OCCUPATIONAL DERMAL EXPOSURE ASSESSMENT - A REVIEW OF METHODOLOGIES AND FIELD DATA

FINAL REPORT

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Submitted to:

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Economics, Exposure and Technology Division
Office of Pollution Prevention and Toxics
U.S. Environmental Protection Agency
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Many individuals and organizations have been helpful in developing this report; for their contributions the project management extends its sincere gratitude.

Ms. Breeda Reilly and Ms. Beth Crowley were the EPA project officers and Ms. Cathy Fehrenbacher was the EPA Work Assignment Manager. The report was prepared by Science Applications International Corporation (SAIC) under EPA Contracts No. 68-D1-0156, No. 68-D4-0098, and 68-D2-0157. Dr. Ching K. Chen was the SAIC Project Manager for this work assignment. The authors would like to thank Mr. Alan P. Nielsen of EPA's Office of Pesticide Programs and Mr. Timothy Leighton of Versar, Inc., for the use of the Pesticide Handlers Exposure Database (PHED).

Peer review was provided by Mr. Mark F. Boeniger, National Institute for Occupational Safety and health; Ms. Christine Whittaker, Occupational Safety and Health Administration; Dr. Richard A. Fenske, University of Washington; Dr. Hans Marquart, TNO Nutrition and Food Research Department of Occupational Toxicology, the Netherlands; Dr. Bert Hakkinen, The Procter and Gamble Company; Mr. Thomas D. Klingner, Colorimetric Laboratories, Inc., and Dr. Franklin E. Mirer, United Auto Workers. Dr. Kim-Chi T. Hoang, EPA Office of Research and Development and Mary Katherine Powers, EPA Office of Pollution Prevention and Toxics provided peer review input during the development of the document.

SUMMARY OF PEER REVIEW COMMENTS AND EPA RESPONSES

A peer review of a draft of this document prepared before June 30, 1994 was completed in August 1994. That draft document was entitled "Occupational-Related Dermal Exposure Assessment Methodology." It contained the same basic information, though organized slightly differently, as in this final version of the document. However, exposure data in that earlier draft were presented in a different form: average exposure from published reports and independently calculated arithmetic and geometric means for various subsets of data from the Pesticide Handlers Exposure Database (PHED) were used. The full peer review comments can be obtained from the EPA's Chemical Engineering Branch. The following is a summary of peer reviewer's comments and EPA responses:

Peer Reviewer and Comment:	EPA Response to Comment:
Mark Boeniger, NIOSH	
Suggested revisions to make some of the terminology more consistent throughout the document. Provided an update on NIOSH research and suggested additional NIOSH and OSHA documents for evaluation. Suggested clarification on the scope of the project, tabulations, and provided comments to clarify issues discussed in the sampling methodology section of the report.	We agree with the comments provided which suggest additional clarification and editorial review. We have revised the report to make the terminology consistent, and have revised the document as suggested to incorporate the clarifications. The scope of the project was also clarified as suggested.
Christine Whittaker, OSHA	
Suggested to clarify the scope and purpose of the document, consider retitling the document to better reflect the scope. Commented that no new research is presented, although the document clearly illustrates the problems associated with assessing dermal exposures in an occupational setting.	We agree with the comments provided. The document title was reworded to more appropriately reflect the scope and purpose of the document. The text was revised to better reflects the scope and purpose as well. It is hoped that this document, which is the first of its kind for industrial occupational environments, will prompt additional research into this important area of dermal exposure assessment.

Peer Reviewer and Comment:	EPA Response to Comment:
Tom Klingner, CLI Laboratories, Inc. Additional information regarding limitations of the sampling methodology, theoretical approaches to predict K_p for organic solvents, biological monitoring, and glove permeation data were presented. In addition, limitations of the film thickness method for liquids was discussed. Suggested that exposure duration for most of the cited studies may not be comparable to industrial exposures, and suggests that pesticide re-entry is a closer comparison of industry exposure issues. Finally, suggested retitling the document to better reflect the scope and purpose.	We agree with the comments provided. A very thorough review of the document was conducted, and the comments were excellent. The additional information was incorporated into the document. With respect to biological monitoring, a detailed evaluation of biological monitoring data is outside the scope of this effort, but it is discussed briefly in several places in the document. The reason for the exclusion is primarily due to the fact that Chemical Engineering Branch (CEB) only assesses dermal "exposure" while another Division is responsible for assessing potential for "absorption" when evaluating dermal exposure issues within EPA's Office of Pollution Prevention and Toxics (OPPT). The cited studies were critically evaluated and characterized with respect to comparison to industrial operations. As mentioned above, the document was retitled in response to comments received.
Bert Hakkinen, The Procter & Gamble Company Recommended an expanded literature search and numerous additional references for inclusion, including work by other Federal Agencies. Suggested revising the title to more accurately reflect the scope and purpose of the research. Provided a great deal of additional information regarding the barrier effect of protective clothing, the OPPT's Exposure Assessment Branch (EAB) DERMAL program, dermal deposition rates from published reports, and transfer of chemicals from fabric to skin. A colleague with expertise in dermal absorption and skin exposure assessment also reviewed the document and provided input. Suggested additional information to provide perspective on the use of the EPA's Office of Research and Development (ORD). K_p approach, and discussion of determination of K_p values.	We agree with the comments and have incorporated the relevant references and additional information into the report. A very thorough review and excellent comments were provided by the reviewer. An expanded literature search was conducted and additional references were obtained. The additional information was incorporated into the document. The discussion of the ORD K_p approach was expanded, including determination of K_p values and experimental methodology. The scope and purpose of the document was clarified and the title was changed to more accurately reflect the content of the document. Information available on maximum skin loading of solids and liquids was added.

Peer Reviewer and Comment:	EPA Response to Comment:
Hans Marquart, TNO, The Netherlands	
Numerous additional references, many from Europe, were recommended for inclusion. Suggested revisiting the methodology used to critically evaluate and analyze the pesticides exposure data in light of the recent study by Van Hemmen which also reviewed and evaluated pesticides exposure data. Suggested clarifying and clearly articulating the conclusions and recommendations, particularly use of the published and PHED data in quantifying amount retained on the skin. Cautioned on the use of the PHED data due to complexity and potential error in calculation of statistical inference. Suggested other areas for additional research, including the effect of washing the skin on the amount available for penetration, and collection of additional data to enable more accurate (less conservative) estimates to be developed. A colleague with expertise in dermal absorption reviewed the relevant portions of the document and found them to be well written. Provided specific comments on the sampling methodology, cautions against grouping of exposure scenarios which may not be similar, and additional information on the use of barrier effect of clothing data.	We agree with the comments provided and have incorporated them into the document where possible. A thorough review of the document and excellent comments were provided by the reviewer. The Van Hemmen study was reviewed and found to be an excellent addition to the report. Additional referances and information from the study were incorporated into the report. The approach for analysis of the data was revised; statistical analysis within PHED were used directly. The statistical approach used in Van Hemmen's paper was adopted for this document. The EPA's Office of Pesticide Programs (OPP) has been involved in reviewing the document as it progressed to ensure appropriate use of PHED database and interpretation of data. According to OPP, the statistical calculations in the PHED database are correct. The additional areas for research were incorporated and other comments were incorporated into the document.
Franklin Mirer, United Auto Workers	
Suggested to include statistical descriptors such as means, standard deviations, and ranges to characterize the exposure data from published reports.	We agree with the comments and have provided the ranges and means of exposure data where available.

Peer Reviewer and Comment:	EPA Response to Comment:
Richard Fenske, Univ. of Washington This reviewer was unable to review and comment on the entire document, but agreed to provide comments on Chapters 3 and 7 of the document, which address the evaluation of the studies gathered from the literature and evaluation of the applications of the data. Numerous additional references from Europe and the State of California were suggested for inclusion. Suggested a greater clarity in the description of data manipulation procedures, and suggested a sample calculation with some real data to add clarity. Recommended to review a recent report which suggests that soil loadings do reach a maximum on the skin. Provided reviews on the complexities of the many issues associated with dermal exposure assessment, and areas needed further research. Questioned why greenhouse studies were not included within the report. Expressed concern with the normalization of exposures to 30-60 minutes per day as a standard daily exposure period, which may be appropriate for pesticides exposures, but not for industrial exposures. Suggested some additional references for further investigation. Concurred with the authors that the extrapolation of data generated in outdoor pesticide application studies to traditional industrial exposures involves many assumptions and uncertainties, and generally agreed that the CEB values can be used.	The review of Chapters 3 and 7 of the document was comprehensive and excellent comments were provided. The attempt to obtain additional references from the State of California was unsuccessful. The data manipulation procedures in Chapters 4 and 5 were clarified. Additional evaluation of soil loading data was conducted to help interpret the data for predicting the amount of solid retention in the skin. Greenhouse studies were excluded as most of the industrial exposure scenarios evaluated by CEB are not comparable to greenhouse spraying. If greenhouse spraying-type scenarios become more prevalent in CEB assessments, additional data will be compiled and evaluated. Normalization of quantity retained on the skin over a standard daily exposure period or a standard daily quantity handled was revisited and a revised approach was adopted.

I. INTRODUCTION

A. OBJECTIVES

Dermal contact with chemical substances during industrial operations represents a potentially significant route of exposure for workers. Unlike other routes of exposure such as inhalation, dermal exposure sampling methods and interpretation of monitoring data have not been well defined. The only situation where dermal exposure has been studied extensively is in pesticide operations.

Exposure is defined by the Agency as the amount of substance contacted by the outer boundary of the organism integrated over time (EPA, 1992a). For dermal exposure, it represents the amount of substance that contacts the skin prior to any penetration. Accurate assessment of dermal exposure hazards must account for the complex mechanism of continuous deposition, retention, removal, evaporation, migration, and absorption at the skin surface. However, there currently is no model that can describe these processes adequately. As a result, dermal exposure has been assessed by determining the amount of chemical deposited or retained on the skin, or by determining the amount of chemical that can be removed from the skin.

Because of a lack of field monitoring data on industrial operations, the Chemical Engineering Branch (CEB) of the EPA Office of Pollution Prevention and Toxics uses a method based on extrapolating an estimated quantity of chemical retained on a unit area over the total exposed skin surface area to estimate dermal exposure. However, only limited knowledge on the input parameters and applications of this method exist. Consequently, validation and improvement of the method are needed.

The objectives of this report are to:

- Provide a literature search of monitoring data on dermal exposure; identify other methods used for predicting dermal exposure when monitoring data is not available;
- Evaluate the CEB method and revise or identify additional values and input parameters (e.g., quantity remained on the skin, skin surface area) for predicting dermal exposure under various exposure scenarios;
- Make recommendations to improve the CEB method based on the literature search and evaluation.

The field monitoring data available are almost exclusively related to pesticide operations such as mixing, loading, spraying, and flagging. When compared to typical industrial operations, only the mixing and loading operations may find some similarity with the corresponding industrial operations. Therefore only dermal exposure data related to pesticide mixing and loading operations are reviewed in this document. In addition to presenting such dermal exposure data, several related topics including dermal exposure monitoring methods, skin surface area estimation, dermal absorption modeling, and barrier effects of protective clothing are discussed within the report. It should be noted that for these topics, a comprehensive literature search was not conducted, and the reader is referred to other sources for additional information.

A review of available monitoring methods for assessing dermal exposure is presented to provide an overview of the difficulties and uncertainties involved in such monitoring. The dermal absorption process and current knowledge on modeling are discussed to reflect how they impact the exposure assessment. The skin surface area at various anatomical regions of the body is critical in estimating total dermal exposure. Thus, a review of the historical practices and current recommendations on skin surface area are presented. Many pesticide studies have included the barrier effects of protective clothing, and a brief review of the available data on this topic is presented.

Biological monitoring, which can be an important tool in evaluating dermal exposure to some contaminants such as polycyclic aromatic hydrocarbons and certain organic solvents, is not addressed in this report. Recognized methods for conducting biological monitoring are not available for the majority of the substances evaluated by OPPT, and interpretation of biological monitoring data in relationship to various routes of exposure is often difficult.

B. BACKGROUND

The Chemical Engineering Branch uses the following equation for estimating dermal potential dose rate (as the amount available for absorption) (CEB, 1991):

$$D = SQC$$

where D = Dermal potential dose rate, mg/day
S = Surface area of contact, cm^2
Q = Amount retained on skin, mg/cm^2
C = Concentration of chemical of concern, percent by weight.

The CEB method assumes that a single contact with the chemical results in the quantity retained on the skin for a complete work day with exposure duration of 4 to 8 hours or longer. It is also assumed that workers wash their hands at meal break time and at the end of the shift. Additionally the CEB method assumes that dermal protection, such as gloves, is not used by the worker to limit exposure. Therefore, the method generates estimates of potential daily dermal exposure at the hands for the sub-population of workers who do not use dermal protection. The estimates provided by this method are believed to be conservative (i.e., overestimates), and this is confirmed by the evaluation of data as discussed in this document.

This dermal exposure assessment method is currently used to develop bounding estimates of the potential dose in terms of the amount of a chemical remaining on a worker's skin (usually expressed in terms of mg/day) and available for absorption, after the worker completes various common industrial activities leading to occupational exposure. The dermal potential dose rate is coupled with an estimate of the amount absorbed through the skin to compute a predicted absorbed dose for purposes of risk assessment. A bounding estimate is an estimate of individual exposure or dose where the estimate is purposely constructed to be higher than the individual in the distribution with the highest exposure or dose. A bounding estimate is useful in developing statements such as "the exposure or dose is no greater than _____." Bounding estimates are quite useful in screening level assessments. However, a bounding estimate cannot be used for an estimate of actual exposure (EPA, 1992a).

Default input values for estimating the potential dose rate on the hands have been developed for use in the above equation, as shown in Table 1-1. The surface area of the hands is based on Popendorf et al. (1983). The quantity of substance remaining on the hands and available for absorption is based on a laboratory study by Versar (1984). In the Versar study, participants immersed their hands in one of several liquids, or performed other activities. The amount of liquid retained on the hands was then measured. The 1984 Versar study has been updated with the most recent review dated 1992 (EPA, 1992c). A summary of the updated data on skin surface retention rates in mg/cm^2 is shown in Table 1-2. The 1992 review followed a more rigorous treatment of the data, however, the experimental subjects and procedures still represent a significant source of variability.

As recommended in the CEB Engineering Manual (CEB, 1991), dermal exposure estimates should be adjusted by the following factors when applicable:

- The concentration of the chemical in the mixture (weight fraction)
- The percent of the hand exposed if less than what would be typically expected for the activity
- Rapid evaporation of the chemical, and
- The effect of an industrial hygiene program.

For substances which are corrosive, handled as hot liquids, or not available for contact due to physical form (e.g., encapsulated within a matrix), dermal exposure is assumed to be negligible and is not quantified.

The focus of this document is to identify pertinent data to refine the "Q" and "S" factors and to evaluate the overall CEB approach in estimating dermal exposure.

TABLE 1-1. TYPICAL FACTORS FOR ESTIMATING DERMAL POTENTIAL DOSE RATE

Activity	Typical examples	S, cm^2	Q, mg/cm^2	Resulting typical contact, mg
Routine immersion, 2 hands	• Handling wet surfaces	1300	5-14	6500 to 18200
	• Filling/dumping containers of powders, flakes granules			
	• Spray painting			
Routine contact, 2 hands	• Maintenance/manual cleaning of equipment	1300	1-3	1300 to 3900
	• Unloading filter cake			
	• Changing filter			
	• Filing drums with liquid			
Routine contact, 1 hand		650	1-3	650 to 1950
Incidental contact, 2 hands	• Connecting transfer line	1300	1-3	1300 to 3900
	• Weighing powder/scooping/mixing (i.e., dye weighing)			
Incidental contact, 1 hand	• Sampling	650	1-3	650 to 1950
	• Lading liquid/bench scale liquid transfer			

Source: CEB, 1991.

TABLE 1-2 SURFACE RETENTION RATES OF SELECTED LIQUIDS ON THE HANDS UNDER VARIOUS EXPERIMENTAL CONDITIONS

	Mineral oil (mg/cm^2)	Cooking oil (mg/cm^2)	Bath oil (mg/cm^2)
Initial wipe			
Initial film thickness of liquid on hands	1.36	2.07	1.49
Film thickness after partial wipe	0.54	0.75	0.51
Film thickness after full wipe	0.24	0.32	0.17
Secondary wipe			
Initial film thickness of liquids on hands	1.22	1.72	1.34
Film thickness after partial wipe	0.41	0.48	0.41
Film thickness after full wipe	0.05	0.06	0.07
Immersion			
Estimated initial film thickness of liquid on hand	10.33	6.02	5.94
Estimated film thickness of liquid remaining after partial wipe	1.75	1.33	1.34
Handling a rag			
Initial film thickness of liquid on palms	1.43	1.38	1.76
Film thickness after partial wipe	0.38	0.31	0.46
Film thickness after full wipe	0.11	0.01	0.18
Spill cleanup			
Estimated initial film thickness of liquid on hand	1.07	0.67	0.77
Estimated film thickness of liquid remaining after partial wipe	0.48	0.47	0.41

Source: Table 4-1, EPA, 1992c or Table 4-1, EPA, 1989b for data under initial wipe, secondary wipe, and immersion. Other data from Table 26, EPA, 1987b.
Note: Surface retention rates not reported for handling a rag and for spill cleanup in EPA 1987b. Values in table are calculated using respective liquid density factors as: mineral oil, 0.87; cooking oil, 0.92; and bath oil, 0.861.

C. TECHNICAL APPROACH

There are three variables in the CEB dermal exposure equation: surface area of contact (S), quantity remaining on skin (Q), and the concentration of chemical (C). The concentration may be known or given or is estimated based on available information. Specific values for Q and S for certain work activities have been defined by CEB. The main focus of this document is to evaluate and revise these values and to develop additional values through the analysis of reported monitoring data.

The key data needed for this document are those that provide dermal exposure data equivalent to "Q," in terms of mg/cm^2 or some other easily convertible units, and "S" in cm^2. Two data sources were used to gather the needed information:

- Dermal exposure data from published reports
- Dermal exposure data contained in the Pesticide Handlers Exposure Database (PHED, 1992)

A literature search was conducted to identify published reports for review and analysis of monitoring methods and data. Then, pertinent dermal exposure data were extracted from PHED. The exposure data were collated under various work activities for use in evaluating the CEB method input parameters. A brief overview of the literature search and data analysis procedures is provided below.

Literature Search

A search of literature through the DIALOG system was conducted to identify reports and papers that may contain dermal exposure data. The DIALOG data files searched included:

- Chemical Safety Newsbase
- Chemsearch
- Enviroline
- Environmental Bibliography
- Pharmaceutical News Index
- NTIS
- Compendex Plus
- Chem Engineering and Biotech Abstracts
- Medline

- Toxline
- Occupational Safety and Health (NIOSH)
- FSTA
- Agrochemicals Handbook
- International Pharmaceutical Abstracts
- Biosis
- EMBASE
- Life Sciences Collection
- Federal Register
- Nursing and Allied Health
- RTECS
- CA Search
- CRIS USDA
- SPIN

The literature search was conducted in several steps. Initially all titles in the DIALOG system whose abstracts contained the selected key words or phrases were identified. Only those reports or papers not already available from the EPA were ordered. Each paper was reviewed to extract pertinent information for analysis of dermal exposure data, work activity, and work practices. Available data under similar work conditions during mixing, loading, bagging, and other similar operations were grouped together and analyzed to establish the exposure range and to estimate the high end exposure. Data relating to barrier effectiveness of the protective clothing were also reviewed.

The DIALOG search was conducted in two phases. In the first phase, which was completed in 1992, the following keywords were used:

dermal or skin exposure and chemical or dust; and
dermal or skin exposure and PCB or hazardous chemicals.

Over 1800 titles in the DIALOG system were identified during this search. The Occupational Safety and Health file and the Toxline file contained the most titles, each with over 700, the EMBASE file with 106 titles had the next highest number. A listing of those titles published since 1980 was then obtained. Abstracts for those titles that suggest the inclusion of human dermal exposure data were retrieved. The abstracts were then reviewed to identify appropriate papers for acquisition.

A follow-up literature search on the DIALOG system was made in September 1994 following the completion of a peer review with a broader search strategy to include the use of the following key words:

dermal or skin with exposure or contamination or wipe or wash and chemical or dust or liquid, or vapor, or pesticide

This search identified more titles than the search conducted in 1992. Approximately 2580 titles were identified on the Occupational Safety and Health and the Toxline files, of which 634 titles were published before 1980 and 1949 titles were published after 1980. From this, additional papers were obtained and reviewed.

In addition to the automated electronic database search, a manual search of relevant secondary papers cited in the documents already obtained was conducted. Reference papers recommended by many peer reviewers of a draft copy of this document were also obtained and reviewed for inclusion into the report.

Data on biological monitoring have been used to assess the risk of dermal exposure or dermal absorption. However, it is difficult to characterize biological monitoring results in terms of relative contribution from inhalation, ingestion, and dermal absorption (Klingner and McCorkle, 1993; Groth, 1992). Using biological monitoring to assess dermal exposure is not the subject of this document and reports related to biological monitoring were not searched or reviewed.

Aside from published reports, OSHA and NIOSH representatives were contacted to inquire whether they have conducted any dermal exposure studies. Both OSHA and NIOSH have expressed an interest in dermal exposure research and assessment technology. OSHA has designated a surface wipe sampling technique for use by its Compliance Safety and Health Officers (OSHA, 1990; OSHA, 1995). However, the technique is designed primarily to evaluate contamination on equipment or tool surfaces. OSHA has participated in a study to evaluate dermal exposure to acrylamide during grouting operations (Cummins et al., 1992). NIOSH reported that they had not conducted dermal exposure studies similar to the Versar (1984) study, but numerous Health Hazard Evaluations (for example, NIOSH, 1982; NIOSH, 1983a; NIOSH, 1983b; NIOSH, 1984; NIOSH, 1985; and NIOSH, 1991) have been conducted to evaluate the potential for dermal exposure (or the effectiveness of controls) via surface wipes, luminoscope readings on worker's skin, vacuum sampling, etc. One study evaluated dermal exposure using cotton gauze pads (NIOSH, 1991). Many of these studies included biological monitoring. NIOSH may someday develop a Criteria Document on dermal exposure.

Another Federal agency that has a keen interest in dermal absorption is the Food and Drug Administration (FDA). FDA is primarily interested in dermal exposure to chemicals, drugs, and cosmetics, and transdermal delivery of drugs. It has developed protocols for testing percutaneous absorption of chemicals and has conducted many of the studies. Such studies contribute to much of the knowledge concerning percutaneous absorption. However, these studies are generally not related to occupational exposure. Typical dermal absorption studies as conducted by FDA can be found in Bronaugh and Maibach (1991) and in Wang et al. (1993).

The Directorate of Health Science with the Consumer Product Safety Commission (CPSC) also has an interest in the evaluation of dermal exposure. Years ago, it conducted research on the potential transfer of fire retardants from treated fabrics to the skin. However, CPSC has not conducted research in the past few years on dermal exposure to or absorption of chemicals from consumer products.

PHED Processing Protocol

The PHED is a generic database containing measured exposure data reported to EPA for workers involved in the handling and/or application of pesticides in the field. It is separated into four files: Mixer/Loader, Applicator, Flagger, and Mixer/Loader/Applicator. For this report, only the Mixer/Loader file was used to extract dermal exposure under various combinations of formulation type and mixing/loading method. The data contained in PHED were developed according to EPA guidelines and met certain quality assurance requirements. Thus, the data derived from PHED were processed separately from the data obtained from published reports. A more detailed description of the data processing protocol is provided in Chapter V where information extracted from PHED data is presented.

Data Analysis

Since dermal exposure data are available primarily from pesticide studies, certain assumptions, analysis, and manipulation of data are necessary for application to industrial settings.

In both the published reports and PHED, pesticide exposure is reported as exposure to active ingredient (AI) only. However, most pesticides are formulated with a certain amount of inert material. Each formulated product is further diluted for use in field spraying applications. In mixing and spraying pesticides, the diluted pesticide mixture, including the active ingredient, inert material, and diluent, actually contacts the skin, but only

the active ingredient in this mixture was analyzed by investigators to assess the exposure hazard. Thus, the reported exposure data represents the quantity of active ingredient, not the amount of chemical mixture, remaining on the skin after a certain period of exposure. Because the focus of this document is to determine "Q", the total mass of chemical retained on the skin for generic uses, as opposed to the active ingredient (a percentage of the total mass) of specific interest, all reported pesticide exposure data were divided by the fractional weight concentration, "C", to back calculate the estimated total mass retained defined herein as estimated gross dermal deposition:

$$\text{Estimated Gross Dermal Deposition} = \frac{\text{Dermal Deposition in Terms of AI}}{\text{Fractional Concentration of AI in Formulated or Mixed Product}}$$

Prior to the standardization of the pesticide testing protocol by EPA in its Pesticide Assessment Guidelines, Subdivision U, Application Exposure Monitoring (EPA, 1987a), the surface area "S", used for each anatomical section of the body varied depending on the investigators. Thus, the "S" value for a given section of the body is not consistent in the studies reviewed. This presents a problem in interpreting unit area exposure when only the exposure in a body section or several body regions is reported. An appropriate "S" value is needed to back-calculate the unit area exposure. To define "S", the data used or recommended in various EPA reports were reviewed. Body surface area measurements used by various investigators were summarized for comparison with the EPA recommended values. Based on this comparison, the EPA recommended skin surface areas (EPA, 1987a) were used to estimate unit area deposition from the total dermal deposition over one or several sections of the body.

The exposure data were collected, categorized, and transformed to present estimated gross dermal deposition data in units of $\mu g/cm^2$. With a uniform measurement unit, the values can then be compared with those reported in published reports, contained in the PHED, and used in the CEB method.

D. REPORT ORGANIZATION

This report is organized into nine chapters:

- Chapter I, an introduction is presented to identify the objectives, background, and technical approach of this document.
- Chapter II, a brief review of dermal exposure assessment methods is presented.

- Chapter III, the skin surface area data are reviewed.
- Chapter IV, dermal deposition data as obtained from published reports are categorized into various operation or work activities for evaluation.
- Chapter V, dermal exposure data in the Mixer/Loader file of the PHED are extracted and analyzed in this section, an overview of the PHED is provided and data processing procedures are described.
- Chapter VI, dermal deposition data developed in Sections IV and V are collated in this section and compared with corresponding input parameters for the CEB method.
- Chapter VII, available data on barrier effects of various types of clothing are presented to evaluate whether the current estimating method can be modified to reflect the barrier effects.
- Chapter VIII, conclusions and recommendations for improving the CEB methods and for future research are presented.
- Chapter IX, References.

II. DERMAL EXPOSURE ASSESSMENT METHODS

A historical perspective and a general review of the techniques of estimating dermal exposure to pesticides have been provided in EPA's Pesticide Assessment Guidelines (EPA, 1987a). More recently, additional reviews of sampling techniques for estimating dermal exposure have been presented by NIOSH (1991), McArthur (1992), Van Hemmen (1992), Fenske (1993), and Ness (1994). Based on these reviews and following Fenske's terminology (1993), dermal exposure sampling techniques can be classified as:

- Surrogate skin
- Removal
- Fluorescent tracer
- Surface sampling.

An overview of the commonly used methods under each of these techniques is presented in this chapter. Additional details can be found in the references cited above. In addition to actual measurements of the amount of contaminants retained on skin surfaces, various modeling parameters have been proposed by EPA. A review of such estimating techniques is also provided in this chapter.

A. DERMAL EXPOSURE MONITORING METHODS

Dermal exposure (the amount of chemical contacted by the skin and available for absorption) can be estimated by directly sampling and measuring the amount of chemicals deposited or retained on the skin. Additionally, the potential for dermal exposure can be estimated by indirectly sampling the chemicals on the surfaces that the skin may come in contact with. This section describes the methods available for such sampling and discusses the advantages and disadvantages of each method.

1. Surrogate Skin Techniques

The surrogate skin techniques involve the use of a sampling medium attached to the skin or clothing. The sampling medium may be in the form of pads or patches, coveralls, special clothing, and gloves. The absorbent patch or pad method described by Durham and Wolfe (1962) is the most frequently used. This method was originally developed to evaluate skin exposure to pesticide and has since become recognized as the standard method for pesticide exposure assessment (EPA, 1987a). With this technique,

alpha-cellulose and multi-layered gauze pads are attached to various sites on the worker's outer clothing or skin to entrap pesticide residue that would have deposited on the skin. Dermal exposure at an anatomical section of the body can be estimated by multiplying the amount of residue collected on a unit area of the absorbent pad by the exposed surface area of the body section on which the pad is placed (and is assumed to represent). The inherent assumption is that the skin loading or the amount of the chemical deposit on a section of the body surface is uniform and is represented by the loading on the pad.

Pad materials used by various investigators have included cotton; denim; cellulose filter paper discs; combined filter paper and surgical gauze pads; entire items of clothing; and pads impregnated with lanolin to simulate the oily surface of the skin (EPA, 1987a). For assessing the deposition of liquids, the pad material must be absorbent enough to retain, without breakthrough, all of the liquid that contacts the pad. If the pads are used for collecting dusts or dried residue, they must be porous enough to collect such materials. In addition, the pads must be strong enough to hold up under the abuse they will receive in the field. They must not contain additives that may interfere with chemical analysis of extracted residues.

A major uncertainty in using the pad method is in extrapolating the data from a small area covered by the pad to a particular section of the skin surface. For instance, Fenske (1993) calculated that a pair of typical pads at the chest represent only 0.73% of the entire chest surface which is analogous to collecting a 4 minute air sample to represent an 8-hour inhalation exposure. In pesticide applications, deposits on the skin and sampling pads are unlikely to be uniform over individual body sections (Fenske, 1990). Misplacement of sampling pads may over- or under-estimate actual exposure because of differences in exposure patterns. Fenske (1993) estimated that a front patch at the head may overestimate the exposure by 35% during pesticide application and yet underestimate by 75% during mixing. Localized high exposure at a certain body section as determined from pad samples may also be the result of incidental contact of the pads with contaminated equipment as observed by Knarr et al. (1985) who found extraordinarily high exposure at the legs because of frequent contacts with the spray nozzles during loading operations.

To overcome such potential biases, clothing covering the exposed skin has been used as a sample collection medium. For instance, absorbent gloves have been used frequently to estimate hand exposure during pesticide mixing and application (Dubelman et al., 1982; Nigg and Stamper, 1983; Wojeck et al., 1983). The World Health Organization (1986) adopts the use of the entire

garment, along with the patches on the garment as standard protocol. The use of clothing as a sample collection medium provides a more thorough representation of the exposure in the body regions being monitored. In fact, pesticide exposure assessment experts currently consider "whole body" (i.e., whole garment) exposure assessment methods superior to pad sampling (Chester, 1993). However, properly removing the garments without contaminating them remains to be a challenging problem. Chemical extraction from the garment requires large volumes of solvents which may cause problems in terms of analytical sensitivity.

Each monitoring device (pads, gloves, garments, etc.,) has its own merits and shortcomings in sample collection, extraction, and data interpretation. Ideally the pads should have adsorption, absorption, and desorption characteristics similar to the skin. Overabsorption by the pads (working as a sponge) compared to the skin is one of the main potential biases in the method. This problem may be of particular concern when gloves are used to estimate hand exposure. In an extensive review of agricultural pesticide exposure databases, Van Hemman (1992) could not find studies that estimated the correlation between the hand exposure and the deposit on gloves. Fenske (1993) stated that the accuracy of glove and other garment samples remains an open question.

The pad method is generally used for sampling of non-volatile contaminants or those with a very low vapor pressure. To sample for volatile compounds, charcoal impregnated cloth has been used as the sampling pad. Popendorf et al. (1983) used such a pad to measure hand exposure to 1,3-dichloropropene during a nematicide application. The treated cloth measured ambient air concentrations as well as direct contact. Cohen and Popendorf (1989) studied the use of a charcoal cloth for sampling volatile liquid on clothing or skin. The charcoal cloth is a 100% charcoal fabric that reportedly has good retention properties to various solvents and vapors. The authors found that evaporation from liquid deposits was inversely proportional to the logarithmic value of the droplet size, vapor pressure, and air humidity; and that the adsorption of vapor was proportional to the vapor concentration. The study concluded that the charcoal cloth's accuracy and precision are optimal for monitoring dermal exposure to materials with low to moderate volatility or with low vapor concentration. However, no actual field measurements of exposure were provided.

Another interest in the estimation of dermal exposure is how much of the material collected on the pads outside the clothing would have eventually penetrated the clothing. Thus, pads have been placed inside the clothing to determine actual exposure and to study pesticide penetration and permeation through the cloth.

Pads have also been constructed with the sample of test fabric backed up by an absorbent pad to provide a rough estimate of the amount of residue that penetrated through the fabric.

2. Removal Techniques

Chemicals can be dissolved in solvents and thus it is possible to remove the chemicals from the skin by washing, wiping, or swabbing to estimate the amount deposited. Water-surfactant mixes or water-alcohol wash solutions are generally used to assess hand exposure in pesticide applications (Fenske, 1993). Accurate measurement of hand exposure is critical in estimating over-all dermal exposure. According to the reviews presented in the EPA Pesticide Assessment Guidelines (EPA, 1987a), 25 to 98 percent of total potential exposure may be from hand exposure.

The EPA Guidelines (EPA, 1987a) suggested a standardized hand rinse procedure for estimating hand exposure to pesticide. With this method, each hand is placed in a plastic bag containing 200 ml of a washing solution. The bag is held tightly just below the wrist bone and the hand is shaken vigorously. However, washing techniques can at best remove the chemicals that have not yet been absorbed by or lost from the skin; removal efficiency can vary with residence time of a chemical on the skin. The type of solvent used will also affect the removal efficiency. Fenske and Lu (1994) found that removal efficiency of the hand rinse varies with chemical loading at the skin, the time between exposure and washing, and the washing solvent. For example, ethanol removed 30% of the chlorpyrifos applied to the hands at loadings of approximately 7 $\mu g/cm^2$ with residence time showing no effect. A 10% isopropanol/distilled water solution removed 43% immediately after exposure. Swabbing or wiping is highly operator-dependent, variability in removal efficiency is likely to be even greater.

3. Fluorescent Tracer and Other Light Sensing Techniques

Fluorescent tracers have been used as another method to identify contaminated areas on the skin or cloth and to quantify dermal exposure. Franklin et al. (1981) added a fluorescent whitening agent to azinphosmethyl in a pesticide spray mixture. After removing exposed pads and clothing, each pesticide applicator was examined with ultraviolet light. The tracer was found in areas such as the face and neck which were not monitored with pads. The tracers were also found underneath the clothing. Fenske et al. (1985, 1986a, 1986b) combined the use of fluorescent compounds and video imaging measurements to produce exposure estimates over virtually the entire body. The investigators used the pre- and post-exposure images, standard

curve relating dermal fluorescence to skin-deposited tracer, and chemical residue sampling to estimate the quantity of chemical deposited on the skin.

The use of tracer technique has several important limitations. As discussed by Fenske (1993), the limitations can include: potential interference with the intended usage and performance of the chemical; different rates of transfer between the tracer and the chemical to the skin; potential degradation of the tracer during field use; and varying penetration characteristics between the tracer and the chemical through clothing.

Analogous to the fluorescent tracer technique, some investigators have used visible spectrum detection to estimate dermal exposure. Hill (1984) described a method utilizing the UV excitation principle to quantify surface or skin fluorescence from contamination. Two developmental instruments, called the Spill Spotter and the Lightpipe Luminoscope developed earlier (Schuresko, 1980; Vo-Dinh and Gammage, 1981) were used in this study. Both instruments produce a beam of low-intensity, longwave UV light to cause emission in the visible range from excited polynuclear aromatic compounds. The emissions were then measured by the instruments which quantify the fluorescence as voltage response. By calibrating the fluorescence against a known area concentration of polynuclear aromatic compounds in a heavy distillate on pigskin, it was possible to estimate the heavy distillate equivalent of skin contamination.

Lengerich and Burroughs (1989) tested a near real-time monitoring procedure for estimating potential dermal exposure during backpack herbicide spraying. In this test, water-sensitive paper strips, which stain blue upon contact with spray droplets, were attached uniformly to the applicator on six regions of the body. After field exposure, the density of stain spots on paper strips was compared to standard strips sprayed with known droplet density. This method provides an almost real-time assessment of potential dermal exposure to various parts of the body, but not the actual exposure.

4. Surface Sampling Techniques

Dermal exposure, especially of the hands, can occur through contact with contaminated surfaces, tools, and equipment. Surface sampling is a logical approach to assess such exposure hazards. OSHA's Technical Manual includes a surface contamination sampling technique for use by its Compliance Safety and Health Officers (OSHA, 1990; OSHA, 1995). It is designed to evaluate potential contact of skin with contaminated surfaces, to determine surface contamination that may come into contact with

food or other materials that are ingested, and to assess the effectiveness of personal protective equipment. Based on the reports of several investigators using the OSHA or modified OSHA procedure, Fenske (1993) indicates that there is a need to develop a surface sampling technique which employs standard materials and procedures, samples a defined surface area, and is operator independent. The author further states that the goal should be to collect "transferable" residues, not 100% of surface residue, to be able to accurately assess the potential transfer of surface residue to the contacted skin and that a Dermal Transfer Coefficient may be estimated for specific work activities.

Technically, it is possible to use the OSHA surface sampling technique to sample for the chemical deposited on the skin. However, the OSHA technical manual contains numerous recommendations against the use of skin wipes. The manual states that "direct skin wipes should not be taken when high skin absorption of a substance is expected. Under no conditions should any solvent other than distilled water be used on skin, ..." (OSHA, 1995). Additionally, special considerations are included in the OSHA technical manual regarding skin wipe samples. It states: "Do not take surface wipe samples on skin if a) OSHA or American Conference of Governmental Industrial Hygienists (ACGIH) exposure limit shows a "skin" notation, the substance has a skin LD50 of 200 mg/kg or less, or an acute oral LD50 of 500 mg/kg or less, b) the substance is an irritant, causes dermatitis, contact sensitization, or is termed corrosive." Aside from these potential problems, the process of collecting wipe samples can be very subjective (e.g., exerted force) which introduces additional biases. Also, removal efficiency of the wipe procedure is unknown.

B. DERMAL EXPOSURE ESTIMATING METHODS

In addition to the equation for estimating dermal exposure used by CEB, the OPPT Exposure Assessment Branch (EAB) and the EPA Office of Research and Development (ORD) have developed other estimating methods. The EAB method and certain aspects of the ORD method follow the same basic approach, in which the total exposure is calculated by extending the estimated exposure based on deposition at unit areas over the entire exposed skin area. Because each method was developed to address a specific need, the input parameters are somewhat different. The following is a review of the EAB and the ORD methods.

1. EAB Method

The EAB assesses exposure to chemicals that results from contact with consumer products. The computer program, DERMAL,

developed by the EAB is to be used in performing screening level estimates of Potential Dose Rates (PDRs) from dermal contact with consumer products (EPA, 1995; EPA, 1987b). The potential dermal dose rate is defined as the amount of chemical contained in the material applied to or contacting the skin (EPA, 1992b). The PDRs resulting from contact with the following list of consumer products are assessed by DERMAL:

1. General Purpose Cleaner - full strength and dilute
2. Liquid Laundry Detergent/Fabric Softener
3. Rug and Upholstery Cleaner
4. Floor Cleaner
5. Bar soap
6. Vinyl Upholstery Cleaner
7. Wax strippers
8. Spray Paint - undiluted
9. Exterior Latex Paint
10. Interior Latex Paint
11. Oil-based Paint
12. News Ink
13. Used Motor Oil
14. Lubricating Greases
15. Diesel Fuel
16. Gasoline

Assessors can also estimate PDRs from other products by using the "generic products" scenario in DERMAL. Users of the program can input product-specific data (e.g., weight fraction of chemical, density of formulation, frequency of events, etc.) for a particular scenario if relevant information is available.

Dermal exposure to the 16 products listed above can be categorized as occurring by one of the following pathways:

1. Deposition of a film of liquid on the skin
   Product Example: Used Motor Oil
2. Contact with solid surfaces
   Product Example: News Ink

PDRs resulting from dermal exposure are calculated by the following equations:

$$PDR = WF \times AV \times T \times DSY \times FQ \times DIL \times 1000\ mg/g \quad (1)$$

$$PDR = WF \times MASS \times FQ \quad (2)$$

where

PDR = potential dose rate (mg/yr)
WF = weight fraction of chemical substance in product (unitless)

AV = skin surface area exposed per event (cm^2/event)
T = film thickness of liquid on the skin surface (cm)
DSY = density of formulation (g/cm^3)
FQ = frequency of events per year (events/yr).
DIL = dilution fraction (unitless)
MASS = mass of formulation

Equation (1) is used for all of the products in DERMAL except for news ink. A slightly altered form of equation (1) is used for bar soap because exposure to chemicals in soap can occur from washing hands as well as taking baths/showers. The number of events per year and the surface area exposed are different for these two events. Equation (2) is used for news ink. The calculation differs because news ink is a solid substance rather than a film of liquid deposited on the skin.

Default values which can be changed by the assessor, are currently used for all of these variables. The weight fraction of the chemical in the product is normally chosen from a list of defaults based on information from the submitter regarding the function (and sometimes the formulation percent) of the chemical in the product. The default values currently in DERMAL come from Standard Scenarios for Estimating Exposure to Chemical Substances During Use of Consumer Products (Versar, 1986) and from exposure scenarios developed by the EAB.

In accordance with EPA's Guidelines for Exposure Assessment (EPA, 1992a), the EAB will also calculate Lifetime Average Daily Doses (LADDs) in terms of mg/kg/day. The same equations for PDRs will be used, with appropriate default values for FQ, in calculating the LADDs. PDRs for both acute and chronic exposures will be calculated. Specific parameters in defining the input values for these calculations have been suggested by the EAB. The EAB currently characterizes their consumer dermal exposure estimates as hypothetical "what-if" estimates because of the numerous uncertainties associated with estimating the dermal PDR. These uncertainties (particularly concerning skin surface area and number of thin films contacts) prelude determining where the estimates lie on the actual distribution of exposures.

The film thickness of a liquid on the skin (T) is the quotient obtained by dividing the mass of liquid retained per square centimeter (cm^2) of skin surface by the density of the liquid as used by the consumer. Table 2-1 presents values for film thickness rate of selected liquids under various experimental conditions based on data presented in EPA, 1992c,

TABLE 2-1 FILM THICKNESS VALUES OF SELECTED LIQUIDS ON THE HANDS UNDER VARIOUS EXPERIMENTAL CONDITIONS

	Mineral oil (μm)	Cooking oil (μm)	Bath oil (μm)
Initial wipe			
Initial film thickness of liquid on hands	1.56	2.25	1.74
Film thickness after partial wipe	0.62	0.82	0.59
Film thickness after full wipe	0.27	0.34	0.20
Secondary wipe			
Initial film thickness of liquids on hands	1.40	1.87	1.56
Film thickness after partial wipe	0.47	0.52	0.48
Film thickness after full wipe	0.06	0.07	0.08
Immersion			
Estimated initial film thickness of liquid on hand	11.87	6.55	6.90
Estimated film thickness of liquid remaining after partial wipe	2.00	1.46	1.55
Handling a rag			
Initial film thickness of liquid on palms	1.64	1.50	2.04
Film thickness after partial wipe	0.44	0.34	0.53
Film thickness after full wipe	0.13	0.01	0.21
Spill cleanup			
Estimated initial film thickness of liquid on hand	1.23	0.73	0.89
Estimated film thickness of liquid remaining after partial wipe	0.55	0.51	0.48

Source: Table 4-2, EPA, 1992c or Table 4-2, EPA, 1989b for data under initial wipe, secondary wipe, and immersion. Other data from Table 26, EPA, 1987b.

and EPA, 1989b. Corresponding data expressed as skin surface retention rates in mg/cm² are already presented in Table 1-2. These data were originally developed and reported in Exposure Assessment for Retention of Chemical Liquids on Hands (Versar, 1984). In addition for use in the above equations, the surface retention rates as found from this study form the basis for the input parameters used in the CEB method.

In the Versar study, selected liquids were applied to the hands of test subjects and then removed. The amount of liquid initially applied and the amount retained after wiping were determined. Originally, 3 aqueous and 3 non-aqueous liquids were used. However, due to the difficulties of accounting for volatilization and evaporation losses, only the data from non-aqueous liquids (mineral oil, cooking oil, and bath oil) were retained. In the study, the liquid was applied to the hands from a saturated cloth. The amount of liquid initially retained on the hands was determined by the difference between the before and after application weights of the cloth (and holding cup). Separate dry removal cloths were then used to wipe hands both partially and fully. The difference between the amount of liquid initially retained on the skin and the removal cloth was determined as the amount remaining on the hands after wipe removal. An "initial wipe" was performed with the hands washed first before application of the liquid, while the "secondary wipe" was performed immediately after the completion of the initial wipe tests without intervening washing of hands. The immersion tests were performed by dipping subjects' hands (after thorough washing) into a container holding the liquid and then wiping partially and then fully with separate dry cloths. In the test of handling a rag, the test subject handles saturated rag and the amount retained on the hands was determir from the partial and full wipes. For testing liquid retention from cleanup, test subjects cleaned up 50 ml of spilled liquid with a dry clean rag and the amount removed from partial and full wipes were determined.

To assess dermal exposure to liquids that are not listed in this table, one can use the data for the liquid that most closely resembles the liquid for which one is trying to assess exposure. Two physical properties that can be used to compare liquids for the purpose of assessing dermal exposure are kinematic viscosity and density. As a comparison, the maximum loading on the skin can be interpreted as approximately 10 mg/cm² based on the immersion test with mineral oil (see Table 1-2). In a study by Rutledge (1988), the maximum retention or the limit of application of an insect repellent was reported to be 4 mg/cm² before runoff will start. This value is very close to the values in Table 2-1, considering the difference in viscosity and density. It should be noted that the data in Tables 1-2 and 2-1

should be applied only for estimating liquid retention on the skin. Retention of solids on the skin was not tested in the Versar Study (1984) and estimation of solid retention should rely on other more relevant data as presented in this document.

2. ORD Method

The ORD method was developed to estimate absorbed dose through dermal contact with contaminated water and soil (EPA, 1992b). Due to the nature of dermal absorption processes, different approaches are used for assessing absorption of chemicals which are liquids versus solid or particulate materials. For solid media such as dust, the assumption is that the process of absorption into the skin is sufficiently slow that one can separate the deposition from the absorption process. However, for liquid media, there could be overlapping between tne deposition and absorption because of the potential rapid absorption. Both processes must be considered together as a continuous process in assessing dermal exposure hazard. The permeability coefficient approach advocated by ORD for liquids represents an attempt to address these considerations.

With the ORD approach, a permeation coefficient (K_p) that represents the rate at which the chemical penetrates the skin (cm/hr) is used to estimate absorbed dose per event from contact with aqueous solutions. For contact with particulate matter such as contaminated soil, an absorbed percent is used to estimate the fraction of the applied dose or the estimated amount adhered to the skin being absorbed across the skin in a specified time.

ORD's method in estimating dermal absorption from exposure to an aqueous solution is based on a theoretical analysis of the physical processes and mathematics involved. To account for the reservoir effect of the skin when in contact with organics, the skin is divided into two layers: the stratum corneum and the epidermis. A differential equation was formulated to describe the movement of the chemical in liquid media through each layer as a function of time and penetration flux. By defining the initial and boundary conditions for these equations, the equations were solved to estimate the absorption rate. The system of partial differential equations requires knowledge of the initial conditions of exposure (i.e., at time 0, what is the concentration of contaminant on each layer of the skin?), and the boundary conditions (i.e., what is the concentration of the chemical on the surface of each layer at the end of the exposure period?). It is important to note that the ORD approach was developed for scenarios such as swimming or bathing where an "infinite" exposure or boundary layer exists. Thus, the system of partial differential equations would need to be modified to

reflect the appropriate boundary conditions for occupational exposure, which would generally be "finite" in comparison.

Based on a steady-state flux, absorption of an inorganic chemical in water through the skin is estimated as:

$$DA_{event} = K_p^{w} C_w t_{event}$$

where:

DA_{event} = Dose absorbed per unit area per event (mg/cm_2 - event)
K_p^{w} = Permeability coefficient from water (cm/hr)
C_w = Concentration of chemical in water (mg/cm^3)
t_{event} = Duration of event (hr/year)

A default value of 10^{-3} cm/hr for K_p^{w} for inorganics is recommended.

For organics in an aqueous matrix, absorption under unsteady-state must be accounted for, and mathematical formulas for estimation of absorbed dose can be found in Chapter 4 of EPA, 1992b.

Experimentally measured K_p values for about 70 chemicals of potential environmental interest in an aqueous solution are available (See Table 5-3 of EPA, 1992b). Predicted K_p values for another 200 chemicals in aqueous solutions are also available (Table 5-7 in EPA, 1992b). An estimating method for other organics not listed is provided in the document referenced (EPA, 1992b). No information is provided on the values of K_p for chemicals in a non-aqueous solution.

This predictive method is very new and the permeability coefficient values will contribute the most to the uncertainty associated with model estimates. Permeability coefficient values can be determined experimentally, but the result is dependent on the experimental conditions. This method is recommended by EPA's ORD for inorganic liquids of infinite volume in aqueous media. EPA recommends making a "reality check" when developing estimates using this method. The estimated absorbed dose should not exceed the amount of contaminant in the water. The estimate should be questioned if the estimated absorbed dose exceeds 50% of the contaminant in water (EPA, 1992b)."

For estimating dermal absorption from contaminated soil, a surface retention or adherence rate is used with percent absorption to calculate per event dose:

$DA_{event} = C_{soil} \times AF \times ABS$

where:

DA_{event} = Absorbed dose per event (mg/cm² - event)
C_{soil} = Contaminant concentration in soil (mg/kg) (10^{-6} kg/mg)
AF = Adherence factor of soil to skin (mg/cm² - event)
ABS = Absorption factor.

Life-time exposures are estimated by accounting for contact time per event, frequency, life-time exposure duration, dose absorbed per event, and total exposed skin surface area. The range of recommended default values for dermal exposure factors as recommended by ORD is presented in Table 2-2. These default values represent the central tendency and upper bound estimates of each parameter. The soil adherence rates of 0.1 and 1.0 mg/cm² are estimates of adherence over the entire potentially exposed skin that covers several regions of the body. However, Kissel et al. (1996a) reported that soil loading encountered in realistic exposure scenarios can extend beyond either end of this range. The authors suggested a geometric mean hand loading of 0.01, 0.1, 1.0, and 10.0 mg/cm² to characterize roughly the solid adherence from background, low, moderate, and high contact activities, respectively. Soil adherence to the skin is also affected by the grain size and moisture content. Kissel et al. (1996b) reported that for dry soil adherence varies inversely with grain size but increases with grain size at moisture content of 12 to 18%.

TABLE 2-2
RANGE OF RECOMMENDED DEFAULTS FOR DERMAL EXPOSURE FACTORS

	Water Contact				Soil Contact	
	Bathing		Swimming			
	Central	Upper	Central	Upper	Central	Upper
Event time and frequency	10 min /event 1 event/day 350 days/yr	15 min /event 1 event/day 350 day/yr	0.5 hr/event 1 event/day 5 days/yr	1.0 hr /event 1 event/day 150 days/yr	40 events/yr	350 events/yr
Exposure duration	9 yr	30 years	9 yr	30 years	9 yr	30 years
Adult skin surface area*	20,000 cm²	23,000 cm²	20,000 cm²	23,000 cm²	5000 cm²	5,800 cm²
Soil-to-skin adherence rate					0.2 mg/cm²-event	1.0 mg/cm²-event

Source: EPA, 1992b, Table 6-6.
* See Table 6-3 of EPA, 1992b for children skin surface area.

3. APPLICATION TO DERMAL ABSORPTION ASSESSMENT

For exposures to particulate or solid materials, the critical factors in estimating dermal exposure are the adherence rate or surface retention rate in terms of mg/cm^2 and the surface area in contact with the contaminant. The EAB method contains two factors, DSY and T, for liquid exposure which translates into mg/cm^2; the ORD method dust adherence factor is also expressed in terms of mg/cm^2. Using such parameters, total exposure can be calculated for the total area of skin surface exposed either on a daily, hourly, yearly, or per event basis. This approach is similar to CEB's approach. In fact, the same database was used to develop the default values in both the CEB and EAB methods.

The ORD adherence rate and the CEB surface retention parameters will be influenced by factors such as the quantity of material handled, the duration and frequency of exposure, and the physical state of the material handled. The current method used by CEB is fairly simplistic and does not fully consider these factors.

The ultimate goal of developing a dermal exposure assessment method is to allow estimation of the amount of chemical absorbed through the dermal route of exposure. The current CEB method generates an estimated potential dose retained on the skin over the duration of one day's work. The estimated potential dermal dose is then used with an estimated percent absorption factor to predict absorbed dose for both the solid and liquid materials. This approach is analogous to ORD's estimating method for absorption from contaminated soil. It should be noted that the percent absorption may be dependent on skin loading, at least for solid materials. Duff and Kissel (1996) reported that relative percent absorption increased significantly with decrease in soil loading from 10 to 5 and from 5 to 1 mg/cm^2. The authors postulated that this inverse relationship was due to incomplete coverage of the skin at the lower loading and multiple layer loading at the higher loading. Loading of solids and coverage on the skin may be important parameters in assessing dermal absorption of solids.

ORD uses a separate approach, the permeation coefficient approach, to estimate dermal absorption of chemicals from water during such activities as swimming and bathing. This approach was developed based on current understanding of the biological mechanism of dermal absorption including skin-structure, transport processes, metabolism, and factors that affect dermal absorption (e.g., body site, hydration level). The mechanism for dermal absorption of chemical from a liquid matrix differs from the dermal absorption from a solid or particulate matrix. The K_p or skin permeation coefficient approach is recommended by ORD for

assessment of dermal exposure to liquid chemicals where applicable, and surface deposition rate with an absorption fraction is recommended for exposure to chemicals in solid form.

It may be possible to modify ORD's approach for use with non-aqueous media to directly estimate absorbed dose in occupational exposure situations. However, K_p values must be available in order to use the ORD method. K_p values for a large number of chemicals in aqueous solutions are available based on experimental data. Some empirical equations have also been developed to estimate K_p values. Information is not yet available to estimate the value of K_p for chemicals in a non-aqueous solution which is more often encountered in many occupational settings. Additionally, as pointed out in the ORD document (EPA, 1992b), the method represents a new and still evolving approach and tends to give overly conservative estimates of absorbed dose. The lack of data and associated uncertainties may limit its applicability in the near future in assessing dermal absorption from occupational exposures.

Much of the data needed in estimating dermal absorption have been developed through in vitro or in vivo studies. Proposed guidelines for testing percutaneous absorption of chemicals by both the in vitro and in vivo methods have been developed by the Organization for Economic Cooperation and Development (OECD). Examples of other procedures that were used by various investigators can be found in Bronaugh and Maibach (1991) and in Wang et al. (1993). The Interagency Testing Committee (ITC) is in the process of reviewing the available dermal absorption data for approximately 600 chemicals submitted by OSHA. The ITC has designated approximately 80 chemicals for dermal absorption rate testing. This dermal absorption data is important not only in determining the need for "skin designations" under OSHA regulations, but also in evaluating the potential impact of dermal exposure.

III. SKIN SURFACE AREA

A. SKIN SURFACE AREA MEASUREMENTS

The CEB dermal exposure estimation method calculates chemical deposition at a certain region of the body by extending the unit area deposition over the entire region. Chapter II describes various sampling methods and modeling techniques to estimate unit area deposition or exposure. The other critical factor needed to assess dermal exposure is the area of the skin exposed. In this chapter, relevant EPA documents and other published dermal exposure literature were reviewed to identify the most current data on skin surface area.

Several recent EPA documents contain reviews and recommendations on skin surface area, including:

- Dermal Exposure Assessment: Principles and Applications, Interim Report, January 1992 (EPA, 1992b)
- Exposure Factors Handbook, July 1989 (EPA, 1989a, currently under revision)
- Pesticide Assessment Guidelines, Subdivision U, Applicator Exposure Monitoring, 1987 (EPA, 1987a)
- Methods for Assessing Exposure to Chemical Substances, Volume 7, April 1987 (EPA, 1987b).

All of the above EPA documents present similar estimates of adult human body skin surfaces. All reference the same data source: EPA Report, Development of Statistical Distributions or Ranges of Standard Factors Used in Exposure Assessments, 1985 (EPA, 1985). A summary of these estimates is presented in Table 3-1.

A literature search for dermal exposure studies revealed that a number of earlier studies have been frequently cited when surface area estimates are required. These studies included Dubois (1916), Boyd (1935), and Berkow (1931). Dubois (1916) used a linear direct measurement technique and made estimates based on the principle that surface area of the parts of the body are proportional to, rather than equal to, the surface area of the solids they resemble. Berkow (1931) used Dubois' formula to apportion surface areas at different parts of the body. Boyd (1935) made direct measurements using body coatings, triangulation, and surface integration. The Berkow (1931) study is the most cited study for skin surface area. Other studies of body surface areas have been reported by Popendorf (1976),

Popendorf and Leffingwell (1982), EPA (1985), and Murray and Burmaster (1992).

TABLE 3-1 SURFACE AREA BY BODY PART FOR ADULTS (cm^2)

	Men		Women	
Body Part	Mean	n	Mean	n
Head	1,180	29	1,110	54
Trunk	5,690	29	5,420	54
Upper Extremities	3,190	48	2,760	57
Arms	2,280	32	2,100	13
Upper Arms	1,430	6	--	--
Forearms	1,140	6	--	--
Hands	840	32	746	12
Lower Extremities	6,360	48	6,260	57
Legs	5,050	32	4,880	13
Thighs	1,980	32	2,580	13
Lower Legs	2,070	32	1,940	13
Feet	1,120	32	975	13
TOTAL	19,400	48	16,900	13

n = Number of observations.
Source: EPA, 1985.

The skin surface area estimates of the studies mentioned above are made with differing methods and many are based on a very small number of subjects, creating some variation in the values provided for the same body region. Variation between studies is also due to differences in definition of the areas that make up a particular portion of the body. One of the most important and widest variations in surface area of a single body part is the hands. Whole hand and finger measurements range from 808 cm^2 (Berkow, 1931) to 1300 cm^2 (Popendorf and Leffingwell, 1982). In addition, there may be measurement differences relating to whether the surface areas measured include only the

nearly flat nonfollicular areas or the three-dimensional follicles as pointed out by Slone (1993). Slone believed that there is insufficient evidence that skin surface areas have ever been measured accurately. Because dermal exposure estimates are proportional to skin surface area, variation or error in the surface area estimate will affect the outcome.

Based on the data reported in various dermal exposure studies, the EPA Pesticide Assessment Guidelines (EPA, 1987a) recommended the values as shown in Table 3-2 for the surface areas for various regions of the body and locations of dermal exposure pads that represent these regions. This set of data matches very well with the data shown in Table 3-1. In addition, this document provides guidance on relating the deposition data from exposure pads to appropriate body sections.

The recommended approach is to use the values presented in Table 3-2 based on the EPA (1987a) guidelines. The guidelines are based on recent data and are used in PHED. It should be noted that the Chemical Engineering Branch method currently uses the Popendorf and Leffingwell (1982) values to estimate surface areas of the hands.

B. SURFACE AREA/BODY WEIGHT DISTRIBUTION DATA

As described in Chapter II, the EAB method recommends the calculation of LADD-type values where exposure assessments will be used to support risk assessment. The LADD equation involves a surface area factor in the numerator and a body weight factor in the denominator. The current OPPT default value for body weight for risk assessment purposes is 70 kg for males and 60 kg for females. However, the skin surface area or surface area distribution values are not necessarily consistent with a 70 or 60 kg body. Thus the EAB Dermal Model suggests the use of a surface area/body weight ratio to replace the surface area and body weight factors (Phillips et al., 1992). For instance, a 50 percentile surface area/body weight ratio for an adult is 0.0286 m^2/kg, while the 95 percentile ratio is 0.0329 m^2/kg. By using this approach, the EAB believes that a more accurate representation of surface area and body weight could be made to calculate dermal exposure.

TABLE 3-2 EPA RECOMMENDED VALUES ON BODY SURFACE AREA AND CORRESPONDING LOCATIONS OF DERMAL EXPOSURE PADS

Region of the body	Surface area (cm^2) of region	Location of pad(s) representing region
Head	1,300[a]	Shoulder, back, chest[b]
Face	650	Chest
Back of neck	110	Back
Front of neck[c]	150	Chest
Chest/stomach	3,550	Chest
Back	3,550	Back
Upper arms	2,910	Shoulder and forearm/upper arm
Forearms	1,210	Forearm
Hands	820	
Thighs	3,820	Thigh
Lower legs	2,380	Shin
Feet	1,310	--

[a] Surface area for the head includes the 650 cm^2 face surface area.

[b] Exposure to the head may be estimated by using the mean of the shoulder, back, and chest patches, or by using a head patch.

[c] Includes "V" of the chest.

Source: EPA, 1987a.

IV. DERMAL EXPOSURE DATA FROM PUBLISHED REPORTS

Dermal exposure data available from published reports are almost exclusively reported as part of pesticide exposure studies which typically include inhalation exposure as well. The extent of exposure obviously is related to the type of operation involved. Therefore, exposure is typically reported on the basis of a pesticide-related operation such as mixing and loading, application, flagging, or a combination of some of these operations. Among these operations, only the mixing and loading operation can find comparable equivalents in an industrial setting. For instance, raw ingredients are routinely weighed, mixed, and loaded into a mixer, reaction vessel, or similar equipment, during chemical manufacturing. Notwithstanding the difference in the equipment, procedures, and the scale of operations, mixing and loading occur both in industrial and in pesticide operations.

Other pesticide operations have little in common with even a similarly termed industrial operation. For instance, the paint spraying operation as used in industries generally involves the use of spray paint booths with the spray jets pointed forward while pesticide spraying is usually performed with the operator in a tractor cab or an airplane cockpit with the spray jets pointed upward or downward. In the case of greenhouse pesticide spraying, the movement of the sprayer and the direction of spray jets also can not find comparable industrial spraying situations. Therefore, data on pesticide spraying operations in both the fields and greenhouses are excluded from this document. Data related to flaggers are also excluded for the same reason. Pesticide reentry dermal exposures also are not believed to be comparable to industrial dermal exposures. After a designated period of time post-application, a worker reenters an area where pesticides have intentionally been applied. The worker may then be potentially exposed to dislodgeable residues from foliage and other surfaces which have been treated. Industrial workers may also be potentially exposed to dislodgeable residues, but the source of the contamination will be quite different. Therefore, pesticide reentry exposure data are not included for analysis.

From the literature search conducted, approximately 100 papers were identified to be related to pesticide mixing and loading operations. A few pesticide studies with data on bagging and stacking operations were also identified. Of the published reports with data on mixing and loading operations, the types of formulation and mixing methods include mixing of dry powder/materials, mixing of powder with a liquid, mixing of liquids, and liquid pumping. Additionally, there are a few papers that contain non-pesticide data, which generally report on

the exposure from intermittent contacts in industrial settings. Based on this analysis of the available studies, the relevant data are grouped into the following categories for discussion: mixing of powders, bagging, stacking, mixing of powder with a liquid, liquid mixing and transfer, and intermittent contact.

Typically, dermal exposure to pesticide was determined by multiplying the amount of the active ingredient retained on absorption pads attached to the skin or work clothing by the area of the body section that the absorption pads represent. For hand exposures, most studies analyzed hand wash solutions to determine dermal exposure. Such data are commonly expressed in terms of hourly exposure (mg/hr) since most tests were conducted for a duration of 30 to 60 minutes. Some studies chose to report the exposure on a daily exposure basis (mg/day) by extending the measured level to an assumed daily exposure duration. Such a time normalized approach is particularly evident in those papers published before the early 1980's. Later papers often reported dermal exposures in terms of the quantity of chemical or quantity of active ingredient handled (mg/lb.AI).

With the CEB method, the potential dermal dose is estimated on the basis of daily exposure (mg/day) and assuming one or two dermal exposure events per day. It does not imply an estimate of 8 continuous hours of exposure. The implication is that the calculated dermal dose represents a daily retention of contaminants on the skin either through a single contact event or multiple events.

Retention of chemicals on the skin surface does not necessarily follow a linear relationship with exposure duration or the quantity of chemical handled. There is a limit to the amount of chemical that can be retained. A single exposure event may be sufficient to reach the maximum retention, for instance, immersion. Therefore, using an hourly retention rate (e.g., in $mg/cm^2/hr$ or mg/hr) to characterize dermal exposure could be misleading as reported by Kilgore et al. (1984) and Knarr et al. (1985). Normalizing exposure on the basis of total quantity of active ingredients (e.g., in $\mu g/cm^2/lb.$ AI) handled was found to be more appropriate to evaluate pesticide exposure (Franklin et al., 1981). However, linear extrapolation of exposure by the quantity handled can also lead to overestimation. For this document, available data are normalized by both time and quantity, where applicable. This way the data can be extrapolated by either factor, whichever is applicable or more appropriate.

As described in Section II, dermal exposure data in pesticide studies are reported only for exposure to the active ingredient. For this report, the total amount of chemical

deposited on the skin, not the active ingredient, is of primary interest. Therefore, a term "Gross Dermal Deposition" is designated to represent the estimated total mass of the chemical product deposited on the skin. It is calculated by dividing the reported exposure by the fractional weight concentration of active ingredient in the chemical. This does not mean the inert material and the diluent in the pesticide mixture are of concern in exposure, rather, it is the numerical value of the "total amount" that is of interest in this document for generic applications.

For example, if a 25% Nitrofen powder is handled, the reported exposure of 10 $\mu g/cm^2$ to the active ingredient on the skin would mean that an estimated 40 $\mu g/cm^2$ (10 divided by 0.25) of the formulated powder product has been deposited on the skin. If the same Nitrofen powder is mixed to make a spray solution with a concentration of 0.5%, a dermal exposure of 10 $\mu g/cm^2$ implies that an estimated 2000 $\mu g/cm^2$ (10 divided by 0.005) of the spray mixture was retained on the skin. Most of the pesticide studies provide information on formulation concentration and dilution factors; therefore the reported dermal exposure can be converted into deposition. However, it should be noted that this approach of calculating the estimated gross deposition from a given amount of active ingredient is rather simplistic and assumes that all ingredients in a pesticide mixture behave the same physically. Different ingredients may have different deposition, evaporation, or absorption rates.

Many different forms of data presentations are found in the available reports. Exposure may be presented in detail with individual data points and certain statistical descriptors; as a range; and as arithmetic or geometric means with or without standard deviations. The data may have been normalized by time or quantity with or without the duration or quantity of chemical reported. Additionally, some investigators only report the total exposure at a body section or at several body sections combined (e.g., mg/hr at forearms), while others report exposure in unit area loading rate, i.e., the data from absorption pad. To be able to combine and compare the data from various reports, a uniform unit must be used. Thus, for this document, the reported dermal exposure data are converted to estimated gross dermal deposition first then normalized by time to obtain a unit as $\mu g/cm^2/hr$ and normalized by quantity of the formulated product to obtain a unit of $\mu g/cm^2/gal$ or $\mu g/cm^2/lb$, where applicable.

In the remainder of this chapter, dermal exposure data are grouped by specific formulation type and operation for discussion. Furthermore, operational factors such as indoor or outdoor operation, manual transfer or mechanical pumping, open or closed mixing, and use of protective clothing are identified and

the underlying data categorized and treated accordingly. For instance, most of the mixing and loading operations found in published reports are performed outdoors, the few data points for indoor mixing were presented but excluded from further statistical analysis. Other factors that may affect dermal exposure such as sampling and analysis method, study protocol, work practices (use of protective clothing), and any unplanned worker actions are usually reported in the papers cited in this document. All these factors were evaluated to ensure that the data can be properly interpreted and compared with other studies. For instance, most of the studies use a hand rinse procedure to determine hand exposure. Dubelman et al. (1982), Everhart and Holt (1982), Nigg and Stamper (1983), and Wojeck et al. (1983) used glove extract to determine hand exposure which may result in overestimates. Their hand exposure data are included in the data tables presented in this chapter but are not included for distributional analysis. For exposure at other parts of the body, absorption pads are used in all studies cited except the study by Chester et al. (1987) who used the entire corresponding sections of Tyvek suits as samplers. Their data are well within the range reported by other investigators and are included for analysis.

A data table summarizing the data, including the reported exposure and the normalized gross dermal deposition data, is prepared for each operation. In each data table, chemical product name and AI concentration is provided in the first column. This is followed by specific body sections for which exposure data are available. The reported average exposure and/or range of exposure in mg/hr or $\mu g/cm^2$ depending on the unit used by the original investigators, is then provided for the body section cited. Exposure duration in hours and quantity of chemicals handled in pounds or gallons then follow. In the next column, the estimated gross dermal deposition in $\mu g/cm^2$ for the body section cited is presented. Where necessary, applicable skin surface areas from an EPA report (EPA, 1987a) are used to convert the data to a unit area gross deposition. If only the hourly exposure rate is reported in the paper the gross dermal deposition is calculated on the basis of the reported duration of exposure, or an assumed exposure period is used. Data in the last two columns are calculated by dividing the estimated gross dermal deposition by the quantity of the formulated product handled and by the exposure time in hours to obtain the respective normalized rate.

Even though only the exposure data from peer reviewed journals or well documented studies are included in this report, any attempt to statistically analyze the combined exposure data for a body section under each operation is inappropriate because of differences in study objective, test protocol, data quality,

and analytical method. Besides, for many of the operations, there are only a limited number of data points and even fewer data points for certain specific body sections.

For two operations, mixing of powder into a solution or slurry and liquid mixing and transfer, a relatively large amount of data are available. The outside clothing exposure data (calculated gross dermal deposition) for these operations are also plotted on scatter diagrams to show the spread of the data. Only the time normalized data are included in these diagrams since there are much fewer data on a quantity normalized basis. Following the approach used by Van Hemmen (1992), the scatter diagrams are used to determine an "Indicative 90th percentile deposition" as a conservative estimate of potential exposure. The "Indicative 90th percentile deposition" is chosen at a rounded value that is exceeded only by approximately 10 percent of the data points for each body section.

Only the calculated gross dermal deposition at an exposed body section or outside the clothing are included in the scatter diagrams for analysis as potential exposure. Exposure inside the clothing would have reflected the barrier effects of the clothing which introduced additional variables (the fabric material, weave type, worker habit, etc.) in estimating dermal exposure. Therefore, such data are excluded from analysis of Indicative 90th percentile exposure at this time.

Since most of the data in this section were derived from pesticide studies, an explanation of some of the chemical terms commonly used in pesticide application is appropriate (Farm Chemical Handbook, 1992).

Dry Concentrate:	A dry, relatively free-flowing powder containing the maximum possible amount of AI. A wetting agent amy be included so that the mixture is ready to be dispensed in water for spray application in which case it is termed a dry wettable powder. Without wetting agent, but suitable for further dilution to form a dust, it is called a dust base.
Emulsifiable Concentrate:	Produced by dissolving the AI and emulsifying agent in an organic solvent.
Encapsulated:	Pesticide enclosed in tiny capsules (or beads) of thin polyvinyl or

	other plastic material to control release of the chemical and extend the period of diffusion, thus providing increased safety to applicators as well as to the environment.
Solution:	Mixture of one or more substances in another substance (usually a liquid) in which all the ingredients are completely dissolved.
Suspension:	Particles of a solid or immiscible liquid dispersed in a liquid or gas but not dissolved in it.
Wettable Powder:	A powdered preparation containing sufficient suitable surface active material (wetting agent) so that the powder will be wetted and suspensible in water as a spray material.

A. Mixing of Dry Powder Materials

Data grouped under this operation pertain to dermal exposure to workers who open bags of powder or granular chemicals and pour the contents into a mixing tank; or scoop out a measured portion of the contents for mixing with other dry chemicals or substances. A summary of the available data is shown in Table 4-1. Some of the available data are expressed in terms of total amount of AI deposited on skin surfaces per hour (mg/hr) and usually represent the total exposure on uncovered areas of the body. In other cases, data on dermal exposure may be reported for various parts of the body.

Of the six studies cited, only one (Fenske et al., 1990) reported unit area deposition rate at the body sections monitored. Other studies reported primarily combined deposition at unclothed areas of the body, typically including face, neck, V of neck, forearms, and hands. Without the studies' original data, it is impossible to back calculate unit deposition rate at individual body sections. However, total gross deposition at these unclothed sections (face, neck, and forearms of the body would be 104 mg based on the mean exposure data from Fenske et al. (1990). This is comparable to the range of 27 to 154 mg derived from mean exposure of other studies that also include hand exposure.

The pesticides used in the six studies included in Table 4-1 were all described as dust or powder except the disulfoton used by Wolfe et al. (1987a) which was described as "granular." It is unclear whether there was a difference in particle size among the various dust, powder, or granules cited in the studies. Nor was it clear whether grain size has any effects on dermal exposure from the studies. Kissel et al. (1996b) conducted a series of laboratory studies to investigate the effect of particle size and moisture content on soil adherence to skin. Their results indicate that for dry soil (<2% moisture) adherence rate in mg/cm^2 varies inversely with grain size and adherence occurs predominantly for particles small than 150 μ or even 65 μ. For wet soil (12-18% moisture), adherence generally varies directly with particle size.

B. Bagging

Bagging operation refers to the operation where workers fill bags of dry powder mix at the filler spout, remove, and then seal the bags. Three studies were found to have included data on dermal exposure during bagging operations. A summary of these data is presented in Table 4-2. The data generally represent total hourly exposure at unclothed areas of the body including face, neck, V of neck, forearms, and gloved or ungloved hands. From these data, the gross dermal deposition including exposure at ungloved hands ranged from 49 to 1986 mg for 1 hr. of exposure. One other study, by Comer et al. (1975), also contained exposure data that included bagging operations. However, the reported exposure represented the combined exposure during mixing and bagging operations and are excluded from this summary.

TABLE 4-1 DERMAL EXPOSURE DATA AND ESTIMATES FOR DRY MIXING OPERATIONS

Chemical Formulation	Body Section or Pad Location	Reported Exposure*	Exposure Duration (hr)	Quantity Handled (lbs)	Estimated Gross Dermal Deposition**	Estimated Gross Deposition by Quantity ($\mu g/cm^2/lb$)	Estimated Gross Deposition by Time ($\mu g/cm^2/hr$)	Reference
50% DDT	Face, neck, V of neck, forearms, and hands (minimum protection)	(mg/hr) 13.3-44.7(32.7)	0.5-1.0	N.A.	(mg) 26.6-89.4(65.4)	--	--	Wolfe and Armstrong, 1971
	Face, neck, and V of neck only (w/PPE)	4.2-18.2(12.9)	0.5-1.0	N.A.	8.4-36.4(25.8)	--	--	
	Exposure from 6 measurements mixing DDT in formulating plants. Hand exposure from hand wash. Exposure determined from layered gauze pads. Exposure duration and amount of DDT handled not reported. 1 hr exposure assumed. Short sleeve shirts and long pants with minimum protection (no gloves). PPE used included coveralls, respirator, and rubber gloves.							
10% Disulfoton	Face, neck, V of neck, forearms, and hands	(mg/hr) 27 ± 36	N.A.	N.A.	(mg) 27 ± 36	--	--	Wolfe et al., 1978a
	Exposure from 7 measurements during mixing of dry granular 10% disulfoton formulation to dry fertilizer. Layered gauze absorbent pads were attached to worker's clothing. Hand exposure from hand wash. No gloves used. Quantity of chemicals handled and duration of exposure not reported. 1 hr. exposure assumed.							
25% Parathion	Face, neck, V of neck, forearms, and hands	(mg/hr) 38.4 ± 37.5	0.5-1.0	N.A.	(mg) 153.6 ± 150	--	--	Wolfe et al., 1978b
	Exposure from 8 measurements during mixing in parathion formulating plants. Exposure determined from layered gauze pads. Hand exposure from hand wash. Workers wore short sleeved shirts, long pants, no gloves. Work lasted 30-60 minutes, amount of chemicals processed not reported. 1 hour exposure assumed.							

* Depending on the original data reported, ranges with the mean value in parenthesis; mean value ± standard deviation; or only the mean value (in parentheses) is presented

** Calculated by dividing percent formulation into the reported exposure and extended for the duration where appropriate; data not provided unless duration data is available or assumed

TABLE 4-1 DERMAL EXPOSURE DATA AND ESTIMATES FOR DRY MIXING OPERATIONS (Cont'd)

Chemical Formulation	Body Section or Pad Location	Reported Exposure*	Exposure Duration (hr)	Quantity Handled (lbs)	Estimated Gross Dermal Deposition**	Estimated Gross Deposition by Quantity ($\mu g/cm^2/lb$)	Estimated Gross Deposition by Time ($\mu g/cm^2/hr$)	Reference
5% Captan		(mg/hr)			($\mu g/cm^2$)			Stevens and Davis, 1981
	Face, neck, V of neck, outdoor	4.5 ± 0.2	1	N.A.	112.5 ± 5.0	--	112.5 ± 5.0	
	Hands, outdoor	3.0 ± 2.0	1	N.A.	73.2 ± 48.8	--	73.2 ± 48.8	
	Face, neck, V of neck, indoor	0.95 ± 0.41	1	N.A.	23.8 ± 10.3	--	23.8 ± 10.3	
	Hands, indoor	0.09 ± 0.07	1	N.A.	2.2 ± 1.7	--	2.2 ± 1.7	
	Total exposure while filling the hoppers of seed dusting machines with Captan (1 1/2 lbs. of Captan dust per 100 lbs. of cut potatoes). Workers wore long-sleeved shirts or jackets, with head covering and canvas-back leather gloves. Exposure other than hands were measured with multi-layered gauze pads; hand exposure was measured with hand rinse techniques and exposure duration ranged 3/4 to 2 hrs (1 hr assumed). 3 outdoor and 7-9 indoor measurements made skin surface areas in EPA 1987a used to calculate gross deposition from reported exposure.							
Lindane (concentration not reported)		(mg/hr)						Grey et al., 1983
	Chest	<0.1	N.A.	N.A.	N.A.	--	--	
	Arms	<0.1	N.A.	N.A.	N.A.	--	--	
	Hands	81.42 & 54.8	N.A.	N.A.	N.A.	--	--	
	Exposure measured while emptying bags of Maneb-Lindane into the hoppers of commercial seed treater. Approximately 18,000 to 20,000 kg of wheat seeds are treated per hour. Exposure was found only in the hands; workers checked the uniformity of application using their bare hands. Dermal exposures other than hand exposures were measured with multi-layered gauze pads. Hand exposures were measured with the rinse technique. Exposure duration and application rates not reported. 2 measurements made.							

* Depending on the original data reported, ranges with the mean value in parenthesis; mean value ± standard deviation; or only the mean value (in parentheses) is presented

** Calculated by dividing percent formulation into the reported exposure and extended for the duration where appropriate; data not provided unless duration data is available or assumed

TABLE 4-1 DERMAL EXPOSURE DATA AND ESTIMATES FOR DRY MIXING OPERATIONS (Cont'd)

Chemical Formulation	Body Section or Pad Location	Reported Exposure*	Exposure Duration (hr)	Quantity Handled (lbs)	Estimated Gross Dermal Deposition**	Estimated Gross Deposition by Quantity	Estimated Gross Deposition by Time	Reference
18.75% Lindane		(mg)			(µg/cm²)	(µg/cm²/lb)	(µg/cm²/hr)	Fenske et al. 1990
	Chest, (inside clothing)	0.07-0.71(0.45)	0.4	7.5	0.11-1.07	0.01-0.14	0.28-2.68	
	Back, (inside clothing)	0.11-2.59(0.71)	0.4	7.5	0.17-3.89	0.02-0.52	0.41-9.73	
	Forearms, (inside clothing)	1.31-16.7(5.43)	0.4	7.5	5.77-73.6	0.77-9.81	14.4-184	
	Upper arms, (inside clothing)	0.12-2.91(1.12)	0.4	7.5	0.22-5.33	0.03-0.71	0.56-13.3	
	Upper legs, (inside clothing)	0.08-9.32(2.88)	0.4	7.5	0.11-13.0	0.01-1.74	0.28-32.5	
	Lower legs, (inside clothing)	0-0.33(0.16)	0.4	7.5	0-0.74	0-0.10	0-1.86	
	Chest, (outer clothing)	0.92-7.64(3.21)	0.4	7.5	1.38-11.8	0.18-1.57	3.46-29.4	
	Back, (outer clothing)	0.85-4.58(2.48)	0.4	7.5	1.28-6.88	0.17-0.92	3.19-17.20	
	Forearms, (outer clothing)	5.57-51.8(17.8)	0.4	7.5	24.6-228.3	3.27-30.4	61.4-570.8	
	Upper arms, (outer clothing)	0.99-10.1(4.43)	0.4	7.5	1.81-18.5	0.24-2.46	4.54-46.3	
	Upper legs, (outer clothing)	2.90-132.6(34.0)	0.4	7.5	4.05-185.1	0.54-24.7	10.1-463	
	Lower legs, (outer clothing)	0.43-5.95(1.34)	0.4	7.5	0.96-13.3	0.13-1.78	2.41-33.3	
	Hands, (inside gloves)	(0.74)			4.81	0.64	12.0	
	Exposed head and neck	(1.72)			--	--	--	
	Workers wore long sleeve shirts, long pants, gloves,and respirators. Absorbant pads with impervious backing were placed outside and inside the clothing. Exposure was measured for manual treatment (scooping Lindane from bags and mixing with a stick) of wheat grain with Lindane powder formulation in planter boxes. Hand exposure measured with a handwash technique. Average duration of mixing was 24.1 minutes and 3.4 kg of Lindane formulation was handled. 12 measurements made.							

* Depending on the original data reported, ranges with the mean value in parenthesis; mean value ± standard deviation; or only the mean value (in parentheses) is presented

** Calculated by dividing percent formulation into the reported exposure and extended for the duration where appropriate, data not provided unless duration data is available or assumed.

TABLE 4-2 DERMAL EXPOSURE DATA AND ESTIMATES FOR BAGGING OPERATION

Chemical Formulation	Body Section or Pad Location	Reported Exposure*	Exposure Duration (hr)	Quantity Handled (lbs)	Estimated Gross Dermal Deposition**	Estimated Gross Deposition by Quantity $\mu g/cm^2/lb$	Estimated Gross Deposition by Time $\mu g/cm^2/hr$	Reference
50% DDT	Face, neck, V of neck, forearms, and hands (workers who filled 4 & 5 lb bags at the spout at Plant A, minimum protection)	(mg/hr) 96-993(524.5)	0.5-1.0	N.A.	(mg) 192-1986	--	--	Wolfe and Armstrong, 1971
	Face, neck, V of neck, forearms, and hands (workers who filled 50 lb bags at the spout at Plant A, minimum protection)	108-227(153.5)	0.5-1.0	N.A.	216-443	--	--	
	Face, neck, V of neck, forearms, and hands (workers who filled 4 lb bags at the spout at Plant B, minimum protection)	24.6-34(31.2)	0.5-1.0	N.A.	49.2-68	--	--	
	Face, neck, V of neck, (workers who filled 4 & 5 lb bags at the spout at Plant A, w/PPE)	26.4-124(72.7)	0.5-1.0	N.A.	52.8-248	--	66-310	
	Face, neck, V of neck, (workers who filled 50 lb bags at the spout at Plant A, w/PPE)	24.3-87.5(43.5)	0.5-1.0	N.A.	48.6-175	--	61-219	
	Face, neck, V of neck, (workers who filled 4 lb bags at the spout at Plant B, w/PPE).	7.8-19.6(14.3)	0.5-1.0	N.A.	15.6-39.2	--	20-49	
	No information on the number of bags handled per unit time. Exposure determined with layered gauze pads and handwash. Each exposure measurement lasted 30-60 minutes, 1 hr exposure assumed. No protective clothing or gloves used under minimum protection. PPE used included coveralls, respirator, and rubber gloves. 4-5 measurements made for each test. EPA 1987a skin areas used to calculate gross deposition by time, where applicable.							

* Depending on the original data reported, ranges with the mean value in parenthesis; mean value ± standard deviation; or only the mean value (in parentheses) is presented.

** Calculated by dividing percent formulation into the reported exposure and extended for the duration where appropriate; data not provided unless duration data is available or assumed

TABLE 4-2 DERMAL EXPOSURE DATA AND ESTIMATES ON BAGGING OPERATION (Cont'd)

Chemical Formulation	Body Section or Pad Location	Reported Exposure*	Exposure Duration (hr)	Quantity Handled (lbs)	Estimated Gross Dermal Deposition**	Estimated Gross Deposition by Quantity $\mu g/cm^2/lb$	Estimated Gross Deposition by Time $\mu g/cm^2/hr$	Reference
0.5% Disulfoton	Face, neck, v of neck, forearms, and hands	(mg/hr) 1.2 ± 2.0	N.A.	N.A.	(mg) 240 ± 400	--	--	Wolfe et al., 1978a
	Exposure from 8 measurements while filling bags with pesticide-fertilizer mix at the filler spout. Layered gauze pads were attached to worker's clothing. Hand exposure from handwash. No gloves used. Number of bags handled and duration of exposure not reported. 1 hr. exposure assumed.							
25% Parathion	Face, neck, V of neck, forearms, and hands	(mg/hr) 82.1 ± 98.4	0.5-1.0	N.A.	(mg) 328 ± 394	--	--	Wolfe et al., 1978b
	Total mean exposure from 17 measurements while filling the bags at the spout. Exposure determined during 30 to 60 minutes of operation, using layered gauze pads and handwash. Number of bags handled not reported. Workers wore work cloth, no gloves used. 1 hr. exposure assumed.							

* Depending on the original data reported, ranges with the mean value in parenthesis; mean value ± standard deviation; or only the mean value (in parentheses) is presented

** Calculated by dividing percent formulation into the reported exposure and extended for the duration where appropriate; data not provided unless duration data is available or assumed

C. Stacking

A summary of dermal exposure data related to stacking operations is presented in Table 4-3. Workers who perform stacking operations generally stack full bags of powder or granular material on pallets, operate the machine for closing bag tops, or pack bags in cartons for shipment.

The three studies identified that contain stacking operation dermal exposure data are all from the same research team. They reported only total exposure at unclothed areas of the body including face, neck, V of neck, forearms, and ungloved hands. Based on 1 hr. of exposure, total gross deposition calculated ranges from 30 to 480 mg.

TABLE 4-3 DERMAL EXPOSURE DATA AND ESTIMATES FOR STACKING OPERATIONS

Chemical Formulation	Body Section or Pad Location	Reported Exposure*	Exposure Duration (hr)	Quantity Handled (lbs)	Estimated Gross Dermal Deposition**	Estimated Gross Deposition by Quantity $\mu g/cm^2/lb$	Estimated Gross Deposition by Time $\mu g/cm^2/hr$	Reference
50% DDT	Face, neck, V of neck, forearms, and ungloved hands	(mg/hr) 68.2-148.7(98.5)	0.5-1.0	N.A.	(mg) 138-293	--	--	Wolfe and Armstrong, 1971
	Face neck, and V of neck (w/PPE)	15.2-32.5(26.2)	0.5-1.0	N.A.	30.4-65.0	--	--	
	Total exposure from 4 measurements while packing filled bags of dry mix into cartons for shipment. Number of bags handled not reported. Exposure determined from layered gauze pads and handwash during 30 to 60 minute period. 1 hr. exposure assumed. PPE used included coveralls, respirator, and rubber gloves.							
0.5% Diulfoton	Face, neck, V of neck, forearms, and hands	(mg) 2.4 ± 2.9	N.A.	N.A.	(mg) 480-580	--	--	Wolfe et al., 1978a
	Total exposure from 6 measurements while stacking bags of Diulfoton powder formulation onto storage pallets. Exposure determined from multi-layered gauze pads and handwash; duration of exposure and quantity of bags handled not reported. 1 hr. exposure assumed. No gloves used.							
25% Parathion	Face, neck, V of neck, forearms, and hands	(mg/hr) 34.0 ± 62.0	0.5-1.0	N.A.	(mg) 136 ± 248	--	--	Wolfe et al., 1978b
	Total exposure from 25 measurements while stacking full bags of dry formulation onto storage pallets, operating bag closure machines, or packing bags in cartons for shipment. Exposure determined with layered gauze pads and handwash during 30 to 60 minutes operation. 1 hr. exposure assumed. Quantity of bags handled not reported.							

* Depending on the original data reported, range with mean values in parenthesis; mean value ± standard deviation; or only the mean value (in parenthesis) is presented.
** Calculated by dividing percent formulation into the reported exposure and extended for the duration where applicable; data not provided unless duration is available or assumed.

D. Mixing of Powder with a Liquid

This operation refers to the mixing of dry powder into a slurry or liquid solution. In such an operation, workers commonly open containers of wettable powder, take the entire content or a measured amount and dump the powder into a tank where it is mixed with water or other liquid. A summary of the available data is shown in Table 4-4. During this mixing operation, the worker would initially be exposed to the powder and then to the mixed liquid. There are no data to estimate the relative percentage contribution of exposure from the concentrated formulation and from the diluted mix. It is believed that the majority of exposure results from contact with the powder. In Table 4-4, the gross dermal deposition calculated assumed that exposure was entirely from the formulated powder product. The actual gross dermal deposition may be higher than the calculated values, because for the same amount of active ingredient reported there must be a larger amount of diluted mix than the concentrated formulation due to concentration differences.

Exposure data from six studies are presented in Table 4-4. All the studies reported unit area or total exposure at various body sections, including chest, back, forearms, upper arms, upper legs, lower legs, and hands. Exposure inside the clothing or under the gloves is generally lower than outside the clothing. In fact, the Knarr et al. (1985) study reported a penetration factor of 0.53 for molinate powder mixing based on comparison of deposition on exposure pad outside and inside the coverall.

Unit area exposure at each body section from the studies cited here usually varies over a range of several orders of magnitude. A scatter diagram of the potential gross dermal deposition data normalized by time as calculated from outside clothing or exposed body section exposure is shown in Figure 4-1 to illustrate this point. From this, the Indicative 90 percentile deposition is determined as: hands, 300 $\mu g/cm^2/hr$; forearms, 200 $\mu g/cm^2/hr$; head or face, 120 $\mu g/cm^2/hr$; chest, 40 $\mu g/cm^2/hr$., back, 15 $\mu g/cm^2/hr$; upper legs, 15 $\mu g/cm^2/hr$, upper arms, 0.5 $\mu g/cm^2/hr$; and lower legs, and 0.1 $\mu g/cm^2/hr$. As expected, the body sections likely to have more direct contact with the chemicals, the hands and forearms, have the highest exposure. Similar analysis on the limited amount of quantity normalized data shows the Indicative 90th Percentile depositions as: hands, 1.5 $\mu g/cm^2/lb$; forearms, 2.0 $\mu g/cm^2/lb$; head or face, 0.4 $\mu g/cm^2/lb$; chest, 1.0 $\mu g/cm^2/lb$; back, 0.15 $\mu g/cm^2/lb$; upper legs, 3.0 $\mu g/cm^2/lb$; upper arms, 0.6 $\mu g/cm^2/lb$; and lower legs, 0.1 $\mu g/cm^2/lb$. These data are summarized in Table 4-5.

TABLE 4-4 DERMAL EXPOSURE DATA AND ESTIMATES FOR MIXING OF POWDER INTO LIQUID

Chemical Formulation	Body Section or Pad Location	Reported Exposure*	Exposure Duration	Quantity Handled (lbs)	Estimated Gross Dermal Deposition**	Estimated Gross Deposition by Quantity ($\mu g/cm^2/lb$)	Estimated Gross Deposition by Time ($\mu g/cm^2/hr$)	Reference
Nitrofen 50% powder		($\mu g/cm^2$)			($\mu g/cm^2$)			Maddy et al., 1980
	Forearms (inside clothing)	0.028-0.053	0.23-0.35	N.A.	0.056-0.10	--	0.16-0.36	
	Upper Legs (inside clothing)	0.013-0.10	0.23-0.35	N.A.	0.026-0.20	--	0.096-0.69	
	Chest (inside clothing)	0.008-0.071	0.23-0.35	N.A.	0.016-0.14	--	0.050-0.21	
	Back (inside clothing)	0.003-0.011	0.23-0.35	N.A.	0.006-0.022	--	0.018-0.072	
	Forearms (outside clothing)	0.5-1.78	0.23-0.35	N.A.	1.0-3.56	--	2.86-12.67	
	Upper Legs (outside clothing)	0.28-2.12	0.23-0.35	N.A.	0.56-4.2	--	2.52-14.9	
	Chest (outside clothing)	0.19-0.89	0.23-0.35	N.A.	0.38-1.8	--	1.08-6.67	
	Back (outside clothing)	0.07-0.41	0.23-0.35	N.A.	0.14-0.82	--	0.44-2.56	
	Hands (inside gloves)	573-1229	0.23-0.35	N.A.	1146-2458	--	1.40-3.00	
	Exposures from 5 measurements during mixing and loading of wettable powder. Workers wore long-sleeved shirts, long pants, waterproof hat, gloves, boots, and respirator. Exposure determined with pads made out of a top layer of cotton duck cloth and inner layers of gauze pinned to exterior of disposable coveralls. Hand exposure determined with the hand rinse technique. Exposure measured for mixing and loading operation of approximately 15 to 20 minutes.							
Carbaryl 50-80% Wettable Powder		($\mu g/cm^2/hr$)						Maitlen et al 1982
	Chest (outside)	0.7-49.13	3-14 min.	N.A.		--	1.4-61.42	
	Back (outside)	0.3-12.91	3-14 min.	N.A.		--	0.24-16.14	
	Shoulders (outside)	0.7-25.12	3-14 min.	N.A.		--	1.4-31.40	
	Forearms (outside)	0.7-48.20	3-14 min.	N.A.		--	1.4-57.76	
	Hands (without gloves)	2.67-390	3-14 min.	N.A.		--	3.34-487	
	Hands (with gloves)	3.43-9.85	3-14 min.	N.A.		--	4.28-12.32	
	Exposure from 3 experiments for 80% powder with up to 10 replicates, and 2 experiments for 50% powder with 1 test each (14-20 measurements). Exposure reported for total per body section, values are back calculated to show per unit area exposure using skin surface area of EPA, 1987a. Ranges of mixing time shown; total amount of formulation not reported. Hand exposure from rinse procedure, other exposure from pads.							

* Depending on the original data reported, ranges with the mean value in parenthesis; mean value ± standard deviation, or only the mean value (in parentheses) is presented

** Calculated by dividing percent formulation into the reported exposure and extended for the duration where appropriate; data not provided unless duration data is available or assumed

TABLE 4-4 DERMAL EXPOSURE DATA AND ESTIMATES FOR MIXING OF POWER INTO LIQUID (Cont'd)

Chemical Formulation	Body Section or Pad Location	Reported Exposure*	Exposure Duration	Quantity Handled (lbs)	Estimated Gross Dermal Deposition**	Estimated Gross Deposition by Quantity ($\mu g/cm^2/lb$)	Estimated Gross Deposition by Time ($\mu g/cm^2/hr$)	Reference
Banlate (50% Benomyl)		($\mu g/cm^2$)			($\mu g/cm^2$)			Everhart and Holt, 1982
	Forearms (outside clothing)	0.62-31.40(7.51)	2.2-5.0 min.	25-60	1.24-62.8	0.03-1.34	15-1256	
	Face (outside clothing)	0.02-12.0(2.67)	2.2-5.0 min.	25-60	0.04-24.0	0.001-0.51	0.5-480	
	Chest (outside clothing)	0.02-4.70(1.63)	2.2-5.0 min.	25-60	0.04-9.4	0.001-0.20	0.5-188	
	Back (outside clothing)	0.02-3.80(0.90)	2.2-5.0 min.	25-60	0.04-7.6	0.001-0.19	0.5-207	
	Hands (on gloves)	2.8-55.2(14.90)	2.2-5.0 min.	25-60	5.6-110	0.22-1.84	94-2210	
	Exposure from 10 trials of opening bags and mixing. Pads on outside of clothing. Hand exposure from cotton gloves. Workers wore long sleeved shirts, long pants, and gloves.							
Ordram 10G Selective (10% molinate) granule		(mg/day)			($\mu g/cm^2$)			Knarr et al., 1985
	Trunk (inside clothing)	1.5 ± 1.6	N.A.	13,000	2.11 ± 2.25	0.0002 ± 0.0002	0.27 ± 0.28	
	Arms (inside clothing)	1.3 ± 1.1	N.A.	13,000	3.16 ± 2.87	0.0002 ± 0.0002	0.40 ± 0.33	
	Legs (inside clothing)	13 ± 17	N.A.	13,000	21.0 ± 27.4	0.002 ± 0.002	2.63 ± 3.43	
	Head (unclothed)	0.065 ± 0.098	N.A.	13,000	0.5 ± 0.76	0.00004 ± 0.0001	0.06 ± 0.09	
	Face and neck (unclothed)	0.73 ± 0.87	N.A.	13,000	9.13 ± 8.38	0.0007 ± 0.0006	1.14 ± 1.05	
	Trunk (outside clothing)	2.83 ± 3.02	N.A.	13,000	4.0 ± 4.25	0.0003 ± 0.0003	0.5-0.53	
	Arms (outside clothing)	2.45 ± 2.08	N.A.	13,000	5.95 ± 5.05	0.0005 ± 0.0004	0.74 ± 0.63	
	Legs (outside clothing)	24.5 ± 32.1	N.A.	13,000	39.5 ± 51.8	0.003 ± 0.004	4.94 ± 6.48	
	Hands (no gloves)	0.4 ± 0.30	N.A.	13,000	4.88 ± 3.65	0.0004 ± 0.0003	0.61 ± 0.46	
	Average exposure reported only for exposed skin area and for inside personal clothing (coverall). Reported inside exposure calculated by authors from outside pad data with a tested penetration factor of 0.53. Values shown here for outside clothing exposure are back calculated. Results for 4 days of testing and reported as daily exposure. Hand exposure from rinse procedure. Mixer/loaders mix and load herbicide, refuel planes, and clean windshields. Daily exposure assumed to be 8 hrs. and skin surface areas in EPA 1997a used for calculation of gross dermal deposition. Leg exposure was high due to repeated contact with the spray nozzle during refueling.							

* Depending on the original data reported, ranges with the mean value in parenthesis; mean value ± standard deviation; or only the mean value (in parentheses) is presented

** Calculated by dividing percent formulation into the reported exposure and extended for the duration where appropriate, data not provided unless duration data is available or assumed

TABLE 4-4 DERMAL EXPOSURE DATA AND ESTIMATES FOR MIXING OF POWER INTO LIQUID (Cont'd)

Chemical Formulation	Body Section or Pad Location	Reported Exposure*	Exposure Duration	Quantity Handled (lbs)	Estimated Gross Dermal Deposition**	Estimated Gross Deposition by Quantity (µg/cm²/lb)	Estimated Gross Deposition by Time (µg/cm²/hr)	Reference
Fosetyl-Al 80% powder		(µg/cm²/hr)						Fenske, et al., 1987
	Chest (inside clothing)	0-0.030(0.016)	75-105 min.	1.51		0-0.037	0-0.04	
	Back (inside clothing)	0-0.007(0.0031)	75-105 min.	1.51		0-0.009	0-0.009	
	Upper arms (inside clothing)	0.007-0.02(0.023)	75-105 min.	1.51		0.009-0.02	0.009-0.03	
	Forearms (inside clothing)	0.007-0.17(0.12)	75-105 min.	1.51		0.009-0.21	0.009-0.21	
	Upper legs (inside clothing)	0-0.013(0.0067)	75-105 min.	1.51		0-0.016	0-0.16	
	Lower legs (inside clothing)	0-0.006(0.0034)	75-105 min.	1.51		0-0.008	0-0.006	
	Chest (outside clothing)	0.01-0.17(0.11)	75-105 min.	1.51		0.01-0.21	0.01-0.21	
	Back (outside clothing)	0.01-0.04(0.02)	75-105 min.	1.51		0.01-0.05	0.01-0.05	
	Upper arms (outside clothing)	0.10-0.57(0.34)	75-105 min.	1.51		0.12-0.70	0.13-0.71	
	Forearms (outside clothing)	0.16-0.64(0.35)	75-105 min.	1.51		0.20-0.78	0.2-0.8	
	Upper legs (outside clothing)	0.03-2.67(0.79)	75-105 min.	1.51		0.04-3.27	0.04-3.33	
	Lower legs (outside clothing)	0.01-0.10(0.04)	75-105 min.	1.51		0.01-0.12	0.01-0.13	
	Hands (inside gloves)	9.2-83.4(35.6)$_{male}$	75-105 min.	1.51		0.01-0.09	0.01-0.10	
	Uncovered face and neck	59.4-353(213)$_{applic}$	75-105 min.	1.51		0.09-0.53	0.09-0.55	
	Exposure measured from 4 mixers. Workers wore long-sleeved shirts, long pants, gloves, and respirator. Exposure determined with multi-layered gauze pads inside and outside the work cloth. Hand exposure was measured with the hand rinse technique. Approximately 684 g. of formulation handled in filling up 12 tanks in an average of 89 minutes.							
Mancozeb 80% Wettable Powder		(µg/cm²)			(µg/cm²)			Mumma et al., 1985
	Face (exposed)	0.19-0.71(0.38)	5-20 min.	N.A.	0.24-0.9	--	0.84-3.55	
	Neck front (chest outside pad)	0.10-3.52(1.14)	5-20 min.	N.A.	0.13-4.4	--	0.83-13.20	
	Neck back (back outside pad)	0.17-0.36(0.26)	5-20 min.	N.A.	0.21-0.45	--	0.75-3.90	
	Forearms (exposed)	0.93-7.77(2.92)	5-20 min.	N.A.	1.16-9.71	--	4.10-29.14	
	Face (under hood)	0.10-0.33(0.18)	5-20 min.	N.A.	0.13-0.41	--	0.50-1.50	
	Neck front (chest inside pad)	0.10-0.71(0.32)	5-20 min.	N.A.	0.13-0.89	--	0.44-3.10	
	Neck back (back inside pad)	0.10-0.36(0.23)	5-20 min.	N.A.	0.13-0.45	--	0.50-2.42	
	Forearms (inside clothing)	0.10-0.93(0.57)	5-20 min.	N.A.	0.13-1.16	--	0.83-13.95	
	Hands (inside gloves)	0.037-0.80(0.22)	5-20 min.	N.A.	0.05-1.0	--	0.16-4.0	
	Exposure of 2 replicates at 3 different sites. Mixing time ranged from 5 to 20 minutes (average 14 minutes). Total amount of formulation used not reported. Hand exposure based on amount of chemical on the cotton gloves used, other exposure from cotton gauze pads. Workers wore unspecified protective clothing and cotton gloves inside protective gloves.							

* Depending on the original data reported, ranges with the mean value in parenthesis; mean value ± standard deviation; or only the mean value (in parentheses) is presented.

** Calculated by dividing percent formulation into the reported exposure and extended for the duration where appropriate; data not provided unless duration data is available or assumed.

FIGURE 4-1 ESTIMATED GROSS DERMAL DEPOSITION DURING MIXING OF POWDER WITH LIQUID

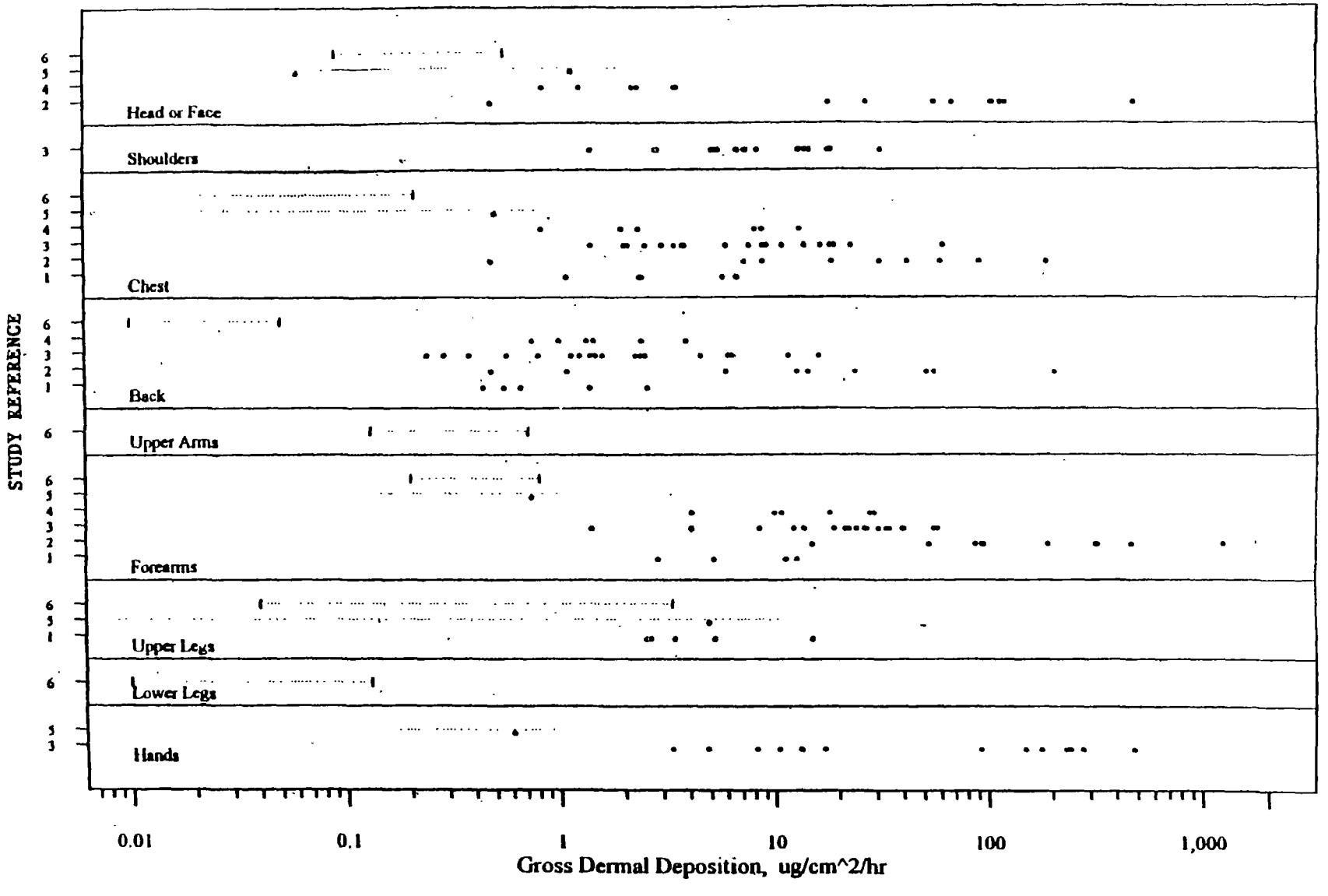

TABLE 4-5
INDICATIVE 90TH PERCENTILE ESTIMATED GROSS DERMAL DEPOSITION
FOR MIXING OF POWDER WITH A LIQUID

	Indicative 90th Percentile Deposition	
	Time Normalized $\mu g/cm^2/hr$	Quantity Normalized $\mu g/cm^2/lb$
Head or Face	120	0.4
Shoulders	30	--
Upper Arms	0.5	0.6
Chest	40	1.0
Back	15	0.15
Forearms	200	2.0
Upper Legs	15	3.0
Lower Legs	0.1	0.1
Hands	300	1.5

Determined from data in Table 4-4 and Figure 4-1 as the value exceeded only by approximately 10% of the data points reported for each body section; number of data points varies between body sections and between normalizing factors.

E. Liquid Mixing and Transfer

Liquid mixing and transfer operations refer to operations where one liquid is added to another liquid either through tank-top transfer or through an enclosed pumping system for mixing. Depending on the type of transfer operation (e.g., manual liquid transfer vs. automated closed system pumping), exposures could be quite different. Available exposure data from 10 studies are summarized in Table 4-6. Other studies on liquid mixing operations, including those of Lavy et al. (1980), Wojeck and Nigg (1980), and Byers et al. (1992) did not report the concentration of the formulated pesticide used which made the calculation for gross deposition impossible. These data are therefore excluded. One study by Knaak et al. (1989) contains some incomplete data on dermal exposure for liquid mixing operation and is also not included.

In pesticide application, liquid transfer occurs when an emulsifiable concentrate, a solution, or a suspension is mixed with a diluent for spraying. Except for spills and splashes, dermal exposure is likely to be the result of incidental contact with contaminated equipment surfaces. Thus, personal work habit can play a critical role in determining the extent of exposure. For instance, Knaak et al. (1992) found a high exposure at the lower leg because most of the mixing/loading operations studied consisted of pouring liquid from one container to another below the waist level and liquid splashing might have caused the relatively high exposure at the lower part of the legs. Unusually high exposure at the legs was found by Knarr et al. (1995) due to frequent contact with spray nozzles during the loading operations. Conversely, Chester et al. (1987) found most of the exposure was concentrated in the arms, trunk, and hands. Lavy et al. (1980) reported high exposure at the thighs and observed that workers frequently rubbed their hands against their pants at the thigh area.

Comparing the estimated gross dermal deposition at the same body section from the studies included in Table 4-6, one will see a wide range of variations. A scatter diagram of the data as shown in Figure 4-2 further illustrates this point. Only the data from 9 of the 12 studies are shown in Figure 4-2; data from the remaining 3 studies do not provide normalized deposition at individual body sections. Of the 12 studies included in Table 4-6, three are related (the last three studies in the table) to exposures during closed-system pumping operations. The range of exposures reported in closed system pumping are generally at the mid- or lower-range of those reported for tank top transfers. These data are included in the scatter diagram but are analyzed separately for the Indicative 90th Percentile estimates. Based on the data points pertaining to open mixing shown in Figure 4-2,

the Indicative 90 Percentile estimated gross depositions for various body sections are estimated as: hands, 200 $\mu g/cm^2/hr$; forearms 10 $\mu g/cm^2/hr$, chest, 8 $\mu g/cm^2/hr$; upper legs, 5.0 $\mu g/cm^2/hr$, back 3.0 $\mu g/cm^2/hr$, shoulder, 3.0 $\mu g/cm^2/hr$; lower legs, 1.0 $\mu g/cm^2/hr$; and head, 0.1 $\mu g/cm^2/hr$. For the quantity normalized data, the Indicative 90th Percentile estimated depositions are: hands, 100 $\mu g/cm^2/gal$; forearms, 4.0 $\mu g/cm^2/gal$; chest, 0.4 $\mu g/cm^2/gal$; upper legs, 10 $\mu g/cm^2/gal$; back, 0.2 $\mu g/cm^2/gal$; shoulders, 0.3 $\mu g/cm^2/gal$; lower legs, 2.0 $\mu g/cm^2/gal$; and head, 0.4 $\mu g/cm^2/gal$. Table 4-7 summarized these data.

TABLE 4-6 DERMAL EXPOSURE DATA AND ESTIMATES FOR LIQUID MIXING OR TRANSFER OPERATION

Chemical Formulation	Body Section or Pad Location	Reported Exposure*	Exposure Duration (hr)	Quantity Handled (gallon)	Estimated Gross Dermal Deposition**	Estimated Gross Reposition by Quantity ($\mu g/cm^2$/gal)	Estimated Gross Deposition by Time ($\mu g/cm^2$/hr)	Reference
Nitrofen 25% emulsifiable concentrate		($\mu g/cm^2$)			($\mu g/cm^2$)			Maddy et al., 1980
	Forearms (inside clothing)	0-0.005	14-21 min	N.A.	0-0.02	--	0-0.061	
	Upper Legs (inside clothing)	0-0.012	14-21 min	N.A.	0-0.048	--	0-0.155	
	Chest (inside clothing)	0-0.0006	14-21 min	N.A.	0-0.0024	--	0-0.008	
	Back (inside clothing)	0-0.0011	14-21 min	N.A.	0-0.0043	--	0-0.014	
	Forearms (outside clothing)	0.003-0.086	14-21 min	N.A.	0.013-0.344	--	0.05-0.984	
	Upper Legs (outside clothing)	0.004-0.36	14-21 min	N.A.	0.017-1.45	--	0.07-4.82	
	Chest (outside clothing)	0.0041-0.0176	14-21 min	N.A.	0.016-0.070	--	0.07-0.23	
	Back (outside clothing)	0.0011-0.060	14-21 min	N.A.	0.004-0.24	--	0.018-0.80	
	Exposures from 4 measurements during mixing and loading of concentrate. Workers wore long-sleeved shirts, long pants, waterproof hat, gloves, boots, and respirator. Exposure determined with pads made out of a top layer of cotton duck cloth and inner layers of gauze pinned to exterior of disposable coveralls. Hand exposure determined with the hand rinse technique. Exposure measured for mixing and loading operation of approximately 15 to 20 minutes.							
Carbaryl 40-48% Liquid Suspension or Concentrate		(mg/hr)						Maitlen et al., 1982
	Chest (outside)	<D.L.-0.29	0.13-0.40	N.A.	--	--	0.07-2.42	
	Back (outside)	<D.L.-0.71	0.13-0.40	N.A.	--	--	0.07-16.13	
	Shoulders (outside)	<D.L.-0.84	0.13-0.40	N.A.	--	--	0.07-3.23	
	Forearms (outside)	<D.L.-6.31	0.13-0.40	N.A.	--	--	0.07-13.04	
	Hands (without gloves)	0.47-68.95	0.13-0.40	N.A.	--	--	1.19-210.21	
	Hands (with gloves)	0.23-3.75	0.13-0.40	N.A.	--	--	0.70-11.43	
	Exposure from 2 experiments for 40% liquid with up to 10 replicates, and 2 experiments for 48% liquid with 1 test each (5-16 measurements). Exposure reported for total per body section, values are back calculated to show per unit area exposure using skin surface area of EPA, 1987a. Ranges of mixing time shown; total amount of formulation not reported. Hand exposure from rinse procedure, other exposure from pads.							

* Depending on the original data reported, ranges with the mean value in parenthesis; mean value ± standard deviation; or only the mean value (in parentheses) is presented

** Calculated by dividing percent formulation into the reported exposure and extended for the duration where appropriate; data not provided unless duration data is available or assumed

TABLE 4-6 DERMAL EXPOSURE DATA AND ESTIMATES FOR LIQUID MIXING OR TRANSFER OPERATION (Cont'd)

Chemical Formulation	Body Section or Location	Reported Exposure*	Exposure Duration (hr)	Quantity Handled (gallon)	Estimated Gross Dermal Deposition**	Estimated Gross Reposition by Quantity ($\mu g/cm^2$/gal)	Estimated Gross Deposition by Time ($\mu g/cm^2$/hr)	Reference
EPN (3-4 lbs/gal, 42%)		(mg/8-hr)			(mg)			Atallah, et al., 1982
	Face, V of neck, back of neck, forearms, and hands (unclothed regions)	8.3±4.3	1.67-2.83	N.A.	3.76	--	--	
	Total (on cloth and exposed skin)	66±52	1.67-2.83	N.A.	39.3	--	--	
	Total exposure of loaders reported for unclothed and clothed region of the body from denim patch samples extrapolated to 8-hr exposure from 3 tests. Loaders opened insecticide container transferred it to holding tank, mixed, then attached to a hose to transfer the mix to sprayer tank on planes. Hand exposure from hand rinse. 2 hr. exposure assumed.							
Dialiate 45% concentrate		($\mu g/cm^2$)			($\mu g/cm^2$)			Dubelman et al., 1982
	Head (open tank fill)	(0.15)	0.047	6	(0.33)	(0.067)	(7.0)	
	Forehead (open tank fill)	(0.67)	0.047	6	(1.49)	(0.30)	(31.7)	
	Shoulder (outer clothing, open tank fill)	(0.06)	0.047	6	(0.13)	(0.027)	(2.77)	
	Chest (outer clothing, open tank fill)	(0.19)	0.047	6	(0.42)	(0.084)	(8.94)	
	Back (outer clothing, open tank fill)	(0.07)	0.047	6	(0.16)	(0.031)	(3.40)	
	Hands (open tank fill)	(71.2)	0.047	6	(158)	(32)	(3362)	
	Head, forehead, shoulder, chest, or back (closed system tank fill)	(<0.005)	0.28	6	(<0.011)	(<0.002)	(<0.039)	
	Hands (closed system tank fill)	(<0.06)	0.28	6	<0.13)	(<0.027)	(<0 48)	
	Other body regions (closed system tank fill)	(0.005)-(0.013)	0.28	6	(0.01)-(0.03)	(0.002)-(0.006)	(0 008)-(0.10)	
	Open tank fill took 2.8 minutes, closed system transfer took approximately 17 minutes. Hand exposure determined from cotton gloves extraction. Other dermal exposure determined from gauze pads. Mean exposure from 6 replicates for open tank fill and 3 replicates each of 3 different systems for closed tank fill.							

* Depending on the original data reported, ranges with the mean value in parenthesis; mean value ± standard deviation; or only the mean value (in parentheses) is presented.
** Calculated by dividing percent formulation into the reported exposure and extended for the duration where appropriate; data not provided unless duration data is available or assumed.

TABLE 4-6 DERMAL EXPOSURE DATA AND ESTIMATES FOR LIQUID MIXING OR TRANSFER OPERATION (Cont'd)

Chemical Formulation	Body Section or Pad Location	Reported Exposure*	Exposure Duration (hr)	Quantity Handled (gallon)	Estimated Gross Dermal Deposition**	Estimated Gross Reposition by Quantity ($\mu g/cm^3/gal$)	Estimated Gross Deposition by Time ($\mu g/cm^3/hr$)	Reference
Esteron 99 (4 lbs/gal, 48% 2,4-D)		(mg/cm²)			($\mu g/cm^2$)			Lavy et al., 1982
	Right wrist (outside)	0.24-9.49 mg	13-78 min	90 gal	0.5-19.8	0.006-0.22	1.25-15.2	
	Left wrist (outside)	0.05-10.0 mg	13-78 min	90 gal	0.10-20.8	0.001-0.23	0.26-16.0	
	Neck (outside)	0.10-0.29 mg	13-78 min	90 gal	0.21-0.60	0.002-0.007	0.16-1.61	
	Head (outside)	0.47-24.8 mg	13-78 min	90 gal	0.98-51.7	0.011-0.57	2.45-163.2	
	Right wrist (under Tyvek)	0.21-4.72 mg	13-78 min	90 gal	0.44-9.83	0.005-0.11	2.02-31.05	
	Left wrist (under Tyvek)	0.05-9.28 mg	13-78 min	90 gal	0.10-19.33	0.001-0.21	0.48 44.4	
	Neck (under Tyvek)	0.05-0.10 mg	13-78 min	90 gal	0.10-0.21	0.001-0.002	0.15 0.96	
	Head (under Tyvek)	0.35-5.30 mg	13-78 min	90 gal	0.73-11.0	0.008-0.12	1.04-34.9	
	Exposure of 3 batchman-loader mixing and loading formulation with open tanks on 3 days, each lasting 13 to 78 minutes. Patch of outer clothing (denim) used as pads for exposure testing.							
4E Acaraben (4 lbs/gal 48%) chlorobenzilate		$\mu g/cm^2/hr$			$\mu g/cm^2$			Nigg and Stamper, 1983
	Back (outside clothing)	0.09 ± 0.02	N.A.	1.125	0.19 ± 0.04	0.17 ± 0.04	0.09 ± 0.02	
	Chest (outside clothing)	0.19 ± 0.05	N.A.	1.125	0.40 ± 0.10	0.35 ± 0.09	0.19 ± 0.05	
	Shoulders (outside clothing)	0.15 ± 0.04	N.A.	1.125	0.31 ± 0.08	0.28 ± 0.07	0.15 ± 0.09	
	Wrist (outside clothing)	0.45 ± 0.13	N.A.	1.125	0.94 ± 0.27	0.83 ± 0.24	0.45 ± 0.13	
	Shin (outside clothing)	0.66 ± 0.32	N.A.	1.125	1.38 ± 0.67	1.22 ± 0.59	0.66 ± 0.32	
	Hand (outside clothing)	1000 ± 300	N.A.	1.125	2080 ± 625	1850 ± 555	1000 ± 300	
	Forearms (outside clothing)	1.44 ± 0.61	N.A.	1.125	3.0 ± 1.27	2.67 ± 1.13	1.44 ± 0.61	
	Thigh (outside clothing)	4.05 ± 1.49	N.A.	1.125	8.44 ± 3.10	7.50 ± 2.76	4.05 ± 1.49	
	Forearms (inside clothing)	0.09 ± 0.03	N.A.	1.125	0.19 ± 0.06	0.17 ± 0.06	0.09 ± 0.03	
	Thighs (inside clothing)	0.03 ± 0.02	N.A.	1.125	0.06 ± 0.04	0.06 ± 0.04	0.03 ± 0.02	
	Exposure at outside clothing (except otherwise noted) of 18 replicates. For forearms and thigh samples, 12 replicates were made for outside patch samples, and 21 to 23 replicates for inside patch samples. Workers wore long sleeved shirts, long pants, wide-brimmed hats, leather shoes, and cloth-lines rubber gloves plus, a rubber apron. Hand exposure from glove wash. Duration not reported, assumed 1 hr. exposure for gross deposition calculation.							

* Depending on the original data reported, ranges with the mean value in parenthesis; mean value ± standard deviation; or only the mean value (in parentheses) is presented.

** Calculated by dividing percent formulation into the reported exposure and extended for the duration where appropriate; data not provided unless duration data is available or assumed

TABLE 4-6. DERMAL EXPOSURE DATA AND ESTIMATES FOR LIQUID MIXING OR TRANSFER OPERATION (Cont'd)

Chemical Formulation	Body Section or Pad Location	Reported Exposure*	Exposure Duration (hr)	Quantity Handled (gallon)	Estimated Gross Dermal Deposition**	Estimated Gross Reposition by Quantity ($\mu g/cm^2$/gal)	Estimated Gross Deposition by Time ($\mu g/cm^2$/hr)	Reference
Diquat 35.3% Concentrate		$\mu g/cm^2$/hr			($\mu g/cm^2$)			Wojeck et al., 1983
	Chest (outside clothing)	0±0	N.A.	N.A.	0	--	0±0	
	Back (outside clothing)	0±0	N.A.	N.A.	0	--	0±0	
	Shoulders (outside clothing)	0±0	N.A.	N.A.	0	--	0±0	
	Forearms (outside clothing)	0.03±0.03	N.A.	N.A.	0.08±0.09	--	0.09±0 09	
	Hands (on glove)	0.11±0.07	N.A.	N.A.	0.31±0.20	--	0.31±0.20	
	Shins (outside clothing)	0.06±0.04	N.A.	N.A.	0.17±0.11	--	0.17±0.11	
	Thighs (outside clothing)	0.02±0.02	N.A.	N.A.	0.06±0.06	--	0 06±0 06	
	Exposure during open mixing from 3 replications. The mixer wore normal work clothes and gloves. Pads attached outside the clothing. Hand exposure from cotton glove samples. Exposure duration not reported, 1 hr. assumed for gross dermal deposition.							
Molinate (Ordram 8E selective, 91% liquid)		(mg/day)			($\mu g/cm^2$)			Knarr et al., 1985
	Trunk (inside clothing)	0.22±0.22	N.A.	41	0.034±0.034	0.0008±0.0008	--	
	Arms (inside clothing)	6.0±16.0	N.A.	41	1.6±4.3	0.04±0.10	--	
	Legs (inside clothing)	1300±3100	N.A.	41	230.0±548	5.61±13.4	--	
	Head (unclothed)	0.007±0.006	N.A.	41	0.006±0.005	0.0002±0.0001	--	
	Face and neck (unclothed)	0.26±0.30	N.A.	41	0.36±0.41	0.009±0.01	--	
	Hands	0.45±0.35	N.A.	41	0.60±0.47	0.015±0.012	--	
	Trunk (outside clothing)	0.73±0.73	N.A.	41	0.11±0.11	0.003±0.003	--	
	Arms (outside clothing)	20.0±53.3	N.A.	41	5.33±14.2	0.13±0.35	--	
	Legs (outside clothing)	4333±10330	N.A.	41	768±1830	18.7±0.45	--	
	Exposure reported only for exposed skin areas and for inside the clothing. Reported inside exposure calculated by authors from outside pad data with a penetration factor of 0.3. Values shown here for outside clothing exposure are back calculated from inside clothing data. Results from 4 days of testing and reported as daily exposure. Exposure at legs were "extraordinary" on 3 of the days. (Without these high exposures, leg exposures would have been 1.4±1.2 mg/day inside the clothing.) Hand exposure from rinse. Mixer/loaders mix and load herbicides, refuel planes, and clean windshields.							

* Depending on the original data reported, ranges with the mean value in parenthesis; mean value ± standard deviation; or only the mean value (in parentheses) is presented.

** Calculated by dividing percent formulation into the reported exposure and extended for the duration where appropriate; data not provided unless duration data is available or assumed

TABLE 4-6 DERMAL EXPOSURE DATA AND ESTIMATES FOR LIQUID MIXING OR TRANSFER OPERATION (Cont'd)

Chemical Formulation	Body Section or Pad Location	Reported Exposure*	Exposure Duration (hr)	Quantity Handled (gallon)	Estimated Gross Dermal Deposition**	Estimated Gross Reposition by Quantity ($\mu g/cm^2/gal$)	Estimated Gross Deposition by Time ($\mu g/cm^2/hr$)	Reference
Cypermethrin (3 lbs/gal, 36%)		(μg)			($\mu g/cm^2$)			Chester et al., 1987
	Hood	2.21-60.3	0.5	4	0.005-1.29	0.0012-0.032	0.0094-0.26	
	Front trunk	3.99-674	0.5	4	0.003-0.53	0.0008-0.13	0.0062-1.05	
	Back trunk	5.07-274	0.5	4	0.004-0.21	0.001-0.05	0.008-0.43	
	Forearms	38.0-330	0.5	4	0.090-0.76	0.022-0.19	0.18-1.61	
	Upper arms	9.16-50	0.5	4	0.0087-0.048	0.0022-0.012	0.18-0.096	
	Thighs (above knee, under apron)	4.8-186	0.5	4	0.0035-0.136	0.0009-0.034	0.007-0.27	
	Lower legs (under apron)	6.9-42.2	0.5	4	0.008-0.049	0.002-0.012	0.016-0.099	
	Socks (inside boots)	8.1-75.5	0.5	4	0.017-0.16	0.004-0.04	0.012-0.32	
	gloves (under rubber gloves)	11.5-274	0.5	4	0.039-0.93	0.010-0.23	0.078-1.82	
	Exposure determined from sections of entire Tyvek suit. Workers also wore ankle-length aprons with full face shield, coated rubber gloves, and calf-length boots. Results are ranges of 6 trials of open top mixing and pumping from two mixer-loaders. Each mixing/loading took no more than 30 minutes. Exposures on body sections with left and right sides are combined in this table (e.g., left and right forearms). Gross dermal deposition calculated based on skin surface areas in EPA 1987a.							
Paraquat (21.1% concentrate)		(mg/hr)			($\mu g/cm^2$)			Chester and Ward, 1984
	Forearms (outside clothing)	(7.16)	N.A.	N.A.	28.0	--	28.0	
	Thighs (outside clothing)	(4.23)	N.A.	N.A.	5.25	--	5.25	
	Head (exposed)	(<D.L.)	N.A.	N.A.	--	--	<0.004	
	V of neck (exposed)	(0.035)	N.A.	N.A.	1.1	--	1.1	
	Back of neck (exposed)	(0.005)	N.A.	N.A.	0.22	--	0.22	
	Trunk (inside clothing)	(0.095)	N.A.	N.A.	0.013	--	0.03	
	Legs (inside clothing)	(0.055)	N.A.	N.A.	0.009	--	0.009	
	Filter pads attached to skin or outer clothing for dermal sampling. Average total hourly exposure reported for body sections from 1 mixer-loader in 2 trials. A closed transfer system was used during mixing and loading. 1 hr. exposure assumed, gross dermal deposition calculated using skin surface areas of EPA, 1987a.							

* Depending on the original data reported, ranges with the mean value in parenthesis; mean value ± standard deviation, or only the mean value (in parentheses) is presented

** Calculated by dividing percent formulation into the reported exposure and extended for the duration where appropriate; data not provided unless duration data is available or assumed

TABLE 4-6 DERMAL EXPOSURE DATA AND ESTIMATES FOR LIQUID MIXING OR TRANSFER OPERATION (Cont'd)

Chemical Formulation	Body Section or Pad Location	Reported Exposure*	Exposure Duration (hr)	Quantity Handled (gallon)	Estimated Gross Dermal Deposition**	Estimated Gross Reposition by Quantity ($\mu g/cm^2$/gal)	Estimated Gross Deposition by Time ($\mu g/cm^2$/hr)	Reference
Alachlor in 96% concentrate		(μg)			($\mu g/cm^2$)			Cowell et al., 1987
	Forehead and face with EC formulate	0-5.33	0.17	10	0-0.0085	0-0.0009	0-0.051	
	Chest (outer clothing), neck and v of neck	0-2.37	0.17	10	0-0.0166	0-0.0016	0-0 099	
	w/EC Chest (inside clothing), with EC	0	0.17	10	0	0	0	
	Back (outer clothing), with EC	0-0.9	0.17	10	0-0.0085	0-0.0009	0-0.051	
	Forehead and face with MT	0-7.8	0.17	10	0-0.813	0-0.0013	0-0.075	
	Chest (outer clothing), with MT	0-48.6	0.17	10	0-0.34	0-0.034	0-2.03	
	Chest (inside clothing), with MT	0	0,17	10	0	0	0	
	Mean exposure at back, outer clothing, with MT	0-1.47	0.17	10	0-0.014	0-0.0014	0-0.084	
	Dermal exposure determined with multi-layered gauze pads, with 1 pad on chest under clothing. Liquid transferred with an enclosed pumping system; each transfer took 5-10 minutes. EC = Emulsified Concentrate. MT = Micro-encapsulated. Workers wore work clothes plus an unspecified protective clothing. Hand exposure or hand protection not discussed. EC tank fill has 4 replicates, MT tank fill has 8 replicates. Exposure at chest under clothing reported as "0".							
DEF 70.6% Concentrate		($\mu g/cm^2$)			($\mu g/cm^2$)			Kilgore et al., 1984
	Chest	0.027-0.131	1-7 hr	N.A.	0.014-0.186	--	0.014-0.186	
	Back	0.014-0.051	1-7 hr	N.A.	0.004-0.072	--	0 004-0.072	
	Flannel patch on outside clothing as pad. Average exposure from 3 days of testing on one mixer-loader with closed system mixing and loading. Data show large variations on hourly flux. 1 hr. exposure assumed for gross dermal deposition.							

* Depending on the original data reported, ranges with the mean value in parenthesis; mean value ± standard deviation; or only the mean value (in parentheses) is presented

** Calculated by dividing percent formulation into the reported exposure and extended for the duration where appropriate; data not provided unless duration data is available or assumed

FIGURE 4-2 ESTIMATED GROSS DERMAL DEPOSITION DURING MIXING AND TRANSFER OF LIQUIDS

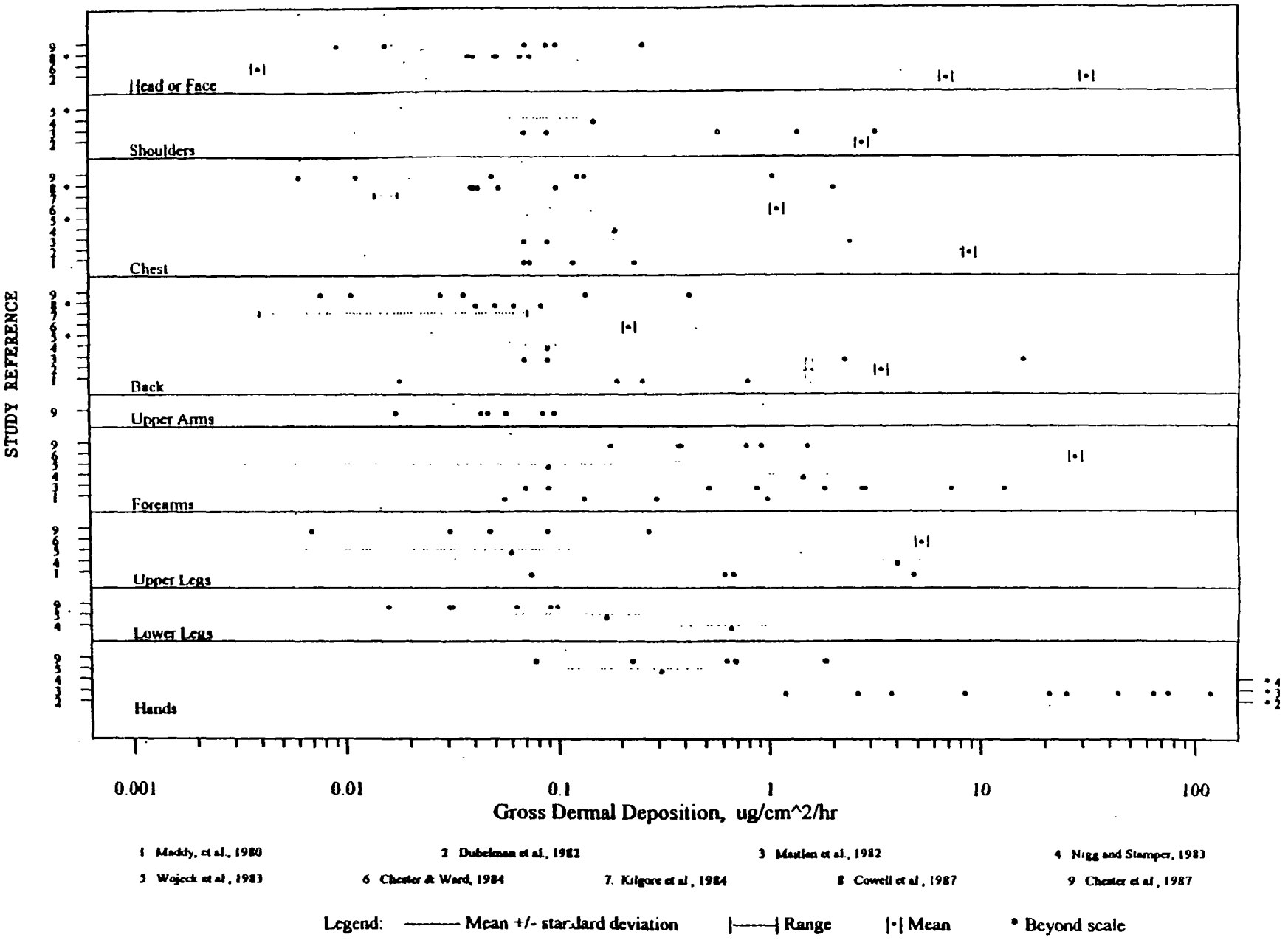

TABLE 4-7
INDICATIVE 90TH PERCENTILE ESTIMATED GROSS DERMAL DEPOSITION
FOR LIQUID MIXING OPERATION

	Indicative 90th Percentile Deposition*	
	Time Normalized $\mu g/cm^2/hr$	Quantity Normalized $\mu g/cm^2/lb$
Head or Face	0.1 (0.07)	0.4
Shoulders	3.0	0.3
Upper Arms	0.1	0.01
Chest	8 (1)	0.4
Back	3 (0.2)	0.2
Forearms	10	4
Upper Legs	5	10
Lower Legs	1	2
Hands	200	100

* Data are for open mixing or transfer except those in parentheses. Data in parentheses pertained to closed pumping operation; not available for all body sections.

Determined from data in Table 4-6 and Figure 4-2 as the value exceeded only by approximately 10% of the data points reported for each body section; number of data points varies between body sections and between normalizing factors.

F. Intermittent Contact

Intermittent contact refers to skin exposure due to splashes or direct contact with contaminated equipment or surfaces. Such contact may result from wiping hands with contaminated rags, wearing contaminated gloves, or handling contaminated tools. There are very few studies that provide actual dermal exposure data from such contact. One report by EPA (EPA, 1987c) presents the results of a study on inhalation exposure and dermal contact to acrylamide during chemical grouting operations in sewer line and manhole leak repairs. Dermal exposures were estimated using absorption pads and hand washes. The study indicates that exposures were caused by contacts with contaminated equipment or from runoff and splashes. A summary of the data is presented in Table 4-8.

A similar study by Cummins et al. (1992) also found that contacts with contaminated work surfaces, equipment, and tools were the major source of dermal exposure. Exposure at the hands constituted the major portion of exposure. Because of pre-existing contamination in the gloves, acrylamide loadings at the hands determined from hand rinse often showed only a slight increase between the post- and pre-shift (shortly after start of work) samples. In three of the four paired tests conducted, the pre-and post-shift samples showed total hand contamination changing from 30, 17, 86 μg to 36, 20, and 90 μg, respectively; the other pair tested actually had a lower post-shift loading. Surface contamination at three sites at the top of the acrylamide mixing tank was found to be 6.2, 834, and 1348 μg per 100 cm^2 of wiped area.

A study by Maroni et al. (1981) reported dermal exposure to polychlorinated biphenyls (PCB) in plants where PCB-containing dielectric fluid was used to fill capacitors. Dermal contact with PCB was believed to occur during the assembling, handling, and testing of capacitors. The study only reported the amount of PCB retained on worker's palms, which ranged from 2 to 28 μg/cm^2 on 6 subjects. PCB contamination on workroom surfaces and tools ranged from 0.20 to 6.17 μg/cm^2 except for the surface of a capacitor basket rolling carrier that showed a surface contamination of 159 μg/cm^2. Lees et al. (1987) investigated worker exposure to PCB during transformer maintenance and repair operations. In addition to air samples, surface wipe and skin wipe samples were collected to asses the potential of dermal exposures. Geometric mean surface contamination was found to be 1.075 μg/cm^2 at the work area, 0.007 μg/cm^2 at an area contiguous to the work area, 0.078 μg/cm^2 on tools and equipment, 0.006 μg/cm^2 on a vehicle steering wheel, 0.018 μg/cm^2 on personal protective equipment, and 0.922 μg/cm^2 per cigarette butt, and 0.008 μg/cm^2 at worker's skin (presumably the hands).

TABLE 4-8 DERMAL EXPOSURE DATA AND ESTIMATES FOR INTERMITTENT CONTACT*

Chemical Formulation	Reported Exposure ($\mu g/cm^2$)	Estimated Gross Dermal Deposition ($\mu g/cm^2$)	Estimated Gross Deposition by Quantity ($\mu g/cm^2/gal$)	Estimated Gross Deposition by Time ($\mu g/cm^2/hr$)	Reported Exposure ($\mu g/cm^2$)	Estimated Gross Dermal Deposition ($\mu g/cm^2$)	Estimated Gross Deposition by Quantity ($\mu g/cm^2/gal$)	Estimated Gross Deposition by Time ($\mu g/cm^2/hr$)	Comments	Reference
	Shoulder				Back					
Acrylamide 9.1%	4.4	48.4	0.74	16.7	0.545	5.99	0.092	2.07	(1)	EPA, 1987c
	0.668	7.34	0.061	2.46	0.25	2.74	0.023	0.91	(2)	
	1.205	13.2	0.22	1.42	0.81	8.90	0.15	0.96	(3)	
	0.79	8.68	0.14	0.93	0.67	7.36	0.12	0.79	(4)	
	0.09	0.99	0.10	0.12	0.08	0.88	0.88	0.11	(5)	
	Chest				Forearms					
Acrylamide 9.1%	33.75	371	5.7	128	0.965	10.6	0.16	3.66	(1)	
	0.10	1.10	0.0092	0.38	5.45	59.9	0.50	20.0	(2)	
	1.23	13.5	0.23	1.45	6.3	69.2	69.2	7.44	(3)	
	0.99	10.8	0.18	1.16	0.43	4.73	4.73	0.51	(4)	
	0.06	0.66	0.066	0.08	0.22	2.42	2.42	0.30	(5)	
	Hands				Thighs					
Acrylamide 9.1%	14.8	163	2.50	22.0					(1)	
	0.54	5.93	0.05	0.77					(2)	
	9.02	99.1	1.65	9.72					(3)	
	5.53	60.8	1.10	5.96					(4)	
	0.60	6.59	0.66	0.80	0.56	6.15	0.62	1.12	(5)	

*Dermal exposure in EPA (1987c) determined for workers involved in grouting repairs of sewer lines and manholes. Exposure determined from pads made out of Whitman chromatographic paper. Hand exposure determined from the hand rinse technique. Hand exposure calculated from total measured amount assuming hand surface area of 820cm^2.

TABLE 4-8 DERMAL EXPOSURE DATA AND ESTIMATES FOR INTERMITTENT CONTACT* (Cont'd)

(1) Mean exposure of maintenance supervisor who performed the grouting operations in a manhole. Tyvek coveralls, hard hat, gloves, boots, and respirator were worn. 60 to 65 gallons of compounds handled, hand rinse at 7.4 hrs, other pads exposed 2.9 hrs.

(2) Mean exposure of utility worker who performed the grouting operation in the manhole. Tyvek coveralls, hard hat, gloves, boots and respirator were worn. 120 gallons of compounds handled, hand rinse at 7.7 hrs, other pads exposed 3.0 hrs.

(3) Mean exposure of grouting foreman who mixed the chemical, assembled the equipment, and operated the equipment remotely for mainline maintenance operations. 60 gallons of compounds used, hand rinse at 10.2 hrs, other pads exposed 9.3 hrs.

(4) Mean exposure of grouting laborer who assisted the grouting foreman in (3). Both the foreman and laborer wore Tyvek coveralls, hard hats, boots, and gloves. 60 gallons of compounds used, hand rinse at 10.2 hrs, other pads exposed 9.3 hrs.

(5) Mean exposure of utility worker who mixed the chemical, assembled, and installed the equipment for lateral line maintenance operation. Only street clothes were worn. 5-10 gallons of compounds used, hand rinse at 8.2 hrs, other pads exposed 8.2 hrs.

Groth (1992) studied dermal exposure to 4,4'-methylene dianiline (MDA) in aircraft maintenance operations through wipe sampling of equipment and work surfaces, air sampling, and urinalysis. The author found that removable MDA was present at <0.004 to 1.0 $\mu g/cm^2$ on all products including those considered cured. However, the measured surface contamination did not provide a viable indicator of the magnitude of absorbed dose from handling MDA-contaminated materials. The author believed a more aggressive sampling approach will be needed to yield useful data to adequately estimate potential dermal exposure hazard.

Clapp et al. (1991) assessed various environmental exposure measurements (air samples, surface wipes, and skin pads) to study worker exposure (urine samples) to 4,4'-methylene bis(2-chloroaniline) (MBOCA) in a cast polyurethane production operation. Gauze pads at palms and the back of the latex gloves worn by workers showed average total MBOCA of 4.7 to 24.6 μg/pair of pads on mixers and 3.0 to 7.3 μg/pair of pads on molders and 2.3 μg/pair of pads on a trimmer. Surface wipe samples showed average contamination levels of 0.01 to 19.1 $\mu g/100\ cm^2$ depending on the surface sampled. The authors concluded that most exposure occurs through direct contact and that even relatively low surface contamination can lead to elevated urinary MBOCA levels.

Van Rooij et al. (1993) conducted a quantitative assessment of both skin contamination and respiratory intake of polycyclic aromatic hydrocarbons (PAHs) in coke oven workers. Based on skin pad samples on 12 workers over five consecutive 8-hour work shifts, average concentrations of pyrene (as a marker compound) on pads were 6.5 $\mu g/cm^2$ at jaw/neck, 1.9 $\mu g/cm^2$ at shoulders, 1.8 $\mu g/cm^2$ at upper arms, 6.4 $\mu g/cm^2$ at wrist, 2.1 $\mu g/cm^2$ at groin, and 2.0 $\mu g/cm^2$ at ankle. Based on these data and PAH absorption rate constants, the authors concluded that 28 to 95% (average 75%) of the total absorbed amount of pyrene enters the body through the skin. In another study related to exposures to PAHs, Jongeneelen et al. (1988) reported on the exposure of paving workers who are exposed to coal tar derived road tars. Contamination of the skin may result from deposition of airborne solid and liquid particles and from direct contact with contaminated surfaces. The end-of-shift hand washing showed a geometric mean total hand exposure of 70 μg (pyrene) from 35 samples. Skin pad samples showed the wrist to have the highest exposure with a geometric mean contamination level (pyrene) of 12.4 $\mu g/cm^2$ from 40 samples. Significant correlations were found between the wrist pad or the hand wash data and the end-of-shift urinary metabolite (1-hydroxypyrene).

Dermal exposures at the hands and forearms to calcium carbonate during filter press and tray drying operations were reported in a pilot plant study by EPA (1992d) that developed

data on inhalation exposure, dermal exposure, and chemical releases for use by PMN reviewers. Dermal exposures were determined by rinsing both hands and forearms of the operator. The measured amount of chemicals from the rinse solution were divided by the total surface area of 2600 cm^2 to determine unit area deposition. The test results indicate a range of 0.039 to 0.60 mg/cm^2 during filter cake removal, 0.0076 to 0.063 mg/cm^2 during tray loading, and 0.0048 to 0.067 mg/cm^2 during tray unloading.

A study (Anonymous, 1996) submitted to EPA recently by a manufacturer for PMN review has included some dermal exposure data on trichloroketone (TCK). For the study, five process operators and six maintenance mechanics were chosen. The study was conducted for a full shift ranging from 6 - 12 hours over one work day. The workers were required to wear full-body cotton underwear and cotton gloves underneath their regular work clothes and nitrile gloves. Workers were also required to change the nitrile gloves every two hours, as required by EPA. Glove permeation data for the TCK had previously been submitted and approved by the Agency. Both cotton and nitrile gloves worn by workers were collected and packaged daily. At the end of the work day, square sections of both coveralls and inner full-body underwear were cut and prepared as samples to represent exposure at various body regions. These samples were packaged and sent to a laboratory.

The study reported two types of dermal exposures, unprotected and protected. The unprotected exposure was determined by analyzing TCK found on outer clothing, namely coveralls and nitrile gloves. The protected exposure was determined by measuring TCK found on inner clothing and cotton gloves. The concentration of TCK found on a unit area of a sample was then multiplied by the surface area corresponding to the body region to yield the exposure levels for a given region. This follows the procedure used by EPA's Office of Pesticide Programs (OPP) for assessing exposure to various regions of the body. For the head region, where sampling was not possible, 70% of the area was assumed to be unprotected. This assumption was based on the fact that hard hats and safety glasses were worn by all workers. For the samples with non-detect or below the level of quantification (LOQ), one-half of the LOQ was assumed to be present for the corresponding body region. The total worker exposure is determined by summing the exposures for each body region and correcting with the percent field recovery. Field fortified samples were used to estimate the percent field recovery. The results of study are summarized in Table 4-9.

TABLE 4-9 DERMAL EXPOSURE TO WORKERS IN TCK MANUFACTURING PLANT

		Hand (mg/day)	Other Parts of the Body (mg/day)	Total (mg/day)	Average (mg/day)
Process Operator	Protected	0.0032-0.0074	0.0073-0.0263	0.0105-0.0337	0.0152
	Unprotected	0.0027-2.422	0.0044-0.035	0.0071-2.457	0.5043
Maintenance Mechanics	Protected	0.0024-0.200	0.0074-0.0413	0.0098-0.2417	0.0801
	Unprotected	0.0009-505.2	0.0073-0.267	0.0081-505.4	163.5

The study results show that the exposures for protected workers range from 0.0105 mg/day to 0.0337 mg/day for process operators and 0.0098 to 0.2417 mg/day for the maintenance mechanics. The unprotected workers' levels range from 0.0071 mg/day to 2.457 mg/day for process operators and 0.0081 to 505.4 mg/day for maintenance mechanics. The results of the study show that the dermal exposure varies widely with the worker activities and worker habits. The range of variability for a given activity can be quite broad between workers. In the case of maintenance mechanics, the range of variability for unprotected exposures to the hands is six order of magnitude. In general, maintenance mechanics in this study were found to be potentially exposed at a higher level than the process operators. For both maintenance workers and process operators, the hands were found to be the major routes of dermal exposures except for the process operators wearing protective equipment. The protective equipment used in this study greatly reduced exposures to TCK, especially at higher levels of exposure.

Dermal exposure data reported for incidental contacts as reviewed above are all reported in terms of the chemical of interest. Only one report provided the concentration data; calculations of gross dermal deposition for generic application are impossible. No attempt is made here to further interpret these data except to note that dermal exposure varies widely and hand exposure tends to be the major contribution to total exposure. One recent study by Popendorf et al. (1995) did report the exposure only in terms of the formulated product (antimicrobial pesticide) during pouring or placing of both the solid and liquid formulations. However, only the combined total dose from inhalation and dermal exposure (from under the clothing and on bare skin) were provided in the report. No data were provided on dermal deposition at various parts of the body. More details were available on hand exposure data. The investigators reported that during pouring and pumping of liquid, non-gloved hands had geometric mean total exposure of 118 mg with a geometric standard deviation of 6.8, while the geometric mean had

exposure during pouring of solid was 250 mg with a geometric standard deviation of 3.1. These hand exposure data are equivalent to an estimated gross dermal deposition of 0.98 mg/cm^2 for liquid and 0.95 mg/cm^2 for solid at one standard deviation away from the geometric mean assuming hand surface area of 820 cm^2.

V. DERMAL EXPOSURE DATA FROM PHED

A. OVERVIEW

The Pesticide Handlers Exposure Database (PHED), developed under contract to EPA's Office of Pesticide Programs, is a generic database containing measured inhalation and dermal exposure data for workers involved in the handling or application of pesticides in the field. The database is designed to allow prediction of pesticide exposure during mixing/loading, application, and flagging operations, based on any selected combination of formulation type, mixing/loading procedure, application equipment/procedure, clothing scenario, or other parameters that may be relevant to exposure. It contains exposure data generated by the EPA and pesticide registrants. In submitting the data, each registrant is required to develop the information following EPA guidelines and use the standard Exposure Survey Forms for recordkeeping.

PHED also provides for certain statistical analysis of the data. For instance, mean exposure, geometric mean exposure, or quantile distribution from the pad or pads for a body section under a particular operating parameter (e.g., outdoor open mixing with an emulsifiable concentrate) with certain data quality requirements can be easily obtained through proper subsetting of the data parameters. Total body dermal exposure (i.e., sum of the products of sampling pad deposition multiplied by the corresponding body section surface area) under specific operating parameters with specific clothing scenarios can also be obtained through the PHED's internal statistical analysis routines.

As a database, PHED possesses certain uniformity in data definition and QA/QC objectives. The dermal exposure data within PHED thus represent a separate yet statistically more valid database than individual studies for evaluating exposure variables in estimating occupational related dermal exposure. The data quality required in PHED is such that most standard statistical analyses can be performed and are available directly through PHED's software. Therefore, all data derived from PHED are presented in this chapter separate from the data from various published reports.

PHED V1.1 (March 1995) currently contains data on measured exposure and on parameters that may determine or affect the magnitude of exposures for over 1700 records, each record being defined as one replicate of data representing a single worker involved in 1 day or less of a given activity. Each record may include either respiratory exposure data or dermal exposure data, or both. PHED is separated into four files: Mixer/Loader,

Applicator, Flagger, and Mixer/Loader/Applicator. Only the dermal data in Mixer/Loader file were analyzed for inclusion in this report.

B. DATA ANALYSIS PROCEDURES

1. Exposure Variables

Several important variables must be considered in analyzing any set of pesticide dermal exposure data. In evaluating the published studies in the previous chapter, the following factors were included for consideration:

- Pesticide active ingredient
- Formulation type and concentration
- Mixing and/or other work procedures
- Quantity of pesticide or active ingredient handled
- Duration of test
- Sampling pad location
- Exposure assessment method
- Clothing scenario (protective or other clothing worn).

These factors have also been considered for PHED data input. In addition, a data quality factor is available for consideration. PHED grades the reported exposure by its quality in terms of laboratory and field recovery data. So a user of the database can choose only the data that meet certain quality criteria (e.g., only analyzing those data graded as A or B). To obtain deposition data under specific operating and control conditions, one needs only to define a subset of data meeting the selection criteria, the PHED will then generate the desired normalized exposure data through its own statistical routines. PHED also will allow data extraction for a specific body section or for total deposition over the entire body under various clothing scenarios.

2. Data Normalization and Correlation

Dermal exposure sampling pad data in PHED are reported in terms of $\mu g/cm^2$ for non-hand body sections and in terms of μg for the hands, where available. As with other pesticide studies, exposures are reported only for the active ingredient. Furthermore, exposure data in PHED can be extracted in a

normalized format, by quantity of AI handled, sampling time, or AI handling rate with the data reported as $\mu g/cm^2/lb.AI$, $\mu g/cm^2/hr$, or $\mu g/cm^2/lb.AI/hr$, respectively.

Normalized data are essential for comparing exposures between different tests and may be useful in extrapolating exposure if a linear relationship exists between the exposure and the normalizing variable. This aspect was further examined using PHED's statistical package. For this analysis, correlation coefficients between the exposure in $\mu g/cm^2$ and either the total quantity of AI handled in lbs. or the sampling time in hours were determined. The Spearman's Rank Correlation and Pearson's Correlation coefficients were also determined using the PHED statistical routines. The results reveal that:

- Dermal exposure at various body sections is only slightly related to either the total quantity of AI handled or the total test time. Only about one third of the potentially available data sets were found to show a significant correlation at the 95% level. (A data set here means a set of exposure data at a body section and the corresponding data for an independent variable. For example, exposure data are available for 9 non-hand body sections under the open mixing and loading of powders packaged in bags. Testing the correlation of this exposure data to the total lbs.AI applied would involve 9 sets of analysis and in this case 5 sets were found to be significantly correlated.)

- The number of data sets found to have significant correlation are about the same for either the lb.AI or duration variable. In other words, there is no advantage of choosing one over the other variable to predict exposure.

- Very high correlation coefficients are found only between the hand exposure and either the total lbs. AI mixed or the total hours of exposure from one operation matrix: mixing and loading of wettable powder.

- Exposure at the hands may be significantly related to the exposure at certain body sections (e.g., forearms, thighs, and chest) but no consistent pattern is observed among all formulation type/mixing method matrices.

- No consistent patterns are seen from the Spearman's Rank Correlation or the Pearson's Correlation coefficients, implying that exposure at a specific body

section may increase or decrease with increases in an independent variable (lb. AI or hour).

3. Data Conversion, Data Quality, and Detection Limit

As the exposure data in PHED are reported for the AI only, a conversion is needed to be able to interpret the exposure in terms of estimated gross dermal deposition (i.e., the estimated total mass of formulated product or mixed solution that is retained in the sampling pad) as was done in Chapter IV. This conversion calls for the reported exposure to be divided by the weight concentration of the formulation. For a solid type formulation, the quantity (lb.AI) normalized data from PHED can be used directly to represent gross deposition normalized by the amount of formulated product. This is because when converting the lb.AI normalized data to lb. formulated product normalized data, both the numerator (exposure) and denominator (quantity of AI) would be divided by the same constant, the weight concentration of the formulation. For a liquid formulation, a convenient normalization parameter is the volume (gallons) as has been used in Chapter IV. Therefore, in the data analyses for liquid type formulations, the PHED normalized data must be multiplied by a factor of 8.34, (assuming the formulation weighs the same as water which would be 8.34 lbs per gallon).

In terms of data quality, only those graded as A, B, or C in PHED are included. At the lowest grade used, C, laboratory recovery rate should fall between 70 and 120% with a coefficient of variation of no less than 33%, field recovery should be 30-120%, and the storage stability should be 50-120%. As required under the PHED sampling protocol, dermal sampling pads are located at the head, neck front, neck back, chest, back, shoulder, upper arms, forearms, thigh, skin, calf, and ankle. Hand exposures are evaluated with the hand rinse technique. For the data extracted for this report, the average exposure is used if more than one pad is used at a body section. Where available, exposures outside the clothing and inside the clothing are extracted and processed separately. It should be noted that not every pesticide registrant reported dermal exposure data at all sections of the body.

In performing the statistical calculation, PHED uses one half of the detection limit for those samples that contain non-detectable quantity of the AI being analyzed. Also, the smallest value reported in PHED's statistical analysis is 0.0001 $\mu g/cm^2$ per pound of AI, this value is used in this report, where it occurs.

C. GROSS DERMAL DEPOSITION NORMALIZED BY QUANTITY OF CHEMICALS FOR MIXING AND LOADING OPERATIONS

Of the over 1700 PHED records, 556 records have dermal exposure data under the Mixer/Loader file. Subsets of this data file were developed to extract dermal exposure data under various parameters including formulation type, mixing method, packaging type, data grade, sampling pad location, and clothing scenario. Within PHED, liquid formulation is classified into five types and solid formulation is classified into 4 types. Mixing methods are classified into 3 types. A matrix of the potential combination of formulation and mixing method is shown in Table 5-1 to show which combinations contain relevant data in PHED. Packaging type may have an effect on dermal exposure as it will dictate the manual actions needed to open the package and mix the contents with a diluent. Examining the data for all formulation types, it appears that only the package type for wettable powder will have a significant effect. The packaging used in other forms of formulation tends to be of a single type (either bags or bottles) or the difference in packaging type will have little effect on dermal exposure, e.g., potential for dermal exposure should be very similar between opening a can or a bottle and pouring the contents into a mixing tank. Thus, only the data matrix for wettable powder is further divided by packaging type into the bag and soluble packet files.

Normalized dermal exposure data at various body sections under each formulation/mixing method matrix can be processed within PHED's statistical package to show sample size, arithmetic mean, standard deviation, median, geometric mean, exposure values at 10th, 25th, 75th, and 90th percentile distribution, and the data's variability including minimum, maximum, range, and 95% confidence intervals. An excerpt of such data, including arithmetic mean, standard deviation, geometric mean, and median values, expressed as gross dermal deposition normalized by the quantity of chemical handled is presented in Appendix A. The type of statistical distribution of the data under each matrix as determined in PHED is also indicated in the Appendix. For this report, estimated gross dermal deposition at mean value and 90th percentile distribution are used.

As described under Section B.2, the lb.AI normalized exposure data in PHED for solid formulation is such that the data can be used directly to represent gross deposition in terms of μg of formulated product. For a liquid type formulation the PHED data is multiplied by a constant of 8.34 to derive a gross deposition in terms of μg of formulated product per gallon of liquid product used. The derived or converted data on gross dermal deposition in terms of formulated product for both outside and inside the clothing exposure are presented in Tables 5-2

through 5-9 under various combinations of formulation/packaging types and mixing methods.

The quantity normalized gross dermal deposition as presented here may be used to estimate total exposure if the amount of chemical handled and operation scenario are known. However, careful interpretation of the results is needed since deposition is not necessarily linear to quantity and there is likely to be a maximum loading under any situation. Such aspects are further explored in Chapter VI where estimating for daily exposure is discussed. The data are probably more useful in interpreting the relative distribution of deposition at various body sections under various operating scenarios. It should also be noted that due to the extremely wide variations of certain data sets (those with large standard deviations), the mean value can exceed the 90 percentile value. In such cases, the estimated median values are also provided for comparison.

TABLE 5-1
A MATRIX OF FORMULATION TYPE AND MIXING METHOD AS CLASSIFIED IN PHED

Liquid Code	Mixing Method		
	1	2	3
1	✓	✓	
2	✓		
3	✓*		
4	✓		
5			
Solid Code	**Mixing Method**		
	1	2	3
1B and 1P	✓		
2	✓		
3			
4	✓		

✓ where relevant data are available from PHED.
* Only has two data points for the body section measured; excluded from this analysis.

Notes: Liquid Codes
1 = Emulsifiable concentrate
2 = Aqueous suspension
3 = Microencapsulated
4 = Solution
5 = Undiluted liquid

Solid Codes
1B = Wettable powder in bags
1P = Wettable powder in soluble packets
2 = Dry-flowable
3 = Dust
4 = Granule

Mixing Method Codes
1 = Open
2 = Closed, mechanical pump
3 = Closed, gravity feed

TABLE 5-2
Estimated Gross Dermal Deposition Normalized by Quantity of Chemical Handled ($\mu g/cm^2/gal$) from PHED for Emulsifiable Concentrate (Liquid Code 1) with Open Mixing (Mixing Code 1)

Body Section	Number of Measurements	Estimated Mean Deposition*	Estimated 90th Percentile Deposition
OUTSIDE CLOTHING			
head	77	0.0817	0.2152
neck front	23	0.0717	0.1476
neck back	13	0.0859/0.0300	0.0809
shoulder	81	0.0359	0.1076
upper arms	15	0.0867	0.1785
chest	80	0.0767	0.1501
back	93	0.0267	0.1076
forearms	109	0.8298/0.0342	0.7890
thigh	64	7.8529/0.0400	1.3261
shin	14	0.5129/0.0050	0.0217
calf	22	0.4445	0.9491
ankle	43	1.7005/0.0467	0.4145
hands	24	141.09	471.7
INSIDE PERSONAL CLOTHING			
head	6	0.0008	0.0017
neck front	0		
neck back	0		
shoulder	28	0.0025	0.0050
upper arms	15	2.5837/0.0008	0.0033
chest	96	0.0409	0.1076
back	82	0.0225	0.1076
forearms	64	0.0459	0.1076
thigh	40	0.0567	0.1776
shin	0		
calf	22	0.0050	0.0050
ankle	32	0.3244/0.0017	0.0317
hands	45	0.7481	2.149

* Except in data sets with large variations where both the estimated mean (the first value shown) and the median (the second value shown) depositions are presented.

TABLE 5-3
Estimated Gross Dermal Deposition Normalized by Quantity of Chemical Handled ($\mu g/cm^2/gal$) from PHED for Emulsifiable Concentrate (Liquid Code 1) with Closed Mixing (Mixing Code 2)

Body Section	Number of Measurements	Estimated Mean Deposition*	Estimated 90th Percentile Deposition
OUTSIDE CLOTHING			
head	20	0.0117	0.0392
neck front	0		
neck back	0		
shoulder	4	0.0025	0.0058
upper arms	13	0.0067	0.0092
chest	20	0.0275	0.0542
back	20	0.0150	0.0417
forearms	14	0.1735	0.2043
thigh	14	0.3987	0.8473
shin	8	0.0350	0.1009
calf	0		
ankle	5	0.0142	0.0325
hands	0		
INSIDE PERSONAL CLOTHING			
head	0		
neck front	0		
neck back	0		
shoulder	0		
upper arms	19	0.0025	0.0042
chest	14	0.0017	0.0042
back	14	0.0017	0.0042
forearms	19	0.0017	0.0042
thigh	14	0.4262/0.0033	0.0042
shin	8	0.0033	0.0042
calf	0		
ankle	11	0.0017	0.0033
hands	15	0.0156	0.0360

* Except in data sets with large variations where both the estimated mean (the first value shown) and the median (the second value shown) depositions are presented.

TABLE 5-4
Estimated Gross Dermal Deposition Normalized by Quantity of Chemical Handled ($\mu g/cm^2/gal$) from PHED for Aqueous Suspension (Liquid Code 2) with Open Mixing (Mixing Code 1)

Body Section	Number of Measurements	Estimated Mean Deposition*	Estimated 90th Percentile Deposition
OUTSIDE CLOTHING			
head	15	0.1668/0.0100	0.0584
neck front	0		
neck back	0		
shoulder	16	0.0292	0.0325
upper arms	6	0.0083	0.0142
chest	16	0.5980/0.0040	0.2919
back	16	0.0200	0.0442
forearms	6	0.0934	0.1776
thigh	16	0.4971	1.1067
shin	10	5.1433	5.6337
calf	0		
ankle	6	0.0809	0.1993
hands	16	10.685	33.42
INSIDE PERSONAL CLOTHING			
head	0		
neck front	0		
neck back	0		
shoulder	0		
upper arms	0		
chest	6	0.0058	0.0100
back	6	0.0025	0.0334
forearms	6	0.0075	0.0142
thigh	0		
shin	6	0.0083	0.0158
calf	0		
ankle	6	0.0042	0.0067
hands	6	1.0821	1.8835

* Except in data sets with large variations where both the estimated mean (the first value shown) and the median (the second value shown) depositions are presented.

TABLE 5-5
Estimated Gross Dermal Deposition Normalized by Quantity of Chemical Handled (µg/cm²/gal) from PHED for Solution (Liquid Code 4) with Open Mixing (Mixing Code 1)

Body Section	Number of Measurements	Estimated Mean Deposition*	Estimated 90th Percentile Deposition
OUTSIDE CLOTHING			
head	23	0.0267	0.0742
neck front	0		
neck back	0		
shoulder	16	0.0334	0.0626
upper arms	16	0.0067	0.0100
chest	23	0.0734	0.2519
back	23	0.0467	0.0384
forearms	23	0.0692	0.1351
thigh	23	0.2769	0.2093
shin	0		
calf	7	0.0058	0.0125
ankle	16	4.3643	14.04
hands	6	0.1665	0.3005
INSIDE PERSONAL CLOTHING			
head	4	0.0350	0.0434
neck front	0		
neck back	0		
shoulder	13	0.0158	0.0292
upper arms	16	0.0067	0.0100
chest	20	0.0133	0.0267
back	19	0.0267	0.0150
forearms	14	0.0175	0.0359
thigh	20	0.0108	0.0292
shin	0		
calf	7	0.0008	0.0008
ankle	13	0.0158	0.0292
hands	14	0.0558	0.1174

* Except in data sets with large variations where both the estimated mean (the first value shown) and the median (the second value shown) depositions are presented.

TABLE 5-6
Estimated Gross Dermal Deposition Normalized by Quantity of Chemical Handled (µg/cm²/lb) from PHED for Wettable Powder in Bags (Solid Code 1B) with Open Mixing (Mixing Code 1)

Body Section	Number of Measurements	Estimated Mean Deposition*	Estimated 90th Percentile Deposition
OUTSIDE CLOTHING			
head	10	0.039	0.075
neck front	0		
neck back	0		
shoulder	13	0.2062	0.4742
upper arms	0		
chest	16	0.1322	0.2143
back	16	0.0666	0.1323
forearms	18	0.9216	1.7605
thigh	16	0.3992	0.5127
shin	4	0.0893	0.1754
calf	0		
ankle	4	0.0458	0.0850
hands	7	18.991	53.21
INSIDE PERSONAL CLOTHING			
head	0		
neck front	0		
neck back	0		
shoulder	11	0.1562	0.1602
upper arms	0		
chest	10	0.1395/0.0083	0.0833
back	10	0.1437	0.1725
forearms	13	0.0598	0.124
thigh	9	0.0097	0.013
shin	4	0.0037	0.0065
calf	0		
ankle	4	0.0083	0.0083
hands	8	0.0488	0.0977

* Except in data sets with large variations where both the estimated mean (the first value shown) and the median (the second value shown) depositions are presented.

TABLE 5-7
Estimated Gross Dermal Deposition Normalized by Quantity of Chemical Handled ($\mu g/cm^2/lb$) from PHED for Wettable Powder in Packets (Solid Code 1P) with Open Mixing (Mixing Code 1)

Body Section	Number of Measurements	Estimated Mean Deposition*	Estimated 90th Percentile Deposition
OUTSIDE CLOTHING			
head	15	0.0027	0.0098
neck front	3	0.0009	0.0014
neck back	6	0.0004	0.0006
shoulder	6	0.0013	0.0020
upper arms	0		
chest	15	0.0028	0.0098
back	15	0.0026	0.0098
forearms	15	0.0072	0.0098
thigh	15	0.0218	0.0808
shin	3	0.0004	0.0005
calf	6	0.0032	0.0046
ankle	3	0.0011	0.0023
hands	5	0.0265	0.0557
INSIDE PERSONAL CLOTHING			
head	6	0.0009	0.0010
neck front	0		
neck back	0		
shoulder	6	0.0009	0.0010
upper arms	0		
chest	12	0.0005	0.0010
back	12	0.0005	0.0010
forearms	6	0.0009	0.0010
thigh	12	0.0013	0.0010
shin	3	0.0001	0.0001
calf	6	0.0009	0.0010
ankle	3	0.0001	0.0001
hands	6	0.0001	0.0001

* Except in data sets with large variations where both the estimated mean (the first value shown) and the median (the second value shown) depositions are presented.

TABLE 5-8
Estimated Gross Dermal Deposition Normalized by Quantity of Chemical Handled ($\mu g/cm^2/lb$) from PHED for Flowable Powder (Solid Code 2) with Open Mixing (Mixing Code 1)

Body Section	Number of Measurements	Estimated Mean Deposition*	Estimated 90th Percentile Deposition
OUTSIDE CLOTHING			
head	21	0.0118	0.0261
neck front	0		
neck back	8	0.0008	0.0013
shoulder	0		
upper arms	16	0.0393	0.0933
chest	16	0.0927	0.2004
back	16	0.0354	0.1195
forearms	24	0.0959	0.2127
thigh	16	0.6240	1.8884
shin	16	0.0366	0.076
calf	0		
ankle	0		
hands	0		
INSIDE PERSONAL CLOTHING			
head	0		
neck front	0		
neck back	0		
shoulder	0		
upper arms	16	0.0026	0.0028
chest	24	0.0018	0.0042
back	24	0.0011	0.0020
forearms	16	0.0029	0.0049
thigh	24	0.0251	0.0610
shin	16	0.0114	0.0181
calf	0		
ankle	8	0.0003	0.0008
hands	25	0.0094	0.0174

* Except in data sets with large variations where both the estimated mean (the first value shown) and the median (the second value shown) depositions are presented.

TABLE 5-9
Estimated Gross Dermal Deposition Normalized by Quantity of Chemical Handled ($\mu g/cm^2/lb$) from PHED for Granule (Solid Code 4) with Open Mixing (Mixing Code 1)

Body Section	Number of Measurements	Estimated Mean Deposition*	Estimated 90th Percentile Deposition
OUTSIDE CLOTHING			
head	3	0.0011	0.0021
neck front	0		
neck back	0		
shoulder	11	0.0025	0.0067
upper arms	3	0.0016	0.003
chest	11	0.0036	0.006
back	11	0.0006	0.0008
forearms	11	0.0095/0.0021	0.0061
thigh	11	0.0273/0.0030	0.0260
shin	0		
calf	0		
ankle	3	0.0336	0.0671
hands	0		
INSIDE PERSONAL CLOTHING			
head	0		
neck front	0		
neck back	0		
shoulder	0		
upper arms	3	0.0001	0.0003
chest	8	0.0005	0.0008
back	8	0.0004	0.0006
forearms	3	0.0007	0.0014
thigh	0		
shin	0		
calf	0		
ankle	3	0.0003	0.0007
hands	3	0.0033	0.0068

* Except in data sets with large variations where both the estimated mean (the first value shown) and the median (the second value shown) depositions are presented.

D. GROSS DERMAL DEPOSITION NORMALIZED BY EXPOSURE DURATION FOR MIXING AND LOADING OPERATIONS

PHED also permits normalization of dermal exposure data by the duration of exposure or sampling test, with the data reported as $\mu g.AI/cm^2/hr$. To convert the AI based data to a formulated product based data, i.e., to derive estimated gross dermal deposition data, data from PHED must be divided by a weight concentration of the AI in formulated product. However, weight concentration of the AI in formulated product varies from test to test. To estimate any statistical parameters on gross dermal deposition, it would have been necessary first to convert the measured raw data in each record to a gross dermal deposition format then to perform the statistical analysis. However, the PHED statistical package does not allow conversion of the raw data before statistical calculations.

Instead of creating a new database for statistical analysis, a simpler approach was used to utilize the statistical data already available from PHED. With this approach, certain single values from weight concentration distribution data were selected to convert statistical parameters available from PHED into gross dermal deposition data. As used in presenting the quantity normalized data, the mean exposure and the 90th percentile exposure will also be used here. To derive these estimates for time normalized data, two concentration levels were selected: the mean concentration of AI under each formulation type/mixing method matrix for converting the mean exposure, and the 10th percentile concentration to convert the 90th percentile exposure to estimated gross dermal deposition. Statistical distribution of the weight concentrations for various matrices of formulation type and mixing method as derived from PHED are shown in Table 5-10. The time normalized gross dermal deposition estimates as calculated for various matrices are shown in Tables 5-11 through 5-18.

The time normalized data may be used to estimate total dermal deposition expected at the end of a certain period of exposure. Obviously, there is a limit on how far this extrapolation can be used because of questions on linear relationship and maximum loading. Further discussion of this is presented in Chapter VI. It should also be noted, as in the case of quantity normalized data, that in some data sets, the mean value is greater than the 90th percentile estimate because of the wide range of data variation. In such cases, the median estimates are also indicated.

TABLE 5-10
Distribution of Weight Concentration of AI in Formulation

Formulation/Mixing Matrix	Number of Field Tests	10th Percentile Concentration	Mean Concentration	90th Percentile Concentration
Emulsifiable concentrate with open mixing	134	1.3 lbs/gal	4.25 lbs/gal	80 lbs/gal
Emulsifiable concentration with closed mixing	21	2 lbs/gal	3.24 lbs/gal	4 lbs/gal
Aqueous suspension with open mixing	17	4.17 lbs/gal	4.16 lbs/gal	4.17 lbs/gal
Solution with open mixing	27	2 lbs/gal	3.09 lbs/gal	8 lbs/gal
Wettable powder in bags with open mixing	35	50%	68.06%	80%
Wettable powder in packets with open mixing	12	40%	45%	50%
Flowable powder with open mixing	26	50%	63.46%	85%
Granule with open mixing	14	10%	10.71%	13.5%

TABLE 5-11
Estimated Gross Dermal Deposition Normalized by Time
($\mu g/cm^2/hr$) from PHED for
Emulsifiable Liquid (Liquid Code 1) with
Open Mixing (Mixing Code 1)

Body Section	Number of Measurements	Estimated Mean Deposition[a]	Estimated 90th Percentile Deposition
OUTSIDE CLOTHING			
head	77	0.1291	1.148
neck front	23	0.2893	2.611
neck back	13	0.0273	0.1443
shoulder	81	0.1338	0.9668
upper arms	15	3.8360	36.99
chest	80	2.4902	3.296
back	93	0.0899	0.8853
forearms	109	1.9062	10.28
thigh	64	71.259/0.1807	59.29
shin	14	7.569/0.0985	1.778
calf	22	1.756	17.07
ankle	43	7.640	13.38
hands	24	520.60	5,246
INSIDE PERSONAL CLOTHING			
head	6	0.0053	0.0366
neck front	0		
neck back	0		
shoulder	28	0.0175	0.1469
upper arms	15	60.844/0.0408	0.8748
chest	96	1.1154/0.0269	0.3862
back	82	0.0361	0.3182
forearms	64	0.2461	0.9405
thigh	40	0.1968	1.476
shin	0		
calf	22	0.0230	0.1123
ankle	32	99.54/0.0077	0.9546
hands	45	7.3681	11.82

[a] Except in data sets with large variations where both the estimated mean (the first value shown) and the median (the second value shown) depositions are presented.

TABLE 5-12
Estimated Gross Dermal Deposition Normalized by Time ($\mu g/cm^2/hr$) from PHED for Emulsifiable Concentrate (Liquid Code 1) with Closed Mixing (Mixing Code 2)

Body Section	Number of Measurements	Estimated Mean Deposition*	Estimated 90th Percentile Deposition
OUTSIDE CLOTHING			
head	20	0.6474	3.639
neck front	0		
neck back	0		
shoulder	4	0.3804	1.380
upper arms	13	0.5725	0.8436
chest	20	1.9568	2.9807
back	20	1.4356/0.0134	0.3411
forearms	14	1.3604	5.087
thigh	14	6.4519/0.5115	5.409
shin	8	0.0620	0.3032
calf	0		
ankle	5	1.4451	5.203
hands	0		
INSIDE PERSONAL CLOTHING			
head	0		
neck front	0		
neck back	0		
shoulder	0		
upper arms	19	0.0757	0.2014
chest	14	0.0049	0.0100
back	14	0.0046	0.0100
forearms	19	0.0623	0.2319
thigh	14	27.056/0.0059	0.0780
shin	8	0.0059	0.0104
calf	0		
ankle	11	0.1511	0.3194
hands	15	0.1197	0.4915

* Except in data sets with large variations where both the estimated mean (the first value shown) and the median (the second value shown) depositions are presented.

TABLE 5-13
Estimated Gross Dermal Deposition Normalized by Time
($\mu g/cm^2/hr$) from PHED for
Aqueous Suspension (Liquid Code 2) with
Open Mixing (Mixing Code 1)

Body Section	Number of Measurements	Estimated Mean Deposition*	Estimated 90th Percentile Deposition
OUTSIDE CLOTHING			
head	15	2.7576	3.215
neck front	0		
neck back	0		
shoulder	16	1.6373/0.4056	1.626
upper arms	6	0.1111	0.2118
chest	16	29.166/0.7839	15.90
back	16	1.1407	2.600
forearms	6	1.1038	2.157
thigh	16	19.825	28.40
shin	10	318.58/42.53	272.06
calf	0		
ankle	6	1.1965	2.921
hands	16	180.55	444.27
INSIDE PERSONAL CLOTHING			
head	0		
neck front	0		
neck back	0		
shoulder	0		
upper arms	0		
chest	6	0.0636	0.1254
back	6	0.0327	0.048
forearms	6	0.0922	0.1842
thigh	0		
shin	6	0.1185	0.2178
calf	0		
ankle	6	0.0527	0.0918
hands	6	13.349	25.11

* Except in data sets with large variations where both the estimated mean (the first value shown) and the median (the second value shown) depositions are presented.

TABLE 5-14
Estimated Gross Dermal Deposition Normalized by Time
($\mu g/cm^2/hr$) from PHED for
Solution (Liquid Code 4) with
Open Mixing (Mixing Code 1)

Body Section	Number of Measurements	Estimated Mean Deposition*	Estimated 90th Percentile Deposition
OUTSIDE CLOTHING			
head	23	0.0667	3.253
neck front	0		
neck back	0		
shoulder	16	0.0699	2.095
upper arms	16	0.0224	1.142
chest	23	0.6729	9.127
back	23	0.0656	1.496
forearms	23	0.7528	13.25
thigh	23	5.2377	7.443
shin	0		
calf	7	0.1671	6.599
ankle	16	1.4623	88.25
hands	6	3.5577	115.2
INSIDE PERSONAL CLOTHING			
head	4	0.0605	1.663
neck front	0		
neck back	0		
shoulder	13	0.0175	0.8913
upper arms	16	0.0113	0.4691
chest	20	0.0351	0.7819
back	19	0.0321	0.7714
forearms	14	0.0221	1.340
thigh	20	0.0165	0.7819
shin	0		
calf	7	0.0162	0.4483
ankle	13	0.0175	0.8913
hands	14	0.3942	5.340

* Except in data sets with large variations where both the estimated mean (the first value shown) and the median (the second value shown) depositions are presented.

TABLE 5-15
Estimated Gross Dermal Deposition Normalized by Time ($\mu g/cm^2/hr$) from PHED for Wettable Powder in Bags (Liquid Code 1B) with Open Mixing (Mixing Code 1)

Body Section	Number of Measurements	Estimated Mean Deposition*	Estimated 90th Percentile Deposition
OUTSIDE CLOTHING			
head	10	0.7217	2.110
neck front	0		
neck back	0		
shoulder	13	8.4135	27.16
upper arms	0		
chest	16	8.9699	28.56
back	16	7.0829	25.60
forearms	18	15.438	59.04
thigh		6.7805	22.73
shin	4	3.7546	8.129
calf	0		
ankle	4	0.0542	0.136
hands	7	197.48	619.51
INSIDE PERSONAL CLOTHING			
head	0		
neck front	0		
neck back	0		
shoulder	11	0.3009	0.4724
upper arms	0		
chest	10	0.0996	0.2896
back	10	0.0893	0.2252
forearms	13	1.0804	2.8144
thigh	9	0.6334	2.34
shin	4	0.1723	0.3896
calf	0		
ankle	4	0.010	0.0152
hands	8	1.2658	3.106

* Except in data sets with large variations where both the estimated mean (the first value shown) and the median (the second value shown) depositions are presented.

TABLE 5-16
Estimated Gross Dermal Deposition Normalized by Time ($\mu g/cm^2/hr$) from PHED for Wettable Powder in Packets (Solid Code 1P) with Open Mixing (Mixing Code 1)

Body Section	Number of Measurements	Estimated Mean Deposition[a]	Estimated 90th Percentile Deposition
OUTSIDE CLOTHING			
head	15	0.0996	0.4865
neck front	3	0.0360	0.0638
neck back	6	0.0142	0.0295
shoulder	6	0.0102	0.0150
upper arms	0		
chest	15	0.1044	0.4865
back	15	0.0953	0.4865
forearms	15	0.2586	0.5358
thigh	15	0.7704	2.928
shin	3	0.0162	0.0258
calf	6	0.0300	0.0703
ankle	3	0.0407	0.0938
hands	5	0.0954	2.185
INSIDE PERSONAL CLOTHING			
head	6	0.0080	0.011
neck front	0		
neck back	0		
shoulder	6	0.0080	0.011
upper arms	0		
chest	12	0.0053	0.011
back	12	0.0053	0.011
forearms	6	0.0080	0.011
thigh	12	0.0333	0.011
shin	3	0.0020	0.012
calf	6	0.0080	0.011
ankle	3	0.0007	0.001
hands	6	0.0006	0.6965

[a] Except in data sets with large variations where both the estimated mean (the first value shown) and the median (the second value shown) depositions are presented.

TABLE 5-17
Estimated Gross Dermal Deposition Normalized by Time ($\mu g/cm^2/hr$) from PHED for Flowable Powder (Solid Code 2) with Open Mixing (Mixing Code 1)

Body Section	Number of Measurements	Estimated Mean Deposition*	Estimated 90th Percentile Deposition
OUTSIDE CLOTHING			
head	21	0.0819	0.18
neck front	0		
neck back	8	0.1045	0.2296
shoulder	0		
upper arms	16	0.0651	0.1976
chest	16	0.1379	0.3676
back	16	0.0627	0.2678
forearms	24	0.5626	1.3912
thigh	16	1.1012	4.098
shin	16	0.0555	0.1586
calf	0		
ankle	0		
hands	0		
INSIDE PERSONAL CLOTHING			
head	0		
neck front	0		
neck back	0		
shoulder	0		
upper arms	16	0.0038	0.0076
chest	24	0.0200	0.0518
back	24	0.0055	0.0136
forearms	16	0.0044	0.0066
thigh	24	0.0572	0.1098
shin	16	0.0214	0.0396
calf	0		
ankle	8	0.0405	0.1256
hands	25	0.0979	0.4069

* Except in data sets with large variations where both the estimated mean (the first value shown) and the median (the second value shown) depositions are presented.

TABLE 5-18
Estimated Gross Dermal Deposition Normalized by Time
($\mu g/cm^2/hr$) from PHED for
Granule (Solid Code 4) with
Open Mixing (Mixing Code 1)

Body Section	Number of Measurements	Estimated Mean Deposition*	Estimated 90th Percentile Deposition
OUTSIDE CLOTHING			
head	3	2.6872	4.121
neck front	0		
neck back	0		
shoulder	11	3.6256	12.16
upper arms	3	5.1382	7.80
chest	11	11.327	14.28
back	11	0.8357	2.029
forearms	11	17.239	58.68
thigh	11	300.80/7.11	39.27
shin	0		
calf	0		
ankle	3	59.20	91.99
hands	0		
INSIDE PERSONAL CLOTHING			
head	0		
neck front	0		
neck back	0		
shoulder	0		
upper arms	3	0.2166	0.276
chest	8	0.9599	1.576
back	8	0.7638	1.54
forearms	3	1.6517	2.981
thigh	0		
shin	0		
calf	0		
ankle	3	0.4127	0.64
hands	3	2.6642	5.476

* Except in data sets with large variations where both the estimated mean (the first value shown) and the median (the second value shown) depositions are presented.

VI. EVALUATION OF AVAILABLE INFORMATION ON POTENTIAL EXPOSURE

Normalized gross deposition rates derived from both the published reports and PHED have been provided in Chapters IV and V. In this chapter, the data from these two sources are summarized and compared to establish an equivalency between the two. The normalized PHED data, believed to be of better quality overall, are then extended by each normalizing factor to determine a daily retention rate equivalent to the "Q" values in the CEB method. These predicted daily retention rates are then evaluated against the "Q" values to establish rules for application of these predicted rates. Lastly, data uncertainties encountered in developing these values are described.

A. SUMMARY OF EXPOSURE ESTIMATES

In this section, appropriate data from Chapters IV and V are extended by their corresponding normalizing factors, i.e., the total quantity of chemical handled (lbs or gallons) or the exposure time (hours), to obtain an estimate of daily total deposition or retention equivalent to the variable "Q" in the CEB method. The CEB input parameters can then be evaluated against these field based data. Since the CEB method is currently believed to provide conservative estimates that are useful in evaluating whether workers can be adequately protected in most cases, only the 90th percentile estimate of gross deposition from PHED and the Indicative 90th Percentile deposition from published reports are used for comparison.

For comparison, the Indicative 90th Percentile estimate and the PHED 90th percentile estimates of normalized gross dermal deposition are extracted from Chapters IV and V and listed side by side by each operation matrix in Table 6-1 for time normalized data and in Table 6-2 for quantity normalized data. As can be seen, where available, data obtained from published reports and from PHED for each applicable body section are generally within an order of magnitude of each other. However, there is no pattern to indicate which data source is more likely to generate a more conservative estimate. It would appear that either set of data can be used to estimate daily dermal retention. However, for data quality consistency, only the PHED data will be used in this document for further analysis.

B. ESTIMATE FOR DAILY POTENTIAL GROSS DERMAL RETENTION

Before a daily exposure can be estimated from the normalized data, a fixed value of the normalizing factor must be developed first. In other words, a daily operating time and a daily handling quantity will need to be defined. In terms of daily

TABLE 6-1
90TH PERCENTILE ESTIMATE OF POTENTIAL GROSS DERMAL DEPOSITION NORMALIZED BY TIME ($\mu g/cm^2/hr$) FROM TWO DATA SOURCES

	Open Mixing of Emulsifiable Concentrate		Closed Mixing of Emulsifiable Concentrate		Open Mixing of Aqueous Suspension		Open Mixing of Solution	
	Literature	PHED	Literature	PHED	Literature	PHED	Literature	PHED
Head	0.1	1.20	0.07	3.60	--	3.20	--	3.30
Neck Front	--	2.60	--	--	--	--	--	--
Neck Back	--	0.14	--	--	--	--	--	--
Shoulder	3.0	0.97	--	1.40	--	1.60	--	2.10
Upper Arms	0.1	37.0	--	0.84	--	0.21	--	1.10
Chest	8.0	3.30	1.0	3.00	--	16.0	--	9.10
Back	3.0	0.89	0.2	0.34	--	2.60	--	1.50
Forearms	10	10.0	--	5.0	--	2.20	--	13.00
Thigh	5.0	59	--	5.0	--	28.0	--	7.40
Shin	1.0	1.80	--	0.30	--	27.0	--	--
Calf	--	17	--	--	--	--	--	6.60
Ankle	--	13	--	5.20	--	2.90	--	88.00
Hands	200	5,200	--	--	--	440	--	120

TABLE 6-1 (Cont'd)
SUMMARY OF 90TH PERCENTILE ESTIMATE OF POTENTIAL GROSS DERMAL DEPOSITION NORMALIZED BY TIME ($\mu g/cm^2/hr$) FROM TWO DATA SOURCES

	Mixing of Wettable Powder (in bags) to Liquid		Mixing of Wettable Powder (in packets) to Liquid		Mixing of Flowable Powder to Liquid		Mixing of Granules	
	Literature	PHED	Literature	PHED	Literature	PHED	Literature	PHED
Head	120	2.10	--	0.49	--	0.18	--	4.0
Neck Front	--	--	--	0.06	--	--	--	--
Neck Back	--	--	--	0.03	--	0.23	--	--
Shoulder	30	27	--	0.015	--	--	--	12.0
Upper Arms	0.5	--	--	--	--	0.20	--	7.80
Chest	40	29	--	0.49	--	0.38	--	14
Back	15	26	--	0.49	--	0.27	--	2.0
Forearms	200	59	--	0.54	--	1.40	--	59
Thigh	15	23	--	2.90	--	4.10	--	39
Shin	0.1	8.0	--	0.026	--	0.16	--	--
Calf	--	--	--	0.07	--	--	--	--
Ankle	--	0.14	--	0.094	--	--	--	92
Hands	300	420	--	2.20	--	--	--	--

TABLE 6-2
SUMMARY OF 90TH PERCENTILE ESTIMATES OF POTENTIAL GROSS DERMAL DEPOSITION NORMALIZED BY QUANTITY OF CHEMICAL HANDLED ($\mu g/cm^2/gal$ or $\mu g/cm^2/lb$) FROM TWO DATA SOURCES

	Open Mixing of Emulsifiable Concentrate		Closed Mixing of Emulsifiable Concentrate		Open Mixing of Aqueous Suspension		Open Mixing of Solution	
	Literature	PHED	Literature	PHED	Literature	PHED	Literature	PHED
Head	0.4	0.22	--	0.039	--	0.058	--	0.074
Neck Front	--	0.15	--	--	--	--	--	--
Neck Back	--	0.081	--	--	--	--	--	--
Shoulder	0.3	0.11	--	0.0058	--	0.033	--	0.063
Upper Arms	0.01	0.18	--	0.0092	--	0.014	--	0.010
Chest	0.4	0.15	--	0.054	--	0.29	--	0.25
Back	0.2	0.11	--	0.042	--	0.44	--	0.038
Forearms	4.0	0.79	--	0.20	--	0.18	--	0.14
Thigh	10	1.30	--	0.85	--	1.10	--	0.21
Shin	2.0	0.022	--	0.10	--	5.60	--	--
Calf	--	0.95	--	--	--	--	--	0.013
Ankle	--	0.41	--	0.03	--	0.20	--	14
Hands	100	470	--	--	--	33	--	0.30

All units are in $\mu g/cm^2/gal$.

TABLE 6-2 (Cont'd)
SUMMARY OF 90TH PERCENTILE ESTIMATES OF POTENTIAL GROSS DERMAL DEPOSITION NORMALIZED BY QUANTITY OF CHEMICAL HANDLED ($\mu g/cm^2/gal$ or $\mu g/cm^2/lb$) FROM TWO DATA SOURCES

	Mixing of Wettable Powder (in bags) to Liquid		Mixing of Wettable Powder (in packets) to Liquid		Mixing of Flowable Powder to Liquid		Mixing of Granules	
	Literature	PHED	Literature	PHED	Literature	PHED	Literature	PHED
Head	0.4	0.075	--	0.0098	--	0.026	--	0.0021
Neck Front	--	--	--	0.0014	--	--	--	--
Neck Back	--	--	--	0.0006	--	0.0013	--	--
Shoulder	--	0.47	--	0.002	--	--	--	0.0067
Upper Arms	0.6	--	--	--	--	0.093	--	0.003
Chest	1.0	0.21	--	0.0098	--	0.20	--	0.006
Back	0.15	0.13	--	0.0098	--	0.12	--	0.0008
Forearms	2.0	1.80	--	0.0098	--	0.21	--	0.0061
Thigh	3.0	0.51	--	0.081	--	1.90	--	0.026
Shin	0.1	0.18	--	0.0005	--	0.08	--	--
Calf	--	--	--	0.0066	--	--	--	--
Ankle	--	0.085	--	0.0023	--	--	--	0.0671
Hands	1.5	53	--	0.056	--	--	--	--

All units are in $\mu g/cm^2/lb$.

exposure time, there is no particularly appropriate duration based on a review of the literature for extension of the time normalized data. For pesticide mixing and loading operations, most of the studies cited in this document used a sampling time of no more than 60 minutes. Some investigators then extrapolated the measured exposure to a selected duration for an estimate of daily exposure. For example, Maddy et al. (1980) used a 2-hour time to calculate daily exposure. Others believed extrapolation of short duration measurement to a daily exposure was inappropriate and measured the exposure for the entire work day (Knarr et al., 1985). Most of the mixing and loading operations reported in PHED show an average sampling time of 0.30 to 2.8 hours among various formulation type and mixing method matrices. For this document, a 4-hour duration is chosen for extending the time normalized data. This is based on the observation that workers typically take a meal break, perhaps with some washing activities, in the middle of an 8-hour work shift.

As for the quantity of chemical handled per day, there is even less data available. In most published reports, the quantity of AI or formulated products handled is often not reported. In PHED, the data on total quantity of AI mixed is available thus permitting calculations of a total quantity of the formulated product used in each test. Table 6-3 presents a selected quantile distribution of the data on total quantity of pesticide product used in each matrix of formulation type and mixing method. A wide variation is seen between different matrices. There is no information on how such data relate to industrial operations. As a preliminary estimate of daily exposure, the 90th percentile quantity of the formulated product reported in PHED is used in this document to extend the quantity normalized data, assuming that larger quantities are more often handled in industrial operations.

Data from PHED, as shown in Tables 6-1 and 6-2, are grouped by pesticide formulation type and mixing method. Such grouping may not always be analogous to industrial operations. An industrial mixing operation often is designed to mix or provide contact between mutually insoluble liquids, between liquids and solids, or between solids. Contrary to pesticide mixing and loading operation, for example, not many industrial mixing operations involve dilution of an emulsifiable concentrate. Of the four liquid formulation types, only the mixing of aqueous suspension and solution may be considered as closer to some equivalent industrial operations. For the mixing of solids, mixing wettable powder in bags into slurries and dry mixing of granule may find some equivalent operations in industries. Therefore, only the data for these four operations are extended to estimate daily exposure. The extended data, defined as Daily Potential Gross Dermal Retention, are presented in Table 6-4,

TABLE 6-3
DISTRIBUTION OF THE QUANTITY OF FORMULATED PESTICIDE HANDLED IN PHED

Formulation Type and Mixing Method	Mean and Quantile Distribution			N
	Mean	50th Percentile	90th Percentile	
Emulsifiable concentrate with open mixing	5.01 gallons	1.42 gallons	9.82 gallons	136
Emulsifiable concentrate with closed mixing	52.10 gallons	10.0 gallons	175 gallons	22
Aqueous suspension with open mixing	31.9 gallons	27.5 gallons	42.5 gallons	17
Solution with open mixing	2.84 gallons	1.25 gallons	4.0 gallons	27
Wettable powder (in bags) with open mixing	74.6 lbs	50 lbs	159 lbs	35
Wettable powder (in packets) with open mixing	8.79 lbs	7.75 lbs	18 lbs	12
Dry flowable powder with open mixing	29.90 lbs	11.8 lbs	74.8 lbs	26
Granule with open mixing	3871 lbs	4020 lbs	9110 lbs	14

TABLE 6-4
ESTIMATED DAILY POTENTIAL GROSS DERMAL RETENTION (outside clothing) IN $\mu g/cm^2$

Body Section	Aqueous Suspension/Open Mixing			Solution/Open Mixing			Wettable Powder (bags)/Open Mixing			Granule/Open Mixing		
	By Time	By Quantity	N	By Time	By Quantity	N	By Time	By Quantity	N	By Time	By Quantity	N
Head/Face	12.8	2.47	15	13.20	0.30	23	8.40	11.9	10	16.0	19.1	3
Shoulder	6.4	1.40	16	8.40	0.25	16	108	74.7	13	48.0	61	11
Upper Arms	0.84	0.60	6	4.40	0.04	16	--	--	0	31.2	27.3	3
Chest	64	12.3	16	36.4	1.0	23	116	3.34	16	56	54.7	11
Back	10.40	1.87	16	6.0	0.15	23	104	20.7	16	8.0	7.29	11
Forearms	8.80	7.65	6	52.0	0.56	23	236	286	18	236	55.7	11
Thigh	112	46.8	16	29.6	0.81	23	92	81.1	16	156	23.7	11
Shin	1080	238	10	--	--	0	32	28.6	4	--	--	0
Calf	--	--	0	26.4	0.052	7	--	--	0	--	--	0
Ankle	11.6	8.50	6	352	56.0	16	0.56	13.5	4	368	611	3
Hands	1,760	1,403	16	480	1.2	6	1,680	8,427	7	--	--	0

Note: 1. Time normalized gross dermal deposition data are extended by a duration of 4 hours to derive time normalized daily potential retention.

2. Quantity normalized gross dermal deposition data are extended by 42.5 gallons for aqueous suspension; 40.0 gallons for solution; 159 lbs for wettable powder; and 9110 lbs for granule to derive quantity normalized potential retention.

3. N = Number of measurements.

with the time and quantity based data listed side by side for comparison. As discussed earlier, a 4-hour duration is used for extension of time normalized data and the 90th percentile quantity under each applicable matrix of formulation type and mixing method is used for extending the quantity normalized data. The number of measurements for each body section under each scenario is also indicated in the table to show the relative strength of each estimated retention rate.

As expected, the data presented in Table 6-4 shows that the hands generally have the highest estimated gross dermal retention among all body sections. The next highest retention is generally found at the forearms, chest, or thigh. These are all body sections more likely to come into direct contact with the chemical during mixing and loading operations. Within each formulation type/mixing method matrix, one or two body sections may be found to have an extraordinary high retention as compared to other body regions. For example, a retention of 56 $\mu g/cm^2/lb.$ is found at the ankle as compared to no greater than 1.2 $\mu g/cm^2/lb.$ for other parts of the body for open mixing of solutions. Further examination of the data often reveals the presence of one or two unusually high exposures among all tests reported for that body section which would have biased the data toward the high end.

Comparing between the time and quantity extended data, the time based data always has a higher value for each body section than the quantity based data, with a few exceptions. It would appear that the time based data would provide a more conservative estimate of gross dermal retention.

C. COMPARISON WITH CEB METHOD PARAMETERS

In reference to the input parameters used in the CEB method, only the retention at the hands can be directly compared to the available PHED data. The CEB method uses 1 to 3 mg/cm^2 for hand exposure during various liquid mixing and solid handling operations. The PHED data generates an estimate of 0.5 mg/cm^2 (open mixing of solution) to 1.8 mg/cm^2 (open mixing of aqueous suspension).

A comparison of the CEB method "Q" values with the equivalent PHED based data is provided in Table 6-5. Due to a lack of data, not all work activities covered by the CEB method can be addressed here. In Table 6-5, the activities implied for any specific formulation type/mixing method were interpreted liberally so that there would be more equivalent data for comparison. Specifically:

TABLE 6-5
EQUIVALENT "Q" VALUE FOR HAND EXPOSURE
FROM CEB METHOD AND MONITORING DATA

Typical Work Activities Grouped by CEB	CEB Value (mg/cm^2)	Monitoring Data* (mg/cm^2)
Handling wet surfaces (immersion)	5-14	--
Filling, dumping containers of powder, flakes, granules	1-3	1.7[a]
Spray painting	1-3	--
Maintenance/manual cleaning of equipment	1-3	--
Unloading filter cake	1-3	0.039-0.6[c]
Changing filter	1-3	--
Filling drums with liquid	1-3	0.5-1.8[b]
Connecting transfer line	1-3	--
Weighing powder/scooping/mixing	1-3	1.7[a]
Sampling	1-3	--
Ladling liquid/bench scale liquid transfer	1-3	0.5-1.8[b]

* PHED data expressed as 90th percentile estimated exposure with 4-hrs of exposure using time normalized data, except otherwise noted

[a] Considered to be represented by open mixing of wettable powder

[b] Considered to be represented by open mixing of aqueous suspension or solution

[c] Data from EPA 1992d.

- Data for open mixing of wettable powder are considered to approximate "filling, dumping containers of powder, flakes, granule," and "weighing powder/scooping/mixing"

- Data for open mixing of aqueous suspension and solution are considered to approximate "filling drum with liquid," and "ladling liquid/bench scale liquid transfer."

As can be seen from this comparison, the CEB "Q" values for hand exposure are very close to the PHED data expressed as 90th percentile estimates of potential gross dermal retention. It goes to reason then, that the PHED data on other parts of the body may be used with the CEB method to develop exposure estimates. The estimates as shown in Table 6-4 are for potential exposure outside the clothing or on unclothed areas of the skin only. Estimate for exposure underneath the clothing, gloves, shoes, or any protective clothing cannot be adequately predicted based on the data available at this time.

D. DATA UNCERTAINTIES

Each source of data used in this document has its own strength, weakness, and uncertainties. Many assumptions and inferences were made to analyze the data for this document. Various degrees of uncertainty are involved in each step of the data development. This explains in part some of the larger variations between different data sets or sources. The following is a discussion of such uncertainties.

Almost all of the reported dermal exposure data available from published literature were developed as part of pesticide studies. PHED is of course all related to pesticide exposure. Even though similar approaches and techniques were followed, the purpose of the studies, the data reporting format, and the assumptions and study conditions often varied widely. The major assumptions and varying conditions which cause uncertainty in evaluating results from different data sources or investigators include the following:

- Dermal exposure is usually determined through extrapolation of deposition on absorbent pads. The assumption of uniform deposition within a specific area of the body may not be true.

- Dermal exposure reported is usually normalized by the quantity of chemicals or by exposure time. In the case of PHED, the data can also be normalized by quantity handling rate. However, as discussed in Chapter V, exposure is not preferentially correlated to any of

these factors. Extrapolation of the normalized data by any factor is necessary for estimating exposure in industrial operations but will introduce additional uncertainty.

- Varying field conditions, such as wind speed and relative humidity, will affect the amount of splash or spray droplets that may impinge and retain on an operator's skin or clothing.

- Retention rate on absorbent pads may be higher than the actual retention rate on smooth skin surface. Conceivably some droplets, when impinged on the skin may quickly drip off the surface of the skin but would be absorbed on the pad. The use of retention rates on pads could thus result in an overestimate of exposure. On the other hand, deposition or absorption at certain parts of the body may be overlooked. In most dermal exposure studies, it is assumed that no absorption through the hair will take place, but materials deposited on or applied to the hair may also come in contact with the skin. Some investigators have taken this into account. For example, Rodricks and Turnbull (1983) assumed a maximum of 2% of material applied to the hair will be in contact with the skin and available for absorption in their study of risk assessment from skin penetration data.

- Several types of surrogate skins have been used as samplers for dermal exposure, and results may not always be comparable. Even if only absorbent pads were used for sampling, variations in material, construction, location, handling, etc., can cause differences in analysis results.

- Duration of test varies among the studies. The results from a shorter duration test will have a higher variability than a longer duration test. One reason is that the effect of time-weighted averaging will tend to minimize the impact of peak exposure more pronouncedly in a longer duration exposure than in shorter exposure. Additional error may be introduced by extending the measured short term exposure to daily exposure.

- Other than the data from PHED, data in published reports might have been developed with a methodology not meeting quality assurance requirements of today's standards. For instance, analytical precision, spiked sample recovery rates, and sampling design can vary among investigators. Any statistical analysis on the

combined data with varying quality is almost meaningless.

Several factors and assumptions were considered when applying the data from published pesticide studies and PHED data to industrial operations. The impacts of these factors and assumptions include:

- Pesticide studies only report the exposure to the active ingredient of the pesticide, which is usually only a minor component of the mixture. For generic applications, the desirable data is the amount of mixture, not the active ingredient, that contacts the skin. Therefore, it is assumed that the mixed solution or the formulated product that contacts the skin has the same concentration of active ingredient as in the mixed solution or the formulated product itself. This is a critical assumption in calculating the estimated amount of mixture reaching the skin (gross dermal deposition). However, different ingredients could vary a great deal in physical properties, leading to differences in deposition rate, evaporation, etc. In some instances, the assumption may overestimate the deposition.

- Data on concentrations of active ingredients in liquid formulations are usually reported on a weight/volume (lbs/gal) basis. A weight/weight ratio is needed if the gross dermal deposition is to be calculated. Since data on the density of active ingredients is not included in published reports or PHED, the density is assumed to be the same as water. Up to a 20% error is introduced if the specific gravity of an active ingredient is 1.4 and its concentration in a liquid formulation is 8 lbs/gal. Most of the pesticides have a specific gravity of 1.0 to 1.4 and the concentration is usually much less than 8 lbs/gal. The error introduced by the assumption is believed to be small in comparison to the other possible errors.

- In mixing a concentrated formulation into a spray mix, a worker will be exposed to the concentrate powder or liquid droplets and the final mix droplets. When converting exposure data from active ingredients to gross dermal deposition, the deposition calculated in this document is assumed to be all from the concentrate. The actual total deposition will likely be higher than the calculated value since a greater quantity of the diluted mix is needed to produce the same amount of AI than from the concentrated mix.

- Typical workplace conditions and work practices in pesticide operations are different than typical industrial operations. For example, a pesticide mixing operation tends to be of intermittent short duration operation. Industrial mixing may be continuous. Pesticide mixing and loading may take place outdoors, and the exposure reported may be affected by weather conditions. Pesticide mixing involves more dilution than a typical industrial mixing would. Another major difference is in the amount of chemical handled. As shown in Table 6-3, the amount of pesticide handled is relatively small, except for open mixing of granule, as compared to a typical industrial operation. Industrial mixing and loading often involve filling of 55-gallon drums, tank cars, and tank trucks.

- The daily dermal retention shown in Table 6-4 is based on the time or quantity normalized data extended to a 4-hr duration or to a quantity found in PHED tests. The time normalized data provides a more conservative estimate and is recommended for use with the CEB method. If the quantity factor can be better estimated, the quantity normalized data may turn out to be more appropriate.

The current "Q" values for hand exposure in the CEB method were developed primarily based on the data developed from a series of experiments involving three kinds of oil applied to and removed from the hands (Versar, 1984; EPA 1989b; EPA 1992c). Though limited in scope and formulation type, this is the only experimental data that were specifically designed to determine generic dermal retention rate. The statistical design and test protocol were such that the data also contain uncertainties especially when applying it to industrial operations:

- Retention varies with individuals and techniques of application on and removal from the hands. The specific procedures tested may not be representative of industrial scenarios.

- Data were reported on a per event basis; factors such as duration or contact frequency were not documented and are important factors that can affect dermal retention.

- Data were developed only for three kinds of oils; they may not apply to other kinds of liquids or solids.

VII. BARRIER EFFECT OF PROTECTIVE CLOTHING

The wearing of protective clothing, work uniforms, or even street clothes presents a barrier in the transmission of chemical agent from the environment to the skin. Not all the chemical deposited on the exterior of clothing will reach the skin. If enough data existed, it might be possible to estimate a "Pass-through" factor, defined as the percent of chemical reaching the skin from outside the clothing, to assess the relative barrier effect of protective clothing. The lower the factor, the better the clothing in preventing the penetration and permeation of the chemical. In this chapter, available information and data on the barrier effect of various types of clothing are evaluated to determine whether there are sufficient data to allow modification of the current estimating method.

The amount of chemical reaching the skin through clothing and or protective equipment should be examined from two aspects: the protection afforded by the clothing or protective equipment per se and the nature of operation and work practices involved. Many factors can affect the protection provided by clothing or personal protective equipment, including permeation, degradation, and penetration. Consideration of the potential for permeation and degradation of the protective clothing requires information on the characteristics of the clothing, fabric construction and finish, garment design and construction, and the characteristics of the chemical (or formulation) which is in contact with the clothing:

- Fabric construction and finishes: Different fabric characteristics such as fiber length, yarn size, and fabric construction will affect chemical transmission (Leonas et al., 1989). For example, fabric porosity will determine how much direct penetration of chemical agents can take place. An open weave fabric will have a higher penetration and permeation factors than a non-woven fabric. Disposable clothing with chemical resistant coating will have a greater barrier effect than uncoated clothing (Leonas and DeJonge, 1986).

- Garment design: The shape, size, fit, and style of the garment will determine how much skin area is covered and how much chemical can enter the covered area through openings. The need for comfort and manual dexterity will dictate the types of clothing and equipment used.

- Characteristics of the chemical: The type of chemical formulation will determine the mechanisms by which the

chemical is actually transmitted through the fabric. A dry powdery agent is likely to pass through the fabric by direct penetration, therefore the tightness of the weave will be the primary factor. A liquid formulation can transmit through the fabric by permeation, i.e., diffusion through wetting of fabric. A strong absorbent such as cotton fabric will permit a faster permeation or penetration than a less absorbing fabric such as certain synthetic fiber. Even for the same chemical, different formulations can result in different transmission rates (Leonas, 1991; Staiff et al., 1982).

Penetration of the chemical through imperfections in the protective clothing can be a significant contributor to dermal exposure. The extent of penetration will be influenced by the operation or work activity and work practices in using the protective clothing:

- Operation or work activity: Body movement during the course of work will affect the movement of chemical agent through the fabric. For instance, movement of the forearms will create a "pumping action" between the sleeve and the arm, promoting the migration of chemical agent beyond the opening of the sleeve. Repeated motion increases direct contact between the skin and the clothing thus enhancing the transfer of permeated chemical from the fabric to the skin.

- Work practices in using protective clothing: How the protective clothing is used also has an effect on chemical pass through. If openings at sleeves, collar, and pant legs are taped tight to the body, very little entry through "pumping action" should occur. How often protective clothing is changed also will affect how much chemical will permeate through. Rips and tears can occur during use, and any openings from rip and tears will become an entry point. Even if the protective clothing is intact, heavier contaminant loading expected near the end of a workshift may cause a high rate of chemical penetration. All such factors are in turn somewhat dictated by cost, comfort during use, worker training and compliance, and other similar factors.

Because of the factors as described above, dermal exposure occurring while wearing work or protective clothing is best determined under actual field conditions for each type of clothing for each chemical. While there is a considerable amount of fabric and glove permeation data on different substances from

laboratory studies, there are a limited number of field studies on the barrier effect of clothing and gloves.

As described in Chapter II, the most commonly used approach to evaluate dermal exposure is by the use of absorption pads. If the pads are placed outside and inside the clothing, a comparison of outside and inside deposition will indicate a pass- through factor. A different approach that uses pads made out of the test fabric as the outer layer with absorption gauze underneath would also allow evaluation of pass-through factor for the fabric. The U.S. EPA's Office of Pesticide Programs suggested using data from the outside patches in conjunction with standard "penetration factors" generated from laboratory studies (EPA, 1987a) to estimate exposure inside the clothing. These approaches generally measure the amount of chemicals underneath the c through penetration and permeation. Direct deposition through openings on the clothing or through "pumping action" may not have been included.

Another approach that had been used to account for the effect of direct deposition used fluorescent tracers in conjunction with video imaging technique (Fenske, 1988). This method provides a visual display of deposition under the clothing and allows an estimate of relative pass-through factors of test clothing covering all pathways of transmission. However, the results provide only qualitative estimates of exposure.

Laboratory glove permeation testing is commonly used to evaluate the permeation characteristics of a given contaminant/glove matrix. Other factors such as elevated temperature, stressing, and pressure applied to the glove during use have been found to significantly reduce the protection provided during actual use when compared with laboratory glove permeation data (Gunderson et al., 1989; Zellers et al., 1993). For those substances that are of high concern due to potential dermal exposure, CEB currently only considers permeation and degradation when evaluating the effectiveness of gloves in providing adequate protection (it is assumed that the glove manufacturer's quality control is acceptable to eliminate imperfections in the glove material that may lead to penetration).

The barrier effects of protective clothing has also been examined by testing the absorption of chemicals through the skin instead of just the chemicals penetrating through the clothing. Keeble et al. (1993) used an in vitro skin model to examine the capability of fabric and skin alone and in combination in reducing the dermal absorption of several organophosphorus insecticides. The investigators found that the knit gloves o 100% cotton were effective in preventing the absorption of

paraoxon and malathion and that the all-cotton, 7-cut knit gloves were effective in preventing absorption of azinphos-methyl. Studies of this type address dermal absorption which is beyond the scope of this study and are not further assessed in this document.

Because of the various approaches used in evaluating the pass-through factor of protective clothing, only a compilation of available data is presented here in Table 7-1. A comprehensive literature review was not conducted, but based on this preliminary evaluation, there are insufficient data to predict a pass-through factor for a specific type of protective clothing under a specific operation for industrial exposure scenarios.

TABLE 7-1 PRELIMINARY DATA ON PASS-THROUGH FACTORS OF VARIOUS TYPES OF CLOTHING

Chemical Formulation	Physical State	Operation	Pass Through Factor			Study Approach	Reference
			Coveralls	Tyvek Suit	Workpants & Workshirt		
Terbufos 15%	Granular	Loading and spreading	10 - 20%			Comparison of deposits on inside and outside pads	Devine et. al., 1986
Several compounds 18-75%	Wettable powder and emulsified concentrate	Mixing and application		0 - 23%		Comparison of deposits on inside and outside pads. Tyvek suits include hood and boots. Gloves also used	EPA, 1988
Fosetyl-Al 80%	Wettable powder in water	Mixing			15.9 % Shirt 3.5% Pants	Comparison of deposits on inside and outside pads	Fenske et. al., 1987
		Spraying			13.37% Shirt 2.1% Pants		
Carbaryl 80%	Wettable powder	Spraying			3.4% Chest 4.8% Back 6.9% Leg	Comparison of deposits on side and outside pads	Leavitt et. al., 1982
Nitrofen 25%	Wettable powder	Mixing			4.12%	Deposit on pads with test fabric and absorbent gauze at outside of clothing*	Maddy et. al, 1980
Nitrofen 75%	Emulsified concentrate	Mixing			3.12%	Deposit on pads with test fabric and absorbent gauze at outside of clothing*	Maddy et. al, 1980

TABLE 7-1 PRELIMINARY DATA ON PASS-THROUGH FACTORS OF VARIOUS TYPES OF CLOTHING (Cont'd)

Chemical Formulation	Physical State	Operation	Pass Through Factor			Study Approach	Reference
			Coveralls	Tyvek Suit	Workpants & Workshirt		
Nitrofen 25%	Wettable powder	Spraying			4.08%	Deposit on pads with test fabric and absorbent gauze at outside of clothing*	Maddy et. al, 1980
Nitrofen 75%	Emulsified concentrate	Spraying			2.24%	Deposit on pads with test fabric and absorbent gauze at outside of clothing*	Maddy et. al, 1980
Lindane 18.75%	Dry powder	Manual seed treatment (mixing)			25.3% Chest 28.6% Back 30.6% Forearms 25.0% Upper Arms 8.44% Upper Legs 11.8% Lower Legs	Comparison of deposits on inside and outside pads	Fenske, et. al, 1990
Ethion 6%	Emulsion	Mixing Spraying	4% 0.7%			Comparison of deposits on inside and outside pads	Davies et al., 1982
Dicofil	Emulsified concentrate	Mixing and Spraying		3%	9%	Comparison of deposits on inside and outside pads	Nigg et al., 1986
Molinate 10%	Granule	Mixing into spraying solution	53%			Comparison of deposits on inside and outside pads	Knarr et al., 1985
Molinate 91%	Liquid	Mixing into spraying solution	30%			Comparison of deposits on inside and outside pads	Knarr et al., 1985

* Pass-through factor calculated from reported dep- - -ntration as: pass through factor = 100x $\frac{\text{Inner layer deposit}}{\text{exterior layer+inner layer deposits}}$ %

VIII. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

This document presents a review of available dermal exposure data from pesticide mixing and loading and other similar operations and evaluates the current method used by CEB in estimating dermal exposure during industrial operations. The important conclusions based on this evaluation are the following:

- The CEB method currently only assesses hand exposure. The field monitoring studies routinely included evaluation of exposure to other parts of the body, even though hand exposure often constitutes the majority of the total body exposure.

- The value of hand surface area used by CEB is not current. Many other EPA publications cite other values. The values as presented in Table 3-2 are more appropriate.

- The current input parameters for hand exposure using the CEB method are found to be very similar to the estimated gross dermal retention at the hands based on the 90th percentile estimate from the PHED time normalized data. The PHED estimated dermal retention at other parts of the body could be used with the CEB method.

- Available data in the literature indicate a maximum dermal retention of 10 mg/cm^2 for solids and 4 to 10 mg/cm^2 for liquid. (Kissel et al., 1996a; Rutledge, 1988; Versar, 1984.) These maximum loading estimates appear reasonable when compared to a calculated equivalent deposition of 0.95 mg/cm^2 for solids and 0.98 mg/cm^2 for liquid based on the study by Popendorf et al. (1995). The maximum loading estimates are also reasonable when compared to the 1.2 mg/cm^2 deposition for powder and 0.8 mg/cm^2 for liquid mixing based on the Indicative 90th percentile estimates of the available data in published reports.

- Where comparable data are available, the 90th percentile estimate from the PHED and the Indicative 90th Percentile deposition from published reports for various body sections are generally within an order of magnitude of each other. However, there is no consistent pattern as to which source of data will

generate a more conservative estimate for any body section.

- In terms of evaluating the dose absorbed through the skin, the deposition approach whereby only a fraction of the deposit is considered absorbed, is acceptable for solid or particulate media. The dermal absorption approach whereby a skin permeation coefficient is used to estimate absorbed dose directly, is theoretically more appropriate for evaluating exposure to chemicals in a liquid media. The methodology for estimating dermal absorption for non-aqueous media for industrial applications must be developed before this will be a viable methodology. The absorption approach for liquid chemical still needs additional research and further evaluation.

- Significant correlation of dermal exposure with either the total quantity of AI handled or the total sampling (exposure) duration was found only at a few body sections based on PHED data. There is no clear indication as to which factor is more appropriate for predicting dermal exposure at any body section. Similar arguments are found in published reports.

- The influence of physical properties such as particle size, moisture content on solids deposition and retention on the skin has been studied for soil particulates, but has not been evaluated for industrial applications. There is limited data with which to estimate the potential for dermal exposure to solids in industrial operations. However, a review of the available data indicates that the current default values used by the EPA for estimating deposition on the skin appear to be reasonable. Two recent studies on soil adherence rates on the skin found that physical properties of the soil such as grain size and moisture content may affect the retention rate on the skin. Similar factors may also have an effect on the retention rate of solids in industrial operations on the skin.

- The impact of clothing on providing a barrier to dermal exposure needs further evaluation.

- There is very limited dermal exposure monitoring data available for industrial activities. This lack of data makes estimation of the potential for dermal exposure during industrial operations very difficult. The available data with which to assess dermal exposure is

limited, but appears to result in reasonable estimates, based on the analysis conducted for this report.

- Standardization of sampling methodologies has largely been conducted in the pesticides areas, but sampling techniques for the industrial environment have not been standardized. Lack of standardization presents difficulties in properly interpreting and comparing data collected using different methodologies. Many sampling and collection methodologies have not been validated in industrial environments, and quality control procedures have not been standardized.

- Reporting of dermal exposure monitoring data is not standardized. The lack of standardization in data reporting makes interpretation of data, and comparison between studies difficult.

- There is very limited information available on activity patterns in industry. Unit area exposure at each body section from the studies evaluated usually varies over a range of several orders of magnitude. Based on a review of the data available, variability in dermal exposure may be influenced by a number of factors including the task performed by the worker, worker habits, and the physical properties of the contaminant. For example, unusually high exposure at the lower leg was found in one study because most of the mixing/loading operations studies consisted of pouring liquid from one container to another below the waist level, and liquid splashing may have cause relatively high exposure at lower part of the legs (Knaak, et al. 1989). Knarr et al. (1985) found unusually high exposure at legs due to frequent contact with the spray nozzle. Conversely, Chester et al. (1987) found that most of exposure was concentrated in arms, trunk, and hands. Lavy et al. (1980) reported high exposure at the thighs, and observed that workers frequently rubbed their hands against their pants at the thigh area.

- Interpretation of results is critical. Retention of chemicals on the skin surface is not necessarily linear with exposure duration or quantity of chemical handled. There is an upper limit to the amount of chemical which can be retained on the skin. Due to extremely wide variations of certain data sets, the mean value can exceed the 90 percentile estimate.

- Hands generally have the highest estimated gross dermal retention among all body sections during pesticide

mixing and loading operations. The next highest retention is generally found at forearms, chest, thigh. These are all body sections more likely to come into direct contact with chemical during mixing and loading operations. Within each formulation type/mixing method matrix, one or two body sections may be found to have an extraordinary high retention as compared to other body regions. Further examination of the data often reveals the presence of one or two unusually high exposures among the data for that body section which would have biased the data towards the upper end of the distribution.

B. RECOMMENDATIONS FOR IMPROVING THE CEB METHOD

The CEB dermal exposure estimating method represents only a preliminary estimate of the quantity of chemicals that may be retained on the hands from a few specific operations. Based on the field monitoring data analyzed in this report, the following approaches can be adopted to improve the application of the current CEB method:

- The current "Q" values in the CEB method for hand exposure tends to generate exposure estimates that fall in the upper range of the distribution of the applicable field data. Use of the CEB method thus provides a conservative estimate of exposure. Any refinement in the estimates will need more field data for validation. Based on a review of the available data and information collected and evaluated, the current methodology and input parameters used by EPA in estimating the potential for dermal exposure during industrial operations appear to be reasonable. However, characterization of CEB estimates as bounding estimates should be reevaluated for some operations. The deposition of material on the skin may vary by several orders of magnitude, depending on factors such as the task performed by the worker, individual worker habits, and other physical characteristics of the contaminant. The data with which to estimate the potential for dermal exposure in individual operations is limited, and additional data and information is needed to improve dermal exposure estimates.

- The estimate of dermal exposure on outside clothing or on bare skin at various body sections can be calculated using the PHED time normalized data. The recommended values are shown in Table 8-1. These rates are recommended for use with the CEB method to estimate daily dermal potential dose rate. If the daily

exposure duration is much different than 4 hours or if a better estimate of the quantity of chemical handled is available, the time or quantity normalized gross deposition rates presented in Chapter VII may be used.

- The EPA (1987a) values (shown in Table 3-2) for skin surface area should be used.

- The deposition approach is appropriate to estimate dermal absorption for solids but does not adequately address the continuous process of deposition and absorption for liquid media. The skin permeation approach is more appropriate for estimating dermal absorption for liquid media but further development is needed before this will be a viable approach for industrial scenarios. Appropriate initial and boundary parameters may be developed from PHED data for use with mathematical equations to estimate dermal absorption of a liquid media in industrial operations.

TABLE 8-1
RECOMMENDED DERMAL RETENTION RATES AS
INPUT PARAMETERS FOR THE CEB DERMAL EXPOSURE ESTIMATING METHOD

Body Section	Dermal Retention ($\mu g/cm^2$)			
	Mixing of Aqueous Suspension	Mixing of Solution	Mixing of Wettable Powder with Liquid	Dry Mixing of Granule
Head/Face	15	15	10	20
Shoulder	10	10	110	50
Upper Arms	1	5	--	30
Chest	60	40	120	60
Back	10	10	100	10
Forearms	10	50	240	240
Thigh	110	30	90	160
Shin or Calf	--	30	30	--
Ankle	10	--	1	--

Source: Table 6-4, time normalized data with rounding to the nearest 1, 5, or 10 and with obviously unusual number excluded. (1100 $\mu g/cm^2$ at shin for mixing of aqueous suspension, 350 $\mu g/cm^2$ at ankle for mixing of solution; and 370 $\mu g/cm^2$ at ankle for dry mixing of granule.)

C. RECOMMENDATIONS FOR FUTURE RESEARCH

The prediction of occupational dermal exposure is very difficult because of the complex physical and physiological processes involved and a lack of pertinent field data. The available field data gathered in this document represent a comprehensive review and analysis of readily available papers on dermal exposure for mixing, loading, and associated operations involving pesticides and a preliminary analysis of one of the data files in PHED. The data should present a fairly accurate description of current knowledge and information on dermal exposure from mixing and loading operations. However, much research remains to be done. The following discussion provides a few recommendations.

Further Analysis of PHED

By far, the PHED represents the most structured source of data, in fact, it is the only statistically valid data base available. The PHED is a source of information which can be extracted to further refine the estimating parameters needed in predicting dermal deposition rate. Based on the data analyzed so far, additional analysis on PHED data should include:

- Analysis of correlation between exposure and handling rate (lb. AI/hr or gal. AI/hr). Current PHED structure does not allow this analysis directly. The data will need to be exported to a different data base file for manipulation. If a better correlation is found with this variable, a better estimate of exposure can be made.

- Comparison of exposure values measured outside of and inside of protective clothing to evaluate the barrier effect of the clothing. Some of the records in PHED contain both the inside and outside exposure values for a body section on the same person. A comparison can be made from such exposure values to evaluate the barrier effect of various types of clothing. Inspection of raw data input will be necessary to determine the type of clothing used. Even if the outside and inside samples are not from the same worker, it is possible to examine all inside and outside data related to a specific type of clothing under similar work conditions to evaluate the barrier effect of the clothing.

- With pass-through factors developed from applicable PHED data to estimate the barrier effect of clothing, it will be possible to estimate actual dermal exposure on bare skin underneath the clothing from the outside

clothing potential dermal retention data as recommended in this document.

- Analysis of other data files in PHED. Dermal exposure data relating to spraying operations are contained in Applicators files and also in the Mixer/Loader/Applicator files of the PHED. An analysis on these additional files may yield results for reference in developing a method to estimate dermal exposure from industrial spray operations.

Field Studies

Ideally, field studies of actual dermal exposure monitoring should be performed to validate a predictive model. At least, laboratory simulation of industrial operations should be conducted to evaluate the various parameters involved in any modeling effort. The current CEB, EAB, and ORD particulate estimating methods all are based on a simple concept of extending skin deposition on a unit area to the entire section of the body. Only a limited estimate of the deposition rate from hand immersion tests and a few specific liquid handling operations has been developed. The data developed in this document corroborate the CEB estimates for hand exposure and add a few more parameters for estimating deposition at other parts of the body. There is a need for standardizing methodologies and interpretation of data. Once the methodologies/interpretations are standardized, the process of chemical deposition to be evaluated should include, in addition to immersion:

- Settling of droplets, mist, or dust on skin
- Impingement of droplet, mist or dust particle on skin
- Chemical transfer through direct contact
- Permeation or penetration through clothing, gloves, and barrier cream
- Retention of volatile compounds on the skin
- Retention of chemical on the skin and the total area of skin contact from specific unit operations such as electroplating, metal cleaning, spray painting, pulverizing, spray drying, or liquid filtration.

Skin retention of chemicals through these processes needs to be investigated and appropriate parameters developed. Furthermore, there are many other factors that may greatly influence the outcome of a dermal exposure assessment method.

Some of the factors may cause overestimates and some may underestimate the true exposure. The impacts of such factors should be evaluated:

1. Work and Protective Clothing

The use of any clothing will present a barrier in the transmission of chemical from a source to the skin. As discussed in Chapter VII, many factors such as fabric type, garment design, use pattern, and work activity will determine how effective the barrier will be. The preliminary "pass-through" factors as summarized in Chapter VII are still too limited to be of use for industrial scenarios at this time. Since the manner in which clothing is used (including donning and doffing gloves) impacts the protection provided, field studies under normal use conditions are recommended. Without considering the barrier effect, the outside clothing deposition data alone can not accurately predict the actual skin exposure.

2. Maximum Retention

There is a limit to the total amount of chemical that can be deposited and retained on the skin. The thin film approach used in the EAB method (EPA, 1987b), the Versar (1984) study, the Kissel et al (1996a) study of soil adherence, and the limiting retention of repellent studied by Rutledge (1988) represent attempts in establishing an upper bound for the estimate of dermal deposition rate. If the limiting factor in dermal retention is overlooked, an overestimate may result.

3. Effects of Washing

Handwashing or showering has been used as standard decontamination procedures for skin. However, there have been a few studies documenting the efficiency of such a hygienic practice. Fenske and Lu (1994) studied the removal efficiency of a standard handwash technique for estimating pesticide residue levels on the hands and found that a substantial amount of pesticide applied to the hands was not recovered from the handwash. If handwashing or bodywashing is used routinely during breaks, a certain portion of the deposited chemical will be removed. Without considering the effect of washing, dermal exposure may be overestimated. However, more specific data are needed to be able to assess the effects of washing on dermal exposure in the actual work environment.

4. Chemical Loss Through Evaporation

Volatile compounds will evaporate from the skin surface. The amount of a volatile compound measured on the skin represents

only the net amount at the end of the sampling period. Obviously, the volatility of the compound, the duration of contact, the original quantity deposited, and the ambient temperature will all have an impact on how much is retained on the skin at any time. A correction factor to adjust the estimate downward needs to be considered.

5. Chemical "Loss" Through Dermal Absorption

For chemicals with a property of rapid absorption through the skin, the amount remaining on the skin will be in constant flux reflecting the balance between the amount deposited and the amount absorbed (assuming little loss from evaporation). If a dermal deposition rate for such chemicals is to be developed through measurement with a pad or wipe sampling technique, the amount measured may not represent the true exposure. Potential "loss" through absorption should be considered to assess exposure hazard through dermal absorption. The skin permeation coefficient method of estimating dermal absorption will be a better approach to addressing such problems.

6. Skin Hydration

Sweating may cause the migration of deposited chemicals from one site to the other or cause the deposited chemicals to fall off the body. It may also cause an increased absorption through the skin. On the other hand, it may increase the adhesion of powdery chemicals. No quantitative estimate of these effects can be made at this time. In general, skin hydration will tend to cause an underestimate of the deposition factor.

7. Transfer Rate from Surface to Skin

Some industrial activities may be more appropriately represented by a method which predicts the amount of contaminant transferred from a surface to the skin. Such activities as monitoring a process from an isolated control room, occasionally entering a process area to visually check equipment and process monitors, taking samples using enclosed sampling apparatus, or opening or closing valves on a piece of equipment are common activities where the primary exposure may result from contact with contaminated surfaces. However, data on the transfer of contaminants from surfaces such as these to the skin is currently not available for industrial operations. This data is important in improving estimates of dermal exposure due to transfer of contaminants from surface to skin in the industrial environment.

8. Activity Patterns

There is very little information available with which to characterize the activity patterns in the industrial environment. Therefore, assumptions regarding the specific worker activities or tasks performed, the duration of exposure, the quantity of material handled, the potential surface area of contact (e.g., 1-hand, 2-hands, palm surface, etc.) are required to be made when estimating the potential for dermal exposure. This information is critical to improving our understanding of the environmental and worker-related factors which contribute to dermal exposure.

Theoretical Studies

In this document, dermal deposition rates are developed for estimating absorption with the fractional absorption approach for both the solid and liquid chemicals. Even though the fractional approach is only appropriate for solids, the lack of adequate skin permeation coefficients for liquid media dictates that the fractional absorption approach be used for liquids.

At the present time, only the theoretical equations for estimating dermal absorption of chemicals in an aqueous solution under "infinite" exposure conditions have been developed by ORD. The permeation coefficients needed for these equations are available for many chemicals either through experimental data or through theoretical estimates.

However, data on permeation coefficients in non-aqueous media, the type of data needed for occupational exposure assessment, are not yet available. This is an obvious area for future research. Furthermore, the ORD equations developed for dermal absorption of contaminants in polluted water will need to be modified or used with different initial and boundary exposure conditions to predict dermal absorption in occupational settings. A wealth of data on surface retention rate for pesticide exposures are available as shown in this document. Studies should investigate how such data can be used in conjunction with the ORD equations to better estimate dermal absorption from occupational exposure.

IX. REFERENCES

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APPENDIX A

STATISTICAL DESCRIPTORS OF ESTIMATED GROSS DERMAL DEPOSITION NORMALIZED BY QUANTITY OF CHEMICAL HANDLED

TABLE A-1

ESTIMATED GROSS DERMAL DEPOSITION RATES NORMALIZED BY QUANTITY OF CHEMICAL HANDLED, ug/cm²/gal, FROM PHED FOR EMULSIFIABLE CONCENTRATE (LIQUID CODE 1) WITH OPEN MIXING (MIXING CODE 1)

OUTSIDE CLOTHING

Body Section	Number of Measurements	Arith. Mean	Standard Deviation	Geometric Mean	Median
head	77	0.0817	0.1551	0.0092	**0.0033**
neck front	23	0.0717	0.0809	0.0367	**0.0450**
neck back	13	0.0859	0.2102	0.0193	**0.0300**
shoulder	81	0.0359	0.0726	0.0075	**0.0050**
upper arms	15	0.0867	0.2235	0.0058	**0.0033**
chest	80	0.0767	0.1593	0.0092	**0.0050**
back	93	0.0267	0.0567	0.0050	**0.0033**
forearms	109	0.8298	4.0432	**0.0292**	0.0342
thigh	64	7.8529	47.9925	**0.0425**	0.0400
shin	14	0.5129	1.8907	**0.0075**	0.0050
calf	22	0.4445	0.8574	**0.0650**	0.0384
ankle	43	1.7005	7.0623	**0.0275**	0.0467
hands	24	141.0904	254.3880	**36.6076**	64.6512

INSIDE PERSONAL CLOTHING

Body Section	Number of Measurements	Arith. Mean	Standard Deviation	Geometric Mean	Median
head	6	0.0008	0.0017	0.0008	**0.0008**
neck front	0				
neck back	0				
shoulder	28	0.0025	0.0042	0.0017	**0.0008**
upper arms	15	2.5837	10.0022	0.0017	**0.0008**
chest	96	0.0409	0.1209	0.0058	**0.0033**
back	82	0.0225	0.0475	0.0033	**0.0017**
forearms	64	0.0459	0.0809	0.0058	**0.0050**
thigh	40	0.0567	0.0909	**0.0092**	0.0133
shin	0				
calf	22	0.0050	0.0158	0.0008	**0.0017**
ankle	32	0.3244	1.7481	0.0025	**0.0017**
hands	45	0.7481	1.5210	**0.0835**	0.1896

Note: Values in shaded area represent the central tendency parameter that best characterizes the distribution of the data: arith. mean for normal distribution, geometric mean for log normal distribution, and median for other distributions.

TABLE A-2

ESTIMATED GROSS DERMAL DEPOSITION RATES NORMALIZED BY QUANTITY OF CHEMICAL HANDLED, ug/cm²/gal, FROM PHED FOR EMULSIFIABLE CONCENTRATE (LIQUID CODE 1) WITH CLOSED MIXING (MIXING CODE 2)

OUTSIDE CLOTHING

Body Section	Number of Measurements	Arith. Mean	Standard Deviation	Geometric Mean	Median
head	20	0.0117	0.0192	0.0033	0.0033
neck front	0				
neck back	0				
shoulder	4	0.0025	0.0042	0.0008	0.0008
upper arms	13	0.0067	0.0125	0.0033	0.0033
chest	20	0.0275	0.0475	0.0083	0.0058
back	20	0.0150	0.0459	0.0017	0.0025
forearms	14	0.1735	0.5079	0.0142	0.0751
thigh	14	0.3987	0.7097	0.0667	0.0801
shin	8	0.0350	0.0542	0.0108	0 0042
calf	0				
ankle	5	0.0142	0.0209	0.0058	0.0025
hands	0				

INSIDE PERSONAL CLOTHING

Body Section	Number of Measurements	Arith. Mean	Standard Deviation	Geometric Mean	Median
head	0				
neck front	0				
neck back	0				
shoulder	0				
upper arms	19	0.0025	0.0017	0.0008	0.0025
chest	14	0.0017	0.0017	0.0008	0.0025
back	14	0.0017	0.0017	0.0008	0.0025
forearms	19	0.0017	0.0017	0.0008	0.0025
thigh	14	0.4262	1.5846	0.0025	0.0033
shin	8	0.0033	0.0008	0.0033	0.0033
calf	0				
ankle	11	0.0017	0.0017	0.0008	0.0008
hands	15	0.0156	0.0185	0.0085	0.0106

Note: Values in shaded area represent the central tendency parameter that best characterizes the distribution of the data: arith. mean for normal distribution, geometric mean for log normal distribution, and median for other distributions.

TABLE A-3

ESTIMATED GROSS DERMAL DEPOSITION RATES NORMALIZED BY QUANTITY OF CHEMICAL HANDLED, $\mu g/cm^2/gal$, FROM PHED FOR AQUEOUS SUSPENSION (LIQUID CODE 2) WITH OPEN MIXING (MIXING CODE 1)

OUTSIDE CLOTHING

Body Section	Number of Measurements	Arith. Mean	Standard Deviation	Geometric Mean	Median
head	15	0.1668	0.5730	**0.0158**	0.0100
neck front	0				
neck back	0				
shoulder	16	0.0292	0.0684	**0.0100**	0.0083
upper arms	6	0.0083	0.0050	**0.0067**	0.0067
chest	16	0.5980	2.1050	**0.0375**	0.0400
back	16	0.0200	0.0284	**0.0917**	0.0067
forearms	6	0.0934	0.1159	**0.0417**	0.0684
thigh	16	0.4971	0.6697	**0.1785**	0.2285
shin	10	5.1433	12.0780	**0.3953**	0.7589
calf	0				
ankle	6	0.0809	0.1218	**0.0309**	0.0142
hands	16	10.6851	16.1038	**2.1101**	3.4866

INSIDE PERSONAL CLOTHING

Body Section	Number of Measurements	Arith. Mean	Standard Deviation	Geometric Mean	Median
head	0				
neck front	0				
neck back	0				
shoulder	0				
upper arms	0				
chest	6	0.0050	0.0067	**0.0033**	0.0025
back	6	0.0025	0.0025	**0.0025**	0.0017
forearms	6	0.0075	0.0067	**0.0050**	0.0050
thigh	0				
shin	6	0.0083	0.0067	**0.0067**	0.0067
calf	0				
ankle	6	0.0042	0.0033	**0.0033**	0.0025
hands	6	1.0821	0.8406	**0.7685**	0.9777

Note: Values in shaded area represent the central tendency parameter that best characterizes the distribution of the data: arith. mean for normal distribution, geometric mean for log normal distribution, and median for other distributions.

TABLE A-4

ESTIMATED GROSS DERMAL DEPOSITION RATES NORMALIZED BY QUANTITY OF CHEMICAL HANDLED, µg/cm²/gal, FROM PHED FOR SOLUTION (LIQUID CODE 4) WITH OPEN MIXING (MIXING CODE 1)

OUTSIDE CLOTHING

Body Section	Number of Measurements	Arith. Mean	Standard Deviation	Geometric Mean	Median
head	23	0.0267	0.0292	**0.0125**	0.0259
neck front	0				
neck back	0				
shoulder	16	0.0334	0.0584	**0.0158**	0.0100
upper arms	16	0.0067	0.0042	**0.0042**	0.0100
chest	23	0.0734	0.1368	**0.0206**	0.0100
back	23	0.0467	0.1334	**0.0075**	0.0100
forearms	23	0.0692	0.1068	**0.0259**	0.0142
thigh	23	0.2769	0.9049	**0.0267**	0.0200
shin	0				
calf	7	0.0058	0.0133	**0.0017**	0.0008
ankle	16	4.3643	11.5709	**0.0776**	0.0575
hands	6	0.1665	0.1215	**0.1363**	0.1082

INSIDE PERSONAL CLOTHING

Body Section	Number of Measurements	Arith. Mean	Standard Deviation	Geometric Mean	Median
head	4	0.0350	0.0125	**0.0334**	0.0292
neck front	0				
neck back	0				
shoulder	13	0.0158	0.0092	**0.0142**	0.0100
upper arms	16	0.0067	0.0050	**0.0033**	0.0100
chest	20	0.0133	0.0158	**0.0058**	0.0100
back	19	0.0267	0.0801	**0.0058**	0.0100
forearms	14	0.0175	0.0150	0.0117	**0.0100**
thigh	20	0.0108	0.0100	**0.0050**	0.0100
shin	0				
calf	7	0.0008	0.0008	**0.0008**	0.0008
ankle	13	0.0158	0.0092	**0.0142**	0.0100
hands	14	0.0558	0.0654	**0.0220**	0.0064

Note: Values in shaded area represent the central tendency parameter that best characterizes the distribution of the data: arith. mean for normal distribution, geometric mean for log normal distribution, and median for other distributions.

TABLE A-5

ESTIMATED GROSS DERMAL DEPOSITION RATES NORMALIZED BY QUANTITY OF CHEMICAL HANDLED, $ug/cm^2/lb$, FROM PHED FOR WETTABLE POWDER (SOLID CODE 1) WITH OPEN MIXING (MIXING CODE 1)

OUTSIDE CLOTHING

Body Section	Number of Measurements	Arith. Mean	Standard Deviation	Geometric Mean	Median
head	25	0.0172	0.0284	0.0032	0.0065
neck front	3	0.0009	0.0008	0.0006	0.0008
neck back	6	0.0004	0.0003	0.0002	0.0003
shoulder	19	0.1415	0.1953	0.0306	0.0764
upper arms	0				
chest	31	0.0696	0.0807	0.0118	0.0157
back	31	0.0356	0.0537	0.0057	0.0130
forearms	33	0.5060	1.4344	0.0345	0.1651
thigh	31	0.2166	0.6961	0.0225	0.0627
shin	7	0.0512	0.0881	0.0055	0.0104
calf	6	0.0032	0.0058	0.0014	0.0010
ankle	7	0.0267	0.0445	0.0038	0.0125
hands	12	11.0889	25.9034	0.3933	1.2306

INSIDE PERSONAL CLOTHING

Body Section	Number of Measurements	Arith. Mean	Standard Deviation	Geometric Mean	Median
head	6	0.0009	0.0002	0.0009	0.0010
neck front	0				
neck back	0				
shoulder	17	0.1014	0.3398	0.0056	0.0020
upper arms	0				
chest	22	0.0637	0.2561	0.0015	0.0010
back	22	0.0656	0.2604	0.0012	0.0010
forearms	19	0.0412	0.0894	0.0094	0.0071
thigh	21	0.0049	0.0065	0.0012	0.0010
shin	7	0.0021	0.0034	0.0005	0.0012
calf	6	0.0009	0.0002	0.0009	0.0010
ankle	7	0.0048	0.0044	0.0007	0.0083
hands	14	0.0279	0.0374	0.0024	0.0127

Note: Values in shaded area represent the central tendency parameter that best characterizes the distribution of the data: arith. mean for normal distribution, geometric mean for log normal distribution, and median for other distributions.

TABLE A-5

ESTIMATED GROSS DERMAL DEPOSITION RATES NORMALIZED BY QUANTITY OF CHEMICAL HANDLED, $\mu g/cm^2/lb$, FROM PHED FOR FLOWABLE POWDER (SOLID CODE 2) WITH OPEN MIXING (MIXING CODE 1)

OUTSIDE CLOTHING

Body Section	Number of Measurements	Arith. Mean	Standard Deviation	Geometric Mean	Median
head	21	0.0118	0.0193	0.0038	0.0037
neck front	0				
neck back	8	0.0008	0.0006	0.0005	0.0007
shoulder	0				
upper arms	16	0.0393	0.0374	0.0235	0.0187
chest	16	0.0927	0.0952	0.0388	0
back	16	0.0354	0.0540	0.0101	0
forearms	24	0.0939	0.1009	0.0374	0
thigh	16	0.6240	1.0084	0.1778	0.[illegible]3
shin	16	0.0366	0.0425	0.0185	0.0246
calf	0				
ankle	0				
hands	0				

INSIDE PERSONAL CLOTHING

Body Section	Number of Measurements	Arith. Mean	Standard Deviation	Geometric Mean	Median
head	0				
neck front	0				
neck back	0				
shoulder	0				
upper arms	16	0.0026	0.0032	0.0020	0.0020
chest	24	0.0018	0.0016	0.0011	0.0015
back	24	0.0011	0.0008	0.0005	0.0015
forearms	16	0.0029	0.0022	0.0023	0.0020
thigh	24	0.0251	0.0729	0.0019	0.0020
shin	16	0.0114	0.0281	0.0035	0.0020
calf	0				
ankle	8	0.0003	0.0004	0.0001	0.0001
hands	25	0.0094	0.0067	0.0047	0.0096

Note: Values in shaded area represent the central tendency parameter that best characterizes the distribution of the data: arith. mean for normal distribution, geometric mean for log normal distribution, and median for other distributions.

TABLE A-7

ESTIMATED GROSS DERMAL DEPOSITION RATES NORMALIZED BY QUANTITY OF CHEMICAL HANDLED, ug/cm²/lb. FROM PHED FOR GRANULE (SOLID CODE 4) WITH OPEN MIXING (MIXING CODE 1)

OUTSIDE CLOTHING

Body Section	Number of Measurements	Arith. Mean	Standard Deviation	Geometric Mean	Median
head	3	0.0011	0.0015	0.0004	0.0003
neck front	0				
neck back	0				
shoulder	11	0.0025	0.0049	0.0006	0.0003
upper arms	3	0.0016	0.0021	0.0009	0.0006
chest	11	0.0036	0.0056	0.0013	0.0007
back	11	0.0006	0.0008	0.0002	0.0004
forearms	11	0.0095	0.0241	0.0023	0.0021
thigh	11	0.0273	0.0654	0.0045	0.0030
shin	0				
calf	0				
ankle	3	0.0336	0.0516	0.0088	0.0065
hands	0				

INSIDE PERSONAL CLOTHING

Body Section	Number of Measurements	Arith. Mean	Standard Deviation	Geometric Mean	Median
head	0				
neck front	0				
neck back	0				
shoulder	0				
upper arms	3	0.0001	0.0002	0.0001	0.0001
chest	8	0.0005	0.0002	0.0004	0.0005
back	8	0.0004	0.0002	0.0003	0.0004
forearms	3	0.0007	0.0010	0.0002	0.0002
thigh	0				
shin	0				
calf	0				
ankle	3	0.0003	0.0005	0.0001	0.0001
hands	3	0.0033	0.0056	0.0002	0.0000

Note: Values in shaded area represent the central tendency parameter that best characterizes the distribution of the data: arith. mean for normal distribution, geometric mean for log normal distribution, and median for other distributions.