

# European Union Risk Assessment Report

CAS No: 109-66-0

EINECS No: 203-692-4

n-pentane





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**RISK ASSESSMENT**

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# **n-PENTANE**

CAS No: 109-66-0

EINECS No: 203-692-4

## **RISK ASSESSMENT**

*Final Report, 2003*

Norway

This document has been prepared by the Norwegian Pollution Control Authority in consultation with the Directorate of Labour Inspection, on behalf of the European Union. The scientific work has been prepared by the National Institute of Public Health, the Norwegian Institute for Water Research (NIVA) and the National Institute of Occupational Health.

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<b>Date of Last Literature Search:</b>	<b>1996</b>
<b>Review of report by MS Technical Experts finalised:</b>	<b>2002</b>
<b>Final report:</b>	<b>2003</b>

(The last full literature survey was carried out in 1996, targeted searches have been carried out subsequently for example on tropospheric ozone formation. Toxicity data have been added up until 2001).

## Foreword

We are pleased to present this Risk Assessment Report which is the result of in-depth work carried out by experts in one Member State, working in co-operation with their counterparts in the other Member States, the Commission Services, Industry and public interest groups.

The Risk Assessment was carried out in accordance with Council Regulation (EEC) 793/93<sup>1</sup> on the evaluation and control of the risks of “existing” substances. “Existing” substances are chemical substances in use within the European Community before September 1981 and listed in the European Inventory of Existing Commercial Chemical Substances. Regulation 793/93 provides a systematic framework for the evaluation of the risks to human health and the environment of these substances if they are produced or imported into the Community in volumes above 10 tonnes per year.

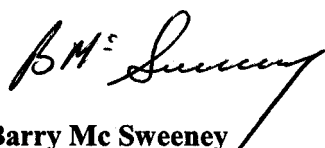
There are four overall stages in the Regulation for reducing the risks: data collection, priority setting, risk assessment and risk reduction. Data provided by Industry are used by Member States and the Commission services to determine the priority of the substances which need to be assessed. For each substance on a priority list, a Member State volunteers to act as “Rapporteur”, undertaking the in-depth Risk Assessment and recommending a strategy to limit the risks of exposure to the substance, if necessary.

The methods for carrying out an in-depth Risk Assessment at Community level are laid down in Commission Regulation (EC) 1488/94<sup>2</sup>, which is supported by a technical guidance document<sup>3</sup>. Normally, the “Rapporteur” and individual companies producing, importing and/or using the chemicals work closely together to develop a draft Risk Assessment Report, which is then presented at a Meeting of Member State technical experts for endorsement. The Risk Assessment Report is then peer-reviewed by the Scientific Committee on Toxicity, Ecotoxicity and the Environment (CSTEE) which gives its opinion to the European Commission on the quality of the risk assessment.

If a Risk Assessment Report concludes that measures to reduce the risks of exposure to the substances are needed, beyond any measures which may already be in place, the next step in the process is for the “Rapporteur” to develop a proposal for a strategy to limit those risks.

The Risk Assessment Report is also presented to the Organisation for Economic Co-operation and Development as a contribution to the Chapter 19, Agenda 21 goals for evaluating chemicals, agreed at the United Nations Conference on Environment and Development, held in Rio de Janeiro in 1992.

This Risk Assessment improves our knowledge about the risks to human health and the environment from exposure to chemicals. We hope you will agree that the results of this in-depth study and intensive co-operation will make a worthwhile contribution to the Community objective of reducing the overall risks from exposure to chemicals.



**Barry Mc Sweeney**  
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DG Joint Research Centre



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Director-General  
DG Environment

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<sup>1</sup> O.J. No L 084, 05/04/199 p.0001 – 0075

<sup>2</sup> O.J. No L 161, 29/06/1994 p. 0003 – 0011

<sup>3</sup> Technical Guidance Document, Part I – V, ISBN 92-827-801 [1234]





CAS No: 109-66-0  
EINECS No: 203-692-4  
IUPAC name: n-pentane

The present report covers assessment of the risks associated with the life cycle of isolated n-pentane, i.e. the production of the commercial product n-pentane (EINECS No 203-692-4) and the production and use of products containing the commercial product n-pentane. The present report does not cover the assessment of risks connected to the presence of n-pentane (non-isolated n-pentane) in other EINECS substances, particularly petroleum products such as gasoline and other crude oil products. According to Council Regulation (EEC) 793/93 non-isolated n-pentane is not a part of the present risk assessment. However, crude estimates of exposure to n-pentane from gasoline have been included for illustrative purposes and for the evaluation of regional n-pentane concentrations.

### Environment

**Conclusion (iii)** There is a need for limiting the risks; risk reduction measures which are already being applied shall be taken into account.

This conclusion is reached for the atmosphere because of the contribution of isolated n-pentane to the formation of ozone and other harmful substances i.e. smog formation.

**Conclusion (ii)** There is at present no need for further information and/or testing and for risk reduction measures beyond those which are being applied already.

This conclusion applies to the aquatic environment and the terrestrial compartment. All PEC/PNEC values for the aquatic environment and the terrestrial compartment are below 1, indicating no cause for concern.

### Human health

#### Human health (toxicity)

##### *Workers*

**Conclusion (ii)** There is at present no need for further information and/or testing and for risk reduction measures beyond those which are being applied already.

##### *Consumers*

**Conclusion (ii)** There is at present no need for further information and/or testing and for risk reduction measures beyond those which are being applied already.

##### *Humans exposed via the environment*

**Conclusion (iii)** There is a need for limiting the risks; risk reduction measures which are already being applied shall be taken into account.

This conclusion is reached because of the contribution of isolated n-pentane to the formation of ozone and other harmful substances i.e. smog formation.

Human health (risks from physico-chemical properties)

**Conclusion (ii)** There is at present no need for further information and/or testing and for risk reduction measures beyond those which are being applied already.

This conclusion is reached because there are no concerns associated with the physico-chemical properties of this substance, as long as information is given and adequate measures are taken.

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# **1 GENERAL SUBSTANCE INFORMATION**

## **1.1 IDENTIFICATION OF THE SUBSTANCE**

CAS No: 109-66-0  
EINECS No: 203-692-4  
IUPAC name: n-pentane  
Synonyms: pentane, normal pentane  
Molecular weight: 72.15  
Molecular formula:  $C_5H_{12}$   
Structural formula:  $CH_3-CH_2-CH_2-CH_2-CH_3$

n-Pentane is a liquid at room temperature.

## **1.2 PURITY/IMPURITIES, ADDITIVES**

### **1.2.1 Purity**

Purity varies among the many commercial grades available on the market. According to the manufacturers most common products have a purity above 95%. Main impurities are butane, isopentane and cyclopentane, that are present at concentrations in the range from a few ppm up to a few percent.

### **1.2.2 Additives**

No additives are declared in IUCLID.

## **1.3 PHYSICO-CHEMICAL PROPERTIES**

Data on the physico-chemical properties of n-pentane have been obtained from the IUCLID entries, from handbooks and a number of other sources. Literature may give the impression that there are a large number of measurements within a narrow range. However, the lack of references to original publications means that it is possible that some of these are derived from the same source. Consequently it is not always possible to evaluate the quality of some of the data presented.

### **1.3.1 Physical state**

Commercially produced n-pentane is a colourless and volatile liquid, with an odour with a detection level of  $1\text{g/m}^3$  or less (Verschuere, 1983).

### 1.3.2 Melting point

freezes at  $-129.7^{\circ}\text{C}$  pure n-pentane Solvent Guide (Marsden, 1963)  
 freezes at  $-130^{\circ}\text{C}$  pure n-pentane (Daubert and Danner, 1989)

### 1.3.3 Boiling point

$36.15^{\circ}\text{C}$  at 101.3 kPa pure n-pentane (CRC Handbook of Chemistry and Physics, 1988)  
 Technical grade n-pentane boils between  $35\text{--}38^{\circ}\text{C}$  at 101.3 kPa (Exxon Chemical International).

The boiling point of  $36^{\circ}\text{C}$  is used in the risk assessment.

### 1.3.4 Relative density

Density: at  $15^{\circ}\text{C}$  is  $630\text{ kg/m}^3$  (Exxon Chemical International)  
 at  $20^{\circ}\text{C}$  is  $626\text{ kg/m}^3$  (CRC Handbook of Chemistry and Physics, 1988)

### 1.3.5 Vapour density

Vapour density 2.49 (air =1) (Clayton & Clayton, 1982)

### 1.3.6 Vapour pressure

There are several reported values of vapour pressure, which are converted to Pa for easier comparison.

**Table 1.1** Reported and converted vapour pressure

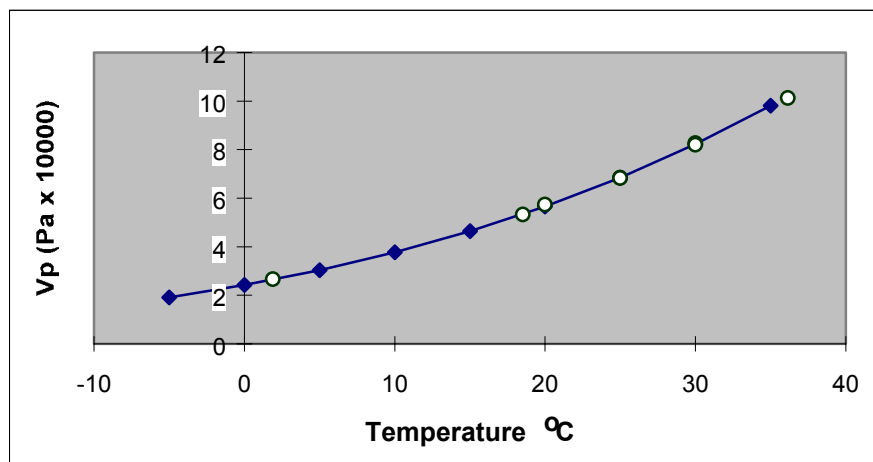
Pa	Measured at $^{\circ}\text{C}$	Reported value	Reference
26,664	1.9	200 mm Hg	Solvent Guide (Marsden, 1963)
53,328	18.52	400 mm Hg	Solvent Guide (Marsden, 1963)
57,300	20	430 mm Hg	Verschueren (1983)
68,393	20	513 mm Hg	Howard (1993)
68,314	25	68,314 Pa	Lu et al. (1990)
82,700	30	620 mm Hg	Verschueren (1983)
82,010	30	82,010 Pa	Thomas et al. (1991)
101,323	36.15	760 mm Hg	Solvent Guide (Marsden, 1963)

Good empirically derived equations are available that accurately predict vapour pressure for simple organic compounds. **Table 1.2** shows calculated values using the procedure of Daubert and Danner (1989). In **Figure 1.1** these calculated values are compared with the reported vapour pressure data.

**Table 1.2** Calculated vapour pressures (Vp) at different temperatures for pure n-pentane

Temperature °C	Vp (Pa) · 10 <sup>4 1)</sup>
-5	1.915
0	2.424
5	3.037
10	3.770
15	4.638
20	5.658
25	6.848
30	8.226
35	9.813

1) The data are calculated according to the procedure from Daubert and Danner (1989)

**Figure 1.1** Graphic presentation of the vapour pressure response to temperature

Black squares: calculated values from Table 1.2

Open circles: reported observed values

Another calculation performed by Soria et al. (1988) gives that the vapour pressure at 20°C is 56,560 Pa. This is very close to the results presented in **Table 1.2**. Experience has shown that calculated vapour pressure values for simple organic molecules are very reliable.

The tabulated value of 56,580 Pa is used in the risk assessment.

### 1.3.7 Solubility

Solubility	in water	38.5 mg/l 20 °C	(McAuliffe, 1966)
	in water	38.5 mg/l 20 °C	(Howard, 1993)
	in water	42 mg/l 20 °C	(IUPAC, 1986)
	in sea water (3.4% S)	28.3 mg/l 20 °C	(Aqua-Yuen et al., 1979)

The study by McAuliffe (1996) gives detailed information to the procedure used. The value 38.5 mg/l was therefore evaluated to be most representative for n-pentane, and this value will be used in the risk assessment.

### 1.3.8 Octanol-water partition coefficient

Both measured and calculated values are reported. The measured values show large variation.

Nine Log Kow values have been found in the Sangster LOGKOW database. They vary between 2.5 and 3.76 (**Table 1.3**).

**Table 1.3** Summary of measured Log Kow data

Log Kow	Method	Phases analysed	Reference
2.5	Shake flask	aqueous	Hansch et al. (1968)
2.5	Shake flask	-	Nys and Rekker (1973)
3.23	Shake flask	both	Pomona college (1987)
3.39	Shake flask	both	Pomona college (1987)
3.6	Chromatograms	-	Shantz and Martire (1987)
3.62	Generator columns	both	Tewari et al. (1982)
3.62	Generator columns	both	Shantz and Martire (1987)
3.64	Chromatograms	-	Wasik et al. (1981)
3.76	Chromatograms	-	

The Sangster research laboratory recommends that a Log Kow of 3.45 be used as the mean of the tests with adequate quality in measurements. This value is used in the risk assessment. This is also close to the QSAR value Log Kow = 3.34. The closest measured data point is 3.39.

### 1.3.9 Surface tension and kinematic viscosity

Surface tension for pure n-pentane: 16.05 mN/m at 20°C (Jasper, 1972)  
 Kinematic viscosity:  $3.58 \cdot 10^{-7}$  m<sup>2</sup>/s at 40°C (Browning, 1992)

Data concerning the surface tension of a water solution containing n-pentane are not found in the open literature. During studies with partition coefficient n-octanol/water by the shake flask method, no emulsification of the two phases has been reported. Therefore it is concluded that n-pentane does not exhibit surface active properties coequal to surfactants.

### 1.3.10 Flash point

Flash point: -46°C Solvent Guide (Marsden, 1963)

**1.3.11                   Autoflammability**

Autoignition temperature:           285°C                   (method ASTM E659 )

**1.3.12                   Explosivity**

Based on structure of the molecule n-pentane it is not expected to have explosive properties.

However, a mixture of air and n-pentane may burn explosively. Its explosive limits in air range from 1.4% (Lower Explosive Limit) to 8% (Upper Explosive Limit) by volume (Exxon Chemical International).

**1.3.13                   Oxidising properties**

No oxidising properties expected based on structural formula.

**1.3.14                   Summary**

The physico-chemical properties of n-pentane are summarised in **Table 1.4**. All further calculations will be performed using these values.

**Table 1.4** Summary of physico-chemical properties of n-pentane

Property	Value	Method / reference
Physical state	liquid	-
Boiling point	36°C	D1078 ASTM
Melting point	-130°C	D2386 ASTM
Vapour pressure	56,580 Pa at 20°C	Solvent Guide (Marsden, 1963)
Water solubility	38.5 mg/l at 20C	The Merck Index (The Merck Index of Chemicals and Drugs 6 <sup>th</sup> edition)
Partition coeff	3.45 log Kow	Several methods
Density	626 kg/m <sup>3</sup> at 20°C	The Merck Index (The Merck Index of Chemicals and Drugs 6 <sup>th</sup> edition)
Surface tension	16.05 mN/m at 20°C	Jasper (1972)
Flash point	-46°C	Solvent Guide (Marsden, 1963)
Autoignition	285°C	E659 ASTM
Vapour density/air	2.49	Exxon Chemical
Henry's Constant	106,030	Calculated

## 1.4 CLASSIFICATION

The classification/labelling in Annex I is (according to 25<sup>th</sup> ATP):

<u>Classification</u>	F+; R12 * Xn; R65-R66-R67 N; R51/53
<u>Labelling</u>	F+; Xn; N R: 12-65-66-67-51/53 S: (2-)9-16-29-33-61-62

F+ indicates: Extremely flammable.  
Xn indicates: Harmful.  
N indicates: Dangerous for the environment

R12 states: Extremely flammable.  
R65 states: Harmful: may cause lung damage if swallowed.  
R66 states: Repeated exposure may cause skin dryness or cracking.  
R67 states: Vapours may cause drowsiness and dizziness.  
R51/53 states: Toxic to aquatic organisms; May cause long-term adverse effects in the aquatic environment.

S2 states: Keep out of the reach of children.  
S9 states: Keep container in a well-ventilated place.  
S16 states: Keep away from sources of ignition – No smoking.  
S29 states: Do not empty into drains.  
S33 states: Take precautionary measures against static discharges.  
S61 states: Avoid release to the environment. Refer to special instructions/safety data sheets.  
S62 states: If swallowed do not induce vomiting: seek medical advice immediately and show the container or label.

Nota C.

(\* The EU Classification and Labelling group has decided that iso-pentane and pentane (n-pentane) should be kept as one entry, this had the consequence that the change that was agreed in the classification for iso-pentane to “Extremely flammable” (R12) also became valid for n-pentane.)

## 2

## GENERAL INFORMATION ON EXPOSURE

### 2.1 PRODUCTION

Normal pentane is a constituent of crude oil and a component of the condensate from natural gas production. Normal pentane is primarily obtained by fractional distillation of a petroleum stream (generally light virgin naphtha) obtained from processing of crude oil. It is produced through a closed batch process in petroleum refineries or petrochemical plants. The use of highly efficient distillation equipment allows isolation of n-pentane of qualities of purity between 80% and up to 99% by weight. The organic impurities consist essentially of butane, iso-pentane and cyclopentane. The production methods involve use of dedicated equipment with production in closed systems. Water is not involved directly in any step of the production process.

For solvent use n-pentane is most often purified by elimination of sulphur through a catalytic hydrodesulfurization process and may be further refined through catalytic hydrogenation or active filtration on adsorption medium.

#### 2.1.1 Production volumes

There are 6 companies producing n-pentane in the European Union:

Company	Country
AGIP Petroleum	Italy
Exxon Chemical	Belgium
Haltermann	Germany
Neste	Finland
Shell Chemicals	The Netherlands
Total Solvants	France

- the total production of the above producers is 55 ktonnes for the year 1994,
- the quantity of n-pentane imported from outside EU is 6 ktonnes for the year 1994,
- the quantity of n-pentane exported outside EU is of 8.5 ktonnes,
- the total quantity of n-pentane used in the EU in 1994 is 50 ktonnes,
- the numbers do not fully match. The difference is considered to be caused by year to year differences in stocks.

In this risk assessment it is assumed that total production within EU is 55 ktonnes/year and that 50 ktonnes/year is used within EU.

#### 2.1.2 Emissions during production

Generally emissions during production are expected to be low because:

- n-pentane is produced in closed batch systems,
- releases into water and soil are negligible, as the product does not come into contact with water along the production process.

Emissions to the atmosphere during production can be estimated at around 0.2% to 0.6% of the produced n-pentane. The atmospheric emissions may come from maintenance, sampling

(minimal), and especially handling and storage. The release based on the available actual release data from industry is in the range of 0.26-0.52%. The Technical Guidance Document (TGD) (EC, 1996) proposes a release fraction of 1.0% for isolated intermediates produced in dedicated equipment and stored off site.

## 2.2 USES AND EMISSIONS FROM USES

The main uses of n-pentane (in terms of the life cycle of commercially produced/imported n-pentane) are listed in **Table 2.1**. The relevant categories as given in the TGD and applied in the EUSES modelling are indicated along with % and tonnage in each use pattern.

**Table 2.1** Main application/use areas of n-pentane as reported by the manufacturers

Use	Use pattern	Main category	Industrial category	Functional use category	Tonnage tonnes/a	% of Use
Foaming agent for Polystyrene	2	2	11	25	27,200	54.4
Foaming agent for Polyurethane	3	2	11	25	6,800	13.6
Process diluent / carrier for polymerisation	4	1B	3	48	8,150	16.3
Aerosol formulation Solvent	5	4	5	48	6,800	13.6
Adhesive formulation Solvent	6	3	15	48	225	0.45
Laboratory chemical	7	3	2	34	50	0.1
Other use	8	3	15	48	750	1.5

### 2.2.1 Foaming agent

The major use of n-pentane is as a foaming agent for expanded polystyrene (EPS) and polyurethane (PUR). The ratio between these use areas is approximately 80:20.

#### 2.2.1.1 Expanded polystyrene (EPS)

##### 2.2.1.1.1 Formulation of polystyrene granulates

The tonnage used for EPS has been estimated at 27,200 tonnes/year by the n-pentane industry. The Association of Plastics Manufacturers Europe (APME) estimates that 675,000 tonnes/year of EPS is produced in Europe and, assuming a n-pentane content of 4.5%, this equates to 30,375 tonnes of n-pentane. The figure of 27,200 tonnes/year is used in this assessment.

EPS is formulated (polymerised) as granules/powder at about 10 plants in Europe. The process involves suspension polymerisation of styrene in water (50:50 styrene:water). The polymerisation is carried out in jacketed, heated stirred baffled reactors. Following initial polymerisation of styrene beads, n-pentane is pumped into the vessel. The reactor is then heated to 120-130°C. After a short “finishing” period the reactor is cooled and discharged. The slurry of beads and water is transferred to a waiting tank, centrifuged and dried. The water may be cooled further in a cooling tower before passing to a wastewater treatment plant. It is assumed that since



the temperature of the effluent from the reactor and drying process is higher than the boiling point of n-pentane, any n-pentane present in the effluent will rapidly evaporate.

The following information is site-specific information from a large plant using >10% of the yearly tonnage for this purpose. Annual release of n-pentane to air from a large plant using 3,800 tonnes of n-pentane was 222 tonnes (**Table 2.2**) amounting to 6%. The other 94% of n-pentane is incorporated into the powder/granules which are sold to moulder companies for processing.

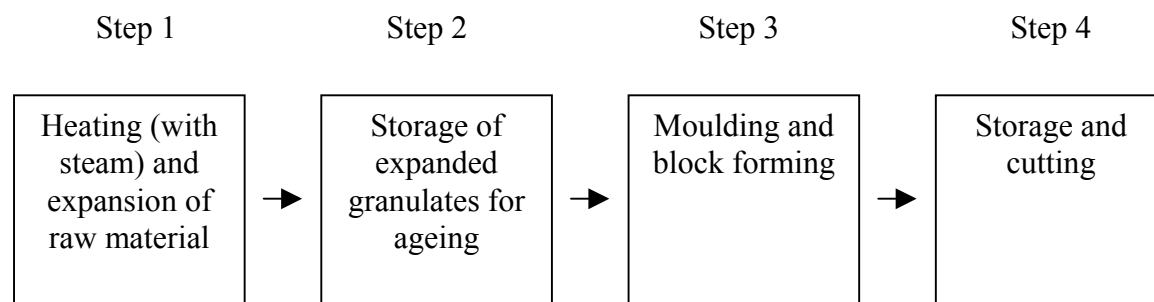
**Table 2.2** Measured emissions of n-pentane from a plant using 3,800 tonnes of n-pentane per year

Production step	Releases (tonnes per year)
Reactors	24.3
Waiting tanks	114.1
Centrifuges	38.4
Dryers	45.6
Total emissions	222.4

#### 2.2.1.1.2 Processing (moulding)

There are more than 1,000 moulder companies in Europe, ranging in size from dedicated small factories producing for a single customer (for example an electronic manufacturer producing their own packaging) to large multi-component moulders.

**Figure 2.1** Schematic representation of the manufacturing process for expanded polystyrene



A schematic representation of the processing of EPS is shown in **Figure 2.1**. In Step 1, granular polystyrene containing about 5% n-pentane is expanded by heating the material with steam. This is performed in an open vessel with the steam escaping to air. In some cases the steam is collected and passed to the waste air treatment unit involving thermal treatment of the residual n-pentane. Any condensate is passed to a wastewater treatment plant. The expanded granules are then transferred to a mesh silo for ageing and drying (Step 2). There is no significant condensation from this step. Silos are installed in ventilated areas in order to get good and fast maturation and to prevent build up of n-pentane in the air.

In Step 3 the beads are transferred to moulds containing vents to permit ingress of steam. For the first few seconds the vents are left open to purge any air using steam. The vents are then closed and the steam pressure is built up. After a few seconds, the steam supply is shut off and the vents

are opened to the atmosphere. The moulded article is left in the mould to cool. Cooling may be achieved either by vacuum or by passing water over the mould. Moulding of EPS may be either a batch process producing discrete objects or a continuous one producing large blocks. Emissions are the same and for the purposes of the risk assessment the two approaches are not considered separately.

The blocks may then be stored again before being cut into smaller items (plates) using heatable wires (Step 4). In some production lines the cutting in Step 4 precedes storage.

n-Pentane emissions during the four processing steps are:

Step 1:	20%
Step 2:	25%
Step 3:	20%
Step 4:	20%

As a result of the high Henry's constant of n-pentane, it is assumed that all n-pentane emissions will be to air. Any n-pentane in the aqueous emissions will rapidly evaporate. In the risk assessment EUSES calculation of emissions is made with an emission factor of 0.85 (sum of step1-4) for a site processing 2,720 tonnes/year. Actual emission factor used is 0.90425 in order to account for the 6% already lost during formulation.

#### **2.2.1.1.3 Private use**

Moulded EPS contains 9% of the n-pentane used in the initial formulation of beads/granules. This is released slowly during use. It is assumed that releases are to air.

#### **2.2.1.2 Polyurethane (PUR) formulation and use**

Based on a consumption in foaming industry of 68% of the total n-pentane quantity used, and a PUR share of this of 20%, the quantity used in PUR production is approximately 6,800 tonnes per year. It is assumed that n-pentane is only used for production of hard (rigid) polyurethane foams.

During formulation of hard PUR approximately 50% of the initial n-pentane remains in the product. There is a subsequent release of n-pentane during sawing, which is done with a hot wire.

In the risk assessment it is assumed that 100% of n-pentane used in the production of PUR is eventually released to air. It is assumed that 50% is released during formulation (PUR production) and 50% during use. The latter is considered wide dispersive use.

#### **2.2.2 Polymer industry, process diluent / carrier for polymerisation**

Due to high reactivity of the catalysts for ethylene and propylene polymerisation towards air and moisture, these catalysts are produced and stored in an inert hydrocarbon solvent. The physical properties of n-pentane make this solvent a good candidate for this use. As moisture and oxygen are to be excluded from these catalysts the production and storage is carried out in closed systems, no emissions to the atmosphere or wastewater are assumed to take place.

During the polymerisation process, the catalyst is continuously added to circumvent the ageing of the catalyst. n-Pentane is especially used in so called super-condensed mode systems for manufacturing polyethylene and polypropylene, in a gas phase polymerisation unit. In the process n-pentane has the function as a “carrier”. While the system is considered to be continuous and closed, there is a sequential downloading of the polymerisation reactor (every 30 seconds) by a process called “Blowdown”. The polymer in the form of powder is sent to a vessel called “purge bin” together with a certain amount of gases (ethylene, n-pentane and impurities). The gas fraction is separated and sent to a flare where it is incinerated, hence there is no emission of n-pentane to atmosphere at this stage. In a second stage the polymer powder, which still contains some n-pentane, is subject to an “aeration phase” where it is put in contact with nitrogen. The blend nitrogen and n-pentane is recovered and recycled into the manufacturing process.

Consumption of n-pentane in the manufacturing process is around 2 kg/tonne of polymer. Most of this n-pentane is lost upon the flare incineration. 20-30 ppm of n-pentane is left in the polymer powder. This n-pentane is probably lost upon the subsequent extrusion of the powder to granulate form performed at processing sites.

There are about 10 production sites for polyethylene/polypropylene in Europe utilising about 8,150 tonnes of n-pentane. Since it could not be verified that all plants burn their emissions in flares as described above, a worst-case approach has been envisaged in the risk assessment, whereby 50% of the sites are assumed to release all used n-pentane directly to air. No water is involved in the production process. Processing of the powder into granulate form results in the release to air of 100% of the remaining 20-30 ppm of n-pentane in the powder.

### **2.2.3                    Aerosols**

Since the use of CFCs was prohibited in aerosols, the expanding agents used have changed. Although the boiling point of n-pentane does not lend itself to be used as a propellant, it does have a function as a pressure adjuster. The use of n-pentane in aerosols has been identified in cosmetic products like hairsprays and antiperspirants, and other products like aerosol paints and certain car care products.

The total use of n-pentane in aerosols in Europe is estimated by the Manufacturers to be 6,800 tonnes/year. The filling of n-pentane during the production of cans is nowadays completely automated and takes place in fully separated production equipment with recovery of the evaporated material. Therefore it is assumed that no release takes place at this stage.

During professional or domestic use of the aerosol formulations the n-pentane will be released to air. In the risk assessment an emission fraction of 0.99 to air and 0.01 to domestic wastewater is assumed. This corresponds to wide dispersive use. Because n-pentane is not a propellant, the use category in the TGD is as solvent and not as aerosol.

### **2.2.4                    Adhesives/glues**

This use is fairly limited, the total volume of n-pentane used in glues is estimated by the manufacturers to be 225 tonnes/year. Normal pentane is generally part of a solvent formulation comprising significant amounts of other solvents (hydrocarbons or oxygenated solvents). Many glues incorporate easily vaporising solvents, which keep the glue fluid/sticky during application. After evaporation the glue/adhesive hardens. Therefore all releases are assumed to air with an

emission fraction of 0.025 (TGD default) during formulation and 1.0 during processing (worst case).

Adhesives with n-pentane are mostly used in dedicated professional applications. Therefore the scenarios selected for the estimation of releases are formulation in a multi purpose installation and processing with a non dispersive use scenario. All releases are expected into the atmosphere, as cleaning will be carried out with organic solvents that are incinerated separately.

### **2.2.5 Laboratory chemical**

A small but well defined use area is the use as a laboratory chemical as an extracting medium, solvent cleaner or reference for analytical purposes. According to **Table 2.1** annual use is assumed to be only 50 tonnes. In contrast to most of the other use areas, some release to water may be expected through spillage into water basins. In the EUSES calculation an emission fraction of 0.05 to water and 0.95 to air (TGD defaults) were applied.

### **2.2.6 Other use areas**

The Product Registers in Norway, Finland and Sweden includes several areas of use that are seemingly not covered by those described above. Additional areas are “pharmaceuticals”, “degreasing agents”, “lubricants”, “solvents”, “stain removers”, “rust preventives”, “cleaning agents” and “contact agents”. It is possible that several of these product types are aerosol products and thereby already covered under Section 2.2.3. The manufacturers have estimated that 750 tonnes per year are used for these purposes.

Limited amounts of n-pentane may be used in a number of small size industrial applications like degreasing agents and lubricating agents in aerosol formulations, solvents for extracting pharmaceuticals or as a component of specific fuels. In the absence of more precise information, these applications have been considered non-dispersive use.

It is not considered necessary to perform separate risk assessments for these use areas as long as the main use areas do not show levels of concern, neither with respect to environmental nor with respect to indirect exposure via the environment. The exception is, if it is found that any of these use areas have water as the main release route. Explicit information indicating direct release to water is not available at present for any of the use areas mentioned here. In the risk assessment and in the EUSES calculations all the above mentioned uses have been gathered under “Other uses”, with “solvent” as functional use category. For life cycle steps formulation, processing and use the TGD defaults have been used, except that a zero emission with respect to release to water during formulation is used while the TGD default is 0.001. Specific information regarding emission factors applied is given in Section 3.1.1.8.

## **2.3 INFORMATION FROM PRODUCT REGISTERS**

Information obtained from the Product Registers in Sweden, Denmark, Finland and Norway is presented in **Table 2.3**. The reported figures from the Norwegian and Swedish Product Register include several petroleum products (e.g. naphta, fuels) and therefore also non-isolated n-pentane is registred. See also Section 4.1.1 for further discussion regarding the different uses/product types.

**Table 2.3** Information on use pattern obtained from the Product Registers in Sweden, Denmark, Finland and Norway

Country	No. of products/ (consumer products)	Tonnage/ year (tonnes)	Examples of product types / functions	Reference
Sweden	110 / (14)	87,301 – 173,433 <sup>1)</sup>	process carrier/process diluent, foaming agent, adhesives/glues*, solvents, lubricants*, laboratory chemicals, car care products*, fuels/motor fuels*, stain removers*, rust preventives/rust removers*, contact agents*, cleaning agents*	The Swedish Product Register (1995)
Denmark	126 / (not stated)	2,888	foaming agents, aerosol propellant, intermediates, solvents	The Danish Product Register (1996)
Finland	45 / (not stated)	Not stated	glues, lubricants, solvents, start aid, brake degreasing agent, anti seize spray, burnishing agent	The Finnish Product Register (1997)
Norway	8/(2)	359,000 <sup>2)</sup>	raw materials (accompany- ing branch code: petroleum refining), foaming agent, car care products*, brake degreasing agent, lubricants, fuel additives	The Norwegian Product Register (1996)

\* indicates that one or more products with this function code is available to consumers

1) the tonnage in the Swedish Product Register included certain petroleum products

2) the tonnage in the Norwegian Product Register included certain petroleum products (e.g. naphta), however the reporting regarding these types of products was variable

## 2.4 SOURCES OF EMISSIONS RELATED TO THE LIFE CYCLE OF OTHER EINECS SUBSTANCES

Normal pentane is a naturally occurring component of crude oil and is contained in light petroleum fractions such as light virgin naphtha or products obtained from cracking processes. Normal pentane therefore occurs in various petroleum products, as a component of fuels and light solvents. Its concentration in those products is variable.

These sources are not included in this risk assessment, because they are not covered by the life cycle of the produced/imported n-pentane. They are regarded as part of the life cycle of other EINECS substances. However, for illustrative purposes, some information regarding emissions from these sources is given below.

Normal pentane is a significant component of motor gasoline, which constitutes a major source of emission during tank filling (gasoline vapours). It can also be present as a component of light hydrocarbon solvents with an initial boiling point of 30 to 45°C. Normal pentane is also released from hazardous waste disposal sites, landfills and waste incinerators.

CONCAWE (1987) has estimated that motor gasoline use in the EU is about  $120 \cdot 10^6$  tonnes per year. The n-pentane content is in the range of 1.1 to 8.1% with a mean value of 4.3% (w/w). More details are given in Appendix B. This indicates that n-pentane use by cars amount to  $5.2 \cdot 10^6$  tonnes per year. Normal pentane is released during all stages of transport and filling, i.e. transferring from ship to land tanks, transferring from land tanks to trucks, transferring from trucks to service stations, filling cars at service stations, evaporation from car tanks, and lastly in car exhaust. It is the vaporisation from filling at service centres and release from car exhaust that are assumed to constitute the major release of n-pentane.

### Release from filling at car service centre

Assuming 12,5% of n-pentane by weight of hydrocarbon losses (mean of Halder et al., 1986; CONCAWE, 1987)) and a VOC emission of 5 kg/tonnes of gasoline (average of 4.5 proposed by Bouscaren et al., 1986; 5.5 of Eggestone, 1987) gives an annual release of 75,000 tonnes per year and 205 tonnes per day within the EU.

### Release from motor exhaust

Assuming that cars have a hydrocarbon release of 3.48 g/l gasoline (Sigsby et al., 1987) during urban driving and that n-pentane amounts to 1.7% of this, would result in an annual release of 7,100 tonnes per year and 19 tonnes per day within EU.

In total n-pentane releases from use of fuel in cars amount to 224 tonnes per day. In Section 3.1.4.1 the regional  $PEC_{air}$  based on releases from non-isolated n-pentane is compared to that of isolated n-pentane.

## 3 ENVIRONMENT

### 3.1 ENVIRONMENTAL EXPOSURE

#### 3.1.1 Environmental releases

It should be noted that this risk assessment only covers the n-pentane emissions from sources related to the life cycle of commercially produced n-pentane (isolated n-pentane). However, for illustrative purposes and for the evaluation of regional n-pentane concentrations some information regarding emissions from sources related to the presence of n-pentane in petroleum products has been included.

Releases of n-pentane to the air compartment are expected to be the main entry route. Accidental losses of n-pentane to water may occur through leaks in barrels, pipes, tanks etc, but this has not been evaluated.

Most of the identified releases are to air. EUSES has been used to calculate local, regional and continental PECs for all life cycle steps. Where site-specific release data are available local PECs have been calculated manually. A summary table of the release data used for different use categories of n-pentane is given in **Table 3.3**.

##### 3.1.1.1 Releases at production

Some site-specific information is available from all 6 n-pentane producers in Europe. This information is summarised in **Table 3.1**. The available site-specific information is the total production in 1994 and for some production sites a yearly release estimate. The reported releases indicate an emission fraction in the range of 0.0026-0.0052. For sites without release data the TGD (EC, 1996) default emission factor of 0.01 is used.

The annual local air concentration of n-pentane can be estimated according to the TGD by the equation:

$$C_{\text{local air ann}} = E_{\text{local air}} \cdot C_{\text{std air}} \cdot T_{\text{emission}}/365$$

where  $E_{\text{local air}}$  is the amount released per day,  $C_{\text{std air}}$  is  $2.78 \cdot 10^{-4}$  and  $T_{\text{emission}}$  is the number of days that emission takes place. **Table 3.1** gives air concentrations in the range of 4.5 to  $140 \mu\text{g}/\text{m}^3$ . In order to maintain confidentiality the tonnage produced and the actual release rates are not specified in the table.

**Table 3.1** Input data and results for the local environmental n-pentane release assessment for air at production sites

	Site A	Site B	Site C	Site D	Site E	Site F
Annual production	confidential	confidential	confidential	confidential	confidential	confidential
Main category	III	III	III	III	III	III
Number of days	300	300	300	300	300	300
F of main source	1	1	1	1	1	1
Release to air (%)	confidential	confidential	confidential	confidential	confidential	confidential
Released to air (kg/d)	132	28.0	19.7	203	220	613
Conc. air ( $\mu\text{g}/\text{m}^3$ ), 100 m from source	30.3	6.4	4.5	46.5	50.3	140

### 3.1.1.2 Releases from use in expandable polystyrene (EPS) industry

#### Formulation

Total use of n-pentane in EPS production is estimated to be 27,200 tonnes. Fairly detailed information is available (**Table 3.2**) for a large plant processing 3,800 tonnes/year of n-pentane during EPS production. The emissions were measured in 1994 by using carbon adsorption. Total release was 222 tonnes/year for this plant, equal to a release fraction of 6%. Daily release is 760 kg/day, assuming 300 days of release. A more detailed description of the industrial process and its release is given in Section 2.2.1.1.1. For this risk assessment it is assumed that the foaming agent comprises completely of n-pentane. This is an overestimation and therefore expresses a worst case. All releases are expected to occur to air and no direct release to water or soil exists according to industry. Using the same calculation method that was used for site-specific n-pentane production, gives an annual local air concentration at 100 m from site of  $174 \mu\text{g}/\text{m}^3$ . The site-specific information on release from processing of n-pentane in EPS production is assumed to be representative for all EPS production sites. Therefore a release of 6% to air is assumed for total EPS production in the EUSES calculation (the TGD default emission is 0.5%). As this site use >10% of the total for this use area, this site is used in the regional scenario. However as regional emissions are averaged over 365 days, the regional daily emission becomes 625 kg/d.

**Table 3.2** Measured releases of n-pentane from a site using 3,800 tonnes/a of n-pentane during production of EPS-granules

Production step	Tonnes/year
Reactors	24.3
Waiting tanks	114.1
Centrifuges	38.4
Dryers	45.6
Total emission	222.4

The emission indicates an emission ratio of 58.8 kg/tonnes handled and is the basis of an emission factor of 6% to air used for EPS production in this risk assessment.



## Processing

Moulding (processing) of EPS occurs at numerous smaller sites and may therefore be considered as wide dispersive use. Releases during different stages of moulding add up to 85% of used n-pentane. A more detailed description of the industrial process and its release is given in Section 2.2.1.1.2. Fraction of main local source is 0.15 and number of emission days is 228. (TGD, Table B3.9). Local release to air is estimated by EUSES to 1,521 kg/d. This gives annual local air concentration at 100 m from site of 189  $\mu\text{g}/\text{m}^3$ . According to industry there is no direct release to water or soil.

## Use

The finished product contains about 9% of the n-pentane used in the initial formulation of beads/granules, which is slowly released during use of the product. This release is considered as wide dispersive release. In the assessment a fraction of main local source of 0.01 and number of emission days per year of 300 has been used. Local release to air is estimated by EUSES to 8.2 kg/d, this gives an annual local air concentration at 100 m from site of 1.9  $\mu\text{g}/\text{m}^3$ . According to industry there is no direct release to water or soil.

### **3.1.1.3 Releases from use in polyurethane industry (PUR)**

Total n-pentane use in PUR production is estimated to be 6,800 tonnes per year. No information is available on the number of PUR production sites. As a worst-case approximation it is assumed that there are ten sites each utilising 680 tonnes per year and a fraction of main local source of 1. No release to water or soil is assumed during formulation and use. 50% of utilised n-pentane is released during formulation to air. Assuming 300 days of production per year gives a release of 1.1 tonnes per day for each site. With respect to estimation of local air concentration the same equation as for the site-specific n-pentane production is used, which gives an annual local air concentration of 259  $\mu\text{g}/\text{m}^3$  at 100 m from the production site.

The remaining 50% of n-pentane in the polyurethane is released during use and storage and is considered as wide dispersive use. Here a fraction of main local source of 0.002 and 300 emission days per year has been used (TGD, Table B4.1). This gives a local daily release to air of 2.27 kg/d.

### **3.1.1.4 Releases from use in polymer production**

According to **Table 2.1**, 8,150 tonnes are used in polymer production. In Section 2.2.2, polymer production is not thought to emit significant amounts of n-pentane for those sites where used n-pentane is burnt in flares after use. Since it could not be confirmed that all sites have flares that burn the used n-pentane, it is assumed as a worst-case approximation that 50% of the production sites emit all used n-pentane not incorporated in the polymer powder to air. Assuming that there are a total of ten sites within EU, five sites then are assumed to use 4,075 tonnes per year. Fraction of local main source is assumed to be 1. As described in Section 2.2.2 some of the used n-pentane remains in the polymer powder giving a n-pentane concentration of 20-30 ppm in the polymer, the release fraction to air during formulation is therefore estimated to be 0.985. With 300 workdays/year, this gives a local emission of 2.67 tonnes per day. According to previously used calculation procedure (Section 3.1.1) this would give an annual local air concentration of 610  $\mu\text{g}/\text{m}^3$  at 100 m from the production site. The estimated 20-30 ppm of n-pentane present in the polymer powder is assumed to be released during processing of the powder to granulate. This

equals 1.5% of applied n-pentane in polymer production released to air. Default emission to soil (emission factor of 0.0001) is assumed during processing but not during formulation.

#### **3.1.1.5 Releases from use in aerosols**

The manufacturers have estimated that 6,800 tonnes n-pentane is used for aerosol formulations per year. Negligible amounts of n-pentane are released on aerosol formulation. However during private use, 99% n-pentane in aerosol formulations is expected to be emitted to air, while 1% is assumed emitted to domestic wastewater. This leads to a local release to air of 3.69 kg/day and a local release of 37.3 g/day to wastewater assuming a fraction of main source of 0.002 and 365 emissions days per year (TGD, Table B4.1). The scenario is somewhat unrealistically high, however as no risks are identified further refinement is not considered necessary.

#### **3.1.1.6 Releases from use in adhesives and glues**

It is assumed that 225 tonnes/year of n-pentane are used in adhesives and glues. The industry category is 15 (others) and use category is 48 (solvents). No information is available on the release of n-pentane during formulation and processing of adhesives. It seems unlikely that there is any direct release to wastewater during formulation and processing therefore only release to air is assumed for this use category. The TGD default emission factor to air of 0.025 is used with respect to formulation and the remaining n-pentane is released in a non-dispersive manner to air during processing. Local emission to air as calculated by EUSES using default assumptions with respect to fraction of main source and number of days (TGD, Tables B2.3 and B3.14) is 1.88 kg/d and 790 kg/d for formulation and processing, respectively.

#### **3.1.1.7 Releases from use as laboratory chemical**

According to **Table 2.1** annual use as laboratory chemical is only 50 tonnes. Some release to water may be expected through spillage into water basins. The TGD defaults (TGD, Table A3.2) assumes 5% is released to water and 95% to air with fraction of main source = 0.8 and number of days = 8 (TGD, Table B2.4). In order to make the scenario more realistic the fraction of the main local source has been set to 0.1 and the number of emission days to 30. With this scenario one laboratory would use 16.6 kg of n-pentane each day. A 5% release to water equals 0.83 kg per day. In order to dissolve this in water at its solubility limit of 38.5 mg/l, it would require 22 tonnes of water. Although this is an unrealistically high water discharge from one laboratory, further refinement is not considered necessary.

#### **3.1.1.8 Releases from other use areas**

Industry has estimated that 750 tonnes per year of n-pentane cannot be accounted for within the use areas described above. Limited amounts of n-pentane may be used in a number of small size industrial formulations like degreasing agents and lubricating agents in aerosol formulations, solvents for extracting pharmaceuticals or components of specific fuels. In the absence of more precise information, these applications have to be considered as non-dispersive use.

As indicated in **Table 2.1**, the industrial category 15 (others) has been used for this use area and the functional use category is 48 (solvents). Emission factors with respect to formulation and

processing are taken from the TGD Tables A2.1 and A3.16 except for release to water which is set to zero for formulation. Fraction of main local source and emission days are taken from the TGD Tables B2.3 and B3.14. No emission tables are suggested for private use therefore worst-case assumptions are applied and an emission factor of 1 to air and 0.001 to water is used. The TGD Table B 4.5 is used with respect to fraction of main local source and emission days. EUSES estimates the local emission to air to be 6.25 kg/d for the formulation stage and 2.2 tonnes for the processing stage. Emission to water is 0.24 kg/d for the processing stage.

### 3.1.1.9 Summary of the release scenarios

**Table 3.3** Summary of the release scenarios used in this risk assessment

Scenario	Life stage	Category	IC	UC	MC	Kt/yr	Release to	Release fraction	Frac. Local source	d/yr	Reg. release kg/d	Loc. release kg/d
2 EPS	formulation	foaming agent	11	25	2	27.2	air	0.06*	1*	300	625	760
	water						0*					
	processing						air	0.90425*	0.15	228	6,334	1,521
	water						0*					
	private use						air	1*	0.01*	300*	671	8.2
	water						0*					
3 PUR	formulation	foaming agent	11	25	2	6.8	air	0.5*	1*	300	932	1,130
	water						0*					
	privatre use						air	0.5*	0.002	300	932	2.27
							water	0*				
4 Polymer diluent	formulation	solvent	3	48	1b	8.15	air	0.985*	1*	300	2,190	2,670
	water						0*					
	processing						air	1*	0.4	300*	33.4	16.3
							water	0*				
5 Aerosol	private use	solvent	5	48	4	6.8	air	0.99*	0.002	365	1,840	3.69
							water	0.1*	0.002	365	18.6	0.037
6 Adhesives	formulation	solvent	15	48	3	0.225	air	0.025	1	300	1.5	1.8
	water						0*					
	processing						air	1	0.9	25	60.1	790
							water	0*				
7 Laboratory	processing	lab. chemical	2	34	3	0.05	air	0.95	0.1	30	13	15.8
	water						0.05	0.1	30	0.69	0.8	
8 Other uses	formulation	solvent	15	48	3	0.75	air	0.025	1	300	5.14	6.25
	water						0*					
	processing						air	0.9	0.8	24	180	2,190
							water	0.0001	0.8	24	0.02	0.2
	private use						air	1*	0.0004	300	20	0.01
							water	0.0001*	0.0004	300	0.002	0.0001
Totals (including production)						50	Air				14,450.5	9,115.5
							Water				19.31	1.037
											14,479.8	9,116.5

When emission data were not available from industry, default factors from the TGD tables were applied

\* Release data are not from the TGD

### 3.1.2 Environmental fate

#### 3.1.2.1 Degradation

##### 3.1.2.1.1 Abiotic degradation

In the aquatic environment n-pentane is not expected to be subjected to hydrolysis or photolysis (Howard, 1993).

It has been demonstrated by experiments that n-pentane is degraded by photo-chemically produced OH-radicals (Atkinson, 1985). Therefore the indirect photodegradation of n-pentane under atmospheric conditions is considered here.

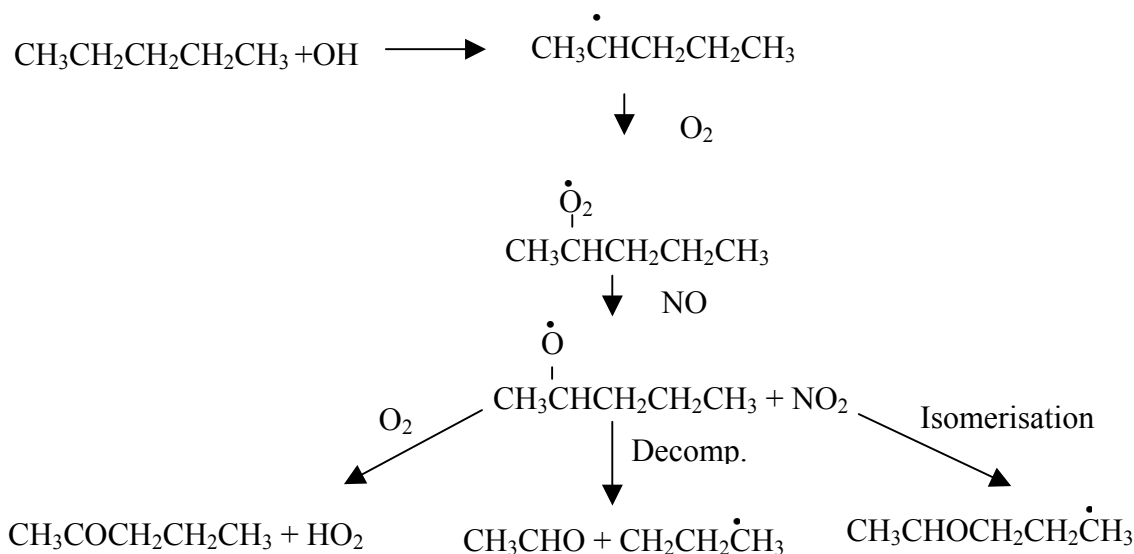
The rate constant of the reaction between n-pentane and OH-radicals has been measured by several researchers. The result of the experiments have been reported and reviewed by Atkinson (1985). The reported values are between  $3.5$  and  $5.3 \cdot 10^{-12} \text{ cm}^3/(\text{molecule} \cdot \text{sec})$  at  $300^\circ\text{K}$  ( $27^\circ\text{C}$ ). On the basis of the review of available data Atkinson recommends a rate of  $4.06 \cdot 10^{-12} \text{ cm}^3/(\text{molecule} \cdot \text{sec})$ .

The latter value will be used in the risk assessment. Taking into account the OH-radical concentration as given in the TGD of  $5 \cdot 10^5 \text{ molecules/cm}^3$ , atmospheric half-life of n-pentane is estimated to 3.95 days according to the equation below.

$$t_{1/2} = \frac{\ln 2}{k_{OH} \times [OH-rad.]} (\text{sec})$$

There are also experimental data that indicate that n-pentane reacts with nitrite radicals (Howard, 1993). This would mean that night-time reactions between n-pentane and these radicals might contribute to the atmospheric transformation and removal of n-pentane, especially in urban areas.

A schematic presentation of possible chemical reactions occurring in the atmosphere is shown below. The reactions are taken from Atkinson (1985). The presentation is meant to illustrate the main chemical reactions occurring in the atmosphere. The order of chemical reactions and site of reactions may vary a lot making predictions with respect to reaction rates and production of breakdown products difficult.



### Tropospheric ozone formation

The formation of tropospheric ozone involves complicated chemical reactions between NO<sub>x</sub> and VOC driven by the solar radiation. In order for these reactions to occur in substantial quantities, meteorological conditions must prevail that prevents dispersion of NO<sub>x</sub> and hydrocarbons. The relation between the ozone precursors in terms of VOC and ozone formation is complicated and depends on the speciation and concentrations of VOC, NO<sub>x</sub>, solar radiation and OH-radicals. The time scale of ozone production is such that ozone concentrations may build up over several days under suitable weather conditions, and that this pollutant and its precursors can be transported over considerable distances (European Commission, DGXI, 1998).

The VOC speciation and concentrations, VOC/NO<sub>x</sub> ratio, solar radiation and meteorological conditions vary from city to city within EU. Since the environmental conditions differ considerably a certain concentration of VOC may lead to very different ozone concentrations within Europe. For example the European Commission, DG XI (1998), used simplified EMEP model calculations and showed how a change in the VOC concentration may affect the ozone formation to a small extent in some parts of Europe (NO<sub>x</sub> limited region), while in other parts a similar change in the VOC concentration will lead to a considerable change in the ozone formation (high NO<sub>x</sub> region).

As explained there is no simple relationship between individual VOC compounds, NO<sub>x</sub> and the resulting tropospheric ozone formation. Nevertheless, the member countries in UNECE have agreed to use a Photochemical Ozone Creation Potential (POCP) factor system where the individual VOC's potential to create ozone is given as a relative equivalence factor expressed as g ethylene/g VOC (Haushild and Wenzel, 1998). Here their relative importance has been evaluated against ethylene, which is given a value of 100. Two sets of factors are given corresponding to a low and high NO<sub>x</sub> situation.

Annex IV (Protocol, 1979) has classified VOC compounds into 3 groups (more, less or least important) according to their importance for the formation of ozone. In this respect n-pentane is grouped as less important. However the POCP estimates for n-pentane varies in the range of 9-105. A theoretical estimate based on the OH reactivity n-pentane gives a relative ozone generation potential of 19.4. Derwent et al. (1996) estimated a POCP value for n-pentane of around 62 based on empirical relationships. A value of 40.8 is used as a representative value for n-pentane in Annex IV (Protocol, 1979). Wensel et al. (1998) give POCP equivalence factors of 30 in a low NO<sub>x</sub> situation and 40 in a high NO<sub>x</sub> situation.

An attempt to evaluate the relative importance of non-isolated n-pentane (gasoline use) and isolated n-pentane has been performed in Sections 3.1.4.5.1 and 3.1.4.5.2.

#### **3.1.2.1.2 Biotic degradation**

The biodegradability of n-pentane has been studied according to OECD 301F "Ready biodegradability: Manometric respiratory test" and the EU Guideline method C.4-D "Manometric respirometry test" (Exxon, 1997). The test material was labelled as MDR-96-575 and was supplied by Exxon Biomedical Sciences Inc. Biodegradability was determined by measuring oxygen consumption in a closed test system inoculated with activated sludge from a domestic sewage treatment plant. Test medium was distilled water amended with nutrient solutions and inoculum. A concentration of approx. 60 mg/l test material was added. Further analytical analysis of the degradation products of MDR-96-575 was not performed. In these studies it has been

demonstrated that 87% of n-pentane was degraded after a period of 28 days. 60% was degraded after 12 days, and significant degradation (10%) occurred between day 7 and 11.

According to this study n-pentane is readily biodegradable, fulfilling the 10-day window criterion.

### 3.1.2.2 Distribution

To assess the environmental distribution of n-pentane, a Mackay level 1 model simulation (Mackay, 1991) was performed. This type of modelling assumes equilibrium partitioning without any removal processes. The result of the simulation is in Appendix A. As expected from the high vapour pressure of n-pentane the model give that all of the n-pentane ( $\approx 100\%$ ) is expected to be encountered in the atmosphere.

As almost all n-pentane will be in the atmosphere, the most dominant environmental removal process will be indirect photo-transformation.

The distribution of n-pentane in a standard wastewater treatment plant according to the TGD is:

	air	water	sludge	degraded
Fraction of emission directed to:	0.633	0.0332	0.0641	0.27

#### 3.1.2.2.1 Volatilisation from water

The high-vapour pressure and low solubility of n-pentane leads to a very high calculated Henry's Law Constant of  $106,030 \text{ Pa} \cdot \text{m}^3/\text{mol}$  ( $20^\circ\text{C}$ ). This means that n-pentane dissolved in water will rather quickly evaporate to air. The constant can be used to estimate volatilisation from water bodies. An elimination half-life in water for n-pentane can be calculated according to equations given in Lyman et al. (1982). The half-life is dependent on depth of water body, current and wind speed. The temperature dependency of the vapour pressure has only a small influence on the half-life relative to the other parameters. The **Table 3.4** below shows how the half-life changes with variable conditions. It is clear that the half-life will be relatively short in rivers, while the half-life in lake/ponds with no or little current is relative long. When the half-life is more than a few days, biodegradation and adsorption may have significant added effect on n-pentane dissipation.

**Table 3.4** Half-life of n-pentane in water at variable conditions due to volatilisation

Wind speed m/s	Depth m	Current m/s	Half-life Hours
1	1	1	7.1
3	1	1	2.5
3	3	1	15.6
3	3	3	5.4
3	3	0.1	145

### 3.1.2.2.2 Adsorption

With a Log Kow of 3.45, the TGD allows calculation of Koc (soil-organic carbon - water partition coefficient), by the equation  $\text{Log Koc} = 0.81 \cdot \text{log Kow} + 0.1$ . This gives a Koc of 784.3 l/kg. The partition coefficients for soil, sediment and suspended matter are estimated according to the TGD by assuming the fraction of organic carbon in these environmental compartments to be respectively 0.02, 0.05 and 0.1. Multiplication of Koc with the partition coefficient then gives the respective solid - water partition coefficients ( $K_d$ ) of 15.7, 39.2 and 78.4 l/kg. A Koc of 784 l/kg indicates a clear affinity to the organic fraction, however it is not high enough to exclude mobility downwards. Though it is thought that this would be counteracted by the high-vapour pressure leading to migration to air as the dominant process.

### 3.1.2.3 Accumulation in biota

No measured bioaccumulation values for n-pentane has been found, however the TGD allows calculation of this according to two equations, one for compounds with Kow between 2 and 6 and one for compounds with Kow > 6. Normal pentane has a Log Kow of 3.45 and the first equation ( $\text{log BCF}_{\text{fish}} = 0.85 \cdot \text{log Kow} - 0.7$ ) gives a BCF of 171 l/kg.

Howard (1993) allows calculation of BCF on either water solubility or Kow. The respective BCF values calculated by these methods are 79 and 224 l/kg. In EUSES and in the risk assessment the calculated value of 171 l/kg will be used. The estimated BCF is larger than 100 indicating potential for bioaccumulation, however rapid biodegradation and elimination will not result in any significant bioconcentration in the food chain.

## 3.1.3 Aquatic compartment (incl. sediment)

### 3.1.3.1 Calculation of predicted environmental concentrations

With no direct release to water of n-pentane during production, formulation or processing except for aerosols, laboratory chemicals and other uses, the PEC estimations is mostly dependent on deposition from air. **Table 3.5** shows the estimated local  $\text{PEC}_{\text{surface water}}$  for all the use categories based on regional deposition and direct release according to EUSES.

**Table 3.5** Summary of calculated local PECs for surface water based on EUSES calculation of regional PEC from depositions from air and direct release when applicable

EUSES use pattern	Life cycle	Step	PEC <sub>surface water</sub> (µg/l)
1	production		$3.7 \cdot 10^{-3}$
2 and 3	foaming agent	all steps	$3.7 \cdot 10^{-3}$
4	polymer diluent	all steps	$3.7 \cdot 10^{-3}$
5	aerosols	private use	$6.5 \cdot 10^{-2}$
6	adhesives	all steps	$3.7 \cdot 10^{-3}$
7	laboratory	processing	1.40
8	other uses	formulation	$3.7 \cdot 10^{-3}$
		processing	0.41
		private use	$3.7 \cdot 10^{-3}$
	regional		$3.7 \cdot 10^{-3}$

It is evident from **Table 3.5** that most use categories have a local PECs equal to the regional PEC for surface water, the exception is laboratory use, other uses and aerosols that all include a small direct release to wastewater.

The relative contribution of different use areas to the regional PEC<sub>water</sub> is indicated in **Table 3.6**. The direct releases to water are small with the widespread use of pentane in aerosols being the main contributor.

**Table 3.6** Regional release to water from all life cycle steps with direct release to wastewater

EUSES use pattern	Life cycle	Step	Regional release (kg/d)
5	aerosols	private use	18.6
7	laboratory	processing	0.685
8	other uses	formulation	
		processing	0.02
		private use	0.002
<b>Total</b>			<b>19.31</b>



**Table 3.7** Summary of calculated local PECs for sediment during emission episodes based on EUSES calculations

EUSES use pattern	Life cycle	Step	PEC <sub>sediment</sub> (µg/kg ww)
1	production		$6.6 \cdot 10^{-2}$
2 and 3	foaming agent	all steps	$6.6 \cdot 10^{-2}$
4	polymer diluent	all steps	$6.6 \cdot 10^{-2}$
5	aerosols	private use	1.17
6	adhesives	all steps	$6.6 \cdot 10^{-2}$
7	laboratory	processing	24.7
8	other uses	formulation	$6.6 \cdot 10^{-2}$
		processing	7.28
		private use	$6.6 \cdot 10^{-2}$
	regional		$5.8 \cdot 10^{-2}$

It is evident from **Table 3.7** that most use categories have a local PEC close to the regional PEC for sediment, the exception is “laboratory use”, “other uses” and “aerosols” that all include a small direct release to wastewater.

Except for a small release to water from “laboratory use”, “aerosol use” and “other uses”, no direct release of n-pentane to water has been evaluated. The regional and continental PECs for surface water and sediment are therefore mainly due to deposition of n-pentane from air to water (**Table 3.8**).

**Table 3.8** Regional and continental PECs for the aquatic environment as calculated by EUSES

	PEC (µg/l or µg/kgww)
Regional <sub>water</sub>	$3.7 \cdot 10^{-3}$
Continental <sub>water</sub>	$3.9 \cdot 10^{-4}$
Regional <sub>sediment</sub>	$5.8 \cdot 10^{-2}$
Continental <sub>sediment</sub>	$7.1 \cdot 10^{-3}$

### 3.1.3.2 Measured concentrations

#### Water

Regular monitoring of n-pentane has not been performed in water. The HSDB database includes several observations of detectable concentrations of n-pentane in water, however only a few values are quantified. A summary of available information from the HSDB database is given below. Only data published after 1980 are included.

#### *Drinking water*

Three reports list detectable concentrations of n-pentane in drinking water from the USA in 1974. The possible origin of this contamination is not commented and no actual concentrations are given.

### *Surface water*

n-Pentane has been identified in water from Delaware River and Lake Ontario, no information on concentrations were available (Howard, 1993). Howard (1993) also incorrectly reported an average concentration of 2.4 µg/l (8 samples) in Lake Pontchartrain, this value was upon examination of the report (MacFall et al., 1985) shown to be measurements of hexane and not pentane.

### *Groundwater*

One of 11 samples taken near a landfill contained 20 µg/l n-pentane (Sawhney and Raabe, 1986)

### Measured concentrations in sediment

The HSDB database only refers to one report with measured concentrations in sediment. The samples were from a bay in SW Africa. Three of four samples had detectable concentrations of n-pentane in the range of 0.12 to 0.78 µg/kg (Whelan et al., 1980).

### **3.1.3.3 Comparison of PECs with measured data**

There are few measurements and none with relevance to the risk assessment. The risk assessment will be performed using the predicted concentrations estimated by EUSES.

## **3.1.4 Atmosphere**

### **3.1.4.1 Calculation of predicted environmental concentrations**

Local emissions (kg/d) for specific production sites were calculated in Section 3.1.1.1, (**Table 3.1**) based on reported emissions from n-pentane producers or TGD defaults. The regional  $PEC_{air}$  ( $0.32 \mu\text{g}/\text{m}^3$ ) was added to these data to give the local  $PEC_{air}$ . The PECs estimated for local production sites range from 4.8 to  $140 \mu\text{g}/\text{m}^3$  and are reported in **Table 3.9** below.  $PEC_{air}$  for all other use categories are shown in **Table 3.10**.

**Table 3.9** Local PEC<sub>air</sub> estimates for production sites

Production site	PEC <sub>air</sub> (µg/m <sup>3</sup> )
Site A	30.6
Site B	6.7
Site C	4.8
Site D	46.7
Site E	50.6
Site F	140

**Table 3.10** Local PEC (annual average concentration) estimates for air for all life cycle steps

EUSES use pattern	Life cycle	Step	PEC <sub>air</sub> (µg/m <sup>3</sup> )
1	production		Table 3.9
2	foaming agent	formulation	174
		processing	189
		private use	1.8
3	foaming agent	formulation	259
		private use	0.52
4	polymer diluent	formulation	610
		processing	3.7
5	aerosols	private use	1.03
6	adhesives	formulation	0.43
		processing	15.0
7	laboratory	processing	0.36
8	other uses	formulation	1.43
		processing	40.1
		private use	0.32
	regional		0.32
	continental		0.11

PEC estimates for the use category foaming agent have also been estimated manually based on site-specific information. In Section 3.1.1.2 site-specific emissions for the formulation of expandable polystyrene industry were available. This gave a daily release of 760 kg/d to air during formulation. This information has been applied in the EUSES calculation and is the basis for calculation of local air concentration for use pattern 2 (EPS formulation).

The relative contribution of different use areas to the regional PEC<sub>air</sub> is indicated in **Table 3.3**. It is clear that n-pentane used as foaming agent gives the largest contribution to the regional PEC<sub>air</sub>. This use area alone stands for 65% of the releases to air.

### Comparison of $PEC_{air}$ for isolated n-pentane with $PEC_{air}$ including emission from car fuel (non-isolated n-pentane)

In Section 2.4 it was estimated that n-pentane release from car fuel would give a daily release in EU of 224 tonnes/d. Adding 1/10 of this volume to the regional emission of isolated n-pentane gives a  $PEC_{air}$  of  $0.84 \mu\text{g}/\text{m}^3$  according to EUSES. Therefore on a regional scale the contribution of isolated n-pentane emissions is less than that from motor cars. From **Table 3.3** the regional average daily emission is 14.5 tonnes compared with 22.4 tonnes from cars.

#### **3.1.4.2 Measured concentrations**

Atmospheric concentrations, only data published after 1980 are included.

##### Urban areas

Indoor mean concentrations in office buildings in New York at different times of the day were found to be 18.6, 20.4 and  $15 \mu\text{g}/\text{m}^3$  (Bozzelli et al., 1983). Street level concentrations in New York were  $37.8 \mu\text{g}/\text{m}^3$  (average of 4 samples) the average of 14 samples taken at the World Trade Centre NY in the morning and afternoon was 26 and  $23 \mu\text{g}/\text{m}^3$ . Another area of New York had a mean concentration of  $82 \mu\text{g}/\text{m}^3$  (Altwicker et al., 1980).

##### Rural areas

Rural areas have lower concentrations, n-pentane concentration in Jones State Forest, Texas (Saila, 1979) was  $6.6 \mu\text{g}/\text{m}^3$ . In Germany (Deulsbach) a measured value of  $0.42 \mu\text{g}/\text{m}^3$  has been found (Rudolph and Khedim, 1985). The concentration in Norwegian arctic (Hopen, Bear Island and Spitsbergen) had an average concentration of  $<0.06 \mu\text{g}/\text{m}^3$  in summer and  $1 \mu\text{g}/\text{m}^3$  in spring (Hov et al., 1984). At an air altitude of 100-700 m above Lake Michigan the average n-pentane concentration was  $7 \mu\text{g}/\text{m}^3$  (Miller and Alkezweeny, 1980). Recent measurements made in the EMEP programme (Solberg et al., 1996) covering six sampling stations in a transect from Spitsbergen (Norway) in the north to Tänikon (Switzerland) in the central Europe showed a north-south gradient. All the stations are in rural areas and therefore represent regional background levels. Maximum values are found in winter at Tänikon with  $1.5 \mu\text{g}/\text{m}^3$ , while Spitsbergen had a level of  $0.018 \mu\text{g}/\text{m}^3$  in summer.

##### Urban and rural concentration in the UK

Bertorelli and Derwent (1995) compiled monitoring values for n-pentane in the UK. They found that based on weekly samples in the period January 1989 to March 1991, from remote rural areas as exemplified by the sampling point Great Dun Fell and West Beckham usually had less than  $3 \mu\text{g}/\text{m}^3$ , with maximal sample values up to  $18 \mu\text{g}/\text{m}^3$ . Only five of more than 200 samples had more than  $6 \mu\text{g}/\text{m}^3$ . Rural areas exemplified by Harwell, Oxfordshire had a three months running mean concentration in the period 1986 to 1990 of approximately  $2 \mu\text{g}/\text{m}^3$ , with a range of 1.2 to  $5 \mu\text{g}/\text{m}^3$ . **Table 3.11** below is an extract of a table in the report of Bertorelli and Derwent (1995) showing variation in monthly average n-pentane concentration for some cities in the UK. The cities may be said to represent both heavily industrialised (Middlesbrough) and less industrialised cities (Eltham). Maximum monthly mean concentration in the table is  $14.1 \mu\text{g}/\text{m}^3$ . The data do not indicate any strong seasonal variation.

**Table 3.11** Monthly average means of n-pentane from 7 cities in the UK

1994-1995 Monthly means, $\mu\text{g}/\text{m}^3$							
Period	Belfast	Birming-ham	Bristol	Cardiff	Edinburgh	Eltham	Middlesborough
Jan 94	2.66	3.48	-	3.78	-	1.03	0.36
Feb 94	3.44	3.61	-	3.71	2.58	1.45	2.03
Mar 94	1.59	1.59	-	2.45	1.47	1.05	2.56
Apr 94	1.68	1.62	4.38	1.66	1.62	0.90	13.34
May 94	2.08	2.03	3.63	3.19	1.17	1.45	1.32
Jun 94	1.66	1.53	1.28	1.72	1.59	1.28	1.20
Jul 94	1.76	1.55	3.61	2.39	2.81	1.87	6.71
Aug 94	2.08	1.74	1.62	2.45	2.73	1.55	3.97
Sep 94	2.92	1.76	1.34	2.52	3.48	1.83	14.08
Oct 94	3.71	3.50	2.73	3.63	3.78	2.87	8.39
Nov 94	2.98	3.50	2.98	3.97	2.35	2.58	6.42
Dec 94	2.98	3.92	2.94	3.34	2.29	3.13	1.89
Jan 95	1.93	1.66	2.52	2.24	1.93	1.95	4.51
Feb 95	1.47	0.92	1.87	2.01	1.32	1.41	1.89

The data were compiled by Bertorelli and Derwent (1995)

#### Other sources of n-pentane concentrations in air

Various sources have been shown to emit n-pentane. Flue gases from waste incineration have been shown to contain up to  $2,100 \mu\text{g}/\text{m}^3$  n-pentane (Junk and Ford, 1980). Landfill gases were found to contain on average  $1,200 \mu\text{g}/\text{m}^3$  n-pentane with a maximum concentration of  $15,000 \mu\text{g}/\text{m}^3$  (Vogt and Walsh, 1985). Normal pentane concentration downwind of a Mobil natural gas facility had a concentration of  $40 \mu\text{g}/\text{m}^3$  (Arnts and Meeks, 1981).

The highest measured concentrations are related to landfill effluent gas. Low concentrations are found far from industrial activities and at high air altitude. Fairly low concentrations are found in a recent study from urban areas in the UK.

#### **3.1.4.3 Comparison of PECs with measured data**

None of the measured data have been connected to specific n-pentane activities and they are therefore not useful with respect to this risk assessment of n-pentane. However they illustrate the importance of other sources to the overall release of n-pentane to the environment. The major source of the n-pentane air concentrations in the cities can be assumed to be. Recent data from the UK seem to indicate concentrations in the range  $1\text{-}14 \mu\text{g}/\text{m}^3$ . The predicted air concentrations in **Table 3.10** will be used for risk assessment purposes.

#### **3.1.4.4 Estimated local concentrations due to car exhaust, the CAR model**

Local concentrations due to car exhaust can be estimated with computer models e.g. the CAR model (Eerens et al., 1993). This has been done for cyclohexane in the EU risk assessment report

on cyclohexane (Draft May 2000). By assuming that all traffic is by gasoline driven vehicles a worst-case estimate can be given for n-pentane. The CAR model requires a specific release rate per driven kilometer. Lacking this for n-pentane a proportional release is estimated using the relative amount of cyclohexane and n-pentane in the VOC from car exhaust. This is 0.006 for cyclohexane and 0.0404 (Henry et al., 1994) for n-pentane, the value for n-pentane includes evaporation losses while driving. The assumptions used in the CAR model are the same used in the cyclohexane report and are: Average wind speed at a height of 10 m of 4 m/s, 10,000 vehicles/day of which 5% are heavy vehicles. Background concentration of  $0 \mu\text{g}/\text{m}^3$ . **Table 3.12** presents the resulting annual average concentrations of n-pentane in the vicinity of roads. The results of the CAR model estimate n-pentane concentrations in the range of 0.2-3.25  $\mu\text{g}/\text{m}^3$  in urban areas.

**Table 3.12** Annual average concentration ( $\mu\text{g}/\text{m}^3$ ) resulting from car exhaust and evaporation during driving, estimated with the CAR model

Type of road		Distance (m)					
		5	10	15	20	25	30
Urban	1	1.01	0.79	0.60	0.44	0.31	0.20
	2	1.81	1.31	0.93	0.66	0.51	0.46
	3A	2.17	1.60	1.14	0.81	0.60	0.50
	3B	3.25	2.40	1.71	1.21	0.89	0.74
	4	3.11	2.23	1.53	1.01	0.68	0.53
Motorway	1	0.30	0.24	0.18	0.13	0.09	0.06
	2	0.54	0.39	0.30	0.20	0.15	0.13

Road types:

- 1) Road in open terrain, no or few building
- 2) Basic street types not defined by 1, 3A, 3B or 4
- 3A) Streets with building at least 3m in height on both sides, no gaps larger than 25m and at least 75 m building per 100 m street. The ratio between height of buildings and distance of these to road axes is from 1.5-3 on one side and less than 3 on the other side
- 3B) As 3A but with the ratio less than 1.5 for both sides of the road
- 4) Street with building at least 3m in height on both sides of the street with the ratio of building-height/road-axis distance less than 3. the other street side has no buildings or a ratio much greater than 3, preferably greater than 10

These theoretical values are in the lower range compared to the monitoring study performed in Copenhagen in 1997 (Christensen, 1999), see **Table 3.13**. For n-pentane an average concentration of 2.4 ppbv (equal to  $7.2 \mu\text{g}/\text{m}^3$ ) was found with a range of 0.4-5.7 ppbv ( $1.2$ - $17.1 \mu\text{g}/\text{m}^3$ ). The CAR model values are also in the lower range compared to the UK study of Bertorelli and Derwent (1995) (**Table 3.11**) from 7 cities in the UK. The n-pentane concentrations predicted by the CAR model are low compared to most local air concentrations estimated for production, formulation and processing steps, as shown in **Tables 3.9** and **3.10**.

### 3.1.4.5 Creation of tropospheric ozone due to n-pentane

As described in Section 3.1.2.1.1, n-pentane is a substance with a Photochemical Ozone Creation Potential (POCP). VOC compounds are variable with their potential to create ozone. Annex IV has classified VOC compounds into 3 groups (more, less or least important) according to their importance for the formation of ozone (Protocol, 1979). In this respect n-pentane is grouped as less important. However the POCP estimates vary in the range of 9-105. On a theoretical

estimate based on the OH reactivity n-pentane has a relative ozone generation potential of 19.4. A value of 40.8 is used as a representative value for n-pentane in Annex IV (Protocol, 1979). Derwent et al. (1996) estimated a POCP value for n-pentane of around 62. Wensel et al. (1998) give a POCP equivalence factors of 30 in a low NO<sub>x</sub> situation and 40 in a high NO<sub>x</sub> situation. The latter values have been used to evaluate the contribution of n-pentane ozone formation in the Christensen study.

### 3.1.4.5.1 Potential creation of ozone due to n-pentane, city survey

In Section 2.6 it was estimated that n-pentane emissions to the atmosphere from use as fuel in cars amounts to 82.1 ktonnes per year. However these emissions are not evenly distributed. The CAR model presented above indicates n-pentane concentrations in the vicinity of roads in the range of 0.2-3.25 µg/m<sup>3</sup>. These theoretical values are in the lower range compared to the monitoring study performed in Copenhagen in 1997 (Christensen, 1999), see **Table 3.13**.

**Table 3.13** Monitoring results of different NMVOCs at Jagtvej, Copenhagen December 1-5 1997, and the relative contribution to potential ozone creation

Substance	Mean	Range	S.D.	Median	POCP g C <sub>2</sub> H <sub>4</sub> /g gas <sup>1)</sup>		Relative O <sub>3</sub> creation <sup>2)</sup>	
	ppbv	ppbv	ppbv	ppbv	low NO <sub>x</sub>	High NO <sub>x</sub>	low NO <sub>x</sub>	High NO <sub>x</sub>
Pentane <sup>5)</sup>	2.4	0.4-5.7	1.2	2.5	0.3	0.4	2.12 · 10 <sup>-3</sup>	2.83 · 10 <sup>-3</sup>
<i>trans</i> -2-Pentene	0.2	0.01-0.5	0.1	0.2	0.4	0.9	2.29 · 10 <sup>-4</sup>	5.16 · 10 <sup>-4</sup>
2-Methyl-2-butene	0.4	0.02-0.9	0.2	0.3	0.5	0.8	5.73 · 10 <sup>-4</sup>	9.17 · 10 <sup>-4</sup>
<i>cis</i> -2-Pentene	0.1	0.01-0.3	0.1	0.1	0.4 <sup>3)</sup>	0.9	1.15 · 10 <sup>-4</sup>	2.58 · 10 <sup>-4</sup>
2,2-Dimethylbutane	0.9	0.04-2.3	0.5	0.9	0.3	0.3	9.51 · 10 <sup>-4</sup>	9.51 · 10 <sup>-4</sup>
Cyclohexane	0.5	0.04-1.1	0.3	0.5	0.25	0.25	4.30 · 10 <sup>-4</sup>	4.30 · 10 <sup>-4</sup>
2,3-Dimethylbutane	0.4	0.03-1.0	0.2	0.4	0.4	0.4	5.64 · 10 <sup>-4</sup>	5.64 · 10 <sup>-4</sup>
2-Methylpentane	2	0.2-5.2	1.1	2.1	0.5	0.5	3.52 · 10 <sup>-3</sup>	3.52 · 10 <sup>-3</sup>
3-Methylpentane	1.1	0.1-2.7	0.6	1	0.4	0.4	1.55 · 10 <sup>-3</sup>	1.55 · 10 <sup>-3</sup>
<i>n</i> -Hexane	0.8	0.1-2.3	0.5	0.8	0.5	0.4	1.41 · 10 <sup>-3</sup>	1.13 · 10 <sup>-3</sup>
Isoprene	0.2	0.01-0.6	0.1	0.2	0.6	0.8	3.34 · 10 <sup>-4</sup>	4.46 · 10 <sup>-4</sup>
2-Methyl-1-Pentene	0.04	0.01-0.1	0.02	0.02	0.5 <sup>4)</sup>	0.9	6.88 · 10 <sup>-4</sup>	1.24 · 10 <sup>-4</sup>
<i>cis</i> -2-Hexene	0.03	0.01-0.1	0.01	0.02	0.5	0.9	5.16 · 10 <sup>-5</sup>	9.29 · 10 <sup>-5</sup>
2,4-Dimethylpentane	0.2	0.01-0.7	0.1	0.2	0.4 <sup>6)</sup>	0.4	3.28 · 10 <sup>-4</sup>	3.28 · 10 <sup>-4</sup>
Methyl-cyclohexane	0.3	0.02-0.6	0.1	0.3	0.5	0.6	6.02 · 10 <sup>-4</sup>	7.22 · 10 <sup>-4</sup>

Table 3.13 continued overleaf

**Table 3.13 continued** Monitoring results of different NMVOCs at Jagtvej, Copenhagen December 1-5 1997, and the relative contribution to potential ozone creation

Substance	Mean	Range	S.D.	Median	POCP g C <sub>2</sub> H <sub>4</sub> /g gas <sup>1)</sup>		Relative O <sub>3</sub> creation <sup>2)</sup>	
	ppbv	ppbv	ppbv	ppbv	low NOx	High NOx	low NOx	High NOx
2- and 3-Methylhexane	1.4	0.1-3.7	0.8	1.3	0.5	0.5	$2.87 \cdot 10^{-2}$	$2.87 \cdot 10^{-3}$
n-heptane	0.7	0.1-1.9	0.4	0.6	0.5	0.5	$1.43 \cdot 10^{-3}$	$1.43 \cdot 10^{-3}$
Benzene	3.4	0.2-8.0	1.7	3.3	0.4	0.2	$4.34 \cdot 10^{-3}$	$2.17 \cdot 10^{-3}$
2- and 3-Methylheptane	0.4	0.01-1.0	0.2	0.3	0.5	0.5	$9.34 \cdot 10^{-4}$	$9.34 \cdot 10^{-4}$
Toluene	10.2	0.8-21.5	5.6	8.9	0.47	0.6	$1.81 \cdot 10^{-2}$	$2.31 \cdot 10^{-2}$
Ethylbenzene	2	0.1-4.9	1.1	1.9	0.5	0.6	$4.34 \cdot 10^{-3}$	$5.21 \cdot 10^{-3}$
o-Xylene	2.7	0.1-6.2	1.4	2.6	0.2	0.7	$2.34 \cdot 10^{-3}$	$8.20 \cdot 10^{-3}$
m- and p-Xylene	5.5	0.3-12.7	2.9	5.5	0.5	0.95	$1.19 \cdot 10^{-2}$	$2.27 \cdot 10^{-2}$
Relative contribution of non-isolated n-pentane%							<b>3.58</b>	<b>3.49</b>

Table from the EU risk assessment report on toluene (EC, 2003)

- 1) POCP equivalence factors from Wensel et al. (1998), except toluene and cyclohexane from the EU risk assessment report
- 2) Calculated at STP
- 3) Data for trans-2-pentene were used
- 4) Average data for alkanes with double bonds used
- 5) According to personal communication with the author the reported values are for n-pentane only
- 6) Average data for alkanes used

Here n-pentane was monitored during 5 days in December close to a road site. Normal pentane was found in the range of 1.2-17.1  $\mu\text{g}/\text{m}^3$  (recalculated from ppbv). In the survey pentane was the fifth largest contributor to VOC.

In **Table 3.13** the different VOCs potential contribution to ozone formation has been estimated based on the actual VOC composition in the Christensen et al. (1999) study and applying a high and low POCP factor. The VOC measurements were performed in winter when very little ozone formation occurs because of lack of ultraviolet rays to initiate the production of free radicals. Theoretically then, n-pentane contributed 3.5% of the total NMVOC caused ozone creation. This value is based on the average concentration of pentane of 2.4 ppbv ( $7.2 \mu\text{g}/\text{m}^3$ ) most of which may be assumed to be derived from vehicles and thus mostly represents non-isolated pentane. One may infer this, based on the co-correlation of alkanes with CO and benzene, which is mainly emitted from petrol fueled motore vehicles. As a reasonable approach one can assume that the regional  $\text{PEC}_{\text{air}}$  as calculated by EUSES based on isolated n-pentane contributes with  $0.32 \mu\text{g}/\text{m}^3$ . Isolated n-pentane would then contribute with 0.16% of the potential ozone formation. With local sources of isolated n-pentane the contribution will be much higher (see **Table 3.10**).

### 3.1.4.5.2 Potential creation of ozone due to isolated n-pentane on a continental scale

As described, the creation of tropospheric ozone is dependant on a number of factors like the VOC speciation and concentrations, VOC/NOx ratio, solar radiation and meteorological conditions. The environmental conditions differ considerably within Europe and a certain concentration of VOC may lead to very different ozone concentrations. Furthermore the VOC composition will be highly variable and depend on the industrial sources, traffic emissions and natural sources. The contribution from isolated commercial n-pentane will therefore depend on



the composition of local and regional industry. Average calculations are therefore likely to underestimate the magnitude of the problem within certain regions with high exposure.

Estimated emissions of n-pentane in the EU:

Total EU isolated n-pentane consumption (= emissions)	55 kt
Total EU n-pentane emissions from filling stations	75 kt
Total EU n-pentane emission from car exhaust	7.1 kt
Total	137.1 kt

The total NMVOC emitted in the EU is given in **Table 3.14** (table from the EU risk assessment report on toluene (EC, 2003)).

**Table 3.14** Emission of ozone precursors in EU15 (EEA, 2000)

NMVOC in EU15 (ktonne)									
1980	1985	1990	1991	1992	1993	1994	1995	1996	1997
14,434	14,315	14,852	14,388	14,037	13,494	13,683	13,257	12,904	12,687

As a worst-case scenario it is assumed that all produced isolated n-pentane is released to air, i.e. 55 ktonnes in the year 1994 (Section 2.2). The total emissions of NMVOC in 1994 were 13,683 ktonnes.

Isolated n-pentane share of NMVOC emissions:  $55 \text{ kt} / 13,683 \text{ kt} = 0.4\%$

The POCP equivalence factor for the total NMVOC is not known because the composition of individual NMVOC species is not available. Based on the average calculations on a continental scale isolated n-pentane contributes in the order of 0.4% to the total NMVOC emission. It is assumed that the n-pentane consumption equals n-pentane emissions, but in practice the emissions will be lower. Based on the Christensen survey and the EUSES calculated regional  $PEC_{\text{air}}$  it could be estimated as a reasonable approach that isolated n-pentane contributed with 0.16% to the potential ozone formation (see Section 3.1.4.5.1). In general isolated n-pentane only contributes to a small extent to the total smog problem. However, this is one substance among hundred of different VOCs and the contribution of 0.16-0.4% from a single substance may therefore not be negligible. Moreover it has to be emphasised that the local and regional NMVOC composition may have a higher contribution from isolated n-pentane than indicated by the average calculations due to differences in local NMVOC sources.

### 3.1.5 Terrestrial compartment

No direct releases to soil have been discovered during the assessment. For “other uses” and “laboratory use” a default release of 0.1% have been used. The only other exposure of soil is therefore through deposition from air and sludge. In **Table 3.15** the EUSES calculated local PECs for soil are summarised. All concentrations are for average after 30 d in agricultural soil. The PEC value for production site assumes a local release to air of 613 kg/d (**Table 3.1**). For use pattern 2 site-specific data have been used.

**Table 3.15** Calculated local  $PEC_{soil}$ 

EUSES use pattern	Life cycle	Step	$PEC_{soil}$ ( $\mu\text{g/kg wwt}$ )
1	production		0.14
2	foaming agent	formulation	0.17
		processing	0.18
		private use	$1.9 \cdot 10^{-3}$
3	foaming agent	formulation	0.25
		private use	$6.3 \cdot 10^{-4}$
4	polymer diluent	formulation	0.59
		processing	$3.7 \cdot 10^{-3}$
5	aerosols	private use	$4.6 \cdot 10^{-3}$
6	adhesives	formulation	$7,465.5 \cdot 10^{-4}$
		processing	$1.5 \cdot 10^{-2}$
7	laboratory	processing	1.0
8	other uses	formulation	$1.5 \cdot 10^{-3}$
		processing	0.33
		private use	$1.4 \cdot 10^{-4}$
	regional		$2.1 \cdot 10^{-4}$
	continental		$5.3 \cdot 10^{-5}$

### Measured concentrations in soil

No measured concentrations in soil have been found in the literature.

### **3.1.6 Secondary poisoning**

Normal pentane is rapidly excreted (Section 4.1.2.1) and is therefore not bioaccumulative in the food chain. Therefore the major route of exposure of organisms higher up in the food chain is likely to be directly through air.

## 3.2 EFFECT ASSESSMENT

### 3.2.1 Aquatic compartment (incl. sediment)

Because of the high vapour pressure and low solubility of n-pentane, toxicity studies that do not especially control the evaporation of n-pentane during the test will severely underestimate the toxicity of n-pentane. For this reasons all studies that do not clearly specify that evaporation is controlled have to be discounted with respect to its usability as basis for PNEC derivation.

#### 3.2.1.1 Toxicity test results

##### 3.2.1.1.1 Fish

A semi-static acute toxicity test on Rainbow trout was performed in 1996 according to OECD Guideline 203 (Exxon, 1996). The study was performed according to GLP compliance and included chemical verification of the n-pentane concentrations in the test solutions. The result of the study was:

96 hours      LC50 *Oncorhynchus mykiss*      4.26 mg/l

During the test a decrease of n-pentane concentration of approximately 80% was observed compared to the nominal values. Therefore LC50 calculation was performed using the geometric mean of the measured concentrations in the fresh and spent medium. A 95% confidence limit of 3.60-5.04 mg/l for the LC50 was established.

The result of this test is considered valid and will be used for further risk assessment.

##### *Oncorhynchus kisutch*

96-hour exposure to 100 ppm of n-pentane. No mortality was observed in the exposure period. The study was performed by Morrow et al. (1975). It is assumed that evaporation was not controlled in this study. Without more information on test details, the study cannot be rated as being of necessary quality for risk assessment purposes.

##### 3.2.1.1.2 Aquatic invertebrates

Abernathy et al. (1986) performed acute toxicity tests with *Daphnia magna* and *Artemia* sp. on 38 hydrocarbons and chlorinated hydrocarbons. The evaporation of n-pentane was minimised by eliminating air in test chambers. The test solutions were made by dilution of a saturated solution. However, no confirmation of the actual test concentrations was made so even if evaporation was controlled, it is not possible to know whether the saturated solution in fact was saturated. Saturated solutions are often quite difficult to prepare, often requiring thorough mixing over several hours. It might be possible that the EC50 values in this study underestimate actual toxicity. The results of the study are:

Organism	Duration	Endpoint	Value
<i>Daphnia magna</i>	48 hours	EC50	9.74 mg/l
<i>Artemia salina</i>	24 hours	EC50	11.9 mg/l

The acute toxicity of *D. magna*, *Cheatogammarus marinus* and *Mysidopsis bahia* was tested with n-pentane by TNO in the Netherlands (Adema and Bakker, 1986). The test solutions were prepared by adding known amounts of n-pentane to dilution water and mixing for 24 hours after which an aqueous solution was drained off. The test concentrations were verified by chemical analysis of selected test solutions at start and after 24 hours (*C. marinus* and *M. bahia*) or 48 hours (*D. magna*). The LC50/EC50 values were calculated using initial analytical concentrations. As a decrease of 20-70% was observed between concentrations initially and in the spent medium, the calculated EC50/LC50 values must be assumed to be maximum estimates (based on measured concentrations). Reanalysis of the original data using mean exposure concentration would probably give somewhat lower values by a factor 0.88-0.51. The available report does not allow exact recalculation but based on available information the EC50/LC50 would be 2.4, 1.7, 1.8 mg/l for *D. magna*, *C. marinus* and *M. bahia* respectively. Below EC50/LC50 values based on both nominal and initial measured concentrations are presented.

Organism	Duration	Endpoint	Value
<i>Daphnia magna</i>	48 hours	EC50	2.7 mg/l (measured)
			9.1 mg/l (nominal)
<i>Cheatogammarus marinus</i>	48 hours	LC50	3.4 mg/l (measured)
			10.5 mg/l (nominal)
<i>Mysidopsis bahia</i>	48 hours	LC50	3.6 mg/l (measured)
			10.2 mg/l (nominal)

On the basis of these results it is concluded that the toxicity of n-pentane towards invertebrates is between 1-10 mg/l. The results of these studies are considered valid and will be used for further risk assessment.

#### 3.2.1.1.3 Algae

An algal growth inhibition test with *Selenastrum capricornutum* was performed in 1996 according to OECD Guideline 201 (Exxon, 1997). The study was certified as a GLP study. The test was performed in closed container with no air head space. Test concentrations were verified by chemical analysis of n-pentane both initially and at the end of the exposure period. During the test exposure period a 30 to 79% decrease in test concentration was observed. The results were based on the statistical evaluation of the average measured concentration in test medium. The 95% confidence interval could not be established. The test gave the following results:

Organism	Duration	Endpoint	Value
<i>S. capricornutum</i>	72 hours	EC50 (growth rate)	10.7 mg/l
		EC50 (biomass)	7.51 mg/l
		NOEC (growth rate)	2.04 mg/l
		NOEC (biomass)	1.26 mg/l

The test is considered valid and the results of the *S. capricornutum* study will be used for further risk assessment.

#### 3.2.1.1.4 Microorganisms

There is no test available that establishes the potential toxicity of n-pentane towards WWTP organisms. However, an indication of the toxicity can be derived from the biodegradation test. The readily biodegradability of n-pentane was established by the "Manometric respiratory test,

OECD 301F" (Exxon, 1997). The nominal concentration added to the test system was designed to give a final concentration of n-pentane of 60 mg/l. The amount is higher than needed to give a saturated solution.

In view of the test result, with n-pentane fulfilling the criteria of being readily biodegradable according to > 60% degradation within a 10-day window, it is concluded that n-pentane does not inhibit the activity of WWTP organisms at the limit of the solubility of n-pentane.

The study indicates that WWTP microorganisms were not inhibited at 38.5 mg/l (solubility limit of n-pentane), however the information does not presently qualify as acceptable test result for deriving  $PNEC_{\text{microorganisms}}$ .

### 3.2.1.2 QSAR derivation of aquatic toxicity

Using a program developed for the US EPA (ECOSAR version 1.01, 1994) gave the following relevant toxicity values:

Organism	Duration	Endpoint	Predicted (mg/l)
Fish (FW)	96 hours	LC50	1.9
Daphnid	48 hours	LC50	2.2
Daphnid	16 days	EC50	0.23
Algae (green)	96 hours	EC50	1.53

The Netherlands made a report on the predicted aquatic toxicity of a number of high volume chemicals in 1993 (Bol et al., 1993). These are based on QSAR estimations. The following results for n-pentane were reported:

Organism	Duration	Endpoint	Predicted (mg/l)
Fish (FW)	96 hours	LC50	3.7
Daphnid	48 hours	EC50	2.8
Daphnid	21 days	NOEC	0.42
Algae (green)	48 hours	EC50	1.7

The QSAR data presented are to a large extent in accordance with the measured data and thereby support the measured data. In the table below a comparison with QSAR data for other petroleum compounds have been made indicating a similar good agreement.

**Table 3.16** Comparison of data for laboratory tests and QSAR data for some petroleum compounds

Compound	LC50 fish 96 h mg/l		EC50 Daphnia mg/l		EC50 Algae mg/l	
	Test range	QSAR	Test range	QSAR	Test range	QSAR
N-Pentane	4.3	3.7	2.7	2.8	10.7	1.7
Cyclohexane	4.5	3.9	3.8	2.9	4.4	1.8
Toluene	5.4-31.7	17.1	11.5-15	15.2	134-207	10.1
Cumene	2.7-5.1	3.6	0.6-91	2.58	2.6-21	1.5

### 3.2.1.3 PNEC for water, sediment and WWTP

Acceptable acute toxicity studies are available for all three groups of aquatic organisms. The lowest acute LC50 or EC50 value is that for *Daphnia magna* with an EC50 of 2.7 mg/l. Following the TGD, derivation of PNEC from 3 acute toxicity studies requires the use of an assessment factor of 1,000, giving a PNEC<sub>aquatic</sub> of 2.7 µg/l. Given the good agreement between test data and QSAR data and based on the chemical structure it can be argued that the toxicity of n-pentane is as a non-polar narcotic chemical. This allows the use of an assessment factor of 100.

$$\text{PNEC}_{\text{aquatic}} = 27 \mu\text{g/l}$$

There are no test results regarding sediment organisms and the PNEC<sub>sediment</sub> has therefore to be estimated using the equilibrium partitioning method described in the TGD. This gives the following result:

$$\text{PNEC}_{\text{sediment}} = \text{PNEC}_{\text{aquatic}} \cdot (K_{\text{sed-water}} \cdot 1,000 / \text{RHO}_{\text{sed}}) = 27 \cdot 15.69 = 424 \mu\text{g/kg wwt}$$

Without test results with inhibitory effects on WWTP organisms, no PNEC<sub>wwtp</sub> can be established. The readily biodegradability test did not show any inhibition at supersaturated concentrations.

### 3.2.2 Atmosphere

#### Direct effects

It is clear from the high-vapour pressure of n-pentane that air is the main compartment of release. The calculated abiotic degradation rate in atmosphere indicates that the atmospheric half-life of n-pentane is approximately 4 days.

No information is available regarding effects of n-pentane on plants. Data about plant toxicity are available on a similar substance n-hexane. Christ (1996) investigated the harmful effects of 49 chemicals including n-hexane and cyclohexane on various plants (tomato, sunflower, soya, bean, wheat, beet and *tropaeolum spec.*) in short-term tests with 3-hour air exposure. Exposure concentrations were achieved by injecting the appropriate amount of test compound directly into an air stream. Each compound was tested at 7 concentrations. Highest tested concentration was about 1/5 of the air saturation of n-hexane. Endpoints observed were visual signs like chlorosis (absence or disappearance of chlorophylls) and effects on photosynthesis. No effects were observed for either at the highest tested concentration of 100 g/m<sup>3</sup> for n-hexane or at 50 g/m<sup>3</sup> for

cyclohexane. The molecular structure of n-pentane does not show any moieties that would strongly indicate the need for additional testing with respect to direct effects of n-pentane to plants.

### Indirect effects

Normal pentane is not assumed to be a significant contributor to the greenhouse gases. This because it has a low half-life in the atmosphere and therefore n-pentane will amount to a very small fraction of organic compounds in the atmosphere. An important greenhouse gas like methane has a 1,000 times higher concentration than n-pentane in the atmosphere.

Normal pentane contributes to tropospheric VOC and to the formation of tropospheric ozone. However, the photochemically formation of ozone and other harmful substances in polluted air depends on emission of all VOCs and other compounds in a complex interaction with other factors. Therefore, a more in-depth evaluation of the contribution of n-pentane to the complex issue of air quality should more appropriately be dealt with by authorities regulating air quality rather than as a part of this substance specific risk assessment.

Regarding effects of ozone (which n-pentane may contribute to the formation of) the CSTEE in their "Opinion on "Risk assessment underpinning new standards and thresholds in the proposal for a daughter directive for tropospheric ozone", adopted at the CSTEE by written procedure on May 21, 1999", comments:

"The effects of ozone on vegetation are also documented. Similarly to humans, oxidative stress/damage due to reaction with unsaturated organic compounds, sulphydryl compounds, formation of aldehydes, hydrogen peroxide, as well as cellular changes including altered membrane permeability are described. More specifically, reduced photosynthesis, impaired CO<sub>2</sub> fixation and altered cell growth leading to reduction in root/shoot ratios and in flower formation are observed. This may result in ecological balance shifts as less ozone-sensitive species are favoured.

Presumably a tolerance phenomenon occurs in plants with continual exposure, though it appears to be poorly documented."

Further: "For neither man, animals nor for plants has a threshold been established for either acute or chronic effects. This raises the issue of what type and degree of change is of health significance.

From an environmental management viewpoint there is a major additional problem as indicated above that in many areas, ozone levels are above those levels where some biological effects are known to occur."

and further;

"However, the CSTEE noted that there are several factors that can affect the toxicity of ozone for plants and large differences in the actual threshold must be expected for different environmental and ecological conditions."

Effects on animals and humans are expected within the same range of exposure. The effects are described in the relevant human health section.

The threshold values in use in the EU according to Directive 92/72/EEC are shown in the table below. It is noted that the threshold values for ozone are approximately at the same level for protection of both the human health and the health of vegetation.

**Table 3.17** Threshold values for ozone concentrations set in Directive 92/72/EEC (EC, 1992)

Threshold for:	Concentration (in $\mu\text{g}/\text{m}^3$ )	Averaging period (h)
Health protection	110	8
Vegetation protection	200 65	1 24
Population information	180	1
Population warning	360	1

A new directive (Directive 2002/3/EC) relating to ozone in ambient air was adopted 12 February 2002. Member States shall implement this directive by 9 September 2003. From that date Directive 92/72/EEC referred above shall be repealed. The approach in the new directive is to set target values (for 2010) and long-term objectives (2020) for ozone levels as well as information and alert thresholds, see **Table 3.16** below. In addition to measurements of ozone concentrations Member States shall also supply data on concentrations of ozone precursor substances. Measurement of ozone precursors must include at least nitrogen oxides, and appropriate volatile organic substances (VOC), the list of VOCs recommended for measurement includes about 30 substances of which n-pentane is one.

**Table 3.18** Target values for ozone set in Directive 2002/3/EC

	Parameter	Target value for 2010
1. Target value for the protection of human health	maximum daily 8-hour mean	120 in $\mu\text{g}/\text{m}^3$ not to be exceeded on more than 25 days per calendar year averaged over three years.
2. Target value for the protection of vegetation	AOT40 <sup>a)</sup> , calculated from 1-hour values from May to July	18,000 $\mu\text{g}/\text{m}^3 \cdot \text{h}$ averaged over five years

a) AOT40 (expressed in  $\mu\text{g}/\text{m}^3 \cdot \text{h}$ ) means the sum of the difference between hourly concentrations greater than 80  $\mu\text{g}/\text{m}^3$  (=40 parts per billion) and 80  $\mu\text{g}/\text{m}^3$  over a given period using only the 1-hour values measured between 8:00 and 20:00. Central European Time each day.

**Table 3.19** Long-term objectives for ozone set in Directive 2002/3/EC

	Parameter	Long-term objective
1. Long-term objective for the protection of human health	maximum daily 8-hour mean within a calendar year	120 in $\mu\text{g}/\text{m}^3$
2. Long-term objective for the protection of vegetation	AOT40 <sup>a)</sup> , calculated from 1-hour values from May to July	6,000 $\mu\text{g}/\text{m}^3 \cdot \text{h}$

a) AOT40 (expressed in  $\mu\text{g}/\text{m}^3 \cdot \text{h}$ ) means the sum of the difference between hourly concentrations greater than 80  $\mu\text{g}/\text{m}^3$  (=40 parts per billion) and 80  $\mu\text{g}/\text{m}^3$  over a given period using only the 1-hour values measured between 8:00 and 20:00. Central European Time each day.

The information threshold value according to Directive 2002/3/EC is 180  $\mu\text{g}/\text{m}^3$  (1-hour average) and the alert threshold value is 240  $\mu\text{g}/\text{m}^3$  (1-hour average).



### 3.2.3 Terrestrial compartment

For the terrestrial effect assessment, no test results of acute or long-term experiments have been reported. Therefore  $PNEC_{soil}$  cannot be derived directly.

#### PNEC for the terrestrial compartment

As the PNEC cannot be derived from terrestrial experimental data, the equilibrium partitioning method described in the TGD is used, applying the results from the aquatic assessment. The TGD gives the following equation and result:

$$PNEC_{soil} = PNEC_{aqua} \cdot (K_{soil-water} \cdot 1,000 / RHO_{soil}) = 27 \cdot (32.7 \cdot 1,000 / 1,700) = 519 \mu\text{g/kg wwt}$$

In the risk assessment a  $PNEC_{soil}$  of 519  $\mu\text{g/kg wwt}$  will be used

### 3.2.4 Secondary poisoning

Normal pentane has a Log Kow of 3.45 and calculation according to the TGD gives a BCF of 171 l/kg. Normal pentane therefore shows a potential for biomagnification through the food chain. However, n-pentane is not classified as toxic or very toxic to mammals, nor is it classified with any of the risk phrases R 40, 45, 46, 48, 60-63. Furthermore studies with mammals (Section 4.1.2.1) indicate that n-pentane is rapidly eliminated.

### 3.3 RISK CHARACTERISATION

It should be noted that this risk assessment only covers the risks associated with the life cycle of n-pentane. Any risks connected to the presence of n-pentane in other EINECS substances particularly petroleum products (non-isolated n-pentane), have not been assessed.

#### 3.3.1 Aquatic compartment (incl. sediment)

There is no direct release to water of n-pentane during production or use except for certain uses (see Section 3.1.3.1). Most of the exposure of surface water is indirectly through deposition as calculated by EUSES for the regional  $PEC_{\text{water}}$ . The calculated  $PNEC_{\text{aquatic}}$  was  $27 \mu\text{g/l}$ , and the calculated  $PNEC_{\text{sediment}}$  was  $424 \mu\text{g/kg wwt}$ . The risk assessment for water also applies for sediment as both PEC and PNEC for sediment are estimated using the partition equilibrium method.

**Table 3.20** PEC/PNEC values for all life cycle steps with respect to local surface water

Use pattern	Life cycle	Step	$PEC_{\text{surface water}} (\mu\text{g/l})$	PEC/PNEC
1	production		$3.7 \cdot 10^{-3}$	$1.37 \cdot 10^{-4}$
2 and 3	foaming agent	all steps	$3.7 \cdot 10^{-3}$	$1.37 \cdot 10^{-4}$
4	polymer diluent	all steps	$3.7 \cdot 10^{-3}$	$1.37 \cdot 10^{-4}$
5	aerosols	private use	$6.5 \cdot 10^{-2}$	$2.42 \cdot 10^{-3}$
6	adhesives	all steps	$3.7 \cdot 10^{-3}$	$1.37 \cdot 10^{-2}$
7	laboratory	processing	1.38	0.051
8	other uses	formulation	$3.71 \cdot 10^{-3}$	$1.37 \cdot 10^{-4}$
		processing	0.407	0.015
		private use	$3.71 \cdot 10^{-3}$	$1.37 \cdot 10^{-4}$
	regional		$3.71 \cdot 10^{-3}$	$1.37 \cdot 10^{-4}$

PNEC applied is  $27 \mu\text{g/l}$

The highest local surface water concentration established by the EUSES calculation (**Table 3.20**) was  $1.38 \mu\text{g/l}$  for the use category “Laboratory chemical”. The PEC/PNEC in this case is 0.051. All other local PEC/PNEC are lower, indicating no cause for concern: **conclusion (ii)**. Also regional and continental PEC/PNECs are low (**Table 3.18**).

**Table 3.21** Regional and continental PEC/PNEC ratios for the aquatic compartment (incl. sediment)

Compartment	PEC $\mu\text{g/l}$ or $\mu\text{g/kg wwt}$	PEC/PNEC
Regional <sub>aquatic</sub>	$3.7 \cdot 10^{-3}$	$1.37 \cdot 10^{-4}$
Continental <sub>aquatic</sub>	$3.9 \cdot 10^{-4}$	$1.44 \cdot 10^{-5}$
Regional <sub>sediment</sub>	$5.8 \cdot 10^{-2}$	$1.37 \cdot 10^{-4}$
Continental <sub>sediment</sub>	$7.1 \cdot 10^{-3}$	$1.67 \cdot 10^{-4}$

All PEC/PNECs for the aquatic environment are well below 1, indicating no cause for concern: **conclusion (ii)**.

### 3.3.2 Atmosphere

A PNEC has not been calculated for the atmosphere, as no effect studies are available. Plant toxicity data from n-hexane and cyclohexane do not show effects even at the highest concentration tested. The molecular structure of n-pentane does not strongly indicate the need for more information and further assessment in this respect.

It is known that n-pentane contributes to tropospheric VOC and contributes to the tropospheric formation of ozone. As stated in Section 3.1.2.1.1, the photochemically formation of ozone depends on emissions of all VOCs and other compounds in a complex interaction with other factors.

The VOC speciation and concentrations, VOC/NO<sub>x</sub> ratio, solar radiation and meteorological conditions vary from city to city within EU. Since the environmental conditions differ considerably a certain concentration of VOC may lead to very different ozone concentrations within Europe. Thus the effects on ozone creation of emissions arising from the production and use of isolated n-pentane may differ substantially between different regions in the EU.

The industrial use of the commercial product n-pentane contributes significantly to the overall emission of n-pentane, however, emission of n-pentane from car fuels and exhaust gases from motor vehicles, i. e. from non-isolated n-pentane, seem to be the largest source. However, locally and regionally this proportion may vary substantially due to differences between regions in the VOC emission pattern from industrial sectors using n-pentane.

The risk assessment of non-isolated n-pentane is outside the scope of the current risk assessment. However, on the basis of monitoring of NMVOCs in city roadside air (Christensen, 1999) there is indication that n-pentane (predominantly non-isolated) can contribute with about 3.5% to the overall ozone formation due to NMVOCs.

Effects of ozone exposure are documented on plants, animals and humans. Reporting on monitoring results are most frequently done in relation to exceedance of thresholds for information or warning of the human population, but this reporting may also give indication on the magnitude of environmental effects, because effect concentrations seem to be in the same order of magnitude for both vegetation and humans. The threshold values set by the European Union to protect human health and the vegetation are frequently exceeded (cf. e.g. De Leeuw et al., 1996).

The severity of exceedance of the EU threshold (see Section 4.1.3.4) for health protection ( $110 \mu\text{g}/\text{m}^3$ , 8-hour average, according to Directive 92/72/EEC) has been estimated by WHO (1999). The 1995 summer ozone incidence is estimated to have caused 1,500-3,700 deaths (0.1-0.2% of all deaths) and further 300-1,000 extra emergency hospital admissions due to respiratory diseases. "It is likely that the total number of health impacts is higher than the estimated impact of the days with high levels only. This is suggested by epidemiological studies where the effects can be seen also below the  $110 \mu\text{g}/\text{m}^3$  level" (WHO, 1999).

Based on n-pentane fraction of NMVOC it was estimated that isolated n-pentane contributes with 0.4% to the total NMVOC emissions. In Section 3.1.4.5.1 it was estimated that the n-pentane share of ozone formation in an urban roadside situation (Christensen, 1999) might account for 3.5% of the ozone formation. The source of the measured n-pentane in this survey can be assumed to be predominantly car fuels and car exhaust. However as a reasonable approximation it could be assumed that the background contribution from isolated n-pentane would be equal to the estimated regional PEC. In that case isolated n-pentane would contribute with 0.16% of the potential ozone formation. With local sources of isolated n-pentane the contribution will be much higher (see **Table 3.10**).

If the WHO figures referred above are used to estimate the impact of emissions from the production and use of isolated n-pentane through formation of ozone then these emissions might very roughly estimated have caused around 3–15 deaths in summer 1995, this assumes a linear relationship between the emission of n-pentane, the emission of NMVOCs and the creation of ozone. However, no simple relationship has been established between the proportion of n-pentane to total NMVOC emissions - and thus also between emissions arising from the use of the isolated n-pentane and the creation of tropospheric ozone. One should also keep in mind that it is the combination of NO<sub>x</sub> and VOC and other factors that causes tropospheric ozone formation, and that cars are the main source of NMVOC compounds in cities.

Similarly, the vegetation and wildlife may be severely affected by ozone incidences and n-pentane is likely to contribute to these effects. However, no quantification has been possible within the scope of this risk assessment.

Based on this, risk reduction measures seem necessary to consider a **conclusion (iii)**. This conclusion is reached because of the contribution of the commercial product (isolated) n-pentane to the formation of ozone. However, a more in-depth evaluation of the contribution of n-pentane to the complex issue of air quality should be more appropriately dealt with by authorities regulating air quality rather than as a part of this substance specific risk assessment. Therefore, in the context of the consideration of which risk reduction measures that would be the most appropriate, it is recommended that under the relevant air quality Directives a specific in-depth evaluation be performed. Such an evaluation should focus on the contribution of isolated as well as non-isolated n-pentane to the complex issue of ozone and smog formation and the resulting impact on air quality.

### 3.3.3 Terrestrial compartment

A PNEC<sub>soil</sub> of 519 µg/kg has been calculated. There are no known direct emissions to soil, soil only being contaminated via depositions and sludge application. The soil PEC/PNEC values are shown in **Table 3.22** and **Table 3.23**.

**Table 3.22** PEC/PNEC values for all local life cycle steps with respect to soil compartment

Use pattern	Life cycle	Step	PEC <sub>soil</sub> (µg/kg wwt)	PEC/PNEC
1	production		0.14	2.6 · 10 <sup>-4</sup>
2	EPS foaming	formulation	0.17	3.2 · 10 <sup>-4</sup>
		processing	0.18	3.5 · 10 <sup>-4</sup>
		private use	1.9 · 10 <sup>-3</sup>	3.7 · 10 <sup>-6</sup>
3	PUR foaming	formulation	0.25	4.8 · 10 <sup>-4</sup>
		private use	6.3 · 10 <sup>-4</sup>	1.2 · 10 <sup>-6</sup>
4	polymer diluent	formulation	0.59	1.1 · 10 <sup>-3</sup>
		processing	3.7 · 10 <sup>-3</sup>	7.2 · 10 <sup>-6</sup>
5	aerosols	private use	4.6 · 10 <sup>-3</sup>	8.9 · 10 <sup>-5</sup>
6	adhesives	formulation	5.5 · 10 <sup>-4</sup>	1.1 · 10 <sup>-6</sup>
		processing	1.5 · 10 <sup>-2</sup>	2.8 · 10 <sup>-5</sup>

Table 3.22 continued overleaf

**Table 3.22 continued** PEC/PNEC values for all local life cycle steps with respect to soil compartment

Use pattern	Life cycle	Step	PEC <sub>soil</sub> (µg/kg wwt)	PEC/PNEC
7	laboratory	processing	1.0	$1.9 \cdot 10^{-3}$
8	other uses	formulation	$1.5 \cdot 10^{-3}$	$2.9 \cdot 10^{-6}$
		processing	0.33	$6.4 \cdot 10^{-4}$
		private use	$2,691.4 \cdot 10^{-4}$	$2.7 \cdot 10^{-7}$
	regional		$2.1 \cdot 10^{-4}$	$4.0 \cdot 10^{-7}$

PNEC<sub>soil</sub> applied is 519 µg/kg wwt

The PEC concentration is related to concentration in agricultural soil averaged over 30 days, except for the regional concentration

Use of n-pentane in laboratories gave the highest calculated concentration in soil (**Table 3.22**) the PEC/PNEC is 0.002, indicating no cause for concern: **conclusion (ii)**. All PEC/PNEC values for the soil environment are well below 1, indicating no cause for concern: **conclusion (ii)**.

**Table 3.23** Continental and regional PEC/PNEC for the soil compartment (agricultural soil)

Compartment	PEC µg/kgwwt	PEC/PNEC
Regional <sub>soil</sub>	$2.1 \cdot 10^{-4}$	$4.0 \cdot 10^{-7}$
Continental <sub>soil</sub>	$5.3 \cdot 10^{-5}$	$1.0 \cdot 10^{-7}$

### 3.3.4 Secondary poisoning

Normal pentane has a Log Kow of 3.45 and calculation according to the TGD gives a BCF of 171 l/kg. Normal pentane therefore shows a potential for biomagnification through the food chain. However, n-pentane is not classified as toxic or very toxic, nor is it classified with any of the risk phrases R 40, 45, 46, 48, 60-63. Furthermore studies with mammals (Section 4.1.2.1) indicate that n-pentane is rapidly eliminated.

Therefore it is not considered necessary to carry out a risk characterisation for secondary poisoning.

## **4 HUMAN HEALTH**

### **4.1 HUMAN HEALTH (TOXICITY)**

#### **4.1.1 Exposure assessment**

##### **4.1.1.1 General discussion**

Normal pentane is a liquid at room temperature. The low boiling point (36°C), implies that the substance evaporates easily. Inhalation is the predominant route of exposure while oral contact is considered negligible. There are no measured data available for dermal exposure, but because of the high volatility of n-pentane the uptake is expected to be low. In this report the exposure of n-pentane via the dermal route is estimated by the dermal model of EASE (Estimation and Assessment of Substance Exposure).

Occupational exposure may occur during the production of n-pentane and in downstream uses of the substance. The main applications are as a foaming agent, as a constituent in aerosols and as an organic solvent for miscellaneous purposes.

The main consumer exposure to n-pentane is from the use of aerosol products where n-pentane is used to adjust the pressure. The exposure is mainly from the use of hair-sprays, antiperspirants, paints and car care products, where the use of hair-spray is assumed to be most important.

Exposure to n-pentane from gasoline production/handling or filling is not part of this risk assessment (cf. Section 2.4 for further explanation). However, for illustrative purposes some information regarding consumer exposure during tank filling and occupational exposure during gasoline handling is given in Appendix B.

##### **4.1.1.2 Occupational exposure**

For occupational exposure, inhalation is the predominant route of exposure, while oral contact is considered negligible. There are no measured data available for dermal exposure, but because of the high volatility of n-pentane the uptake is expected to be low. In this report the exposure of n-pentane via the dermal route is estimated by the dermal model of EASE.

The scenarios considered for occupational exposures to n-pentane are presented below, and are selected on the basis of the information given by the industry.

Scenario 1 Production of n-pentane

Scenario 2 Industrial use of products containing n-pentane

Scenario 2A: Production of polystyrene granulates (formulation)

Scenario 2B: EPS manufacturing (processing)

Scenario 2C: Production of rigid polyurethane foam

Scenario 2D: Manufacturing of aerosol-containers

### Scenario 3 Professional end use of products containing n-pentane

Scenario 3A: Hair salons

Scenario 3B: Professional use of car-care products

Scenario 3C: Miscellaneous applications

The term “exposure data” is used for both personal sampling and stationary sampling data. Air concentration data are given in  $\text{mg}/\text{m}^3$ . Results originally reported in units of ppm have been converted to  $\text{mg}/\text{m}^3$  by multiplying the ppm values with the conversion factor  $1 \text{ ppm} = 2.99 \text{ mg}/\text{m}^3$ .

Measured data on working exposure are scanty. It is therefore chosen to give all available data in the risk assessment report even if there is a lack of information on measurement procedures for some series. For some scenarios where the measurements are insufficient, exposures also have been predicted by the use of the EASE model as recommended in the TGD.

The main result of the estimations is the so-called reasonable worst-case estimate. This value intends to estimate the exposure level in a reasonable worst-case situation, i.e. in a situation with exposures in the higher ranges of the full distribution of exposure levels, but below the extremes reached. Because of a limited number of measurements, the 90 percentile is not estimated. The measurements are also provided with very little detail on task, working conditions, e.g. and therefore the highest value is taken as the reasonable worst-case value.

The dermal exposure time is usually short because of n-pentane’s high volatility. However, if e.g. hands are covered with liquid n-pentane, then dermal absorption occurs. Because no measured data are available on dermal exposure, exposure to n-pentane will be estimated with the dermal model of EASE.

### Occupational exposure limits (OEL)

OEL values or administrative norms for n-pentane in some countries are listed in **Table 4.1**.

**Table 4.1** OEL values or administrative norms for n-pentane in some countries

Country	Year	OEL values or adm.norms (short-time value)	
		$\text{mg}/\text{m}^3$	ppm
Norway ** (adm. norm)	2000	750	250
Sweden	2000	1,800 (2,000)	600 (750)
Denmark (all isomers)	2000	1,500	500
Finland	2000	1,500 (1,900)	500 (630)
The Netherlands	1997-1998	1,800	600
Germany MAK (all isomers)	1999	2,950	1,000
United Kingdom	EH40/2000	—	—
ACGIH	1999	1,770	600
Japan	1998-1999	880	300

\*\* Before 1988 the irritating effect on mucous membranes was the predominant health hazard in assessing the Norwegian administrative norms for solvents. Epidemiological studies have indicated that long-time exposure for organic solvents may be harmful to the nervous system, as well. As a preventive measure to reduce the risk for possible chronic CNS-effects, the Norwegian Directorate of Labour Inspection decided in 1988 to lower the norm values for all the organic solvents with norm > 50 ppm, by 50%.

#### 4.1.1.2.1 Scenario 1: Production of n-pentane

There are 6 production sites in the European Union. The production of n-pentane in refineries is being performed essentially in closed systems. Therefore exposure to n-pentane occurs primarily during sampling/monitoring the batches, drumfilling and truckloading. Terminal operators and truck drivers are the main exposed worker groups. **Table 4.2** shows exposure data from two different production sites.

In the EU, approximately 500 workers may be exposed during production of n-pentane. This number is mainly composed of:

- operators on the manufacturing facility: 170. Their exposure is mainly associated with the sampling operations during production,
- operators acting in the storage, loading and drumfilling facilities: 250.

During one shift, operators will have peak exposures corresponding to a few minutes, as taking samples during production. In addition they will have background exposure with low concentrations of longer duration. n-Pentane manufacturing is limited in each plant to a few batches of production per year and each production batch requires a range of 2 to 5 days of operation. Industry has estimated that the average duration of peak exposures to n-pentane for an operator working in shifts during batch production is of 10 minutes per shift. This gives an approximate cumulative exposure period of about 1 to 2 hours per year per exposed employee with the highest concentrations in the working atmosphere.

**Table 4.2** Measured air concentrations of n-pentane during production and loading of n-pentane

Job operation	Method	Exposure level (mg/m <sup>3</sup> )			Sampling time	Comments	Reference
		Range (no of samples)	Median mg/m <sup>3</sup>	Mean mg/m <sup>3</sup>			
Production site: crude lights ends	3M badges (passive)	<0.1-158.5 (19)	0.2	9.3	8 hours	ambient temperature: 3-8.5°C	Exxon Chemical Belgium (1996)
Production site: solvent dearomatisation unit	3M badges (passive)	<0.1 – 7.4 (19)	0.5	1.2	8 hours		
Sampling	low flow pumps, char coal tubes (active)	3-599 <sup>1)</sup> (13)	52.5	176	2 minutes	ambient temperature: 6-22°C	
Truck loading	low flow pumps, char coal tubes	5.7-21.8 <sup>2)</sup> (4)	16.5	15.1	19-33 minutes	ambient temperature: 8°C	
Barrellfilling	low flow pumps, char coal tubes	73 (1)			50 minutes	30 barrels	
Coupling/uncoupling of transferlines and regular inspections during loading	gas diffusion monitor type 3M 3,500	< 0.4-180 <sup>3)</sup> (9)	42	66.5	55-210 minutes		Shell Nederland Chemie (1997)

1) A measurement of 673 mg/m<sup>3</sup> was also reported, but it came from a sample that was not carried out according to the procedure

2) 21.8 mg/m<sup>3</sup> was only measured during disconnecting transferlines

3) Analyses on 8 operators



Available measurements are limited for this scenario. As shown in **Table 4.2**, the measurements are provided by Exxon Chemical Belgium and Shell Nederland Chemie, and is done during production, storage and loading and at the loading bay, respectively. Only the measurements done at the production site (crude lights ends and solvent dearomatisation unit) at Exxon has a sampling time of 8 hours.

From the available data it can be concluded that the highest exposure occurs during loading of n-pentane. Loading of tanks or trucks is carried out by coupling and uncoupling of transferlines at the top of the tanks. During loading regular inspections are made. Loading is an activity which is assumed to take place only a few times a day, lasting for 0.5 hour each time. Tank filling is assumed to take place at ambient temperatures.

According to industry, cleaning and maintenance of plant items that have contained or may have been contaminated by pentane is only undertaken under strict permit-to-work systems, because of the flammability risks inherent in such operations. A basic requirement of such cleaning and maintenance activities is that they involve the draining and purging (with nitrogen) of the plant items e.g. vessels and lines, in order to remove all traces of residual pentane. For major items e.g. storage tanks or spheres, then nitrogen purging will be followed by flushing with water.

#### Inhalation exposure

In the process of sampling, exposures up to  $599 \text{ mg/m}^3$  were reported (Exxon Chemical Belgium). All the measured values for sampling were short-time values (duration 2 minutes). During the measurements, a temperature ranging from 3 to  $11.1^\circ\text{C}$  was noted. For work operations related to the loading of n-pentane, coupling/ uncoupling of transferlines and regular inspections, Shell reported values of up to  $180 \text{ mg/m}^3$ .  $180 \text{ mg/m}^3$  (sample time 72 minutes), was measured during loading of a product containing 100% n-pentane. During the loading of a product containing 85% n-pentane/15% isopentane, a value of  $170 \text{ mg/m}^3$  was reported (sample time 55 minutes). The report did not give any information about the ambient temperature.

#### Dermal exposure

Dermal exposure to n-pentane during the production is possible during sampling, drumming, coupling and uncoupling of road tankers and cleaning and maintenance. The dermal exposure time is usually short because of n-pentane's high volatility, and hence the exposure will be considerably lower than estimated below.

According to the industry, there are several features of the engineering and operational controls that characterise the loading of n-pentane, and related cleaning and maintenance activities, which mitigate against the potential for significant dermal exposure. Because of the flammability of pentane, strict measures are taken to prevent uncontrolled releases during loading. Historically, bottom loading of road tankers has taken place. But increasingly use is now made of dry-lock couplings, overspill devices and loading using enclosed vapour recovery systems, all of which can be expected to further reduce both dermal and airborne exposures. Heavy-duty PVC gloves are considered as standard workwear for all operations on the production facilities. These include those tasks where contact with liquid pentane is foreseen, including all activities associated with dis/connecting transfer lines and cleaning and maintenance

Dermal contact may occasionally occur if liquid pentane happens to leak to the skin of the hands during the sampling. Assuming incidental contact and direct handling the dermal exposure is predicted by the EASE model, to be  $0\text{-}0.1 \text{ mg /cm}^2\text{/day}$ . The fingers and palms of both hands

may be exposed, which corresponds to an area of 420 cm<sup>2</sup>. This corresponds to a reasonable worst-case estimate of 0-42 mg/person/day.

Exposure to n-pentane may also occur during connecting and/or disconnecting the transfer lines. Assuming non-dispersive use, direct handling and intermittent contact, EASE predicts exposure to 0.1-1 mg/cm<sup>2</sup>/day. It is further assumed that fingers and palms on both hands will be exposed which corresponds to an area of 420 cm<sup>2</sup>. This corresponds to a reasonable worst-case estimate of 42-420 mg/person/day.

Maintenance and cleaning of equipment is considered to lead to dermal exposure. The practice described above minimises the exposure to a low level. Moreover, all cleaning and maintenance activities require the use of standard protective equipment, including heavy-duty PVC gloves or gauntlets. Assuming direct handling and incidental contact then EASE predicts an exposure level of 0-0.1 mg/cm<sup>2</sup>/day. During maintenance of the tanks it is assumed that both hands can be exposed. This corresponds to an exposed area of 840 cm<sup>2</sup>, and an estimated reasonable worst-case estimate of 84 mg/person/day.

Due to the high volatility of n-pentane actual dermal exposure will probably be lower.

#### Conclusion for scenario 1

During production of n-pentane, inhalative and dermal exposure may occur during sampling, drumming, coupling and uncoupling of transfer lines, as well as during cleaning and maintenance. Lower exposure levels will occur during the rest of the day.

The highest exposure occurs during loading. Reasonable worst case is estimated to be 180 mg/m<sup>3</sup> while typical full-shift exposure levels are estimated to be 66.5 mg/m<sup>3</sup>. Also, the highest short-term value of 599 mg/m<sup>3</sup> is measured for the sampling-operation. The highest estimated value for dermal exposure was 420 mg/person/day during loading. These values are taken forward to the risk characterisation (see **Table 4.15**).

#### **4.1.1.2.2 Scenario 2: Industrial use of products containing n-pentane**

n-Pentane has for decades been used as a foaming agent in the production of expanded polystyrene (EPS). n-Pentane is also used as a foaming agent in rigid polyurethane foams.

##### Scenario 2A: Production of polystyrene granulates (formulation)

Granular polystyrene containing typically 4.5-5% n-pentane (APME, 1997), is the raw material in the manufacturing of EPS. This raw material is produced in about 10 plants, which supply the EPS industry. One of these plants is in Norway.

According to information from the Norwegian producer, the production takes place in closed systems. Pentane is added under enhanced pressure and temperature. Normally, the operators are not in direct contact with n-pentane and they are therefore not using personal protective equipment. On the other hand, under the packing of the product the operators are in the immediate vicinity of the product and can be exposed by n-pentane. As stated by the producer, the premises where the job operations take place are without heating and have mechanical, in addition to natural, ventilation. Measurements (personal samples) taken during the production of polystyrene granulates is given in **Table 4.3** (Norwegian plant 1996; 1998) and **Table 4.4** (Finnish plants, 2001).

There have also been available monitoring data from the Finnish Institute of Occupational Health, (Finnish Environment Institute, 1996), which show an exposure level of 118 mg/m<sup>3</sup> (range 71.8-206 mg/m<sup>3</sup>). This, together with the measurements given in **Tables 4.3** and **4.4**, indicates that the exposures are not higher for this scenario compared to EPS manufacturing (described below).

**Table 4.3** Measured air concentrations of n-pentane during the production of polystyrene granulates (Norwegian plant, 1996; 1998)

Job operation	Exposure level in mg/m <sup>3</sup>			Comments
	Range (no of samples)	Median mg/m <sup>3</sup>	Mean mg/m <sup>3</sup>	
Monitoring and controlling of the polymerization-process	7.2-35.6 (5)	12.3	15.3	april 1996
Finalizing and packing of the product	35.0-57.1 (5)	45.2	40.7	
Wrapping and closing of the products packing	75.6-222.5 (11)	157.3	151.5	december 1998 measurements with traces of methylbutane in the samples

All the samples are taken with a dosimeter type 3M 3500, analysed by gas chromatography and measured over a full shift

**Table 4.4** Measured air concentrations of n-pentane (personal samples) at two polystyrene production plants in Finland (2001), in addition to a Finnish pilot-reactor

Job operation	Exposure level in mg/m <sup>3</sup>		Sampling time given in hours (median)	Comments
	Range (no of samples)	Median		
PS-,SB-operator	<0.3-13.2 (7)	4.5	7.2-7.5 (7.4)	plant 1:  the measurements were taken in the period 1985-1999
Drying operator	10.2-62.8 (3)	11.4	7.4-7.5 (7.5)	
PS-,SB-operator	<3-3 (3)	<3	7.1-7.4 h (7.4 h)	
PS-,SB-operator	<3-6 (3)	3	0.1h (0.1 h)	
PS-operator	0.3-15 (8)	2.7	6.5-7.8 h (7.5)	plant 2:  the measurements were taken in the period 1988-2000
PS-operator	1.2-25.7 (4)	2.7	0.2-1.8 (0.7)	
Drying-operator	1.8-6.3 (4)	2.4	6.3-7.9 (7.5)	
PS-operator	<3-3 (4)	3	7.7-8.0 h (7.8 h)	
Drying-operator	3-6 (4)	3	7.5-7.7 h (7.7 h)	
Head of shift	<3-3 (4)	3	6.9-7.8 h (7.4 h)	
Packing operator	9-68.8 (4)	41.9	7.0-7.8 h (7.6)	

Table 4.4 continued overleaf

**Table 4.4 continued** Measured air concentrations of n-pentane (personal samples) at two polystyrene production plants in Finland (2001), in addition to a Finnish pilot-reactor

Job operation	Exposure level in mg/m <sup>3</sup>		Sampling time given in hours (median)	Comments
PS-operator	3-38.9 (2)	-	7.1-7.2 h	
Drying-operator	3-6 (2)	-	4.7-7.7 h	
Packing-operator	9 (2)	-	6.5-6.9 h	
Technician (shift)	0.9-23.9 (4)	4.8	6.7-12.1 h (9.4 h)	pilot reactor
Sampling	3-9 (3)	3	1 min (1 min)	the measurements were taken in the period 1999-2001
Emptying of toluene washing solution	6-9 (3)	6	17-18 min (17 min)	
Taking out the batch from the reactor	272-1016 (3)	448.5	5-6 min (6 min)	
Taking out the batch from the reactor and drying	47.8-287 (4)	164	34-49 min (39)	

All the samples were collected with portable pumps to charcoal tubes (100/50 mg) and analysed by gas chromatography with FID detector

**Table 4.5** Measured air concentrations of n-pentane (stationary samples) at two polystyrene production plants in Finland (2001), in addition to a Finnish pilot-reactor

Job operation	Exposure level in mg/m <sup>3</sup>		Sampling time given in hours (median)	Comments
	Range (no of samples)	Median		
Not given	<0.3-263 (60)	10.2	2.8-7.6 h (7.3 h)	plant 1:  the measurements are taken in the period 1985-1999
Not given	3-15 (3)	3	6.5-7.2 h (7.0 h)	
Not given	<3-12 (3)	<3	0.5-0.7 h (0.6 h)	
Not given	1.5-4.8 (11)	1.8	6.1-8.5 h (6.2 h)	plant 2:  the measurements are taken in the period 1988-2000
Not given	0.9-4.2 (5)	2.4	0.1-3.7 (2.0)	
Not given	6-116.6(15)	9	5.8-7.8 h (6.3 h)	
Not given	6-98.7 (8)	32.9	2.4-7.0 h (6.8 h)	
Not given	6-26.9 (2)	-	6.8-12 h	pilot reactor
Taking out the batch from the reactor	17.9 (1)	-	7 min	the measurements are taken in the period 1999-2001
Taking out the batch from the reactor and transfer to the dryer	116.6 (1)	-	48 min	

All the samples were collected with portable pumps to charcoal tubes (100/50 mg) and analysed by gas chromatography with FID detector

### Scenario 2 B: EPS manufacturing (processing)

There are more than 1,000 EPS processing (moulding) plants in West Europe. 10-15 plants are situated in Norway, and the consumption of EPS in Norway is about 2% of the annual consumption in West Europe (APME, 1997). In modern EPS plants about 5 workers control the

whole production which means that about 5,000 workers are employed in the processing of EPS in West Europe.

The processing line of expanded polystyrene is shown in **Figure 2.1**. In the first step of the production line, the raw material (granular polystyrene containing about 5% n-pentane) is expanded by heating the material with steam. After being expanded the granulates are transferred into a silo for ageing and drying (step 2). The storage time is from a few hours until three days. In step three, the pre-expanded beads are transferred to moulds and again heated with steam. The beads expand still more and while growing in the moulds they are pressed together and the blocks of polystyrene are formed (the moulding process). The blocks are then stored for ageing for 1-3 days, before the blocks are cut into smaller items (plates) by use of heatable wires (step 4). In some production lines the moulding and the cutting of the blocks are performed successively, before the blocks are stored for ageing.

**Table 4.6** shows the exposure to n-pentane measured in three Norwegian EPS plants. **Table 4.7**, **4.8** and **4.9** displays monitoring data from the Finish Industrial Hygiene database, from a Finnish plant and other plants in Europe, respectively.

**Table 4.6** Exposure to n-pentane in Norwegian EPS production plants  
(Labour Inspection, National Institute of Occupational Health, Norway, 1997)

Job operation	Method	Exposure level in mg/m <sup>3</sup> (no of samples)	Median mg/m <sup>3</sup>	Mean mg/m <sup>3</sup>	Plant
Raw material expansion	char coal tubes. Gas chromatography.  sampling time: 3-4 hours  area and personal samples.	69.7-208 (5)	90.0	121	2
Raw material expansion		79.5-139 (8)	117.0	113	3
Cutting		19-152 (13)	66.0	79	1
Cutting		61 – 164 (4)	118.0	115	2
Cutting		12.6-25.5 (4)	17.1	18.1	3
Expansion/Moulding		35-187 (17)	78.0	96.4	1
Moulding		139-308 (5)	210.0	206	2
Unspecified		56.5-88.2 (4)	70.7	71.5	3
Unspecified		47.5-217 (4)	120.0	127	2
Unspecified		36.8-70.2 (4)	54.0	53.7	3
Storage of blocks for ageing (diluted ventilation)		185-338 (4)	276.0	269	3

**Table 4.7** Exposure to n-pentane in Finnish EPS production plants registered in the Finnish Industrial Hygiene database

Job operation	Sampling site	Sampling time in minutes (range)	Exposure level in mg/m <sup>3</sup> (no of samples)	Mean (mg/m <sup>3</sup> )	Year
Foaming of polystyrene granulates	breathing zone	57 (44-71)	208-643 (3)	371	1986
Cutting of polystyrene sheets	breathing zone	49 (22-66)	<15-190 (5)	73	1986-1995
Cutting of polystyrene sheets	stationary	47	102 (1)	102	1995
Hopper	exhaust air	50	250 (1)	250	1986
Grinding and packaging	breathing zone	56 (29-70)	<15-60 (3)	30	1987-1988
Machinist	breathing zone	47 (30-63)	(<15-63 (2)	<39	1987-1988
Cleaning	breathing zone	71	99-111 (2)	105	1988
Packaging	breathing zone	67 (62-71)	96-185 (2)	141	1988
Near molds	breathing zone	58(46-69)	60-126 (2)	93	1988
Element production	breathing zone	71	4 (1)	4	1989
Sawing	breathing zone	58 (37-73)	33-161 (5)	86	1988-1990
Sawing	stationary	39 (32-45)	39-90 (2)	65	1990
Between splitting machines	stationary	110	(1)	70	1989
Foaming hall	stationary	54 (45-60)	60-206 (3)	149	1990-1995
Foaming	breathing zone	49 (37-60)	36-57 (2)	46	1995

Method: sorbent tube (char coal), gas chromatography (Finnish Institute of Occupational Health, 2001)

**Table 4.8** Measured air concentrations of n-pentane (personal samples) in packaging EPS at a polystyrene production plant in Finland (2001)

Job operation	Exposure level in mg/m <sup>3</sup>		Sampling time given in hours (median)	Comments
	Range (no of samples)	Median		
EPS-operator	5.1-47.8 (6)	16.7	7.3-7.6 (7.5)	the measurements were taken in the period 1985-1999
Packing-operator	179.4 (1)	-	1.2 h	
EPS-operator	<3-3 (3)	3	6.5-7.4 h (7.2 h)	
EPS-operator	<3-23.9 (6)	15	0.1-0.7 h (0.4 h)	
Packing-operator	23.9-83.7 (4)	53.8	0.6-1.6 h (1.5 h)	
Packing-operator	32.9 (1)	-	1.2 h	

All the samples were collected with portable pumps to charcoal tubes (100/50 mg) and analysed by gas chromatography with FID detector

**Table 4.9** Exposure to n-pentane in EPS manufacturing plants in Europe

Job operation	Method	Exposure in mg/m <sup>3</sup> (no of samples)	Median mg/m <sup>3</sup>	Mean mg/m <sup>3</sup>	Sampling time	Reference
Unspecified <sup>1)</sup>	–	47-173 (4)	71	90		Nat. Inst. of Occ. Health, Sweden (1996)
Cutting	–	10-100	–	–		Bundesanstalt für Arbeitsschutz (1996)
Miscellaneous	3M gas diffusion badges type 3,500	1-40 (5)	10	13.2	8 hours	Exxon Chemical Europe Inc. (1996)

**Table 4.10** Measured air concentrations of n-pentane (stationary samples) in packaging EPS at a polystyrene production plant in Finland (2001)

Job operation	Exposure level in mg/m <sup>3</sup>		Sampling time given in hours (median)	Comments
	Range (no of samples)	Median		
Not given	41.9-870 (4)	74.8	1.2 h (1.2)	Plant 1 the measurements are taken in the period 1985-1999
Not given	9-508 (12)	38.9	0.5-1.6 h (0.9 h)	
Not given	<3-38.9 (5)	17.9	1.3 h (1.3 h)	

All the samples were collected with portable pumps to charcoal tubes (100/50 mg) and analysed by gas chromatography with FID detector

### *Inhalation exposure*

The highest exposure level with a mean concentration of 269 mg/m<sup>3</sup> (**Table 4.6**) is detected in the area of the storage of blocks for ageing. The measured data in **Tables 4.6 to 4.9** are regarded as representative for all types of plants. The value of 338 mg/m<sup>3</sup> (**Table 4.6**) is carried forward to the risk characterisation as a reasonable worst-case value, the typical value is set to 269 mg/m<sup>3</sup> (see **Table 4.6**), while 643 mg/m<sup>3</sup> (**Table 4.7**) is considered as a short time value.

### *Dermal exposure*

A description of the process is given in Section 2.2.1, that states that only residues of n-pentane are left in the moulded EPS. Dermal exposure to pentane is therefore considered to be insignificant.

### Scenario 2 C: Production of rigid polyurethane foams

n-Pentane is one of the blowing agents used in the production of polyurethane foams. Monitoring data on n-pentane in polyurethane production have been available from one plant (SGS EcoCare b.v, 1992), where the pentane was measured at different sites of the production line and analyzed by flame-ionisation (direct reading). The exposure levels were in the range 13-393 mg/m<sup>3</sup>. The highest concentration (393 mg/m<sup>3</sup>) was measured in a ventilation duct at the polyurethane foam production unit and is therefore not relevant for the exposure of workers. In the report it is concluded that the emission of n-pentane is of no concern when the ventilation system is placed in the right position. The plant was a research plant and it is difficult to determine if the exposure level is typical for polyurethane plants in general.

In addition, the Finnish Industrial Hygiene database contains measured data from this scenario (Institute of Occupational Health, 2001). The measurements are given in **Table 4.11**. There was no information on the method used.

**Table 4.11** Exposure to n-pentane during production of polyurethane, registered in the Finnish Industrial Hygiene database (Finnish Institute of Occupational Health, 2001)

Job operation	Sampling site	Sampling time in minutes (range)	Exposure level in mg/m <sup>3</sup> (no of samples)	Mean exposure (mg/m <sup>3</sup> )	Year
Unknown	stationary	25	1.8 (1)	1.8	1990
Casting	breathing zone	43 (23-60)	9-24 (4)	18	1997
Casting	stationary	42 (24-60)	6-24 (2)	15	1997
Filling of pots	breathing zone	17 (16-18)	33-42 (2)	38	1997
Filling of pots	stationary	17 (16-18)	3-18 (2)	11	1997

Mixtures of pentane and e.g. polyol and isocyanate are flammable. To minimise the risk, BASF has recommended that the pentane be added from a reservoir via a pipe directly to the mixing head (Technical information from BASF). The pentane is transported by means of an explosion-proof high-pressure pump. This also minimises the pentane-contamination of the working atmosphere.

#### *Inhalation exposure*

Assuming that n-pentane exists in a matrix and that there is local exhaust ventilation, EASE predicts an exposure of 30-150 mg/m<sup>3</sup> (10-50 ppm). This corresponds well with the measurements reported in **Table 4.11**.

#### Scenario 2 D: Miscellaneous applications

##### *Manufacturing of aerosol-containers*

Due to the flammability of n-pentane, the filling of aerosol boxes are generally carried out automatically at dedicated places without workers present (CEFIC, 1997). Exposure to n-pentane in manufacturing of aerosol boxes is therefore negligible.

There are no actual data available for n-pentane related to the manufacturing of aerosol. EASE provides therefore the best basis upon which to predict exposure. In a document on human exposure to n-pentane, provided by Exxon Chemical Europe (1997), exposure was estimated by EASE. For the manufacture of aerosols in a contained system with no significant leaks, an 8-hour exposure in the range of 0-0.3 mg/m<sup>3</sup> (0-0.1 ppm) was estimated. When leaks occur in the manufacture, i.e. non-dispersive use but segregation of the affected article, EASE predicted exposures in the range of 598-1,495 mg/m<sup>3</sup> (200-500 ppm).

Assuming that the manufacturing of aerosol is done in a closed system, LEV, non-dispersive use, and a processing temperature of 25°C, the estimation by EASE gives an air concentration of 0-0.3 mg/m<sup>3</sup>.



### *Manufacture of ink*

In the printing industry it is mainly the offset printing that uses n-pentane. Ink manufacture consists basically of three stages: mixing and blending of ingredients (ink, resin and solvent) in large open containers, reduction of the particle size in a dispersing unit, and packing of the finished ink in suitable containers. The final step sometimes includes further dilution with the solvent. Pentane in the air arises from solvents which are used. In a study on solvent exposure of workers during printing ink manufacture (Winchester, 1985), which covered 27 workers in five plants manufacturing liquid or flexographic inks, mean exposure levels of  $< 3 \text{ mg/m}^3$  n-pentane (range  $< 3\text{--}3 \text{ mg/m}^3$ ) was reported. The measurements were done on 3 workers and were both personal (Casella SP-15 personal sampling pumps with charcoal pumps or 3M passive samplers) and stationary (Foxboro Century OVA-128 organic vapour analyser), and analysed by gas chromatography. Personal samples were mostly taken for a full working day of 7-8 hours.

### Dermal exposure for Scenario 2

The work operations described for industrial use of products containing n-pentane is done in closed systems and therefore dermal exposure is considered to be negligible. On the other hand, maintenance and cleaning of the equipment may represent skin-contact with n-pentane. Given the parameters direct handling and incidental contact, an EASE-value of  $0\text{--}0.1 \text{ mg/cm}^2/\text{day}$  is estimated. Assuming exposure of both hands, corresponding to an exposed area of  $840 \text{ cm}^2$ , this results in a dermal exposure of  $0\text{--}84 \text{ mg/day}$ .

### Conclusion for Scenario 2

During the industrial use of products containing n-pentane, inhalation exposure may occur during the scenarios described above. The highest inhalation exposure occurs during manufacturing of EPS. Reasonable worst case is estimated to be  $338 \text{ mg/m}^3$ , while a typical value is estimated to be  $269 \text{ mg/m}^3$ .

The highest estimated value for dermal exposure was  $84 \text{ mg/person/day}$  was found for maintenance and cleaning of equipment. These values are taken forward to the risk characterisation (see **Table 4.15**).

#### **4.1.1.2.3 Scenario 3: Professional end-use of products containing n-pentane**

According to the European Aerosol Federation the use in aerosols is mainly in consumer products such as hairsprays, antiperspirants, spray-paints, and car care products (European Aerosol Federation, 1996). Further it was informed that the use of solvent in aerosols in Europe would not exceed 5,000 to 10,000 tonnes as a maximum.

No measurements of occupational exposure to n-pentane from the use of the aerosols have been available. Empirical calculations have been carried out for Scenario 3 A.

### Scenario 3 A: Hair salons

Measured data of n-pentane in hair salons have not been available. Based on data (**Table 4.12**) provided by Exxon Chemical Europe (1996), an empirical calculation of exposure to professional hairdressers in hair salons has been performed.

**Table 4.12** Parameters used in the calculation of exposure to n-pentane in hair salons (Exxon Chemical Europe, 1996)

Parameter	Value	Comment
Room size	50 m <sup>3</sup>	small EU salon
Air change	3 air changes per hour	low end of typical range for natural ventilation
Amount of aerosol used	1.15 g/sec	
Weight fraction of n-pentane	40%	upper end of range
Typical duration of spraying	3 seconds	
Number of customs/day	60	
Percentage requiring hairspray (%)	50	

$1.15 \text{ g/sec} \cdot 1,000 \text{ mg/g} \cdot 0.4 \text{ (fraction pentane)} \cdot 3 \text{ sec (duration of spraying)} \cdot (60 \cdot 0.5) \text{ number of customers} = 41,400 \text{ mg n-pentane}$

Assuming uniform distribution in the air passing through the salon during a day ( $50 \cdot 3 \text{ m}^3/\text{h} \cdot 8 \text{ h}$ ), the emitted pentane corresponds to 8-hour TWA of  $35 \text{ mg/m}^3$ .

The exposure to n-pentane has also been estimated by the use of the EASE-model. The parameters process-temperature  $25^\circ\text{C}$ , vapour pressure  $46.38 \text{ kPa}/15^\circ\text{C}$ , formation of aerosols, uncontrolled direct handling and wide dispersive use, gives an estimated exposure of  $1,000 \text{ ppm}$  ( $3,000 \text{ mg/m}^3$ ). Direct handling with dilution ventilation and wide dispersive use gives an exposure of  $500\text{--}1,000 \text{ ppm}$  ( $1,500\text{--}3,000 \text{ mg/m}^3$ ). Consequently there is a great discrepancy between the exposure estimated from the EASE model and the empirical calculations.

A Dutch study showed daily ethanol consumption in aerosols in hairdressing salons of  $80\text{--}130 \text{ g}$  (van Muiswinkel, 1997). The study showed exposures to ethanol in the range  $6.5\text{--}17.5 \text{ mg/m}^3$ .

A study of Hartop et al. (1991) assessed the exposure arising from the use of dimethylether (DME) and liquefied petroleum gas (LPG), containing 11% propane, 29% isobutane and 60% n-butane. Measurements were made in an unventilated room of approximately  $3.3 \cdot 2.7 \cdot 2.4$ , total volume approximately  $21 \text{ m}^3$ . The hairspray was sprayed for 10 seconds every 15 minutes for 2 hours in a room with the door left open. The results were extrapolated to obtain representative exposure values for an 8-hour working day. The authors estimated that the exposure for the two hairsprays over an 8-hour period gave the stylist an exposure level of  $55 \text{ ppm DME}$  ( $\sim 104 \text{ mg/m}^3$ ) and  $88 \text{ ppm LPG}$  ( $198 \text{ mg/m}^3$ ), respectively. Both DME, propane, butane and isobutane has lower boiling points than n-pentane, and this estimate can therefore be considered as a worst case for the exposure of n-pentane in hair salons. On the basis of these considerations it is reasonable to believe that the exposures to n-pentane estimated by the above empirical calculations are more realistic than the EASE estimates.

### *Inhalation exposure*

This value calculated by the empirical calculation is taken as a typical value. The value of  $198 \text{ mg/m}^3$  reported for LPG described above (Hartop et al., 1991), is taken as a reasonable worst-case value.

### *Dermal exposure*

As the boiling point of n-pentane is lower than the body temperature, it is considered that settlement of aerosol on the skin is insignificant.

### Scenario 3B: Professional use of car-care products

Other aerosol products are car care products. In the Norwegian Product register we found several n-pentane containing car-care products for use in professional garages. The weight % of n-pentane in the different products varies greatly:

Greasing	(9-35%)
Degreasing	(5-50%)
Coolants	(13-83%)
Cleansing agents	(15%)
Car-wax	(13%)
Anti-rust treatments	(13%)
Cleaning-agents	(2-5%)

These products come mainly in spray boxes of 500 ml. According to information from the professional garages and distributors these products is sporadically used in the workshop, from 0 to 5-10 times per worker/day for very short periods, usually not more than about one second each time, depending on the type of car-service. Furthermore, the aerosolboxes contains different propellants.

**Table 4.13** Parameters used in the calculation of exposure to n-pentane in workshops

Parameter	Value	Comment
Room size	300 m <sup>3</sup>	10 · 10 · 3 m <sup>3</sup>
Air change	3 air changes per hour	low end of typical range for natural ventilation
Amount of aerosol used	1.15 g/sec	
Typical duration of spraying	1 second	
Number of sprayings per mechanics/day	10	
Number of mechanics	10	

**Table 4.13** gives the parameters used in an empirical calculation of the exposure to n-pentane for mechanics in workshops. Assuming an aerosol-use of 1.15 g/sec, with a duration of every spray of 1 second and that ten mechanics are spraying ten times a day, a total aerosol-use of 115,000 mg/dag (10 · 10 · 1,150 · 1 mg/day) is calculated.

Assuming a room size of 300 m<sup>3</sup> and uniform distribution in the air passing through the workshop during a day (300 · 3 m<sup>3</sup>/h · 8h), the emitted pentane corresponds to an 8 hour TWA of 16 mg/m<sup>3</sup>.

Seen in relation to the hairspray calculation the number of car-customers is less pr. day and the room size is much bigger. The number of cars needing a spray of greasing, degreasing, wax or cleaning-agents per day is less than 30 which is the number of customers used for the hairspray calculation. The n-pentane exposure for the worker using car care products is therefore considered to be smaller than for workers in the hair salons, e.g. less than 198 mg/m<sup>3</sup>.

### Scenario 3 C: Miscellaneous applications

Exposure to n-pentane in different other occupational settings have been compiled and is presented in **Table 4.14**. This is just to demonstrate the exposure level of n-pentane in different working atmospheres. According to the rubber-, pharmaceutical-, glue- and plastic-industry in Norway the use of n-pentane is limited and only small volumes of n-pentane are used. As written in Section 2.4.6 it is not considered to perform a separate risk assessment for these use areas.

Regarding n-pentane use in the tyre industry in Europe, it seems that there has been some use of wide boiling range hydrocarbon solvents containing n-pentane 25 to 20 years ago. **Table 4.14** shows the air concentrations of n-pentane from 10 large manufacturing plants in the US. The exposure was found to vary within a plant depending on the task and process performed. The result for the highest exposed worker group, i.e. workers who were preparing the batch lots of rubber ingredients for subsequent mixing, are included in **Table 4.14**. However, it is reported that no use of such light products containing n-pentane occurs in Europe and has not occurred for the past 10 years or more (Exxon Chemical Europe, 1997).

Pure n-pentane is also used as a solvent in chemical laboratories. According to the largest pharmaceutical laboratory in Norway only small volumes of n-pentane are used in these applications (less than 1 litre per year) and the use is assumed to be incidentally. National Institute of Occupational Hygiene in Norway has registered some measurements that have been done in a research-/development laboratory in Norway (**Table 4.14**). The measurements ( $n = 16$ ) have a mean of  $1.8 \text{ mg/m}^3$  (0.61 ppm) with the range being  $< 0.03\text{--}14.7 \text{ mg/m}^3$  ( $< 0.01\text{--}4.93$  ppm).

It has been reported that there is a potential exposure from the use of inks in the printing industry and glues. A report from the Norwegian tradeorganisations for the graphical industry, gives the results from an assessment done on chemicals used in this trade. n-Pentane is not an ingredient in any of the products used, including ink. Furthermore, n-pentane is also used as a binding agent in glues. In a report on n-pentane from the Norwegian Product Register (1999) only one product was found. The product had a content of 1 weight% n-pentane. We have received two measurements done during gluing of glass doors, showing an exposure of 6 and 3  $\text{mg/m}^3$  n-pentane (2 and 1 ppm). The data were registered in the Finish Industrial Hygiene database in 1992 and was measured in the workers breathing zone for 58 and 51 minutes, respectively (see **Table 4.14**). The composition of the glue was not known. The value was measured as a worst-case value. We therefore expect the use of n-pentane in such products to be limited and the eventually exposure to be low. Therefore, as written in Section 2.2.6 it is not considered to perform a separate risk assessment for these use areas.

**Table 4.14** Air concentration of n-pentane in various applications

Job operation	Method	Exposure level in mg/m <sup>3</sup> (no of samples)	Median mg/m <sup>3</sup>	Mean mg/m <sup>3</sup>	References
Tyre-/ tube manufacture	area samples char coal gas chromatography	2.7-183 (103)	–	36.2	Van Ert (1980)
Gluing	sorbent tube (char coal) gas chromatography	3 and 6 (2) sampling time: 58 and 51 minutes, respectively	–	4.5	Finnish Institute of Occupational Health (2001)
Gas works <sup>1)</sup>	area samples char coal gas chromatography	13.9 - 32	–	19.1	Fung (1988)
Manufacture of pharmaceuticals	not known	9 – 48 (4)	26.0	27.0	National Institute of Occupational Health, Sweden
Chemical laboratories	not known	< 0.03-14.7 (16)	Not given	1.8	National Institute of Occupational Health, Norway (EXPO)

1) Since pentane is a component in natural gas, the gas is most likely the source of pentane in the air in gas works

### Conclusion for Scenario 3

During the professional end-use of products containing n-pentane, inhalative exposure may occur during the use of aerosols.

The highest exposure occurs when using hairspray in hair salons. Reasonable worst-case is estimated to be ~198 mg/m<sup>3</sup>, while typical values are estimated to be 35 mg/m<sup>3</sup>. These values are taken forward to the risk characterisation (see **Table 4.15**). No short-term value is available and is also not considered relevant. Dermal exposure is considered negligible because of the low boiling point.

#### 4.1.1.2.4 Summary of occupational exposure

**Table 4.15** Summary of exposure levels for occupational exposure of n-pentane taken forward to the risk characterisation

Workplace operation	Inhalation (mg/m <sup>3</sup> )	Short time value (mg/m <sup>3</sup> )	Dermal (mg/person/day)
Scenario 1: Production of n-pentane	typical value: 66.5 reasonable worst-case: 180	599	420 (E)
Scenario 2: Industrial use of products containing n-pentane	typical value: 269 reasonable worst case: 338	643	84 (E)
Scenario 3: Professional end-use of products containing n-pentane	typical value: 35 reasonable worst case: ~198	not relevant	negligible because of the low boiling point

Abbreviations: E = EASE

### 4.1.1.3 Consumer exposure

It is assumed that the main consumer exposure in the EU to n-pentane is from the use of aerosol products. This exposure covers a range of products, but it is assumed that the most important consumer exposure is connected with the use of hairsprays, antiperspirants, paints, and car care products (European Aerosol Federation, 1996). The major exposure determinants are the “spray time” and the dynamics of the environment in which the product is used.

The Product Registers in the various countries are different with respect to the requirements for the reporting of products. Consequently the number and types of products containing n-pentane that are registered, as well as the quantities, will vary. For example cosmetics (i.e. hairspray) are not included in the Product Registers in Norway, Sweden and Finland.

Information from the Swedish Product Register (1995) showed that n-pentane was found in 110 products, 14 of which were available to consumers. The n-pentane concentration in 3 of the Swedish consumer products was  $0 < C \leq 10\%$ , in 5 of the Swedish consumer products  $10 < C \leq 20\%$ , and in 6 of the Swedish consumer products  $20 < C \leq 80\%$ .

According to data from the Swedish Product Register in (1997) 16 products were available to consumers. The product types are listed in **Table 4.16**. It is possible that several of these products are aerosol products, however this is not apparent from the information received.

**Table 4.16** Information from the Swedish Product Register concerning consumer available products that contain n-pentane

Product type/ function	Trade description	Concentration of n-pentane (%)
Fuels	wholesale and retail trade	0,1
Contact agent	industry for electric components and instruments	80
Adhesives/glues	wholesale and retail trade	12
Stain removers	wholesale and retail trade	20
Cleaning agents	wholesale and retail trade	9–40
Lubricants (car care)	wholesale and retail trade	10–58
Solvents	industry for office machinery and computers, electric components and instruments	90
Rust preventives	wholesale and retail trade	18
Car care products	wholesale and retail trade	4–48

Information from the Finnish Product Register (1997) showed that n-pentane was found in 45 products grouped into 8 different product types / functions; “solvent” (100% n-pentane), “lubricant” (18-35% n-pentane), “anti seize spray” (37% n-pentane), “burnishing agent” (< 5% n-pentane), “start aid”(engines) (30-50% n-pentane), “brake degreasing” (10-30% n-pentane), “glue” (5-15% n-pentane) and “unknown”. No information on the consumer exposure to the different product types was available.

In Germany n-pentane is used in the following consumer products; “stain removers”, “disinfectants”, “cosmetics”, “brake-cleaning products” and “start aid sprays”. In Norway n-pentane is found in 8 products (Norwegian Product Register, 1996), one of which is available to consumers (i.e. car care products).

#### 4.1.1.3.1 Aerosols

##### Hair spray

Hair spray probably counts for 50% of total consumer use of aerosols, where the weight fraction of n-pentane is 40%. The highest consumer exposure to n-pentane is therefore assumed to result from the normal use of hair spray in a confined space, e.g. poorly ventilated toilet. A consumer exposure estimate for n-pentane in aerosols in hair sprays has been made according to the TGD. Furthermore, an empirical estimate and a worst-case exposure scenario have been performed (Hartop et al., 1991).

##### *TGD Estimate*

Weight of product used per event	= 10 g (TGD default)
Weight fraction of n-pentane	= 40% (upper end of range)
Inhalation fraction	= 100% (gas)
“Room Volume”	= 1.5 m <sup>3</sup> (immediate volume of air surrounding head)
Volume air inhaled	= 0.8 m <sup>3</sup> /hour (TGD default)
Exposure time	= 6 min (0.1 hour)
Body-weight	= 55 kg (standard default, female)
Exposures/day	= 2

$$\text{Inhaled dose} = \frac{10,000 \cdot 0.4 \cdot 1}{1.5} \cdot \frac{0.8 \cdot 0.1}{55} \cdot 2 = 7.8 \text{ mg/kg/day}$$

##### *Empirical Estimate*

Room size	= 3.3 m <sup>3</sup> (2.3 · 1.1 · 1.3: typical EU dimension)
Size of aerosol	= 240 g (300 ml · 0.8 mg/l density, equivalent to a 400 ml container)
Amount aerosol used	= 1.15 g/second (derived from data in ECETOC Report No. 58)
Typical duration for use	= 4 seconds (estimate)
Weight fraction of n-pentane	= 40% (upper end of range)

Assume full mixing in room and, no air change.

Body weight	= 55 kg (standard default, female)
Inhalation rate	= 0.8 m <sup>3</sup> /hour (TGD default) 10 min
Exposures/day	= 2

$$\text{Inhaled dose} = \frac{4 \cdot 1.15 \cdot 1,000 \cdot 0.4}{3.3} \cdot \frac{0.17 \cdot 0.8}{55} \cdot 2 = 2.75 \text{ mg/kg/day}$$

##### *Worst-case exposure*

This would equate to an extended discharge of the aerosol in a small room. Full discharge takes approximately 210 seconds (1.15 g/second for 400 ml container). A worst case of 30 seconds has been taken.

Using the data described under TGD Estimate, but for a single event, then worst-case exposures are predicted to result in (internal) exposures of 10.3 mg/kg/day. This is equivalent to an air

concentration of approximately 1,390 ppm when averaged over the same 10-minute period. Worst-case predictions using the TGD are limited by the fact that no “spray time” is given for the (typical) 10 g weight of product discharged.

#### 4.1.1.3.2 Car care products

There are a large number of car care product formulations, mostly occasionally used, which consist of 5-58% n-pentane. n-Pentane is a constituent of products for starting aid and stain removing (deasphalting). Since most of the car care products are used only occasionally and outdoors, consumer exposure to n-pentane by the use of car care products is assumed not to be of great importance.

#### 4.1.1.4 Humans exposed via the environment

In accordance with the TGD, the indirect exposure of humans to n-pentane via the environment e.g. via food, drinking water, and air, must be determined. Due to the physico-chemical properties of n-pentane, the only important exposure of the general population to n-pentane via the environment is in air. The local predicted environmental concentrations (PEC<sub>local</sub>) in air at production sites 100 m from source, are estimated to range from 0.0048 to 0.140 mg/m<sup>3</sup> (from Section 3.1.4.1, **Table 3.9**). This corresponds to an inhalation dose in humans from 1.37 to 40.0 µg/kg/day [when it is estimated that the volume air inhaled in humans is 20 m<sup>3</sup>/day (TGD value), the human body weight is 70 kg (TGD value), and the exposure time is 24 hours]. The indirect exposure via environmental pathways given in µg/m<sup>3</sup> (see **Table 3.10**) has also been calculated with the EUSES programme for different use patterns and life cycle stages (see **Table 4.17**), and range from 0.174 to  $9.1 \cdot 10^{-5}$  mg/kg/day. In these calculations it is also estimated that the volume air inhaled in humans is 20 m<sup>3</sup>/day (TGD value), the human body weight is 70 kg (TGD value), and the exposure time is 24 hours.

**Table 4.17** Humans exposed via the environment based on air concentrations calculated by EUSES

EUSES use pattern	Life cycle	Step	mg/kg/day
1	production		0.031
2	EPS foaming	formulation	0.05
		processing	0.054
		private use	$5.1 \cdot 10^{-4}$
3	PUR foaming	formulation	0.074
		private use	$1.5 \cdot 10^{-4}$
4	polymer diluent	formulation	0.174
		processing	$1.05 \cdot 10^{-3}$
5	aerosols	private use	$2.9 \cdot 10^{-4}$

Table 4.17 continued overleaf



**Table 4.17 continued** Humans exposed via the environment based on air concentrations calculated by EUSES

EUSES use pattern	Life cycle	Step	mg/kg/day
6	adhesives	formulation	$1.23 \cdot 10^{-4}$
		processing	$4.3 \cdot 10^{-3}$
7	laboratory	processing	$1.02 \cdot 10^{-4}$
8	other uses	formulation	$4.08 \cdot 10^{-4}$
		processing	0.0117
		private use	$9.1 \cdot 10^{-5}$
	regional		$9.1 \cdot 10^{-5}$

## 4.1.2 Effects assessment: Hazard identification and dose (concentration) - response (effect) assessment

### 4.1.2.1 Toxicokinetics, metabolism and distribution

#### 4.1.2.1.1 Studies in animals

##### Studies *in vitro*

n-Pentane was used as a substrate for the monooxygenase system in liver microsomes of control or phenobarbital treated rats (Wistar, strain AF/Han, 100-120g) and rabbits (“Gelbsilver”). 2-Pentanol was the major metabolite (83-89%) formed by rat and rabbit liver microsomes. 3-Pentanol was also detected as a minor metabolite (11-16%), (Frommer et al., 1970). Incubation of liver microsomes from mice (strain: ICR) exposed to saturated n-pentane resulted in the formation of 2-pentanol, 3-pentanol, and 2-pentanone. The same metabolites were found in blood in control rats and phenobarbital pre-treated rats exposed to 5% n-pentane for one hour. The concentrations of 2-pentanol, 3-pentanol, and 2-pentanone in phenobarbital pre-treated rats were 280 mM, 65 mM, and 400 mM, respectively. In control rats the concentrations of 2-pentanol, 3-pentanol, and 2-pentanone in blood were 206 mM, 80 mM, and 300 mM, respectively. It was therefore suggested by the authors that n-pentane was metabolised chiefly by liver microsomes. (Chiba and Oshida, 1991).

The skin penetration rate of n-pentane (purity more than 98%) through excised abdominal skin *in vitro* was studied using rat (SD-JCL, weight 400 to 600 g) (Tsuruta, 1982). The skin of the abdominal region was clipped and then completely depilated. The rat was sacrificed and the abdominal skin, freed of subcutaneous tissue, was stripped with scissors. A glass diffusion cell was prepared to measure the penetration of n-pentane through the excised rat skin. The lower chamber of the cell was filled with a 0.9% NaCl solution. The rat skin area was 2.55 cm<sup>2</sup>. 1 ml n-pentane was added to the upper chamber, and after different applications times (from 2.5 hours to 18.5 hours) the amount of n-pentane that had penetrated the skin into the 0.9% NaCl solution was determined by gas chromatography. Thirty-three experiments were performed with application times of 2.5 to 5.5 hours, whereas 6 experiments were performed with application times of 17.5 to 18.5 hours. The results were as following: For application times of 3-5.5 hours

the amount of n-pentane penetrated was from 5.19–10.4 µg and for application times 17.5–18 hours the amount of n-pentane penetrated was from 82.4–88.9 µg. The skin penetration rate of n-pentane *in vitro* through full thickness rat skin was shown to be 31.14 nmol/hour/cm<sup>2</sup>. This gives an absorption rate of 2.2 µg/hour/m<sup>2</sup>. Compared to other aliphatic hydrocarbons (2-methyl pentane, n-hexane, n-heptane and n-octane) the penetration of n-pentane was considerably higher. The highest amount of solvents penetrated was for n-heptane, 7.37 µg with an application time of 20 hours. A close correlation was observed between the penetration rate of the aliphatic solvents and their solubility in water. The smallest penetration rate was for the solvents having the lowest solubility in water (n-octane) and the greatest for that with the highest solubility in water (n-pentane). This *in vitro* method (penetration of solvents through excised rat skin) has also been used with chlorinated solvents. For these solvents the *in vitro* data correlated well with those obtained from an *in vivo* method.

### Studies *in vivo*

The *in vivo* metabolism of [1.5-<sup>14</sup>C] n-pentane (specific activity, 10 mCi/mmol) was studied in Sprague-Dawley rats (375 g average weight). n-Pentane was injected into a enclosed chamber system containing a rat. The chamber was constructed from plexiglass tubing with an inside diameter of 10 cm. Two experiments with 6 rats in no. I and 4 rats in no. II were performed. An average of 3.44 µCi (approximately 0.34 µmol) of [1.5-<sup>14</sup>C] n-pentane plus 0.1 ml of 10.1 µmol/ml unlabeled n-pentane was injected into the chamber at the beginning of experiments I and II. Chamber air concentrations of n-pentane was measured by GC and obtained 5 minutes before and 5, 10, 15, 20, 30, 45, 60, 90, 120, 150, 180, 210, 240, 300, 360, 420 and 480 minutes after injection of n-pentane into the chamber. In experiment I radioactivity was measured in whole blood and various tissues (liver, kidney, lung, testes, brain, muscle, heart, small and large intestine, spleen and fat) at the end of the 8 hours experiment. In experiment II urine samples were collected and the total volume was measured and the radioactivity determined. At the end of the exposure period (8 hours) approximately 4.7% of the total unlabeled n-pentane injected into the chamber at time zero remained in the chamber system. Approximately 50% of the total radioactivity added to the chamber as [<sup>14</sup>C] n-pentane was recovered as carbon dioxide in both experiments at the end of 8 hours in a CO<sub>2</sub> trap. Tissue samples from the various organs were obtained at the end of the 8 hours experiment (I), and the total radioactivity nCi/g of wet tissue was determined. Liver, small intestine and kidney contained the highest radioactivity per gram of wet tissue, 9.11, 8.81 and 7.11 nCi/g wet tissue, respectively. Muscle and liver accounted for the largest proportion of the estimated total recovery of radioactivity in tissue, expressed as a percentage of the total radioactivity injected into the chamber, 6.98 and 3.37%, respectively. Total <sup>14</sup>C activity recovered in wet tissue was 14.92%, however, the total recovery of radioactivity from tissues cannot be assured due to the volatility of n-pentane. The recovery of <sup>14</sup>C activity in blood was 2.1%. In experiment II the recovery of <sup>14</sup>C activity in urine presented as % of total activity injected was 7.6%. If recovery values of experiment I and II were combined, the proportion of total <sup>14</sup>C activity added to the chamber that is accounted for in the chamber air, CO<sub>2</sub> trap, urine, tissue and blood is estimated to be approximately 78.9%. The recovery of approximately 50% of the total <sup>14</sup>C activity given as [<sup>14</sup>C] n-pentane in the CO<sub>2</sub> trap, presumably as <sup>14</sup>CO<sub>2</sub> at the end of the 8 hours experiment period indicates that n-pentane is metabolised *in vivo*. The major product of n-pentane metabolism appears to be CO<sub>2</sub> however, there was also a small proportion of radioactivity present in urine, indicating that n-pentane may be excreted in other forms than CO<sub>2</sub>. No analysis of the metabolites in urine was performed (Daugerty et al., 1988).

A gas-uptake study has been performed in male rats. Wistar rats of different weights were exposed by inhalation to air concentrations of n-pentane ranging from 2,990 to 14,950 mg/m<sup>3</sup> n-pentane (1,000 to 5,000 ppm) in a 6.4 l desicator jar chamber. Kinetic parameters were determined based on the two compartment open pharmacokinetic model (Filser and Bolt, 1983). n-Pentane concentrations in the gas phase were determined by gas chromatography. The study by Filser et al. (1983) indicated that a “first order” of metabolic elimination of n-pentane was observed below 100 ppm in the atmosphere. Concentrations higher than 100 ppm n-pentane displayed saturation kinetics. This can formally be explained by a competitive action of two distinct enzymes of different  $K_m$  and  $V_{max}$  as introduced by Anderson (1981 a;b). A rapid elimination of n-pentane was reported with a elimination half-life of approximately 0.13 hour (Filser et al., 1983).

#### 4.1.2.1.2 Studies in humans

The tissue/air and blood/air partition coefficients have been determined in several human tissues (lung, kidney, heart, brain, liver, muscle and fat) and in human blood. The tissues were collected from two men (30 and 40 years) who had died suddenly from heart attack. The death was not due to n-pentane exposure. Stored human blood was obtained from a hospital blood bank. The solubility of n-pentane (20 to 40 µg/ml of tissue) in blood and homogenised tissue was determined by gas chromatography according to the method described by Sato and Nakajima (1979). The blood/air partition coefficient was 0.38; selected tissue/air partition coefficients were: liver 2.1, kidney 0.6, brain 2.2, fat 39.6, muscle 0.7, heart 0.2 and lung 0.5 (Perbellini et al., 1985).

#### 4.1.2.1.3 Summary of toxico-kinetics, metabolism and distribution

Oxidation *in vitro* of n-pentane to the alcohols 2-pentanol (83-89%) and 3-pentanol (11-16%) in the rat was observed to be the major pathway of n-pentane metabolism, and it was suggested that n-pentane was chiefly metabolised by microsomes. The skin penetration rate of n-pentane *in vitro* through excised abdominal full-thickness rat skin was shown to be 31.14 nmol/hour/cm<sup>2</sup>. Compared to other aliphatic hydrocarbons (n-hexane, n-heptane, and n-octane) the skin penetration of n-pentane was considerably higher. A gas uptake study in rats indicated “a first order” of metabolic elimination below 100 ppm in the atmosphere. Concentrations higher than 100 ppm displayed saturation kinetics. An *in vivo* metabolism study in rats, where n-pentane was injected into a closed chamber system, showed that the major products of n-pentane metabolism appears to be CO<sub>2</sub> (approx. 50% of total radioactivity, [<sup>14</sup>C] n-pentane, added to the chamber), which indicate that n-pentane is metabolised *in vivo*. The total radioactivity in wet tissues were approx. 15% and in urine 7.6%. In humans, the tissue/air and blood/air partition coefficients were determined for several tissues. The highest tissue/air coefficient was measured in fat (39.6) and the lowest in heart (0.2). This is in accordance with n-pentane’s log  $P_{ow}$  > 3. Considering the rapid metabolism and excretion of n-pentane, tissue accumulation is considered to be low. In the risk characterisation 100% absorption is used for inhalative and dermal exposure to n-pentane.

#### 4.1.2.2 Acute toxicity

##### 4.1.2.2.1 Studies in animals

###### Oral

An acute toxicity study by oral intubation of n-pentane (MRD-96-575, purity: 100%) revealed a  $LD_{50} > 2,000$  mg/kg (limit test). n-Pentane was administered as a single oral dose at a dose level of 2,000 mg/kg to 5 male (206-221 g) and 5 female (206-213 g) Crl:CDBR rats. Clinical observations were made 1, 2, 4, and 6 hr after dose administration and once daily for 14 days. A gross necropsy that included an examination of the external surface of the body, all orifices, the cranial, thoracic, and abdominal cavities and their contents, was performed on all animals. No histopathology was performed. In this study oral intubation of n-pentane at a dose level of 2,000 mg/kg did not produce treatment-related mortality or consistent signs of systemic toxicity. This study was performed according to EC Annex VB1 and under GLP conditions (Exxon Biomedical Sciences, Inc., Project no: 157502, 1996).

Based on a kinematic viscosity of  $3.58 \cdot 10^{-7}$  m<sup>2</sup>/s ingestion of n-pentane may cause lung damage due to aspiration.

###### Dermal

No studies on acute toxicity of n-pentane following dermal administration were located.

###### Inhalation

The LC<sub>50</sub> value after 2 hours exposure to n-pentane was reported to be approximately 295 mg/l (98,662 ppm or 295,000 mg/m<sup>3</sup>) in mice (Stoughton and Lamson, 1936). In this study, groups of 5 mice (strain, sex, housing and feeding conditions, methods for determining air concentrations were not specified) were exposed to an atmosphere reported to contain 4.2 millimoles/l (303.03 mg/l, 101,348 ppm), 4.5 millimoles/l (324.68 mg/l, 108,589 ppm), or 4.9 millimoles/l (353.54 mg/l, 118,239 ppm) in a closed system (20-litre bottle in which was suspended a bag of soda lime). Lethality was determined by noting the percentage of animals that died after 2 hours exposure. No control group was reported. The observation period was 48 hours. No necropsy was performed. This study also included experiments where the time taken to produce “light anaesthesia” was determined by placing two mice in a closed atmosphere in a 2-litre bottle filled with a known concentration of n-pentane, and rotating the bottle mechanically at fourteen revolutions per minute. The endpoint used was the time taken to produce that degree of anaesthesia in which the mouse was unable to obtain an upright position. A concentration of 3.0 millimoles/l (216.45 mg/l, 72,391 ppm) resulted in light anaesthesia after 10 minutes, whereas 4.2 millimoles/l (303.03 mg/l, 101,348 ppm) gave the same effect after 1.3 minutes. This study is not in accordance with the EC Annex VB 2 test for determining acute toxicity by inhalation.

In a 5-day whole body inhalation rangefinding study in Crl:CDBR rats exposed to n-pentane at 5,000 - 10,000 and 20,000 mg/m<sup>3</sup> (1,665 - 3,330 and 6,660 ppm) no adverse effects with respect to clinical signs, including mortality and obvious toxic signs during the first and last hours of exposure, body weight gain, or post-mortem findings were observed. The inhalation LC<sub>50</sub> from this study exceeded 20,000 mg/m<sup>3</sup> (6,660 ppm). In this study three groups of five males (245 to 275 g) and five female (204 to 236 g) rats were exposed whole-body for six hours per day for

five consecutive days to vapour atmospheres of n-pentane. The mean analytical exposure concentrations were 5,446 - 10,680 and 21,418 mg/m<sup>3</sup> (1,813 -3,556 and 7,132 ppm) as measured by on-line gas chromatography. An additional group of rats served as the controls and were exposed to air only. Individual clinical observations were recorded before and after each exposure and once daily on non-exposure days. Gross post-mortem examinations were performed on all animals. All rats were free of macroscopic abnormalities at the gross post-mortem examination. The study was performed according to GLP conditions (Exxon Biomedical Sciences Inc., Project no: 157517, 1997).

Exposure to 388,700 mg/m<sup>3</sup> (130,000 ppm) n-pentane (Bp. 30-35°C) resulted in death of mice after 37 min. Death was preceded by loss of reflexes, prostration, especially when the concentration was  $\geq$  299,000 mg/m<sup>3</sup> (100,000 ppm) (Fuhner, 1921). The exposure conditions were similar to those used by Stoughton and Lamson (1936) above. Important information needed to evaluate the study is lacking. This study is not in accordance with the EC Annex VB 2 test for determining acute toxicity by inhalation.

Swann and co-workers (1974) found that light anaesthesia occurred from 96,000 mg/m<sup>3</sup> (32,000 ppm; 5 min exposure) and at 382,720 mg/m<sup>3</sup> (128,000 ppm) a deep anaesthesia was observed in Swiss mice (see study description under Section 4.1.2.3.1, respiratory system). Furthermore, Stoughton and Lamson (1936) reported that 328,900 mg/m<sup>3</sup> (110,000 ppm) n-pentane induced loss of posture in mice within 2 min and deaths in 90% of the mice after 2 hours exposure. Light anaesthesia occurs in mice after a 10-min exposure to 216,450 mg/m<sup>3</sup> (72,391 ppm) n-pentane (Stoughton and Lamson, 1936).

Behavioral effects of n-pentane were studied in two different recent studies in male rats after short-time inhalation exposure. In both studies male WAG/RijCHBR rats (8 rats/group) were exposed to air (control animals), 2,000 mg n-pentane/m<sup>3</sup> (675 ppm), 6,500 mg n-pentane/m<sup>3</sup> (2,200 ppm) or 20,000 mg n-pentane/m<sup>3</sup> (6,800 ppm) 8 hours per day for 3 consecutive days in a modified H 1,000 inhalation chamber. In both studies the rats were tested prior to the exposure to n-pentane. In the first study (1) the effects of n-pentane on motor activity and functional observational measures were evaluated. In the second study (2) the effects of n-pentane on learned performance of a discrete-trial visual discrimination task was evaluated. In study No. 1 the neurobehavioral function was evaluated by using a standardised functional observational battery (FOB), and a motor activity assessment protocol similar to that used in the WHO/IPCS Collaborative study on Neurotoxicity Assessment (Moser and McPhail, 1992; Moser et al., 1997a; 1997b). The FOB included simple tests designed to evaluate gross changes in neurological and behavioral functioning in the rat using measures taken from different functional domains such as: Autonomic function, neuromuscular function, arousal and excitability and sensimotor reactivity. Changes in motor activity were assessed using an automated quantitative microprocessor-based video image analysis system (EthoVision, Noldus Information Technology b.v., The Netherlands, [www.noldus.com](http://www.noldus.com)). The position of the rat was continuously monitored throughout the test session of 30 min. In addition, quantitative measures of locomotor speed and patterns of locomotor activity were also recorded. Observations of all endpoints were performed 6 days prior to the start of exposure, and immediately following the first and third exposure day. Rats were tested in two subgroups on separate days, and each subgroup consisted of 4 rats. Results study No. 1: Exposure to n-pentane did not induce any dose-related effects on FOB or motor activity measures.

In study No. 2 effects of n-pentane on cognitive performance were evaluate using a discrete-trial two-choice visual discrimination task. On days of exposure, rats were tested immediately after the end of the exposure period, and the test session consisted of 100 trials or 60 min. The trials

were separated by an intertrial interval of 10 seconds. A post-exposure test was performed the day after the last exposure day in order to evaluate a possible persistence of the effects. Results study No. 2: Mild and reversible changes in measures of learned performance was reported. At 2,000 mg n-pentane/m<sup>3</sup> (675 ppm) and 6,500 mg n-pentane/m<sup>3</sup> (2,200 ppm) differences in measures of performance speed (significantly larger latencies) were reported during or after 3 consecutive 8-hour exposures, compared to the control group. However, exposure to 20,000 mg n-pentane/m<sup>3</sup> (6,800 ppm) on a group basis did not induce exposure-related neurobehavioral effects. The post-exposure test indicated that there were no effects on n-pentane one day after the end of exposure. In both studies no changes in body weights or remarkable clinical signs between the groups were reported. The study was performed in accordance with the OECD principles of GLP (TNO report No. V98.791, 1999).

In an acute inhalation toxicity study the ability of n-pentane to impair performance and to activate the hypothalamic-pituitary axis, was studied in adult male CD-1 mice (35-40 g). This study reported a 30-min EC<sub>50</sub> of 108,030 mg/m<sup>3</sup> (36,130 ppm). Impaired performance was studied from 100 to 100,000 ppm, and was assessed by studying the responding maintained under a fixed interval 60-second schedule of milk presentation. Concentrations less than 29,900 mg/m<sup>3</sup> (10,000 ppm) n-pentane slightly increased the responding, whereas larger concentrations decreased responding in a concentration related manner with 89,700 and 149,500 mg/m<sup>3</sup> (30,000 and 50,000 ppm) decreasing responding approximately 50% and 100%, respectively. An effect on the hypothalamic-pituitary axis was studied by exposing mice (6 mice per concentration) to n-pentane (100 to 10,000 ppm) for 30 minutes and then immediately sacrificed. Afterwards the ACTH (Adrenocorticotropin) levels in serum were measured. Serum ACTH levels increased in this study after exposure to 14,950 to 29,900 mg/m<sup>3</sup> (5,000 to 10,000 ppm) n-pentane. The increase in ACTH was not dose-related. The ACTH level was the same from 100 to 1,000 ppm (approximately 80% of control), then it increased slowly from 1,000 to 5,000 ppm (approximately 240% of control), and higher from 5,000 to 10,000 ppm (approximately 1,100% of control). The EC<sub>50</sub> values for the other aliphatic alkanes tested were as following: n-hexane 7,051 ppm, n-heptane 3,872 ppm, and n-octane 2,474 ppm compared to the EC<sub>50</sub> value for n-pentane at 36,730 ppm. It was concluded from the study that the potency to disrupt normal behavioural function was directly related to the carbon chain length of the n5–n8 aliphatic alkanes. For n-pentane, responding recovered completely 30 min after exposure (Glowa, 1991).

Acute neurotropic effects of n-pentane were studied in male rats (Wistar, 0.5 to 1 year of age) and female mice (H-strain, 2 to 4 month of age) exposed whole body to n-pentane for 2 hours (mice) or 4 hours (rats), 4 animals per exposure group. Neurotropic effects were measured as inhibition of propagation and maintenance of the electrically evoked seizure discharge. The method used has a high sensitivity since generation, propagation, and maintenance of the seizure discharge require repeated passages through serially connected neurons of reverberating circuits. An original slight change in neuronal excitability is thus effectively amplified. The EC<sub>50</sub> in this study was reported to be 62,790 mg/m<sup>3</sup> (21,000 ppm) for rats and 70,265 mg/m<sup>3</sup> (23,500 ppm) for mice. The gas concentration of n-pentane in the 80-litre glass chamber was measured using gas chromatography (Frantik et al., 1994).

In an acute toxicity study rats were exposed to a mixture of 50% pentane and 50% hexane (no information if it was normal pentane/hexane) (10.4, 50.9, 94.7 mg/m<sup>3</sup>) for 12 hours. Effects were reported on the central nervous system which conveyed to a strongly pronounced change in motor chronaxy of muscles-antagonists, and lesion of higher dendrites of neurones. A correlation between the functional changes and the concentrations of the hydrocarbone mixture was revealed. A decrease in liver glycogen content was observed after exposure to 50.9 and

94.7 mg/m<sup>3</sup> of the hydrocarbon mixture. The neurohistological changes reported in this study may be due to the n-hexane exposure. (Bonashevskaya and Partseff, 1971). No conclusion can be drawn from this study in the risk assessment of n-pentane.

#### Other studies

A LD50 of 446 mg/kg bw was found in mice after i.v. injection (Di Paolo, 1978).

#### **4.1.2.2.2 Studies in humans**

No human studies are available concerning acute effects of pure n-pentane. The lack of data reflects that industrial exposure to individual members of the family of saturated aliphatic hydrocarbons are rare. Standard textbooks refer to, e.g. the range from pentane to octane (Hamilton and Hardy, 1974) or even to solvents in general (Andrews and Snyder in Casarett and Doull, 1996) as one group, with similar general acute health effects: irritation of mucous membranes, giddiness, vertigo, headache and narcotic stupor. Massive, acute exposures may lead to CNS depression and death (Hamilton and Hardy, 1974).

In a human study from 1929 (Patty and Yant, 1929) the odour intensity and physiological response indicated as temporary fatigue and/or vertigo, produced by vapours of a mixture of 76.5% n-pentane, 20.8% isopentane, 1.4% hexane and 1.3% butane in air were studied by exposing persons (3 to 6 for each observation) for 10 min to concentrations of vapour ranging from zero to concentrations which produced a strong odour. The results from this study indicate that human exposure to vapours of the mixture (76.5% n-pentane, 20.8% isopentane, 1.4% hexane and 1.3% butane) up to 5,000 ppm for 10 min was without observable effects.

#### **4.1.2.2.3 Summary of acute toxicity**

A recent acute toxicity study by oral intubation of n-pentane in rats revealed a LD50 > 2,000 mg/kg (limit test). At this dose level no treatment-related death or consistent signs of systemic toxicity were observed. The LC50 value of n-pentane after 2 hours exposure was reported to be approximately 295,000 mg/m<sup>3</sup> (98,662 ppm) in mice. The time taken to produce "light anaesthesia" was also investigated in this study, and anaesthetic effects were observed in mice after 1.3 minutes when exposed to 4.2 millimoles/l (303,030 mg/m<sup>3</sup>, 101,348 ppm) air concentrations of n-pentane. Swann and co-workers (1974) found that light anaesthesia occurred from 96,000 mg/m<sup>3</sup> (32,000 ppm; 5 min exposure) and at 382,720 mg/m<sup>3</sup> (128,000 ppm) a deep anaesthesia was observed in Swiss mice. From the 5-day range-finding study in rats the inhalation LC50 exceeded 20,000 mg/m<sup>3</sup> (6,660 ppm). Exposure to 388,700 mg/m<sup>3</sup> (130,000 ppm) n-pentane resulted in death of mice after 37 min. However, this study is old (1921) and important information needed to evaluate the study is lacking. In a recent study performed in accordance with GLP the behavioral effect of n-pentane was studied in rats after short-time inhalation exposure by using a standardised functional observational battery (FOB). In this study no effect of n-pentane on motor activity was reported after exposure up to 20,000 mg n-pentane/m<sup>3</sup> (6,800 ppm) for 8 hours. per day for 3 days. On cognitive behavior a mild and reversible effect of n-pentane was reported after exposure to 2,000 mg n-pentane/m<sup>3</sup> (675 ppm) and 6,500 mg n-pentane/m<sup>3</sup> (2,200 ppm) 8 hr. per day 3 days, however, no effect was reported at 20,000 mg n-pentane/m<sup>3</sup>. The ability of n-pentane to impair performance in mice revealed a 30 min EC50 of 108,030 mg/m<sup>3</sup> (36,130 ppm). Neurotropic effects of n-pentane were observed in rats and mice exposed whole body to 62,790 and 70,265 mg/m<sup>3</sup> (21,000 ppm and 23,500 ppm) n-pentane

respectively. An LD<sub>50</sub> of 446 mg/kg bw was found in mice after i.v. injection. In a study, a mixture of 50% pentane and 50% hexane was reported to have effects on the central nervous system, however, the effects observed in this study may be due to the hexane exposure.

A human study from 1929 indicates that no physiological responses were observed in humans after exposure to 5,000 ppm of a mixture of 76.5% n-pentane, 20.8% isopentane, 1.4% hexane and 1.3% butane for 10 min. However, this study is of little relevance for the evaluation of acute toxic effects observed by inhalation of n-pentane in humans. There is no specific information on acute toxicity from exposure to pure n-pentane in humans. Acute effects are considered similar to that of other saturated aliphatic hydrocarbons of similar length (C3-C8).

#### **4.1.2.2.4 Recommendations**

Based on the values of the kinematic viscosity for n-pentane ( $3.58 \cdot 10^{-7} \text{ m}^2/\text{s}$ ), n-pentane has the potential to cause chemical pneumonia and should be classified with R65.

The saturated vapour concentration of n-pentane is 1,585 mg/l (Browning, 1992). Pentane has caused narcotic effects in mice at a concentration of 96 mg/l and after 5 min exposure (Swann et al., 1974). Thus, the ratio of narcotic effect concentration to the saturated vapour concentration is 0.06 (i.e. less than 0.1 required for classification with R67). Based on these data n-pentane should be classified with R67.

#### **4.1.2.3 Irritation**

##### **4.1.2.3.1 Studies in animals**

###### Skin

New Zealand White rabbits (4 males and 2 females) were dermally exposed to 0.5 ml n-pentane (MRD-89-527, purity: 100%), introduced under a gauze patch and secured with tape (Exxon Biomedical Science, Inc., Project no. 252704, 1990). The patch was loosely held in contact with the skin by means of a semi-occlusive dressing. After approximately 4 hours of exposure, the dressing and gauze patch were removed together with residual test material. Dermal responses were evaluated 45 minutes, 24, 48, and 72 hours following patch removal, and on Day 7. All scoring was made according to the Draize method of scoring. Topical application of n-pentane elicited dermal responses in five animals. Two animals were noted with well-defined erythema (score 2) and three animals were noted with very slight erythema (score 1) at the 45-min observation. At the 24-hour observation, one animal displayed well-defined erythema (score 2) and three animals displayed very slight erythema (score 1). One animal displayed well-defined erythema (score 2) at both the 48 and 72-hour observation (scale erythema: 0 to 4). By study termination, all animals were free of any dermal irritation. One animal was noted with slight oedema (score 2) at the 45 minutes observation and very slight oedema (score 1) at the 24 hours observation (scale oedema: 0 to 4). Based on these findings and according to Annex VB4 the primary irritation index (PI) was calculated to be 0.67 (scale 0-8, where  $> 8$  = severe irritant) and pentane was considered to be a mild skin irritant ( $0 < \text{PI} \leq 2$ ) in rabbits. This test was performed according to OECD Test Guideline 404 and according to GLP.



## Eye

Ocular exposure to a single installation of 0.1ml n-pentane (MRD-96-575, purity; 100%), in 3 New Zealand White rabbits (2.29 to 2.34 kg), where the treated eyes of all animals remained unwashed, caused a transient injury to the conjunctiva, whereas no corneal or iridial responses were observed in any animals. Observations were made at 1, 24, 48, and 72 hours. Ocular irritation was most prominent at the 1-hour observation when using the Draize scores (graded according to Draize standard irritation grading scale; Draize, 1959) (total score maximum 110, including conjunctiva, iris and cornea scores). The total scores for rabbit 1, 2, and 3 after 1 hour were 4, 4, and 10, respectively. The total scores after 24 hours for rabbit 1, 2, and 3 were 2, 2, and 4, respectively, and the total scores after 48 hours for rabbit 1, 2, and 3 were 0, 0, and 2, respectively. After 72 hours the total scores were 0 for all three rabbits. Therefore, all signs of ocular irritation were cleared in all animals after the 72-hour observations period. The study was performed according to EC Annex VB5 guidelines and under GLP conditions. (Exxon Biomedical Sciences, Inc., Project no. 157513, 1996).

## Respiratory tract

Swann and co-workers (1974) studied the respiratory irritating properties of n-pentane (99% pure) in male Swiss mice (25 g). Four animals were exposed at each concentration of n-pentane (2,990; 5,980; 11,960; 23,920; 47,840; 95,680; 191,360; 382,720 mg/m<sup>3</sup> or 1,000; 2,000; 4,000; 8,000; 16,000; 32,000; 64,000 and 128,000 ppm). The exposure time was 5 min, and the respiratory rate, depth, and configuration were counted and recorded for 15-second intervals while the animals were inhaling n-pentane with their heads in a “head-only” apparatus using a one-litre exposure chamber (Alarie, 1966). Concentrations up to 47,840 mg/m<sup>3</sup> (16,000 ppm) produced no irritation or anaesthesia. At 95,680 mg/m<sup>3</sup> (32,000 ppm) periodic body movements during exposure indicated irritation. Some slight anaesthesia occurred during the recovery period. At 191,360 mg/m<sup>3</sup> (64,000 ppm) there was considerably more body movement during exposure than at 95,680 mg/m<sup>3</sup> (32,000 ppm), and these animals did not go into anaesthesia until the recovery period. At 382,720 mg/m<sup>3</sup> (128,000 ppm) a deep anaesthesia was observed. At this exposure level one mouse out of 4 showed considerably irritation during the first minute, followed by deep expirations with a pause, and then a short expiration. This was then followed by an increasing inspiratory effort then a decreasing expiratory effort. A progressive return of expiratory effort was seen during the recovery period. Respiratory rate greatly increased during the first minute of exposure in all mice. One mouse had a steady decrease in respiratory rate during the exposure period (5 min) 387,720 mg/m<sup>3</sup> n-pentane (128,000 ppm) until respiratory arrest occurred at approximately 4.75 min. The other three mice had increases and decreases in respiratory rate during the exposure, but no respiratory arrest. This study substantiates what was seen by Gerarde (1960), that vapours of the volatile hydrocarbons n-pentane to octane are mildly irritating to the mucous membranes, the irritating increasing in intensity with length of the carbon chain. Whether the irritation was directly on the CNS or directly on the upper airways was not established in the study by Swann et al. (1974).

### **4.1.2.3.2 Studies in humans**

Five volunteers were exposed to n-pentane vapours (forearm 1 hour and thigh 5 hours). Erythema, hyperaemia, swelling, and pigmentation were observed after 5 hours of exposure (Oettel, 1936).

One test showed no skin irritation (Hill Top Research, 1991). In this study 15 humans received an application of 0.2 ml n-pentane under semi-occlusive conditions. The sample remained in contact with the skin for 24 hours. Dermal responses were evaluated 30 minutes and 24 hours after patch removal. In this study n-pentane was considered to be a non-irritant to human skin. (The study was performed according to GLP).

#### **4.1.2.3.3 Human experience**

No information is available on n-pentane specifically, however, for solvents in general, it is well known from clinical experience in humans that they have a defatting action on the skin, which after repeated exposure may cause skin dryness and accompanying symptoms like itching, tingling and burning. Continued exposure may lead to development of irritant contact dermatitis. Skin lipids play an important role in the barrier function of the skin, and agents, which cause changes in the skin lipid content, and structure may damage this barrier. The damage may not only lead to impaired ability to maintain the epidermis hydrated but also to an enhanced penetration of toxic substances. Data indicate that a small structural change of the skin lipids may result in a multiple increase in the penetration. Thus, substances and preparations which have skin defatting properties may not only cause local skin reactions but may cause an enhancement in the penetration and uptake of toxic substances. However, the boiling point of n-pentane is lower (36°C) than the body temperature and will evaporate, and thus the skin contact will be of short duration.

Based on the available clinical experience in man, n-pentane should be classified with R 66; repeated exposure may cause skin dryness or cracking.

#### **4.1.2.3.4 Summary of irritation**

n-Pentane was reported to be a mild skin irritant according to the Draize method of scoring in White rabbits exposed dermally to 0.5 ml n-pentane. Transient injury to the conjunctiva was observed after ocular exposure to a single installation of 0.1 ml n-pentane, whereas no corneal or iridal responses were observed. There is suggestive evidence that n-pentane is a slight respiratory irritant in mice.

In five humans, n-pentane exposure of the forearm and thigh caused irritation at the exposure site, however this study is old (1936) and is therefore not easy to evaluate. Furthermore, in another study no skin irritation was observed in 15 humans exposed to n-pentane. No studies on the irritating effects of n-pentane on the eye or respiratory tract in humans have been reported.

From clinical experience in man it is well known that solvents in general have a defatting action on the skin, which after repeated exposure may cause skin dryness and flaking. This may cause local skin reactions and enhancement in the penetration and uptake of toxic substances.

#### **4.1.2.4 Corrosivity**

See Section 4.1.2.3.

#### **4.1.2.5 Sensitisation**

##### Skin

In a dermal sensitisation study (Guinea Pig Maximisation Test, GPMT) 20 female guinea pigs (strain Hartley Albino, 324 to 409 g) were treated with n-pentane (MRD-91-962, purity: 100%). The control group consisted of 20 animals. The induction dose was 5% n-pentane. At day 7 a dose of 100% n-pentane was administered and a challenge dose of 1% was administered at day 21. Based on the lack of signs of dermal irritation during this study it was concluded that n-pentane showed no sensitisation potential (Exxon Biomedical Sciences, Inc., project no. 196221, 1991). The sensitisation test was performed according to EC Annex VB6, and under GLP conditions.

##### Respiratory tract

No data on specific studies were available.

#### **4.1.2.6 Repeated dose toxicity**

##### **4.1.2.6.1 Studies in animals**

##### Oral

The mortality in a four-week gavage screening study in groups of 10 male Fisher 344 rats (170-190 g) primarily designed to study n-pentane nephrotoxic potential, was 2/10 at a dose level of 500 mg/kg bw and 4/10 at 2,000 mg/kg bw. In addition 1/10 and 2/10 were lethargic in the low-dose and high-dose groups, respectively. No hydrocarbon-induced nephropathy (hyaline droplet changes, regenerative epithelium and tubular dilation with granular material) was noted by histopathological examination of the kidneys of exposed animals (or in controls). The average nephropathy score was 3.0 in controls (saline), 2.7 in the low-dose group, and 2.3 in the high-dose group (Grade scale 1-12). Stomach lesions, which were found in some of the exposed animals in the high-dose group, consisted of raised, pale, white or dark foci in the nonglandular area. Terminal body and absolute kidney weights were significantly lower in exposed animals compared to control animals (American Petroleum Institute, 1985). The study was performed under GLP conditions.

##### Dermal

No studies on repeated dose toxicity of n-pentane following dermal administration were located.

##### Inhalation

In this 2-week study groups of 10 male Crl:CD rats (44 days old) were exposed by inhalation, 6 hours/day, 5 days a week for 2 weeks to either 0, (control), 1,000, 3,000, or 10,000 ppm n-pentane (3,003, 9,009 and 30,030 mg/m<sup>3</sup>) (Stadler et al., 2001). Five rats per group were killed following the 10<sup>th</sup> exposure, and the remaining 5 rats per group were killed after a 14-day post-exposure recovery period. The highest concentration at 10,000 ppm was chosen based on a pre-test screen in which a limited number (4) of rats generally appeared unaffected following four days exposure to 10,000 ppm. Parameters investigated in the two-week study were clinical

signs of toxicity, functional behaviour, body weights, clinical pathology, and gross and microscopic pathology including organ weights. Results: In n-pentane treated rats no clinical signs of toxicity were reported, and body weight was not altered. Normal behaviour responses were reported in all exposure groups, when using a functional observation battery (FOB). A statistically significant increases in serum calcium (11.6 and 12.1 mg/l at 3,000 and 10,000 ppm, respectively compared to 11.1 mg/l in controls) and phosphorus concentrations (10.4 and 11.0 mg/l at 3,000 and 10,000 ppm, respectively compared to 9.8 mg/l in controls) were seen in rats exposed to 3,000 or 10,000 ppm. However, these changes were reversible during the two-week recovery period. The combination of increased concentration of calcium and phosphorus was considered to be a potentially adverse effect by the authors, since it indicated that alterations in mineral metabolism or homeostasis might have occurred, however, ascribing these effects as treatment-related was also by the authors described as a fairly conservative position. No other clinical pathology changes were reported, and no n-pentane-related tissue pathology was seen in any of the treatment groups. The NOAEL was 1,000 ppm with reversible clinical pathology changes reported at 3,000 and 10,000 ppm.

In a 13-week subchronic inhalation toxicity study, three groups of ten female (184.8 to 213.4 g) and ten male (229.8 to 255.8 g) rats (CrI:CDBR) were exposed 6 hours per day, 5 days per week to vapour atmosphere of n-pentane (purity: 97.4) 5,000 mg/m<sup>3</sup> (1,650 ppm), 10,000 mg/m<sup>3</sup> (3,330 ppm), and 20,000 mg/m<sup>3</sup> (6,660 ppm). An additional group served as control and was exposed to air only. The mean actual chamber concentrations for the exposed groups were 5,097 ± 79 mg/m<sup>3</sup> (1,697 ± 26 ppm), 10,203 ± 151 mg/m<sup>3</sup> (3,367 ± 50 ppm) and 20,483 ± 734 mg/m<sup>3</sup> (6,821 ± 245 ppm), respectively, determined by on-line gas chromatography. Clinical observations were recorded daily, and body weights were performed weekly and prior to terminal sacrifice. Haematology, clotting potential, and serum chemistry studies were performed on all animals at termination. Ophthalmoscopic examination was performed during the final week of the study. Necropsy was performed on all animals and selected tissues and organs were weighed and preserved at study termination. Selected tissues from the control and high exposure groups were examined microscopically. The lungs, trachea, larynx, and nasal tissues of the low and mid exposure level groups were also examined microscopically. No signs of systemic toxicity were observed during the study or at study termination. There were no adverse effects with respect to clinical signs, body weight changes, food consumption, clinical pathology parameters, organ weights, post-mortem observations, or microscopic changes. Accordingly, the NOAEL was set at approximately 20,000 mg/m<sup>3</sup> (6,660 ppm) under conditions of this study. This study was performed according EC Annex VIII and VB 29, and under GLP conditions (Exxon Biomedical Sciences Inc., Project no. 157518, 1997).

In a 16-week comparative study of the neurotoxicity of n-pentane, n-hexane, and n-heptane, male Wistar rats (308 ± 18 g) were exposed by inhalation in chambers to nominal concentrations of 8,970 mg/m<sup>3</sup> (3,000 ppm) n-pentane (9,209 ± 598 mg/m<sup>3</sup>; 3,080 ± 200 ppm measured by GC; purity > 99%) 12 h/d, 7 d/week for 16 weeks. The control rats were housed in similar chambers with fresh air. Each group consisted of seven rats. The conduction velocity of tail nerves was measured to determine the functional status of the peripheral nerves. No signs of neurobehavioral effects of n-pentane were noted in the exposed animals; motor activity was normal and no evidence of peripheral neuropathy was found (Takeuchi et al., 1981a) (see also Takeuchi et al., 1980). n-Hexane was used as a positive control and was neurotoxic in this study (not conducted in accordance with GLP). In a similar study, no signs of neurobehavioral effects of n-pentane were noted in the exposed animals; motor activity was normal and no evidence of peripheral neuropathy was found (Takeuchi et al., 1981b).

A 30-week chronic inhalation neurotoxicity study was conducted in groups of 6-9 Sprague-Dawleys rats (230-260 g), exposed to  $8,970 \text{ mg/m}^3$  (3,000 ppm) n-pentane (99% pure), 9 hours/day; 5 days/week for 30 weeks (Frontalli et al., 1981). At weekly or monthly intervals the rats were weighed and subjected to a physiological test of neuromuscular function, based on the measure of the hind-limb spread on landing, after dropping from a 32 cm height (Edwards and Parker, 1979). A significant decrease in body weight was noted. However, a difference in neuromuscular function observed in treated and control rats was not statistically significant. Furthermore, the test employed turned out to be scarcely effective because of high individual variability. No morphological giant axonal degradation was observed by histological examination of the nerve tissue. This study is not according to EU Annex VB.

#### Exposure to mixtures of aliphatic hydrocarbons

In a 13-week subchronic study 20 male and 10 female, 6-week-old Fisher rats were exposed whole body 6h/day, 5 days/week for 13 weeks to a 1,000 or 4,500 ppm mixture of 50/50 wt % of n-butane/n-pentane. The exposures were conducted in Rochester-type  $1 \text{ m}^3$  inhalation chambers. The rats were observed daily following exposure. They were weighed weekly and immediately prior to sacrifice. Complete necropsies were performed at designated times, during which the presence of lesions or other abnormal conditions were observed, and kidney and liver weights determined. The kidneys were fixed and sectioned for histopathology. No test animals died during the study. Possible treatment-related, but not dose-related effects of the n-butane/n-pentane exposure included transient hunched posture and/or lethargy and intermittent tremor. Body weight was unaffected relative to controls at the end of the study. Generally, all gross lesions observed during necropsy were considered spontaneous. The renal histopathology examination revealed a treatment-related effect at the 28-day interim sacrifice in the kidneys of one group of male rats exposed to 1,000 ppm of the n-butane/n-pentane mixture relative to their associated controls. Despite this effect seen at day 28, no differences in kidney histopathology were observed between treated and control groups at study termination. The renal lesions included excessive phagolysosome accumulation in the cytoplasm of epithelial cells lining the proximal convoluted tubules, degeneration/regeneration of the epithelial cells in the renal cortex, and development of granular, proteinaceous casts in the lumen of tubules located principally between the inner and outer strips of the medulla. However, these lesions occurred commonly in untreated rats, and are fully reversible. Therefore, it was concluded that the response seen was not an indication of a frank nephrotoxic response to the n-butane/n-pentane mixture, since no differences between treated and control animals were seen at 90 days (Aranyi et al., 1986). Neurotoxic effects observed included transient hunched posture and/or lethargy and intermittent tremor, however, these effects were not dose-related. This study was performed according to EC Annex VB, however, only the kidneys were examined histopathologically.

In a subacute 21-day inhalation nephrotoxicity study, male and female Sprague-Dawley rats (36-45 days) were exposed to a mixture of 25% (w/w) of n-pentane, isopentane, n-butane and isobutane. The study consisted of four groups of rats: three of the groups were exposed to  $120 \text{ mg/m}^3$  (44 ppm),  $1,150 \text{ mg/m}^3$  (432 ppm) or  $11,800 \text{ mg/m}^3$  (4,437 ppm) of the  $\text{C}_4/\text{C}_5$  hydrocarbon mixture, respectively, and the fourth group was exposed to filtered air. All groups were exposed 6 hours/day, 5 days/week for 3 weeks. Each group consisted of ten rats per sex. The animals were monitored daily for mortality, morbidity and adverse clinical signs. Body weights were recorded at study initiation and on a weekly basis thereafter. At study termination all animals were necropsied, and the brain, heart, liver, spleen, kidneys, adrenals and gonads were removed. These organs were weighed and fixed for histological examination, with special attention on the kidneys to identify those lesions that are recognised to represent effects of

hydrocarbon-induced nephropathy in male rats. During the study the rats showed no clinical signs of distress, and no treatment related pathological lesions were noted upon either gross or microscopic examination. Furthermore no hydrocarbon-induced nephropathy was observed at concentrations up to 11,800 mg/m<sup>3</sup> (4,437 ppm) (Halder et al., 1986). This study is in accordance with EC Annex VB, however, not all organs were examined histopathologically.

#### Other

S.c injections of n-pentane have been shown to cause temporary impairment of liver function in rats. Small aliphatic hydrocarbons (C2-C5) are capable of sensitising the myocardium, however, n-pentane has not been studied in this context. The chemical has, following s.c. injection, caused neutropenia.

#### **4.1.2.6.2 Studies in humans**

Three cases of polyneuropathy appeared among employees of a belt manufacturing shop. The employees were exposed to a solvent containing 80% n-pentane, 14% n-heptane and 6% n-hexane (Gaultier et al., 1973). The results were attributed to the presence of n-hexane. However, as pointed out by the author, there was no a priori hypothesis linking polyneuropathy to n-hexane, when this was first observed in exposed workers. Consequently Gaultier made two suggestions; that tests of n-alkanes, particularly n-pentane in rats should be carried out, and that more careful clinical examinations to determine the precise nature of the neurotoxic agent(s) should be made. Animal tests on n-pentane have been carried out, as described above. As for humans, no further reports discussing the long-term consequences of n-pentane exposure were found.

#### **4.1.2.6.3 Summary of repeated dose toxicity**

##### Studies in animals

In a 4-week oral nephrotoxicity screening study no histopathologic changes were noted in the kidneys of exposed rats up to 2,000 mg/kg bw, however, mortality was reported at 500 mg/kg bw/day (2/10) and at 2,000 mg/kg bw/day (4/10), and some animals were lethargic. Furthermore, stomach lesions were reported in some animals at 2,000 mg/kg bw/day.

No systemic toxicity was observed in a recent 13-week sub-chronic study in rats after inhalative exposure up to 20,000 mg/m<sup>3</sup> (6,660 ppm), and a NOAEL from this study was set at  $\geq$  20,000 mg/m<sup>3</sup> (6,660 ppm). This study was performed according to EC Annex VB2 and GLP conditions.

No systemic toxicity was observed in rats in a 13-week sub-chronic study after inhalative exposure up to 4,500 ppm mixtures of 50/50 wt % of n-butane/n-pentane. Furthermore, in a 21-day inhalation nephrotoxicity study in rats exposed to 25% (w/w) of n-pentane/isopentane/n-butane/isobutane up to 13,266 mg/m<sup>3</sup> (4,437 ppm), no treatment related pathological findings were observed. The results of the mixture studies summarised in this paragraph are consistent with the studies of pure n-pentane described above but do not provide any additional information.

In a 16- and 30-week neurotoxicity study no neurotoxic effects were observed in rats after exposure to (8,970 mg/m<sup>3</sup>) (3,000 ppm) n-pentane.

## Studies in humans

Based on the available information, questions have been raised about the potential neurotoxicity of n-pentane in humans. In humans the mixture of 80% n-pentane, 14% n-heptane and 6% n-hexane caused peripheral neurotoxic effects. It is not known to what extent n-pentane may enhance the toxic effect of n-hexane. Anaesthetic effects of n-pentane are demonstrated in animal studies, and are expected in humans. Neurotoxicity of n-pentane has not been demonstrated in animal studies. Studies of CNS - effects from prolonged exposure to high concentrations of n-pentane in humans have not been reported.

### **4.1.2.7 Mutagenicity**

#### **4.1.2.7.1 *In vitro* studies**

n-Pentane was reported to be negative in the Ames Salmonella/microsome assay. *Salmonella typhimurium* strains TA1535, TA1537, TA1538, TA98 and TA100 were used with and without an activation system prepared from livers of rats pre-treated with Aroclor 1254. The bacteria were exposed to 0.2 ml of n-pentane in a desiccator containing magnetic stirrers which served as fans to assure rapid evaporation of the liquid and even distribution of vapours. The desiccator was placed in a 37°C room for 7 to 10 hours. The plates were removed, and were further incubated for 40 hours at 37°C before being counted (Simmon et al., 1977).

n-Pentane was reported to be negative in one reverse mutation assay in bacteria (*Salmonella typhimurium* tester strains TA1535, TA1537, TA1538, TA98, and TA100) with and without the addition of an exogenous metabolism system (S9 from livers of Aroclor 1254 pre-treated rats) at vapour concentrations of 1, 2, 5, 8, 25, and 50 (v/v)% (295,000 mg/m<sup>3</sup>) of n-pentane. The bacteria were exposed to n-pentane in a desiccator for 6 h (Kirwin et al., 1980). Both the 25 and 50% concentrations were cytotoxic. This study was not performed according to EU Annex VB10. However, due to the relatively low boiling point of n-pentane, this compound is not easily tested by the standard procedure, and the results have to be viewed with caution.

An *in vitro* test for chromosomal aberrations (CA) consisting of two phases: an initial 20 hours, a repeat 20 hours, and a repeat 44 hours activated and non-activated tests were performed. Nominal concentrations of 1,000, 1,200, and 1,500 µg/ml were selected for evaluation of the 20- and 44-hour harvests with metabolic activation, and 600, 900, and 1,100 µg/ml were selected for evaluation without metabolic activation. The assay was modified for volatile test materials. Glass flasks were used and filled to capacity, and the test material was dosed through septums to achieve zero head space during the exposure period. The septums were removed and replaced with caps to allow gas exchange during the incubation period. In this study n-pentane did not induce any biologically significant increases in CA in Chinese Hamster Ovary cells (CHO cells) exposed to nominal concentrations up to 1,500 µg/ml n-pentane (purity: 97.4%) with metabolic activation (+S9) and with nominal concentrations up to 1,100 µg/ml without metabolic activation (-S9). However, there was an increasing dose-related trend in the percentage of aberrant cells in the repeat metabolic activated series in the 20-hour harvest, with statistically significant increases in aberrant cells at 1,200 µg/ml and 1,500 µg/ml relative to the non-treated control. However, these increases were observed only at nominal concentrations which may be in excess of 10 mM, and such high concentrations have been shown to produce artefacts (Scott et al., 1991). The study was performed according to EU Annex VB 10 guidelines and under GLP conditions (Exxon Biomedical Sciences, Inc., Project no. 157532, 1997).

#### 4.1.2.7.2 *In vivo* studies

n-Pentane did not induce any increase in micronuclei formation, and did not induce bone marrow cytotoxicity in rats at any exposure level of n-pentane in a study conducted to evaluate the potential of n-pentane (purity: 97.4%) to induce micronucleated polychromatic erythrocytes (MNEs) in the bone marrow of Crl:CDBR rats. Furthermore, no clinical signs of toxicity were reported. The administration of n-pentane was performed as part of a 90-day subchronic inhalation toxicity study (Exxon Biomedical Science, Inc., project number 157518, 1997). Three groups of 5 male (230 to 256 g) and 5 female (185 to 213 g) rats were exposed six hours per day, five days per week to vapour atmosphere of n-pentane. Mean actual chamber concentration determined by on-line gas chromatography were  $5,097 \pm 79 \text{ mg/m}^3$  ( $1,705 \pm 26 \text{ ppm}$ ),  $10,203 \pm 151 \text{ mg/m}^3$  ( $3,412 \pm 50 \text{ ppm}$ ), and  $20,483 \pm 734 \text{ mg/m}^3$  ( $6,850 \pm 245 \text{ ppm}$ ). Two additional groups (5 rats/sex/group) served as the carrier control (exposed to air in a manner similar to the exposed group) and the positive control (cyclophosphamide 20 mg/kg administered at a dose volume of 10 ml/kg, once daily by gavage for a three day period). There were no statistically significant differences in micronuclei formation at any exposure level of n-pentane compared with carrier controls. Cyclophosphamide induced a statistically significant ( $p < 0.01$ ) increase in the mean number of MNEs, indicating that this substance was clastogenic and that the test system responded in an appropriate manner. Therefore, n-pentane was considered inactive in the rat bone marrow micronucleus test under the conditions of this study. The study was performed according to EC Annex VB 12, with some modifications, and under GLP conditions (Exxon Biomedical Sciences, Inc., Project no. 157530, 1997).

#### 4.1.2.7.3 Summary of mutagenicity

*In vitro*: n-pentane was negative in two reverse mutation assay in *Salmonella typhimurium*. Furthermore, no biologically significant increases in chromosomal aberrations were observed in CHO cells. *In vivo*: in a recent study, n-pentane did not induce any increase in micronuclei formation and did not induce bone marrow cytotoxicity in rats at doses up to  $20,000 \text{ mg/m}^3$  (6,660 ppm) n-pentane. No information on the genotoxic potential of n-pentane in humans is available. Based on EU criteria, there is no need for further testing for mutagenicity *in vitro* or *in vivo*.

#### 4.1.2.8 Carcinogenicity

No data were available.

#### 4.1.2.9 Toxicity to reproduction

##### 4.1.2.9.1 Reproductive toxicity (fertility)

No one or two generation reproductive toxicity studies with n-pentane were available. In a 13-week subchronic inhalation toxicity study (Exxon Biomedical Science Inc. Project no. 157518, 1997) the toxicity of n-pentane on the reproductive system in male and female rats were evaluated. Three groups of ten female (184.8 to 213.4 g) and ten male (229.8 to 255.8 g) rats (Crl:CDBR) were exposed 6 hours per day, 5 days per week to vapour atmospheres of n-pentane (purity: 97.4)  $5,000 \text{ mg/m}^3$  (1,665 ppm),  $10,000 \text{ mg/m}^3$  (3,330 ppm), and  $20,000 \text{ mg/m}^3$



(6,660 ppm). An additional group served as the control and were exposed to air only. The mean actual chamber concentrations for the exposed groups were  $5,097 \pm 79 \text{ mg/m}^3$  ( $1,697 \pm 26 \text{ ppm}$ ),  $10,203 \pm 151 \text{ mg/m}^3$  ( $3,398 \pm 50 \text{ ppm}$ ) and  $20,483 \pm 734 \text{ mg/m}^3$  ( $6,821 \pm 244 \text{ ppm}$ ), respectively, determined by on-line gas chromatography. The epididymis, seminal vesicles, prostate, testes or ovaries and uterus were weighed prior to placement in fixative. Furthermore, the epididymis, ovaries and oviduct, prostate, seminal vesicles, testes, uterus, vagina and cervix were examined microscopically. At termination of the study no statistically differences in the mean absolute reproductive organ weight between control and exposed animals of either sex was observed. Furthermore, no microscopic changes in the preserved tissues were observed that were considered related to the exposure to n-pentane. The study was performed under GLP conditions.

#### 4.1.2.9.2 Developmental toxicity (teratogenicity)

In a developmental toxicity rangefinding study in rats exposed by oral gavage to n-pentane signs of maternal toxicity were apparent at the 1,000 mg/kg dose level as indicated by suppression of body weight gain and decreased food consumption during the treatment period and/or the overall gestation interval. However, there were no adverse clinical or post-mortem signs or adverse effects on uterine implantation parameters in dams at this dose level. In this study n-pentane was administrated by oral gavage to 5 groups of mated Crl:CDBR female rats (7 animals per group) (233-281 g) at doses of 250, 500, 750, and 1,000 mg/kg (limit dose). Group 1 served as control and received the carrier (corn oil) only. Mated females were dosed once daily from gestation day (GD) 6 through GD 15. Clinical observations were made daily to terminal sacrifice on GD 21. There were no clinical signs or post-mortem observations, which were attributed to treatment with n-pentane. A suppression in body weight gain was observed in the 1,000 mg/kg dams when compared with controls during the overall treatment period (GD 6 to 15). There was also possible suppressed body weight gain in the 750 mg/kg dams compared with controls. No biologically significant external observations and no differences in foetal body weight were observed between treated and control foetuses of either sex. This study was performed according to EU Annex VB31 guidelines and under GLP conditions. Based on the lack of maternal or foetal mortality at 1,000 mg/kg, the high dose level for a subsequent definitive developmental study in rats with n-pentane is recommended to be 1,000 mg/kg (the limit dose for developmental studies as per EU guidelines) (Exxon Biomedical Science Inc., Project no. 157533, 1997).

In a developmental toxicity study in female Crl:CDBR rats (243 to 316 g) the maternal and developmental NOAEL were  $\geq 1,000 \text{ mg/kg}$ . In this study 100, 500, and 1,000 mg/kg n-pentane was administrated once daily via oral gavage to 4 groups (25 animals per group) of pregnant rats during the period of major organogenesis, Gestation Day (GD) 6 to GD 15. Group 1 served as a control and received the carrier (corn oil) only. Maternal toxicity was not evident at any dose level tested, up to and including 1,000 mg/kg. There were no statistically significant differences in mean body weight, body weight change, uterine weight, corrected body weight, or uterine implantation data between treated and control dams. Additionally, there was no mortality observed, and no adverse clinical /post-mortem signs which were considered treatment-related. There was no evidence of growth retardation or increased foetal death in the treated group compared to controls. Additionally, there was no statistically significant differences in total or individual variations or malformations (external, visceral, or skeletal) in the treated group compared to controls. n-Pentane was not a developmental toxicant in this study. The study was performed according to EU Annex V, B31 guidelines and under GLP conditions (Exxon Biomedical Science Inc., Project no. 157534, 1997).

#### **4.1.2.9.3 Summary of toxicity to reproduction**

No one- or two-generation study with n-pentane is available, however, in a 13-week subchronic inhalation toxicity study in male and female rats no signs of toxicity were observed on the reproductive system by macroscopic or microscopic evaluation after exposure to n-pentane up to 20,000 mg/m<sup>3</sup> (6,660 ppm). Therefore, no study investigating effects on fertility and/or the reproductive organs after exposure to n-pentane was recommended. In a developmental toxicity study in female rats the NOAEL was  $\geq 1,000$  mg/kg bw both for the dams and the offspring. No information on the potential of n-pentane to cause developmental toxicity in humans is available.

### 4.1.3 Risk characterisation

#### 4.1.3.1 General aspects

It should be noted that this risk assessment only covers the risks associated with the life cycle of n-pentane, with the EINECS number 203-692-4. Any risks connected to the presence of n-pentane in other EINECS substances, particularly petroleum products (non-isolated n-pentane), have not been assessed.

The human population may be exposed to n-pentane at the workplace, from the use of consumer products, and indirectly via the environment (see Sections 4.1.1.2, 4.1.1.3, and 4.1.1.4). The main exposure route to workers, consumers and indirectly via the environment is by inhalation due to n-pentanes physico-chemical properties.

In the data set for health effects both animal and human data were available. However, the human data are from exposure to mixtures of alkanes (n-pentane, n-hexane and n-butane), and are consequently of minor relevance for the evaluation of toxic effects observed by inhalation of pure n-pentane in humans.

A gas uptake study performed on rats demonstrated that n-pentane is rapidly eliminated by exhalation or metabolism. The half-life is approximately 0.13 hour. Considering the rapid metabolism and excretion, tissue accumulation is expected to be low.

Some of the acute toxicity studies have been performed according to accepted test guidelines and according to GLP. Based on the available data, n-pentane has a low acute oral and respiratory toxicity, LD<sub>50</sub> being > 2,000 mg/kg (limit test) and LC<sub>50</sub> ≥ 300,000 mg/m<sup>3</sup> (100,000 ppm). Furthermore, the EC<sub>50</sub> value for impaired performance, assessed by studying the responding maintained under a fixed interval 60-second schedule of milk presentation, was 108,030 mg/m<sup>3</sup> (36,130 ppm) in mice, with a decreased responding from 29,900 mg/m<sup>3</sup> (10,000 ppm) (Glowa et al., 1991). The EC<sub>50</sub> value for neurotrophic effects were 62,790 mg/m<sup>3</sup> (21,000 ppm) in rats and 70,265 mg/m<sup>3</sup> (23,500 ppm) in mice (Frantik et al., 1994). n-Pentane has the potential to cause anaesthetic effects at air concentrations of 96,000 mg/m<sup>3</sup> and higher and lung damage if swallowed.

In a recent study performed in compliance with GLP the behavioural effect of n-pentane was studied in rats after short-time inhalation exposure. On cognitive behaviour a mild and reversible effect of n-pentane was reported after exposure to 2,000 mg/m<sup>3</sup> and 6,500 mg/m<sup>3</sup> (2,200 ppm) 8 hours per day for 3 days. However no effect was reported at 20,000 mg/m<sup>3</sup> (6,600 ppm). Since this effect was not dose-related, this study has not been taken into account in the risk characterisation of workers and consumers.

As regard the available skin, and eye irritation studies, n-pentane is not irritating to skin or eye, however, there is suggestive evidence that n-pentane is a slight respiratory irritant in mice. From clinical experience in man it is well known that solvents in general have a defatting action on the skin, which after repeated exposure may cause skin dryness and flaking. This may cause local skin reactions and enhancement in the penetration and uptake of toxic substances. No sensitising effect of n-pentane has been observed.

With respect to repeated dose toxicity the available data from a 13 week sub-chronic inhalation toxicity study (performed according to GLP and EU Annex V, B2) revealed an overall NOAEL ≥ 20,000 mg/m<sup>3</sup> (6,660 ppm), and this NOAEL is used in the risk assessment. Regarding chronic

neurotoxicity, no effects of n-pentane have been demonstrated in animal studies. No reports discussing long-term consequences of n-pentane exposure on the nerve system were found. The only human studies available are from exposure to mixtures of alkanes (n-pentane, n-hexane, and n-butane), and no conclusions on neurotoxic effects of n-pentane can be drawn from these studies.

Based on the mutagenicity data, n-pentane is considered not to be genotoxic. Given the results from the mutagenicity studies and the chronic toxicity studies, there is no apparent reason for further carcinogenicity testing.

Regarding toxicity to reproduction a 13-week sub-chronic inhalation study in rats (performed according to GLP and EU Annex V, B2) revealed no effects on reproduction and the NOAEL was set to  $\geq 20,000 \text{ mg/m}^3$  (6,660 ppm). A developmental toxicity study in female rats exposed by oral gavage (performed according to GLP and Annex V, B31), revealed a NOAEL  $\geq 1,000 \text{ mg/kg/bw}$  both for the dams and the offspring. In a developmental toxicity rang-finding study in rats the NOAEL in offspring was  $\geq 1,000 \text{ mg/kg bw}$ , and the NOAEL in dams was  $750 \text{ mg/kg bw}$ . At  $1,000 \text{ mg/kg bw}$  maternal effects were evident as suppression of body weight gain, decreased food consumption during the treatment period or/and the overall gestation interval.

**Table 4.18** Exposure scenarios for occupational exposure, consumer exposure, and humans exposed via the environment used in the risk characterisation of n-pentane

Scenario	Air concentration ( $\text{mg/m}^3$ )	Dermal exposure ( $\text{mg/person/day}$ ) <sup>b)</sup>	Calculated dose ( $\text{mg/kg bw/day}$ ) <sup>a)</sup>
<b>Occupational exposure</b>			
Production of n-pentane			
• Typical value	66.5		9.5
• Reasonable worst case	180		25.7
• Short-term value	599		85.6
• Dermal value		420	6.0
Industrial use of products containing n-pentane			
• Typical value	269		38.4
• Reasonable worst case	338		48.3
• Short-term value	643		91.86
• Dermal value		84	1.2
Professional end-use of products containing n-pentane (hair salons)			
• Typical value	35		5
• Reasonable worst case	~198		28.3
• Short-term value	Not relevant		Not relevant
• Dermal value		Negligible	
<b>Consumer exposure</b>			
Hair spraying, TGD estimates			7.8
Hair spraying, empirical estimate			2.75
Hair spraying, worst-case estimate			10.3

Table 4.18 continued overleaf

**Table 4.18 continued** Exposure scenarios for occupational exposure, consumer exposure, and humans exposed via the environment used in the risk characterisation of n-pentane

Scenario	Air concentration (mg/m <sup>3</sup> )	Dermal exposure (mg/person/day) <sup>b)</sup>	Calculated dose (mg/kg bw/day) <sup>a)</sup>
<b>Humans exposed via the environment</b>			
Local min.	0.0048		0.00137
Local max.	0.140		0.04
Regional	0.00032		$9.1 \cdot 10^{-5}$

a) See Section 4.1.1.4 for calculation

b) Estimated by EASE

### 4.1.3.2 Workers

#### Introduction

The main occupational exposure to n-pentane occurs in production of n-pentane, in expanded polystyrene (EPS) manufacturing plants, and in hair salons where aerosols containing n-pentane are being used. The exposure to pentane from petroleum products is outside the scope of this report.

It is assumed that oral exposure is prevented by personal hygienic measures and the risk characterisation for workers is limited to the dermal and respiratory routes of exposure. Based upon the evaluated information on the exposure scenarios presented in Section 4.1.1.2, i.e. production of n-pentane, industrial use of products containing n-pentane and professional end-use of products containing n-pentane, the values presented in **Table 4.18** are used in the risk characterisation of n-pentane.

The manufacturing of n-pentane is performed in closed systems. At manufacturing and distribution sites exposure takes place in tasks when the systems are opened. These tasks include drum filling and emptying, sampling, and maintenance. In hair salons and in production of EPS, the presence of n-pentane in the working atmosphere is occasional

The information with respect to sampling and analytical methods used has been scanty for most of the quoted monitoring data. In the following risk characterisation it is therefore assumed that all the results are 8-hour TWA values. Experiences show that most of the exposure measurements are performed for time periods less than four hours, and that the results are usually higher from short-term sampling than from long-term.

The quoted exposure data show low values compared to reported harmful concentrations of n-pentane, and the data represent normal work situations. It is not unlikely to believe that some maintenance tasks, for example the maintenance of the processing equipment, can cause much higher exposure to workers. It is anticipated that personal protective equipment (PPE) is worn when performing maintenance of long duration. Accidental scenarios at work are not addressed in the risk evaluation, and it is assumed that adequate risk reduction measures are taken to prevent accidental exposure. As a consequence of n-pentanes highly flammable property, high concentrations are mostly avoided in the workplace.

### Inhalation exposure

The inhaled dose of pentane by a man during a working day can be calculated by the formula:

$$\text{Calculated inhaled dose} = \frac{V \cdot E \cdot B_{\text{inh}}}{B_w}$$

- V = inhaled air volume by man during a working day assuming normal working burden, is estimated to be 10 m<sup>3</sup> air/day  
 E = external exposure, measured values from air samples (mg/m<sup>3</sup>)  
 B<sub>w</sub> = average body weight of an adult 70 kg according to the TGD  
 B<sub>inh</sub> = bioavailability for inhalative exposure = 1 (100% absorption)

Data on absorption in the lungs after inhalation are lacking. Therefore, 100% respiratory absorption is used as a default value.

### Dermal exposure

Theoretically it is possible with an additional uptake of n-pentane through skin. It has been shown that n-pentane penetrates full-thickness rat skin at a rate of 31.14 nmol/h/cm<sup>3</sup> (Tsuruta, 1982). This gives an absorption rate of 2.2 µg/h/cm<sup>2</sup>.

$$\text{Calculated dermal dose} = \frac{R \cdot A \cdot WD}{B_w}$$

- R = absorption rate (rat skin at a rate of 31.14 nmol/h/cm<sup>3</sup>=2.2 µg/h/cm<sup>2</sup>)  
 2,2 µg/h/cm<sup>2</sup>=0.0022 mg/h/cm<sup>2</sup>  
 A = areal of skin contact (an area of 2,000 cm<sup>2</sup> to both hands and forearms according to the TGD)  
 WD = workday (8 hours)  
 B<sub>w</sub> = workers bodyweight (70 kg)

This gives an estimated dose of 0.5 mg/kg bw/day. In reality the skin contact will be of short duration (<<8 hours/day), and it is unlikely that it will cover both the hands and the forearms. Therefore the potential dermal adsorption will be <<0.5 mg/kg bw/day. This additional uptake is of negligible amount compared to the inhaled amount.

Dermal exposure can also be estimated with the dermal model of EASE (see Section 4.1.1.2). Since there is no adequate knowledge about the absorption after dermal exposure of n-pentane, 100% absorption is used as a default value. The EASE value given in **Table 4.15**, rather than the estimated uptake calculated by an absorption factor, is therefore considered as a worst-case value and is preferred used in the risk characterisation.

### MOS values

To calculate the MOS values for the different scenarios, the NOAEL value for the respective endpoints are divided by the measured exposure for each scenario (mg/m<sup>3</sup>) and each route. For dermal exposure the NOAEL is calculated to the responding internal exposure. The MOS value for the scenario where there is an estimated EASE value for dermal exposure (Scenario 1), a MOS value for the combined route (dermal and inhalation) based on internal doses (mg/kg/day), is considered. Because of the lack of measured data and that the available measurements is

provided with very little detail on task, working conditions, e.g., there are uncertainties connected to these data.

### Acute toxicity

#### *Inhalation exposure*

Due to n-pentane's highly flammable property, high concentrations are consequently avoided in the workplace.

The LC50 value of n-pentane after 2 hours of exposure was reported to be 98,662 ppm (294,999 mg/m<sup>3</sup>) in mice. This suggests that n-pentane has low acute toxicity. The LC50 value is considerably higher than the observed/measured exposure levels, which has a maximum of about 600 mg/m<sup>3</sup> for short time measurements in the production of EPS and about 1,000 mg/m<sup>3</sup> measured at a pilotreactor for production of polystyrene granulates. n-Pentane has the potential to cause anaesthetic effects at air concentrations of 96,000 mg/m<sup>3</sup> and higher (Swann et al., 1974). Also, from a study in mice, Glowa and co-workers (1991) have reported impaired performance from 29,900 mg/m<sup>3</sup> (10,000 ppm), and an increase in the levels of ACTH in serum from 14,950 mg/m<sup>3</sup> (5,000 ppm) after exposure to n-pentane for 30 minutes. It was not found relevant to derive a LOAEC value from the latter study to be able to calculate a MOS value for the endpoint acute toxicity. Considering the reported exposure concentrations, it is not believed that an anaesthetic effect will occur. As for other solvents n-pentane vapour may cause drowsiness and dizziness at higher exposure levels. The peak exposure measurements that have been reported do not seem to give rise to concern.

Given the low toxicity observed in the acute inhalation studies and the anticipated occupational exposure levels it is concluded that n-pentane is of no concern for workers with regard to acute effects: **conclusion (ii)**.

### Irritation

#### *Skin*

n-Pentane was shown to be a mild skin irritant in a study with rabbit (Section 4.1.2.3.1), and caused irritation at the exposure site in another study with five humans exposed to n-pentane on the forearm and thigh (Oettel, 1936). On the contrary a third study reported no skin irritation in one human exposed to n-pentane. All together the study results indicate that n-pentane should not be classified as a skin irritant. However, for solvents in general, it is well known from clinical experience in humans that they have a defatting action on the skin, and that continued exposure may lead to development of irritant contact dermatitis (Section 4.1.2.3.3). Certain individuals with dermatitis, like atopic, are especially susceptible to these products since their skin barrier is constitutionally impaired. Atopic individuals constitutes about 15-20% of the general population (Boman, 1996).

Because of high volatility, dermal exposure is reduced due to the fast evaporation of n-pentane from the skin. The boiling point of n-pentane is 36.1°C, slightly below the body temperature (37°C), but above the skin temperature (normally 28-32°C).

Pentane is a volatile and flammable solvent. According to the industry, considerable measures are established within production facilities to prevent vapour losses, fires and explosions, see Section 4.1.1.2 Scenario 1. These measures also serve to reduce the potential for both dermal and

inhalation exposure. Moreover, in the case of dermal exposure, standard protective workwear mandates that gloves resistant to permeation by pentane be worn during high-risk tasks.

Based on the above arguments it is concluded that n-pentane is of no concern with respect to skin irritation: **conclusion (ii)**.

#### *Eyes*

Despite the mild irritation effects observed in the acute eye irritation study (Section 4.1.2.3.1) in rabbits, there is no evidence that n-pentane cause eye irritation in humans. Exposure to eyes in the workplace is possible via vapours or accidentally by splashing, but goggles are usually worn when the pure substance is handled and thus exposure to eyes are unlikely to occur: **conclusion (ii)**.

#### *Respiratory tract*

In an inhalation study in mice (Section 4.1.2.3.1), concentrations up to 16,000 ppm (47,840 mg/m<sup>3</sup>) produced no irritation or anaesthesia, and it is concluded that n-pentane is of no concern for workers with regard to respiratory irritation: **conclusion (ii)**.

#### Corrosivity

Given the results from the skin and eye irritation studies (Section 4.1.2.3.1) it is concluded that n-pentane is of no concern for workers with regard to corrosivity: **conclusion (ii)**.

#### Sensitisation

##### *Skin*

Given the results from the dermal sensitisation study with guinea pigs it is concluded that n-pentane is of no concern for workers with regard to skin sensitisation (see Section 4.1.2.5): **conclusion (ii)**.

##### *Respiratory tract*

There are neither data from human experience nor other indication for respiratory sensitisation: **conclusion (ii)**.

#### Repeated dose toxicity

The overall NOAEL of  $\geq 20,000$  mg/m<sup>3</sup> n-pentane from a 90-day repeated dose inhalation toxicity study is used in the risk characterisation, and the NOAEL for inhaled dose of n-pentane is calculated to 1,766 mg/kg/day based on the exposure conditions in the rat study (see Section 4.1.2.6.1). The last value is used in the calculation of MOS values for exposure both via the dermal (**Table 4.20**) and the combined route (**Table 4.21**). Following factors are used in converting the inhalatory exposure dose in rats to an estimated internal dose (from mg/m<sup>3</sup> to mg/kg bw rats/day): bodyweight of 300 g, an inhalatory volume of 4.4 l/hour of rats and exposure-duration of 6 hours/day. For the inhalation route the NOAEL-value is used directly in the calculation of the MOS (**Table 4.19**).



### *Inhalation exposure*

The highest measured level of n-pentane was found at the storage site for EPS blocks and hence this is the worst-case scenario (see **Table 4.6**). The EPS blocks are transferred from the expansion machine on a transfer belt to the storage room where the blocks cool down and n-pentane evaporates.

**Table 4.19** Inhalation MOSs calculated for repeated dose toxicity as a critical effect for each scenario (Exxon Biomedical Sciences, 1997)

Occupational scenario	Air concentration <sup>1)</sup> (mg/m <sup>3</sup> )			MOS (NOAEL/measured value)		
	Typical Value	RWC <sup>2)</sup>	Short-term value	Typical value	RWC <sup>2)</sup>	Short-term value
Scenario 1: Production of n-pentane	66.5	180	599	≥ 300	≥ 111	>33
Scenario 2: Industrial use of products containing n-pentane (EPS production)	269	338	643	≥ 74	≥ 59	> 31
Scenario 3: Professional end-use of products containing n-pentane (Hair salons)	35	~ 198	Not relevant	≥ 571	≥ 101	Not relevant

NOAEL is ≥ 20,000 mg/m<sup>3</sup>

1) Data from Section 4.1.1.2, Table 4.13

2) RWC = reasonable worst-case value

### *Dermal exposure*

For dermal exposure, an EASE-value of 420 mg/person/day is estimated for Scenario 1 and 84 mg/person/day for Scenario 2. For Scenario 3 the dermal exposure is considered negligible (see Section 4.1.1.2). For a worker that is 70 kg, assuming 100% absorption, an uptake of 420 mg n-pentane/person/day and 84 mg n-pentane/person/day gives an internal dose of 6 mg/kg/day and 1.2 mg/kg/day, respectively.

**Table 4.20** MOS calculated for dermal exposure with the repeated dose toxicity as a critical effect

Exposure scenario	Dermal (mg/kg/day)	NOAEL (calculated internal dose) (mg/kg/day)	MOS
Scenario 1: Production of n-pentane	6	1,766	≥ 294
Scenario 2: Industrial use of products containing n-pentane	1.2	1,766	1,472
Scenario 3: Professional end-use of products containing n-pentane	Negligible	1,766	High

*Exposure by the combined route*

For Scenarios 1 and 2 there are both an estimated EASE-value for dermal exposure and a measured value for the exposure by inhalation. A MOS value for the combined route (dermal and inhalation) based on internal doses (mg/kg/day), is therefore considered (**Table 4.21**).

**Table 4.21** Combined MOS calculated for repeated dose toxicity

Exposure scenario	Inhalation <sup>1)</sup>		Dermal (mg/kg/day)	Combined route mg/kg/day)	MOS
	(mg/m <sup>3</sup> )	Internal (mg/kg/day)			
Scenario 1: Production of n-pentane	180	25.7	6	31.7	≥ 56
Scenario 2: Industrial use of products containing n-pentane	338	48.3	1.2	49.5	> 36
Scenario 3: Professional end-use of products containing n-pentane (Hair salons)	~ 198	28.3	Negligible	28.3	> 101

The NOAEL for inhaled dose of n-pentane is calculated to 1,766 mg/kg/day

1) Reasonable worst-case value

There are uncertainty factors inherent in the calculated margin of safety. The real margin of safety is likely to be substantially higher taking into consideration that the NOAEL of 20,000 mg/m<sup>3</sup> probably is too low and the uptake of n-pentane in the lungs is less than 100%. Besides it is not likely that the workers will stay in the storage room the whole working day, and the duration of the exposure will be << 8 hours a day. Also, because of the high volatility of n-pentane the dermal uptake is expected to be low. When this is considered, together with the lowest MOS values (reasonable worst case) of ≥ 59 for the inhalative exposure and ≥ 36 for the combined route based on internal dose, a **conclusion (ii)** for the worst-case scenario (Scenario 2) is reached.

As can be seen from the table above, the air concentrations in the other occupational settings are lower than those from the worst-case scenario. For the inhalation route, the interval of MOS values for estimated for typical values and worst-case values for the different scenarios are ranging from ≥ 59 to ≥ 588. This indicates that inhalation of n-pentane in occupational settings should not be of immediate concern for repeated dose toxicity: **conclusion (ii)**.

According to n-pentane measurements made in the Norwegian industry (given in Section 4) it is feasible for the industry to keep the level of exposure far below the Norwegian administrative norm of 750 mg/m<sup>3</sup> (given in **Table 4.1**). In European countries beside Norway the current OEL varies from 1,500 to 3,000 mg/m<sup>3</sup>.

### Mutagenicity

n-Pentane was not positive in any of the studies reported on mutagenicity (see Section 4.1.2.7.1), and it is concluded that n-pentane is of no concern: **conclusion (ii)**.

### Carcinogenicity

Based on the mutagenicity data (see Section 4.1.2.7.1), n-pentane is considered not to be genotoxic to workers.

There are no data available on carcinogenicity of n-pentane. Given that the substance is not genotoxic and that there are no case reports on carcinogenic effects suspecting n-pentane to be the cause, it is considered that n-pentane is of no concern: **conclusion (ii)**.

### Toxicity for reproduction

No signs of toxicity were observed on the reproductive system after exposure to n-pentane up to 20,000 mg/m<sup>3</sup> in a 13-week sub-chronic inhalation study. In a developmental toxicity study in female rats exposed to n-pentane by oral gavage from gestation day 6-15, the NOAEL was  $\geq 1,000$  mg/kg/day for dams and offspring (Section 4.1.2.9). It is concluded that n-pentane is of no concern: **conclusion (ii)**.

## **4.1.3.3 Consumers**

### Introduction

Consumers may be exposed by inhalation to n-pentane mainly by the use of hair spray, antiperspirants, paints and car care products.

### Comparison of exposure and effects

Quantitative exposure data are available for two consumer exposure scenario, namely from the use of hair spray, which is estimated to be the highest consumer exposure to n-pentane, and from inhalation of n-pentane during filling a car fuel tank. However, the risk characterisation of the latter will be assessed if petroleum product risk assessment reports will be elaborated.

#### *Consumer exposure by use of hair spray*

The inhalation dose from a TGD estimate is calculated to be 7.8 mg/kg/day, from an empirical estimate 2.75 mg/kg/day, and from a worst -case exposure estimate 10.3 mg/kg/day.

The overall NOAEL of  $\geq 20,000$  mg/m<sup>3</sup> n-pentane from a 90-day repeated dose inhalation toxicity study is used in the risk assessment. In order to estimate a Margin of Safety (MOS), the NOAEL for the inhaled dose of n-pentane based on the exposure conditions need to be calculated. The following calculation was used: 20,000 mg/m<sup>3</sup> (rat) = 1,766 mg/kg/day (rat) (when it is estimated that the volume inhaled in rat is 4.4 L/hour (Gad and Chengelis, 1992), inhalation time is 6 hours (see study description), and the rat body weight is 0.3 kg). This gives a MOS value greater than 226 for the TGD estimate, a MOS greater than 642 for the empirical estimate, and a MOS for the worst-case estimate greater than 171 (see **Table 4.22**). These MOS values are only estimates, and the most reliable MOS value is greater than 642 (empirical estimate), since in the TGD estimate it is assumed that the exposure time is 6 min, which is a really long hair spray time.

No concern for consumers is expected: **conclusion (ii)**.

**Table 4.22** MOS values for consumer exposure to n-pentane during hair spraying

Exposure estimates (see Section 4.1.1.3.1)	MOS values
TGD estimates (7.8 mg/kg/day)	226
Empirical estimate (2.75 mg/kg/day)	642
Worst-case estimate (10.3 mg/kg/day)	171

#### 4.1.3.4 Humans exposed via the environment

##### Introduction

The only important exposure route of the general population to n-pentane via the environment is in air. The local predicted environmental concentration (PEC<sub>local</sub>) of n-pentane in air is from industrial or private use. Because of the rapid breakdown of n-pentane in air, the regional concentration (PEC<sub>regional</sub>) is not expected to contribute significantly to the indirect exposure to n-pentane. However, PEC<sub>regional</sub> (0.32 µg/m<sup>3</sup>, see **Table 3.10**) is added to the local PECs.

##### Comparison of exposure and effect

The exposure to humans in the environment via air is estimated to be the main contribution of exposure to n-pentane, and the predicted environmental concentration (PEC<sub>local</sub>) is estimated in Section 3.1.4.1, **Table 3.9** and range from 0.0048 to 0.14 mg/m<sup>3</sup>, which corresponds to a human inhalation dose from  $1.37 \cdot 10^{-3}$  to 0.04 mg/kg/day (see Section 4.1.1.4 for calculations). No chronic effects due to inhalation of n-pentane in animals are observed at high concentrations of n-pentane. The overall NOAEL from a 90-day repeated dose inhalation toxicity study is  $\geq 20,000$  mg/m<sup>3</sup> and is the NOAEL value used in the risk assessment. This NOAEL value corresponds to an inhalation dose at 1,766 mg/kg/day (rat) (see Section 4.1.3.2 for calculations). The Margin of Safety (MOS) calculated from PEC<sub>local</sub> ranged therefore from  $4.4 \cdot 10^4$  to  $1.3 \cdot 10^6$ . The indirect human exposure values based on EUSES calculations (see **Table 4.17**) and the corresponding MOS values is given in **Table 4.23**. These MOS values based on EUSES calculations range from  $1.0 \cdot 10^4$  to  $1.9 \cdot 10^7$ . Accordingly, the MOS values calculated from PEC<sub>local</sub> and indirect exposure based on EUSES calculations are considered sufficient.

The substance is of no concern in relation to indirect exposure via the environment: **conclusion (ii)**.

**Table 4.23** MOS values for humans exposed via the environment, local and regional

Life cycle	Step	Dose (mg/kg/day)	MOS values <sup>1)</sup>
Production		0.031	$5.7 \cdot 10^4$
EPS Foaming	formulation	0.05	$3.5 \cdot 10^4$
	processing	0.054	$3.3 \cdot 10^4$
	private use	$5.1 \cdot 10^{-4}$	$3.5 \cdot 10^6$
PUR Foaming	formulation	0.074	$2.4 \cdot 10^4$
	private use	$1.5 \cdot 10^{-4}$	$1.2 \cdot 10^7$

Table 4.23 continued overleaf

**Table 4.23 continued** MOS values for humans exposed via the environment, local and regional

Life cycle	Step	Dose (mg/kg/day)	MOS values <sup>1)</sup>
Polymer diluent	formulation	0.174	$1.0 \cdot 10^4$
	processing	$1.05 \cdot 10^{-3}$	$1.7 \cdot 10^6$
Aerosols	private use	$2.9 \cdot 10^{-4}$	$6.1 \cdot 10^6$
Adhesives	formulation	$1.23 \cdot 10^{-4}$	$1.4 \cdot 10^7$
	processing	$4.3 \cdot 10^{-3}$	$4.1 \cdot 10^5$
Laboratory	processing	$1.02 \cdot 10^{-4}$	$1.7 \cdot 10^7$
Other uses	formulation	$4.08 \cdot 10^{-4}$	$4.3 \cdot 10^6$
	processing	0.011	$1.6 \cdot 10^5$
	private use	$9.1 \cdot 10^{-5}$	$1.9.5 \cdot 10^7$
Regional		$9.1 \cdot 10^{-5}$	$1.9.5 \cdot 10^7$

1) Based on a NOAEL  $\geq 20,000$  mg/m<sup>3</sup> (i.e. 1,766 mg/kg/day)

As discussed in Sections 3.1.2.1.1 and 3.1.4.5 it is known that n-pentane contributes to tropospheric VOC and contributes to the tropospheric formation of ozone. The photochemically formation of ozone and other compounds depends on emission of all VOCs and other compounds in a complex interaction with other factors.

The VOC speciation and concentrations, VOC/NO<sub>x</sub> ratio, solar radiation and meteorological conditions vary from city to city within EU. Since the environmental conditions differ considerably a certain concentration of VOC may lead to very different ozone concentrations within Europe. Thus the effects on ozone creation of emissions arising from the production and use of the isolated commercial product n-pentane may differ substantially between different regions in the EU.

The industrial use of the commercial product n-pentane contributes significantly to the overall emission of n-pentane, however, emission of n-pentane from car fuels and exhaust gases seem to be the largest single source.

It was estimated that emission of n-pentane from the use and production of isolated n-pentane may be in the order of 0.16–0.4% of the total NMVOC emissions. Locally and regionally this proportion may vary substantially due to differences between regions in the VOC emission pattern from industrial sectors using n-pentane.

The current risk assessment does not cover non-isolated n-pentane. Thus evaluation of the possible effects of emission of n-pentane from car fuels is outside the scope of this risk assessment. However, on the basis of monitoring of NMVOCs in street air (see Section 3.1.4.5.1) there is indication that non-isolated pentane can contribute with about 3.5% to the overall ozone formation due to NMVOCs.

Ozone exposure has been documented to give rise to severe effects in humans.

In 1995, 90% of the EU population (both urban and rural) experienced an exceedance of the current EU threshold for health protection ( $110 \mu\text{g}/\text{m}^3$ , 8 hours average, directive 92/72/EEC) for at least one day during summer 1995. Over 80% experienced exposure above the threshold for more than 25 days. The highest concentrations ( $\geq 240 \mu\text{g}/\text{m}^3$ ) were recorded in Italy and Greece (WHO, 1999).

In 1999 the threshold for information of the public in EU ( $180 \mu\text{g}/\text{m}^3$ , 1-hour average) were not exceeded in 4 member states while up to 70% of the monitoring stations in other member states did exceed this threshold (Sluyter and Camu, 1999). On average 27% of all monitoring stations in EU did exceed the threshold. The number of days that the threshold was exceeded ranged from 2 days in Luxembourg to 68 days in Italy (out of 153 days in the reporting season).

The severity of exceedance of the EU threshold for health protection ( $110 \mu\text{g}/\text{m}^3$ , 8-hour average, directive 92/72/EEC) has been estimated by WHO (1999). The 1995 summer ozone incidence is estimated to have caused 1,500-3,700 deaths (0.1-0.2% of all deaths) and further 300-1,000 extra emergency hospital admissions due to respiratory diseases. "It is likely that the total number of health impacts is higher than the estimated impact of the days with high levels only. This is suggested by epidemiological studies where the effects can be seen also below the  $110 \mu\text{g}/\text{m}^3$  level" (WHO, 1999).

If these figures are used to estimate the impact of emissions from the production and use of isolated n-pentane through formation of ozone then this emission may very roughly estimated have caused around 3–15 deaths in summer 1995, this if a linear relationship exists between the emission of n-pentane, the emission of NMVOCs and the creation of ozone.

However, no simple relationship has been established between the proportion of n-pentane to total NMVOC emitted - and thus also between emissions arising from the use of the commercial product n-pentane - and the creation of tropospheric ozone. One should also keep in mind that it is the combination of  $\text{NO}_x$  and VOC and other factors that causes tropospheric ozone formation, and that cars are the main source of NMVOC compounds in cities.

However, based on this risk reduction measures it seems necessary to consider **conclusion (iii)**. This conclusion applies, in the context of the Regulation on Existing Substances, to the contribution of the commercial product (isolated) n-pentane to the formation of ozone. Considering the most appropriate risk reduction measures, it is recommended that under the relevant air quality Directives a specific in-depth evaluation be performed. Such an evaluation should focus on the contribution of isolated as well as non-isolated n-pentane to the complex issue of ozone and smog formation and the resulting impact on air quality.

## 4.2 HUMAN HEALTH (PHYSICO-CHEMICAL PROPERTIES)

### 4.2.1 Effect assessment: Hazard identification

#### 4.2.1.1 Explosivity

Based on the structure of the molecule n-pentane is not expected to have explosive properties as such. However, n-pentane is a volatile liquid and a mixture of air and n-pentane may burn explosively. Its explosive limits in air range from 1.4% (Lower Explosive Limit) to 8% (Upper Explosive Limit) by volume.

Normal pentane can accumulate static charges which can cause an incendiary electrical discharge (ignition source).

#### 4.2.1.2 Flammability

Normal pentane is highly flammable (flash point – 46°C, auto ignition temperature 285°C). According to Annex I to Directive 67/548/EEC n-pentane is classified as Extremely flammable, F+; R12. Cf. Classification in Section 1.4.

#### 4.2.1.3 Oxidising potential

No oxidising properties expected based on structural formula.

### 4.2.2 Risk characterisation

Regarding physico-chemical properties flammability is of concern for n-pentane since it is a volatile liquid which is highly flammable and can form explosive mixtures with air.

In production and occupational use the flammability risk is not of concern provided that adequate measures are taken. According to the EU classification, packaging and labelling directives information about the flammability hazard must be provided on the label and in the safety data sheets.

Concerning use by consumers information about the flammability hazard and precautionary measures must be given by a label on the product. In the EU, symbol, risk phrases and safety phrases are used for labelling of extremely flammable substances and preparations cf. Classification in Section 1.4.

Furthermore the electrostatic accumulation hazard is of concern for n-pentane. Facilities must be designed to avoid possible ignition by static discharge, for example by earthing of equipment. According to the the EU classification, packaging and labelling directives, particularly the provisions concerning safety data sheets, information about the risks and about precautionary measures during storage and handling must be given in the safety data sheet. Provided that the information is given and adequate measures are taken the risk of static charges and electric discharges (ignition source) is not of concern: **conclusion (ii)**.

## 5 RESULTS

The present report covers assessment of the risks associated with the life cycle of isolated n-pentane, i.e. the production of the commercial product n-pentane, EINECS No. 203-692-4, and the production and use of products containing the commercial product n-pentane. The present report does not cover assessment of risks connected to the presence of n-pentane (non-isolated n-pentane) in other EINECS substances, particularly petroleum products such as gasoline and other crude oil products. According to Council Regulation (EEC) 793/93 non-isolated n-pentane is not a part of the present risk assessment. However, crude estimates of exposure to n-pentane from gasoline have been included for illustrative purposes and for the evaluation of regional n-pentane concentrations.

### 5.1 ENVIRONMENT

**Conclusion (iii)** There is a need for limiting the risks; risk reduction measures which are already being applied shall be taken into account.

This conclusion is reached for the atmosphere because of the contribution of isolated n-pentane to the formation of ozone and other harmful substances i.e. smog formation.

**Conclusion (ii)** There is at present no need for further information and/or testing and for risk reduction measures beyond those which are being applied already.

This conclusion applies to the aquatic environment and the terrestrial compartment. All PEC/PNEC values for the aquatic environment and the terrestrial compartment are below 1, indicating no cause for concern.

### 5.2 HUMAN HEALTH

#### 5.2.1 Human health (toxicity)

##### 5.2.1.1 Workers

**Conclusion (ii)** There is at present no need for further information and/or testing and for risk reduction measures beyond those which are being applied already.

##### 5.2.1.2 Consumers

**Conclusion (ii)** There is at present no need for further information and/or testing and for risk reduction measures beyond those which are being applied already.

##### 5.2.1.3 Humans exposed via the environment

**Conclusion (iii)** There is a need for limiting the risks; risk reduction measures which are already being applied shall be taken into account.



This conclusion is reached because of the contribution of isolated n-pentane to the formation of ozone and other harmful substances i.e. smog formation.

### **5.2.2 Human health (risks from physico-chemical properties)**

**Conclusion (ii)** There is at present no need for further information and/or testing and for risk reduction measures beyond those which are being applied already.

This conclusion is reached because the flammability risk risk of static charges and electric discharges (ignition source) are not of concern provided that the information is given and adequate measures are taken.

According to the EU classification, packaging and labelling directives, information on the flammability hazard and on precautionary measures during storage and handling must be provided on the label and in the safety data sheets.

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## ABBREVIATIONS

ADI	Acceptable Daily Intake
AF	Assessment Factor
ASTM	American Society for Testing and Materials
ATP	Adaptation to Technical Progress
AUC	Area Under The Curve
B	Bioaccumulation
BBA	Biologische Bundesanstalt für Land- und Forstwirtschaft
BCF	Bioconcentration Factor
BMC	Benchmark Concentration
BMD	Benchmark Dose
BMF	Biomagnification Factor
BOD	Biochemical Oxygen Demand
bw	body weight / <i>Bw</i> , <i>bw</i>
C	Corrosive (Symbols and indications of danger for dangerous substances and preparations according to Annex II of Directive 67/548/EEC)
CA	Chromosome Aberration
CA	Competent Authority
CAS	Chemical Abstract Services
CEC	Commission of the European Communities
CEN	European Standards Organisation / European Committee for Normalisation
CEPE	European Committee for Paints and Inks
CMR	Carcinogenic, Mutagenic and toxic to Reproduction
CNS	Central Nervous System
COD	Chemical Oxygen Demand
CSTEE	Scientific Committee for Toxicity, Ecotoxicity and the Environment (DG SANCO)
CT <sub>50</sub>	Clearance Time, elimination or depuration expressed as half-life
d.wt	dry weight / <i>dw</i>
dfi	daily food intake
DG	Directorate General
DIN	Deutsche Industrie Norm (German norm)
DNA	DeoxyriboNucleic Acid
DOC	Dissolved Organic Carbon
DT50	Degradation half-life or period required for 50 percent dissipation / degradation
DT90	Period required for 90 percent dissipation / degradation

E	Explosive (Symbols and indications of danger for dangerous substances and preparations according to Annex II of Directive 67/548/EEC)
EASE	Estimation and Assessment of Substance Exposure Physico-chemical properties [Model]
EbC50	Effect Concentration measured as 50% reduction in biomass growth in algae tests
EC	European Communities
EC10	Effect Concentration measured as 10% effect
EC50	median Effect Concentration
ECB	European Chemicals Bureau
ECETOC	European Centre for Ecotoxicology and Toxicology of Chemicals
ECVAM	European Centre for the Validation of Alternative Methods
EDC	Endocrine Disrupting Chemical
EEC	European Economic Communities
EINECS	European Inventory of Existing Commercial Chemical Substances
ELINCS	European List of New Chemical Substances
EN	European Norm
EPA	Environmental Protection Agency (USA)
ErC50	Effect Concentration measured as 50% reduction in growth rate in algae tests
ESD	Emission Scenario Document
EU	European Union
EUSES	European Union System for the Evaluation of Substances [software tool in support of the Technical Guidance Document on risk assessment]
F(+)	(Highly) flammable (Symbols and indications of danger for dangerous substances and preparations according to Annex II of Directive 67/548/EEC)
FAO	Food and Agriculture Organisation of the United Nations
FELS	Fish Early Life Stage
foc	Organic carbon factor (compartment depending)
GLP	Good Laboratory Practice
HEDSET	EC/OECD Harmonised Electronic Data Set (for data collection of existing substances)
HELCOM	Helsinki Commission -Baltic Marine Environment Protection Commission
HPLC	High Pressure Liquid Chromatography
HPVC	High Production Volume Chemical (> 1000 t/a)
IARC	International Agency for Research on Cancer
IC	Industrial Category
IC50	median Immobilisation Concentration or median Inhibitory Concentration
ILO	International Labour Organisation
IPCS	International Programme on Chemical Safety
ISO	International Organisation for Standardisation
IUCLID	International Uniform Chemical Information Database (existing substances)

IUPAC	International Union for Pure and Applied Chemistry
JEFCA	Joint FAO/WHO Expert Committee on Food Additives
JMPR	Joint FAO/WHO Meeting on Pesticide Residues
K <sub>oc</sub>	organic carbon normalised distribution coefficient
K <sub>ow</sub>	octanol/water partition coefficient
K <sub>p</sub>	solids-water partition coefficient
L(E)C <sub>50</sub>	median Lethal (Effect) Concentration
LAEL	Lowest Adverse Effect Level
LC <sub>50</sub>	median Lethal Concentration
LD <sub>50</sub>	median Lethal Dose
LEV	Local Exhaust Ventilation
LLNA	Local Lymph Node Assay
LOAEL	Lowest Observed Adverse Effect Level
LOEC	Lowest Observed Effect Concentration
LOED	Lowest Observed Effect Dose
LOEL	Lowest Observed Effect Level
MAC	Maximum Allowable Concentration
MATC	Maximum Acceptable Toxic Concentration
MC	Main Category
MITI	Ministry of International Trade and Industry, Japan
MOE	Margin of Exposure
MOS	Margin of Safety
MW	Molecular Weight
N	Dangerous for the environment (Symbols and indications of danger for dangerous substances and preparations according to Annex II of Directive 67/548/EEC)
NAEL	No Adverse Effect Level
NOAEL	No Observed Adverse Effect Level
NOEL	No Observed Effect Level
NOEC	No Observed Effect Concentration
NTP	National Toxicology Program (USA)
O	Oxidizing (Symbols and indications of danger for dangerous substances and preparations according to Annex III of Directive 67/548/EEC)
OC	Organic Carbon content
OECD	Organisation for Economic Cooperation and Development
OEL	Occupational Exposure Limit
OJ	Official Journal
OSPAR	Oslo and Paris Convention for the protection of the marine environment of the Northeast Atlantic

P	Persistent
PBT	Persistent, Bioaccumulative and Toxic
PBPK	Physiologically Based Pharmacokinetic modelling
PBTK	Physiologically Based Toxicokinetic modelling
PEC	Predicted Environmental Concentration
pH	logarithm (to the base 10) (of the hydrogen ion concentration $\{H^+\}$ )
pKa	logarithm (to the base 10) of the acid dissociation constant
pKb	logarithm (to the base 10) of the base dissociation constant
PNEC	Predicted No Effect Concentration
POP	Persistent Organic Pollutant
PPE	Personal Protective Equipment
QSAR	(Quantitative) Structure-Activity Relationship
R phrases	Risk phrases according to Annex III of Directive 67/548/EEC
RAR	Risk Assessment Report
RC	Risk Characterisation
RfC	Reference Concentration
RfD	Reference Dose
RNA	RiboNucleic Acid
RPE	Respiratory Protective Equipment
RWC	Reasonable Worst Case
S phrases	Safety phrases according to Annex IV of Directive 67/548/EEC
SAR	Structure-Activity Relationships
SBR	Standardised birth ratio
SCE	Sister Chromatic Exchange
SDS	Safety Data Sheet
SETAC	Society of Environmental Toxicology And Chemistry
SNIF	Summary Notification Interchange Format (new substances)
SSD	Species Sensitivity Distribution
STP	Sewage Treatment Plant
T(+)	(Very) Toxic (Symbols and indications of danger for dangerous substances and preparations according to Annex III of Directive 67/548/EEC)
TDI	Tolerable Daily Intake
TG	Test Guideline
TGD	Technical Guidance Document
TNsG	Technical Notes for Guidance (for Biocides)
TNO	The Netherlands Organisation for Applied Scientific Research
ThOD	Theoretical Oxygen Demand

UC	Use Category
UDS	Unscheduled DNA Synthesis
UN	United Nations
UNEP	United Nations Environment Programme
US EPA	Environmental Protection Agency, USA
UV	Ultraviolet Region of Spectrum
UVCB	Unknown or Variable composition, Complex reaction products of Biological material
vB	very Bioaccumulative
VOC	Volatile Organic Compound
vP	very Persistent
vPvB	very Persistent and very Bioaccumulative
v/v	volume per volume ratio
w/w	weight per weight ratio
WHO	World Health Organization
WWTP	Waste Water Treatment Plant
Xn	Harmful (Symbols and indications of danger for dangerous substances and preparations according to Annex II of Directive 67/548/EEC)
Xi	Irritant (Symbols and indications of danger for dangerous substances and preparations according to Annex II of Directive 67/548/EEC)

## Appendix A Environmental distribution of n-pentane model simulation

Fugacity Level 1: Mackay and Peterson 1990

DB 4 v.0.1 Miljøstyrelsen 27.06.91 j.r.n.

### Compound Properties

Molecular weight	72.15	g/mol
Vapour pressure	56,580	Pa
Solubility water	38.5	mg/l
	0.53	mol/m <sup>3</sup>
Henry const.	106,030	Pa · m <sup>3</sup> /mol
Log Kow	3.45	
Octanol-water partition coefficient	2,818.38	
Organic C-water partition coefficient	1,155.54	
Air-water partition coefficient	43.50	
Soil-water partition coefficient	34.67	
Sediment-water partition coefficient	69.33	
Amount of compound (mol)	1,000	
Fugacity (Pa)	4.0619 · 10 <sup>-2</sup>	

### Phase properties

	Air	Water	Soil	Sediment
Volume	6.0 · 10 <sup>9</sup>	7.0 · 10 <sup>6</sup>	4.5 · 10 <sup>5</sup>	2.1 · 10 <sup>5</sup>
Density (kg/m <sup>3</sup> )	12.06	1.0 · 10 <sup>3</sup>	1.5 · 10 <sup>3</sup>	1.5 · 10 <sup>3</sup>
Conc. (g/m <sup>3</sup> )	1.202 · 10 <sup>-5</sup>	2.764 · 10 <sup>-7</sup>	9.581 · 10 <sup>-6</sup>	1.916 · 10 <sup>-5</sup>
Amount (mol)	999.96	2.681 · 10 <sup>-2</sup>	5.976 · 10 <sup>-3</sup>	5.577 · 10 <sup>-3</sup>
%	100	2.681 · 10 <sup>-3</sup>	5.976 · 10 <sup>-4</sup>	5.577 · 10 <sup>-4</sup>

## Appendix B Exposure from n-pentane in gasoline and gasoline vapours

In the EU the annual consumption of motor gasoline is about 120 M tonnes (CONCAWE, 1996). This volume of fuel will contain about 5.2 M tonnes of n-pentane.

Gasoline is a complex mixture of volatile hydrocarbons, mainly C<sub>4</sub> to C<sub>11</sub>-hydrocarbons. The composition will vary depending on the origin and quality of the crude oils used, processing technique and the required performance characteristics and product specifications. The correct volatility is achieved by blending light hydrocarbons such as butanes and pentanes into the gasoline.

Distillation, cracking, and reforming plants produce most blending components, from which the end product, gasoline, is blended in line. In this way all the processing takes place in closed systems.

When liquid gasoline, which has a boiling point in the range of 25-220°C, is exposed to air, the more volatile components will evaporate first. Therefore, the lighter hydrocarbons, including n-pentane, is somewhat enriched in the vapour compared to the liquid petrol. The predominant compounds in the vapour are C<sub>3</sub>-C<sub>8</sub> alkanes. McDermott and Killany (1978) reported the vapour content of C<sub>3</sub>-C<sub>8</sub> alkane compounds to be approximately 83% by volume. The content of C<sub>4</sub> and C<sub>5</sub> compounds, constitute from 55 to 85% by weight of a typical vapour (Halder et al., 1986; Kearney and Dunham, 1986; CONCAWE, 1995). The four compounds n-butane, isobutane, n-pentane and isopentane together contribute to > 90% of all the C<sub>4</sub>/C<sub>5</sub> components present (Halder et al., 1986; CONCAWE, 1995). The content of n-pentane in liquid and vapour gasolines are shown in **Table B.1**.

**Table B.1** Content of n-pentane in liquid and vapour gasolines

Liquid Gasoline (wt%)		Gasoline Vapour (vol%)		Comments	Reference
Range	Mean	Range	Mean		
4.5-12.4	9.7	16.7-30.4	23.3	10 european gasolines analysed	CONCAWE (1987)
1,1-8,1	4,3			analyses from 12 German refineries	18
			7,0	U.S. analyses during truck loading	McDermott and Killany (1978)
		8,1-10,9(+)		analyses of gasoline from 3 companies	Halder et al. (1986)

### Occupational exposure

Occupational exposure to workers can occur in all steps of gasoline handling: in refineries, in tank storage depots, when loading gasoline into tank trucks, unloading trucks at service stations and when dispensing into automobile tanks at service stations. The three main worker groups who are exposed are: Terminal operators, truck drivers/salesmen, and service station attendants.

Exposure to pentane in the refineries occurs primarily during drumfilling, truckloading, and sampling/monitoring the batches. Leaking fill lines and spillage of gasoline may also contribute to the workers' exposure. However, such scenarios are incidentally and the exposure to n-pentane

is assumed to be negligible. **Table B.2** shows exposure data for n-pentane from handling gasoline.

**Table B.2** Exposure to n-pentane from handling gasoline

	Mean mg/m <sup>3</sup>	Min. - Max. mg/m <sup>3</sup>	Reference
Truck drivers		0-337 <sup>1) 2)</sup>	Phillips and Jones (1978)
Truck drivers	70	1-465 <sup>1)</sup>	CONCAWE (1987)
Terminal operators Marine loading facilities	5,3 <sup>3)</sup> 5,1 <sup>3)</sup>	0,1-24 <sup>3)</sup>	Halder et al. (1986)
Transport drivers	4.6	2.6-6.6 <sup>4)</sup>	Rappaport et al. (1987)
<u>Service attendants</u> With vapour recovery Without vapour recovery	0.15 21		Berglund and Petersson (1990)
High volume service station <sup>5)</sup>		0.3-5	Kearney and Dunham (1986)
Service station		0,2 -51 <sup>6)</sup>	McDermott and Vos (1979)
Service station	0,6 <sup>7)</sup>	- 20	Halder et al. (1986)

- 1) estimated from TWA total gasoline vapour concentrations, assuming a n-pentane content of 15% by volume
- 2) 90% of the samples did not exceed 113 mg/m<sup>3</sup>
- 3) estimated values from monitoring data of C<sub>4</sub>/C<sub>5</sub> components, see Appendix A
- 4) 95% confidence limits
- 5) on average 19 cars/hour were served
- 6) estimated from TWA total gasoline vapour concentrations, assuming a pentane content of 15% by volume.
- 7) geometric mean

At the refinery terminals, gasoline of various grades is pumped from storage tanks to loading racks and delivered to the tank trucks through flexibly jointed loading arms. Exposure to truck drivers is essentially determined by the number of loading and unloading operations, whereas driving the tanker is of little significance (CONCAWE, 1987). One driver may handle from one to seven loads per shift, but three to five loads are common (Phillips and Jones, 1978). Typical loading time is 10-20 min.

In a Swedish study (Berglund and Petersson, 1990) the breathing zone concentration of pentane during refuelling was investigated at different service stations with and without vapour recovery. The study demonstrated a large difference in the exposure levels between the two types of stations, an average air concentration of 0.15 and 21 mg/m<sup>3</sup>, respectively. These results were considered to be fairly typical for the composition of petrol vapours in Western Europe.

#### Consumer exposure to gasoline

Exposure to n-pentane may arise as a result of inhalation of gasoline vapour during filling a car fuel tank. Halder et al. (1986) found that n-butane, iso-butane, n-pentane and iso-pentane together accounted for approximately 61-67% of the total gasoline vapour, and the average content of n-pentane in gasoline vapour was found to be 23.3% by volume (DGMK project 477, 1995). Short-term exposure of self-service customers during filling from 21 samples was found to be 244 (52.3-729) mg/m<sup>3</sup> total hydrocarbons. The n-pentane concentrations from these exposures are calculated to be 56.8 mg/m<sup>3</sup> (12.2-169.8 mg/m<sup>3</sup>) or 19 (4-57) ppm [23.3% of 244 (52.3-729) mg/m<sup>3</sup>]. The human exposure to n-pentane during filling a car gasoline tank is then



estimated to be 0.0066 mg/kg bw/day when the concentration of n-pentane in petrol vapour is 56.8 mg/m<sup>3</sup> and man (70 kg body weight, TGD default value) has an average lung ventilation rate of 20 m<sup>3</sup>/day (0.014 m<sup>3</sup>/min, TGD default value). Furthermore, the average time taken to fill a gasoline tank is 2 min, and it is assumed that the gasoline tank is filled two times per week. However, the consumers exposure to n-pentane due to its being a constituent of gasoline, should be further assessed if a petroleum products risk assessment report will be elaborated.



European Commission

**EUR 20845 EN      European Union Risk Assessment Report  
n-pentane, Volume 40**

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Environment and quality of life series

The report provides the comprehensive risk assessment of the substance n-pentane. It has been prepared by Norway in the frame of Council Regulation (EEC) No. 793/93 on the evaluation and control of the risks of existing substances, following the principles for assessment of the risks to humans and the environment, laid down in Commission Regulation (EC) No. 1488/94.

The evaluation considers the emissions and the resulting exposure to the environment and the human populations in all life cycle steps. Following the exposure assessment, the environmental risk characterisation for each protection goal in the aquatic, terrestrial and atmospheric compartment has been determined. For human health the scenarios for occupational exposure, consumer exposure and humans exposed via the environment have been examined and the possible risks have been identified.

The human health risk assessment for n-pentane concludes that there is no concern for workers and consumers. For humans exposed via the environment there is concern because of the contribution of isolated n-pentane to the formation of ozone and other harmful substances i.e. smog formation.

The environmental risk assessment for n-pentane concludes that there is concern for the atmosphere because of the contribution of isolated n-pentane to the formation of ozone and other harmful substances i.e. smog formation. There is no risk identified for the aquatic and terrestrial ecosystems.

The conclusions of this report will lead to risk reduction measures to be proposed by the Commissions committee on risk reduction strategies set up in support of Council Regulation (EEC) N. 793/93.

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