5. POTENTIAL FOR HUMAN EXPOSURE

5.1 OVERVIEW

3,3'-Dichlorobenzidine is currently used in the production of insoluble dyes and pigments. Almost all 3,3'-dichlorobenzidine is now manufactured outside the United States and is imported for on-site processing or for use as a reactant to synthesize pigments. "Processing" means preparing a chemical after its manufacture for commercial distribution either as the same physical compound, in a different form or physical state, or as part of another article (for instance, a mixture) containing the chemical (40 CFR 372.3).

Use of the compound to synthesize soluble dyes ceased as of 1986, when better dyes from other sources were introduced. The distinction between dyes and pigments is not always clear. Pigments are almost without exception insoluble and exist as finely divided solid powders that are insoluble but wettable under the conditions of use. Dyes are almost always soluble organic substances used in coloring textiles or other fibrous substances.

Release routes of 3,3'-dichlorobenzidine to the environment appear to be waste waters, sludges, and solid wastes where emissions are not properly controlled during the use of 3,3'-dichlorobenzidine or during its chemical transformation to pigments. The compound has been found in water and soil at hazardous waste sites, a result of the improper land disposal of solid wastes.

Concern for human health derives primarily from inhalation of airborne dust or skin contact during careless handling or accidental spillage in occupational settings or drinking of contaminated well water by persons living in the proximity of hazardous waste sites. However, occupational case reports suggest that risk to workers exposed to 3,3'-dichlorobenzidine through the use of 3,3'-dichlorobenzidine-based pigments may be minimal. No adverse health effects were reported among 20 workers engaged in the manufacture and handling of 3,3'-dichlorobenzidine alone (concentration not specified) in a Japanese facility (DCMA 1989). No detectable levels of 3,3'-dichlorobenzidine or its monoacetyl metabolite (at a detection limit of 0.2 ppb) were seen in urine samples of workers who were exposed to pigments derived from 3,3'-dichlorobenzidine on the day the samples were collected (Hatfield et al. 1982). The urine analysis results for workers with high potential for pigment exposure suggest that these pigments are not metabolized in humans although, without pigment exposure data, this conclusion is somewhat tentative.

The hydrochloric acid salt of 3,3'-dichlorobenzidine readily photolyses in water exposed to natural sunlight, but may not readily biodegrade in soil and acclimated sludges. It has a strong tendency to partition to soils and sediments, a property which reduces the potential for human exposure (Boyd et al. 1984; Chung and Boyd 1987; Sikka et al. 1978). Once partitioned to soil, the compound apparently binds further with humic substances to form humic-like materials that presumably would be non-hazardous (Sikka et al. 1978). However, in a recent paper, Nyman et al. (1997) stated that dehalogenation of 3,3'-dichlorobenzidine to form benzidine (also a toxic substance) occurs in sediment/water mixtures under anaerobic conditions. The compound does not volatilize or hydrolyze in solution, but it may slowly oxidize (Banerjee et al. 1978; Callahan et al. 1979). 3,3'-Dichlorobenzidine may be bioconcentrated by aquatic organisms (Appleton and Sikka 1980), but it is not certain if it is biomagnified by transfer through the food chain. 3,3'-Dichlorobenzidine accumulates in freshwater fish during aquatic exposure to either 5 ppb or 0.1 ppm concentrations of the chemical. After returning the fish to fresh, uncontaminated water, clearance of the compound from edible flesh was initially rapid (half-life of approximately 48 hours), but residues remained even after 14 days (Appleton and Sikka 1980). Steady-state concentrations in fish from ambient (unspiked) water exposures would be expected to be very low.

The reductive cleavage *in vivo* of azo dyes in general was first observed by Rinde and Troll (1975). Since then, several research groups have published articles that relate to the potential for human exposure to 3,3'-dichlorobenzidine that might arise via various chemical and biochemical mechanisms that degrade 3,3'-dichlorobenzidine-based synthetic dyes. A study by Hoffman and Schmidt (1993) found no evidence for metabolic cleavage of Pigment Yellow 17 to produced 3,3'-dichlorobenzidine in rats that inhaled the pigment. However, Zwirner-Baier and Neumann (1994), based on analysis of hemoglobin adducts from rats that drank the pigments, concluded that intestinal cleavage processes release very small amounts of 3,3'-dichlorobenzidine from Pigment Yellow 17 and Direct Red 46 (0.6% and 3%, respectively, of the total dose administered over 4 weeks). In another study (Sagelsdorff et al. 1996), the lack of appearance of 3,3'-dichlorobenzidine from Pigment Yellow 13 and 17 is shown, but a marked formation of 3,3'-dichlorobenzidine occurs from a soluble azo dye, C. I. Direct Red 46, which was an impurity in the pigments they studied.

In metabolism studies of azo dyes and pigments in the hamster, in viva cleavage of the benzidine-based dye, Direct Black 38, to benzidine was shown by analysis of the urine. However, studies of the 3,3'-dichlorobenzidine-based pigment, Pigment Yellow 12, showed no evidence for *in vivo* cleavage to release 3,3'-dichlorobenzidine (Nony et al. 1980).

3,3'-Dichlorobenzidine has been identified in at least 32 of the 1,467 current or former EPA National Priorities List (NPL) hazardous wastes sites (HazDat 1998). However, the number of sites evaluated for 3,3'-dichlorobenzidine is not known. The frequency of these sites within the United States can be seen in Figure 5-l. The manufacture and use of 3,3'-dichlorobenzidine has been strictly regulated by OSHA since 1974. All work with the compound is done in closed systems and any residues are destroyed by chemical reaction. Such precautions, if conscientiously practiced, make it unlikely that significant quantities of 3,3'-dichlorobenzidine have been disposed of in landfills or at NPL sites after 1974.

NPL Superfund Records of Decision (RODS) were located for 24 of the 27 currently listed NPL sites where the HazDat database lists 3,3'-dichlorobenzidine as a contaminant. A ROD is a legally binding document that states the results of investigation and feasibility testing at hazardous waste sites and tells what techniques will be used to remediate the site. At four of the sites, 3,3'-dichlorobenzidine was verified as a contaminant. The RODS for the other 20 sites did not mention 3,3'-dichlorobenzidine as a contaminant of concern (i.e., one that warrants development of cleanup criteria and a choice of remedy). Affected soil was removed from three of the four contaminated sites. Only one site, Bofors Nobel in Michigan, required development of a cleanup criteria (CPMA 1998).

5.2 RELEASES TO THE ENVIRONMENT

According to the Toxics Release Inventory (TRI), in 1996, a total of 2 pounds (1 kg) of 3,3'-dichlorobenzidine was released to the environment from one processing facility (TR196 1998). Table 5-l lists amounts released from this facility. In addition, an estimated 250 pounds (118 kg) were released by manufacturing and processing facilities to publicly owned treatment works (POTWs), and an estimated 51,550 pounds (23,432 kg) were transferred offsite (TR196 1998). The TRI data should be used with caution because only certain types of facilities are required to report. Therefore, this is not an exhaustive list.

Table 5-1. Releases to the Environment from Facilities That Manufacture or Process 3,3'-Dichlorobenzidine

		Total of reported amounts released in pounds per year [a]						
STATE [b]	NUMBER OF FACILITIES	AIR [c]	WATER	LAND	UNDERGROUND INJECTION	POTW TRANSFER	OFF-SITE WASTE TRANSFER	TOTAL ENVIRONMENT [d]
MI	1	2	0	0	0	250	51,550	51,802

Source: TRI96 1998

[a] Data in TRI are maximum amounts released by each facility
[b] Post office state abbreviations used
[c] The sum of fugitive and stack releases are included in releases to air by a given facility
[d] The sum of all releases of the chemical to air, land, and water, and underground injection wells; and transfers off-site by a given facility

POTW = publicly-owned treatment works

5. POTENTIAL FOR HUMAN EXPOSURE

3,3'-Dichlorobenzidine has been identified in a variety of environmental media (air, surface water, groundwater, soil, and sediment) collected at 32 of the 1,467 current or former NPL hazardous waste sites (HazDat 1998). The frequency of these sites within the United States can be seen in Figure 5-l.

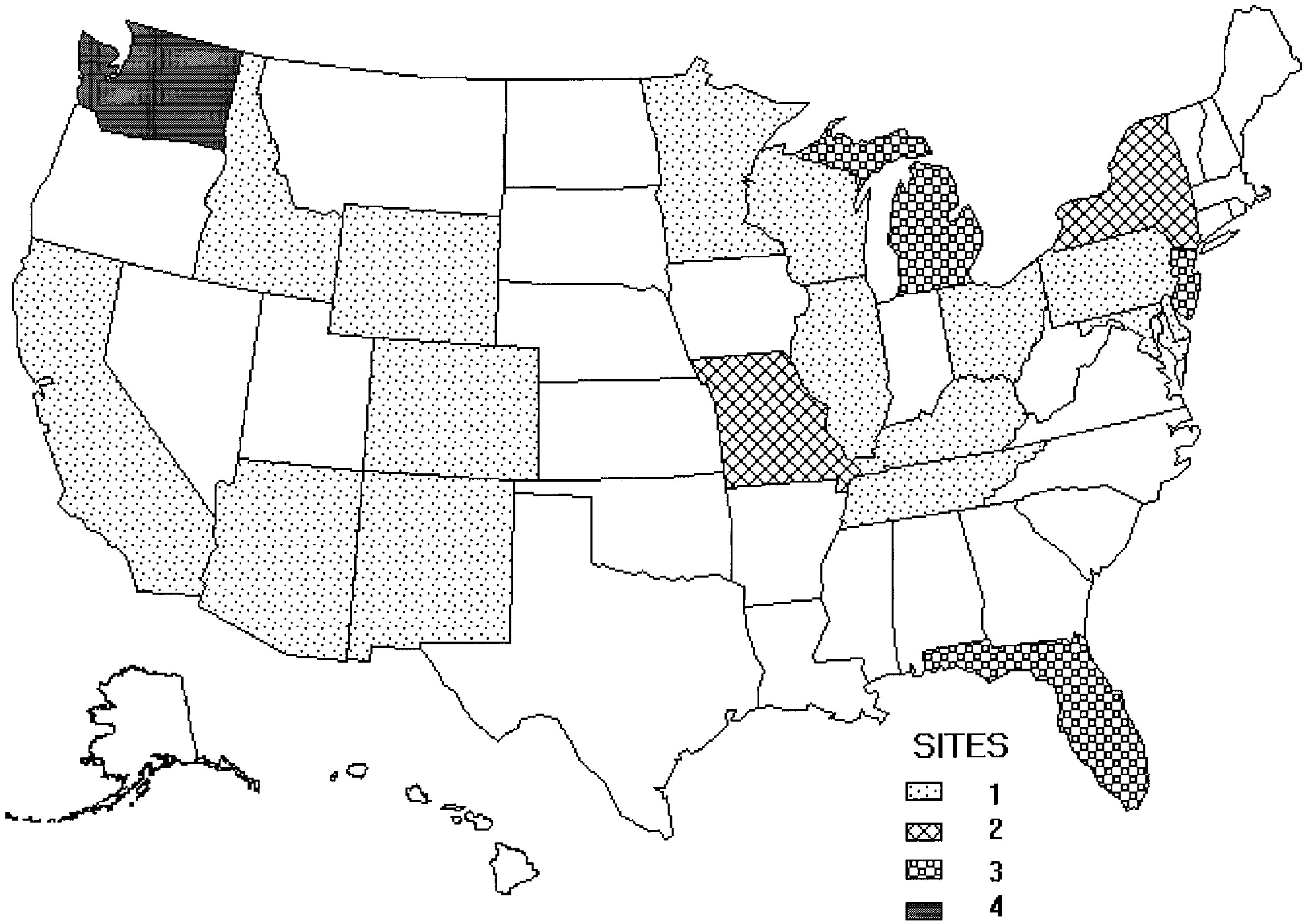
5.2.1 Air

The free base form of 3,3'-dichlorobenzidine is no longer utilized by industry in the United States. It is primarily supplied as the dihydrochloride salt (CPMA 1998). When it was used as the free base, it was handled as a powder or a moist paste (NIOSH 1980). 3,3'-Dichlorobenzidine is not a volatile chemical. A vapor pressure of $4.5x10x^{-9}$ mm Hg at 20 ºC has been reported (DCMA 1989). Prior to OSHA 1974 regulations, benzidine and 3,3'-dichlorobenzidine were manufactured in open systems that permitted atmospheric releases of suspended particles at the work site (Shriner et al. 1978), but no historical data were located specifically for 3,3'-dichlorobenzidine emissions (atmospheric or in water). The absence of data may be attributed to analytical methods used at that time that could not distinguish benzidine from its derivatives or many other aromatic amines (Shriner et al. 1978). Under OSHA regulations adopted in 1974, only closed manufacturing systems are permitted, and atmospheric emissions are presumably reduced because of this regulation.

Estimated releases of 2 pounds (0.9 kg) of 3,3'-dichlorobenzidine to the atmosphere from one facility in 1996, accounted for 100% of the estimated total environment releases (TR196 1998). These releases are summarized in Table 5-1. The TRI data should be used with caution because only certain types of facilities are required to report information to the Toxics Release Inventory only if they employ more than 10 full-time employees, if their facility is classified under Standard Industrial Classification (SIC) codes 20 through 39, and if their facility produces, imports, or processes 25,000 or more pounds of any TRI chemical or otherwise used more than 10,000 pounds of a TRI chemical in a calendar year (EPA 1997). A member company of the Color Pigment Manufacturers Association, Inc., which monitors 3,3'-dichlorobenzidine under state regulations, reports that only *de minimus* values are found (CPMA 1998).

3,3'-Dichlorobenzidine was not identified in any air samples collected at any of the 32 NPL hazardous waste sites where it was detected in some other environmental media (HazDat 1998).

Figure 5-1. Frequency of NPL Sites with 3,3'-Dichlorobenzidine Contamination



Derived from HazDat 1998

5.2.2 Water

The free base form of 3,3'-dichlorobenzidine is sparingly soluble in water. The solubility of 3,3'-dichlorobenzidinem-2HCl in water is 4 mg/L at a pH of 6.9 (Banerjee et al. 1978). A solubility of 3.1 mg/L is also quoted (CPMA 1998). 3,3'-Dichlorobenzidine may be released into the environment in waste waters generated by the production of dyes and pigments.

No releases of 3,3'-dichlorobenzidine to the surface water were reported in 1996 (TR196 1998). Two hundred and fifty pounds (550 kilograms) were released to publicly owned treatment works (POTWs) (TR196 1998). These releases are summarized in Table 5-1. The TRI data should be used with caution because only certain types of facilities are required to report information to the Toxics Release Inventory only if they employ more than 10 full-time employees, if their facility is classified under Standard Industrial Classification (SIC) codes 20 through 39, and if their facility produces, imports, or processes 25,000 or more pounds of any TRI chemical or otherwise used more than 10,000 pounds of a TRI chemical in a calendar year (EPA 1997). As a result of secondary treatment processes in POTWs, only a small percentage of any 3,3'-dichlorobenzidine that might enter POTWs is subsequently released into surface water.

3,3'-Dichlorobenzidine has been identified in surface water and groundwater samples collected at 19 of the 32 NPL hazardous waste sites where it was detected in some other environmental media (HazDat 1998).

5.2.3 Soil

According to the Toxics Release Inventory, in 1996, there were no reported releases of 3,3'-dichlorobenzidine to soil from any large processing facilities (TR196 1998). The TRI data should be used with caution because only certain types of-facilities are required to report information to the Toxics Release Inventory only if they employ more than 10 full-time employees; if their facility is classified under Standard Industrial Classification (SIC) codes 20 through 39; and if their facility produces, imports, or processes 25,000 or more pounds of any TRI chemical or otherwise used more than 10,000 pounds of a TRI chemical in a calendar year (EPA 1997).

3,3'-Dichlorobenzidine has been identified in soil and sediment samples collected at 18 of the 32 NPL hazardous waste sites where it was detected in some environmental media (HazDat 1998).

5.3 ENVIRONMENTAL FATE

Because 3,3'-dichlorobenzidine adsorbs to airborne dust particles or is otherwise bound to particulate matter, it is subject to dispersion, gravitational settling, and wash-out by rain. In water, 3,3'-dichlorobenzidine is sparingly soluble, does not volatilize or hydrolyze, and may slowly oxidize in solution (Banerjee et al. 1978; Callahan et al. 1979; Mabey et al. 1982). 3,3'-Dichlorobenzidine may be strongly adsorbed to soils, clays, and sediments, depending on the pH of the soil-water system. It may be strongly bound by soil organic matter (Boyd et al. 1984; Chung and Boyd 1987; Sikka et al. 1978). Although earlier research indicates that the compound does not appear to be readily biodegradable in soil or waste water sludges, recent work by Nyman (Nyman et al. 1997) indicates that more than 80% of 3,3'-dichlorobenzidine may be microbially degraded to benzidine under anaerobic conditions. 3,3'-Dichlorobenzidine is bioconcentrated by aquatic organisms under experimental conditions (Appleton and Sikka 1980), but it is not certain if it is bioaccumulated or transferred through the natural food chain.

5.3.1 Transport and Partitioning

In the atmosphere, 3,3'-dichlorobenzidine stays attached to dust particles or bound to particulate matter. As such, suspended 3,3'-dichlorobenzidine is subject to atmospheric convection, dispersion, gravitational settling, and wash-out by rain.

The Henry's law constant for a compound is useful in estimating the partitioning of the compound between its vapor phase and aqueous media. At 25 ºC, a value of 5.11×10^{-11} atm-m^3/mole has been estimated (SRC 1994). This very low value suggests that 3,3'-dichlorobenzidine essentially remains dissolved in water, and does not migrate from water into air.

3,3'-Dichlorobenzidine in solution has a strong tendency to be adsorbed onto soils and sediments. The extent of adsorption of hydrophobic (sparingly water soluble) compounds has been shown to be highly correlated with the organic carbon content of the adsorbents (Hassett et al. 1983). When adsorption is expressed as a function of organic carbon content, an organic carbon-water partition coefficient (K_{oc}) is generated, which is a unique property of the compound and may be used to rank the relative mobility of organic contaminants in saturated soil-water systems. A K_{oc} value for 3,3'-dichlorobenzidine of 1,553 (based on an octanol-water partition coefficient (K_{ow}) of 3,236) was calculated by Mabey et al. (1982). This relatively high value implies that 3,3'-dichlorobenzidine would exhibit "low" mobility in soil (see Roy and Griffin 1985). However, 3,3'-dichlorobenzidine is not strictly a hydrophobic compound but can exist as a weak base in water, and exists in both neutral and cationic forms. Written as an acid-base reaction, the amine groups may be protonated as follows:

$$3,3'\text{-DCB} + H_2O \leftrightarrow 3,3'\text{-DCBH}^+ + OH^-$$
$$3,3'\text{-DCBH}' + Hz0 \leftrightarrow 3,3'\text{-DCBH}_2^{2+} + OH^-$$

pK_a values reported for the conjugate acids (DCBH' and DCBH,") vary somewhat. Sikka (Sikka et al. 1978) and Boyd (Boyd et al. 1984) reported that they are <4. Nyman (Nyman et al. 1997) reported $pK_{a,1}$ and $pK_{a,2}$ values of 1.6 and 3.2, respectively. Thus, in the pH range of most environmental situations (pH 6-8) the dominant state of 3,3'-dichlorobenzidine in water would be the non-ionic form. As pH increases, the proportion of cationic forms of 3,3'-dichlorobenzidine decreases, and the extent of adsorption to sediments via Coulombic interactions would also decrease and 3,3'-dichlorobenzidine adsorption would be dominated by hydrophobic processes. This expectation was demonstrated by Sikka and coworkers (Sikka et al. 1978), who found that the adsorption constant (K_f) decreased with increasing pH; the decrease was more rapid in the range of pH 7-9. The adsorption data conformed to the Freundlich equation, $C_a = K_f C_s^{1/n}$ where C_a is the concentration of 3,3'-dichlorobenzidine adsorbed per mass of adsorbent, and C_s is the equilibrium concentration of 3,3'-dichlorobenzidine in solution. K_f and l/n are empirically derived constants. No correlation was found between K_f and the organic carbon content of the sediments (Boyd et al. 1984; Sikka et al. 1978). Similarly, the extent of benzidine adsorption does not correlate to the organic carbon content of soils and sediments (Graveel et al. 1986; Zierath et al. 1980). It was concluded that nonprotonated 3,3'-dichlorobenzidine is subject to hydrophobic bonding to some extent (Boyd et al. 1984). It is clear from these studies that adsorption constants for 3,3'-dichlorobenzidine cannot be accurately predicted for a given soil based only on a K_{oc} value.

The adsorption of 3,3'-dichlorobenzidine by soils and sediments may not be readily reversible (Boyd et al. 1984; Chung and Boyd 1987; Sikka et al. 1978). The extent of 3,3'-dichlorobenzidine desorption decreased with an increase in the age of the sample. Also, the adsorbed 3,3'-dichlorobenzidine was resistant to extraction. After 24 hours of 3,3’-dichlorobenzidine-sediment contact, only 36% of the parent compound could be extracted by methanol. It is speculated that 3,3’-dichlorobenzidine forms covalent bonds with soil humic components (Sikka et al. 1978; Boyd et al. 1984). Experiments have indicated that covalent binding of ring-substituted anilines to humates is not a readily reversible reaction (Parris 1980). 3,3’-Dichlorobenzidine was highly immobile in soil column experiments (Chung and Boyd 1987). Water was passed through sandy soil (Entic Haplorthod) and 3,3’-dichlorobenzidine-contaminated sewage sludge samples. Only small amounts of radioactive 3,3’-dichlorobenzidine added to columns of sandy soil or sewage sludge were eluted with water over extended time periods. Extractable radioactivity from these soils and sludge samples decreased with time of chemical contact. There was greater adsorption of 3,3’-dichlorobenzidine to soil than to sludge, apparently as a result of the greater humus content of the soil samples, which suggested that the compound may favor migration from sludge to soil substrates (Chung and Boyd 1987).

Since 3,3’-dichlorobenzidine is lipophilic, it may be concentrated from aqueous media by aquatic organisms. Bluegill sunfish were exposed to radiolabeled 3,3’-dichlorobenzidine in dynamic-flow experiments for 130-168 hours (Appleton and Sikka 1980) . Moderately low bioconcentration factors (BCF) of 495-507 were calculated for the whole fish. BCFs in fish (golden ide) of 610 and in green algae of 940 have been reported (Freitag et al. 1985). A BCF in edible portions of bluegill sunfish of 114-170 has also been reported (EPA 1980b). Bioaccumulation by plants or terrestrial animals has not been studied. Assuming a log K_{ow} (range, 3.02-3.78) (DCMA 1989; Mabey et al. 1982) 3,3’-dichlorobenzidine is not likely to bioaccumulate appreciably. However, Law states that some bioaccumulation in aquatic organisms might be expected (Law 1995). The flesh of freshwater fish exposed to 5 ppb or 0.1 ppm concentrations of the chemical in water showed some accumulation. After returning the fish to clean water, clearance of the compound was rapid (a half-life of approximately 48 hours), but residues remained even after 14 days (Appleton and Sikka 1980).

5.3.2 Transformation and Degradation

5.3.2.1 Air

3,3’-Dichlorobenzidine in the sunlit, ambient air atmosphere may react with photochemically produced hydroxyl radicals and ozone, but there are no quantitative data on reaction rates. The persistence of “all benzidines" in the atmosphere has been estimated by assuming a hydroxyl radical concentration of $8x10^{-10}$ mole/L (an average value in a 24-hour day-night cycle) (EPA 1975). Treating the oxidation process as a first-order reaction, the rate constant was $7.2x10^{12}$/mole-hour and the corresponding half-life was 12 hours. This estimation approach was based on data on the rates of reaction of hydroxyl radicals with olefins, aromatics, and alkanes in the atmosphere. The estimated half-life of 3,3'-dichlorobenzidine in air has ranged from 1 to 60 days (EPA 1980b; Shriner et al. 1978). The most recently published value for the degradation half-life in air via reaction with OH radicals is 9.7 hours (SRC 1995a). The reason for this disparity among the half-life estimates is not known. No other information on the fate of 3,3'-dichlorobenzidine in the atmosphere was located.

5.3.2.2 Water

The limited information that is available suggests that 3,3'-dichlorobenzidine may photolyze in water to yield benzidine, which is more photostable yet still toxic. It does not appear that the chemical is susceptible to any other transformations in water except protonation by acid-base reactions.

There are no data to suggest that the hydrolysis of 3,3'-dichlorobenzidine is significant (Callahan et al. 1979). A hydrolysis rate constant of 0/mole-hour for 3,3'-dichlorobenzidine has been proposed (Mabey et al. 1982).

It has been speculated that aqueous solutions of aromatic amines can be oxidized by organic radicals, but there are no actual data on reaction rates. Based on a study of reaction rate data for compounds with structures similar to 3,3'-dichlorobenzidine, an estimate of the half-life of aromatic amines in water is approximately 100 days, assuming a peroxy radical concentration of 10^{-10} mole/L in sunlit, oxygenated water (EPA 1975). Based on the oxidation rates of similar compounds, the direct oxidation of 3,3'-dichlorobenzidine by singlet oxygen in solution may be treated as a first-order reaction, to arrive at an estimated reaction constant of $<4x10^{7}$/mole-hour (Mabey et al. 1982). The oxidation rate constant with peroxy radicals was estimated to be approximately $4x10^{7}$/mole-hour. However, no information was located that demonstrates that 3,3'-dichlorobenzidine is significantly oxidized in water.

3,3'-Dichlorobenzidine was found to be extremely photolabile in water (Sikka et al. 1978; Banerjee et al. 1978). 3,3'-Dichlorobenzidine photolyzed yielding monochlorobenzidine, benzidine, and a number of colored, water-insoluble products. In natural sunlight, the half-life of 3,3'-dichlorobenzidine in water was determined to be approximately 90 seconds. While 3,3'-dichlorobenzidine is very rapidly photolyzed under environmental conditions, the process may yield benzidine, a relatively photostable carcinogen (Banerjee et al. 1978).

3,3'-Dichlorobenzidine in lake water samples was not metabolized by microorganisms over a 4-week period (Sikka et al. 1978) although 1 lake sample of the 2 tested contained approximately 5 million microorganisms per mL. The composition of the biological community was not described. Minor decreases in 3,3'-dichlorobenzidine concentrations were attributed to adsorption onto suspended sediment.

5.3.2.3 Sediment and Soil

Earlier reports gave little indication that 3,3'-dichlorobenzidine is significantly degraded in soil or that it is transformed to other substances. More recent research (Nyman et al. 1997) reports that sediment/water mixtures spiked with 3,3'-dichlorobenzidine display evidence of the chemical's degradation. In the experiments reported by these authors, silty-clay to sandy sediments collected from a lake near Holland, Michigan, were spiked with 3,3'-dichlorobenzidine and incubated at 20 °C for 12 months under anaerobic conditions. Time-course analysis of this mixture showed that dehalogenation of 3,3'-dichlorobenzidine to produce benzidine appears to take place through a transient intermediate, 3-monochlorobenzidine. Up to 80% of the 3,3'-dichlorobenzidine was transformed to benzidine over a l-year incubation period. No metabolites were observed in autoclaved samples, suggesting that dehalogenation is mediated by microbial activity. The final product, benzidine, shows more affinity for the solution (aqueous) phase and thus has a greater potential for transport in the environment.

Unsubstituted benzidine may be oxidized at clay surfaces when mixed with some types of clay minerals (Tennakoon et al. 1974; Theng 197 1). Benzidine is oxidized to a monovalent radical cation by iron (III) in the silicate lattice and by aluminum at crystal edges. However, there is no experimental evidence that demonstrates that 3,3'-dichlorobenzidine is subject to the same type of surface oxidation at solid-liquid interfaces.

Activated sludge did not degrade 3,3'-dichlorobenzidine after weekly subculturing. The sludge was not described or chemically characterized. Observed decreases in 3,3'-dichlorobenzidine concentration were attributed to adsorption by the sludge.

The results of seven laboratories conducting aerobic biodegradation experiments with 3,3'-dichlorobenzidine have been summarized (Brown and Laboureur 1983). There was a clear dependence of the extent of degradation on the concentration of yeast extract added to the batch containers. The role of the extract was uncertain, but without it, no degradation was detected. The authors hypothesize that the yeast may be a food source to allow buildup of large concentrations of active bacteria that are able to break down the amines. The authors felt that these results showed the "inherent biodegradability" of 3,3'-dichlorobenzidine, but that the compound should not be classified as "readily biodegradable" (Brown and Laboureur 1983). Possible degradation mechanisms and degradation by-products were not discussed.

3,3'-Dichlorobenzidine degraded very little when incubated with soil. In a study by Boyd et al. (1984), a Brookston clay loam soil (a typic Argiaquoll fine loamy, mixed mesic) containing [^{14}C]-3,3'-dichlorobenzidine at concentrations of 40 and 4 mg/kg of dry soil was incubated aerobically and anaerobically in batch experiments (Boyd et al. 1984). Under aerobic conditions, 3,3'-dichlorobenzidine degradation occurred at a very slow rate; accumulative $^{14}CO_2$ production was approximately 2% after 32 weeks. Under anaerobic conditions, no gas evolution was detected after 1 year of incubation. The authors did not comment on the population or type of microorganisms in the soil sample (Boyd et al. 1984). Additional studies indicated that 3,3'-dichlorobenzidine was very persistent in soil and sludge-amended soil (Chung and Boyd 1987). Biodegradation of [^{14}C]-3,3'-dichlorobenzidine was evaluated during a 182-day incubation period in a sandy soil (Entic Haplorthod) amended with sewage sludge. The total amount of [^{14}C]-3,3'-dichlorobenzidine recovered as $^{14}CO_2$ was <2%. It should be noted that biodegradation when measured by $^{14}CO_2$ evolution may provide a conservative estimate of the extent of decomposition. This technique does not account for carbon that is incorporated into the biomass or into soil organic matter, or for the compound being only partially metabolized (Graveel et al. 1986). The disparity between the results of this work and the results of Nyman (Nyman et al. 1997) is probably related to the nature of their respective biotic communities.

5.4 LEVELS MONITORED OR ESTIMATED IN THE ENVIRONMENT

Reliable evaluation of the potential for human exposure to 3,3'-dichlorobenzidine depends in part on the reliability of supporting analytical data from environmental samples and biological specimens. In reviewing data on 3,3'-dichlorobenzidine levels monitored or estimated in the environment, it should also be noted that the amount of chemical identified analytically is not necessarily equivalent to the amount that is bioavailable. The analytical methods available for detection and measurement of 3,3'-dichlorobenzidine are detailed in Chapter 6.

3,3'-Dichlorobenzidine was not detected in the ambient air at production facilities at detection limits of 0.1-5.0 ng/m^3 (Narang et al. 1982; Riggin et al. 1983). The median concentration of 3,3'-dichlorobenzidine in waste effluents (<10 ppb), groundwater (<10 ppb), surface water (<10 ppb), and soils (<1 ppb) is very low, although significant contamination may be associated with hazardous waste sites (Staples et al. 1985). Moreover, the production and use of 3,3'-dichlorobenzidine-based dyes has decreased to zero over the last 30 years, while environmental and health regulations have been implemented to reduce the release of 3,3'-dichlorobenzidine to the environment.

5.4.1 Air

3,3'-Dichlorobenzidine does not naturally occur in the environment (IARC 1982a). 3,3'-Dichlorobenzidine was not detected in ambient air of two dyestuff production plants at detection limits of 5 (Narang et al. 1982) and 0.1 ng/m^3 (Riggin et al. 1983). More recent data on occupational exposure levels indicate the presence of levels ≤0.6-2.5 μg/m^3 in 3,3'-dichlorobenzidine production and pigment manufacturing plants in Germany (DCMA 1989).

The concentration of 3,3'-dichlorobenzidine in the Canadian environment was estimated by Liteplo and Meek (1994) by applying the Level III Fugacity Computer Model of Mackay and Paterson (Mackay and Paterson 1991). Assuming that 1% of the total amount produced in and imported to Canada is released into various media in proportions similar to those given in the U.S. TRI, the average concentration of 3,3'-dichlorobenzidine in air, as estimated by the model, is 7.6×10^{-16} μg/m^3.

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5.4.2 Water

EPA's computerized water quality database (STORET) was used to determine the median concentration of 3,3'-dichlorobenzidine in surface water, groundwater, and municipal and industrial inflow and outflow (Staples et al. 1985). The median concentration of 3,3'-dichlorobenzidine detected in 12 of 1,239 samples of waste effluent collected from about 1980 to 1984, was reported to be <10 ppb. The median concentration of 3,3'-dichlorobenzidine in both surface and groundwater was also reported to be <10 ppb. The EPA reported that water samples collected from drinking-water wells near a waste disposal lagoon that contained 3,3'-dichlorobenzidine-manufacturing wastes had concentrations of the chemical ranging from 0.13 to 0.27 ppm (EPA 1980b). EPA indicated that 3,3'-dichlorobenzidine concentrations in waste waters from metal finishing operations were 0.07 ppb or less (EPA 1983c). Discharge concentrations from other industrial sources were at most 10 ppb. Using a Fugacity Computer Model, Liteplo and Meek estimated the concentration of 3,3'-dichlorobenzidine in Canadian water to be 3.4×10^{-7} ng/L (Liteplo and Meek 1994). Because the model does not address the possibility of bound residue in sediment, the concentration in water is certainly overestimated.

Capillary gas chromatography/mass spectrometry (GC/MS) was used to identify, but not quantify, 3,3'-dichlorobenzidine in the dissolved phase (that is, smaller particles and dispersed colloids not retained by the filter) of water concentrates from the Besos River in Spain (Grifoll et al. 1992). Valls et al. identified 3,3'-dichlorobenzidine in urban wastewater in the same region (Valls et al. 1990).

5.4.3 Sediment and Soil

The estimated median concentration of 3,3'-dichlorobenzidine in sediments in the United States has been reported to be <l ppm on a dry sediment basis (Staples et al. 1985). Of the 34 sediment or soil measurements recorded in the STORET database, none of the samples contained detectable concentrations of 3,3'-dichlorobenzidine.

5.4.4 Other Environmental Media

There is a potential for 3,3'-dichlorobenzidine to occur in waste water sludges and industrial solid wastes. A 3,3'-dichlorobenzidine concentration of 16 ppm in municipal sludge from Michigan has been reported

(Chung and Boyd 1987). 3,3'-Dichlorobenzidine was detected at concentrations of 3.13 mg/kg dry sewage sludge in 2 of a total of 253 sewage treatment plants examined (Fricke et al. 1985). These plants were all in the United States (Arizona, Indiana, Michigan, Missouri, New Mexico, New York, and Texas). Concentrations up to 535 μg/L were detected in a communal sewage treatment plant (Lopez-Avila et al. 1981). The chemical was detected at 8.55 mg/kg in sewage sludge of an aeration basin in Muskegon, Michigan (Demirjian et al. 1984).

Because the chemical has no agricultural or food chemical application, it is very unlikely that 3,3'-dichlorobenzidine occurs in food in general. [^{14}C]-3,3'-Dichlorobenzidine was found to rapidly accumulate in bluegill sunfish as a result of their exposure to water in which either 5 or 100 μg/L of the chemical was intentionally added. Residues were distributed in both the edible and nonedible portions (Appleton and Sikka 1980). However, 3,3'-dichlorobenzidine was not detected in fish samples obtained from rivers near nine textile dyestuff manufacturers known to use 3,3'-dichlorobenzidine-based pigments (Diachenko 1979).

5.5 GENERAL POPULATION AND OCCUPATIONAL EXPOSURE

Years ago, benzidine and its congeners such as 3,3'-dichlorobenzidine were likely to be found only in the vicinity of pigment plants (EPA 1980b; Shriner et al. 1978) where wastes may escape or be discharged. 3,3'-Dichlorobenzidine may also be found in locations where it is used in formulating other products such as rubber and plastic (HSDB 1996) or in producing polybenzimidazole (PBI) (Celanese 1985). However, 3,3'-dichlorobenzidine is no longer used to manufacture soluble dyes in the United States (CPMA 1998). Based on available data, the potential for nonindustrial exposure via air, soil, or water is expected to be negligible. The greatest chance of exposure by the general public is from the improper land disposal of compounds. The significance of this exposure route can only be evaluated on a site-by-site basis.

No uses of 3,3'-dichlorobenzidine in commonplace consumer products are known. In the past, the general public may have been exposed to minute amounts of 3,3'-dichlorobenzidine during the use of pressurized spray containers of paints, lacquers, and enamels containing traces of benzidine yellow, a pigment derived from 3,3'-dichlorobenzidine (Shriner et al. 1978). 3,3'-Dichlorobenzidine-based pigments are normally used in printing ink applications; their use in paints is rare and, thus, its presence in present-day pressurized paint spray would not be expected (CPMA 1998).

Today the most likely possibilities for occupational exposure exist in the processing of 3,3'-dichlorobenzidine in the synthesis of pigments, the compounding of PBI, and for workers in the garment, leather, printing, paper, and homecraft industries where benzidine-based pigments are used. However, there appears to be no information available on current levels of occupational exposure in the United States. Since 1974, OSHA regulations have set strict standards for worker protection, required the use of closed manufacturing vessels, and prescribed methods to chemically destroy residues. Although there is limited evidence for *in vivo* cleavage of 3,3'-dichlorobenzidine-derived pigments to free 3,3'-dichlorobenzidine in animals, urinary tract data from pigment workers suggest that 3,3'-dichlorobenzidine-derived pigments are not significantly metabolized in humans. Less than 0.2 ppb of 3,3'-dichlorobenzidine was detected in urine samples of 36 workers exposed to pigments derived from the compound (Hatfield et al. 1982).

In Canada, the estimated daily intake of 3,3'-dichlorobenzidine by various segments of the population has been calculated. The calculations are based on the predicted levels of 3,3'-dichlorobenzidine in air, water, and soil, as well as on the estimated daily intake of each (air, water, soil) by Canadians (Government of Canada 1993). The predicted concentrations or human intake levels are not measured values but rather predicted values based on output from mathematical models using worst-case assumptions that do not take into consideration removal mechanisms such as photolysis, oxidation, or irreversible binding to substrates. The total intake by adults (20 or more years of age) is predicted to be 7.4×10^{-9} ng/kg body weight/day. For infants up to 6 months of age (the group with the greatest predicted exposure on the basis of body weight), the total intake is estimated at 3.6×10^{-8} ng/kg body weight/day.

5.6 EXPOSURES OF CHILDREN

This section focuses on exposures from conception to maturity at 18 years in humans and briefly considers potential pre-conception exposure to germ cells. Differences from adults in susceptibility to hazardous substances are discussed in Section 2.6, Children's Susceptibility.

Children are not small adults. A child's exposure may differ from an adult's exposure in many ways. Children drink more fluids, eat more food, and breathe more air per kilogram of body weight, and have a larger skin surface in proportion to their body volume. A child's diet often differs from that of adults. The developing human's source of nutrition changes with age: from placental nourishment to breast milk or formula to the diet of older children who eat more of certain types of foods than adults. A child's behavior and lifestyle also influence exposure. Children crawl on the floor; they put things in their mouths; they may ingest inappropriate things such as dirt or paint chips; they spend more time outdoors. Children also are closer to the ground, and they do not have the judgment of adults in avoiding hazards (NRC 1993).

No specific references on exposures of infants or children to 3,3'-dichlorobenzidine were located. Young children may be exposed to 3,3'-dichlorobenzidine by ingesting paint chip debris, colorful objects or paints, and soil if the material contains the chemical. Mathematical models (using somewhat unrealistic worstcase assumptions) predict that the estimated total intake of 3,3'-dichlorobenzidine by infants up to 6 months of age would be $3.6x10^{-8}$ ng/kg bodyweight/day, about 5 times greater than the estimate of $7.4x\ 10^{-9}$ ng/kg body weight/day for adults age 20 or older (Government of Canada 1993).

Children sometimes put dirt in their mouths. Because the adsorption of 3,3'-dichlorobenzidine to soils and sediments may not be readily reversible (Boyd et al. 1984; Chung and Boyd 1987; Sikka et al. 1978), the bioavailability of the compound is limited. A child who ingested contaminated dirt would be expected to incur less exposure as compared to that from other, more direct routes.

Another potential exposure route for children is through exposure to clothing and tracked-in dirt brought in by parents who work in factories that produce 3,3'-dichlorobenzidine. A public health assessment study conducted in Michigan in 1981 (ATSDR 1996) found the compound in the homes of 9 employees. Samples collected from vacuum cleaner bags had up to 10.5 ppm and dryer lint contained up to 0.74 ppm. If these homes have not been adequately cleaned, exposure could continue.

5.7 POPULATIONS WITH POTENTIALLY HIGH EXPOSURES

In addition to individuals who are occupationally exposed to 3,3'-dichlorobenzidine (see Section 5.5) there are several groups within the general population that have the potential for exposures to 3,3'-dichlorobenzidine at levels above those of the general population. These groups include individuals living in proximity to sites where 3,3'-dichlorobenzidine was produced or sites where 3,3'-dichlorobenzidine was disposed, and individuals living near one of the 32 NPL hazardous waste sites where 3,3'-dichlorobenzidine has been detected in some environmental media (HazDat 1998). 3,3'-Dichlorobenzidine was not detected in fish samples obtained from rivers near nine textile dyestuff manufacturers known to use 3,3'-dichlorobenzidine-based pigments (Diachenko 1979), nor were there any fish consumption advisories for 3,3’-dichlorobenzidine in 1996. Therefore, recreational and subsistence fishers are not at risk.

NIOSH, in 1980, concluded that during the use of benzidine-based dyes, the greatest potential for exposurewould be expected to be by dermal absorption or inhalation by personnel who routinely handle dry powders (NIOSH 1980). However, EPA (1980b) has generalized that dermal absorption in the workplace is probably a minor route of 3,3’-dichlorobenzidine exposure, although dermatitis has occurred in workers in plants where 3,3’-dichlorobenzidine and 3,3’-dichlorobenzidine-based pigments were manufactured. It may be that health risks with regard to 3,3’-dichlorobenzidine exposure depend on the specific operations of the individual plant and the extent of personal protective practices of the individual operator.

5.8 ADEQUACY OF THE DATABASE

Section 104(i)(5) of CERCLA, as amended, directs the Administrator of ATSDR (in consultation with the Administrator of EPA and agencies and programs of the Public Health Service) to assess whether adequate information on the health effects of 3,3’-dichlorobenzidine is available. Where adequate information is not available, ATSDR, in conjunction with the NTP, is required to assure the initiation of a program of research designed to determine the health effects (and techniques for developing methods to determine such health effects) of 3,3’-dichlorobenzidine.

The following categories of possible data needs have been identified by a joint team of scientists from ATSDR, NTP, and EPA. They are defined as substance-specific informational needs that, if met, would reduce the uncertainties of human health assessment. This definition should not be interpreted to mean that all data needs discussed in this section must be filled. In the future, the identified data needs will be evaluated and prioritized, and a substance-specific research agenda will be proposed.

5.8.1 Identification of Data Needs

Physical and Chemical Properties. It has been demonstrated that 3,3’-dichlorobenzidine is strongly adsorbed by soils and sediments, and that it may not readily desorb. Adsorption cannot be accurately predicted *a priori;* such data are soil-system specific and must be determined experimentally for each system under study. Because there is some discrepancy regarding the volatility of the free base form of 3,3'-dichlorobenzidine (Gerarde and Gerarde 1974; CPMA 1998) research in this area is indicated.

Production, Import/Export, Use, Release, and Disposal. According to the Toxics Release Inventory (TRI) report (TR196 1998), 3,3'-dichlorobenzidine is manufactured at one facility in Michigan. Three of the five facilities listed by TR196 that process the compound depend on imports for their supply. The chemical is no longer used to produce dyes in the United States (better dyes based on other chemicals are available); its main use is in the production of pigments (DCMA 1989). It also finds some use in the formulation of rubber and plastic (HSDB 1996) and in the production of PBI (Celanese 1985). The compound is not used in the home or in the open environment; however, there is evidence that the compound can be brought into the home on the shoes and clothing of adults who work with 3,3'-dichlorobenzidine (ATSDR 1996) but the quantity that might be present is unknown. In the workplace, OSHA regulations require that the compound be handled in closed systems and that shipping containers be cleaned thoroughly (again, within a closed system) before disposal (DCMA 1989). The free base or salt form of the compound is not used in the home or in the general environment. It is handled only by industry to make pigments; thus there seems to be little chance the chemical could contaminate the food supply. No evidence of the compound in fish taken downstream from nine facilities known to handle 3,3'-dichlorobenzidine was found (Diachenko 1979). Citations regarding disposal techniques for 3,3'-dichlorobenzidine are found in the Hazardous Substances Data Base (HSDB). Small quantities can be destroyed by chemical reaction, for example, with sodium hypochlorite solution, which converts 3,3'-dichlorobenzidine to a quinone-type compound. Incineration at high temperatures can be used to destroy work garments and miscellaneous solid wastes exposed to the compound. Presumably only small amounts would need to be disposed since the compound is mainly consumed by conversion to pigments.

According to the Emergency Planning and Community Right-to-Know Act of 1986,42 U.S.C. Section 11023, industries are required to submit chemical release and off-site transfer information to the EPA. The TRI, which contains this information for 1996, became available in May of 1998. This database will be updated yearly and should provide a list of industrial production facilities and emissions.

Environmental Fate. It is not known if 3,3'-dichlorobenzidine, like benzidine, is oxidized by clay minerals or if cations in water can have the same oxidizing effect. 3,3'-Dichlorobenzidine does not appear to biodegrade easily, but the few studies in this area did not state the type(s) or concentrations of microorganisms used in each study. More systematic studies with other organisms may prove useful. A recent study (Nyman et al. 1997) provides evidence that in the span of a year up to 80% of 3,3'-dichlorobenzidine can degrade to benzidine in anaerobic mixtures of sediment/water. Further research to identify the pathways and products of decomposition of 3,3'-dichlorobenzidine in various soils is needed. The toxicological profile for benzidine contains information on the environmental fate of that compound (ATSDR 1995).

Bioavailability from Environmental Media. No information on the presence of 3,3'-dichlorobenzidine in foods was located in the available literature. The Canadian Government's Priority Substances List Assessment Report for 3,3'-dichlorobenzidine (Government of Canada 1993) also reports that no data on the levels of 3,3'-dichlorobenzidine in drinking water or foodstuffs were identified within either Canada or the United States. Because 3,3'-dichlorobenzidine has been found to bind strongly to soil constituents (Berry and Boyd 1985; Chung and Boyd 1987), Law (1995) concluded that it would also bind strongly to sedimentary material in the marine aquatic environment and thus may have limited bioavailability.

Food Chain Bioaccumulation. 3,3'-Dichlorobenzidine is bioconcentrated by aquatic organisms under experimental conditions. Whole-fish BCFs of around 500, with equilibration occurring in 96-168 hours, have been published (Appleton and Sikka 1980). In view of the n-octanoywater partition coefficient for 3,3'-dichlorobenzidine, limited bioaccumulation could be expected (Law 1995) because the retention time of the chemical in exposed fish is short (Appleton and Sikka 1980). The ability of aquatic organisms to concentrate the compound could present a human health hazard if contaminated fish were eaten. However, 3,3'-dichlorobenzidine was not found in fish taken from waters in the vicinity of dye or textile manufacturing plants on the Buffalo and Delaware rivers in the United States (Diachenko 1979). It was concluded that monitoring for 3,3'-dichlorobenzidine in marine waters of the United Kingdom is unwarranted at present (Law 1995).

Exposure Levels in Environmental Media. There were no quantitative data on current atmospheric levels of 3,3'-dichlorobenzidine emissions or on the chemical's potential to act as a surface contaminant of soil environments. It is difficult to determine 3,3'-dichlorobenzidine levels in the aquatic environment because the concentrations tend to be at or below analytical detection limits. In general, it may only be possible to ascertain fully the environmental fate of 3,3'-dichlorobenzidine as analytical advances permit the routine determination of very low concentrations. Moreover, determination of the nature and environmental fate of breakdown products of 3,3'-dichlorobenzidine would be useful.

Reliable monitoring data for the levels of 3,3'-dichlorobenzidine in contaminated media at hazardous waste sites are needed so that the information obtained on levels of 3,3'-dichlorobenzidine in the environment can be used in combination with the known body burdens of 3,3'-dichlorobenzidine to assess the potential risk of adverse health effects in populations living in the vicinity of hazardous waste sites.

Exposure Levels in Humans. It has been speculated that the 1974 OSHA regulations have reduced workplace air levels of 3,3'-dichlorobenzidine (CPMA 1998). However, it would be important to conduct exposure studies to monitor air levels in the workplace to confirm this premise. The need for more information on the extent of air, water, and soil contamination by industrial plant emissions or waste sites containing 3,3'-dichlorobenzidine continues. There is little information on exposure of children to 3,3'-dichlorobenzidine (or products derived from the compound). The compound has a very limited distribution and is not present in consumer goods (other than in insoluble pigmented forms). This information is necessary for assessing the need to conduct health studies on these populations.

Exposures of Children. There is no available information on exposure of children to 3,3'-dichlorobenzidine (or products derived from the compound). The compound has a very limited distribution and is not present in consumer goods (other than in insoluble pigmented forms). Thus, there is no pressing need to gather data related to children's exposure. However, given sufficient resources, the topic of inadvertent take-home exposure by occupationally exposed parents could be explored. A public health assessment (ATSDR 1996) found measurable levels of 3,3'-dichlorobenzidine (10.5 ppm in vacuum cleaner bags and 0.74 ppm in clothes dryer lint) in the homes of workers who were employed in manufacturing or processing the compound.

Exposure Registries. No exposure registries for 3,3'-dichlorobenzidine were located. This substance is not currently one of the compounds for which a subregistry has been established in the National Exposure Registry. The substance will be considered in the future when chemical selection is made for subregistries to be established. The information that is amassed in the National Exposure Registry facilitates the epidemiological research needed to assess adverse health outcomes that may be related to exposure to this substance.

5.8.2 Ongoing Studies

No information was located regarding ongoing studies.