Hydrocarbon Solvent Exposure Data: Compilation and Analysis of the Literature

AUTHORS
Daniel J. Caldwell
Thomas W. Armstrong
Neil J. Barone
Joseph A. Suder
Malcolm J. Evans

ExxonMobil Biomedical Sciences, Inc., 1545 Route 22 East, P.O. Box 971, Annandale, NJ 08801–0971

An occupational exposure database for hydrocarbon solvent end-use applications was constructed from the published literature. The database provides exposure assessment information for such purposes as regulatory risk assessments, support of industry product stewardship initiatives, and identification of applications in which limited exposure data are available. It is quantitative, documented, and based on credible data. Approximately 350 articles containing quantitative hydrocarbon solvent exposure data were identified using a search of computer databases of published literature. Many articles did not report sufficient details of the exposure data for inclusion in the database (e.g., full-shift exposure or task-based exposure data). Others were excluded because only limited summary statistics were provided, which precluded statistical analysis of the data (e.g., arithmetic mean concentration presented, but no sample number). Following evaluation, 16,880 hydrocarbon solvent exposure measurements from 99 articles were entered into a database for analysis. Methods used to identify and evaluate published solvent exposure data are described along with more detailed analysis of worker exposure to hydrocarbon solvents in three major end-use applications: painting and coating, printing, and adhesives. Solvent exposures were evaluated against current ACGIH® threshold limit values (TLVs®) and trends were identified. Limited quantitative data are available prior to 1970. In general, reported hydrocarbon solvent exposures decreased fourfold from 1960 to 1998, were below the TLVs applicable to specific hydrocarbon solvents at the time, and on average have been below 40% of the TLV since 1980. The database already has proved valuable; however, the utility of published exposure data could be further improved if authors consistently reported essential data elements and supporting information.

Keywords: exposure assessment, exposure database, hydrocarbon solvent, occupational exposure, organo-psycho syndrome (OPS), TLV

APPLIED STUDIES

Funding for this project was provided by the Hydrocarbon Solvents Producers Association (HSPA) of the European Chemical Industry Council and by the Hydrocarbon Solvents Panel of the American Chemistry Council, formerly the Chemical Manufacturers Association (CMA).

Numerous epidemiological studies have been conducted over the years to investigate the potential impact of solvents on the health of exposed workers. In many of these studies, there were difficulties in completing an adequate exposure assessment. This limits the usefulness of the studies because good exposure data are an essential part of quantitative risk evaluations. For example, organo-psycho syndrome (OPS), also known as painter's syndrome, is characterized by neurobehavioral effects that include changes in psychomotor skills, attention, learning, and memory. OPS can occur in workers as a result of excessive long-term exposure to solvents. Epidemiology studies of OPS often contain assumptions regarding workplace exposure because the intensity and duration of exposure has been difficult to quantify. This is because historic exposure data are rare; a mixture of solvents often is used, making exposure assessment difficult; and both the solvents and the working conditions change over time. However, good exposure data are essential if the relationship between long-term exposure to solvents and health effects (e.g., OPS, reproductive or developmental effects) is to be adequately defined. A comprehensive database of

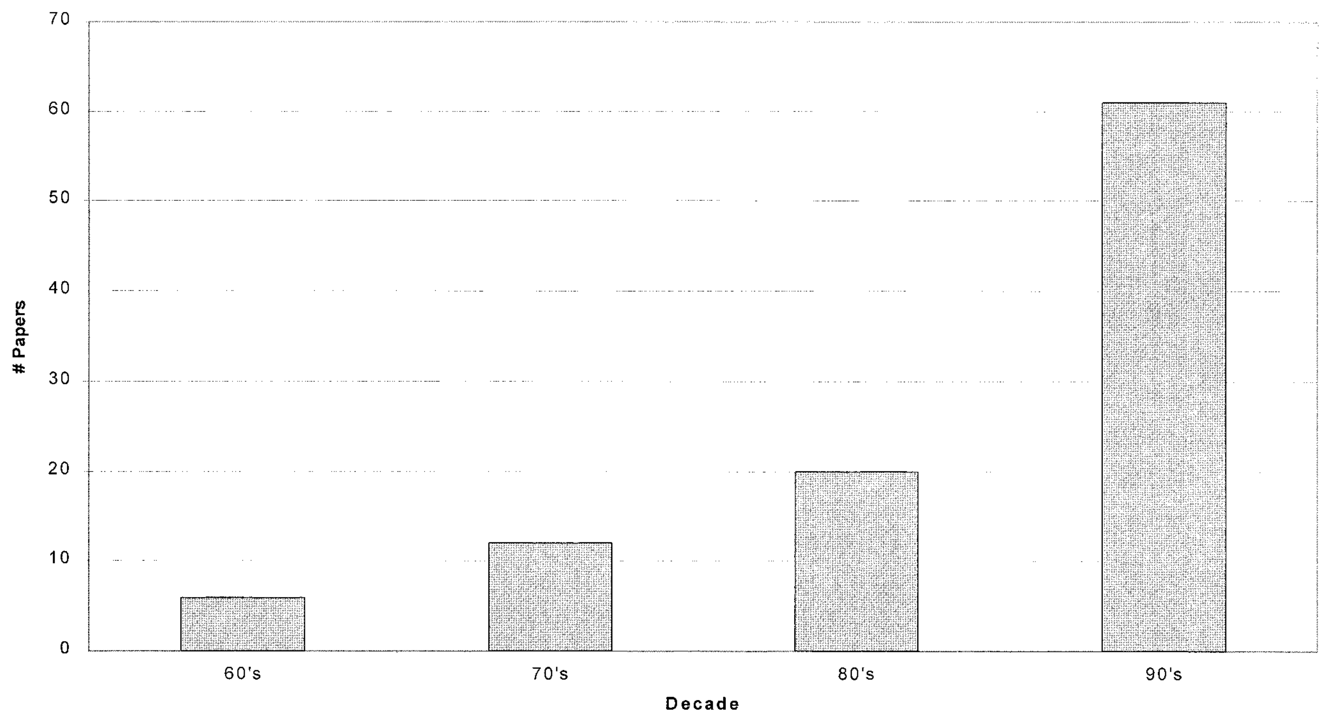

FIGURE 1. Number of papers by decade

solvent exposure data would improve exposure assessments and therefore contribute to the understanding of health risks.

A critical evaluation of the published exposure data will provide an important input to both the on-going public debate on the health effects of solvent exposure and to regulatory risk assessments. Furthermore, information about the potential exposure to solvents in user industries is important in determining whether occupational exposure limits are, in fact, adequately protective. Quantitative exposure information also will assist in the prioritization of product stewardship efforts by identifying the need for safe handling procedures. Lastly, the accuracy of predictions from exposure modeling can be validated using measured solvent exposure data collected from a range of exposure scenarios.

METHODS

Literature Search Strategy

A stepwise approach was developed to compile and critically review available published data on exposure to hydrocarbon solvents in user industries. Initially, a broad search of the computer databases was undertaken using key solvent and petroleum terms. That search showed approximately 1.7 million articles containing the key search terms, but many were obviously irrelevant (for example, "Waxing Poetic on the Works of Shelly," or "Varnished Tales: History and Artifice in the Novel, 1789–1830").

The next stage used improved search terms to limit irrelevant results and limited the search to articles published between 1996 and 1998 and possibly containing data on exposure to hydrocarbon solvents in user industries. The search included terms for specific industries (e.g., automotive, printing), solvent products (e.g., paint thinner, mineral spirits), components (e.g., cyclohexane, benzene, toluene, xylene), and branched, cyclic, and straight chain alkane solvents with carbon numbers between 5 and 15, using Chemical Abstract Service registry numbers and focused nomenclature. The search also included exposure terms to cover personal breathing zone and general area samples. The search identified 22,000 articles. Restricting the search to occupational exposure in selected industries reduced this to 6000 articles. After examination of the titles, abstracts were obtained for 250 (4%). Review of the abstracts suggested 50 (20%) were relevant and the full publications were obtained. A review of these 50 publications indicated approximately one-half of them contained useful data.

This appeared to be a reasonable methodology for identifying the relevant articles. Therefore, the refined search strategy was applied without time limits and resulted in the identification of additional relevant articles. After the computer search, further articles potentially containing useable data were identified from references cited in articles reviewed. This technique served two purposes: It targeted resources to journals that routinely published sampling data, and it enabled additional historic data to be obtained, as the computer databases contain little information prior to the 1970s.

Database Assembly

The relevant data from each article were entered into a Microsoft™ Access™ database for subsequent analysis. The database was designed so that the data collected could be analyzed in a flexible manner. The appendix shows the database structure and provides brief descriptions of the database fields. An examination of the database structure reveals numerous database fields (e.g., PPE). However, this report discusses the analysis of only the personal breathing zone sample results.

The focus of this project was on articles containing hydrocarbon solvent exposure data; however, if other (nonhydrocarbon solvent) data also were reported in the same article, these data

TABLE I. Summary of Personal Breathing Zone Sample Results for Hydrocarbon Exposure Indicators

Exposure Indicator	IBP[A]	Papers[B]	Single[C]	AM[C]	n[C]	Total N[D]	WAM[E]	MIN[F]	MAX[F]	TLV[G]	% TLV[H]
Pentane[A]	36	2	7	32	196	203	9.5	0	567	1771	0.5
Rubber solvent naphtha[A]	45	1	8			8	263.0	0	584	1590	17
Hexanes[A]	50	1	2			2	0.7	0	0.7	1762	0.1
Hexane[A]	69	19	86	65	1223	1309	92.9	0	1426	176	53
Benzene[A]	80	9	18	44	719	737	8.4	0	765	32	26
Cyclohexane[A]	81	4		5	301	301	159.8	0	1288	1033	15
VM&P naphtha	95	3		11	267	267	47.5	0	9640	1371	3
Heptane[A]	98	9	25	36	370	395	36.6	0	1291	1639	2
Toluene	111	53	168	138	5097	5265	98.7	0	6236	188	52
Octane	126	3		2	28	28	0.02	0	0.2	1402	0
Ethyl benzene	136	11	4	26	781	785	14.1	0	104	434	3
Xylene	138	38	95	91	3548	3643	32.8	0	2218	434	8
White Spirit/Stoddard Solvent	150	10	30	25	370	400	466.5	0	2231	525	89
Nonane	151	3		2	28	28	0.2	0	2	1049	0.02
Propyl benzene	152	2		6	178	178	0.2	0	1	246	0.1
C10–C12 HC	174	4		5	96	96	1.8	0	10	N/A	
Trimethyl benzene	176	4	1	1	70	71	4.1	0	15	123	3.3
Total volatile HC	N/A	21	84	53	1594	1678	66.7	0	1483	N/A	
Total			528	542	14866	15394	75.1	0	9640		

[A]IBP is initial boiling point in °C, which is an indicator of volatility.
[B]Number of citations containing data on particular exposure indicator (multiple exposure indicators may be reported in one article).
[C]Discrete sample data point, whereas AM & n indicate the arithmetic mean value and corresponding number of samples.
[D]Total number of sample data points represented by the weighted arithmetic mean (WAM) in mg/m^3.
[E]The WAM exposure in mg/m^3.
[F]MIN & MAX indicate the range of values reported in the literature, in mg/m^3.
[G]1996 ACGIH 8-hr TWA, in mg/m^3, rounded to the nearest whole number.
[H]% TLV is the WAM divided by the 1996 TLV.

were entered into the database. Thus, summary data representing over 33,500 data points were entered into the exposure database.

- Articles covering 27,000 data points had enough information to permit statistical analysis;
- of these, 16,880 data points were for hydrocarbon solvents; and
- of these, 15,394 were personal breathing zone samples.

Other solvent exposures captured in the database but not evaluated or discussed in this report include acetone (3200), styrene (2900), various alcohols (1600), acetates (1500), and other ketones (1300). Limited data on other solvents and chlorinated hydrocarbons are also included in the database.

TABLE II. Change in ACGIH TLVs by Year for Selected Constituents

		TLV	
Solvent	Year	mg/m^3	ppm
Benzene	1948	112	35
	1957	80	25
	1974	32	10
	1997	1.6	0.5
Ethyl benzene	1948	868	200
	1967	434	100
n-Hexane	1948	1762	500
	1976	352	100
	1982	176	50
Propyl benzene (cumene)	1967	246	50
Toluene	1948	754	200
	1973	377	100
	1992	188	50
Trimethyl benzene	1970	123	25
Xylene	1948	868	200
	1967	434	100

Approximately 20% of the articles presented limited summary statistics (i.e., the authors presented the arithmetic mean [AM] but no sample number, or presented the geometric mean [GM] but no geometric standard deviation [GSD], or presented the GM and GSD, but no "n"), thus precluding statistical analysis of the data.

Quality Assurance on Data Entry

An industrial hygienist who was not involved in the primary data entry verified the integrity of the entries. This was accomplished during preliminary analysis of the data by checking the summary statistics, such as GM, AM, and number of samples from the original articles. During further work to combine specific process categories into broader industrywide categories, the number and type of samples, sample duration, and sample results were comprehensively verified. The project sponsors also verified the final analyses of the database contents.

RESULTS

During this project, 99 articles published between 1961–1998 were critically reviewed and exposure data entered into the database. Full citations are contained in the bibliography.

Hydrocarbon solvents can consist of individual chemicals (e.g., xylene or toluene), but often contain a large number of individual chemical species. To account for different ways exposure data were reported by the various authors, the concept of an exposure indicator was developed. For the purpose of this study, the term "exposure indicators" is defined as measured analytes that are constituents of, or surrogates for, the constituents of the solvent. This project identified a total of 77 solvent exposure indicators. However, even this approach presents problems when the exposure was to a mixture of solvents, or to a complex hydrocarbon solvent for

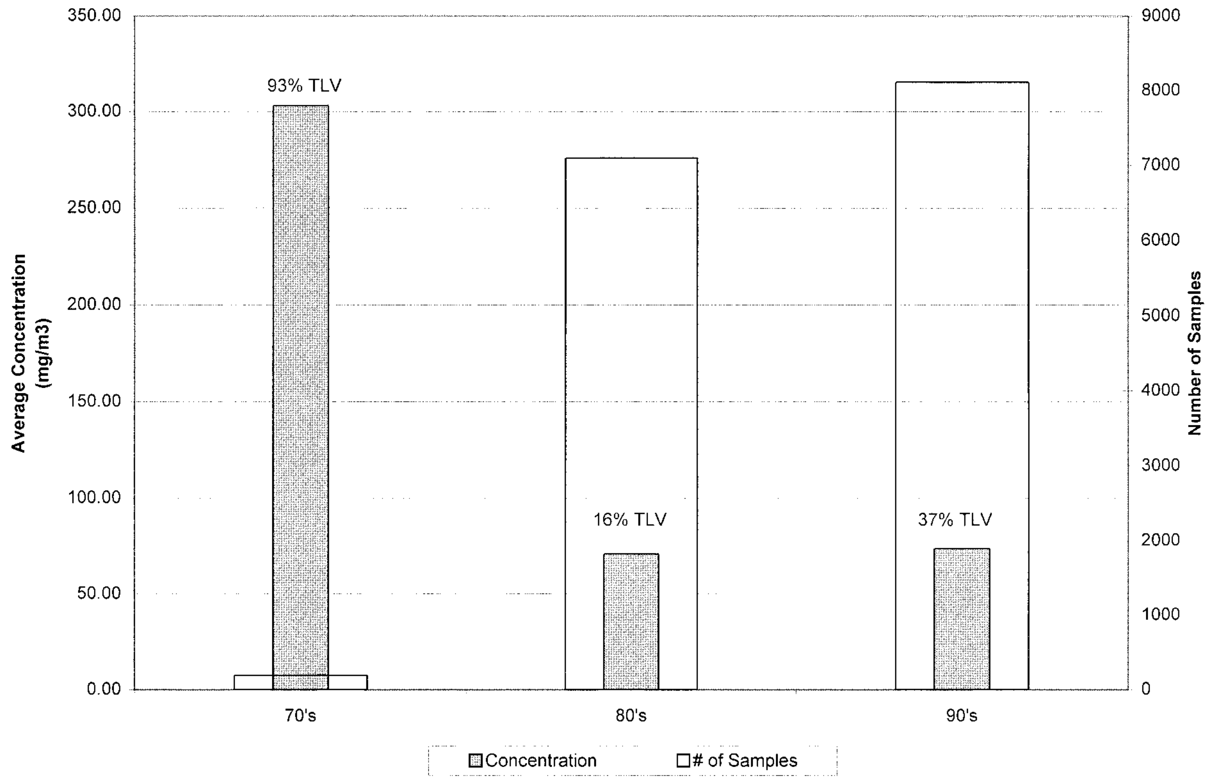

FIGURE 2. Average concentration and average %TLV of PBZ results by decade

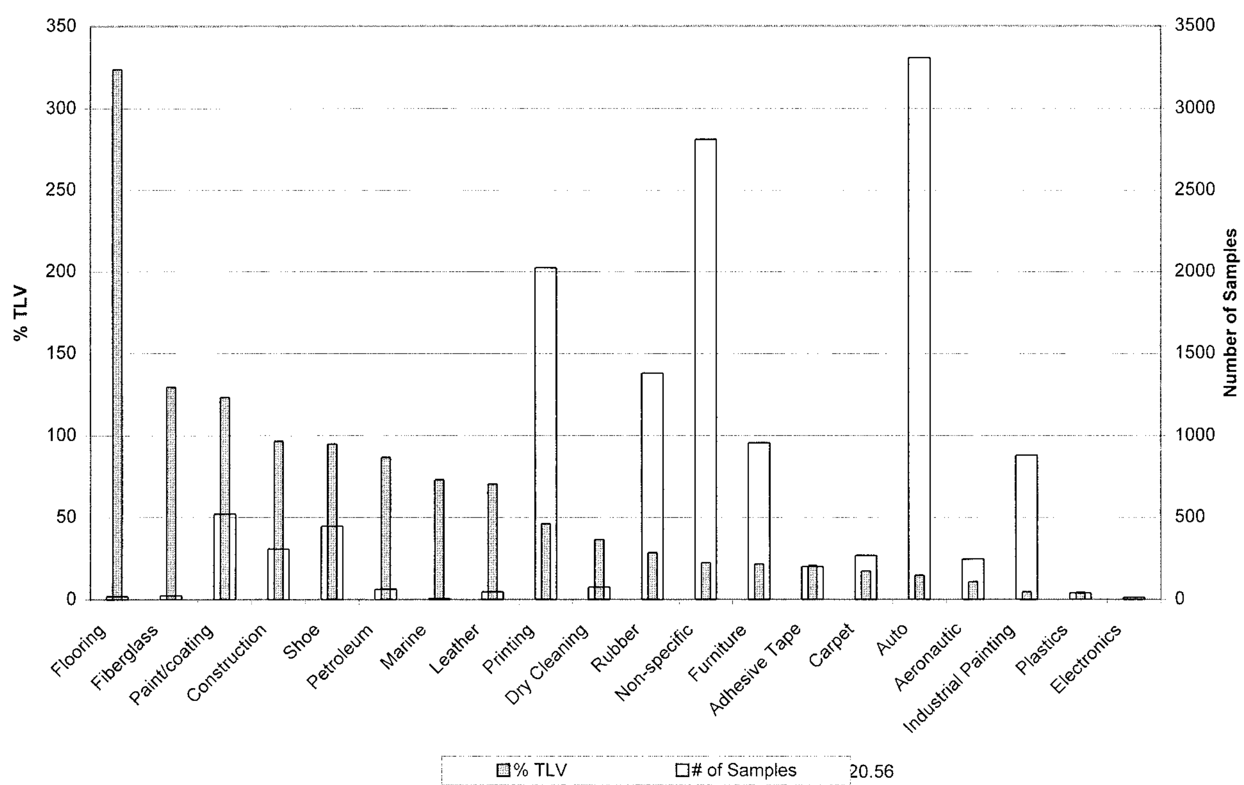

FIGURE 3. Average concentration of PBZ results as percentage of 1996 TLV by industry

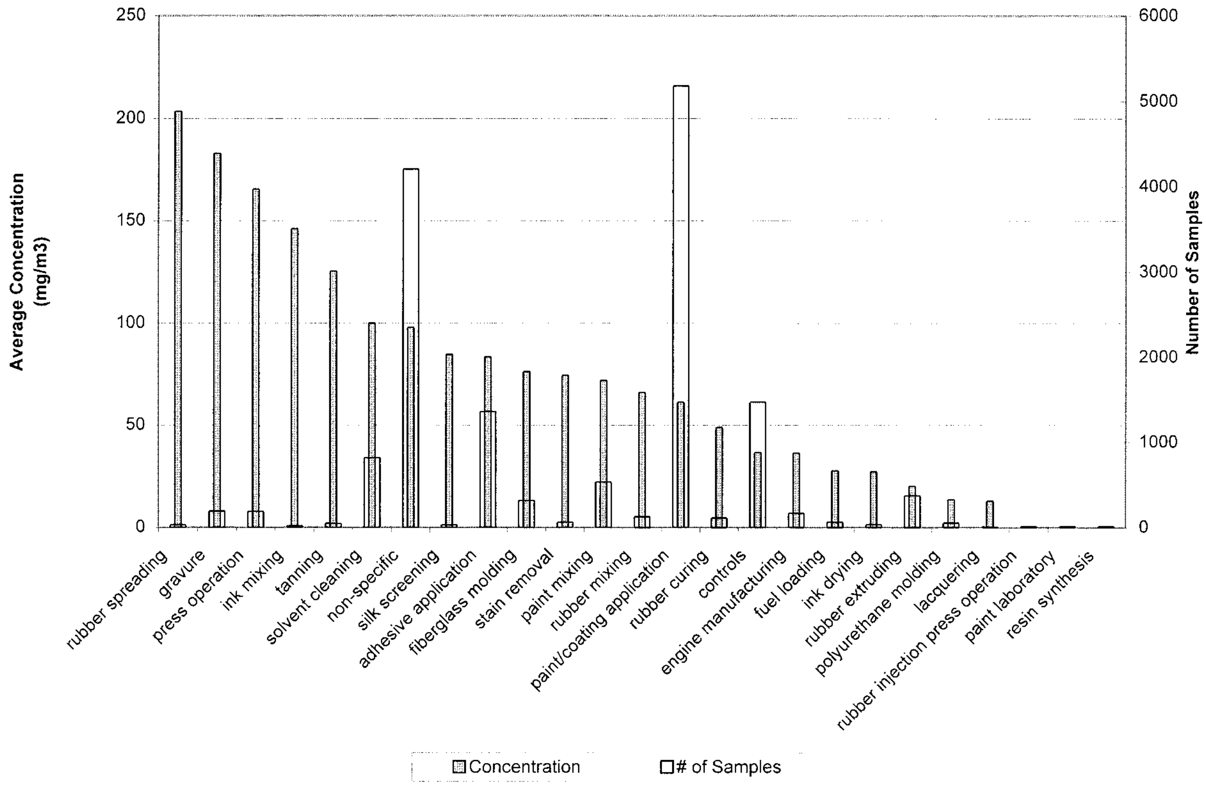

FIGURE 4. Average concentration of PBZ results by process

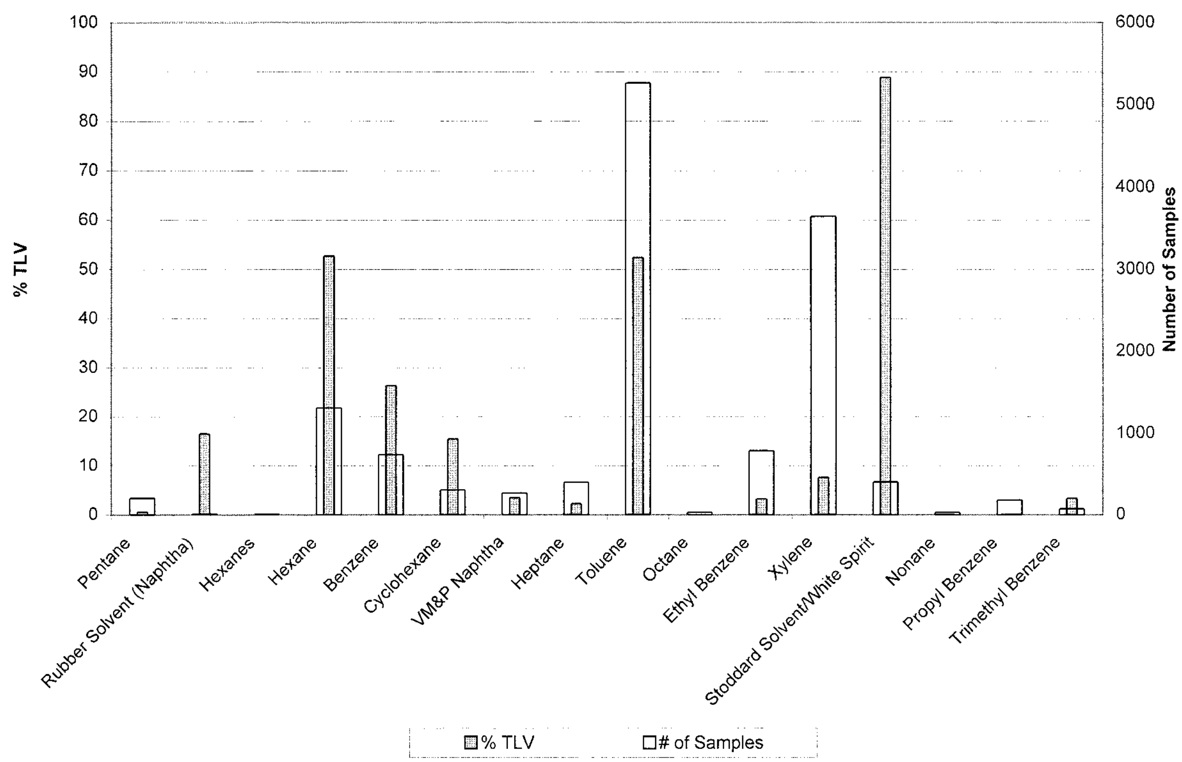

FIGURE 5. Average concentration as percentage of 1996 TLV by exposure indicator

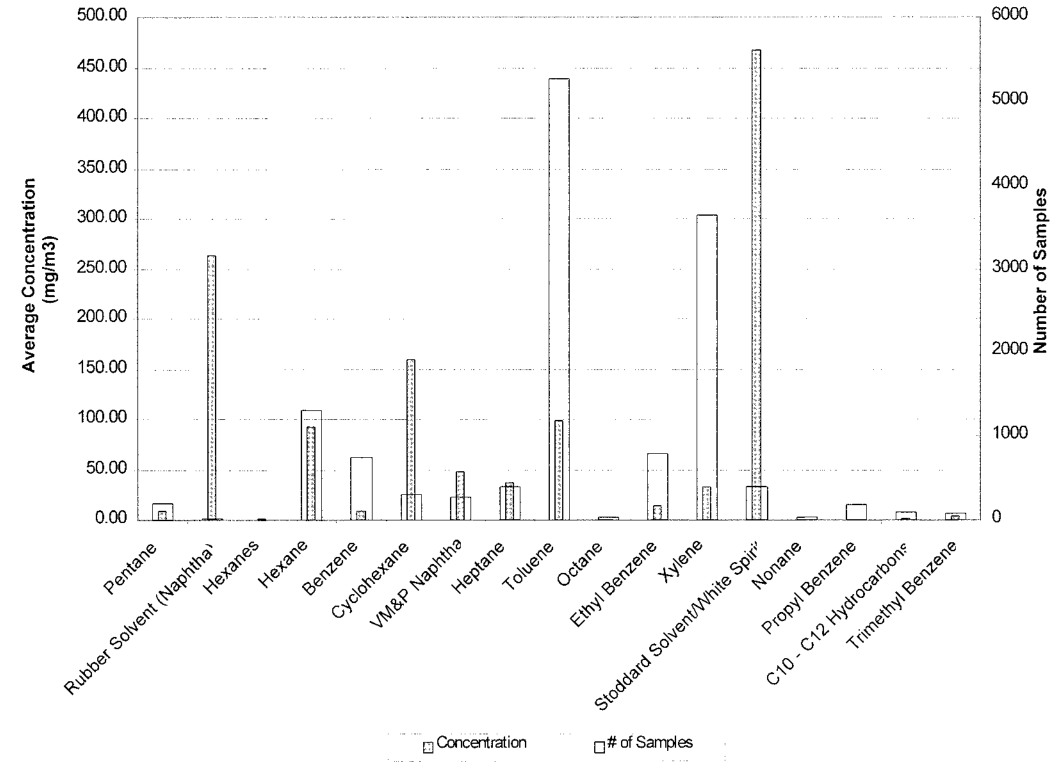

FIGURE 6. Average concentration by exposure indicator

which each exposure indicator result represented only part of the overall (total hydrocarbon) exposure. The remainder of this report is concerned only with the analyses conducted on the hydrocarbon solvent exposure indicators, which represented 35 of the 77 exposure indicators.

Age and Origin of Articles

Figure 1 shows the number of articles by decade of publication. Most of the articles in the database (>80%) were published within the past 20 years. All 6 articles published during the 1960s were by American authors, whereas 9 of 12 articles published in the 1970s were by European authors. The increase in the total number of articles published probably reflects an increased interest and concern regarding occupational exposure to solvents throughout Europe and North America and the parallel development of the science of occupational hygiene.

Overall Analysis of Hydrocarbon Solvent Data

Table I presents a summary of the personal breathing zone (PBZ) hydrocarbon solvent data, by exposure indicator. Certain exposure indicators were grouped together, such as White Spirit with Stoddard Solvent, C10-C12 hydrocarbons, and hexanes (other than n-hexane) to facilitate analysis.

The majority of solvent exposures were below the relevant occupational exposure limit (OEL) for each exposure indicator. The 1996 American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit values (TLVs®) were selected as the referent OELs for this analysis for several reasons:

- The vast majority of the authors compared their results with the ACGIH TLV,
- changes in the value of the TLV over time are well documented and readily available, and
- the benzene TLV significantly changed in 1997 (i.e., a 20-fold decrease).

Use of the new benzene TLV would inflate the %TLV calculation and would not accurately portray the level of compliance with the TLV in effect at the time of the study.

Table II presents the values of the ACGIH TLVs as they changed over time for selected hydrocarbon solvents/components. Figure 2 summarizes the weighted arithmetic mean (WAM) solvent exposure concentration by decade and the total number of solvent samples by decade:

$$WAM = \frac{n_1 AM_1 + n_2 AM_2 + \cdots + n_n AM_n}{\sum_{1}^{n} n}$$

where WAM = weighted arithmetic mean; n = number for measurements for the AM in a particular report; and AM = the arithmetic mean of the data for a particular report.

The %TLV for Figure 2 was calculated in a multistep process. First, the %TLV for each sample result was determined by dividing the sample concentration by the TLV for the exposure indicator in effect during the year of publication. Next, the average %TLV for all samples in a given year was calculated. Finally, the weighted average of the %TLV for all years in a given decade was calculated.

A review of Figure 2 indicates that, in general, data prior to 1980 are limited. Further, where available, the reported hydrocarbon solvent exposures were considerably higher in the 1970s compared with subsequent decades in terms of both average concentration and average %TLV.

TABLE III. Reported Exposures Greater Than the TLV, Sorted by Year of Publication

Year	Industry	Process	EI Name[A]	% TLV[B]	N[C]
1978	printing	gravure	toluene	149	53
1978	shoe	nonspecific	hexane	155	65
1980	auto	paint/coating application	toluene	205	61
1980	auto	paint/coating application	xylene	158	9
1985	printing	nonspecific	hexane	169	12
1986	flooring	adhesive application	benzene	497	10
1986	printing	gravure	toluene	125	53
1987	printing	nonspecific	toluene	751	2
1987	rubber	nonspecific	toluene	130	83
1987	rubber	rubber mixing	toluene	127	5
1991	auto	paint/coating application	benzene	530	9
1991	auto	paint/coating application	toluene	172	61
1991	auto	paint/coating application	xylene	231	9
1991	leather	tanning	hexane	119	23
1992	auto	paint/coating application	toluene	148	9
1992	shoe	adhesive application	toluene	384	7
1993	auto	nonspecific	toluene	266	21
1994	printing	ink mixing	toluene	172	13
1994	printing	nonspecific	toluene	424	282
1994	printing	nonspecific	xylene	135	6
1994	printing	solvent cleaning	toluene	1409	5
1994	printing	solvent cleaning	xylene	135	5
1995	paint/coating	paint mixing	hexane	130	119
1995	printing	nonspecific	toluene	498	110
1995	shoe	adhesive application	toluene	169	7
1996	furniture	paint/coating application	toluene	382	5
1996	printing	nonspecific	toluene	199	64
1997	fiberglass	fiberglass molding	toluene	130	23

Note:
[A]EI is exposure indicator.
[B]% TLV calculated based on ACGIH TLV at date of publication.
[C]N is number of samples for specific EI reported in publication on which calculation is based.

Figure 2 indicates that the published hydrocarbon solvent exposure concentrations have decreased more than fourfold from the 1970s to the 1980s and 1990s—from an average of approximately 300 mg/m³ to less than approximately 70 mg/m³. The number of samples collected in the 1980s and 1990s increased by an order of magnitude compared with the 1970s. Over the same time period, the average %TLV decreased—from 93% in the 1970s, to 16% in the 1980s, to 37% in the 1990s. These findings suggest that exposures have been reduced in response to new information regarding health effects of solvents as reflected by reductions in the TLV for key hydrocarbon solvent components. The trend of adopting lower TLVs is also apparent by the increase of the average %TLV from the 1980s to the 1990s; the average %TLV in the 1990s was double that of the 1980s even though the average exposure concentrations were the same.

Analysis of Solvent Exposures by Industry and Process

The data were analyzed by both industry and process. The results are summarized in Figures 3 and 4, which present the average solvent concentration as a percentage of the 1996 TLV along with the number of samples.

Figure 3 suggests that the highest exposures occurred in the flooring industry. There were also significant exposures (average >50% of the 1996 TLV) in the fiberglass, paint/coating, construction, shoe, petroleum, marine, leather, and shoe industries, although the number of samples was low for some of these. Industries with the highest number of samples tended to have lower reported solvent exposures; all six industries with over 500 data points each had average concentrations below 50% of the TLV. The fiberglass industry had high styrene exposures that are not discussed further in this report. However, there also were significant toluene exposures in the fiberglass industry; these toluene exposure data were used in the analyses that follow.

Figure 4 shows the specific processes associated with solvent exposure. Rubber spreading had the greatest reported exposure concentrations but may not reflect typical exposures, given the small number of samples reported.

Figures 3 and 4 show that hydrocarbon solvents are used in a very wide range of industries and processes. Average exposures and the number of data points vary considerably between industry and process. In many applications exposure would appear to be well controlled, whereas in others exposure potential is clearly higher.

Analysis by Solvent/Exposure Indicator

Figure 5 summarizes the hydrocarbon solvent personal breathing zone exposure data contained in the database by presenting the average percentage of the 1996 TLV and number of samples for the hydrocarbon solvent exposure indicators of interest. With the exception of Stoddard Solvent/White Spirit, toluene, and n-hexane, all of the average %TLV numbers are below 50% of the respective TLV (also shown in Table I). Note that the solvent exposure indicators are listed by increasing initial boiling point, which is indicative of relative volatility.

The airborne exposure concentration would be expected to decrease as the boiling point increases. Figure 6 confirms that the measured average concentrations generally are inversely related to initial boiling point. The notable exception is Stoddard Solvent/White Spirits. The reason in unclear, but perhaps is related to its

TABLE IV. Reported Exposures Greater Than One-Half the TLV, Sorted by Year of Publication

Year	Industry	Process	EI Name[A]	% TLV[B]	N[C]
1978	printing	gravure	toluene	82	48
1980	auto	paint/coating application	xylene	62	23
1980	rubber	rubber curing	hexane	58	19
1985	printing	nonspecific	hexane	78	26
1985	printing	nonspecific	toluene	78	2
1985	printing	nonspecific	xylene	87	6
1986	flooring	adhesive application	toluene	54	8
1986	printing	gravure	toluene	69	48
1987	printing	nonspecific	toluene	58	26
1987	rubber	nonspecific	toluene	53	202
1987	rubber	rubber spreading	toluene	54	30
1991	auto	paint/coating application	benzene	68	70
1991	auto	paint/coating application	xylene	80	52
1991	nonspecific	paint/coating application	xylene	69	29
1992	auto	paint/coating application	toluene	58	23
1992	nonspecific	nonspecific	hexane	80	49
1992	paint/coating	nonspecific	toluene	62	396
1993	auto	nonspecific	xylene	79	21
1993	printing	gravure	toluene	67	53
1994	aeronautic	paint/coating application	toluene	80	23
1994	printing	nonspecific	toluene	65	1368
1994	rubber	paint/coating application	toluene	83	5
1995	auto	paint/coating application	toluene	82	9
1995	nonspecific	paint/coating application	xylene	81	29
1995	printing	nonspecific	toluene	80	172
1996	printing	gravure	toluene	77	53
1996	printing	nonspecific	toluene	92	46

Note:
[A]EI is exposure indicator.
[B]% TLV calculated based on ACGIH TLV at date of publication.
[C]N is number of samples for specific EI reported in publication on which calculation is based.

widespread use in open applications (e.g., painting/coating and parts cleaning).

Tables III and IV present data for specific industries and processes in which the average solvent concentrations were greater than the TLV (Table III), or between one-half of the TLV and the TLV (Table IV) in effect at the time of publication. These data are sorted by year of publication.

It is clear from Tables III and IV that many of the higher exposures reported in the literature occur to n-hexane, toluene, and xylene in the auto industry (during paint/coating applications) and in the printing industry. High concentrations of benzene also were reported in several older articles; however, solvents currently marketed in Europe and the United States contain less than 0.1% benzene.

Analysis of Exposure in Adhesive, Paint/Coating, and Printing Applications

Of the 15,394 hydrocarbon solvent PBZ sample data points, a subset representing sample results for the adhesive, printing, and paint/coating applications (three major current uses of hydrocarbon solvents) was selected for detailed analysis.(1) This analysis is summarized in the following paragraphs.

The main hydrocarbon solvent exposure indicators reported for three applications were:

- adhesive—toluene, xylene, hexane, cyclohexane, and naphtha;
- paint/coating—toluene, xylene, ethyl benzene, benzene, hexane; and
- printing—benzene, ethyl benzene, xylene, and toluene.

The average solvent concentration in the printing application appears to indicate a steady downward trend over time. Similar marked trends are not evident for adhesives and paint/coating applications. For the latter, more recent articles seem to indicate lower exposures. This could be due to improved exposure controls or the introduction of modern paint formulations containing less solvent (e.g., "high-solids" and "water-based" paints).

Review of Semiquantitative Articles

In addition to the quantitative data assembled in the database, approximately 20 publications detailed exposures in adhesives, painting, or printing industries usefully, but in insufficient detail, or in units difficult to abstract for inclusion in the database. Several of the publications in the database also contained additional qualitative information useful for evaluating historical trends. These publications provide some additional information about total solvent (rather than just exposure indicator compound) exposures. Conclusions that can be drawn from these articles follow.

Adhesives

Limited data were provided in two articles. Ekberg et al.(2) found for floor layers that the mixture (additive effects) formula showed exposures of 1.8 versus the mixture limit of 1.0. Mutti et al.(3) showed an exposure for shoe gluing of 1.5 for the solvents as a mixture, versus the mixture limit of 1.0. These semiquantitative articles are in agreement with the quantitative data discussed earlier in this article. Ekberg et al.(2) further commented that exposures "were higher" (p. 105) in the 1950s and 1960s when more solvent-based glues were used. The longer-term data (243 to 317 min) presented as fraction of the TLV showed water-based glue

TABLE V. Summary of Semiquantitative Papers for the Paint Industry

	Operation	Total Solvent Exposure, as Fraction of TLV	Comments
Hanninen 1976	car spray paint	0.32	mainly aromatics and white spirit
Elofsson 1980[A]	industrial spray painting	0.24	mainly aromatics, ketones, trichloroethylene
Elofsson 1980[A]	car spray painting	0.3	mainly aromatics, white spirits, ketones
Riala 1984[A]	house type painting, interior, poor ventilation	0.91	solvent naphtha (calculated with 300 ppm TLV)
Maizlish 1987	spray painting and spray gluing	0.09	mainly aromatics, aliphatics, ketones
Triebig 1988	house painters	0.53	as given by Triebig; mainly aromatics, acetates, ketones
Triebig 1992[A]	spray painters	0.92	calculated from Triebig's data; mainly aromatics, aliphatics

[A]Denotes article in the database.

exposures (additive mixture calculations) of 0.02 and 0.03, but for work including solvent-based adhesives the results were 0.2 to 0.5. The authors further comment that water-based glues were introduced in the 1970s.[2]

Painting

Of the 13 additional articles reviewed on painting operations, six provided insights on total solvent exposure.[4–9] Range or other variance measures generally were not given with the summary statistics. Key results are presented in Table V as a fraction of the TLV (additive effects, mixture calculation).

Nelson et al.[10] provide an assessment of solvent exposures in an automotive assembly operation, including assessments by decade from the 1950s to the 1980s. Unfortunately, the assessment is aggregated, and not available by operation; degreasing, painting, and other solvent uses are grouped together. Recognizing that these data are of uncertain applicability, the trends are presented in Table VI.

Note that Nelson et al.[10] reported data for aliphatic hydrocarbons; gasoline; heptane; kerosene; VM&P naphtha (a total of 81 data points); and petroleum distillates, not further defined (a total of 286 data points). Presumably, the petroleum distillates are other fractions not reported individually.

Printing

Five articles provided useful information about exposures in printing operations. Of particular note, two articles[11,12] assessed toluene exposures over time. Orbaek's and Nise's earliest data were from 1969, although estimates are provided back to the 1950s.[12] The time trends from these articles indicate toluene exposure decreased from 300–450 ppm in the 1960s to 50–70 ppm by the mid- to late 1980s. These trends are in agreement with the quantitative data in the database as already discussed.

Several additional studies derived from the epidemiology literature were identified. These provided estimates of exposure to house painters; however, since they lacked any quantitative information they were not included in the semiquantitative articles review.

Summary of Review of Semiquantitative Articles

These articles contain data that would have been a valuable addition to the quantitative database if adequate details had been reported. A limited number of articles were published prior to 1970; the data they contain are inadequately characterized. However, review of qualitative data reported in the 1960s revealed potentially high exposures. Thus, these articles are informative and give likely ranges of past exposure. However, they are not necessarily indicative of typical worker exposures.

DISCUSSION

Articles published prior to the 1970s usually contained incomplete descriptions of the sampled operation and employed a plethora of reporting approaches. Even at present, there is a wide range in the details provided that restricts the ability to combine data sets for further analysis. Authors often reported "average concentrations," without reporting the number of samples, duration of sample, and so forth. These practices limited any meaningful statistical analysis. More consistent and more detailed descriptions of the sampling survey rationale, operating conditions (routine and typical versus worst case or upset conditions), and other exposure descriptors would help improve the utility of published articles and occupational exposure databases. The essential data elements have been described by Rajan et al.[13] and the Joint ACGIH-American Industrial Hygiene Association Task Force.[14]

There is an upward trend in the number of reported exposure measurements from the 1970s to the present, with a corresponding downward trend in the reported hydrocarbon solvent exposures. Although the date of publication may not in all cases reflect

TABLE VI. Trends of Solvent Exposure in Automotive Assembly Operations

Units: ppm	1950s	1960s	1970s	1980s
Petroleum distillates	26 (n = 12) range 2–1000	275 (n = 62) range 0–4000	5 (n = 22) range 2–290	15 (n = 190) range 0–1890
VM&P naphtha	17 (n = 25) range 3–200	325 (n = 7) range 125–548	92.5 (n = 10) range 3–380	5 (n = 39) range 2–2110

Source: Nelson et al., 1993.

the date of sampling, hydrocarbon solvent exposure indicator average concentrations were generally below the TLVs applicable at the time of publication. Furthermore, TLVs for some key hydrocarbon solvent exposure indicators have been reduced considerably since the 1960s.

As indicated in Figure 2, occupational exposures to individual exposure indicators are, on average, below 40% of the TLV for results reported since 1980. However, exposure to more than one exposure indicator (i.e., chemical substance) can occur at the same time. To calculate an OEL for such mixtures or blends of hydrocarbons, a reciprocal calculation procedure (RCP) that uses the OELs of constituent compounds is most appropriate.[15,16] ACGIH has described the use of the RCP to calculate exposure limits for mixtures for 60 years. Proposed OEL guidance values for hydrocarbon solvents, based on the RCP, recently were adopted by the European Hydrocarbon Solvents Producers Association.[17]

This database can be used as a "reality check" on the exposure estimates used in epidemiology studies that allege effects and report only subjective, qualitative estimates of solvent exposure by extracting data for specific industries, solvents, or time periods. Approximate RCP-based historic hydrocarbon solvent exposures can be estimated from the information in this database.

Evaluated overall, most exposure data are related to benzene, toluene, xylene, n-hexane, and ethyl benzene. This likely reflects concern over the unique toxicity exerted by some of these materials (i.e., benzene and blood effects, n-hexane and peripheral neuropathy). Industry and government regulations have responded to these concerns. The benzene concentration in solvents is now less than 0.1% and use of n-hexane in solvents is much reduced.

This exposure database can be used to validate existing exposure estimating models and future models that may be under development.

ACKNOWLEDGMENTS

The authors acknowledge the HSPA Occupational Health Task Force, particularly Dr. Tom Farmer and Mr. Doug Rhodes, and Ms. Janet Catanach of the ACC Hydrocarbon Solvents Panel, who reviewed a draft of this manuscript and provided helpful comments and guidance.

REFERENCES

1. **Caldwell, D.J., T.W. Armstrong, N.J. Barone, and J.A. Suder:** "Hydrocarbon Solvent Exposure Assessment" (Report prepared for CEFIC Hydrocarbon Solvents Producers Association). 1998. Exxon Biomedical Sciences, Inc. 1545 Route 22 East, P.O. Box 971, Annandale, NJ 08801–0971.
2. **Ekberg, K., L. Barregard, S. Hagberg, and G. Sallsten:** Chronic and acute effects of solvents on central nervous system functions in floorlayers. *Bri. J. Ind. Med. 43*:101–106 (1986).
3. **Mutti, A., M. Falzoi, S. Lucertine, G. Arfini, et al.:** n-Hexane metabolism in occupationally exposed workers. *Bri. J. Ind. Med. 41*:533–538 (1984).
4. **Hanninen, H., L. Eskelinen, J. Husman, and M. Nurminen:** Behavioral effects on long-term exposure to a mixture of organic solvents. *Scand. J. Work Environ. Health 2*:240–255 (1976).
5. **Elofsson, S.-A.:** Exposure to organic solvents, a cross-sectional epidemiologic investigation on occupationally exposed car and industry spray painters with special reference to the nervous system. *Scand. J. Work Environ. Health 6*:239–273 (1980).
6. **Rialla, R.:** Solvent exposure in construction and maintenance painting. *Scand. J. Work Environ. Health 10*:263–266 (1984).
7. **Maizlish, N.A., L.J. Fine, J.W. Albers, L. Whitehead, and G.D. Langolf:** A neurological evaluation of workers exposed to mixtures of organic solvents. *Bri. J. Ind. Med. 44*:14–25 (1987).
8. **Triebig, G., D. Claus, I. Csuzda, K.-F. Druschky, et al.:** Cross-section epidemiological study on neurotoxicity of solvents in paints and lacquers. *Int. Arch. Occup. Environ. Health 60*:233–241 (1988).
9. **Triebig, G.:** Neurotoxicity of solvent mixtures in spray painters. *Int. Arch. Occup. Environ. Health 64*:353–359 (1992).
10. **Nelson, N.A.:** Historical characterization of exposure to mixed solvents for an epidemiologic study of automotive assembly plant workers. *Appl. Occup. Environ. Hyg. 8*:693–702 (1993).
11. **Svensson, B.-G.:** Hormone status in occupational toluene exposure. *Am. J. Ind. Med. 22*:99–107 (1992).
12. **Orbaek, P., and G. Nise:** Neurasthenic complaints and psychometric function of toluene-exposed rotogravure printers. *Am. J. Ind. Med. 16*:67–77 (1989).
13. **Rajan, B., R. Alesbury, B. Carton, M. Gerin, et al.:** European proposal for core information for the storage and exchange of workplace exposure measurements on chemical agents. *Appl. Occup. Environ. Hyg. 12*:31–39 (1997).
14. **Joint ACGIH-AIHA Task Group on Occupational Exposure Databases:** Special report. Data elements for occupational exposure databases: Guidelines and recommendations for airborne hazards and noise. *Appl. Occup. Environ. Hyg. 11*:1294–1311 (1996).
15. **European Centre for Ecotoxicology and Toxicology of Chemicals (ECETOC):** *Occupational Exposure Limits for Hydrocarbon Solvents* (Special report no. 13). Brussels, Belgium: ECETOC, 1997.
16. **Health and Safety Executive, United Kingdom (HSE):** *Occupational Exposure Limits* (Report EH 40/96). London: HSE, 1996.
17. **Daughtrey, W.C., A.M. Medeiros, C.S. Nessel, M.J. Evans, and D.E. Owen:** "Documentation for Proposed Group Guidance Values for OEL Setting for Hydrocarbon Solvents" (Report prepared for CEFIC Hydrocarbon Solvents Producers Association). 1999. Exxon Biomedical Sciences, Inc., 1545 Route 22 East, P.O. Box 971, Annandale, NJ 08801-0971.

BIBLIOGRAPHY

1. Akbar-Khanzadeh, F. Exposure to isocyanates and organic solvents, and pulmonary-function changes in workers in a polyurethane molding process. *J. Occup. Environ. Med. 38*:1205–1212 (1996).
2. Angerer, J. Occupational chronic exposure to organic solvents, XVI. Ambient and biological monitoring of workers exposed to toluene. *Int. Arch. Occup. Environ. Health. 69*:91–96 (1997).
3. Angerer, J. Occupational chronic exposure of varnish workers: effects on hematopoetic system *Int. Arch. Occup. Environ. Health 56*:307–321 (1985).
4. Angerer, J. Occupational chronic exposure to organic solvents, VIII. Phenolic compounds—metabolites of alkylbenzenes in man. Simultaneous exposure to ethyl benzene and xylenes. *Int. Arch. Occup. Environ. Health 43*:145–150 (9179).
5. Bartolucci, G.B. Occupational exposure to solvents: Field comparison of active and passive samplers and biological monitoring of exposed workers. *Ann. Occup. Hyg. 30*:295–306 (1986).
6. Berardinelli, S. *NIOSH Health Hazard Evaluation Report: Parsons Footwear, Parsons, West Virginia* (HETA 95-0209-2515). Cincinnati, Ohio: National Institute for Occupational Safety and Health, 1995.
7. Brugnone, F. Blood toluene as a biological index of environmental toluene exposure in the "normal" population and in occupationally exposed workers immediately after exposure and 16 hours later. *Int. Arch. Occup. Environ. Health* 66:421–425 (1995).
8. Brugnone, F. Solvent exposure in a shoe upper factory. *Int. Arch. Occup. Environ. Health 42*:51–62 (1978).
9. Brugnone, F. Toluene concentrations in the blood and the alveolar air of workers during the workshift and the morning after. *Bri. J. Ind. Med. 43*:56–61 (1986).
10. Campell, L. Towards a biological monitoring strategy for toluene. *Ann. Occup. Hyg. 31*:121–133 (1987).

11. Chen, J.D. Effects of occupational and non occupational factors on liver function tests in workers exposed to solvent mixtures. *Arch. Environ. Health 52*:270–274 (1997).

12. Chen, J.-D. Exposure to mixtures of solvents amoung paint workers and biochemical alterations of liver function. *Bri. J. Ind. Med. 48*:696–701 (1991).

13. Chen, Z. Exposure of workers to a mixture of toluene and xylenes. II Effects. *Occup. Environ. Med. 51*:47–49 (1994).

14. Cherry, N. An Investigation of the acute behavioral effects of styrene on factory workers. *Bri. J. Ind. Med. 37*:234–240 (1980).

15. Cherry, N. Neurobehavioural effects of repeated occupational exposure to toluene and paint solvents. *Bri. J. Ind. Med. 42*:291–300 (1985).

16. Clark Buton, N. *NIOSH Health Hazard Evaluation Report: Michigan Printers Chicago, Illinois* (HETA 93-0366-2370). Cincinnati, OH: National Institute for Occupational Safety and Health, 1993.

17. Cook, C.K. *Health Hazard Evaluation Report: Geneva Rubber Co., Geneva, Ohio* (HETA 91-0377-2383; NTIS no. 91-0377). Springfield, Va.: National Technical Information Service, 1994.

18. Cook, C.K. *NIOSH Health Hazard Evaluation Report: American Buildings Company, El Paso, Illinois* (HETA 93-0035-2481). Cincinnati, OH: National Institute for Occupational Safety and Health, 1993.

19. Crouch, K.G. *In-Depth Survey Report: Control of Airborne Solvents in a Small Offset Print Shop at Express Service Printing, Indianapolis, Indiana.* U.S. Department of Health and Human Services/Public Health Service, Centers for Disease Control and Prevention ECTB 205-13a, 1997.

20. Daniell, W. Neuropsychological Performance and solvent exposure among car body repair shop workers. *Bri. J. Ind. Med. 50*:368–377 (1993).

21. Daniell, W. The contributions to solvent uptake by skin and inhalation exposure. *Am. Ind. Hyg. Assoc. J. 53*:124–129 (1992).

22. De Rosa, E. Hippuric acid and ortho-cresol as biological indicators of occupational exposure to toluene. *Am. J. Ind. Med. 11*:529–537 (1987).

23. Earnest, G.S. In-depth survey report: Chemical exposures and fire safety in commercial dry cleaners at A-One Cleaners Cincinnati, Ohio. U.S. Department of Health and Human Services/Public Health Service, Centers for Disease Control and Prevention ECTB: 201-18a, 1995.

24. Ekberg, K. Chronic and acute effects of solvents on central nervous system functions in floorlayers. *Bri. J. Ind. Med. 43*:101–106 (1986).

25. Elkins, H.B. Industrial benzene exposure from petroleum naphtha, II. Pertinent physical properties of hydrocarbon mixtures. *Am. Ind. Hyg. Assoc. J. 24*:99–102 (1963).

26. Elofsson, S.-A. Exposure to organic solvents, a cross-sectional epidemiologic investigation on occupationally exposed car and industry spray painters with special reference to the nervous system. *Scand. J. Work Environ. Health 6*:239–273 (1980).

27. Engstrom, K. Evaluation of occupational exposure to xylene by blood, exhaled air, and urine analysis. *Scand. J. Work Environ. Health 4*:114–121 (1978).

28. Fairfax, R. OSHA compliance issues: Solvent and noise exposure at a wood manufacturing facility. *Appl. Occup. Environ. Hyg.* 11:1045–1047 (1996).

29. Forni, A. Chromosome studies in workers exposed to benzene or toluene or both. *Arch. Environ. Health 22*:373–378 (1971).

30. Gardner, R. A Statistical analysis of data on exposure to xylene at selected workplaces in the U.K. *Ann. Occup. Hyg. 40*:411–422 (1996).

31. George, D.K. Autocorrelation of interday exposures at an automobile plant. *Am. Ind. Hyg. J. 56*:1187–1194 (1995).

32. Hallock M.F. Assessment of task and peak exposures to solvents in the microelectronics fabrication industry. *Appl. Occup. Environ. Hyg. 8*:945–954 (1993).

33. Hansen, D.J. The influence of task and location on solvent exposures in a printing plant. *Am. Ind. Hyg. Assoc. J. 49*:259–265 (1988).

34. Heitbrink W.A. *Control Technology for Autobody Repair and Painting Shops at Kay Parks/Dan Meyer Autorebuild Tacoma, Washington.* Cincinnati, OH: U.S. Department of Health and Human Services/Public Health Service, Centers for Disease Control and Prevention, Report No. ECTB 179-12a, 1992.

35. Heitbrink, W.A. *In-Depth Survey Report: Control Technology for Autobody Repair and Painting Shops at Cincinnati Collision Autobody Shop, Blue Ash, Ohio.* Cincinnati, OH: U.S. Department of Health and Human Services/Public Health Service, Centers for Disease Control and Prevention, Report No. ECTB 179-16a. 1993.

36. Hendricks, N.V. A review of exposures to oil mist. *Arch. Environ. Health 4*:21–27 (1962).

37. Hewett, D. *NIOSH Health Hazard Evaluation Report: Ohio Department of Transportation, Columbus, Ohio* (HETA 95-0308-2611). Cincinnati, Ohio: National Institute for Occupational Safety and Health, 1995.

38. Husman, K. Symptoms of car painters with long-term exposure to a mixture of organic solvents. *Scand. J. Work Environ. Health 6*:19–32 (1980).

39. International Agency for Research on Cancer (IARC) Working Group. *Evaluation of Carcinogenic Risks to Humans, Printing Processes and Printing Inks, Carbon Black, and Some Nitro Compounds* (IARC monograph, vol. 65). Lyon, France: IARC, 1996. pp. 33–58.

40. Jang, J.Y. Biological exposure indices of organic solvents for Korean workers. *Int. Arch. Occup. Environ. Health 65(Suppl.)*:219–222 (1993).

41. Jensen, A.A. Occupational exposures to styrene in Denmark 1955–88. *Am. J. Ind. Med. 17*:593–606 (1990).

42. Jones, J.G. An investigation into the effects of exposure to an oil mist on workers in a mill for the reduction of steel strip. *Ann. Occup. Hyg. 3*:264–271 (1961).

43. Jylha H.J. *Solvent Evaporation from Washing Pools in a Paint Factory* (NTIS no. PB97-133847). Springfield, Va.: National Technical Information Service, 1996.

44. Kawai, T. Dose-dependent increase in 2,5 hexanedione in the urine of workers exposed to n-hexane. *Int. Arch. Occup. Environ. Health 63*:285–291 (1991).

45. Keil, C.B. The development and evaluation of an emission factor for a toluene parts-washing process. *Am. Ind. Hyg. Assoc. J. 59*:14–19 (1998).

46. Knave, B. Long term exposure to jet fuel, II. A cross-sectional epidemiologic investigation on occupationally exposed workers with special reference to the nervous system. *Scand. J. Work Environ. Health 4*:19–45 (1978).

47. Kromhout, H. Agreement between qualitative exposure estimates and quantitative exposure measurements. *Am. J. Ind. Med. 12*:551–562 (1987).

48. Kumagai, S. Fluctuations of occupational exposure indices to mixtures. *Ann. Occup. Hyg. 36*:131–143 (1992).

49. Kumagai, S. Models describing variation of short-term exposure levels of two chemicals. *Ann. Occup. Hyg. 39*:7–20 (1995).

50. Larsen, P.B. *White Spirit (Stoddard Solvent) Environmental Health Criteria No. 187.* Geneva: World Health Organization, 1996.

51. Lemasters, G.K. Genotoxic changes after low-level solvent and fuel exposure on aircraft maintenance personnel. *Mutagenesis 12*:237–243 (1997).

52. Lewis, P. Reports of airborne solvent concentrations in a printing ink manufacturing plant in Cape Town, Republic of South Africa. *Appl. Occup. Environ. Hyg. 9*:147–151 (1994).

53. Lippmann, M. Oil mist studies, environmental evaluation and control. *Arch. Environ. Health 21*:591–599 (1970).

54. Liu, S.J. Toluene vapor exposure and urinary excretion of hippuric acid among workers in China. *Am. J. Ind. Med. 22*:313–323 (1992).

55. Maizlish, N.A. Behavioural evaluation of workers exposed to mixtures of organic solvents. *Bri. J. Ind. Med. 42*:579–590 (1985).

56. McCammon, C. *NIOSH Health Hazard Evaluation Report: Martin's Carstar, Inc., Lakewood, Colorado* (HETA 95-0311-2593). Cincinnati, Ohio: National Institute for Occupational Safety and Health, 1995.

57. McCammon, C. *NIOSH Health Hazard Evaluation Report: Matrix*

Auto Body, Englewood, Colorado (HETA 95-0406-2609). Cincinnati, Ohio: National Institute for Occupational Safety and Health, 1995.

58. McCammon, C. *NIOSH Health Hazard Evaluation Report: Spence's Carstar Denver, Colorado.* (HETA 95-0405-2600). Cincinnati, Ohio: National Institute for Occupational Safety and Health, 1995.
59. Mikulski, P.I. Investigation of exposure of ships' painters to organic solvents. *Bri. J. Ind. Med. 29*:450–453 (1972).
60. Miller, A. Health Hazard Evaluation Report: U.S. Shoe Cincinnati, Ohio (HETA 91-270-2279; NTIS no. 91-270). Springfield, Va.: National Technical Information Service, 1993.
61. Monster, A.C. Evaluation of biological monitoring parameters for occupational exposure to toluene. *Int. Arch. Occup. Environ. Health 65(Suppl.)*:159–162 (1993).
62. Moszczynski, P. The Effects of cigarette smoking on the indexes of immunity and acute phase reactions in subjects with occupational exposure to organic solvents. *Cent. Eur. J. Public Health 1*:41–45 (1993).
63. Muijser, H. Behavioral effects of exposure to organic solvents in carpet layers. *Neurotoxicol Teratol.* 18:455–462 (1996).
64. Mutti, A. N-Hexane metabolism in occupationally exposed workers. *Bri. J. Ind. Med. 41*:533–538 (1984).
65. Myer H.E. A Survey of airborne HDI, HDI based polyisocyanate and solvent concentrations in the manufacture and application of polyurethane coatings. *Am. Ind. Hyg. Assoc. J. 54*:663–670 (1993).
66. Nelson, N.A. Historical characterization of exposure to mixed solvents for an epidemiologic study of automotive assembly plant workers. *Appl. Occup. Environ. Hyg. 8*:693–702 (1993).
67. Norback, D. Occupational exposure to volatile organic compounds (VOCs), and other air pollutants from the indoor application of water based paints. *Ann. Occup. Hyg. 39*:783–794 (1995).
68. Oberg, M. A survey of the petroleum solvent inhalation exposure in detroit dry cleaning plants. *Am. Ind. Hyg. Assoc. J. 29*:547–550 (1968).
69. Ott, M.G. Mortality among individuals occupationally exposed to benzene. *Arch. Environ. Health 33*:3–10 (1978).
70. Ovrum, P. Exposure to toluene in a photogravure printing plant. *Scand. J. Work Environ. Health 4*:237–245 (1978).
71. Pagnotto, L.D. Industrial benzene exposure from petroleum naphtha: I. Rubber coating industry. *Am. Ind. Hyg. Assoc. J. 21*:417–421 (1961).
72. Pagnotto, L.D. Urinary hippuric acid excretion as an index of toluene exposure. *Am. Ind. Hyg. Assoc. J. 28*:129–134 (1967).
73. Perbellini, L. Alveolar air and blood dichloromethane concentration in shoe sole factory workers. *Int. Arch. Occup. Environ. Health 40*: 241–247 (1977).
74. Periago, J.F. Biological monitoring of occupational exposure to n-hexane by exhaled air analysis and urinalysis. *Int. Arch. Occup. Environ. Health 65*:275–278 (1993).
75. Priha, E. Exposure to formaldehyde and solvents in finnish furniture factories in 1975–1984. *Ann. Occup. Hyg. 30*:289–294 (1986).
76. Rialla, R. Solvent exposure in construction and maintenance painting. *Scand. J. Work Environ. Health 10*:263–266 (1984).
77. Rocskay, A.Z. Estimation of cumulative exposures to naphtha at an automobile fuel-injector manufacturing plant. *Am. Ind. Hyg. Assoc. J. 54*:480–487 (1993).
78. Rosen, G. Reduction of exposure to solvents and formaldehyde in surface-coating operations in the woodworking industry. *Ann. Occup. Hyg. 34*:293–303 (1990).
79. Sherwood, R.J. Evaluation of exposure to benzene vapour during the loading of petrol. *Bri. J. Ind. Med. 29*:65–69 (1972).
80. Spies, G.J. Monitoring acrylic fiber workers for liver toxicity and exposure to dimethyacetamide 1. Assessing exposure to dimethylacetamide by air and biological monitoring. *J. Occup. Environ. Med. 37*: 1093–1101 (1995).
81. Spies, G.J. Monitoring acrylic fiber workers for liver toxicity and exposure to dimethyacetamide 2. Serum clinical chemistry results of dimethylacetamide-exposed workers. *J. Occup. Environ. Med. 37*:1102–1107 (1995).
82. Svensson, B.-G. Hormone status in occupational toluene exposure. *Am. J. Ind. Med. 22*:99–107 (1992).
83. Triebig, G. Neurotoxicity of solvent mixtures in spray painters. *Int. Arch. Occup. Environ. Health 64*:353–359 (1992).
84. Tsai, S.-Y. Neurobehavioral effects of occupational exposure to low-level organic solvents among Taiwanese workers in paint factories. *Environ. Res. 73*:146–155 (1997).
85. Ukai, H. Occupational exposure to solvent mixtures: effects on health and metabolism. *Occup. Environ. Med.* 51:523–529 (1994).
86. Van Ert, M.D. Worker exposures to chemical agents in the manufacture of rubber tires: Solvent vapor studies. *Am. Ind. Hyg. Assoc. J. 41*: 212–219 (1980).
87. Vincent, R. Occupational exposure to organic solvents during paint stripping and painting operations in the aeronautical industry. *Int. Arch. Occup. Environ. Health 65*:377–380 (1994).
88. Vinzents, P. Comparison of exposure measurements stored in European databases on occupational air pollutants and definition of core information. *Appl. Occup. Environ. Hyg. 10*:351–354 (1995).
89. Wadden, R.A. Determination of VOC emission rates and compositions for offset printing. *Air Waste Manag. Assoc. 45*:547–555 (1995).
90. Wadden, R.A. VOC emission rates and emission factors for a sheeted offset printing shop. *Am. Ind. Hyg. J. 56*:368–376 (1995).
91. Wesolowski, W. Occupational exposure in Polish paint and lacquer industry. *Int. J. Occup. Med. Environ. Health 10*:79–88 (1997).
92. Whitehead, L.W. Solvent vapor exposures in booth spray painting and spray gluing, and associated operations. *Am. Ind. Hyg. Assoc. J. 45*: 767–772 (1984).
93. Wieslander, G. Occupational exposure to water based paint and symptoms from the skin and eyes. *Occup. Environ. Med.* 51:181–186 (1994).
94. Winchester R.V. Short communication, solvent exposure of workers during printing ink manufacture. *Ann. Occup. Hyg. 29*:517–519 (1985).
95. Winder, C. Solvent exposure and related work practices amongst apprentice spray painters in automotive body repair workshops. *Ann. Occup. Hyg. 36*:385–394 (1992).
96. Wolff, M.S. Blood styrene and urinary metabolites in styrene polymerisation. *Bri. J. Ind. Med. 35*:318–329 (1978).
97. Yasugi, T. Exposure monitoring and health effects studies of workers occupationally exposed to cyclohexane vapor. *Int. Arch. Occup. Environ. Health 65*:343–350 (1994).
98. Yin, S.-N. Occupational exposure to benzene in China. *Bri. J. Ind. Med. 44*:192–195 (1987).
99. Yoshikawa, M. Biological monitoring of occupational exposure to methyl ethyl ketone in Japanese workers. *Arch. Environ. Contam. Toxicol. 29*:135–139 (1995).

TABLE A1. Database Table-Field Descriptions

Table	Field	Description
TblApplication	Application_ID	unique application identification number
	Application	end use application (e.g., spray painting)
	Citation_ID	link to citation
TblAuthor	Citation_ID	link to citation
	Author_Last	last name of author
	Author_Initial	initials of author
tblCitation	Citation_ID	unique citation identification number
	Title	title of journal article
	Journal_Name	name of journal
	Journal_Volume	volume of journal
	Journal_Page_Start	first page of range of pages article found on
	Journal_Page_End	last page of range of pages article found on
	Journal_Year	date of journal issue
	Language	language of reference text
	Country	country where study was performed
	Study_Reason	reason sampling was done (worker complaint, regulatory compliance, exposure assessment, process change)
	Data_Quality	study quality (1, 2, or 3) good, fair, poor
	Abstract	journal abstract
tblControl	Application_ID	link to citation and end use application
	Control	type of engineering control used to reduce exposure
tblExposureIndicators	Application_ID	link to citation and end use application
	ExpInd_ID	exposure indicator ID
	No_Samples	number of sample results provided for this solvent
	No_Exposed	number of individuals exposed (not necessarily sampled)
	RefVal	reference value used in study
	Unit	unit of measurement for RefVal (ppm or mg/m3)
	Source	organization which established RefVal (e.g., ACGIH TLV or OSHA PEL)
	Type	TWA, STEL, or CEILING
tblPPE	Application_ID	link to citation and end use application
	PPE	type of personal protective equipment used by workers to reduce exposure
tblSampleResults	Sample_No	unique identification for sample
	Application_ID	link to citation and end use application
	ExpInd_ID	link to exposure indicator
	Strategy	sample strategy (worse case, targeted, random)
	Type	sample type (PBZ or Area)
	Sample_Method	sample collection method (pump & tube, diffusive monitor, direct reading instrument, etc.)
	Analytical_Method	reference to standard analytical method used (NIOSH, OSHA, etc.)
	Duration	sample collection period in minutes
	Single	single sample result concentration
	AM	arithmetic mean
	GM	geometric mean
	Unit	unit of measure
	No_Samples	number of samples if result is mean
	StdDev	standard deviation if result is mean
	GSD	geometric standard deviation
	Min	minimum of range if result is mean
	Max	maximum of range if result is mean
tblSolventExpInd	Application_ID	link to citation and end use application
	Solvent_ID	link to solvent look-up table (tlkpSolvents)
	Solvent_Name	link to solvent name (tlkpSolvents)
	ExpInd_ID	exposure indicator ID
tblSolventsUsed	Application_ID	link to citation and end use application
	Solvent_ID	link to solvent look-up table (tlkpSolvents) = category of solvent
	Solvent_Name	name of the solvent (product) used
	No_Samples	number of sample results provided for this solvent
	No_Exposed	number of individuals exposed (not necessarily sampled)

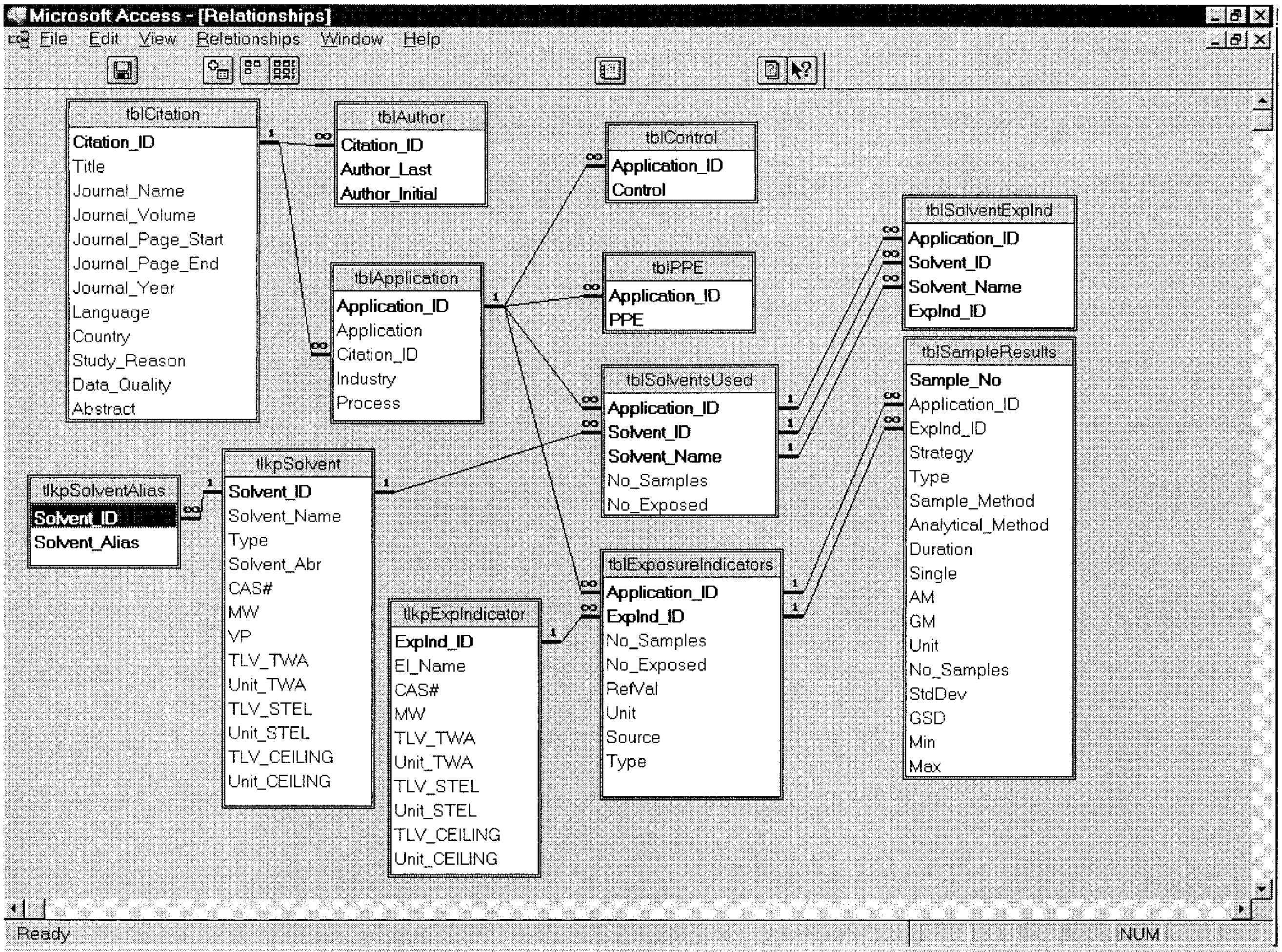

FIGURE A1. Database structure