800 mg/kg/day (vehicle=water); controls received water	Food and water were available ad libitum; procedures followed were in accordance with GLP and OECD TG 422 (Combined Repeated Dose Toxicity Study with the Reproduction/ Developmental Toxicity Screening Test); dose administered daily by gavage for 42 days (males) and from 14 days prior to mating until day 3 of lactation (females); non-fasting blood samples collected after final exposure	Offspring male/female NOEL of 400 mg/kg/day (pup weight slightly, but statistically significantly decreased on lactation day 4 at 800 mg/kg/day, effect was secondary to maternal reduced food consumption and body weight); Transient hyperactivity (with 200 and 400 mg/kg/day in parents) was observed following administration; neurological effects (hypoactivity and recumbency followed by coma in some animals) observed at ≥ 400 mg/kg/day but reversed 5 h post-dosing; no parental reproductive parameters were changed by treatment; offspring viability and morphological abnormalities were unaffected by treatment	[13,22]
Hexanediol	Rat, Wistar	10/sex/ dose	0, 100, 400, or 1000 mg/kg/day, controls received water vehicle only	Food and water available ad libitum; procedures followed were in accordance with GLP and OECD TG 421 (Reproduction/Developmental Toxicity Screening Test; animals dosed daily by gavage; duration of treatment for males was approximately 4 weeks (2 weeks premating); duration of treatment for females was about 6 weeks (2 weeks premating); study termination was post-partum day 4; animals killed at study conclusion and necropsy performed	Parental (female) NOAEL of 1000 mg/kg/day; parental (male) NOAEL of 400 mg/kg/day; offspring (male/female) NOAEL of 1000 mg/kg/day; male parents (1000 mg/kg/day) showed treatment-related (stat. sig) decrease in food consumption and body weight; male fertility index was 90%-100%; female mating index was 90%-100% and fertility index was 100%; offspring exhibited no treatment-related effects	[15]

(continued)

Table 10. (continued)

Test Substance(s)	Species/ Strain	Test Population	Dosage (Vehicle)	Procedure	Results	Reference
Hexanediol	Rat, Wistar	25 females/ group	0, 100, 400, 1000 mg/kg/day (controls received water vehicle only)	Food and water were available ad libitum; procedures followed were in accordance with GLP and OECD TG 414 (Prenatal Developmental Toxicity Study); animals were dosed by gavage during days 6 through 19 of gestation; on day 20 of gestation females were killed and necropsies performed	Maternal and developmental NOAEL of 1000 mg/kg/day; no maternal mortalities or clinical signs; maternal body weight and food consumption unaffected; maternal necropsies revealed no findings; conception rate 96%-100%; female fetus weight (1000 mg/kg dose) was slightly but statistically-significantly decreased, and still within historical control range; a few external malformation were reported in test groups and the control group, but agreed with historical control data; 2 fetal soft tissue malformations (1000 mg/kg) and skeletal malformations (all test groups) occurred, but data were not significantly different from controls and agreed with historical control data	15
Hexanediol	Rat, Wistar	10/sex/ dose	0, 100, 400, 1000 mg/kg/day (controls received water vehicle)	Food and water were available ad libitum: procedures were in accordance with GLP and OECD TG 421 (Reproduction/Developmental Toxicity Screening Test); animals were dosed by gavage; duration of treatment for males was approximately 4 weeks (2 weeks premating); duration of treatment for females was about 6 weeks (2 weeks premating); test duration of treatment and exposure was until day 4 postpartum of F1 generation; at study termination uterus, ovaries, and offspring were examined	Maternal and developmental NOAEL of 1000 mg/kg/day; no maternal toxic or embryotoxic effects were observed	15
Methylpropanediol	Rat, Sprague-Dawley	10/sex/ dose	0, 100, 300, 1000 mg/kg/day	A 2-generation reproduction study was conducted; animals were dosed by gavage (no further details provided)	Maternal and neonatal NOAEL of 1000 mg/kg/day	115
Methylpropanediol	Rat, Wistar	Females	Up to 1000 mg/kg, negative controls were used (no further details specified)	Animals were dosed by gavage on days 0 through 20 of gestation (no further details specified); this study was repeated due to possibly skewed results (outcomes of both studies are summarized in the Results column)	No maternal toxicity or changes in fetal development were reported; potential embryotoxicity reported because of a statistically significant increase (compared to controls) in early resorptions (maternal 600 and 1000 g/kg/day doses), but results may have been skewed by 1 female at those dose levels with atypically high incidences so the study was repeated; the follow-up study results were unremarkable and indicated that interuterine growth and survival were unaffected by treatment (with up to 1000 mg/kg/day maternal dose)	100
Methylpropanediol	Rabbit, New Zealand White	Females	0, 250, 500, 1000 mg/kg	Animals were dosed by gavage on days 0 through 29 of gestation (no further details provided)	Maternal toxicity, fetotoxicity, and teratogenic effects NOAEL of 1000 mg/kg/day; intrauterine growth and survival was not affected by treatment, no treatment-related effects were observed for malformations or changes in soft or skeletal tissues	32

(continued)

Table 10. (continued)

Test Substance(s)	Species/ Strain	Test Population	Dosage (Vehicle)	Procedure	Results	Reference
Butyl Ethyl Propanediol	Rat, Sprague-Dawley	24 females	0, 15, 150, 1000 mg/kg/day (controls received the aqueous hydroxypropyl methylcellulose vehicle only)	Food and water were available ad libitum; procedures followed were in accordance with GLP and OECD TG 414 (Prenatal Development Toxicity Study); dose administered by gavage on days 6 through 19 of gestation; animals were killed on gestation day 20; necropsy performed	Maternal NOAEL of 150 mg/kg/day; Developmental NOAEL of 1000 mg/kg/day; maternal clinical signs included subdued behavior, reduced activity, staggering, limb dragging, slow/ wheezing respiration, excess salivation, piloerection, partially closed eyes (1000 mg/kg); small decrease in maternal body weights/food consumption (day 7-8 of gestation, 1000 mg/kg) which returned to normal by gestation days 9-12; no embryotoxic/teratogenic effects were observed	[17]

GLP, good laboratory practice; LOAEL, lowest observed adverse effect level; NOAEL = no observed adverse effect level; OECD TG= Organization for Economic Co-operation and Development Test Guideline.

cholinesterase activity was reduced, the ratio of blood serum protein fractions changed, the thiol groups in whole blood and the brain decreased, liver glycogen and choline esterase activity decreased, vitamin C in organs decreased, and there was an increase in blood serum transaminases. A substantial increase in the auto-diffusion coefficient of tissue fluid (herein, owing to variation in the permeability of cell membranes) was found in the liver and brain with the 3 and 30 mg/kg dosages. Liminal morphological changes were noted with the 3 mg/kg dosage. At the 30 mg/kg dosage, the morphological changes observed were a reduction in Nissl bodies, glial element growth in cerebral tissue, fatty dystrophy, hyperemia in organs, and sclerotic growth in liver.

Developmental and Reproductive Toxicity (dart) Studies

Provided below is a summary of DART studies that are presented in detail in Table 10.

Oral

Developmental and reproductive toxicity studies were conducted in animals that were orally exposed to Propanediol, 1,4-Butanediol, Hexanediol, Methylpropanediol, or Butyl Ethyl Propanediol. In rat studies evaluating Propanediol at dose rates up to 1000 mg/kg/day, spermatogenic endpoints were unaffected (90-day exposure duration)[88] and no maternal (dosing on days 6 - 15 of gestation) or fetal toxic effects were observed (maternal and fetal NOAEL 1000 mg/kg/day).[12] In a mouse study evaluating 1,4-Butanediol at up to 600 mg/kg/day (dosing on days 6 - 15 of gestation), a maternal and developmental NOAEL of 100 mg/kg/day and a LOAEL of 300 mg/kg/day were reported; maternal central nervous system intoxication (300-600 mg/kg/day) and maternal and fetal body weight reduction (maternal 300 - 600 mg/kg/day) were observed.[91] For male and female rats dosed with up to 800 mg/kg/day 1,4-Butanediol (14 days prior to mating and for females through day 3 of lactation), the following were reported: developmental NOEL of 400 mg/kg/day (pup weight slightly but statistically significantly decreased on lactation day 4 at 800 mg/kg/day, secondary to maternal reduction in body weight), parental transient hyperactivity (200 and 400 mg/kg/day) and reversible parental hypoactivity (≥400 mg/kg/day), but no parental reproductive parameters were changed by treatment.[13,22] A maternal and developmental NOAEL of 1000 mg/kg/day was reported in animal studies on Hexanediol (rats dosed on days 6-19 of gestation)[15] and for Methylpropanediol (rats dosed on days 0 - 20 of gestation; rabbits on days 0 - 29).[2,32] In a rat study evaluating Butyl Ethyl Propanediol (up to 1000 mg/kg/day on days 6 - 19 of gestation), a maternal NOAEL of 150 mg/kg/day (reduced activity, staggering, limb dragging, slow respiration, and reduced food consumption/body weight at 1000 mg/kg dose) and a developmental NOAEL of 1000 mg/kg/day were reported.[17]

Genotoxicity

Provided below is a summary of genotoxicity studies that are presented in detail in Table 11.

In Vitro

Genotoxicity data are available for Propanediol, 1,4-Butanediol, 2,3-Butanediol, 1,5-Pentanediol, Hexanediol, 1,10-Decanediol, Methylpropanediol, Butyl Ethyl Propanediol and Isopentyldiol. Experiments conducted in vitro evaluating Propanediol were negative for genotoxicity in a mammalian cell gene mutation assay (up to 5000 µg/mL), a chromosomal aberration test (up to 5000 µg/mL), and an Ames test (up to 5000 µg/plate).[12] A mammalian chromosomal aberration test

Table 11. Genotoxicity Studies.

Test Substance(s)	Species/Strain	Sample Type or Test Population-Sex	Concentration/ Dosage (Vehicle)	Procedure	Results	Reference
			IN VITRO			
Propanediol	*Salmonella typhimurium*	TA1535, TA1537, TA98, TA100, TA102	33.3, 100, 333.3, 1000, 2500, 5000 μg/plate (vehicle=water)	Bacterial reverse mutation assay (Ames Test) was performed, with and without metabolic activation, in accordance with GLP and OECD TG 471 (Bacterial Reverse Mutation Assay); negative, vehicle, and positive controls were used	Negative; controls performed as expected	12
Propanediol	Hamster	Chinese Hamster Lung Fibroblasts (V79)/ HPRT	0, 250, 1000, 2500, 5000 μg/mL	Mammalian cell gene mutation assay was performed, with and without metabolic activation, in accordance with GLP and OECD TG 476 (In vitro Mammalian Cell Gene Mutation Test); 2 independent experiments using the same test conditions were performed; negative, vehicle, and positive controls were used	Negative; controls performed as expected; cytotoxicity was reported (low survival) at 5000 μg/mL without using metabolic activation	12
Propanediol	Hamster	Chinese Hamster Lung Fibroblasts (V79)	625, 1250, 2500, 5000 μg/mL (vehicle=water)	Mammalian chromosomal aberration test was performed, with (4 h exposure) and without (4 or 20 h exposure) metabolic activation, in accordance with GLP and OECD TG 473 (In vitro Mammalian Chromosome Aberration Test); vehicle and positive controls were used	Negative; controls performed as expected; cytotoxicity was noted at 5000 μg/mL without metabolic activation (20 h exposure)	12
Propanediol	Hamster	Chinese Hamster Lung Fibroblasts (V79)	250, 1000, 2500 μg/mL (18 h, without activation); 500, 2500, 5000 μg/mL (18 h, with activation); 375, 1250, 2500 μg/mL (18 h, without activation); 1250 μg/mL (28 h, without activation); 2500, 3750, 5000 μg/mL (18 h, with activation); 5000 μg/mL (28 h, with activation)	Mammalian chromosomal aberration test was performed, with and without metabolic activation, in accordance with GLP and OECD TG for Testing of Chemicals, section 4, No. 473); vehicle and positive controls were used	Positive for genotoxicity (18 h interval with 2500 μg/mL concentration) without metabolic activation (controls performed as expected); negative for genotoxicity with metabolic activation (controls performed as expected)	12
1,4-Butanediol	*S. typhimurium* and *Escherichia coli*	*S. typhimurium*: TA98, TA100, TA1535, TA1537; *E. coli*: WP2 uvrA	0, 313, 625, 1250, 2500, 5000 μg/plate	Ames Test was performed, with and without metabolic activation, in accordance with GLP and OECD TG 471 (Bacterial Reverse Mutation Assay) and 472 (Genetic Toxicology: *E. coli*, Reverse Mutation Assay); vehicle and positive controls were used	Negative; controls performed as expected	13
1,4-Butanediol	*S. typhimurium*	TA1535, TA1537, TA1538, TA98, TA100	500, 1000, 2500, 5000, 7500, and 10,000 μg/plate (vehicle=distilled water)	Ames Test was performed with and without metabolic activation; negative, vehicle, and positive controls were used	Negative: controls performed as expected	13
1,4-Butanediol	*S. typhimurium*	TA98, TA100, TA1535, TA97	0, 1, 3, 10, 33, 100, 333, 1000, 3333, and 10,000 μg/plate	Mutagenicity test performed; .05 mL of test compound was incubated @ 37°C with *S. typhimurium* and a buffer; tests were performed with and without metabolic activation; negative and positive controls were used	Negative	92
1,4-Butanediol	Hamster	Chinese Hamster Ovary cells	20, 60, 200, 600, 2000, 5000 μg/mL (vehicle=Ham's F12 cell culture medium)	Mammalian cell gene mutation assay was performed, with and without metabolic activation in accordance with GLP and OECD TG 476 (In vitro Mammalian Cell Gene Mutation Test); vehicle, negative, and positive controls were used	Negative; controls were validated	13
1,4-Butanediol	Hamster	Chinese Hamster Lung Fibroblasts (V79)	400, 3000, 5000 μg/mL (vehicle=MEM cell culture medium)	Chromosomal aberration test was performed, with and without metabolic activation, in accordance with GLP and OECD TG 473 (In vitro Mammalian Chromosome Aberration Test); vehicle and positive controls were used	Negative; controls performed as expected	13
1,4-Butanediol	Hamster	Chinese Hamster Lung (CHL/IU) cells	0, 230, 450, 900 μg/mL (vehicle=distilled water)	Chromosomal aberration test was performed, with and without metabolic activation, in accordance with GLP and OECD TG 473 (In vitro Mammalian Chromosome Aberration Test); vehicle and positive controls were used	Negative; controls performed as expected	13
2,3-Butanediol	*S. typhimurium*	TA98 and TA mix (TA7001-7006)	4 to 5000 μg/mL	Ames II™ Assay test was performed (GLP), with and without metabolic activation; negative, vehicle, and positive controls were used	Negative; controls performed as expected	16

(continued)

Table 11. (continued)

Test Substance(s)	Species/Strain	Sample Type or Test Population-Sex	Concentration/ Dosage (Vehicle)	Procedure	Results	Reference
1,5-Pentanediol	*S. typhimurium*	TA1535, TA1537, TA98, TA100	0, 20, 100, 500, 2500, 5000 μg/plate (vehicle=water; application by agar plate incorporation)	Ames Test was performed, with and without metabolic activation, in accordance with GLP and OECD TG 471 (Bacterial Reverse Mutation Assay); negative, vehicle, and positive controls were used	Negative; controls performed as expected	14
1,5-Pentanediol	*S. typhimurium*	TA1535, TA1537, TA98, TA100	0, 20, 100, 500, 2500, 5000 μg/plate (vehicle=water; application by preincubation @ 37°C for 20 min)	Ames Test was performed, with and without metabolic activation, in accordance with GLP and OECD TG 471 (Bacterial Reverse Mutation Assay); negative, vehicle, and positive controls were used	Negative; controls performed as expected	14
Hexanediol	*S. typhimurium*	TA1535, TA1537, TA98, TA100	20, 100, 500, 2500, 5000 μg/plate (vehicle=dimethyl sulfoxide or DMSO; application by agar plate incorporation)	Ames Test was performed (non-GLP), with and without metabolic activation, in accordance with OECD TG 471 (Bacterial Reverse Mutation Assay); negative, vehicle, and positive controls were used	Negative; controls performed as expected	15
Hexanediol	*S. typhimurium*	TA1535, TA1537, TA98, TA100	20, 100, 500, 2500, 5000 μg/plate (vehicle=DMSO; application by preincubation @ 37°C for 20 min)	Ames Test was performed (non-GLP), with and without metabolic activation, in accordance with OECD TG 471 (Bacterial Reverse Mutation Assay); negative, vehicle, and positive controls were used	Negative; controls performed as expected	15
Hexanediol	Hamster	Chinese Hamster V79 cells	.3, .6, 1.2 μg/mL (vehicle=MEM; application by agar plate incorporation and preincubation in suspension)	Mammalian chromosomal aberration test was performed, with and without metabolic activation, in accordance with GLP and OECD TG 473 (In vitro Mammalian Chromosome Aberration Test); negative, vehicle, and positive controls were used	Negative; controls performed as expected	15
Hexanediol	Hamster	Chinese Hamster (V79)/ Hypoxanthine-guanine phosphoribosyl transferase (HPRT)	500, 1000, 2500, 5000 μg/mL	Mammalian cell gene mutation assay was performed, with and without metabolic activation, in accordance with GLP and OECD TG 476 (In vitro Mammalian Cell Gene Mutation Test); negative, vehicle, and positive controls were used	Negative; controls performed as expected	15
1,10-Decanediol (supplier reported >98% pure); Propylene Glycol	*S. typhimurium*	TA98, TA100, TA1537	Test mixture: 1.2% 1,10-Decanediol in a trade name mixture containing unspecified amount of Propylene Glycol; evaluated up to 10,000 μg/plate (~120 μg/plate 1,10-Decanediol)	Ames test was performed with and without metabolic activation	Non-mutagenic; no cytotoxicity observed	84
1,10-Decanediol (supplier reported >98% pure); Butylene Glycol	*S. typhimurium*	TA98, TA100, TA1535, TA1537, TA1538	Test mixture: 1.2% 1,10-Decanediol in a trade name mixture also containing unspecified amount of Butylene Glycol; Test mixture was evaluated at 10, 50, 100, 1,000, 5,000 μg/plate (up to ~60 μg/plate 1,10-Decanediol)	Assay was performed, with and without metabolic activation, to evaluate mutagenicity (positive and vehicle controls were used)	Non-mutagenic (revertant frequencies of test substance were similar to controls); no cytotoxicity observed	84
Methylpropanediol	*S. typhimurium*	TA98, TA100, TA1535, TA1537	100 to 5000 μg/plate	Reverse mutation assay was performed, with and without metabolic activation, in accordance with OECD Guidelines for Testing of Chemicals (no further details)	Negative	20
Methylpropanediol	Hamster	Chinese Hamster V79 cells	333 to 5000 μg/plate	Chromosomal aberration test was performed, with and without metabolic activation, in accordance with OECD Guidelines for Testing Chemicals; positive controls were used	Negative; controls performed as expected	20
Methylpropanediol	Human	Human lymphocytes	333 to 5000 μg/plate (3 h, with metabolic activation); 10 to 5000 μg/plate (24 and 48 h, without metabolic activation) Vehicle=F10 medium buffered with 20 mM HEPES	Chromosomal aberration test was performed, with and without metabolic activation, in accordance with OECD Guidelines for Testing Chemicals; positive controls were used	Negative; controls performed as expected	20
Butyl Ethyl Propanediol	*S. typhimurium*	TA1535, TA1537, TA98, TA100	0, 50, 150, 500, 1500, 5000 μg/plate (vehicle=ethanol; application by plate incorporation)	Ames Test was performed (non-GLP), with and without metabolic activation, in accordance with OECD TG 471 (Bacterial Reverse Mutation Assay); Ames Test was conducted independently 2x (for initial assessment and then for confirmation); vehicle, and positive controls were used	Negative; controls performed as expected; cytotoxicity was reported at 5000 μg/plate with TA98 without activation in both initial and confirmatory experiments	17

(continued)

Table 11. (continued)

Test Substance(s)	Species/Strain	Sample Type or Test Population-Sex	Concentration/ Dosage (Vehicle)	Procedure	Results	Reference
Butyl Ethyl Propanediol	Mouse	Thymidine kinase locus in mouse lymphoma L5178Y cells	.03, .06, .11, .22, .45, .90, 1.3, 1.8, 2.6, 3.1, 3.6, 4.2, 5.0 mmol/L (24 h, without activation); .06, .11, .22, .45, .9, 1.8, 2.6, 3.7, 5.2, 6.1, 7.2, 8.5, 10 mmol/L (4 h, with activation); .06, .11, .22, .45, .9, 1.8, 2.6, 3.7, 5.2, 6.1, 7.2, 8.5, 10 mmol/L (4 h in a confirmatory assay with and without activation)	Mammalian cell gene mutation assay was performed, with and without metabolic activation, in accordance with GLP and OECD TG 476 (In vitro Mammalian Cell Gene Mutation Test); negative and positive controls were used	Negative for genotoxicity; cytotoxicity (with and without activation) limited the confirmation assay to a maximum concentration of 7.2 mmol/L; controls performed as expected	[17]
Isopentyldiol (purity 97%)	*S. typhimurium* and *E. coli*	*S. typhimurium*: TA98, TA100, TA1535, TA1537; *E. coli*: WP2 uvrA (pKM101)	33 to 10,000 μg/plate (vehicle=DMSO)	Bacterial reverse mutation assay was performed , with and without metabolic activation, in accordance with OECD TG 471 (Bacterial Reverse Mutation Test) and EC Directive 2000/32/EC B.12/14 Mutagenicity-Reverse Mutation Test using Bacteria; 10,000 μg/plate exceeds the 5000 μg/plate limit recommended for non-cytotoxic substances; positive controls were used	Negative; controls performed as expected	[19]
Isopentyldiol	*Bacillus subtilis*	M45, H17	6.25, 12.5, 25, 50, 100 mg/plate (vehicle=DMSO)	Preliminary rapid streak test was conducted to determine dose levels; liquid suspension assay was performed with and without metabolic activation; negative, vehicle, and positive controls were used	No toxicity reported in preliminary test; liquid suspension assay was negative for genotoxicity; controls performed as expected	[19]
			IN VIVO ***Oral***			
Propanediol	Rat, Sprague-Dawley	Rat liver and testicular homogenates	500 ppm Propanediol in the diet	For up to 15 weeks, rats were dosed in the diet (control rats were fed a plain diet); 3 rats/group were killed at 5, 10, and 15 weeks; tissues from the liver and one testicle from each rat were homogenized and assayed to isolate the DNA; bound tryptophan was measured (effect of DNA concentration on fluorescence was evaluated); DNA template activity was determined; hepatic and testicular DNA was assayed for cross-linking	The metabolism results from the homogenized liver and testes are summarized in the Toxicokinetics Section of this safety assessment. No substantial difference in control vs. treated rats was observed in the evaluation of lipid-soluble testicular fluorophores; tryptophan bound to testicular DNA of treated rats was not different from the controls; tryptophan bound to hepatic DNA in treated rats killed at 5 and 15 weeks was statistically significantly higher than in corresponding controls; treated rats showed a statistically significantly lower template activity in hepatic DNA in rats killed at 10 and 15 weeks compared to controls; template activities of testicular DNA showed no difference from controls; in treated rats the hepatic DNA-protein and DNA-crosslinking at 10 and 15 weeks were higher than controls; testicular DNA-protein and DNA-crosslinking of treated rats were slightly higher than controls at 15 weeks; given the above results and the toxicokinetics results presented in Table 8 (rat liver homogenates converted Propanediol to malondialdehyde) the authors concluded that there were indications that Propanediol produced malondialdehyde in vivo, resulting in damage to rat DNA	[72]
Propanediol	Mouse, Hsd/Win: NMRI	14/sex/dose (main test); 6/sex/dose (repeated test)	Main Test: single dose of 2150 mg/kg Repeated Test: single dose of 1000, 1470, or 2150 mg/kg (vehicle=water)	Micronucleus assay to test for chromosomal aberrations was performed in accordance with GLP and European Commission ECC Directive 92/69/EEC Part B: Methods for the Determination of Toxicity, B.12. Micronucleus Test); single dose administered orally; positive controls were used for each test; mice were killed 24 or 48 h post-exposure	Genotoxicity results were negative (non-mutagenic) for males and females; controls performed as expected; in the main test a statistically significant increase in micronucleated polychromatic erythrocytes at 48 h sampling was reported. Therefore, as per the method, a repeat test was performed; repeat test did not verify findings from the main test (findings were considered incidental)	[12]
Butyl Ethyl Propanediol	Mouse, NMRI	6/sex/dose (1250 mg/kg dose was performed 2x, reason why not specified); only 5/sex/dose were evaluated (no further details)	312.5, 625, 1250 mg/kg (controls received PEG 400 vehicle only)	Micronucleus assay was performed in accordance with GLP and OECD TG 474 (Mammalian Erythrocyte Micronucleus Test); single dose administered by oral gavage; negative, vehicle, and positive controls were used; bone marrow smears were prepared from each femur	Negative for genotoxicity; controls performed as expected; clinical signs of toxicity were observed (summary data is presented in the Acute Toxicity Table 8)	[17]

DMSO, dimethyl sulfoxide; GLP (or non-GLP), good laboratory practice; HPRT, Hypoxanthine-guanine phosphoribosyl transferase; OECD TG, Organization for Economic Co-operation and Development Test Guideline.

(2500 µg/mL) evaluating Propanediol resulted in positive responses for genotoxicity without metabolic activation, but was negative with metabolic activation.[12] 1,4-Butanediol was negative for genotoxicity in a *Salmonella typhimurium* mutagenicity test (up to 10,000 µg/plate),[92] in an Ames test (up to 10,000 µg/plate),[13] in a mammalian cell gene mutation assay (up to 5000 µg/mL),[13] and in a chromosomal aberration test (up to 5000 µg/mL).[13] 2,3-Butanediol was negative in an Ames II™ test (up to 5000 µg/mL).[16] In an Ames test (up to 5000 µg/plate) 1,5-Pentanediol was negative for genotoxicity.[14] Hexanediol was negative for genotoxicity in an Ames test (up to 5000 µg/plate), in a mammalian chromosomal aberration test (up to 1.2 µg/mL), and in a mammalian cell gene mutation assay (up to 5000 µg/mL).[15] 1,10-Decanediol (1.2% in a trade name mixture also containing unspecified amounts of Propylene Glycol or Butylene Glycol) was nonmutagenic in an Ames test (up to ~ 120 µg/plate 1,10-Decanediol).[84] Methylpropanediol was negative in a reverse mutation assay (up to 5000 µg/plate) and in a chromosomal aberration test (up to 5000 µg/plate).[20] Butyl Ethyl Propanediol was negative for genotoxicity in an Ames test (up to 5000 µg/plate) and in a mammalian cell gene mutation assay (up to 7.2 mmol/L).[17] Isopentyldiol was negative for genotoxicity in an Ames test (up to 10,000 µg/plate) and in a liquid suspension assay (up to 100 mg/plate).[19]

In Vivo

Oral. Tests performed in rat liver and testicular homogenates from rats that were fed 500 ppm Propanediol in the diet for 15 weeks (controls fed plain diet), showed that the DNA-protein and interstrand DNA-crosslinking in the hepatic DNA at 10 and 15 weeks were greater than in controls, and the DNA-protein and interstrand crosslinking in testicular DNA of treated rats were slightly greater than in controls at 15 weeks.[72] The study authors concluded that Propanediol was converted to malondialdehyde in vivo, causing damage to rat DNA. Mouse micronucleus tests conducted in vivo were negative for Propanediol (single oral dose of 2150 mg/kg)[12] and for Butyl Ethyl Propanediol (single oral dosage up to 1250 mg/kg).[17]

Carcinogenicity Studies

Carcinogenicity studies data on alkane diol ingredients were not found in the published literature, and unpublished data were not submitted. A carcinogenicity study of diacetyl (potential metabolite of 2,3-Butanediol) in rats and mice is described.[89]

Inhalation

Diacetyl (potential metabolite of 2,3-Butanediol). The carcinogenic potential of diacetyl (≥98.5%) was evaluated by the National Toxicology Program (NTP) in inhalation studies in mice and rats.[89] Groups of 50 male and 50 female B6C3F1/N mice and Wistar Han [CRL:WI (Han)] rats were exposed to diacetyl vapor by whole body inhalation at concentrations of 0, 12.5, 25, or 50 ppm, for 6 h + T_{90} (12 min)/day, 5 days/wk, for 105 wk; T_{90} refers to the time to achieve 90% of the target concentration after the beginning of vapor generation.

In the mouse study, mean body weights of the 50 ppm groups were reduced to 65% (males) and 62% (females) of those of the respective chamber control groups. Clinical observations, which were most prominent in the 50 ppm groups, included abnormal breathing, thinness, sneezing, and eye abnormality in both males and females. Adenocarcinomas occurred in the nose of two female mice at the 50 ppm dose level; nasal adenocarcinomas have not been recorded historically in the NTP database. Statistically significant increases in several non-neoplastic lesions were observed in the nose and larynx (all test groups), the trachea (25 and 50 ppm groups), and the lungs (50 ppm group; most common bronchial lesion in both males and females was bronchus epithelium regeneration). Effects on the cornea of the eye were observed in the 25 and 50 ppm diacetyl groups. It was concluded that there was *no evidence of carcinogenic activity* of diacetyl in male B6C3F1/N mice exposed to 12.5, 25, or 50 ppm, but there was *equivocal evidence of carcinogenic activity* in female B6C3F1/N mice based on the occurrences of adenocarcinoma of the nose.

In the rat study, survival of males exposed to 50 ppm diacetyl was significantly less than that of the chamber control group, and survival was moderately reduced in females exposed to 25 ppm. At the end of the study, mean body weights of both sexes exposed to 50 ppm were decreased relative to the respective control groups, with more of an effect in males (81% of controls) than in females (91% of controls). Exposure-related clinical observations were reported and included thinness, abnormal breathing, eye abnormality, and nasal/eye discharge in males and eye abnormality and abnormal breathing in females. Three squamous cell carcinomas and one squamous cell papilloma of the nasal mucosa occurred in male rats exposed to 50 ppm, and three squamous cell carcinomas of the nasal mucosa occurred in females exposed to 50 ppm; no squamous cell carcinomas or papillomas of the nose occurred in the concurrent male or female controls, and none were recorded historically in the NTP database. Statistically significant increases in several non-neoplastic lesions were observed in the nose, larynx, the trachea, and the lungs of rats of the 25 and 50 ppm groups. Effects on the cornea of the eye were also observed in rats of the 25 and 50 ppm diacetyl groups. It was concluded that there was *some evidence of carcinogenic activity* of diacetyl in male and female Wistar Han rats based on the combined incidences of squamous cell papilloma and squamous cell carcinoma of the nose in males and incidences of squamous cell carcinoma of the nose of females.

Table 12. Dermal Irritation, Sensitization, and Photoirritation/Photosensitization Studies.

Test Substance(s)	Species/ Strain	Sample Type or Test Population-Sex	Concentration (Vehicle)	Procedure	Results	Reference
			IRRITATION			
			In Vitro			
1,10-Decanediol (supplier reported >98% pure); Butylene Glycol	Human	Epidermis (RhE)	Test mixture: 1.2% 1,10-Decanediol in a trade name mixture also containing unspecified amount of Butylene Glycol	10 μL of test mixture was applied to top of reconstructed human epidermis for 15 min; % viability was evaluated compared to untreated controls; IL1-α concentration released at 15 min post-application and 42 h culture was also assessed	Non-irritating; average % viability (compared to controls) was 92%; IL1-α concentration released was < 5 pg/mL	[84]
			Animal			
Propanediol	Rabbit, New Zealand White	6 (abraded skin), 6 (intact skin)	Undiluted	Procedures followed were in accordance with OECD TG 404 (Acute Dermal Irritation/ Corrosion); .5 mL test compound was applied (1 x1 cm patch) to shaved back skin (abraded and intact) and occlusively covered for 24 h; at 24 h post-application patch was removed; skin examined immediately and 48 h after patch removal (72 h post-application); no controls were used	Slightly irritating (well-defined erythema); mean Draize scores for intact skin at 24 h post-application was 1.3 and at 72 h was .3; mean Draize score for abraded skin at 24 h post-application was 1.3 and at 72 h was .8; these effects were reversible and cleared up in 48 h	[12]
Propanediol	Rabbit	n=8	Undiluted	Procedures followed (non-GLP) were in accordance with OECD TG 404 (Acute Dermal Irritation/ Corrosion); test substance was applied to shaved skin (abraded and non-abraded) and occlusively covered for 24 h; skin was observed for 7 days post-application	Mild erythema and edema were reported on abraded and non-abraded skin for 7 of 8 rabbits; this cleared by 3 days post-exposure	[12]
1,4-Butanediol	Rabbit, Vienna White	n=4	Undiluted; control areas of skin were untreated and treated with water	Food and water were available ad libitum; fur was clipped and shaved from sides of trunk; .3 mL test substance was applied to hair-free skin (intact on right side and abraded on left side) and occlusively covered with a 2 x 2 cm patch for 24 h; at 24 h post-exposure the patch was removed and skin examined at 1, 24, 48, and 72 h following patch removal Additionally, the rabbits' right ears (internal area) were coated with undiluted or 50% (water dilution) 1,4-Butanediol for 10 days; controls used were left ears coated with water; the 1st day after applying coating the ears were examined	No reactions were observed on the intact or abraded trunk skin test sites; minimal redness was noted 10 days post-application of undiluted 1,4-Butanediol to the right ears of 2 of 4 rabbits; no reaction in rabbit ears was observed with 50% test solution	[82]
1,4-Butanediol	Rabbit	Unknown	Unknown	Repeated treatments were applied to abraded and intact skin (no further details provided)	No irritation observed; no signs of absorption of toxic quantities of 1,4-Butanediol	[22,37]
2,3-Butanediol	Rabbit, Vienna White	n=6 (no controls)	Undiluted	An irritation/ corrosion test (non-GLP) was performed; test substance was applied to skin and covered occlusively (no further details provided); skin was examined at 24 h post-application and for up to 8 days	Non-irritating; erythema and edema reactions were reported, but were reversible within 8 days	[16]
1,5-Pentanediol	Rabbit, albino	n=5	Undiluted or in solutions of water, propylene glycol, or acetone (no further specifications provided)	Fur was clipped from skin; .1 mL test substance was applied and left uncovered for 24 h, at which point skin was examined	Non-irritating (rated grade 1 on a scale from 1-non-irritating to 10-necrosis)	[79]
1,5-Pentanediol	Rabbit, Vienna White	1 male, 5 females; no controls	Undiluted	Procedures followed (non-GLP) were in accordance with OECD TG 404 (Acute Dermal Irritation/ Corrosion); 1 mL of test substance saturated on a cotton patch (2.5 x 2.5 cm area) was applied to intact or scarified back skin and occlusively covered for 20 h, then patch was removed and skin was washed with 50% polyethylene glycol in water; skin was examined for irritation 24, 48, and 72 h post-application and also 7 days post-application	Non-irritating: For the 24, 48, and 72 h post-application time points the mean erythema score was .5 (very slight effect) and mean edema score was .1 (very slight effect); this erythema and edema were reversible within 48 h; additional findings were at 48 h spotted appearance (scarified skin of 2 animals), at 72 h desquamation (scarified skin of 3 animals), and at 7 days observation desquamation (scarified skin of 4 animal)	[14]
Hexanediol	Rabbit, albino	n=5	Test substance was applied in an appropriate vehicle (no further specifications provided)	Fur was clipped from skin; .1 mL test substance was applied and left uncovered for 24 h, at which point skin was examined	Estimated reaction was a grade 2 on a scale from 1-non-irritating to 10-necrosis	[79,80]
Hexanediol	Rabbit, Vienna White	n=2	80% solution; vehicle=water	A non-GLP irritation test was performed; 1 mL of test substance was applied to intact back skin and occlusively covered (2.5 x 2.5 cm) for 1 min, 5 min, 15 min, or 20 h, then the patch was removed and test substance washed off with a Lutrol®-water mixture; skin was examined at various points over a 3 day period	Non-irritating; mean erythema and edema scores were 0 out of 4	[15]
Hexanediol	Guinea Pig; Hartley	Primary Skin Irritation Test: 3/test concentration Cumulative Skin Irritation Test: 3/test concentration	45 wt % (Hexanediol)	Primary Skin Irritation Test: To the shaved flank skin of animals, 200 μL of test solutions soaked into filter paper were applied and occlusively covered for 24 h; at 24, 48, and 72 h post-application the skin was examined and rated based on criteria of the ICDRG Cumulative Skin Irritation Test: To the shaved flank skin of animals, 200 μL of test solutions soaked into filter paper were applied and left uncovered; 1x/day for 5 days the test solution was reapplied; 5 days post-application the skin was examined and rated based on criteria of the ICDRG	No irritation for primary or cumulative skin irritation test	[97]

(continued)

Table 12. (continued)

Test Substance(s)	Species/ Strain	Sample Type or Test Population-Sex	Concentration (Vehicle)	Procedure	Results	Reference
1,10-Decanediol (supplier reported >98% pure); Propylene Glycol	Rabbit	n=not stated	Test mixture: 1.2% 1,10-Decanediol in trade name mixture containing unspecified amount of Propylene Glycol	.5 mL of test mixture was occlusively applied for 24 h; skin was examined at 25, 48, and 72 h after application	Non-irritating; transient erythema was seen 48 h post-application, but resolved by 72 h	84
Methylpropanediol	Rabbit, New Zealand White	n=6	Undiluted	.5 mL test substance was applied and semi-occlusively covered for 24 h for each of 4 sites/animal (2 abraded and 2 intact); period of observation was 72 h (no further details provided); procedures followed were in accordance with OECD Guidelines for Testing Chemicals	Non-irritating (no erythema or edema reported)	20,100
Butyl Ethyl Propanediol	Rabbit, New Zealand White	n=3 (no controls)	Undiluted	To the shaved dorsum skin, .5 mL of heated (44°C) test substance was applied (6 cm^2 area) and covered with a bandage (semi-occluded) for 4 h then covering was removed, skin was washed with water and dried; skin was examined at 24, 48, and 72 h post-application	Non-irritating; mild erythema was reported up to 48 h post-application but cleared within 72 h; no edema observed	17
Butyl Ethyl Propanediol	Rabbit, New Zealand White	n=3 (no controls)	Undiluted	An irritation test was performed in accordance with GLP and OECD TG 404 (Acute Dermal Irritation/ Corrosion); to the shaved dorsal skin .5 g of crystalline test substance moistened with water was applied and covered with a bandage (semi-occlusively) for 4 h; covering was removed after 4 h and skin washed; skin was examined at 24, 48, and 72 h post-application	Minimally irritating; very slight, transient reactions (erythema and edema) were noted in all animals 30 min after removing covering, but skin cleared by 48 to 72 h post-application	17
Butyl Ethyl Propanediol	Rabbit	Not specified	Unknown	Ingredient was tested on rabbit skin (no further details provided)	Non-irritating	81
Isopentyldiol	Rabbit, New Zealand White	n=3/sex	Undiluted	Procedures followed were a variation of OECD TG 404 (Acute Dermal Irritation/Corrosion); test substance was applied and occlusively covered for 24 h, then the patch was removed; skin was examined at 24 and 72 h post-application	Non-irritating	19
Isopentyldiol	Rabbit, New Zealand White	n=9 males	Not specified	15 μL of test substance was applied to dorsal trunk area (clipped) while another site in the vicinity was used as a control; sites were covered (semi-occlusively) for 24 h, then patches were removed and skin examined; another treatment of test substance was applied to the same site and procedures used during the first application were repeated each day for 28 days; at the completion of the study the animals were killed and skin cells examined	No substantial irritation with repeated skin application On day 10 of study an animal died (cause was gastrointestinal disease and unrelated to treatment) and another was added to test group; an animal died on day 22, but cause was unknown On days 15, 18, and 27 slight erythema and/or edema was observed in 4 animals, but by the following day irritation had resolved At the treatment site of 4 animals, mild inflammatory cell infiltration was reported, but in 2 of those 4 animals the control sites yielded similar results	19
				Human		
Propanediol	Human	n=40	Undiluted	Single treatment of test substance was applied (no further details provided)	No substantial irritation	98
1,4-Butanediol	Human	n=200	Unknown	A patch test was performed (no further details provided)	Non-irritating	22
1,5-Pentanediol	Human	n=30	5% in a topical formulation	Patch test was performed; test substance was applied (single application) to inner forearms and occlusively covered with a patch; 24 h post-application the patch was removed and skin was immediately assessed and assessed again 48 and 72 h after patch removal; standard light conditions used	Non-irritating, no indications of hypersensitivity or photo-sensitivity	45
1,10-Decanediol (supplier reported >98% pure); Butylene Glycol	Human	n=10	Test mixture: 1.2% 1,10-Decanediol in a trade name mixture also containing unspecified amount of Butylene Glycol	Test mixture was occlusively applied to inside upper arm for 48 h; skin was examined at 1, 24, and 48 h after patch removal	Study authors reported that test mixture was well-tolerated; placebo treated sites showed erythema throughout experiment; 2 subjects showed mild erythema 1 h following patch removal; no other observations were reported	84
Methylpropanediol	Human	25 sensitive skin subjects, male and females	100%, 50% aqueous dilution	.2 mL test substance was applied to .75 x .75 in^2 occlusive dressing and secured between the scapulae; test substance applied for 5 consecutive days and patch left in place on weekends for 14-day total cumulative irritation study; patch sites were examined prior to each application	Non-irritating; all treated areas were normal	32,32,75
Isopentyldiol	Human	13 males and 17 females	Not specified	An unspecified concentration of Isopentyldiol or water (control) were soaked into filter paper and applied to medial brachium area of skin and covered with a Finn chamber; 48 h post-application the test substance/Finn chamber were removed and skin examined at 30 min, 24 h, and up to 7 days	Slightly irritating; slight erythema reported 30 min after Finn chamber removal (in 66 yr old female and in 49 yr old female), but this resolved within 24 h	19

(continued)

Table 12. (continued)

Test Substance(s)	Species/ Strain	Sample Type or Test Population-Sex	Concentration (Vehicle)	Procedure	Results	Reference
			SENSITIZATION			
				Animal		
Propanediol	Guinea Pig, SPF albino	8 males/group	Induction Phases 1 & 2: 25%; Challenge: 10% (vehicle=water for all dilutions)	A Landsteiner/ Draize test was performed (time lapse between induction and challenge was not specified) Induction Phase 1: .05 mL of test substance was intradermally injected (1st injection) Induction Phase 2: .01 mL of test substance was intradermally injected (2nd through 10th injections) Challenge: .05 mL of test substance was intradermally injected skin examined 24 h post-challenge Negative controls were used (.05 mL of 10% at challenge with no treatment during induction)	Non-sensitizing; reactions at challenge were very mild or mild and were not considered to vary substantially from controls; during repeated induction phase exposures mild to severe reactions were reported	12
Propanediol	Guinea Pig	2/sex (preliminary test); n=10/sex (test animals); 5/ sex (controls used at induction and challenge)	Induction: 2.5% (intradermal) and undiluted (epicutaneous) Challenge: 50% (epicutaneous and semi-occlusive) vehicle=water	A guinea pig maximization test was performed (non-GLP) in accordance with OECD TG 406 (Skin Sensitization) Preliminary Test: conducted to find the concentrations for intradermal and topical challenge Induction: 6 intradermal injections (within a 4 x 4 cm area) were made on shaved back of each animal; 1 week later, to the same back skin site (freshly shaved), a test substance (undiluted) soaked filter paper patch was applied and occlusively covered for 48 h Challenge: 2 weeks after induction,50% test substance soaked filter paper patch (2.5 x 2.5 cm) was applied to shaved flanks and covered by adhesive tape and a bandage for 24 h; at 24 h post-application bandage was removed and skin was examined immediately and 24 h (site shaved 3 h prior to 24 h reading) and 48 h after patch removal	Non-sensitizing; no reactions in any tests	12
1,4-Butanediol	Guinea Pig, Hartley albino	10 controls; 20 test animals	Both induction and challenge phase concentrations were 10% (intradermal injection) and 30% (topical application)	Food and water (containing 400 mg/L vitamin C) were available ad libitum; a Magnusson and Kligman guinea pig maximization test was performed	Non-sensitizing	82
2,3-Butanediol	Guinea Pig	10 females	Intradermal Induction: 5% test substance in Freund's adjuvant/.9% aqueous sodium chloride solution Epicutaneous Induction: 50% test substance in distilled water Topical Challenge: 25% test substance in distilled water	A guinea pig maximization test was performed (GLP) in accordance with OECD TG 406 (Skin Sensitization); controls were used Intradermal Induction: injections were as follows (no volumes provided): Freund's adjuvant/ .9% aqueous sodium chloride; .9% aqueous sodium chloride; test substance in Freund's adjuvant/ .9% aqueous sodium chloride solution; test substance in .9% aqueous sodium chloride solution Epicutaneous Induction: no further details were provided explaining this induction other than concentration Challenge: no further details were provided explaining challenge other than concentration	Non-sensitizing The following reactions were reported: -All animals injected with only Freund's adjuvant/ .9% aqueous sodium chloride showed erythema and swelling at injection sites -Animals injected with only .9% aqueous sodium chloride had no skin reactions -Test group animals injected with 5% test substance in Freund's adjuvant/ .9% aqueous sodium chloride showed erythema and swelling at injection sites -Test group animals injected with 5% test substance in .9% aqueous sodium chloride showed moderate and confluent erythema and swelling -Test group animals epicutaneously exposed to 50% test substance during induction showed incrustation and confluent erythema with swelling -Test group animals exposed to 25% test substance at challenge showed no reactions	16

(continued)

Table 12. (continued)

Test Substance(s)	Species/ Strain	Sample Type or Test Population-Sex	Concentration (Vehicle)	Procedure	Results	Reference
Hexanediol	Guinea Pig, Pirbright-Hartley	Range-finding study n=4; main study: 10 females,5 controls	Intradermal Induction: 5% Hexanediol in .9% aqueous sodium chloride solution containing Freund's adjuvant Epicutaneous Induction: 50% Hexanediol in double distilled water Challenge: 25% Hexanediol in double distilled water	Food and water were available ad libitum; A guinea pig maximization test was performed (GLP) in accordance with European Union (EU) Method B.6 (Skin Sensitization) Range-finding study was conducted (2 x 2 cm filter paper soaked in approximately .15 g of test substance was applied 2x to flank skin and occlusively covered for 24 h; skin was examined at 24 and 48 h post-application) Intradermal Induction: 6 injections total (2 injections/animal) as follows: 2 injections each of .1 mL Freund's adjuvant emulsified with .9% sodium chloride (1:1) not containing test substance; 2 injections each of .1 mL Freund's adjuvant emulsified with .9% sodium chloride (1:1) containing test substance; 2 injections each of .1 mL test substance only Epicutaneous Induction: 1 week following intradermal induction; 2 x 4 cm filter paper soaked in .3 g of test substance was applied to shoulder skin and occlusively covered for 48 h Challenge: 21 days following induction; 2 x2 cm filter paper soaked in .15 g of test substance was applied to flank skin (hair clipped) and occlusively covered for 24 h; then patch was removed and skin was examined at 24 and 48 h post-application	Non-sensitizing	15
Hexanediol; Ethylene Glycol	Guinea Pig, Hartley	n=19 total	Induction Phases 1 & 2: Test solutions (% by wt) were experimental dentin primers: .2% 2-hydroxyethyl methacrylate (2-HEMA); .2% Ethylene Glycol; or .2% Hexanediol (vehicle=7:3, v/v, olive oil: acetone)	A Magnusson and Kligman guinea pig maximization test was performed; below are the compounds used as the sensitizer followed by test substance used at challenge (neither time lapse between induction and challenge nor challenge concentrations were specified): 2-HEMA sensitizer/ Ethylene Glycol challenge (n=5) 2-HEMA sensitizer/ Hexanediol challenge (n=5) Ethylene Glycol sensitizer/ Ethylene Glycol challenge (n=2) Hexanediol sensitizer/ Hexanediol challenge (n=2) 2-HEMA sensitizer/ 2-HEMA challenge (n=5) Induction Phase 1: 50 µL of each test solution was intradermally injected (also injected was 50:50 Freund's complete adjuvant: distilled water) into back skin Induction Phase 2: 1 week after Phase 1, .2 mL (100%) of test solution soaked into filter paper was applied to shaved back; .1 mL (100%) test solution soaked into filter paper was applied to 2 skin sites and occlusively covered for 24 h	There were positive results for 2-HEMA sensitizer/ Hexanediol challenge with a mean response of 1.5 (24 h) and .8 (48 h) indicating strong erythema (no vesicles present); positive responses were also noted with 2-HEMA sensitizer/ 2-HEMA challenge; the results for Hexanediol sensitizer/ Hexanediol challenge were negative	97
1,10-Decanediol (supplier reported >98% pure); Propylene Glycol	Guinea Pig	Not stated	Test mixture: 1.2% 1,10-Decanediol in a trade name mixture also containing unspecified amount of Propylene Glycol; Test mixture used (1.2% 1,10-Decanediol) at induction and 25% dilution of test mixture used at challenge (.3% 1,10-Decanediol)	Buehler test was performed; test mixture was occlusively applied to shaved skin for an induction period of at least 6 h on days 1, 9, and 15 (negative controls were used); challenge phase occurred on day 28 for 6 h; skin was examined 24 and 48 h post-challenge	Non-sensitizer; no erythema observed during challenge	84
1,10-Decanediol (supplier reported >98% pure); Butylene Glycol	Guinea Pig	20 treated males; 10 controls	Test mixture: 1.2% 1,10-Decanediol in a trade name mixture also containing unspecified amount of Butylene Glycol; Induction concentration not specified; test mixture used at 25% dilution during challenge (.3% 1,10-Decanediol)	A Buehler test was performed; treated (shaved skin) was observed for 11 days following induction (negative controls used); challenge phase occurred on day 28; skin was examined 24 and 48 h post-challenge	Non-sensitizer; no erythema or clinical signs indicating sensitization reaction	84

(continued)

Table 12. (continued)

Test Substance(s)	Species/ Strain	Sample Type or Test Population-Sex	Concentration (Vehicle)	Procedure	Results	Reference
Methylpropanediol	Guinea Pig, Himalayan	20 test animals, 10 controls	Intradermal Induction: 10% test substance in saline; 50:50 Freund's Complete Adjuvant (FCA)/ distilled water; and 20% test substance emulsified in FCA Epidermal Induction: 100% test substance Challenge: 0, 25, 50, or 100% test substance in distilled water	Guinea pig maximization test was conducted in accordance with OECD Guidelines for Testing Chemicals Induction Phases: .1 mL intradermal injections were performed at the indicated concentrations; on the 6th day following intradermal inductions a treatment of 10% sodium-dodecyl-sulfate in petrolatum was applied; on the 7th day, .5 mL of the test substance (100%) was applied to injection sites and covered with a patch for 48 h Challenge: 2 weeks following the epidermal induction phase the test material was applied at the indicated concentrations and covered with a patch for up to 48 h	Mild sensitization potential was reported; 24 h after the patch from the challenge treatment was removed positive responses were noted in 1 animal with 25% and 1 animal with 50% challenge concentrations, but not at 100%; by 48 h after the patch was removed following challenge, 1 animal with 25%, 3 animals with 50%, and 1 animal with 100% challenge concentrations showed positive reactions; controls performed as expected	[20]
Butyl Ethyl Propanediol	Guinea Pig, Dunkin-Hartley	Males,10 test animals 5 controls	Intradermal Induction: 2.5% (v/v) Topical Induction: 100% Topical Challenge: 100% and 50% (v/v) (vehicle=triglycerides of coconut oil)	A guinea pig maximization test was performed (GLP) in accordance with EU Method B.6 (Skin Sensitization) Intradermal Induction: 3 pairs of injections as follows: 2 injections of .1 mL Freund's adjuvant diluted with water (1:1); 2 injections of .1 mL test substance in triglycerides of coconut oil; 2 injections of .1 mL test substance in 50:50 of Freund's adjuvant/ triglycerides of coconut oil Epicutaneous Induction: 6 days following intradermal induction; shaved skin (same site as injection) was pretreated with .5 mL 10% sodium lauryl sulfate in petroleum (w/w); after 24 h a patch soaked with .4 mL of test substance was applied to same skin area and occlusively covered for 48 h Challenge: .2 mL of test substance was applied to anterior site and 50% test substance (diluted in triglycerides of coconut oil) was applied to posterior site; both sites were occlusively covered for 24 h; then patches were removed and skin was examined at 24, 48, and 72 h post-application	Non-sensitizing; no reaction were observed	[17]
Isopentyldiol	Guinea Pig, Dunkin-Hartley	20 test animals, 10 controls	*Main Study:* Intradermal Induction: 10% in distilled water Topical Induction: 100% undiluted Challenge: 50% in distilled water	Guinea pig maximization test was performed in accordance with OECD TG 406 (Skin Sensitization-Magnusson & Kligman) Preliminary study was conducted using an intradermal concentration of 10% test substance in distilled water and a topical induction concentration of 50% test substance in distilled water; these were the maximum non-irritating concentrations Induction Phases: test substance was applied at indicated concentrations (volumes were not specified) Challenge: test substance was applied at indicated concentration (volumes were not specified); skin was examined 24 and 48 h post-challenge application; positive and negative controls were used	Induction Phases: moderate and confluent erythema was reported 24 h post-application at intradermal injection sites and topical application sites; controls showed slight or discrete erythema Challenge: Non-sensitizing; no reactions in test group or negative controls; positive controls performed as expected	[19]
				Human		
Propanediol	Human	n=100	Both induction and challenge phase concentrations were 5%, 25%, 50%; controls used water vehicle only	For the induction phase .1 mL of test solution was applied to pad (1 inch), covered with clear adhesive, and pressed onto left arm; this patch was removed 24 h post-application to examine skin (skin examined again at 48 h post-application); at 48 h post-application a new patch was applied to the same site and the procedure above repeated for 9 applications total; a 2 week rest period was allowed prior to challenge; application of test solution for challenge was the same as for the induction phase; to a previously untreated site on the other arm, a duplicate challenge treatment was applied; after 24 h the challenge patches were removed and skin examined immediately and again 48 h after patch removal (72 h post-application)	Propanediol was non-sensitizing; no skin reactions or irritation at any concentration levels nor with controls were observed	[98]

(continued)

Table 12. (continued)

Test Substance(s)	Species/ Strain	Sample Type or Test Population-Sex	Concentration (Vehicle)	Procedure	Results	Reference
Propanediol; propylene glycol*	Human	n=207	Propanediol: 25% (pH 7), 50% (pH 7), and 75% (pH 4, 7, 9); propylene glycol: 25% (pH 7); 50% (pH 7); 75% (pH 7); vehicle=water; negative controls were used at pH 4, 7, and 9	For the induction phase . 1 mL of test solution was applied to pad (1 inch), covered with clear adhesive, and pressed onto the upper back; this patch was removed 24 h post-application to examine skin (skin examined again at 48 h post-application); at 48 h post-application a new patch was applied to the same site and the procedure above repeated for 9 applications total; a 2 week rest period was allowed prior to challenge; application of test solution for challenge was the same as for the induction phase; to a previously untreated site on the back, a duplicate challenge treatment was applied; after 24 h the challenge patches were removed and skin examined immediately and again 48 h after patch removal (72 h post-application)	Propanediol: Very slight erythema at test sites was noted 24 or 72 h post-challenge application in a few subjects (at all concentration levels), however these findings were considered clinically insignificant; during induction 4 subjects showed mild erythema after the 1st of 9 applications (with 75% only); non-sensitizing Propylene Glycol: During 9 applications of induction phase and 24 and 72 h post-challenge, mild to moderate skin irritation and cumulative skin irritation were observed in 8.2% of subjects treated with 25%, 21.7% of subjects with 50%, and 22.7% of subjects with 75%; non-sensitizing	98
1,4-Butanediol	Human	n=200	Unknown	Sensitization test was performed (no further details provided)	Non-sensitizing	22
1,5-Pentanediol	Human	n=20 (males)	5% in a scalp wash formulation	Scalp wash was used ≥ 2 times/day for 4 weeks (no other products were used on hair during this time); scalp skin was assessed periodically throughout study; after 4 weeks, test substance was applied (single application) to inner forearms and occlusively covered with a patch; 24 h post-application, the patch was removed and skin was immediately assessed and assessed again 48 and 72 h after patch removal	Non-irritating, non-sensitizing	45
1,5-Pentanediol	Human	n=30	25% in a topical formulation	Sensitization test according to Magnuson in which 3 applications patches were applied to the forearm of subjects within 6 wk	Non-irritating, non-sensitizing	45
Methylpropanediol	Human	n=104	Unknown	4 patch tests were conducted; they included 9 induction applications (occlusive and semi-occlusive); no further details provided	Non-sensitizing	
Methylpropanediol	Human	n=110 (male and female)	Both induction and challenge phase concentrations were 50% aqueous dilution	.2 mL of test substance was applied to .75 x .75 in^2 patch and secured between the scapulae; test substance applied 3 times/ week for 10 applications total; patches removed 24 h after application and skin examined 48 h and 72 h after initial application; 2 weeks following the 10th application a challenge patch was applied to the initial site and a new site on forearm; patch was removed after 24 h and examined immediately and again 48 h post-application If a subject showed a reaction on challenge the subject was re-challenged 7 days later with 100% and 50% aqueous dilution of test substance (occlusive and semi-occlusive conditions were used)	At the 9th and 10th days during induction "mild dermal responses" were observed in 3 subjects indicating irritation or a potential allergic reaction; another subject exhibited skin reactions on days 2-19 of inductions indicating a potential atopic reaction; at challenge 5 subjects showed "mild dermal responses" 24 h and 48 h post-application that lasted until 72 h post-application; 2 subjects had skin reactions at the forearm site; the re-challenge in 4 subjects showed mild, well-defined delayed reactions at 48 h post-application (occlusive, semi-occlusive showed less reaction); subjects re-challenged with propylene glycol or butylene glycol (occlusive) showed mild-to-well-defined reactions at 24 h post-application; it is unclear as to whether irritation, allergy, or an unrecognizable atopic condition were the cause of the above reactions; Methylpropanediol was not considered to be a strong irritant or potent sensitizer	2,32,75
Methylpropanediol	Human	n= 205	21.2% in facial serum (used during induction and challenge phases)	*Induction:* .2 mL test substance was applied to a 2 x 2 cm^2 area of skin on the left or right infrascapular location of the back or to upper arm under occlusive conditions for 24 h; patch was removed 24 h post-application and skin assessed at 48, 72 or 96 h post-application depending on the occurrence of weekends/ holidays; following assessment, test substance was applied again to same skin area under occlusive conditions and assessed as described above; this process was repeated until 9 applications of test substance were administered *Rest:* Subjects received no treatment during the 10-15 days after completion of induction and prior to challenge phase *Challenge:* at week 6, .2 mL test substance was applied to 2 x 2 cm^2 skin site not previously exposed to test substance during induction; same procedures for patch removal and skin assessment were followed as in induction phase; if evidence of potential sensitization was noted, a rechallenge was conducted; during rechallenge, test substance was applied to skin (previously unexposed to test substance) using occlusive and semi-occlusive patches to distinguish between irritation and sensitization reactions	Study researchers stated that test substance was non-sensitizing and the irritation responses were considered acceptable *Induction:* 41 subjects exhibited definite erythema with no edema, 3 of those subjects also showed damage to epidermis (a protocol deviation occurred for the 1st subject resulting in an inadvertent discontinued use of test substance, 2nd subject declined to complete patch tests for the remainder of study, 3rd subject showed no further reactions for remainder of induction phase when test substance was applied to a new site under semi-occlusive conditions during 6th induction, but subject declined to participate at challenge); on another day, 31 subjects showed definite erythema with no edema, and 7 of those subjects showed damage to epidermis; those 7 subjects did not experience any additional reactions after test substance was applied to a new site under semi-occlusive conditions	75,101

(continued)

Table 12. (continued)

Test Substance(s)	Species/ Strain	Sample Type or Test Population-Sex	Concentration (Vehicle)	Procedure	Results	Reference
PHOTOIRRITATION/PHOTOSENSITIZATION						
				Animal		
1,10-Decanediol (supplier reported >98% pure); Butylene Glycol	Guinea Pig, albino	n=/group	Test mixture: 1.2% 1,10-Decanediol in a trade name mixture also containing unspecified amount of Butylene Glycol	1 mL of test mixture was applied with or without UVA irradiation; UVA irradiation was applied for 20 min with 310 nm light source located 5 cm away from treatment area; treatment areas were examined 1, 6, and 24 h following irradiation; no further details were provided	Non-Phototoxic; no dermal reactions in treated or control animals	84
Isopentyldiol	Guinea Pig, Dunkin-Hartley	10 test animals, 10 controls	Undiluted	To the shaved back of each animal .025 mL of test substance and a positive control (8-methoxysporalen or 8-MOP) were applied epicutaneously to test animals; animals were exposed to 20 J/cm^2 of UVA radiation (320-400 nm); when exposure of UVA radiation reached 2.5 J/cm^2 the positive control site was concealed with lightproof tape; control animals were not exposed to UVA radiation; skin of all animals examined 24, 48, and 72 h post-application	Isopentyldiol was a not a photoirritant; positive control performed as expected	19
Isopentyldiol	Guinea Pig, Dunkin-Hartley	10 test animals, 10 negative controls 10 positive controls	Undiluted (used on test animals during induction and challenge); distilled water (controls); .1% tetrachlorosalicylani-lide in petrolatum (positive controls)	Induction: to the shaved and chemically depilated back of each test animal, .025 mL of test substance was epicutaneously applied; animals were exposed to 485 mJ/cm^2 of UVA radiation and 185 mJ/cm^2 of UVB radiation for 10 min; this procedure was repeated 5x every 48 h for a total of 6 applications in 2 weeks (animals were shaved/depilated as needed); control and positive control animals were similarly treated except with distilled water and tetrachlorosalicylanilide, respectively; skin was examined 24, 48, and 72 h post-application Challenge: 12 days after induction phase was complete, test substance was applied epicutaneously (open) to the backs (shaved/depilated) of test and control animals following the same procedures used in the induction phase; 30 min post-application test and control animals were exposed to 10 J/cm^2 of UVA radiation, then test substance was applied to a nearby skin site of the test and control animals and no radiation exposure applied to those sites; skin of all animals was examined 24, 48, and 72 h post-application of test substance, distilled water, or positive control substance	Isopentyldiol was non-photosensitizing; 1 animal was killed before challenge because of probable pneumonia; no skin reactions post-application of treatment during induction or challenge phases; positive controls performed as expected	19
				Human		
1,5-Pentanediol	Human	n=30	5% in a topical formulation	Test substance was applied (single application) to inner forearms; test sites on skin were then exposed to UV-A light (30 J/cm^2) and UV-B light (.05 J/cm^2); test skin sites were covered with occlusive patch for 24 h and then patch was removed; skin was assessed immediately after patch removal and again at 48, 72, and 96 h post-application	Non-phototoxic and non-photoirritant; study authors stated that 1,5-Pentanediol does not absorb in long-wave ultra-violet range	45,64

2-HEMA, 2-hydroxyethyl methacrylate; EU, European Union; FCA, Freund's Complete Adjuvant; GLP, Good Laboratory Practice; HRIPT, Human Repeat Insult Patch Test; ICDRG, International Contact Dermatitis Research Group; non-GLP, non-Good Laboratory Practice; OECD TG, Organization for Economic Co-operation and Development Test Guideline; *_Dictionary_ name is Propylene Glycol.

Other Relevant Studies

Cytotoxicity

1,10-Decanediol. An agarose overlay test was performed by evaluating the diffusion in an agarose gel of a trade name mixture containing 1.2% of 1,10-Decanediol and an unspecified amount of Butylene Glycol. Average diameters (total score) were 1.075 cm; results indicated that cytotoxicity was low. No further details were provided.[84]

Neurotoxicity

"Hexacarbon neurotoxicity" describes the ability of *n*-hexane and 2-hexanone (methyl *n*-butyl ketone; M*n*BK) to produce structural damage to the central and peripheral nervous system.[93] Both of these compounds are metabolized to similar metabolites, ie, 2-hexanol, 5-hydroxyl-2-hexanone, 2,5-hexanediol, and 2,5-hexanedione.[94] 2,5-Hexanediol and 2,5-hexanedione are neurotoxic agents, and 2-hexanol and 5-hydroxyl-2-hexanone may be neurotoxic, because they are metabolized to 2,5-hexanedione.

Peripheral neuropathy develops in several species with exposure to these 6 metabolically-interrelated hexacarbons.[93] The relative neurotoxicity of these compounds in Charles River CD COBS rats (2,5- hexanedione > 5-hydroxy-2-hexanone > 2,5-hexanediol > M*n*BK > 2-hexanol > *n*-hexane) has been attributed to differential serum levels of the common metabolite, 2,5- hexanedione, and is in proportion to the peak serum value that each compound generates.

The specific molecular configuration of the hexacarbon compounds plays a role in neuropathy.[93] Neuropathy did not develop in Sprague-Dawley rats exposed to the diketones 2,4-hexanedione, 2,3-hexanedione, 3,5-heptanedione, or 2,6-heptanendione. In addition, the mono-ketone, 2-heptanone, did not produce neuropathy in rats, but 2,5-heptanedione and 3,6-octanedione produced neuropathological alterations.[95] These findings support the requirement for a diketone with γ-spacing to produce neuropathy. Additional studies suggested that although pyrrole formation is necessary for the pathogenesis of γ-diketone neuropathy, autoxidation to reactive intermediates, resulting in inter- or intraneurofilament crosslinking, is required for the neurotoxic effects of γ--diketones to be manifested.[96]

1,4-Butanediol. Central nervous system effects have been reported for exposures to 1,4-Butanediol.[74] Central nervous system depression, anesthetic effect, loss of righting reflex, struggle response, and voluntary motor activity were documented in rats administered 496 mg/kg 1,4-Butanediol (no further details were provided). During oral, intraperitoneal, or intravenous exposure, neuropharmacologic responses have been reported. These effects were also observed after administration of GHB. Endogenous levels of GHB in the brain of mammals are in micromolar concentrations, while in the liver, heart, and kidneys concentrations are 5 to 10 times higher. Although 1,4-Butanediol can be converted to GHB in the brain, liver, kidney, and heart, the liver has the greatest capacity (per gram of tissue) to metabolize GHB. When GHB was administered at dosages exceeding 150 mg/kg in rats, a state of behavioral arrest was observed, with bilaterally synchronous electroencephalogram readings resembling those of humans undergoing seizures (non-epileptic).

Dermal Irritation and Sensitization Studies

A summary of dermal irritation, sensitization, and photoirritation/photosensitization studies is provided below; details are presented in Table 12.

Irritation

In vitro. 1,10-Decanediol (1.2% in a trade name mixture also containing an unspecified amount of Butylene Glycol) was non-irritating in an in vitro test evaluating the test substance on reconstructed human epidermis.[84]

Animal. Skin irritation testing of Propanediol, 1,4-Butanediol, 2,3-Butanediol, 1,5-Pentanediol, Hexanediol, 1,10-Decanediol, Methylpropanediol, Butyl Ethyl Propanediol, and Isopentyldiol was conducted. Results indicated the following observations: Propanediol (undiluted) was mildly irritating to rabbit skin in 24-hour occlusive patch tests[12]; 1,4-Butanediol (undiluted) caused only minimal redness after application to rabbit ears and no irritation was observed in a 24-hour occlusive patch test on intact and abraded rabbit skin;[82] 2,3-Butanediol (undiluted) was non-irritating to rabbit skin in a 24-hour occlusive patch test;[16] 1,5-Pentanediol (undiluted) was non-irritating to rabbit skin in both a 24-hour non-occlusive skin test[79] and a 20-hour occlusive patch test on intact and scarified skin;[14] Hexanediol (45 to 80%) was non-irritating to animal skin in both non-occlusive and occlusive tests performed with approximately 24-hour dermal exposure;[15,79,80,97] 1,10-Decanediol (1.2% in a trade name mixture also containing an unspecified amount of Propylene Glycol) was non-irritating to rabbit skin in a 24 h occlusive patch test;[84] Methylpropanediol (undiluted) was non-irritating to animal skin;[20] Butyl Ethyl Propanediol (undiluted) was non-to-minimally irritating to rabbit skin in 4-hour semi-occlusive patch tests;[2,17] Isopentyldiol (undiluted) was non-to-slightly irritating to rabbit skin in 24-hour occlusive and semi-occlusive patch tests.

Human. Skin irritation testing of Propanediol, 1,4-Butanediol, 1,5-Pentanediol, 1,10-Decanediol, Methylpropanediol, and Isopentyldiol in human subjects showed the following: Propanediol (undiluted) was non-irritating after a single application of test substance (no further details provided);[19,98] 1,4-Butanediol (concentration not specified) was non-irritating in a patch test (no additional details provided);[22] 1,5-Pentanediol (5%) was non-irritating in an occlusive patch test;[45]

Table 13. Ocular Irritation Studies.

Test Substance	Species/Strain	Sample Type or Test Population-Sex	Concentration (Vehicle)	Procedure	Results	Reference
				IN VITRO		
1,10-Decanediol (supplier reported >98% pure); Butylene Glycol	Chicken/ Leghorn (Lohmann)	Chorioallantoic membrane, n=4 eggs	Test mixture: 1.2% 1,10-Decanediol in a trade name mixture also containing unspecified amount of Butylene Glycol	Shell and shell membrane were removed to reveal chorioallantoic membrane from fertilized hen's eggs after 10 days of incubation; .3 mL of test mixture was applied to this membrane for 20 sec, then membrane was rinsed with .9% NaCl (5 mL); membrane was observed for 5 min and scored for signs of potential irritancy (i.e., hyperemia, hemorrhage, coagulation)	Mean score (6.5) of 4 eggs indicated moderate irritation	[84]
1,10-Decanediol (supplier reported >98% pure); Butylene Glycol	Human	Corneal epithelium	Test mixture: 1.2% 1,10-Decanediol in a trade name mixture also containing unspecified amount of Butylene Glycol	30 μL of test mixture was applied to top of reconstructed human corneal epitheliums for 1 and 24 h (controls were used)	Non-irritating; based on the quantitative 3-(4,5-Dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide assay, viability compared to control was 76% (after 1 h) and 86% (after 24 h)	[84]
				ANIMAL		
Propanediol	Rabbit, New Zealand White	n=6	Undiluted	Procedures followed were in accordance with OECD TG 405 (Acute Eye Irritation/ Corrosion); .1 mL of test substance was applied to the everted lower lid of one eye (remaining eye was the control), upper and lower lid were held together for 1 second, no eye washing occurred; eyes were examined 24, 48, and 72 h and 7 days post-application	Slight conjunctivae redness was observed in 4 of 6 rabbits, but had cleared by 48 h post-application; results were considered to be non-irritating	[12]
Propanediol	Rabbit	n=4	Undiluted	Procedures followed (non-GLP) were in accordance with Federal Register 28 (110), 1963 para 191.12 Test for eye irritants; .2 mL of test substance was instilled into the conjunctival sac of one eye (remaining eye served as control); 2 treated eyes were rinsed and 2 treated eyes were unrinsed; eyes were examined 30 min and 1, 2, 3, and 7 days post-application	Transient, mild conjunctival reddening/swelling was reported in 3 rabbits, 2 of the eyes had been rinsed and 1 was not rinsed, however all symptoms had resolved by 48 h post-application	[12]
1,4-Butanediol	Rabbit, New Zealand White	n=4	Undiluted	A single application (.1 mL) of test substance was instilled into the conjunctival sac of the right eye (left eyes were used as controls); eyes were examined at 1, 24, 48 and 72 h post-application	Slightly irritating; all rabbits showed small discharge and slight redness of conjunctives at 1 h post-application, however these symptoms lessened by 48 h post-application	[82]
1,4-Butanediol	Rabbit	Not specified	Not specified	Test substance was instilled into the conjunctival sac of rabbit eyes (no further details provided)	Slight conjunctival irritation without corneal damage was reported	[37]

(continued)

Table 13. (continued)

Test Substance	Species/Strain	Sample Type or Test Population-Sex	Concentration (Vehicle)	Procedure	Results	Reference
2,3-Butanediol	Rabbit, Vienna White	n=6	Undiluted	This non-GLP study evaluated the effect of the test substance on rabbit eyes (no mention of controls used); the eyes were observed for 72 h post-application (no further details specified)	Non-irritating	16
1,5-Pentanediol	Rabbit	Unknown	Unknown	Test substance was instilled into the conjunctival sac (no further details specified)	On a scale of 1 (very small area of necrosis) to 10 (a severe burn) 1,5-Pentanediol application resulted in a rating of 2, suggesting mild irritation	79
1,5-Pentanediol	Rabbit	Not specified	Not specified	Not specified	Mildly irritating	33
1,5-Pentanediol	Rabbit, Vienna White	2 male, 4 female	Undiluted	Procedures followed (non-GLP) were in accordance with OECD TG 405 (Acute Eye Irritation/ Corrosion); .1 mL test substance was instilled into the conjunctival sac of one eye (remaining eye served as control); eye were unwashed; examination of eyes occurred 24 to 72 h post-application and for up to 8 days post-application	Results were considered to be non-irritating; average eye ratings were: slight irritation, fully reversible by 72 h for cornea, iris, conjunctivae, chemosis	14
Hexanediol	Rabbit	Unknown	Concentration unknown, a suitable vehicle was used	Test substance was instilled into the conjunctival sac (no further details specified)	On a scale of 1 (very small area of necrosis) to 10 (a severe burn), application resulted in a rating of 3, suggesting it is mildly irritating	79,80
Hexanediol	Rabbit, Vienna White	n=2	Undiluted	Non-GLP study; 50 mg of test substance was instilled into the conjunctival sac of the eye (the other eye was talcum-treated and served as control); eyes were at 1, 3, 24, 48, 72 h post-application and at 5 days post-application; eyes were washed with Lutrol® and Lutrol®/water (1:1) mixture 20 h post-application	Results were considered to be non-irritating; average eye ratings were: cornea=slightly irritating, fully reversible by 72 h; chemosis=slightly irritating, fully reversible by 48 h; conjunctivae=slightly irritating, fully reversible by 72 h; discharge was noted in 1 eye 1 h post-dosing	15
1,10-Decanediol (supplier reported >98% pure); Propylene Glycol	Rabbit	Not specified	Test mixture: 1.2% 1,10-Decanediol in a trade name mixture also containing unspecified amount of Propylene Glycol	Study authors stated that a modified Kay and Calendra method was used; .1 mL of test mixture was instilled into the conjunctival sac of the right eye and left for 24 h (unwashed); eyes were examined at 24, 48, 72, 96, and 120 h post-instillation	Slightly irritating; transient, reversible irritation was observed during study	84
Methylpropanediol	Rabbit, New Zealand White	n=6	Unknown	Procedures followed were in accordance with OECD Guidelines for Testing Chemicals; .1 mL was instilled into the conjunctival sac of one eye of each rabbit; eyes were observed up to 72 h post-application	Non-irritating	20
Methylpropanediol	Rabbit	n = 2	Undiluted	Not specified	Non-irritating	2

(continued)

Table 13. (continued)

Test Substance	Species/Strain	Sample Type or Test Population-Sex	Concentration (Vehicle)	Procedure	Results	Reference
Butyl Ethyl Propanediol	Rabbit	Unknown	Not specified	Test substance was instilled into rabbit eye, but the method used was not described	Results indicate severe eye injury	81
Butyl Ethyl Propanediol	Rabbit, New Zealand White	n=3	Undiluted	Procedures followed were in accordance with GLP and European Union Method B.5 (Acute Toxicity: Eye Irritation/ Corrosion); .1 mL of warm liquid test substance was applied to the lower everted lid of one eye of each rabbit (other eye served as control); eyes were not washed; eyes examined at 1 h and at 1, 2, 3, 4, 7, and 14 days post-application	Irritating; all 3 rabbits showed corneal opacification and diffuse crimson conjunctiva coloration with swelling and partial eyelid eversion or eyelids half-closed, 1 rabbit exhibited iridial inflammation; eyes returned to normal 7 to 14 days post-application; no toxic signs in rabbits during observation period	17
Isopentyldiol	Rabbit, New Zealand White	n=6	Not specified	Procedures followed were in accordance with OECD TG 405 (Acute Eye Irritation/ Corrosion); eyes were examined at 1, 24, 48, and 72 h and up to 7 days post-application	Non-irritating	19

GLP, Good Laboratory Practice; OECD TG, Organization for Economic Co-operation and Development Test Guideline.

1,10-Decanediol (1.2% in a trade name mixture also containing an unspecified amount of Butylene Glycol) was well-tolerated, according to study authors (2 subjects showed mild erythema 1 h following patch removal), in a 48 h occlusive patch test;[84] Methylpropanediol (100%, 50% aqueous dilution) was non-irritating to subjects with sensitive skin in a 14-day cumulative irritation study;[99] Isopentyldiol (concentration not specified) was slightly irritating in a 48-hour Finn chamber skin test.[2,19,100]

Sensitization

Animal. Skin sensitization testing of Propanediol, 1,4-Butanediol, 2,3-Butanediol, Hexanediol, 1,10-Decanediol, Methylpropanediol, Butyl Ethyl Propanediol, and Isopentyldiol was performed in guinea pigs. Propanediol (2.5% intradermal and 100% epicutaneous concentrations applied at induction, 50% epicutaneous and semi-occlusive at challenge) was non-sensitizing;[12] 1,4-Butanediol (10% intradermal and 30% topical concentrations applied at induction and challenge) was non-sensitizing.[82] 2,3-Butanediol (5% intradermal and 50% epicutaneous concentrations applied at induction, 25% at challenge) was non-sensitizing, although during epicutaneous induction animals showed incrustation and confluent erythema with swelling.[16] Hexanediol (5% intradermal and 50% epicutaneous concentrations applied at induction, 25% at challenge) was non-sensitizing in one test.[15] In another test, strong erythema was reported with Hexanediol challenge (no concentration specified) following induction (sensitization) with another compound (.2% hydroxyethyl methacrylate). However no Hexanediol induction (.2%)/Hexanediol challenge (no concentration specified) tests showed a positive sensitization reaction.[97] 1,10-Decanediol (1.2% in a trade name mixture containing an unspecified amount of Propylene Glycol or Butylene Glycol) was non-sensitizing in a Buehler test (1.2% 1,10-Decanediol in trade name mixture used at induction and .3% 1,10-Decanediol in trade name mixture used at challenge).[84] Methylpropanediol showed mild sensitization potential (10% intradermal to 100% epidermal concentrations applied at induction, up to 100% at challenge).[20] Butyl Ethyl Propanediol (2.5% intradermal and 100% topical concentrations applied at induction, 50% and 100% at challenge) was non-sensitizing.[17] Isopentyldiol (10% intradermal and 100% topical concentrations applied at induction, 50% at challenge) was non-sensitizing. However, during intradermal injection at induction and topical induction, moderate and confluent erythema were observed.[19] The alkane diols showed mild or no sensitization potential and some positive skin irritation reactions were observed during induction.

Human. Clinical skin sensitization studies of Propanediol, 1,4-Butanediol, 1,5-Pentanediol, and Methylpropanediol showed the following results: Propanediol was non-sensitizing (5% to 75% concentrations applied at induction and at challenge) with mild erythema reported in 4 subjects of 207 during induction (75% only) after the 1st of 9 applications;[98] 1,4-Butanediol (concentration not specified) was non-sensitizing;[22] 1,5-Pentanediol (5% and 25% in different tests) was non-sensitizing;[45] Methylpropanediol (concentration not specified) was non-sensitizing in one test; in another test Methylpropanediol (50% aqueous dilution applied at induction and challenge) showed mild skin sensitization potential, however the study authors concluded that it was unclear as to whether or not the skin reactions were caused by irritation, allergic response, or an atopic condition.[2,99] An additional test showed that Methylpropanediol (21.2% applied at induction and challenge) caused erythema and damage to epidermis in some subjects during the induction phase. However, the reactions were not reproducible after a new skin site was tested on those subjects under semi-occlusive conditions; Methylpropanediol was non-sensitizing in this study.[101] The alkane diols evaluated were non-sensitizing in human skin.

Photoirritation/Photosensitization

Animal. 1,10-Decanediol (1.2% in a trade name mixture also containing an unspecified amount of Butylene Glycol) was non-phototoxic in guinea pig skin.[84] Isopentyldiol (undiluted) was neither a photo-irritant nor a photo-sensitizer when tested in guinea pig skin; positive controls were used in both experiments and yielded expected results.[19]

Human. 1,5-Pentanediol (5%) was not phototoxic and not photosensitizing in a 24-hour occlusive patch test performed following long-wave ultraviolet light (UVA)/short-wave ultraviolet light (UVB) exposure to the treated skin. The study authors stated that it does not absorb in UVA range.[45,64]

Ocular Irritation

Below is a synopsis of ocular irritation studies that are presented in detail in Table 13.

In Vitro

1,10-Decanediol (1.2% in a trade name mixture also containing an unspecified amount of Butylene Glycol) was evaluated in a hen's egg experiment and found to have moderate irritation potential when tested on the chorioallantoic membrane.[84] The same 1,10-Decanediol test substance was also evaluated on reconstructed human corneal epithelium in vitro and found to be non-irritating.

Animal

Ocular irritation was evaluated in rabbit eyes for Propanediol, 1,4-Butanediol, 2,3-Butanediol, 1,5-Pentanediol, Hexanediol, 1,10-Decanediol, Methylpropanediol, Butyl Ethyl Propanediol, and Isopentyldiol. No-to-slight irritation (resolved within 48 hours post-application) was reported for undiluted

Table 14. Case Reports.

Test Substances(s)	Patients	Concentration/ Dosage (Vehicle)	Investigation and Method (when available)	Observations/Results	Reference
			Dermal		
1,5-Pentanediol	n=1 (39 yr old male); n=10 controls for each of Test 2 and Test 3	Test 2: .5%, 5%, and 10% 1,5-Pentanediol (in water); .1%, 1%, and 10% resveratrol (in 70% ethanol); 10 controls were patch tested with the doses of test substances above Test 3: .1%, 1%, and 5% resveratrol (in petrolatum); 10 more control subjects were patch tested with same doses of resveratrol in Test 3	A patient was prescribed a resveratrol-containing cream (also contained 1,5-Pentanediol, concentration not specified) for recurrent scaling erythematous dermatitis; dermatitis intensified after 2 weeks of cream application; after use of cream was discontinued eczema eventually cleared Patient underwent patch testing (Test 1: propylene glycol and the resveratrol cream unchanged were applied) 4 months later an additional patch test (Test 2) was performed on the patient and controls using the ingredients in the resveratrol cream A final patch test (Test 3) was performed on the patient and controls using resveratrol diluted in petrolatum	Test 1 on patient: the resveratrol cream produced +/++ reactions by days 2 and 3 Test 2 on patient and controls: patient had strong reaction to 1,5-Pentanediol (++ with 5% and 10% doses and +/++ with .5% dose); patient had slight reactions to resveratrol showing erythema on days 2 and 3 with all dose levels; 9 of 10 controls were negative and 1 control subject developed slight erythema with all doses levels of 1,5-Pentanediol and resveratrol (this control subject had not been previously exposed to resveratrol and had no prior reactions to cosmetics, but did report hyperirritable skin type) Test 3 on patient and controls: patient reacted to 5% resveratrol only (+ by days 2 and 3); controls were negative Final conclusion: patient was diagnosed with allergic contact dermatitis from resveratrol containing cream attributed to sensitization to 1,5-Pentanediol and potential co-sensitization to resveratrol	[104]
1,5-Pentanediol	56 yr old female; 3 control subjects	5% in water	A patient used a cream for a month and developed facial dermatitis with edema of eyelids; patch testing using European standard series, Belgian cosmetic pharmaceutical series, and patient's cream was performed; patient had a positive reaction to cream but not to other series tested; 2 months later patch testing was conducted with ingredients in cream, but had no reaction; patient began using another lotion and developed facial dermatitis; patch testing was conducted with cream and lotion, which both produced positive responses; propylene glycol ingredient in lotion caused a positive reaction; patient was retested with cream because it contained 1,5-Pentanediol	Patient was negative to 1,5-Pentanediol in patch test, but exhibited a positive reaction to 1,5-Pentanediol in repeated open application test (3 control subjects were negative)	[105]
Hexanediol; ethylene glycol	32 yr old female	Test compounds used were experimental dentin primers (by wt %): 62.5% Ethylene Glycol; 45% Hexanediol; 35% Hydroxyethyl methacrylate	A dentist worked with ethylene glycol dentin primer for a year, which required repeated dermal contact with the compound; this dermal contact resulted in 2 months of symptoms including cracked fingertip skin, reddening desquamation, desiccation and inflammatory dolorific sclerosis; she was diagnosed with (irritant) contact dermatitis; a patch test was performed on the dentist with the test compounds indicated; test compounds were soaked into a cotton patch and occlusively applied to healthy brachial skin for 48 h; 48 h post-application the patches were removed and skin was examined immediately, 24, and 48 h after patch removal	Slight erythema was noted with ethylene glycol 48 h after patch removal; study researchers noted that dental professionals sensitized to hydroxyethyl methacrylate should take precautions if using Hexanediol in a dentin primer (no further patch test results specified); other supporting tests in animals were conducted in conjunction with this case report (results presented in Table 12)	[97]
			Oral		
1,4-Butanediol	Report of n >100	Unknown	US FDA reported more than 100 people were ill and 3 died as a result of taking unregulated 'party drugs', also sold as dietary supplements to induce sleep, containing 1,4-Butanediol	Side effects reported by FDA were dangerously low respiratory rates, unconsciousness, vomiting, seizures, and death; effects were amplified when consumed with alcohol or depressant drugs	[34]

(continued)

Table 14. (continued)

Test Substances(s)	Patients	Concentration/ Dosage (Vehicle)	Investigation and Method (when available)	Observations/Results	Reference
1,4-Butanediol	n ≥ 8 (14 months to 10 yrs old)	Approximately 14% of extractable 1,4-Butanediol by weight	Children developed vomiting, ataxia, self-limited coma after swallowing small, colored plastic beads (sold in toy craft kits); in biological samples collected from some of the children GHB was found; in 2007 a voluntary recall of the beads was issued by the US Consumer Product Safety Commission; investigation determined that 1,4-Butanediol had been substituted for the more expensive 1,5-Pentanediol (used in glues) in the plastic beads; 1,4-Butanediol converts to GHB in the body	Small, plastic toy beads were found to have 14% 1,4-Butanediol and no 1,5-Pentanediol or GHB; clinical signs reported were consistent with ingestion of several dozen of the plastic toy beads containing 1,4-Butanediol (approximately 9-12 mg of 1,4-Butanediol per bead)	[107]
1,4-Butanediol	8 patients (22 to 51 yrs old)	Non-fatal cases of 1,4-Butanediol ingestion were 1 to 14 g; Fatalities occurred at doses between 5.4 to 20 g	Patients having toxic effects from oral ingestion of 1,4-Butanediol were identified (from emergency room department visits and/or from public health officials and family members); analysis of 1,4-Butanediol and/or GHB in urine, serum, or blood was performed and/or hospital records or autopsy reports were examined	Patients ingested 1,4-Butanediol for recreational use, enhancement during body building, or for the treatment of depression or insomnia; evidence of addiction and withdrawal were seen in some cases; clinical signs included vomiting, urinary and fecal incontinence, agitation, combativeness, labile level of consciousness, respiratory depression, and death; in 6 patients (2 of whom died) no additional toxicants were detected; the 2 other patients reported that they did not ingest other toxicants; GHB was detected in blood, serum, and urine at levels exceeding normal concentrations; 1,4-Butanediol was not detected in non-fatal cases potentially because ingested doses were smaller, conversion to GHB in the body is rapid, and there were limits on detection of the assay used	[108]
1,4-Butanediol	1 male (44 yrs old)	Unknown	A man was taken to the emergency room with signs of intoxication, agitation, loss of consciousness, vomiting, and myoclonic jerking (heart rate 40 and respiration rate 8); negative blood ethanol; man was awake and alert after 3 h	Man reported ingesting nine yohimbine tablets and pine needle oil; 3 oz spray bottle reported to contain 'pine needle oil' was determined to contain 1,4-Butanediol	[13]
1,4-Butanediol	n=1	Unknown	A patient ingested an illicit product called 'liquid ecstasy'; blood, urine, and gastric content were analyzed for 1,4-Butanediol and GHB by immunoassay and GC-MS; identification of the 'liquid ecstasy' substance was determined by GC-MS	The 'liquid ecstasy' substance was found to contain 1,4-Butanediol; in the patient 1,4-Butanediol was found at 82 μg/mL (in blood), 401 μg/mL (in urine), and 7.4 μg/mL (in gastric content); GHB was found at 103 μg/mL (in blood) and 430 μg/mL (in urine); other drugs detected were methylenedioxymethylamphetamine (.23 μg/mL in blood) and its metabolite methylenedioxyphenylamphetamine (.1 μg/mL in blood); benzoylecgonine (.1 μg/mL in urine)	[13]
			Other Exposure Routes		
1,4-Butanediol	n=7	15 or 30 g (.21 or .43 g/kg, assumed body weight of 70 kg)	Single dose rectally administered (no further details specified)	Clinical signs observed 10 to 20 min post-administration included coma, miosis and areflexia (sustained for 1 to 16 h); 2 deaths within 72 h post-administration (both found to have renal disorder); 5 remaining patients were given analeptic and recovered	[13]
1,4-Butanediol	Unknown	30 mg/kg (intravenous) or 15 to 22 mg/kg/h (by infusion) for 38 to 68 h (initial dose 30 mg/kg)	Dose administered intravenously (no further details provided)	Clinical signs after dosing included sleep, restlessness, clonic spasms of muscles of the extremities	[22]

GC-MS, Gas Chromatography-Mass Spectrometry; GHB, Gamma-Hydroxybutyric Acid.

Propanediol.[12] Undiluted 1,4-Butanediol was slightly irritating.[37,82] Undiluted 2,3-Butanediol was non-irritating to rabbit eyes.[16] No-to-mild irritation was observed for undiluted 1,5-Pentanediol[14,33,79] and undiluted Hexanediol.[15,79,80] 1,10-Decanediol (1.2% in a trade name mixture also containing an unspecified amount of Propylene Glycol) was slightly irritating.[84] Methylpropanediol (undiluted, n = 2) was non-irritating to rabbit eyes.[20,100] Butyl Ethyl Propanediol (concentration not specified) resulted in severe eye injury in one test.[81] In another experiment, undiluted Butyl Ethyl Propanediol was considered to be irritating, with corneal opacification and diffuse crimson conjunctiva coloration, swelling, and partial eyelid eversion; the rabbit eyes returned to normal by 14 days post-application.[17] Isopentyldiol (concentration not specified) was non-irritating.[19] Generally, the alkane diols were non-to-mildly irritating, with the exception that Butyl Ethyl Propanediol was irritating.

Clinical Studies

1,5-Pentanediol

A controlled, double-blind comparative study was conducted to evaluate the treatment of atopic dermatitis with hydrocortisone and 1,5-Pentanediol.[102] Patients with atopic dermatitis were treated 2x/day with either 1% hydrocortisone (n = 31) or 1% hydrocortisone with 25% 1,5-Pentanediol (n = 32) in a cream formulation for 6 weeks. Quantitative bacteria cultures were taken for *Staphylococcus aureus* (commonly seen in the skin of atopic dermatitis patients) from the lesional skin prior to treatment and at weeks 2, 4, and 6 of treatment. The results indicated that the hydrocortisone-only formulation was effective for 68% of the patients in that test group; the hydrocortisone plus 1,5-Pentanediol formulation was effective for 69% in that group. There was a statistically significant reduction in *S. aureus* (baseline to week 2 and baseline to week 6) in the hydrocortisone plus 1,5-Pentanediol group, which was not observed in the hydrocortisone-only group. There were 2 instances in each treatment group of "slight burning sensation" following cream application. The study authors noted that bacteria are not likely to develop resistance to 1,5-Pentanediol because of the interaction of diols on membranes.

The therapeutic effect of 1,5-Pentanediol was investigated for the treatment of herpes simplex labialis (cold sore virus) in a placebo-controlled, randomized, double-blind clinical trial.[103] Patients included in the trial were those with known, frequent recurrences of herpes labialis. The treatment group (n = 53) received 25% 1,5-Pentanediol in a gel formulation, which was applied to both lips (.04 g total/day) during the 26-week prophylactic evaluation. The placebo group (n = 52) received the same gel formulation without 1,5-Pentanediol for 26 weeks. During the occurrence of herpes labialis episodes the treatment gel or placebo was applied to both lips (.16 g total/day) for 5 days and then the prophylactic treatment resumed until the next herpes episode. The herpes episodes reported during the trial were 109 for the treatment group and 120 for the placebo group. 1,5-Pentanediol did not demonstrate a prophylactic effect, compared to the placebo, in preventing the recurrence of herpes labialis. However, there was a statistically significant improvement in blistering, swelling, and pain for the therapeutic use of 1,5-Pentanediol as compared to the placebo. There were no treatment-related adverse events attributable to 1,5-Pentanediol or the placebo reported. In the treatment and placebo groups, body weight and temperature, heart rate, and clinical parameters were nearly unchanged.

Case Reports

Below is a synopsis of case reports that are presented in detail in Table 14.

Information from case reports for the alkane diols included allergic contact dermatitis as a result of dermal exposure to 1,5-Pentanediol (.5 to 10%) in various creams,[104,105] a recommendation by study researchers for dental professionals exposed to Hexanediol in dentin primers to take precautions because of the potential to cause contact dermatitis following repeated occupational exposure,[97] and adverse effects reported in adults (including death) and poisoning in children from oral exposure to 1,4-Butanediol (varying doses).[13,22,106-108]

Risk Assessment

Occupational Standards

1,4-Butanediol. In Germany, the occupational limit value for 1,4-Butanediol is 50 mL/m^3 (ppm) or 200 mg/m^3.[109]

Diacetyl (potential metabolite of 2,3-Butanediol). As of 2012, the American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit value (TLV) for diacetyl is .01 ppm (.04 mg/m^3) time-weighted average (TWA) and .02 ppm (.07 mg/m^3) short-term exposure limit (STEL); diacetyl has an A4 classification (not classifiable as a human carcinogen).[110] A permissible exposure limit (PEL) has not been established by the US Occupational Safety and Health Administration (OSHA).

In 2016, the US National Institute for Occupational Safety and Health (NIOSH) established a recommended exposure limit (REL) of 5 ppb for diacetyl as a TWA for up to 8 h/day during a 40-h work week.[111] NIOSH recommends a STEL for diacetyl of 25 ppb for a 15-minute time period.

Summary

The 10 alkane diols included in this safety assessment reportedly function in cosmetics as solvents, humectants, and skin conditioning agents.

VCRP data received from the FDA in 2018 indicated that the highest reported uses are for Propanediol (1528 uses), and Methylpropanediol (570 uses). The Council industry survey data from 2015 indicated that the highest maximum use concentration in leave-on products was 39.9% Propanediol in non-spray deodorants.

1,4-Butanediol and Hexanediol are permitted as indirect food additives. The FDA has issued warnings about dietary supplements containing 1,4-Butanediol because of associated adverse health effects, including death. 1,4-Butanediol is considered to be a Class I Health Hazard by the FDA, as well as a Schedule I Controlled Substance Analog by the DEA, if illicit human consumption is intended.

A permeability coefficient of 1.50×10^{-5} cm/h was calculated for Propanediol after abdominal skin from human cadavers was exposed for 48 hours in a static diffusion cell to a 1.059 g/mL Propanediol solution (infinite dose, 99.953% purity).

The ability of Propanediol, 1,4-Butanediol, or 1,5-Pentanediol to enhance the penetration of the drug estradiol (.12% [^{3}H]-estradiol in 1:10 alkane diol/ethanol solution) in human skin was evaluated in an in vitro experiment using a Franz diffusion cell. After ~ 85 - 90 minutes the permeability of [^{3}H]-estradiol in human skin was determined to be ~ 5 - 6 μg/cm^2 with Propanediol and <1 μg/cm^2 with 1,4-Butanediol or 1,5-Pentanediol. In vitro tests of pharmaceutical formulations containing .1% mometasone furoate and 25% 1,5-Pentanediol or 1% hydrocortisone and 25% 1,5-Pentanediol or 1% terbinafine and either 5% or 20% 1,5-Pentanediol, showed that 1,5-Pentanediol was a penetration enhancer in human breast skin samples exposed to the formulations for 60 hours.

1,4-Butanediol was a competitive inhibitor of ethanol metabolism by alcohol dehydrogenase. Diacetyl, acetoin, and 2,3-Butanediol were interconvertible with a molar equilibrium ratio of 0:3:7, respectively, in rat liver homogenates. Methylpropanediol was demonstrated to be a substrate for alcohol dehydrogenase in vitro.

Rat liver homogenates metabolized Propanediol to yield malondialdehyde in treated rats (500 ppm in the diet for 15 weeks) and in control rats (plain diet). A single dose of Propanediol, 1,4-Butanediol, 2,3-Butanediol, or Hexanediol administered orally to rabbits yielded the corresponding glucuronic acid conjugates in the urine representing 2 to 26% of the administered dose. Orally administered 1,4-Butanediol and 1,5-Pentanediol produced succinic acid and phenacyl glutarate, respectively, in the urine.

Endogenous concentrations of 1,4-Butanediol in rats were 30 to 165 ng/g in aqueous phase tissues (aqueous portion of supernatant generated from homogenized tissues) and 150 to 180 ng/g in lipid phase tissues (lipid portion of supernatant generated from homogenized tissues). 1,4-Butanediol concentrations were 96 μg/g, 52 μg/g, and 58 μg/g in the brain, liver, and kidney, respectively, of rats 75 minutes after oral exposure to 1 g/kg 1,4-Butanediol. In rats orally exposed to up to 400 mg/kg 1,4-Butanediol (radiolabels on C1 and C4), >75% of the radioactivity was excreted as [^{14}C]-CO_2 by 24 hours post-dosing; up to 6% was eliminated in feces 72 hours post-dosing. Experiments in rats orally administered 1M diacetyl, acetoin, or 2,3-Butanediol showed interconversion among these compounds in vivo. Methylpropanediol (100 or 1000 mg/kg, [^{14}C]-labeled) orally administered to rats was reported to be rapidly metabolized and eliminated as 3-hydroxybutyric acid in the urine (31% - 45% dosed radioactivity), as CO_2 in exhaled breath (42% - 57%), and in the feces (<1% dosed radioactivity).

In human subjects dermally exposed to 25% 1,5-Pentanediol (2 applications, 12 hours apart), increasing levels of glutaric acid were detected in urine and serum (no concentrations were provided). Oral exposure to 25 mg/kg 1,4-Butanediol resulted in measurable plasma concentrations of GHB in human subjects within 5 to 30 minutes after exposure, indicating rapid conversion of 1,4-Butanediol to GHB; GHB concentrations were below the limit of quantitation within 4 hours. Clearance of 1,4-Butanediol was rapid in some subjects and relatively slow in others; the latter were confirmed to have a genetic mutation of variant alleles of ADH-1B. Nearly 100% of 1,4-Butanediol was rapidly converted to GHB in a study in which 15 or 30 mg/kg 1,4-Butanediol was intravenously injected into human subjects.

Dermal exposure animal studies evaluating the toxicity of the alkane diols indicated an LD_{50} >20 g/kg in rats for Propanediol, >20 mL/kg in rabbits for 1,5-Pentanediol, >10 g/kg in rabbits for Hexanediol, and >2 g/kg in rabbits for Butyl Ethyl Propanediol. A single dermal exposure to 5 g/kg 1,4-Butanediol caused dermal lesions within 48 hours and liver abnormalities within 14 days, but no mortalities in rats. In rabbits, a single 2 g/kg dermal application of Methylpropanediol caused kidney, lung, liver, and gastrointestinal tract abnormalities, among other effects, but no mortalities.

Acute oral LD_{50}s reported in multiple studies of mammalian test species included 14.9 mL/kg Propanediol, 1.2 to 2.5 g/kg 1,4-Butanediol, 10 g/kg 1,5-Pentanediol, 3 g/kg Hexanediol, 3 to 5 g/kg Butyl Ethyl Propanediol, >.20 mL/kg 1,10-Decanediol (1.2% in a 20 mL/kg trade name mixture also containing unspecified amounts of Propylene Glycol), and ≥5 g/kg for 2,3-Butanediol, Methylpropanediol and Isopentyldiol.

A single, 4-hour inhalation exposure of 2000 to 5000 mg/L Propanediol caused moderate weight loss but no deaths in rats. A single 4.6 to 15 mg/L exposure to 1,4-Butanediol resulted in lethargy, labored breathing, and lung noise/dry nasal discharge in rats 1 to 9 days post-dosing, and 1 death at 15 mg/L 1 day post-dosing. Rats exposed for 4 hours to 5.1 mg/L 1,4-Butanediol exhibited shallow respiration that resolved within 48 hours post-exposure; gross pathology examination revealed no abnormalities. No deaths were reported after a single 7- to 8-hour inhalation exposure to 2,3-Butanediol (up to .85 mg/L in air), 1,5-Pentanediol (concentrated vapor), or Hexanediol (concentrated vapor). An LC_{50} > 5.1 g/L for inhalation (duration of inhalation not specified) was reported for Methylpropanediol.

Reported NOELs and NOAELs for short-term oral exposures in rats included 200 mg/kg/day 1,4-Butanediol (~42 days), 500 mg/kg/day 1,4-Butanediol in females and 50 mg/kg/day in males (28 days), and 1000 mg/kg/day Propanediol and Methylpropanediol (14 days) or Hexanediol and Butyl Ethyl Propanediol (28 days). The 28-day experiment in rats evaluating the toxicity of 1,4-Butanediol revealed liver abnormalities in treated animals. The rat study (approximately 42 days exposure duration) examining 1,4-Butanediol, showed lower body weight gains and food consumption (400 and 800 mg/kg/day), a statistically significant dose-related decrease of blood glucose (male treated animals), and bladder abnormalities (400 and 800 mg/kg/day). The 28-day experiment evaluating oral exposure to Butyl Ethyl Propanediol in rats resulted in abnormalities in the liver (in males at 1000 mg/kg/day) and kidney (in males at 150 or 1000 mg/kg/day). Rabbits orally exposed to Hexanediol (up to 2000 mg/kg for 25 doses, duration unknown) exhibited thrombosis and treatment-related effects (unspecified) on the liver and kidneys.

Results were unremarkable in a study in which rats inhaled up to 1800 mg/L Propanediol, 6 h/day, for 2 weeks (9 total exposures). Rats exposed to up to 5.2 mg/L 1,4-Butanediol, 6 h/day, 5 days/week, for 2 weeks, showed slight red nasal discharge (at levels .2, 1.1, and 5.2 mg/L), lower body weights (at 5.2 mg/L only), and abnormal blood chemistry parameters (at 5.2 mg/L only); a 1.1 mg/L NOAEC was reported.

The NOAELs reported in subchronic oral exposure studies were 15 mg/kg/day and 150 mg/kg/day Butyl Ethyl Propanediol (90 days) in male and female rats, respectively. In 90-day studies, a NOAEL of 600 mg/kg/day was reported for Methylpropanediol and NOAELs of 1000 mg/kg/day were reported for Propanediol and Hexanediol (in females; 400 mg/kg/day NOAEL in males) in oral exposure studies in rats. An evaluation of oral exposure to 5 or 10 mL/kg Propanediol for 15 weeks in rats resulted in 100% mortality (5 deaths) at 10 mL/kg and 2 deaths at 5 mL/kg. In the male rats dosed with Hexanediol, mentioned above, a treatment-related decrease (in males at 1000 mg/kg/day) in mean body weights and a statistically significant increase in organ weights (in males at 400 and 1000 mg/kg/day) were observed. The rats dosed with Methylpropanediol showed decreased liver enzymes and inorganic phosphate (at 1000 mg/kg/day). In rats dosed with Butyl Ethyl Propanediol, there were 4 treatment-related deaths (males at 150 or 1000 mg/kg/day), abnormal respiration 1 to 2 hours post-dosing (after which animals returned to normal), and urinary (at 150 and 1000 mg/kg/day) and kidney abnormalities (at ≥15 mg/kg/day) reported.

In subchronic inhalation studies, rats were exposed to 1,4-Butanediol 2 hours/day for 4 months; a NOAEC of 500 mg/L (equivalent to approximately 23 mg/kg/day) and a LOAEC of 1500 mg/L (equivalent to about 85 mg/kg/day) were reported. Effects at the reported LOAEC included a sleepy condition 20 minutes after each exposure and a histopathological exam revealed pulmonary abnormalities. In 14-wk studies of diacetyl (potential metabolite of 2,3-Butanediol) in mice and rats, significant increases in neutrophil counts consistent with inflammation were observed at 50 and 100 ppm (mice) and at 100 ppm (rats). Significantly increased incidences of exposure-related, non-neoplastic lesions occurred in the respiratory tract of male and female rats and mice, primarily in the 50 and 100 ppm groups, and the highest number of lesions occurred in the nose.

In a chronic study, rats were orally exposed to .25, 3, or 30 mg/kg 1,4-Butanediol for 6 months. At the 30 mg/kg dosage, blood cholinesterase activity was reduced, the ratio of blood serum protein fractions changed, the –SH (thiol) groups in whole blood and the brain decreased, liver glycogen and choline esterase activity decreased, vitamin C in organs decreased, and there was an increase in blood serum transaminases. A substantial increase in the auto-diffusion coefficient of tissue fluid was found in the liver and brain with the 3 and 30 mg/kg dosages. At the 30 mg/kg dosage, the morphological changes were observed.

In rat studies evaluating oral Propanediol exposures up to 1000 mg/kg/day, spermatogenic endpoints were unaffected (90-day exposure) and no maternal or fetal toxic effects were observed (dosing on days 6-15 of gestation). A NOAEL of 100 mg/kg/day and a LOAEL of 300 mg/kg/day 1,4-Butanediol were reported for maternal (dosing on days 6-15 of gestation) and developmental toxicity in an oral exposure mouse study; maternal central nervous system intoxication and maternal and fetal body weight reduction were observed at the LOAEL. Results reported in male and female rats orally exposed to 1,4-Butanediol for 14 days before mating and, with dosing continuing in females through day 3 of lactation, included a developmental NOEL of 400 mg/kg/day (pup weight was slightly, but statistically significantly decreased on lactation day 4 at 800 mg/kg/day, effect was secondary to maternal reduction in body weight), parental transient hyperactivity (at 200 and 400 mg/kg/day) and reversible parental hypoactivity (≥400 mg/kg/day), but no parental reproductive parameters were changed by treatment. A NOAEL of 1000 mg/kg/day Hexanediol (dosing on days 6-19 of gestation) and Methylpropanediol (dosing on days 0-29 of gestation) was reported in oral exposure studies for maternal and developmental effects in rats. In another oral exposure study, the NOAEL for maternal effects was 150 mg/kg/day Butyl Ethyl Propanediol in rats (dosing on days 6-19 of gestation); 1000 mg/kg/day caused staggering, slow respiration, and reduced food consumption and body weights in the dams. The NOAEL for developmental effects was 1000 mg/kg/day Butyl Ethyl Propanediol in this study.

Genotoxicity experiments conducted in vitro evaluating Propanediol were negative in a mammalian cell gene mutation assay (up to 5000 μg/mL), a chromosomal aberration test (up to 5000 μg/mL), and an Ames test (up to 5000 μg/plate). Another mammalian chromosomal aberration test (2500 μg/mL, without metabolic activation) that evaluated Propanediol resulted in positive responses for genotoxicity, however the

same test (up to 5000 µg/mL Propanediol) performed with metabolic activation yielded negative results. 1,4-Butanediol was negative for genotoxicity in a *Salmonella typhimurium* mutagenicity test (up to 10,000 µg/plate), in an Ames test (up to 10,000 µg/plate), in a mammalian cell gene mutation assay (up to 5000 µg/mL), and in a chromosomal aberration test (up to 5000 µg/mL). 2,3-Butanediol was negative in an Ames II™ test (up to 5000 µg/mL). In an Ames test (up to 5000 µg/plate) 1,5-Pentanediol was negative for genotoxicity. Hexanediol was negative for genotoxicity in an Ames test (up to 5000 µg/plate), in a mammalian chromosomal aberration test (up to 1.2 µg/mL), and in a mammalian cell gene mutation assay (up to 5000 µg/mL). 1,10-Decanediol (1.2% in a trade name mixture also containing unspecified amounts of Propylene Glycol or Butylene Glycol) was negative in an Ames test (up to ~120 µg/plate 1,10-Decanediol). Methylpropanediol was negative in a reverse mutation assay (up to 5000 µg/plate) and in a chromosomal aberration test (up to 5000 µg/plate). Butyl Ethyl Propanediol was negative for genotoxicity in an Ames test (up to 5000 µg/plate) and in a mammalian cell gene mutation assay (up to 7.2 mmol/L); Isopentyldiol was negative for genotoxicity in an Ames test (up to 10,000 µg/plate) and in a liquid suspension assay (up to 100 mg/plate). Tests performed in rat liver and testicular homogenates from rats that were fed 500 ppm Propanediol in the diet for 15 weeks (controls fed plain diet), showed that the hepatic DNA-protein and DNA-crosslinking at 10 and 15 weeks were higher than controls, and the testicular DNA-protein and DNA-crosslinking of treated rats were slightly higher than controls at 15 weeks. The study authors concluded that Propanediol was converted to malondialdehyde in vivo, causing damage to rat DNA. Mouse micronucleus tests conducted in vivo were non-mutagenic for Propanediol (single dose of 2150 mg/kg bw) and for Butyl Ethyl Propanediol (single dose up to 1250 mg/kg).

Carcinogenicity studies data on alkane diol ingredients were not found in the published literature, and unpublished data were not submitted. An inhalation study was conducted by NTP in which B6C3F1/N mice and Wistar Han [CRL:WI (Han)] rats were exposed to diacetyl vapor by whole body inhalation at concentrations up to 50 ppm, for 6 hours and 12 min/day, 5 days/wk, for 105 wks. In mice, there was no evidence of carcinogenic activity of diacetyl in males, but there was equivocal evidence of carcinogenic activity in females, based on the occurrences of adenocarcinoma of the nose. In rats, there was some evidence of carcinogenic activity of diacetyl in males and females based on the combined incidences of squamous cell papilloma and squamous cell carcinoma of the nose in males and incidences of squamous cell carcinoma of the nose of females.

The degree of structural damage induced by certain hexacarbon compounds (6-carbon compounds) to the central and peripheral nervous system has been attributed to differential serum levels of the common metabolite, 2,5-hexanedione. The production of neuropathy is dependent on the specific molecular configuration of hexacarbon compounds, and a γ-spacing of the two keto groups is needed. Additionally, it is suggested that although pyrrole formation is necessary for the pathogenesis of γ-diketone neuropathy, autoxidation to reactive intermediates, resulting in inter- or intraneurofilament crosslinking, is required for the neurotoxic effects of γ-diketones to be manifested.

1,10-Decanediol (1.2% in a trade name mixture also containing an unspecified amount of Butylene Glycol) was non-irritating in an in vitro test evaluating the test substance on reconstructed human epidermis.

Undiluted Propanediol, 1,4-Butanediol, 2,3-Butanediol, 1,5-Pentanediol, or Isopentyldiol was non-irritating to slightly or minimally irritating to the skin of rabbits in 20-to 24-hour patch tests. Undiluted 1,4-Butanediol was minimally irritating when applied to rabbit ears. Hexanediol was non-irritating to guinea pig skin (45% test substance applied) and rabbit skin (80% test substance applied) in 24-hour patch tests. 1,10-Decanediol (1.2% in trade name mixture also containing an unspecified amount of Propylene Glycol) was non-irritating to rabbit skin in a 24 h occlusive patch test. Methylpropanediol (concentration not specified) was non-irritating to rabbit skin. Undiluted Butyl Ethyl Propanediol was non-to-mildly irritating to rabbit skin in 4-hour semi-occlusive patch tests.

A single, dermal application of undiluted Propanediol was non-irritating in human subjects (no further details). 1,4-Butanediol was non-irritating in a patch test on human subjects (concentration not specified). 1,5-Pentanediol (5%) was non-irritating in a 24-hour occlusive patch test in human subjects. 1,10-Decanediol (1.2% in trade name mixture also containing an unspecified amount of Butylene Glycol) was well-tolerated, according to study authors (2 subjects showed mild erythema 1 h following patch removal) in a 48-hour occlusive patch test. Methylpropanediol (100%, 50% aqueous dilution) was non-irritating to subjects with sensitive skin in a 14-day cumulative irritation study. Slight irritation was observed in a 48-hour Finn chamber skin test evaluating unspecified concentrations of Isopentyldiol. Generally, the alkane diols were non-to-slightly irritating in human skin.

The following treatments were negative in tests for the induction of dermal sensitization in guinea pigs: Propanediol (2.5% intradermal and 100% epicutaneous concentrations applied at induction, 50% at challenge), 1,4-Butanediol (10% intradermal and 30% topical concentrations applied at induction and challenge), 2,3-Butanediol (5% intradermal and 50% epicutaneous concentrations applied at induction, 25% at challenge), Hexanediol (5% intradermal and 50% epicutaneous concentrations applied at induction, 25% at challenge), 1,10-Decanediol (1.2% in a trade name mixture containing an unspecified amount of Propylene Glycol or Butylene Glycol) in a Buehler test (1.2% 1,10-Decanediol in trade name mixture used at induction and .3% 1,10-Decanediol in trade name mixture used at challenge), Butyl Ethyl Propanediol (2.5% intradermal and 100% topical concentrations applied at induction, 50% and 100% at challenge), and Isopentyldiol (10%

intradermal and 100% topical concentrations applied at induction, 50% at challenge). In another test, strong erythema was reported in guinea pigs with Hexanediol challenge (no concentration specified) following induction (sensitization) with another compound (.2% hydroxyethyl methacrylate); however no Hexanediol induction (.2%)/Hexanediol challenge (no concentration specified) tests showed a positive sensitization reaction. Methylpropanediol showed mild sensitization potential in guinea pigs (10% intradermal to 100% epidermal concentrations applied at induction, up to 100% at challenge).

Propanediol (5 to 75% concentrations applied at induction and challenge) was non-sensitizing in human subjects; mild erythema was reported in 4 subjects during induction (75% only) after the 1st of 9 applications. 1,4-Butanediol (concentration not specified), and 1,5-Pentanediol (5% or 25% in different tests) were non-sensitizing in human subjects. Methylpropanediol (undiluted) was non-sensitizing in one test and showed mild skin sensitization potential in another test (50% aqueous dilution applied at induction and challenge). However, the study authors concluded that it was unclear as to whether or not the skin reactions were caused by irritation, allergy, or an atopic condition. An additional study showed that Methylpropanediol (21.2% applied at induction and challenge) induced erythema and damage to epidermis in some subjects during induction, however the reactions discontinued after a new skin site in those subjects was tested under semi-occlusive conditions; Methylpropanediol was non-sensitizing in that study. Overall, the alkane diols were non-sensitizing to human subjects.

1,10-Decanediol (1.2% in a trade name mixture also containing an unspecified amount of Butylene Glycol) was non-phototoxic in guinea pig skin. Undiluted Isopentyldiol was neither a photo-irritant nor a photo-sensitizer when tested in guinea pig skin.

Human subjects were treated with 1,5-Pentanediol (5%) on the forearms, followed by UVA/UVB exposure. Results from a 24-hour occlusive patch test to the treated skin revealed that the test substance was non-phototoxic and non-photosensitizing.

Experiments evaluating 1,10-Decanediol (1.2% in a trade name mixture also containing an unspecified amount of Butylene Glycol) performed in vitro showed moderate irritation potential in a hen's egg test, and was non-irritating in a test on reconstructed human corneal epithelium.

Undiluted Propanediol, 1,4-Butanediol, 2,3-Butanediol, 1,5-Pentanediol, and Hexanediol were non-to-slightly irritating or mildly irritating in rabbit eyes. 1,10-Decanediol (1.2% in a trade name mixture also containing an unspecified amount of Propylene Glycol) was slightly irritating to rabbit eyes. Methylpropanediol (undiluted) was non-irritating to rabbit eyes. Isopentyldiol was also non-irritating to rabbit eyes (concentration not specified). In contrast, undiluted Butyl Ethyl Propanediol caused severe injury in rabbit eyes, including irritation, corneal opacification, partial eyelid eversion, all of which were reversible.

In a 6-week study investigating the therapeutic effect of 1,5-Pentanediol (25% in a cream formulation) plus hydrocortisone (1%) compared to only hydrocortisone (1%) on patients with atopic dermatitis, there were 2 instances in each treatment group of a slight skin burning sensation after application. In the group treated with hydrocortisone and 1,5-Pentanediol, a statistically significant decrease in *S. aureus* colonies at weeks 2 and 6 of treatment was observed, which was not seen with treatment of hydrocortisone alone.

In a 6-month clinical trial evaluating the therapeutic effect of 1,5-Pentanediol (25% in a gel formulation) on herpes labialis in patients with recurrent herpes episodes, there were no treatment-related adverse events reported; body weight and temperature, heart rate, and clinical parameters were nearly unchanged.

Information from case reports for the alkane diols included allergic contact dermatitis as a result of dermal exposure to 1,5-Pentanediol (.5 to 10%) in various creams; recommendations by study researchers for dental professionals exposed to Hexanediol in dentin primers to take precautions because of the potential to cause contact dermatitis following repeated occupational exposure; the adverse effects in adults (non-fatal cases occurred with doses between 1 to 14 g, fatalities occurred with 5.4 to 20 g doses) and poisoning in children (with 14% 1,4-Butanediol by weight) from oral exposure to 1,4-Butanediol.

Discussion

The Panel reviewed the safety of 10 alkane diols and determined that the data were sufficient to determine safety for seven of the ingredients, but insufficient to determine safety of the remaining three ingredients (i.e., 1,4-Butanediol, 2,3-Butanediol, and Octanediol). Maximum concentrations of use were reported for several of the ingredients, and these concentrations ranged from .006% (1,10-Decanediol) to 39.9% (Propanediol) in leave-on products. 1,4-Butanediol has uses reported in the VCRP, but concentrations of use were not reported in response to the industry survey. Therefore, because 1,4-Butanediol can be metabolized into gamma-hydroxybutyric acid (GHB), which is a controlled substance in the United States, and because of the wide range of use concentrations reported for the other ingredients, the Panel stated that concentration of use data are needed to determine safety of 1,4-Butanediol.

Concentration of use data were not available for 2,3-Butanediol (not reported to be in use) and Octanediol, and additional data were also lacking. The complete list of data needed to assess safety of these two ingredients includes:

- Concentration of use;
- 28-day dermal toxicity studies;
- Dermal and reproductive toxicity data; and
- Mammalian genotoxicity studies, if the ingredients are not used at low concentrations.

2,3-Butanediol can exist as 3 different stereoisomers. Data on the toxicities of these isomers would help to inform the safety assessment.

Variations in the regiochemistry of small alkane diols may lead to significant differences in toxicity. For example, 2,5-hexanediol, which is not a cosmetic ingredient, is known to be a neurotoxic metabolite of hexane. However, the structurally similar cosmetic ingredient, Hexanediol (i.e., 1,6-hexanediol), is not a neurotoxin. The Panel discussed whether there was concern that 2,5-hexanediol could be present as a significant impurity of Hexanediol (aka 1,6-hexanediol). The Panel determined that, based on the low maximum concentration of Hexanediol reported (.5% in leave-on dermal contact cosmetics) and the >96% purity reported for Hexanediol, the potential presence of 2,5-hexanediol would be toxicologically insignificant.

During the initial review of this safety assessment, the Panel requested neurotoxicity data for Isopentyldiol. No data were received in response to this request. However, because oral toxicity studies with Isopentyldiol reported no adverse clinical or histopathological changes, and due to the fact that bioactivation to a diketone similar to 2,5-hexanediol requires a very specific pathway and was not likely to occur, the Panel no longer felt these data were needed.

Although positive results were obtained in one mammalian chromosomal aberration test at one concentration of Propanediol (2500 µg/mL without metabolic activation), another mammalian chromosomal aberration test reported negative results at concentrations up to 5000 µg/mL Propanediol (with metabolic activation). Additionally, the genotoxicity data for the other alkane diols were largely negative, supporting the fact that genotoxicity was not a likely concern for Propanediol. Furthermore, the Panel noted that carcinogenicity data were absent, but because the genotoxicity data were largely negative, carcinogenicity data were not needed.

Alkane diols, especially lower molecular weight alkane diols such as 1,3-Propanediol, can enhance the penetration of other ingredients through the skin. The Panel cautioned that care should be taken in formulating cosmetic products that may contain these ingredients in combination with any ingredients whose safety was based on their lack of dermal absorption data, or when dermal absorption was a concern.

Some of the alkane diols used as cosmetic ingredients, such as Propanediol and 2,3-Butanediol, can be derived from plant sources. The Panel expressed concern about pesticide residues and heavy metals that may be present in botanically sourced ingredients, and they stressed that the cosmetics industry should continue to use current good manufacturing practices (cGMPs) to limit any potential impurities.

The Panel discussed the issue of incidental inhalation exposure from perfumes, hair sprays, deodorant sprays, and face powders. The data that are available from animal inhalation studies, including acute and short-term exposure data, suggest little potential for respiratory effects at relevant doses by the ingredients that are used in products that could incidentally be inhaled. Propanediol (up to 3%) and Isopentyldiol (up to 5%) are reportedly used in cosmetic products that may be aerosolized and Isopentyldiol is used up to .33% in face powder that may become airborne. The Panel noted that most of the droplets/particles produced in cosmetic aerosols and loose-powder cosmetic products would not be respirable to any appreciable amount. The potential for inhalation toxicity is not limited to respirable droplets/particles deposited in the lungs. In principle, inhaled droplets/particles deposited in the nasopharyngeal and thoracic regions of the respiratory tract may cause toxic effects depending on their chemical and other properties. However, coupled with the small actual exposure in the breathing zone and the concentrations at which the ingredients are used, the available information indicates that incidental inhalation would not be a significant route of exposure that might lead to local respiratory or systemic effects. A detailed discussion and summary of the Panel's approach to evaluating incidental inhalation exposures to ingredients in cosmetic products is available at https://www.cir-safety.org/cir-findings.

Lastly, the Panel noted that for the most part, the alkane diols were not irritants. However, Butyl Ethyl Propanediol (undiluted in one study, concentration not specified in another) was irritating to rabbit eyes. Butyl Ethyl Propanediol is not reported to be used in formulations that are used in the eye area. However, if it were to be included in products used near the eye, those products must be formulated to be non-irritating.

Conclusion

The Expert Panel for Cosmetic Ingredient Safety concluded that the following 7 ingredients are safe in cosmetics in the present practices of use and concentration described in this safety assessment:

Propanediol	Methylpropanediol
1,5-Pentanediol*	Butyl Ethyl Propanediol
Hexanediol	Isopentyldiol
1,10-Decanediol	

**Not reported to be in current use. Were the ingredient in this group not in current use to be used in the future, the expectation is that it would be used in product categories and at concentrations comparable to others in this group.*

The Panel also concluded that the available data are insufficient to make a determination that 1,4-Butanediol, 2,3-Butanediol, and Octanediol are safe under the intended conditions of use in cosmetic formulations.

Author's Note

Unpublished sources cited in this report are available from the Director, Cosmetic Ingredient Review, 1620 L Street, NW, Suite 1200, Washington, DC 20036, USA.

Author Contributions

The articles in this supplement were sponsored by the Cosmetic Ingredient Review.

Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: The articles in this supplement were sponsored by the Cosmetic Ingredient Review.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: The articles in this supplement were sponsored by the Cosmetic Ingredient Review. The Cosmetic Ingredient Review is financially supported by the Personal Care Products Council.

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