

Special Report No. 13

Occupational Exposure Limits for Hydrocarbon Solvents

August 1997

ISSN-0773-8072-13

Brussels, August 1997
® ECETOC copyright

ECETOC Special Report No. 13

© Copyright - ECETOC (European Centre for Ecotoxicology and Toxicology of Chemicals), 4 Avenue E. Van Nieuwenhuysse (Bte 6), 1160 - Brussels, Belgium.

All rights reserved. No part of this publication may be reproduced, copied, stored in retrieval system or transmitted in any form or by any means, electronic, mechanical, photocopying, recording or otherwise without the prior written permission of the copyright holder. Applications to reproduce, store, copy or translate should be made to the Secretary General. ECETOC welcomes such applications. Reference to the document, its title and summary may be copied or abstracted in data retrieval systems without subsequent reference.

The content of this document has been prepared and reviewed by experts on behalf of ECETOC with all possible care and from the available scientific information. It is provided for information only. ECETOC cannot accept any responsibility or liability and does not provide a warranty for any use or interpretation of the material contained in the publication.

ECETOC SPECIAL REPORT No. 13
on
Occupational Exposure Limits for Hydrocarbon Solvents

CONTENTS

SUMMARY	1
1. INTRODUCTION	2
1.1 HYDROCARBON SOLVENTS, PRODUCT DESCRIPTION	2
1.2 OCCUPATIONAL EXPOSURE LIMITS (OELs)	3
1.3 BLENDING AND PROCESSING	3
2. PROCEDURES FOR ASSIGNING OELS TO COMPLEX HYDROCARBON SOLVENTS	5
2.1 GENERAL	5
2.2 TYPICAL HYDROCARBON SOLVENTS AND BLENDS	7
2.3 CHARACTERISTICS OF HYDROCARBON SOLVENTS IN RELATION TO ASSIGNING OELs	9
2.4 EXISTING METHODOLOGIES FOR ASSIGNING OELs TO MIXTURES	14
2.5 COMPARISONS OF GENERIC APPROACHES	20
2.6 CRITERIA FOR SELECTION	25
3. EXPOSURE MONITORING	28
3.1 INTRODUCTION	28
3.2 SAMPLING AND ANALYSIS	28
3.3 ANALYTICAL METHOD STANDARDISATION	29
3.4 WORKPLACE MONITORING METHODS	29

4. TOXICOLOGICAL OVERVIEW.....	33
4.1 INTRODUCTION	33
4.2 CENTRAL NERVOUS SYSTEM EFFECTS.....	34
4.3 NEPHROTOXICITY	37
4.4 TOXICITY OF SPECIFIC HYDROCARBONS.....	40
4.5 SUMMARY OF THE TOXICOLOGY INFORMATION.....	42
4.6 UNDERLYING ASSUMPTIONS FOR THE JUSTIFICATION OF THE APPLICATION OF THE RCP	42
4.7 CONCLUSION.....	44
5. CONCLUSIONS	45
BIBLIOGRAPHY	47
APPENDIX I. THRESHOLD LIMIT VALUES FOR MIXTURES.....	52
APPENDIX II. CHROMATOGRAPHIC ANALYSIS OF A STANDARD WHITE SPIRIT	56
MEMBERS OF THE TASK FORCE	58
MEMBERS OF THE SCIENTIFIC COMMITTEE.....	60

SUMMARY

The objectives of this work were to review the generic methods currently available for deriving occupational exposure limits (OELs) for complex hydrocarbon solvents and to determine the most scientifically-acceptable procedure.

To accomplish that objective the Task Force has defined hydrocarbon solvents, identified their important physical and chemical properties and reviewed the existing approaches for setting OELs. A critical review of monitoring methods and the toxicological and epidemiological information was also carried out. Criteria were set by which the merits of the available approaches could be judged. This process led to the conclusion that the best available method was a reciprocal calculation procedure (RCP), following the general guidance provided by the American Conference of Governmental Industrial Hygienists (ACGIH). It was noted that, of the procedures currently being used in Europe, the one recommended by the UK Health and Safety Executive (UK-HSE) is the most consistent with the views of the ECETOC Task Force. It was agreed that the assignment of OELs to groups of constituents as recommended by the UK-HSE, a prerequisite for the application of a RCP, was reasonable and pragmatic and makes the best use of the available information. Thus the Task Force recommends that, for calculating an OEL of a mixture or a blend of hydrocarbons, the most appropriate procedure is to use a RCP and to take account of all constituents.

The use of the RCP is only justified if the various constituents of hydrocarbon solvents have similar toxicity and act in an additive manner. A review of the toxicology of hydrocarbons concluded that, with the exception of n-hexane, the molecules which comprise hydrocarbon solvents are toxicologically similar and act in an additive manner. For hydrocarbons in general it was found that the most sensitive health effect is central nervous system (CNS) depression, and it was concluded that this effect could be a basis for setting OELs. The peripheral neurotoxicity of n-hexane is unique and not additive, but n-hexane has its own OEL to protect from this effect. If the OEL for n-hexane is used in a RCP with OELs for other constituents, the resulting OEL for the solvent will assure that exposure to n-hexane would not exceed its own OEL. Thus the exceptional character of n-hexane does not invalidate the use of the RCP approach.

The method does not apply if the ratios of the vapour concentrations of the constituents are significantly different from those of the constituents in the liquid. In the exceptional case where this occurs the RCP should be applied to the vapour composition. The RCP method should not be applied to high-boiling solvents, as at boiling points above 220° C a RCP method could produce a calculated OEL, which exceeds the saturated vapour concentration.

1. INTRODUCTION

1.1 HYDROCARBON SOLVENTS, PRODUCT DESCRIPTION

Hydrocarbon solvents are produced by the distillation of petroleum feedstock, sometimes followed by additional processing steps, such as solvent extraction, hydrodesulphurisation or hydrotreatment, and by blending. They contain a large number of individual hydrocarbons of between 5 and 15 carbon atoms and boil within the range of 35-320° C. Altogether they could contain over 5,000 different molecular species. They are generally described as being either "aliphatic" (normal- and iso-paraffinic or alkanes), "alicyclic" ("naphthenic" or cycloalkanes) or "aromatic" but in practice they are often mixtures of these three types of molecules. Hydrocarbon solvents are manufactured according to specification depending on the solvent properties required and consequently differ in composition. Many different substances and preparations (blends) are marketed, and health and safety properties may differ depending on chemical composition.

Hydrocarbon solvents manufactured directly from feedstock are considered to be substances under present regulations and appropriate CAS/EINECS numbers (further indicated as CAS) have been assigned. During the preparation of the inventories of existing substances for the US Toxic Substances Control Act (TSCA) and the European Directive 67/548/EC, all refinery streams were characterised on the basis of their refining history and given unique CAS numbers in order to include them in the inventories of existing substances. These definitions indicate carbon range, preferential type of hydrocarbon molecules and the last refinery step. Currently there are at least 52 CAS numbers which could be used to describe hydrocarbon solvents as substances. It is anticipated that the majority of products in commerce in Europe are described by 30. Blends of those substances are considered as 'preparations' for regulatory purposes.

Hydrocarbon solvents* form a group of products clearly distinguished from other petroleum derived mixtures such as fuels and lubricants as they are produced specifically for solvent purposes and are highly refined. Contamination with molecules of molecular weights over 250 Daltons (e.g. carcinogenic

* The following definitions from R.J. Lewis (Ed.), Hawley's Condensed Chemical Dictionary (12th Ed. Van Nostrand Reinhold Co. 1993) are relevant to the terms used in this report:

1. Solvent: A substance capable of dissolving another substance to form a uniform dispersed mixture at the molecular or ionic-size level.
2. Organic Solvent: An organic (carbon) based substance capable of dissolving another substance.
3. Hydrocarbon: An organic compound consisting exclusively of the elements carbon and hydrogen.
4. Hydrocarbon Solvent: Chemical compounds composed of carbon and hydrogen capable of dissolving another substance.
5. Gasoline: A mixture of volatile hydrocarbons suitable for use in a spark-ignition internal combustion engine having an octane number of at least 60.

polycyclic aromatic hydrocarbon species) is excluded through the manufacturing process. Furthermore other problematic hydrocarbon molecules that may influence the health and safety properties of hydrocarbon solvents are removed (e.g. benzene) during manufacturing, or controlled (e.g. n-hexane, aromatics fraction) to reduce health hazards.

Hydrocarbon solvents have to be distinguished from other organic solvents such as oxygenated solvents and halogenated solvents which are not covered by this report. For the toxicological assessment of organic solvents the reader is referred to the ECETOC report on the Chronic Neurotoxicity of Solvents (ECETOC, 1996). The main elements of the toxicity of hydrocarbon solvents are reviewed in Section 4.

1.2 OCCUPATIONAL EXPOSURE LIMITS (OELs)

This report reviews the methods currently in use to derive OELs for complex hydrocarbon mixtures. There are two procedures which can be used for this purpose; OELs can be derived either from an assessment of the toxicology data on the complex solvent, or, by calculation, from data on its constituents. Because of the large number of products and the way in which the existing toxicology data have been obtained, there are only a few solvents for which sufficient data are available to produce OELs based solely on the assessment of toxicological data. Therefore the second approach seems more pragmatic as a general methodology. However, there may be situations in which sufficient data are available for a particular hydrocarbon solvent. In such situations these data take precedence over the results of a calculation method.

As will be further described below, the methodology for developing OELs is based on a reciprocal calculation procedure (RCP) which takes into account the properties of the individual constituents. However, as there are hundreds if not thousands of these constituents, it is necessary for these to be grouped in some reasonable way. The grouping and the use of the RCP to calculate OELs, require assumptions about similarity in physico/chemical and toxicological properties and that the individual constituents act in an additive manner. As will be shown, these assumptions are satisfied for the constituents of hydrocarbon solvents. Thus the use of the RCP is valid for these products.

1.3 BLENDING AND PROCESSING

In principle the recommended approach, discussed in this report, is applicable to hydrocarbon solvents in general, whether they are called substances or preparations (blends) for regulatory purposes, as long as all of the constituents are of the types described in Section 1.1.

When hydrocarbon solvents are blended with other solvents, the RCP as described by the American Conference of Governmental Industrial Hygienists (ACGIH, see Appendix 1) can be used for calculating OELs if the underlying assumptions of additivity (i.e. substances act on the same organ systems with similar toxicity) are legitimate. Additivity is addressed and supported for hydrocarbon solvents, but it is beyond the scope of this report to carry out this assessment for other solvents.

The assumption of additivity is not justified for all organic solvents. For example methyl ethyl ketone may potentiate the neurotoxic effects of n-hexane. In the case of blends of hydrocarbon solvents with other substances which are not additive, the OELs may need to be assessed independently for the different components in the blend. For example gasoline blending stocks contain a range of hydrocarbon constituents including benzene. Benzene has its own OEL and is not additive with other hydrocarbons. For such products the OEL of benzene needs to be separated from that of the other hydrocarbon constituents and independently met.

2. PROCEDURES FOR ASSIGNING OELs TO COMPLEX HYDROCARBON SOLVENTS

2.1 GENERAL

The most widely acknowledged view on the application of individual OELs of the components in a mixture to determine an overall OEL is expressed by ACGIH (Appendix 1). ACGIH recommends that effects of components with similar toxicological properties be considered as additive, and a RCP be used to calculate the overall OEL. This approach is inappropriate when there is information showing the effects may be synergistic, potentiating or antagonistic. No reference to the scientific basis for the introduction of the formula by the ACGIH has been found although the approach may be explained by accepting that the individual effects of the components may be summed in the form of effective doses with respect to their OELs. The German MAK Commission (Henschler, 1991) acknowledges the scientific weaknesses of the method but accepts its usefulness and practicability. Similar principles are adopted in other areas including the evaluation of the toxic hazards of gaseous emissions from fires (ISO, 1993). The approach has been recommended by ACGIH since 1940 without amendment although there does not appear to be any published record of its application to complex hydrocarbon mixtures prior to 1976 (Farmer, 1992).

A number of authors have commented on technical aspects of applying the RCP approach to simple mixtures with a small number of components. There is evidence that this method can be improved by recognising the non-ideal behaviour of some components in the mixture (Bishop *et al*, 1982). Scheffers *et al* (1985) suggested exposure indices based on the sum of the ratios of the air concentrations and the corresponding effect-specific limit values for the components. Findings by Sokal and Korsak (1990) suggest that the RCP approach may require modification to fit interactive effects of toluene and xylenes. Mutti *et al* (1982) questioned the importance of synergism for n-hexane and cyclohexane based on electroneurographic abnormalities. An alternative approach has been suggested by Blinova (1990) linking substance ratios to toxicological parameters. However, application of the suggested approaches to hydrocarbon solvents would be extremely complex due to the number of components in the product.

Since 1976, the Solvents Industry Association (formerly the UK Hydrocarbon Solvents Association) has applied the RCP to complex mixtures of hydrocarbons producing a table of OELs for the major hydrocarbon solvents, based on assumed values for components. These figures have been circulated to the solvents and user industries as guidance.

Toxicological studies carried out on hydrocarbon solvents, and related materials, provide data on a broad range of materials covering both the different distillation ranges and molecular types represented by these products (Cavender, 1994a; 1994b; 1994c). These studies showed that hydrocarbon molecules as described in Section 1.1 are of relatively low toxicity and molecules of similar structure have similar toxic properties. There are a few notable exceptions, e.g. benzene and n-hexane. In most cases recommendations were made for OELs based on the potential to produce discomfort or central nervous system (CNS) depression.

Since the majority of the studies have been on commercial mixtures or surrogates of generic composition, rather than on pure substances, they only provide sufficient information to enable a limited

Table 1: Typical Compositions of Volatile Hydrocarbon Solvents

SOLVENT	b.p. Range °C	Main Carbon Number Range	Average MW	% w/w n-hexane	% w/w aliphatic	% w/w alicyclic	% w/w aromatic
1. Pentane fraction	35-38	5	72	<1	99	1	0.01
2. Commercial hexane	65-70	6	86	50	88	12	<0.1
3. SBP 60/95	62-95	5-8	94	2	68	32	<0.1
4. SBP 80/110	86-106	6-8	100	<5	64	36	<0.1
5. SBP 100/140	103-136	7-9	112	<1	64	36	<0.1
6. Rubber Solvent	104-150	7-10	112	<1	62	38	<0.1
7. SBP 140/165	141-161	8-11	130	<1	63	37	<0.1
8. Standard White Spirit	150-200	8-12	141	neg.	57	22	21
9. Dearomatised White Spirit	155-200	8-12	142	neg.	51	49	<0.1
10. High flash point White Spirit	180-215	10-13	159	neg.	56	23	21
11. Aromatic naphtha 160/180	163-180	8-10	124	neg.	neg.	neg.	>99.5
12. Aromatic naphtha 180/215	181-215	9-11	130	neg.	neg.	neg.	>99.5

b.p. = Boiling Point
neg. = Negligible

MW = Molecular Weight
SBP = Special Boiling Point solvent

number of OELs to be set either for individual substances or for typical commercially available complex hydrocarbon solvents .

To enable OELs to be assigned to the broad range of complex hydrocarbon solvents, a generic approach is required.

2.2 TYPICAL HYDROCARBON SOLVENTS AND BLENDS

2.2.1 Standard Product Types

Hydrocarbon solvents span a boiling point range of 35-320° C, pentane fractions and printing ink distillates being illustrative of the extremes. Complex hydrocarbon solvents may contain 100-200 components. Normally only solvents boiling below 220° C are considered when assigning OELs, as those boiling above this temperature have low vapour pressures under ambient conditions (Section 2.3.3). Table 1 summarises the basic compositions of 12 volatile and commonly-employed hydrocarbon solvents.

Hydrocarbon solvents may be classified as 'aliphatic' ('n-paraffinic' or 'isoparaffinic'), 'alicyclic' ('naphthenic') or 'aromatic' according to the type of molecule predominantly present. Many solvents contain more than one of the above classes, e.g. standard White Spirit typically is a mixture of 80% aliphatic/naphthenic and 20% aromatic molecules. Special Boiling Point solvents (SBPs) are almost pure 'aliphatic' solvents; the aromatic naphthas are examples of the 'aromatic' grades.

Many hydrocarbon solvents are produced as discrete streams within the refinery. Different feedstocks and differences in manufacturing lead to slight variations in composition. Overall there have been few attempts to establish standard product specifications for these solvents other than to describe the product performance. Hydrocarbon solvents are considered as 'substances' for regulatory purposes and have been assigned CAS numbers (EEC, 1990). The product definitions relating to these CAS numbers tend to be very broad and consequently CAS numbers are not a good basis for assigning OELs. Frequently, the same CAS number is allotted to several products as illustrated in Table 2.

Hydrocarbon solvents which can be generically described as "White Spirit" are given CAS numbers which relate to petroleum refinery processes, i.e. hydrotreatment, hydrodesulphurisation or straight run. In the USA the equivalent to "White Spirit" is called Stoddard Solvent; it is assigned a different CAS number and a description which does not refer to its mode of manufacture.

Table 2: CAS Numbers Associated with Hydrocarbon Solvents

TYPE	CAS No.	EINECS No.	SOLVENTS
HT	64742-49-0	265-151-9	SBPs 60/95, 80/110, 100/140, 140/165
STR	64742-89-8	265-192-2	SBPs 60/95, 80/110, 100/140
HT	64742-48-9	265-150-3	SBP 140/165, dearomatised White Spirit
HDS	64742-82-1	265-185-4	Standard White Spirit, High flash point White Spirit
STR	64742-88-7	265-191-7	Standard White Spirit, High flash point White Spirit
REFD	64742-95-6	265-199-0	Aromatic naphtha 160/180
REFD	64742-94-5	265-198-5	Aromatic naphtha 180/215

HT = Hydrotreated
STR = Straight run

HDS = Hydrodesulphurised
REFD = Reformed

SBP = Special Boiling Point solvent

2.2.2 Blends

Solvent blends may be produced from two or more solvents of different CAS numbers. The resulting products are called 'preparations' in regulatory terms and, as such, do not receive CAS numbers. Examples of blends employed in user industries are given in Table 3.

Table 3: Examples of Concentrations of Aromatics and n-Hexane in Hydrocarbon Solvent Blends

PRODUCT	n-Hexane %	Aromatic %
90% SBP 140/165, 6% aromatic naphtha 160/180, 4% toluene	-	30
20% Aromatic naphtha, 80% standard White Spirit	-	38
95% High flash point White Spirit, 5% aromatic naphtha 180/215	-	27
90% Heptane, 10% toluene	-	10
80% SBP 140/165, 20% xylene	-	20
38% Aromatic naphtha 160/180, 62% standard White Spirit	-	49
99% Heptane, 1% toluene	-	1
75% Heptane, 25% toluene	-	25
74% Heptane, 26% toluene	-	26
8% Aromatic naphtha 160/180, 92% standard White Spirit	-	24
50% Isohexane, 50% n-hexane	50	-
90% Isohexane, 10% n-hexane	10	-
94% Isohexane, 6% n-hexane	6	-

2.3 CHARACTERISTICS OF HYDROCARBON SOLVENTS IN RELATION TO ASSIGNING OELs

2.3.1 Theoretical Considerations

In theory the toxic effects of substances may be independent, additive, synergistic or may exhibit antagonism or potentiation. In the absence of any evidence to support synergism, potentiation or antagonism, which is the case for hydrocarbon solvents as is shown in Section 4, only 'independent' and 'additive' effects have to be considered.

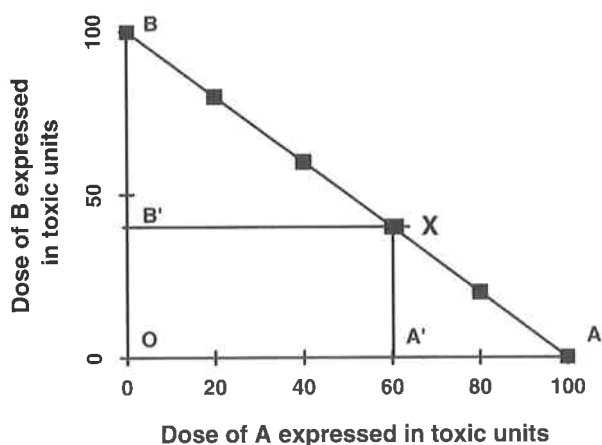
Where components act independently in the vapour exposure situation, the exposure limit of any single component should not be exceeded. Hence the permissible exposures are given by the individual component exposure limits and the total permissible exposure by the sum of these OELs, e.g. for components A, B, C...with exposure limits of OEL_a, OEL_b, OEL_c...and concentrations in air of a, b, c... the ratios

$$\frac{a}{\text{OEL}_a}, \frac{b}{\text{OEL}_b}, \frac{c}{\text{OEL}_c}, \dots$$

individually must not exceed 1. In practice, the differences in the volatilities of the components, or in the OELs, will ensure that the OEL of one component is reached before those of the remaining components; the OEL for this component would become the limiting OEL for exposure to the mixture.

The constituents of hydrocarbon solvents have similar toxicological properties with the exception of n-hexane (Section 4.4.1). It is therefore reasonable to assume that the components act in an additive fashion. The mathematical implications of additivity are derived from Niessink *et al* (1995) and are illustrated in Figure 1.

Figure 1: Graphic presentation of additivity of toxic effects



OA and OB represent the respective 'doses' expressed in toxic units of components A and B which produce the same toxicological effect and the line AB describes the 'additivity situation'. The mixture represented by point X relates to concentrations of OA' (60) of component A plus OB' (40) of component B, and produces the same effect as any mixture derived by a point on the line AB.

For a multi-component mixture, accepting that the 'effective dose' of any substance is directly proportional to its concentration and indirectly to its OEL, the following equation applies:

$$\frac{K_1 \cdot Fr_a \cdot C_s}{OEL_a} + \frac{K_2 \cdot Fr_b \cdot C_s}{OEL_b} + \dots = \frac{K_s \cdot C_s}{OEL_s}$$

where C_s is the concentration of the mixture in mass units and Fr_a , Fr_b are the fractions of components a, b... in the mixture and K_1 , K_2 , ... are constants. K_1 , K_2 , ... will be the same for all components if similar criteria have been used in the assignment of OEL_a , OEL_b , ... , the equation then reduces to:

$$\frac{Fr_a}{OEL_a} + \frac{Fr_b}{OEL_b} + \dots = \frac{1}{OEL_s}$$

the numerators and denominators being in mass units. This principle is applied in the RCP developed by ACGIH (ACGIH, 1996). This procedure is reproduced in full in Appendix I to this report.

2.3.2 Workplace Situations to be Considered

In practice, exposures to solvent vapours arise basically from three situations:

Vapours evaporating from a 'pool' of liquid solvent

In this situation, which is the most common, vapour arises directly from the solvent in use. The vapour composition may differ from that of the liquid. The worst case is represented by equilibrium conditions where the vapour concentration may be higher than the OEL. (This will not be the case for less volatile products, see Section 2.3.3).

Fugitive emissions from closed systems

These tend to arise from equipment such as faulty valves leaking minute amounts of the liquid. In this case the vapour is likely to have the same composition as the liquid solvent. When high boiling solvents are involved the escape may give rise to the formation of a mist at ambient temperature.

Vapour arising from a 'drying film'

In this situation the composition of the vapour may vary with time although with narrow boiling range mixtures the differences are not of practical significance.