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Hydrocarbon Exposure Assessment Methodology for an Epidemiologic Study of Renal Disease

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Historical exposure assessment was conducted for a community-based case-control study of renal cell disease and total hydrocarbon exposure. Based on occupational histories of 658 subjects, each job held by each subject was coded with the standard industrial classification (SIC) and the standard occupational classification (SOC), and entered into a Paradox (relational database) file, resulting in 3159 SIC/SOC/decade combinations. Expert industrial hygienists were asked to provide exposure estimates for occupations in industries for which they professed at least moderate expertise; between two and five experts were identified for each two-digit SIC code. Because it was not possible to obtain expert panel estimates for all of the SIC/SOC combinations reported by subjects, the assessments were supplemented when possible with values obtained from the literature and from the Occupational Safety and Health Administration's computerized information system (OCIS). Data from the expert panel, the literature, and the OCIS database were individually evaluated to develop an estimated exposure for each SIC/SOC/decade combination, which was stored in a second Paradox file. This file was cross-matched with the subject data file to calculate an estimated lifetime occupational hydrocarbon exposure in ppm-years for each subject. Recommendations include use of interviewers trained in industrial hygiene, solicitation of exact employment dates from subjects, use of coders familiar with the area from which the study subjects are drawn, and careful evaluation of the occupational coding scheme. Finally, OCIS would be much more useful if it included coding for job titles.
Nelson, D.I.; Nelson, R.Y.; Hart, K.J.; Asal, N.R.: Hydrocarbon Exposure Assessment Methodology for an Epidemiologic Study of Renal Disease. Appl. Occup. Environ. Hyg. 10(4):299–310; 1995.

Researchers seeking to access exposures in historical epidemiology studies often find limited data resources available for this purpose. Industry-based studies have utilized multiple sources, including industrial hygiene records, company operating records, engineering records, work histories, employee recollections, observations of current operations, and interviews with knowledgeable plant personnel, to develop historical exposure estimates.[1–3] However, these sources may not be available to researchers conducting community-based case-control studies in which subjects have been employed in many different jobs in multiple industries. Literature searches often yield little information on exposure to chemicals, and records of air samples taken by industry are often inadequate or inaccessible to noncompany personnel. However, there are techniques that can be successfully employed to estimate exposures for subjects in epidemiology studies. Two such research techniques—expert panel and exposure database—were used along with data from the literature in an exposure assessment for 658 subjects in a community-based case-control epidemiologic investigation of the relationship between renal cell disease and occupational hydrocarbon exposure.

Project Industrial Hygiene Team

The project industrial hygiene team was led by two certified industrial hygienists (CIHs), both of whom hold earned doctorates in environmental health, and who have over 45 years of combined experience, most of which occurred in the geographical area of the subjects' employment. The major task accomplished by the project team was the determination of lifetime total hydrocarbon exposure estimates for each subject.

Occupational History Data

Under the supervision of the project epidemiology team, extensive interviews were conducted by trained interviewers (not industrial hygienists) with cases (persons with renal cell disease) and controls. The project industrial hygiene team received only the occupational history interview forms, which included for each job the following information as recalled by the subject:

1. year of birth;
2. jobs held for 6 months or longer, organized by decade of the subject's life, starting with the teen years (This approach was preferred to structuring the interview by calendar decade, as subjects might be able to recall employment more easily by decades of their own lives. However, it created a difficulty in that the lifetime hydrocarbon exposure estimate could not be adjusted for exposures that occurred after date of diagnosis.);
3. for each job, the job title, employer/location/type, duties, hours worked per week, years employed, and a self-reported list of the materials to which the subject was exposed;
4. additional chemical exposure information, including recall of exposure to large chemical spills or leaks, acute exposures resulting in illness, or nonoccupational exposure to any

chemicals related to farming, home maintenance, yard work, gardening, hobbies, or painting; and
5. an industrial checklist, which was intended to refresh the subject's memory of employment in industries with potential for hydrocarbon exposure.[4]

The project industrial hygiene team was not aware of any subject's status as a case or control until after the exposure estimates had been derived.

All interview data received by the project industrial hygiene team were entered into a Paradox 3.5 file (operated in a personal computer network with a DEC 5000 computer). Team members codified the occupational histories of the subjects, using the *Standard Industrial Classification Manual*[5] and the *Standard Occupational Classification Manual*[6] for guidance. (All codings and data entry were reviewed by a second team member.) The standard industrial classification (SIC) codes are utilized by the Occupational Safety and Health Administration (OSHA) in management of inspection data. The four-digit classification is hierarchical, with a two-digit major group, three-digit industry group, and four-digit industry code. To be included in the SIC codes, an industry must be statistically significant in terms of number of employees or volume of business; therefore, not all industries are represented. When a specific SIC was not available for a particular industry type in the project, the establishment was coded to the nearest SIC code, which often had a 9 in the fourth-digit position, indicating "miscellaneous" or "not elsewhere classified." In about eight cases, there was not enough information given to classify the employer's SIC.

The four-digit standard occupational classification (SOC) codes are similarly organized, with division (which includes several two-digit major groups), three-digit minor group, and four-digit unit group for the specific occupation. The primary basis of the SOC codes is the nature of the work performed, with a secondary consideration of the place of work if the work setting significantly alters the nature of the work. Chemical exposures associated with the work are not considered in the SOC system; therefore, difficulties were frequently encountered in selecting the best SOC code for a particular job. Occupations that may receive significant hydrocarbon exposure are frequently classified with occupations that would normally have limited hydrocarbon exposure. For example, vehicle washers have the same code as equipment cleaners, although the first typically involves only water-based cleaners, while the second could often represent dip-tank operators. Gluers and hand nailers have the same code as assemblers, although the two occupations would receive very different hydrocarbon exposures. The classification seemed somewhat archaic; parlor chaperons were coded but industrial hygienists were not. For this study, because of the frequency of oil field employment in this geographic region, the SOC category for 652 drillers, oil well, was further subdivided into 6521 drillers, roughnecks, and 6522 roustabouts, oil well maintenance. In general, jobs were coded to the most appropriate SOC code, and any discrepancies were corrected during the *a posteriori* review described below.

The 658 subjects held a lifetime average of seven jobs each (range 0 to 22), for a total of 4689 jobs that were SIC and SOC coded by the project industrial hygiene team. When the closest calendar decade in which the job was held was combined with the SIC and the SOC codes and duplicates eliminated, the 4689 jobs collapsed to 3159 unique SIC/SOC/decade combinations. (Approximately 30 combinations represented students or housewives and were not classifiable in the SOC system.) This reduction in the number of jobs requiring hydrocarbon exposure estimates was an important feature of the design, as it significantly reduced the task load on the expert panel, all of whom served as volunteers.

Development of Expert Panel Estimates

A panel of expert industrial hygienists was assembled for the purpose of generating hydrocarbon exposure estimates for each of the SIC/SOC/decade combinations. (For purposes of this study, hydrocarbon was defined as compounds containing hydrogen and carbon, with or without halogens.) Criteria for selection on the panel were certification or long-term experience in the practice of industrial hygiene in the geographical area. All 37 industrial hygienists who were contacted initially agreed to serve. Panel members were not asked to evaluate all SIC/SOC combinations, but rather were assigned to subpanels on the basis of their self-reported experience. A list of the two-digit major industrial group codes was submitted to the panel members, who were asked to rank their own level of experience in that industrial group on a scale of 0 to 5. Self-reported expertise of panel members was similar to the distribution of jobs reported by interview subjects. The panel members failed to report expertise for only 8 of the 82 two-digit SIC codes. These eight industry groups tended to represent occupations with low levels of hydrocarbon exposure—general merchandise (104 jobs), insurance carriers (37 jobs), insurance brokers (18 jobs), real estate (21 jobs), lodging (52 jobs), and business (103 jobs)—although nonmetallic mining (7) and water transportation (4) were not covered, for a total of 346 (7%) of the 4717 jobs that were classifiable. For each two-digit SIC code, a three- to six-member subpanel was then selected, based on the self-reported expertise of the panel members. (Due to lack of expertise, five subpanels had three members, and one group had only two members.) In nearly all cases, the resulting subpanels were composed of members with the highest self-reported expertise. The primary selection was panel members with self-reported scores of 4 or 5; for two-digit codes with a low degree of self-reported expertise, a panel member with a score of 3 was selected. Occasionally, a panel member with a score of 2 was selected; in no case was a panel member with a score of 1 or 0 assigned to an industry group. Subpanel assignment was balanced by the need to not overload any single panel member, all of whom served as volunteers.

Survey forms requesting hydrocarbon exposure estimates were submitted to the industrial hygienists based on their subpanel assignments to the two-digit industry groups. Several options for the format of hydrocarbon exposure estimates were considered: (1) as a function of OSHA permissible exposure limits or American Conference of Governmental Industrial Hygienists threshold limit values; (2) semiquantitatively (i.e., low, medium, or high); or (3) quantitative exposure estimates. The first option was discarded as too complex for panel members, as it would require a weighting function where more than one hydrocarbon was involved. Use of descriptive categories, while easier for the panel members to provide, would somewhat limit the mathematical manipulations to be performed later. Quantitative exposure assessments based on a familiar scale (parts per million, ppm) would be more challenging for the respondents to provide; however, they could be collapsed into semiquantitative categories at a future date if necessary, and might force the assessors to evaluate the exposures more carefully.[7] Therefore, respondents were asked to provide for each SIC/SOC/decade combination the time-weighted average exposure to total hydrocarbon, expressed in ppm, and the fraction composed of chlorinated or aromatic hydrocarbons. (According to toxicokinetic modeling, when the rates of elimination and repair are first order, the cumulative exposure should be a valid predictor of damage.[8])

Requests for estimates were submitted to the 34 panel members. Despite follow-up calls and letters to nonresponders, only 19 completed the study: nine were CIHs, one was a PhD, and four were both CIHs and PhDs. Three were employed by OSHA, four more were in other branches of government, four were employed in university settings, four were working for private industry, and four were employed primarily as consultants. Four more had extensive consulting experience. Two-thirds had over 10 years' experience in industrial hygiene.

Over 5200 exposure estimates were returned by panel members. All SIC/SOC/decade combinations represented by subjects in the first portion of the study had at least one expert estimate of hydrocarbon exposure. At least two estimates were received for about 1700 combinations, and at least three for about 770 combinations; in these cases, the arithmetic average of estimates was used. Even after follow-up letters and telephone calls to 15 nonresponding panel members, it was not possible to obtain expert panel estimates for all of the SIC/SOC/decade combinations reported by subjects. Also, the returned survey forms did not always provide all the information requested. (Frequently only the time-weighted average or range of hydrocarbon exposure was estimated, with no estimate provided on the fraction composed of chlorinated or aromatic hydrocarbons, limiting analysis to total hydrocarbon exposure.)

Literature Search

Estimates obtained from the expert panel were supplemented when possible with (1) semiquantitative exposure descriptors for a limited number of occupational categories gleaned from an extensive search of the literature, and (2) data from the OSHA computerized information system (OCIS),[9] discussed below. As it was not known which SIC/SOC combinations would eventually be represented in the subjects' occupational histories, a systematic search of the literature was conducted to locate hydrocarbon exposure data. The primary strategy was a computerized search of bibliographic databases, supplemented by manual search of major professional journals. Relevant titles located through the following sources were searched for content related to hydrocarbon exposure, and filed as appropriate under the two-digit SIC code.

1. Computer searches were conducted at two different times through both Medline and Toxline, with key words including "hydrocarbon," "solvent," and/or "occupational exposure."
2. Extensive manual searches were conducted of 18 major industrial hygiene and occupational health journals, including *American Industrial Hygiene Association Journal*, *Applied Occupational and Environmental Hygiene*, and *Journal of Occupational Medicine*.
3. The contents of the University of Oklahoma Library government documents section, which is a full repository, were searched by computer using key words such as "hydrocarbon," "solvent," and/or "occupational exposure"; no hydrocarbon exposure data were found. The Environmental Protection Agency bibliography on total human exposure data was also searched.[10]

The majority of the literature located by these methods was concerned with the health effects of exposure to various hydrocarbons, with very few exposure data presented. Those data that were located were primarily associated with occupations that would be expected to have relatively high exposures[11] (e.g., employees in dry cleaning,[12–14] petroleum refining,[15] service stations,[16–18] or paint manufacturing[1]). Several studies presented semiquantitative estimates of hydrocarbon exposures to broad occupational categories.[19–23]

OCIS

The OCIS database,[9] which is maintained by the OSHA laboratory in Salt Lake City, Utah, is perhaps the country's largest data set of occupational air sample results. [OCIS is periodically reconciled with OSHA's integrated management information system (IMIS, formerly MIS), which is maintained in Washington, DC.] OCIS houses information on approximately 400,000 personal and area air samples taken by OSHA compliance officers since 1981. This seldom-utilized source contains information on the employer's name, SIC code, chemical name, purpose of sampling, job title (personal samples), date of sampling, OSHA regional office, as well as other information. Although sometimes available on the original report generated by the compliance officer, the OCIS database does not contain information on determinants of exposure such as type of equipment, process, ventilation or other controls, production volume, or weather conditions, which would assist in interpreting the exposure measurements.[24] The use of the OCIS database was not a part of the original study design, due largely to a concern that the data might not be representative of typical employee exposure.[25] Since the data were collected primarily to determine compliance with the OSHA standards, it is possible that many of the samples represent worst case situations rather than typical exposures, particularly when samples were taken in response to employee complaints. However, as a result of reports of recent findings that the presence of such biases may not be as significant as originally thought,[26] the OCIS database was included in the project. The worst case sampling approach may actually target worst-case job titles, yielding exposure data for the occupations that receive the highest exposures.[24] With respect to the accuracy of data entry in the OSHA IMIS database, a comparison of the database entries and the inspection records for 33 companies found one error in the worker exposure level out of 366 samples for respirable silica or lead.[27] A study of OSHA data from 1972 to 1979 found that complaint-generated inspections did not result in overexposures any more often than did general schedule inspections.[28]

The OSHA IMIS database has been used to evaluate silica exposures[29] and lead exposures[25] to workers in selected SIC codes. Silica exposure levels tended to be highest in complaint-initiated inspections at union facilities in several of the SIC codes; however, because of high exposure levels also found in general inspections and in nonunion plants, the bias was not severe. It has been pointed out that a large amount of data can compensate for day-to-day variations in exposure levels but not for biases introduced when merging data originating from different sampling strategies.[30] Therefore, despite some evidence of the absence of bias, these data should be classified into groups having similar bias before they are pooled, which may result in a large amount of data being disregarded for historical use. As a result, the use of OCIS data in this study was to provide guidance in assigning estimates of hydrocarbon exposure and not as the sole source of exposure data.

The OCIS data were obtained directly from the OSHA lab in Salt Lake City, but they are also available by modem. Of about 72,500 samples in the database which were taken for 57 liquid hydrocarbons and halogenated hydrocarbons, only about 22,500 contained complete information on job title, date of sampling, company name, and SIC code. These data were then screened for samples with SIC codes that were reported in the study. Samples that had identical job descriptions were averaged by job title within company, and then across companies, so that a large number of samples taken at one company would not have a disproportionate influence on the mean. This procedure yielded about 3300 records with SIC codes (but not necessarily job titles) that matched those in the epidemiology exposure assessment. Then, for each separate SIC/SOC combination reported by the subjects, the identical SIC code match was first located in the OCIS database. Next, the SOC codes were matched to the job title descriptions in OCIS, a difficult task due to the range of job titles in the OCIS database.

Integration of Exposure Estimates into Final Exposure Estimates

Final exposure estimates were individually developed for each of the first set of 2456 SIC/SOC/decade combinations by the two project industrial hygienists using the following sources:

1. over 5200 hydrocarbon exposure estimates developed by the 19-member expert panel,
2. quantitative and semiquantitative exposure data obtained from the literature, and
3. over 3300 values for individual SIC/job title combinations from the OSHA OCIS database.

For each SIC/SOC/decade combination, the mean of the expert panel estimate was compared with any available estimates from OCIS or the literature (See Tables 1 and 2) and adjusted accordingly. In cases where estimates from the expert panel, OCIS, and/or the literature varied, the estimates provided by the expert panel were given the most weight. Professional judgment was a critical component of the evaluation process.

A data-rich example is presented in Table 3, which displays data from all three sources—expert panel, the literature, and OCIS—used to develop exposure estimates for jobs in industry group number 721, laundry, cleaning, and garment services, and the final exposure estimates. For this industry group, the entire panel was asked to provide estimates of hydrocarbon exposure. Table 3 presents the mean and the coefficients of variation of the estimates provided by the full panel, along with the estimates provided by the three-member subpanel assigned on the basis of their self-reported expertise. The coefficients of variation for the full panel estimates tended to be lower for higher estimates, indicating more inter-rater agreement on higher exposures. The subpanel estimates were lower than those provided by the larger panel, but followed the same trend of diminishing hydrocarbon exposure with passage of time. Where appropriate, job title matches were found in the OCIS database, which contains data from 1981 to the present, and the values were averaged and presented next to the most appropriate decade. The literature values presented in Table 3 were summarized from data contained in Table 4 (which contains perchloroethylene exposure data from three published studies) and are also presented next to the most appropriate decade. In assigning final exposure estimates for the first entry in Table 3, SOC 7658 laundering and dry cleaning, in SIC 7210 laundry, cleaning, and garment services, in 1970, the full panel estimate of 95 ppm, the subpanel estimate of 67 ppm, and OCIS value of 118 ppm, and the literature estimate of 50 ppm were subjectively evaluated. Starting with (in this case) the full panel estimate, and comparing it with the higher OCIS value and lower literature value, a final estimate of 93 ppm was subjectively derived.

Occupational history interview forms continued to be received by the project industrial hygienists after the submission of survey forms to the expert panel. These interview forms yielded about 700 new SIC/SOC/decade combinations. About 110 represented previously assigned SIC/SOC combinations, but from a different calendar decade. An additional 80 were previously assigned SOC classifications from new SIC codes, and 330 were new combinations of previously evaluated SIC and SOC codes. Final exposure estimates for the combinations from new calendar decades were determined by extrapolating the exposure estimates already assigned to existing SIC/SOC combinations, and assuming declining exposures with time. Final exposure estimates were made for these jobs by comparison with estimates in similar SIC codes. The remaining approximately 180 SIC/SOC/decade combinations (<6% of the total) were assigned hydrocarbon exposure estimates by the project industrial hygienists based on the OCIS database, the literature values, and professional experience.

All the 3159 SIC/SOC/decade combinations with their exposure estimates were sorted from their original format (SIC/SOC/decade) so that the primary sorting order was SOC, followed by SIC, and then decade. This allowed all jobs with the same title from all SIC codes to be adjusted for any inconsistencies. (For example, it would be expected that office personnel generally would be expected to have similarly low hydrocarbon exposures, except in industries that use or process large quantities of solvents, for example, petroleum refineries or dry cleaning.) The final hydrocarbon estimate values were contained in a second Paradox file.

Estimation of Lifetime Hydrocarbon Exposure

The capabilities of Paradox as a relational database were utilized in this phase to develop lifetime hydrocarbon exposure estimates for each of the 658 subjects in the epidemiologic

TABLE 1. Comparisons of Hydrocarbon Exposure Estimates from the Expert Panel, OSHA OCIS, and Literature for Selected Job Titles

Job Title[A]	Literature[B] (Reference No.)	OSHA OCIS[C] ppm (No. of Samples/ No. of Companies)	Mean Expert Panel Estimates[D] (No.-of Estimates)
Painting			27 estimates
Painter/lacquerer	Inevitable/heavy (20)		9 industries
House painting	Heavy (21) Heavy (19)		53 ppm
Industrial	Heavy (21) Heavy (19)	22–481 ppm[E]	
Outdoor	Slight (21) Slight (19)		
Artists (USC 188)	Probable (22) Likely (23)	"Artist" 6 ppm (17/8)	
Construction (USC 579)	Probable (22) Likely (23)	Painting and paperhanging (SIC 1721) 153 ppm (177/32)	
Maintenance (USC 579)	Probable (22) Likely (S)		
Machine operation (USC 759)	Probable (22) Likely (S)		
Hand painting (USC 789)	Likely (S)		
Paint manufacture	Heavy (21)	Paints and allied products (SIC 2851) 49 ppm (345/29)	N/A
Mixing/blending machine operator (USC 756) in paints	Likely (23)	"Mixer" 33 ppm (58/12)	
Mixer/grinder	18.5 ppm[F] (1)		
Other operators	15–31 ppm[F] (1)	"Batchmaker" 48 ppm (57/4) "Fillers" 100 ppm (54/8)	
Shipping office supervisor	1.7 ppm[F] (1)		
Warehouse	0.4–1.9[F] (1)		
Cabinetmakers, bench carpenters (USC 657)	Probable (22) Occasional (20)	"Cabinet" workers 158 ppm[G] (34/4)	4 estimates 2 industries 21 ppm
Furniture and (USC 658) wood finishers	Probable (22)		
Carpenters, parquetry workers	Occasional (20)	"Carpenters" 27 ppm (77/15) "Wood Finishers" 55 ppm[G] (3/1)	12 estimates 6 industries 4 ppm
Carpet and floor laying	Heavy (21) Heavy (19)	"Carpet layers" 119 ppm (44/7) "Floor layers" 87 ppm (11/2)	
Tile setters, hard and soft (USC 565)	Probable (22)	"Tile setters" 285 ppm (4/2)	2 estimates 1752 (floor laying) 10 ppm
Metal degreasing	Moderate (21) Moderate (19)	"Degreaser" 64 ppm (253/37)[E]	
Washing, cleaning, pickling (USC 764)	Likely (23)	"Cleaners"[H] 49 ppm (106/20)	3 estimates 3714 (motor vehicle parts) 20 ppm

(continued)

TABLE 1. Continued

Job Title[A]	Literature[B] (Reference No.)	OSHA OCIS[C] ppm (No. of Samples/ No. of Companies)	Mean Expert Panel Estimates[D] (No. of Estimates)
Motor repair	Slight (21)		
Mechanics	Probable (22)	"Mechanics" 63 ppm (130/37)[E]	32 estimates 8 industries 11 ppm
Auto (USC 505)	0.4–8 ppm[I] (17)		
Bus, truck (USC 507)			
Aircraft engine (USC 508)			
Auto body (USC 514)		9 ppm (3/1)	
Aircraft mechanics (USC 515)		"Heavy equipment repair" 0 ppm (2/1)	
Use of hair spray	Slight (21)	N/A	3 estimates 7231 (beauty shops) 7 ppm
Handling petrol	Slight (21)		
Garage/service station attendant (USC 885)	Likely (23) 25 ppm[J] (18) 0.7–5 ppm[I] (17) 3.6–22 ppm[K] (16)	Attendant 189 ppm (1/1)	5 estimates 5541 (gas stations) 16 ppm
Transport drivers	17 ppm[J] (18)	"Driver" 10 ppm (15/10)	74 estimates 26 industries
during offloading	8 ppm[I] (17)		4 ppm
Outside operators (refinery)	7 ppm[J] (18)	3 ppm benzene (87/14)	3 estimates 2911 (petroleum refining) 50 ppm
Anesthesiology work	Slight (21) Moderate (19)	Health services[L] 2 ppm (56/17)	Doctors, nurses 4 estimates 3 ppm
Clinical lab technologists (USC 203)	Probable (22) Likely (23)		
Medical scientists (USC 83)	Possible (22)		
Dental lab technician (USC 678)	Possible (22)		
Printing work	Moderate (19)	"Printer" 48 ppm (416/67)[E]	12 estimates 6 industries 34 ppm
Printing machine operators (USC 734)	Probable (22) Likely (23)		
Misc. printing machine operators (USC 737)	Possible (22)		
Photoengravers and lithographers (USC 735)	Probable (22)		
Typesetters (USC 736)	Likely (23)		
Typographers/lithographers	Inevitable (20)		
Electrical technicians	Possible (22)		
Electronic repairers	Possible (22)		
Data processing equipment repairers	Possible (22)		
Electrical equipment repairers	Possible (22)		
Electricians	Occasional (20)	15 ppm[M] (17/8)	7 estimates 2 industries 8 ppm
Tool and diemakers	Possible (22)	133 ppm (5/1)	5 estimates 2 industries 58 ppm

(continued)

TABLE 1. Continued

Job Title[A]	Literature[B] (Reference No.)	OSHA OCIS[C] ppm (No. of Samples/ No. of Companies)	Mean Expert Panel Estimates[D] (No..of Estimates)
Welders and cutters	Possible (22)	"Welders" 11 ppm (55/10)	33 estimates 13 industries 13 ppm
Solderers and brazers	Possible (22)	"Solderers" 1 ppm (14/2) "Brazers" 16 ppm (3/1)	
Farm workers, machinery operators	Occasional (20)	N/A	106 estimates 11 industries 6 ppm
Motor vehicle drivers Truck drivers	Occasional (20) Occasional (20)	"Driver" 10 ppm (15/6)	74 estimates 26 industries 4 ppm
Building caretakers	Occasional (20)	"Janitor" 19 ppm (6/3)	41 estimates 16 industries 6 ppm
Secretaries	N/A	N/A	91 estimates 36 industries <1 ppm

[A]Job titles are from the 1980 U.S. Census Code.
[B]Information presented in this table represents the majority of hydrocarbon exposure data from the literature search.
[C]Hydrocarbon exposure measurements were averaged within job title, and then across companies. Data for job titles in paint manufacturing, refineries, and health care were taken from facilities with appropriate SICs. Job titles in quotations were taken from all industries. See text for further explanation.
[D]Arithmetic average of estimates from panel members.
[E]See Table 2 for further information.
[F]Values represent means of total hydrocarbon exposures from multiple samples taken on a variety of paint manufacturing job titles.
[G]Primarily petroleum distillates.
[H]Excluding dry cleaners and cleaners of cars, shoes, jewelry, and tanks.
[I]Based on a molecular weight of 67.5 g/mol for gasoline (see Reference 18), $N = 8$ for attendants (average 400 minutes), $N = 4$ for mechanics (average 430 minutes), and $N = 1$ for driver/loader (average 26 minutes).
[J]Based on a molecular weight of 67.5 g/mol for gasoline ($N = 49$ for service station attendants, 49 for transport drivers, and 56 for outside operators).
[K]Range of the means of seven groups of time-weighted samples from different service stations; the number of samples in each group ranged from 10 to 19. The range of the individual samples was 0.4 to 114 ppm.
[L]SIC 80, excluding nonmedical personnel.
[M]Values skewed by high exposures (mean 76 ppm) to petroleum distillates at one company.

study. The file containing the SIC/SOC/decade and length of employment for each job reported by each subject was cross-matched with the file containing the final exposure estimates for each SIC/SOC/decade combination, using Paradox 3.5 in a PC network supported by a DEC 5000 computer. For each subject, the length of employment (in years) in each decade (of his/her lifetime) for each job was multiplied by that job's final hydrocarbon exposure estimate in ppm to generate a dose estimate in ppm-years. The individual job dose estimates were summed for each subject in the study to generate a lifetime hydrocarbon exposure estimate.

Subject interview forms also contained information on additional chemical exposures, including exposure to large chemical spills or leaks, acute exposures resulting in illness, or nonoccupational exposure to any chemicals related to farming, home maintenance, yard work, gardening, hobbies, or painting. Interview data from 658 subjects (334 cases and 324 controls) were used to classify the subject as exposed or nonexposed in that category. These data were analyzed with the Statistical Analysis System for Personal Computers[31] (Table 5). More controls (150) than cases (113) were involved in yard/home maintenance ($p = 0.003$). The distribution of type of chemicals self-reported in this maintenance varied ($p = 0.007$), with controls having slightly more self-reported exposure to cleaning and household products and pesticides. Controls (72) were more likely than cases (51) to report hobbies involving solvents ($p = 0.033$). No differences were seen with respect to exposure to large chemical spills, inhalation or skin contact episodes, incidence of acute exposure leading to illness, being raised on a farm, driving a tractor, repairing a tractor, the type of tractor, home painting, or type of paint. As a result of these findings, additional chemical exposures beyond occupational exposures were not estimated for the lifetime hydrocarbon exposure estimate.

Discussion

Key findings of the literature search, which tended to be semiquantitative in nature, are presented in Tables 1 and 3. The most information tended to be concentrated in areas where exposures were rated highest, such as painting, paint manufacturing, gasoline refining and dispensing, and dry cleaning. Jobs that are likely to have very little hydrocarbon exposure, such as secretarial work, received little mention in the literature. Table 1 also presents a summary of the hydro-

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TABLE 2. Additional Mean Hydrocarbon Concentrations for Selected Jobs/Industries from OSHA OCIS

SIC	Industry	No. of Samples	No. of Companies	Mean Concentration (ppm)[A]
Painters				
2499	Wood products, nec	78	4	404
3441	Fabricated structural metal	59	16	118
3443	Fabricated plate work (boiler shops)	72	15	48
3444	Sheet metal work	51	9	22
3479	Metal coating and allied services	151	16	102
3523	Farm machinery and equipment	76	15	61
3731	Ship building and repairing	134	20	481[B]
3732	Boat building and repairing	91	15	54
3799	Transportation equipment, nec	82	9	96
5511	New and used car dealers	75	19	43
7532	Top and body repair and paint shops	162	39	42
Degreasers				
3471	Plating and polishing	69	12	70
3585	Refrigeration and heating equipment	41	4	58
3592	Carburetors, pistons, rings, valves	21	2	26
3728	Aircraft parts and equipment, nec	16	3	56
Mechanics				
3089	Plastics products, nec	14	1	4[C]
3721	Aircraft	15	2	1[C]
5511	New and used car dealers	33	11	111[C]
Printers	Screen printers	175	21	66
	Offset printers	9	1	18
	Press operators	9	3	8
	"Printers"	192	22	50

[A]Hydrocarbon exposure measurements were averaged within job title, and then across companies. Data for painters, degreasers, and mechanics were taken from facilities with the indicated SIC. Data for printers were taken from all industries. See text for further explanation.
[B]Includes seven samples that were over 1000 ppm for 710 or Stoddard solvent.
[C]Hydrocarbon concentrations were primarily for heptane and hexane for SIC 3089, benzene for SIC 3721, and Stoddard solvent for SIC 5511.

carbon concentrations from the OSHA OCIS for the jobs/industries mentioned in the literature, and the corresponding estimates from the expert panel survey. Where two or three data sources were available, the hydrocarbon exposure estimates were frequently consistent, improving confidence in estimates with only one available data source. For example, the panel gave a high composite estimate for painters (53 ppm), compared with literature estimates such as inevitable/heavy and probable. Estimates from the OSHA OCIS for painters ranged from 22 to 481 ppm for industry averages. Washing and cleaning were rated in the literature as likely to have hydrocarbon exposure. The OSHA OCIS average exposure for cleaners was 49 ppm, based on 106 measurements from 20 industries. A representative expert panel estimate was that for cleaners in SIC 3714, motor vehicle parts, which was 20 ppm based on three estimates. The literature characterized printing work in general as having moderate, probable, or likely exposure. Jobs that had "printer" in the title in OSHA OCIS had an average exposure of 48 ppm (based on 416 measurements in 67 companies). The 12 expert panel estimates of six industries averaged 34 ppm for printers. The literature did not mention secretaries; the expert panel estimated an average hydrocarbon exposure of <1 ppm, based on 91 estimates in 36 industries.

Where there was more than one hydrocarbon exposure estimate provided by the expert panel, the estimates tended to be in general agreement. A procedure adapted from Macaluso *et al.*[32] was used to evaluate the degree of concordance in hydrocarbon exposure estimates for 229 SIC/SOC/decade combinations for which there were estimates provided by at least four experts. The estimates were first placed in categories according to the following scale: 1 (≤1), 2 (>1, ≤10), 3 (>10, ≤50), 4 (>50, ≤100), and 5 (>100, ≤500). A concordant set was defined as one in which at least three of the four estimates were in the same category. Using these criteria, 66 percent of the sets were concordant. Slightly altering the criteria to collapse the first two categories (i.e., any estimate ≤10 was in category 1) resulted in a concordance of 93 percent, indicating that much of the variation in estimates occurred at low levels. (Macaluso *et al.*[32] observed good agreement between estimates related to frequent exposures at a single plant. Lower agreement seen at low exposure levels was related more to the low frequency of these exposures than to discordance between the raters.)

Several limitations of the OSHA OCIS database involve classification of job titles, and number of analytes for each sample. The job titles in the OCIS database were selected by the OSHA compliance officer who conducted the air monitoring; SOC or other numerical coding was not used by OSHA. As a result, there was a wide range of job titles for similar jobs. For example, under SIC 7216, dry cleaning plants, except rugs, there were over 60 separate titles for dry cleaners

TABLE 3. Comparison of Experts' Estimates in Industry Group Number 721, Laundry, Cleaning, and Garment Services

Decade	SIC/SOC[A]	Number of Estimates, Full Panel	Mean Panel Estimate (ppm)	CV	Mean Subpanel Estimate[B] (ppm)	OCIS Values (ppm)	Literature Estimates[C] (ppm)	Final Estimate (ppm)
	SIC 7210	Laundry, cleaning, and garment services						
1950	SOC 7658	10	95	0.80	67			93
1970	SOC 7658	12	75	0.99	50	118[D]	~50	84
	SIC 7211	Power laundries, family and commercial						
1940	SOC 7658	10	99	0.72	70	118[D]	~50	94
	SIC 7215	Coin-operated laundries and cleaning						
	SOC 6179	10	20	0.89	12			17
1970	SOC 7658	11	50	0.74	35			40
1980	SOC 7658	12	39	0.86	22	44[E]	~50	33
	SIC 7216	Dry cleaning plants, except rug						
1930	SOC 4362	8	18	0.97	18			9
1970	SOC 4363	10	22	1.29	14	8[F]	~7	11
	SOC 4364	10	21	1.32	14	8[F]	~7	11
1940	SOC 4490	8	16	1.09	13			9
1930	SOC 7658	8	110	0.83	83			69
1940	SOC 7658	9	104	0.84	70			63
1950	SOC 7658	10	93	0.95	70			63
1960	SOC 7658	10	87	0.95	62			49
1970	SOC 7658	10	72	0.96	35			45
1980	SOC 7658	11	60	1.01	22	55[G]	~50	39
1980	SOC 7850	8	19	1.02	25			25
1960	SOC 8214	9	25	1.19	6			7
1970	SOC 8617	9	51	1.46	8			31
	SIC 7217	Carpet and upholstery cleaning						
1970	SOC 5244	9	25	0.92	14			11
1980	SOC 5244	9	21	0.85	14			11
	SIC 7219	Laundry and garment services						
1960	SOC 4490	6	18	0.99	5			6
1970	SOC 4490	6	13	1.02	5	8[F]	~7	6
1940	SOC 7658	9	98	0.91	70			71
1950	SOC 7658	10	88	1.01	70	71[H]	~50	71
1950	SOC 8617	7	83	1.14	53			53
1930	SOC 8769	7	80	1.18	50			53

[A]The following SOCs are represented:
SOC 4362 sales clerks
SOC 4364 cashiers
SOC 4490 sales occupations
SOC 5244 janitors and cleaners
SOC 6179 mechanics and repairers
SOC 7658 laundering and dry cleaning
SOC 7850 graders and sorters
SOC 8214 truck drivers, light
SOC 8617 helper, textile, apparel
SOC 8769 manual occupations
[B]Based on two to three estimates from subpanel.
[C]See Table 4.
[D]Based on eight values in SIC 7211, power laundries.
[E]Based on two values in SIC 7215, coin-operated laundries.
[F]Based on three values in SIC 7211, power laundries.
[G]Based on 63 values in SIC 7216, dry cleaning plants, except rug.
[H]Based on four values in SIC 7219, laundry and garment services.

alone, not including any job titles with "presser." The titles ranged from cleaner to dry cleaning operator, and included misspellings and abbreviations. A further limitation of the OSHA OCIS data is that for most samples they contain analytical results for only one analyte. In a complex exposure scenario, for example, a petroleum refinery, employees are typically exposed to a range of hydrocarbons; however, OSHA OCIS contained data only for benzene exposures.

TABLE 4. Perchloroethylene Exposures Reported in Dry Cleaning (ppm)

Job Title	Exposure	Samples	Reference
Operator	46.5 ± 34.1	12	14[A]
Dry-to-dry closed system	28.3	3	13[B]
All transfer operations	86.6	17	13
Local exhaust ventilation	5.3	3	13
Poor or no ventilation	159.7	14	13
Machine operators	31/22[C]	45	12[D]
Presser	14.83 ± 15.5	12	14
Presser	5.7/3.3[C]	52	12
Clerk	11.67 ± 11.1	12	14
Front counter	5.9/3.1[C]	31	12
Seamstress	6.6/3.0[C]	12	12
Seamstress	19.0	1	14
Other	5.00 ± 7.1	2	14

[A]Based on a study of 13 dry cleaning plants.
[B]Based on a study of 20 dry cleaning plants.
[C]Arithmetic mean/geometric mean.
[D]Based on a study of 44 dry cleaning plants.

A major source of error in case-control studies is misclassification of subject exposure. According to Stewart and Correa-Villasenor,[33] when the exposure prevalence in a community-based case-control study is low (commonly <10%), and if nondifferential misclassification is assumed, the principal source of error is false positive exposure errors (i.e., nonexposed subjects being classified as exposed). Negligible bias would be introduced by even a relatively large number of false negative exposure errors. Random misclassification of cases and controls tends to reduce the observed degree of association between exposure and disease.[34] Three possible sources of exposure errors have been listed: respondent, data coding, and exposure assessment.

As the respondents are the primary source of information in a community-based case-control study, the quality of the questionnaire and the interview process itself assume great importance; the structure of the questionnaire, the language used, and even the attitude of the interviewer can influence the outcome of the interview.[34] Unfortunately, there are few data validating self-reported exposures in community studies.[4]

TABLE 5. Chi-Square Analysis of Additional Chemical Exposures of Cases and Controls

Source of Exposure	Chi-Square	Probability
Chemical spills	0.969	0.325
Inhalation episode	1.403	0.236
Skin contact episode	0.649	0.420
Acute exposure (resulting in illness)	0.037	0.847
Early years on a farm	0.144	0.704
Drive a tractor	0.370	0.543
Type of tractor	2.526	0.773
Repair tractor	1.043	0.307
Yard/home maintenance	8.974	0.003
Type of chemicals	14.258	0.007
Hobbies with solvents	4.554	0.033
Paint (home maintenance)	2.814	0.093
Paint type	4.504	0.342

Data coding errors can result from mistakes by personnel doing the coding, from data entry, or by occupational codes that are ambiguous with regard to exposure status.[33] To guard against data coding errors, all coding (both SIC and SOC) in this study was reviewed by a second team member. The very few jobs that were ultimately nonclassifiable were students and housewives. The use of SIC codes in combination with SOC codes reduced the ambiguity of job classifications. Finally, the *a posteriori* review served as a final check on coding errors.

Exposure assessment errors can result from job titles being falsely designated as exposed or not exposed, or from arbitrary assignment of exposure.[33] Strategies to reduce classification errors included obtaining independent estimates from the OCIS database, the literature, and several industrial hygienists who had indicated a degree of expertise in the area. The *a priori* approach of basing exposure estimates on job title does not take into account individual variability in work patterns, which can contribute significantly to variations in exposure between workers.[2,34] The *a posteriori* approach was found to yield higher and more precise risks than an *a priori* method (using job exposure matrices) in a case-control study of asbestos exposure and lung cancer.[34] The combination of interviews with evaluation of each job history by a team of experts is believed to produce exposure data at least as valid as other approaches to historical exposure assessment.[35] Therefore, the final stage in developing historical exposure assessments was an *a posteriori* review by the project industrial hygienists of hydrocarbon exposure estimates for each job held by each subject.

The first step in this *a posteriori* review was to combine the file that contained all subject information captured by interview with the file that contained exposure estimates for each SIC/SOC/decade combination. The result was a database which allowed the reviewer (1) to evaluate each SIC/SOC/decade combination reported by each subject, along with the subject's comments on chemicals used in that job and length of exposure, and (2) to make adjustments to the exposure estimates as appropriate. This final review provided a check on the correct SIC and SOC classification of the job and industry information provided by the subject, and allowed individual exposure assessments for ambiguous job classifications or jobs with a wide range of potential exposures. For example, the exposure estimate for a job originally coded as construction labor was revised upward (consistent with similar job categories) to reflect the subject's description of the job as involving floor covering and tile. A house painter who reported use of latex paints only was assigned a lower hydrocarbon estimate than house painters who indicated use of enamel, varnish, lacquer, etc.

Lifetime hydrocarbon exposure estimates were calculated as above, using the *a posteriori* exposure estimates, and case-control status was added to the database. As seen in Table 6, the changes in lifetime exposure estimates were similar for cases and controls. On average, *a posteriori* review lowered the average lifetime hydrocarbon exposure estimate by 20 percent for cases and by 28 percent for controls, changes that did not alter the conclusions of the epidemiologic study.

TABLE 6. Case/Control Distributions of *A Posteriori* Revisions in Lifetime Hydrocarbon Exposure Estimates

Change in Status	Cases	Controls
Increase in LHEE (≥10 ppm-years)	36	28
Increase in LHEE (0–10 ppm-years)	51	51
No change in LHEE	78	70
Decrease in LHEE (0–10 ppm-years)	42	49
Decrease in LHEE (≥10 ppm-years)	127	126
Total	334	324

Conclusions and Recommendations for Future Studies

A combination of methods—expert panel, literature survey, and exposure database—was used to develop historical exposure assessments for a retrospective study of hydrocarbon exposure and renal cell disease. Over 94 percent of the exposure estimates made for 3159 combinations of job, industry, and calendar decade were based on data obtained from at least one of these sources. Based on reported lower sensitivity and specificity of the *a priori* method of exposure evaluation, *a posteriori* evaluations of each subject's reported jobs were conducted; revisions in lifetime hydrocarbon exposure estimates were evenly distributed between cases and controls, and did not alter the final conclusions of the epidemiologic study.

As a result of the experience gained in developing historical hydrocarbon exposure estimates, the following suggestions are made.

1. As has been previously suggested,[36] the use of interviewers trained in industrial hygiene would decrease the probability of misclassification of exposures. Also, more specific exposure-related questions could be asked (e.g., a house painter could be questioned in depth about types of paints used).
2. Wherever possible, the approximate dates of employment should be determined for each job held by the subject. While recalling employment periods by decade of lifetime (i.e., jobs held in the teens, twenties, etc.) is probably easier for the subject, certain methodological difficulties result. Without knowing the exact dates of employment, it was not possible to adjust lifetime hydrocarbon exposure estimates for latency period, or to remove exposures that occurred after diagnosis of the disease. As a minimum, cases should be asked to differentiate between jobs held before and after diagnosis.
3. When dealing with a community-based sample, persons coding the interview data should be familiar with the area and employers. In many cases, there may not be enough data recorded in the interview to allow interpretation by a coder from another state. For example, the name of a locally well-known company may have been recorded, but not the type of business.
4. Occupational coding systems created for administrative purposes should be carefully evaluated before use in exposure assessment. The SOC classification did not allow enough specificity to distinguish between jobs that involved different types and quantities of solvents. For example, there was no code for dip-tank operators, who were classified as 875, vehicle washers and equipment cleaners. Vehicle washers primarily use water-based cleaners, while equipment cleaners may use solvent-based cleaners. A higher degree of specificity was obtained by linking the SIC and SOC codes [i.e., an SOC 875 in SIC 5511, new and used car dealers, would be rated lower than an SOC 875 in SIC 3531, construction machinery (manufacturing)].
5. As reported by other researchers,[24,25,28,29] the OSHA OCIS database would be much more useful in historical exposure assessment if jobs were entered by code number—not necessarily the SOC code, but one that would facilitate searching the database for exposure information. This should not prove any more difficult for the compliance officers than entering the SIC codes, a task that is quickly learned.

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