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SELECTED PESTICIDE RESIDUES AND METABOLITES IN URINE FROM A SURVEY OF THE U.S. GENERAL POPULATION

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Residues of toxic chemicals in human tissues and fluids can be important indicators of exposure. Urine collected from a subsample of the second National Health and Nutrition Examination Survey was analyzed for organochlorine, organophosphorus, and chlorophenoxy pesticides or their metabolites. Urine concentration was also measured. The most frequently occurring residue in urine was pentachlorophenol (PCP), found in quantifiable concentrations in 71.6% of the general population with an estimated geometric mean level of 6.3 ng/ml. Percent quantifiable levels of PCP were found to be highest among males. Quantifiable concentrations of 3,5,6-trichloro-2-pyridinol (5.8%), 2,4,5-trichlorophenol (3.4%), para-nitrophenol (2.4%), dicamba (1.4%), malathion dicarboxylic acid (0.5%), malathion alpha-monocarboxylic acid (1.1%), and 2,4-D (0.3%) were found, but at much lower frequencies. No quantifiable levels of 2,4,5-T or silvex were found. Preliminary analyses showed an apparent relationship between residue concentration and two measures of urine concentration (osmolality and creatinine). A large segment of the general population of the United States experienced exposure to certain pesticides, including some considered biodegradable, during the years 1976–1980.

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INTRODUCTION

Residues of pesticides and their metabolites in various human tissues and fluids collected from the general population are indicative of the total body burden of these pesticides and of past and present exposure to them. Most members of the general population are not occupationally exposed to pesticides; their exposure comes from such subtle pathways as food, water, air, or direct contact.

This article is the first publication of national population estimates of exposure for pesticides and related compounds that were measured in human urine specimens collected during the second National Health and Nutrition Examination Survey (NHANES II). Previous publication of data summaries of pesticide residue and metabolite levels in the NHANES II urine specimens did not take into account the complex sample design, and therefore cannot be considered representative of the total U.S. population (Kutz et al., 1977, 1978; Murphy et al., 1983). This presentation also provides a more detailed analysis of the pentachlorophenol (PCP) residue data. Results have already been published from the analysis of pesticide residue and metabolite levels in NHANES II serum (Kutz et al., 1977; Murphy and Harvey, 1985; Murphy et al., 1983).

METHODS

NHANES II Study Design

NHANES II was designed to gather health and nutritional status information that could best be obtained by direct physical examinations, tests, and measurements performed on a representative sample of the civilian, noninstitutionalized population of the United States. NHANES II was conducted during 1976–1980 on a probability sample of 6-mo- to 74-yr-old persons living in the United States. A total of 27,801 sample persons were selected using a stratified, multistage sampling scheme of households. In addition to a household interview, sample persons were given a detailed health examination in a mobile examination center. This examination included (depending on age of the examinee) dietary interviews, body measurements, hematological tests, biochemical analyses of whole blood and serum, oral glucose tolerance tests, blood pressures, electrocardiograms, urine tests, and x-rays of the cervical and lumbar spine and chest.

In collaboration with the U.S. Environmental Protection Agency (EPA), a pesticide component was designed to include analysis of blood and urine specimens from all 12- to 19-yr-old examinees and half of all 20- to 74-yr-old examinees. Out of the 11,952 persons 12–74 yr old who were selected for the pesticide study, 8563 were interviewed and examined. Urine specimens were collected from 6990 persons, for an overall response rate of 58.5%. The goals of this pesticide component were (1) to

provide first-time data on the prevalence of pesticide residue body burdens in the general U.S. population; (2) to establish baseline estimates for future studies so as to monitor changes in exposure over time; (3) to provide external reference data against which localized special studies could be compared; and (4) to explore relationships between pesticide body burdens and demographic, nutritional, and medical parameters. A more detailed description of NHANES II sample selection, survey content, and design is available (National Center for Health Statistics, 1981).

Laboratory Methods

The urine specimens were analyzed for 20 multiphenol, malathion, carbamate, and alkyl phosphate residues. Urine specimens were collected in 20-ml glass vials and placed in pesticide-free glass bottles with aluminum foil-lined caps. No preservatives or fixatives were used. Specimens were frozen immediately after collection and kept frozen until analysis. Before the survey began, no apparent contaminating materials were identified in collection and handling equipment.

Two laboratories under contract to the EPA conducted the chemical analyses using similar methodologies. Each urine specimen was analyzed by the multiphenol (Shafik et al., 1973) and malathion (Bradway and Shafik, 1977) methods, and for osmolality and creatinine. The urine specimens were also measured using experimental alkyl phosphate and carbamate methods (U.S. EPA, 1984b). This article does not include findings for the alkyl phosphate and carbamate metabolites, because recovery data from these methods were highly variable and median recoveries were below 50%. Further information on laboratory procedures is given in an EPA publication (U.S. EPA, 1984b).

The multiphenol method, used to analyze urine for halo- and nitrophenols, involved acid hydrolysis of the urine followed by extraction with diethyl ether. The extract was then derivatized with diazoethane and cleaned up on a silica gel chromatographic column with three different percent eluates of benzene-in-hexane. These compounds were then detected by electron capture-gas chromatography. Approximately 20% of the specimens were selected randomly for individual confirmatory analysis. Compounds were confirmed by gas chromatography using another column and a Hall electrolytic conductivity detector in the halogen mode. In the few cases where confirmational analysis was unsuccessful, a value of undetected was entered in the data file.

Exposure to the insecticide malathion was documented by the measurement of urinary metabolites, malathion alpha-monocarboxylic acid (MCA) and malathion dicarboxylic acid (DCA). The urine was acidified with hydrochloric acid and extracted with a mixture of diethyl ether and acetonitrile. It was then alkylated with diazomethane followed by a silica gel cleanup. The urine extract was analyzed on a gas chromatograph with a flame photometric detector. All positive determinations were con-

firmed by reextracting the sample, derivatizing with diazoethane, and analyzing for malathion by flame photometric-gas chromatography.

Quality Assurance Considerations

In addition to the confirmatory measures previously discussed, one of the two laboratories performing the urine analyses coordinated an informal quality assurance program. Spiked urine samples were prepared that contained known concentrations of the compounds of interest. Both laboratories analyzed the spiked samples. Results were compared to the known concentrations and corrections were made, if necessary, in the analytical procedures. This "spike" was then used as an internal quality control sample for 6 mo.

Both laboratories analyzed survey samples in a set of 12 analytical runs. A set included 10 survey samples, 1 spiked internal control sample, and 1 blank control sample (one that did not contain detectable amounts of the compounds being studied). The blank gave an indication of contamination that might have occurred during extraction and analysis, while the spiked sample, prepared when the analytical program began, served to indicate any chemical degradation. Quality control charts were used to document the recoverability of compounds in the spiked samples.

The limits of quantification for compounds detectable in urine are presented in Table 1. If a residue was found in an amount that was less than the quantifiable limit (i.e., could not be reliably quantified), then it was termed a trace amount. A trace specimen was not included as positive in the estimates of percent quantifiable.

Overall median percent recovery results are also shown in Table 1.

TABLE 1. Limits of Quantification, Range of Spiking Levels, and Overall Median Recovery Rates of Spiked QA Samples

Compound	Limit of quantification (ng/ml)	Range of spiking levels (ng/ml)	Median percent recovery
	Malathion method		
Malathion dicarboxylic acid	30	500	71
Malathion alpha-monocarboxylic acid	30	500	81
	Multiphenol method		
Dicamba	5	25–50	68
para-Nitrophenol	10	50	54
Pentachlorophenol	2	7.5–50	96
Silvex	5	25–50	80
2,4-D	30	50–200	68
2,4,5-T	10	50	70
2,4,5-Trichlorophenol	5	25–50	62
3,5,6-Trichloro-2-pyridinol	5	25–50	66

Residue data were not adjusted to reflect recovery percentages. Recoveries over the 4½-yr analytical time period were variable. This reflected the difficulty in recovering certain pesticide residues from human urine specimens. Overall, median recoveries ranged from 54% for *para*-nitrophenol to 96% for PCP (Table 1). Generally, the laboratories averaged 70–100% recovery for the malathion residues. Recovery rates for PCP were consistently around 100%. Recovery rates for 2,4,5-trichlorophenol, *para*-nitrophenol, and 2,4-D showed considerable variability over time and between laboratories. Therefore, levels of these residues may be underestimated.

Although the quality assurance (QA) data did not present concrete evidence to suggest that certain test data be excluded from data analysis, caution should be exercised when interpreting results. QA data do not give specific information on the sensitivity of the methods to find levels near the quantifiable limits. Spiking levels of the QA samples were generally much higher than the quantifiable limits of the residues and the values reported for the test samples (Table 1). Spikes were prepared within the same laboratories that performed the chemical analyses.

Urine Concentration

Laboratory analysis of the urine specimens for pesticide and toxic substance residues included two measurements of urine concentration: osmolality and creatinine. These measurements were obtained in an effort to provide further baseline information on spot urine collections. NHANES II examinees provided one-time urine specimens at the mobile examination centers during examinations that were scheduled throughout the day. Creatinine and osmolality determinations were made on each urine specimen at the time of the multiphenol method residue analysis. Creatinine was measured by combining urine with a trichloroacetic acid protein-free filtrate and adding a mixture of picric acid and sodium hydroxide. The alkaline creatinine picrate that was subsequently formed was read photometrically (U.S. EPA, 1984b). The osmolality determination was based on freezing point depression. Measurements were obtained by using a commercially available osmometer (Settergren, 1983).

Statistical Methods

The primary analytic variable for each of the residues was the percent of specimens with residue levels greater than or equal to the quantifiable limit. The percent with trace amounts is not presented. Because the distribution of quantifiable amounts was positively skewed, geometric means were computed. The arithmetic mean of the log values was computed and then back-transformed to give the geometric mean. Variability was represented by the 95% confidence interval about the geometric mean. Because the confidence intervals were computed in the log scale, they were not symmetric about the geometric mean. Confidence intervals (95%) were compared to determine statistical significance.

Analyses were performed using SESUDAAN (Shah, 1981). SESUDAAN uses the linearization approach (Taylor series expansion) in variance estimation and incorporates the complex sample design and appropriate sampling weights. Because NHANES II involved a complex sample design, rather than a simple random sample design, standard statistical methods may not be appropriate for data analysis. Sample weights were used to produce correct population estimates, because each person does not have the same probability of selection. These sample weights were calculated at the end of the survey to take into account the probabilities of selection, and adjusted for nonresponse and poststratification. Weighted means provide approximately unbiased estimates of population means (Korn and Graubard, 1991). The estimates presented in this paper, therefore, represent civilian, noninstitutionalized 12- to 74-yr-old persons in the United States during 1976–1980. Projecting to the estimated population, a single percentage point represented roughly 1.5 million people.

Of the 6990 persons for whom urine specimens were collected, 1068 (15.3%) had missing data for osmolality, creatinine, or at least one residue. Reasons for missing data included insufficient specimen volume, shipping loss, and laboratory technical errors. To compensate for the missing data, a strategy was developed that first would adjust the sampling weights for persons with no residue data, and then would impute a value for the missing data items for persons with data for some, but not all, residues, and creatinine and osmolality.

The imputation procedure used was the weighted sequential hot deck procedure (WSHD) developed by Cox. Details of the imputation procedures used are available in a separate report (Potter and Settergren, 1983).

RESULTS

The most frequently occurring residue was PCP, detected in 71.6% of the general population (Table 2). This result indicates that during 1976–1980, almost 119 million 12- to 74-yr-old persons had been exposed to PCP. The second most prevalent residue found was 3,5,6-trichloro-2-pyridinol (5.8%). Residues of several other pesticides were found, although only in a small proportion of the sample. *para*-Nitrophenol was found in quantifiable levels in 2.4% of the sample, while 2,4,5-trichlorophenol was found in 3.4%. Because the recovery rates were extremely variable for both *para*-nitrophenol and 2,4,5-trichlorophenol, caution should be exercised when interpreting these results.

About 1% of persons in the sample were found to have quantifiable levels of dicamba (1.4%) and MCA (1.1%). Less than 1% were found to have quantifiable levels of DCA. Quantifiable levels of 2,4,5-T, silvex, and 2,4-D were never or rarely found. Because of the variable recovery rates for 2,4-D, care must be taken when interpreting these results.

TABLE 2. Percent of 12- to 74-Year-Olds with Quantifiable Levels of Certain Pesticide-Related Phenolic Residues and Malathion Metabolites in Urine: United States, 1976–1980

Residue	Percent quantifiable (standard error)[a,b]	Estimated population with residue (in thousands)[b,c]	Maximum detected (ng/ml)
	Multiphenol method		
Pentachlorophenol	71.6 (2.44)	118,700	2670
3,5,6-Trichloro-2-pyridinol	5.8 (0.47)	9600	104
2,4,5-Trichlorophenol	3.4 (1.04)	5600	56
para-Nitrophenol	2.4 (0.40)	4000	143
Dicamba	1.4 (0.37)	2300	58
2,4-D	0.3 (0.08)	500	212
2,4,5-T	0.0	—	—
Silvex	0.0	—	—
	Malathion method		
Malathion alpha-monocarboxylic acid	1.1 (0.32)	1800	970
Malathion dicarboxylic acid	0.5 (0.15)	800	250

[a]Greater than or equal to the quantifiable limit.
[b]Weighted estimate.
[c]Rounded to nearest 100,000.

For the residues for which quantifiable levels were found, the maximum levels reported were often considerable. For example, the quantifiable limit for PCP was 2 ng/ml, while the maximum detected level was 2,670 ng/ml. In general, the distribution of quantifiable values tended to be positively skewed, or more likely to occur at or near the quantifiable limit.

Pentachlorophenol

Because PCP in urine was so common, it was possible to explore relationships between PCP levels and various social and demographic factors. These factors included age, sex, race, income, degree of urbanization, and geographic region.

Percent Quantifiable by Age, Sex, and Race Table 3 shows the percent quantifiable by age and sex. Ten-year age intervals were used because preliminary analyses indicated that using 10-yr age intervals adequately preserved the distribution of the sample while maintaining sufficient sample sizes within the groups.

Overall, males showed a significantly higher percent with quantifiable levels compared to females (75.9 vs. 67.7%). Within age-specific groups, males continued to have a higher percent quantifiable than females, although these differences were not statistically significant. No age trend was apparent for males, but the percent quantifiable de-

TABLE 3. Percent of 12- to 74-Year-Olds with Quantifiable Pentachlorophenol (PCP) Levels in Urine by Sex and Age: United States, 1976–1980

Sex and age	Number examined	Percent quantifiable (standard error)[a,b,c]	Estimated population with quantifiable levels in thousands[c]
Both sexes			
All ages	6990	71.6 (2.44)	118,700
12–19 yr	1969	80.2 (2.03)	25,800
20–29 yr	1080	70.6 (2.84)	26,400
30–39 yr	735	71.7 (2.78)	18,700
40–49 yr	658	63.8 (3.34)	14,700
50–59 yr	655	70.8 (2.89)	15,700
60–74 yr	1893	69.9 (2.74)	17,300
Males			
All ages	3431	75.9 (2.35)	60,500
12–19 yr	1067	82.4 (1.99)	13,300
20–29 yr	522	70.8 (3.25)	12,600
30–39 yr	354	78.0 (2.67)	10,100
40–49 yr	315	67.8 (3.58)	7600
50–59 yr	300	80.8 (2.95)	8400
60–74 yr	873	75.5 (2.82)	8400
Females			
All ages	3559	67.7 (2.72)	58,200
12–19 yr	902	78.0 (2.49)	12,500
20–29 yr	558	70.5 (3.08)	13,800
30–39 yr	381	65.4 (3.74)	8600
40–49 yr	343	60.0 (4.58)	7100
50–59 yr	355	62.0 (3.72)	7100
60–74 yr	1020	65.4 (3.17)	8900

[a]As of the midpoint of the survey, March 1, 1978. Estimated populations are rounded to nearest 100,000 and may not sum to the totals due to rounding.

[b]Percent of persons with levels of PCP in urine that are greater or equal to the quantifiable limit of 2 ng/*ml*.

[c]Weighted estimates.

creased among females from 78% for 12- to 19-yr-old persons to 60% for 40- to 49-yr-old persons.

Although not statistically significant, blacks were more likely than whites to have quantifiable levels of PCP (77.1 vs. 70.6%). Because several age-specific estimates for blacks are based on a small number of observations, these estimates are not shown.

Quantifiable Levels of PCP by Age, Sex, and Race For those 71.6%, or 5011 specimens, with quantifiable levels of PCP, the actual residue amount was determined. Because actual residue amounts were measured only for those specimens that had quantifiable levels of PCP, the statistics presented in Table 4 should not be considered to represent the

entire range of PCP levels in the U.S. population. The measured residue amounts do not represent those specimens that did not have detectable amounts or had only trace amounts of PCP.

Males at each age had higher geometric mean PCP levels than females (6.7 vs. 5.9 ng/ml overall). Although not statistically significant, PCP levels for both sexes tended to decrease with age up to 50 yr (Table 4). The geometric mean for PCP was highest, although not statistically significant, for 12- to 19-yr-old persons (6.9 ng/ml).

Overall, blacks had higher, although not statistically significant, geometric mean PCP levels than whites (6.7 vs. 6.2 ng/ml). Age-specific estimates are not shown because the estimates for blacks are based on small numbers of observations and therefore are likely to be unstable.

Percent Quantifiable by Income, Sex, and Race Although not shown, there was no consistent trend in percent quantifiable with income. Al-

TABLE 4. Geometric Means and Percentiles for Persons with Quantifiable Pentachlorophenol (PCP) Levels[a] in Urine: United States, 1976–1980

Sex and age	Number with quantifiable levels[a]	Geometric mean (ng/ml)[b]	95% Confidence interval[b]	Percentiles[b]		
				10	50	90
Both Sexes						
All ages	5011	6.3	(5.9, 6.6)	2.6	6.0	15.5
12–19 yr	1567	6.9	(6.4, 7.4)	2.9	6.8	17.0
20–29 yr	746	6.2	(5.8, 6.7)	2.7	5.8	15.5
30–39 yr	507	6.1	(5.6, 6.6)	2.6	6.0	14.1
40–49 yr	417	5.9	(5.2, 6.6)	2.4	5.3	15.0
50–59 yr	455	6.2	(5.6, 6.7)	2.5	6.0	15.8
60–74 yr	1319	6.1	(5.7, 6.4)	2.5	5.9	14.7
Males						
All ages	2603	6.7	(6.3, 7.1)	2.7	6.3	16.9
12–19 yr	866	7.1	(6.6, 7.6)	3.0	7.1	16.7
20–29 yr	367	6.7	(5.9, 7.5)	2.8	6.0	16.0
30–39 yr	267	6.6	(5.9, 7.3)	2.6	6.5	17.0
40–49 yr	215	6.3	(5.4, 7.4)	2.4	5.7	17.2
50–59 yr	236	6.6	(6.0, 7.3)	2.6	6.6	17.7
60–74 yr	652	6.6	(6.1, 7.1)	2.7	6.3	16.0
Females						
All ages	2408	5.9	(5.5, 6.2)	2.5	5.5	14.2
12–19 yr	701	6.6	(6.0, 7.3)	2.7	6.2	17.2
20–29 yr	379	5.9	(5.5, 6.3)	2.6	5.4	14.1
30–39 yr	240	5.6	(5.0, 6.1)	2.6	5.5	12.2
40–49 yr	202	5.4	(4.8, 6.1)	2.5	5.0	13.9
50–59 yr	219	5.7	(5.1, 6.5)	2.5	5.0	13.9
60–74 yr	667	5.6	(5.3, 6.0)	2.4	5.3	14.0

[a]Greater than or equal to the quantifiable limit of 2 ng/ml.
[b]Weighted estimates.

though not statistically significant, males had higher percent quantifiable than females and blacks had higher percent quantifiable than whites within income categories.

Percent Quantifiable by Urbanization, Sex, and Race The percentage of persons with quantifiable PCP by degree of urbanization (defined by size of place of residence) and sex is shown in Figure 1. Although not statistically significant, the percent quantifiable was highest for urban residents of areas with at least 1 million persons. It should be noted that the estimate of the standard error of the percent quantifiable may be unstable for the category "urban with 1 million persons or more."

Percent Quantifiable by Region, Sex, and Race The percent of specimens with PCP by region and sex is shown in Figure 2. Although not statistically significant, the South had the highest percent quantifiable for males, females, blacks, and whites, while the Midwest had the lowest percent quantifiable. Within each region, males consistently had nonsignificantly higher percent quantifiable than females. Although not shown, blacks consistently had nonsignificantly higher percent quantifiable than whites (about 10 percentage points higher) for each region except the West. The percent quantifiable for blacks in the West was found to be nonsignificantly lower than for other regions. After further analysis, though, it was found that intralaboratory differences are a likely explanation for this lower estimate (Settergren, 1982).

Urine Concentration

Because osmolality and creatinine were similar in their relationship to other variables, and creatinine showed greater variability between laboratories than osmolality, only osmolality is reported here. Residue levels and these measures of urine concentration appeared to be related. The percentage of persons with quantifiable levels of PCP and the actual measured value of PCP in persons with quantifiable levels increased with urine concentration. A detailed analysis of both measurements is available in a separate report (Settergren, 1983).

In general, the distribution of osmolality values was positively skewed, with the median somewhat larger than the mean. Males showed higher geometric mean values than females (649.0 vs. 540.1 osmol/kg), blacks had higher mean values than whites (677.3 vs. 580.9 osmol/kg), and osmolality decreased with age (from 695.5 for 12- to 19-yr-olds to 513.2 for 60- to 74-yr-olds).

DISCUSSION

These NHANES II findings can prove useful in estimating the extent of pesticide exposure for the general population. Apart from the National Human Adipose Tissue Survey (NHATS) (Kutz et al., 1991) and the National and Hispanic Health and Nutrition Examination Surveys, very

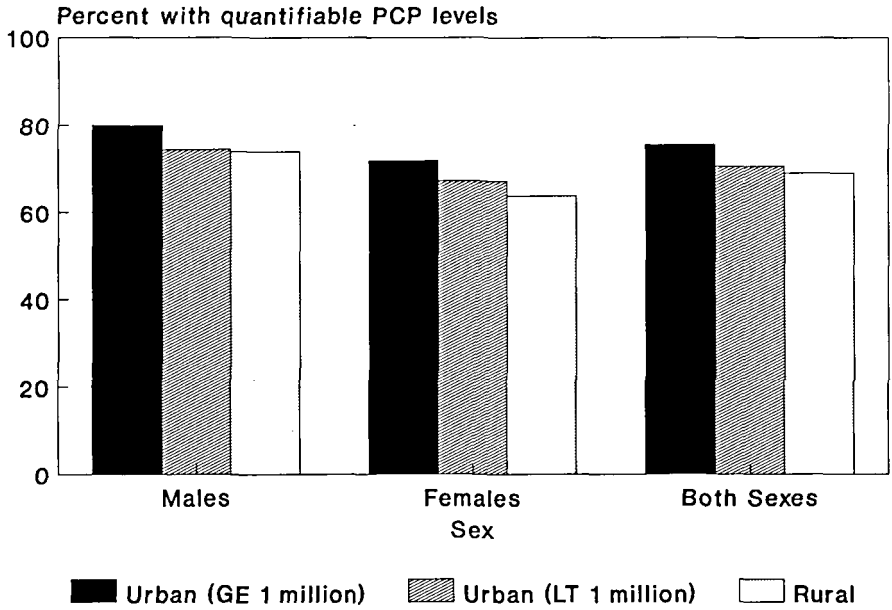

FIGURE 1. Percent of 12- to 74-yr-olds with pentachlorophenol in urine by sex and urbanization status.

little information has been collected on body burdens of pesticides in the general population. Analysis of urine specimens is useful in studying pesticide residues that are rapidly metabolized and excreted. The presence of these residues in urine generally indicates recent exposure to specific pesticides, as outlined in Table 5. These NHANES II results demonstrate the wide distribution of pesticide exposure among 12- to 74-yr-olds during 1976–1980.

This survey was designed to investigate human exposure to pesticides, rather than to study the health effects of pesticide exposure. Examining physicians were not specifically asked to look for symptoms of pesticide poisoning. Therefore, although the physicians performing the NHANES II examinations did not report evidence of pesticide poisoning, it is possible that they may have overlooked some subtle, adverse health effects associated with pesticide exposure.

The findings from the weighted analysis presented here generally verify previously published unweighted analyses of data from the same survey (Kutz et al., 1977, 1978; Murphy et al., 1983). Exposure to PCP was found to be fairly common: 71.6% of 12- to 74-yr-olds during 1976–1980 were found to have quantifiable levels. Males consistently had higher percent quantifiable of PCP, and higher geometric mean PCP levels, than females.

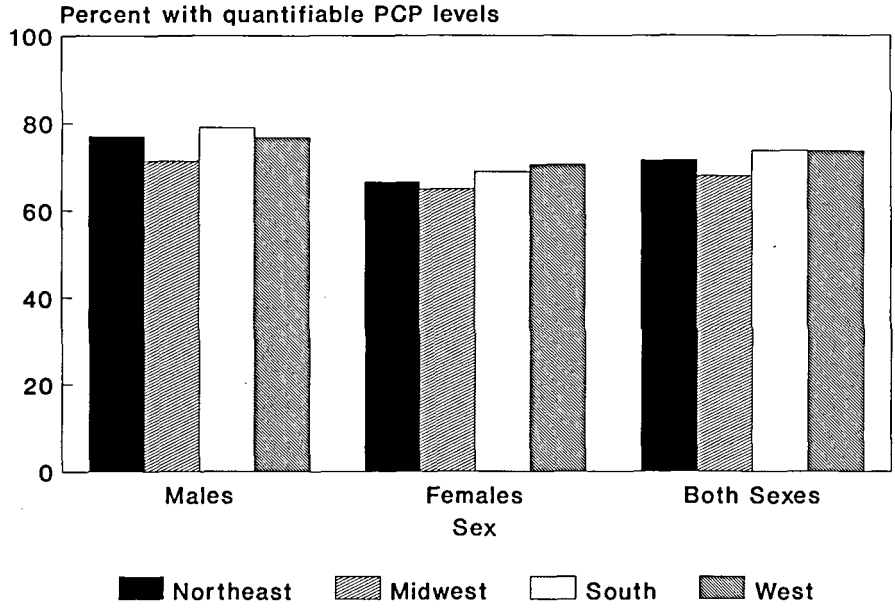

FIGURE 2. Percent of 12- to 74-yr-olds with pentachlorophenol in urine by sex and region of the country.

TABLE 5. Potential Sources of Exposure for Chemicals Detected in Urine

Compound	Potential source(s) of exposure
Dicamba	Use as a herbicide
Malathion dicarboxylic acid	Metabolite of the insecticide malathion
Malathion alpha-monocarboxylic acid	Metabolite of the insecticide malathion malathion
para-Nitrophenol	Metabolite of the insecticides methyl and ethyl parathion
	Use of compound in leather tanning process
Pentachlorophenol	Use as a wood preservative and insecticide
	Metabolite of the insecticide lindane and/or the fungicide hexachlorobenzene
Silvex	Use as a herbicide
2,4,D	Use as a herbicide
2,4,5-T	Use as a herbicide
2,4,5-Trichlorophenol	Use as a antimicrobial agent
	Metabolite of certain organophosphorus insecticides[a]
3,5,6-Trichloro-2-pyridinol	Metabolite of the insecticide chloropyrifos[b]

[a]Includes insecticides ronnel and stirofos.
[b]Includes also insecticides fospirate and chlorpyrifos-methyl.

Quantifiable levels of 3,5,6-trichloro-2-pyridinol, 2,4,5-trichlorophenol, *para*-nitrophenol, dicamba, MCA, DCA, and 2,4-D were found in 12- to 74-yr-olds during 1976–1980. For 2,4,5-T and silvex, no information was available to help determine whether these residues really did not exist in the NHANES II population, or whether the chemical methodologies used were insufficient to detect them at levels in which they might have been present. Because EPA suspended turf and aquatic use of silvex in 1979, and canceled many agricultural and domestic uses of 2,4,5-T in the same year, it is likely that few people would have had quantifiable levels in their urine during 1976–1980.

PCP is largely used as an active ingredient in wood preservatives. Residues of PCP have been found in such environmental pathways as food, water, and consumer products (textiles, leather, disinfectants, stains, and paints) (World Health Organization, 1987). In a study of pesticides found in the indoor environment, PCP residues were detected in all households sampled and in all matrices sampled, including house dust, hand rinses, dislodgeable residues from carpets, air, and soil (Lewis et al., 1991). During the last decade, PCP was the subject of intense regulatory attention by the U.S. Environmental Protection Agency. As with all chemicals sold as pesticides, PCP had to be registered and was regulated under the authority of the Federal Insecticide, Fungicide and Rodenticide Act, as amended (FIFRA). The risk criteria of concern for PCP and its sodium salt were teratogenicity and fetotoxicity as demonstrated in laboratory animal tests (U.S. EPA, 1984a). The human exposure data presented in this article provide an important contribution to the risk assessment used to guide regulatory changes. The major regulation of PCP to date involves the discontinuance of all uses inside buildings, including residences, and other restrictions on its use for external wood applications. Studies have shown that residents of log homes treated with PCP for sap stain control and other reasons had particularly elevated serum and urinary levels (Centers for Disease Control, 1980, 1982). Some minor microbiological uses of this chemical are currently under regulatory review.

PCP, like some other chlorinated phenols, nas been shown to be contaminated with other chemicals, including polychlorinated dibenzo-*para*-dioxins and polychlorinated dibenzofurans. In 1987, the EPA issued regulations that limited the concentrations of certain dioxin isomers in products containing PCP (U.S. EPA, 1987).

The other pesticides to which exposures were detected during this survey are undergoing regulatory reviews within the responsible office at the EPA. These reviews are for reregistration purposes and are mandated by several amendments to the FIFRA. Readers are directed to the *Federal Register* for current regulatory activities regarding these pesticides.

The quality of the data limited the presentation of findings. In particular, because the median percent recoveries for the experimental carbamate and alkyl phosphate methods were below 50%, the results using

these methods were not presented. The multiphenol method for 2,4,5-trichlorophenol, *para*-nitrophenol, and 2,4-D was more variable than expected. These findings have already been beneficial to improving laboratory methods at EPA and other laboratories that analyze human urine specimens for pesticide residues and metabolites.

No attempt was made to control for factors relating to specimen volume and, hence, concentration. Interpretation of urine concentration ideally should take into account dietary and fluid intake, time since previous void, and certain diseases and medication. Historically, residue analyses have been performed on specimens that represent a 24-h void.

The fact that the associations between osmolality and age, sex, and race closely parallel the associations between these demographic factors and the occurrence of PCP raises several issues. Unfortunately, very little information is available on the relationship between urine concentration and residue detection for low residue levels, particularly for spot or one-time urine specimen collection. Low levels of several nanograms per milliliter, such as those found in this population, may not make a significant contribution to the solute. Both osmolality and the presence of residues may reflect body metabolism. It is possible that the low residue levels could affect general body metabolism and be reflected in urine concentration. Conversely, varying metabolic rates may affect urine excretion of residues. If urine concentration affects the ability to detect residues, then the occurrence of residues (i.e., percent quantifiable) could also increase with concentration. The findings from this study suggest that adjustment for urine concentration should be seriously considered for studies of residue levels. Literature on the relationship of urinary creatinine to the excretion of low levels of abused substances should be considered to determine whether they have relevance to pesticide residue adjustments. Further research is needed to detail these procedures.

Information on body burdens and the extent of exposure to pesticides in the general population (such as provided by the NHANES and NHATS programs) can prove useful in completing risk assessments and management strategies. When combined with data demonstrating biological effects in laboratory animals, the resulting analysis may also be used to predict potential health effects in humans.

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