DERMAL AND NON-DIETARY INGESTION EXPOSURE WORKSHOP

NERL Human Exposure Research Program
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by

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ABSTRACT

A dermal and non-dietary ingestion exposure workshop was sponsored by U.S. EPA's National Exposure Research Laboratory (NERL) on September 17, 1998. The purpose of this workshop was to gather information on the state-of-the-art in measuring and assessing children's exposures to pesticides via dermal contact with contaminated surfaces and objects as well as by non-dietary ingestion. Although the NERL human exposure research program covers exposure from source to dose, this workshop focused on characterizing concentrations of pesticides in the exposure media (on surface/object) and on quantifying the transfer of contaminants to the skin surface or mouth. The following report discusses the focus of the dermal exposure workshop, summarizes the workshop discussions and identifies research priorities based on a review of the literature, workshop discussions, and expert input.

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I. Introduction

A dermal and non-dietary ingestion exposure workshop was sponsored by U.S. EPA's National Exposure Research Laboratory (NERL) on September 17, 1998. The purpose of this workshop was to gather information on the state-of-the- art in measuring and assessing children's exposures to pesticides via dermal contact with contaminated surfaces and objects as well as by non-dietary ingestion. The workshop agenda and a list of participants are provided in Appendices A and B, respectively. The following report discusses the focus of the dermal exposure workshop, summarizes the discussions held during the workshop, and identifies research priorities based on review of the literature, workshop discussions, and expert input.

II. Goal and objective

NERL is currently evaluating and expanding its dermal and non-dietary ingestion exposure research program. In addition, NERL is charged under the Food Quality Protection Act (FQPA) to study children's total exposure to pesticides. Because direct dermal exposure and non-dietary ingestion are potentially important pathways that are currently difficult to quantify, NERL will be focusing a significant effort on understanding the important factors influencing these exposures. We then plan to develop the data and models required to quantify exposure (contact with a contaminated medium or potential dose) by these routes. We also hope to structure our dermal exposure research program to address the uncertainties and data gaps that can be used to meet NERL's long-term objectives of developing methods for exposure assessments, conducting exposure studies, and reducing the uncertainties associated with exposure estimates.

The September dermal and non-dietary ingestion exposure workshop was part of this research effort. **The goal of this workshop was to gather information on the state-of-the-art in measuring and assessing children's exposures to pesticides via dermal contact with contaminated surfaces and objects as well as by non-dietary ingestion**. Although the NERL human exposure research program covers exposure from source to dose, this workshop focused on characterizing concentrations of pesticides in the exposure media (on surface/object) and on quantifying the transfer of contaminants to the skin surface or mouth.

The five specific objectives of the workshop were to:

1. determine the best approach (quantifying micro versus macro activity exposures) for assessing dermal and non-dietary ingestion exposure,
2. identify methods available to measure dermal and non-dietary ingestion exposure, characterize strengths and weaknesses of each method, and understand how these methods can be used to assess exposure,
3. identify data available to characterize and quantify dermal and non-dietary ingestion exposure,
4. determine what additional data, measurement methods, and models are required to assess dermal and non-dietary ingestion exposure, and
5. identify significant dermal and non-dietary research needs.

III. NERL dermal and non-dietary ingestion exposure research materials

The following materials were prepared for use during the workshop.

A. Conceptual model of the dermal and non-dietary ingestion exposure process

A conceptual model of the dermal and non-dietary ingestion exposure process (Figure 1), including detailed descriptions of the model components for the contaminated surface (Figure 2) and the skin surface (Figure 3), was developed. This model will be used by NERL researchers to identify and prioritize dermal exposure research needs.

The overall model depicted in Figure 1 shows the dermal exposure process from source to absorbed dose. Only dermal contact and non-dietary ingestion are depicted in this figure. Pesticides may be released into the outdoor or indoor environment by residential, commercial, or agricultural use. Once released into the environment, pesticides can transfer from one medium to another (e.g., air to soil) and from one microenvironment to another (e.g., yard to house). Contact with an exposure medium results in an exposure. For these routes, exposure is a function of the mass transfer of pesticide from the exposure medium to the skin or mouth per contact. Contacts resulting in exposure are a function of human activity patterns (indicated by the shaded ovals). Finally, uptake of the pesticide through the skin or the gastrointestinal tract will result in an absorbed dose. The transfer from source to exposure media and from exposure media to the body are only superficially presented in the conceptual model. Each box on the model could be expanded to show in detail the fate and transport of pesticides in the given compartment.

For the purposes of this workshop, two of the model components were developed further. The mass balance for pesticide on the contaminated surface is depicted in Figure 2. Pesticide residues are initially deposited from the air onto the surface. Residues bound to soil and dust can be transferred from the air onto the surface or directly deposited from shoes during track-in events. Important losses from the surface include those due to vaporization and cleaning. Both residues and contaminated particles can be transferred to and from the skin surface during contact activities or irreversibly to the body during mouthing of the contaminated surface.

The mass balance for pesticide on the skin surface is presented in Figure 3. Pesticide can be transferred during contact with any contaminated exposure media. For residential pesticide exposure, transfer from contaminated surfaces such as floors and furniture is potentially significant. Once on the skin, pesticide residues and contaminated particles can be transferred back to the contaminated surface during subsequent contact, loss by dislodgement or washing, or transferred into the body by percutaneous absorption or hand-to-mouth activity.

B. Dermal Exposure Assessment Approaches

Application of this conceptual model will depend on the assessment approach selected. Different assessment approaches provide different ways of integrating exposure over time and space. It is important to understand that the temporal and spatial scale of activity patterns, surface concentrations, and transfer efficiencies that must be measured, will depend on the assessment

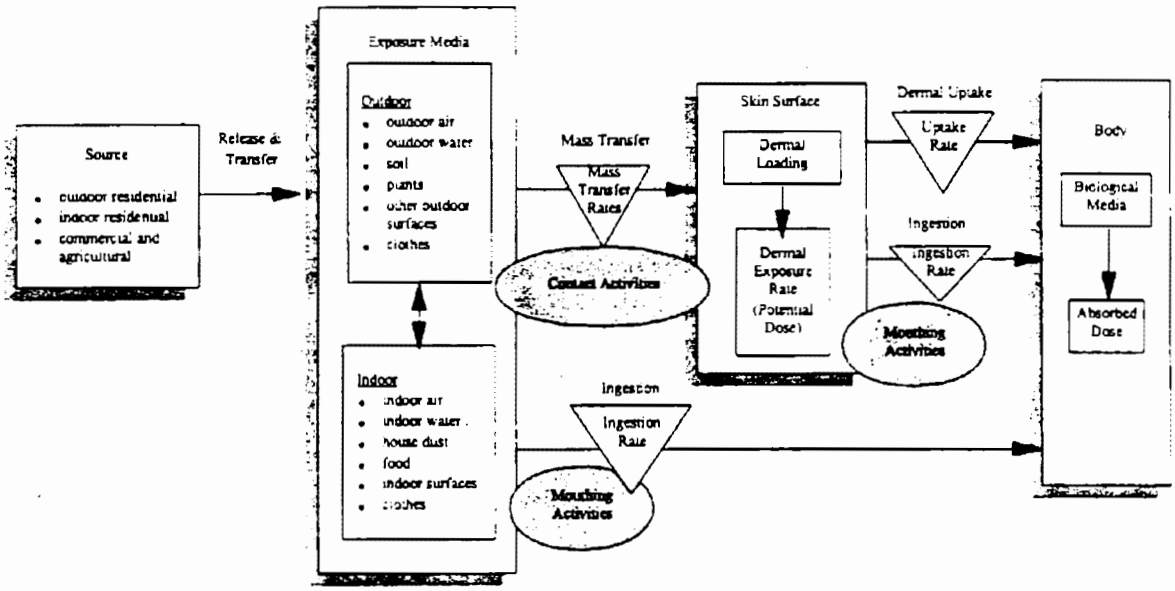

Figure 1: Conceptual Model of Dermal Exposure

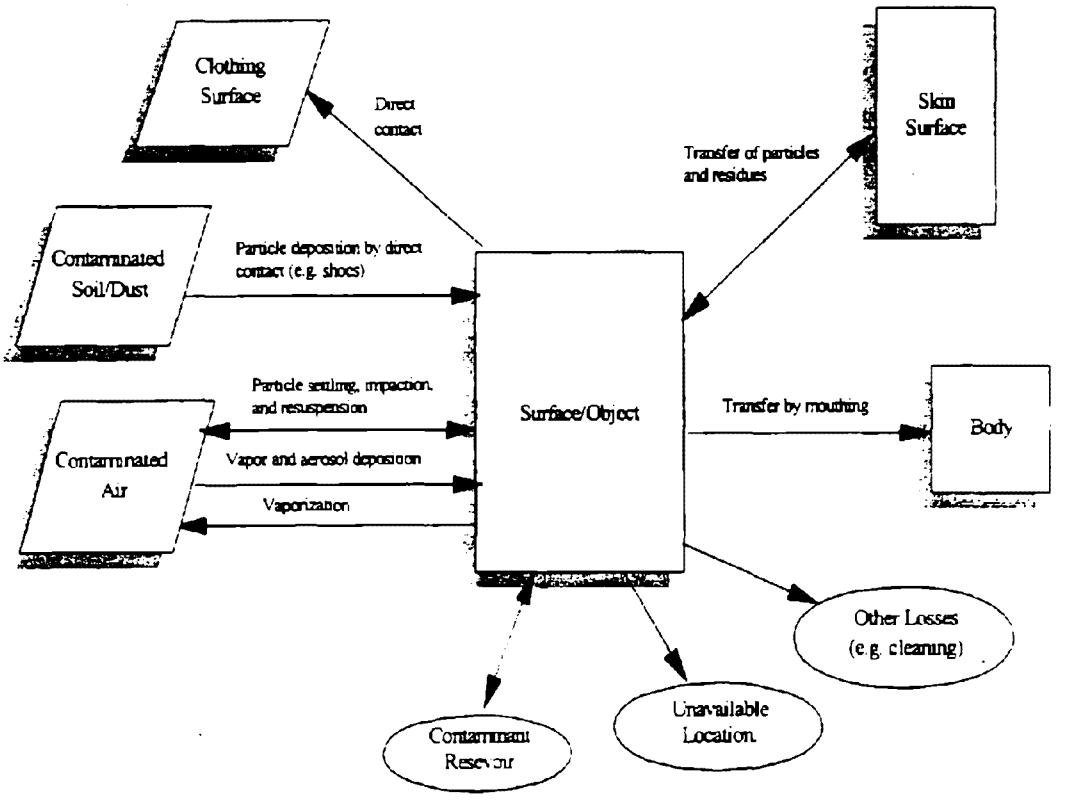

Figure 2 Mass Balance on Contaminated Surface

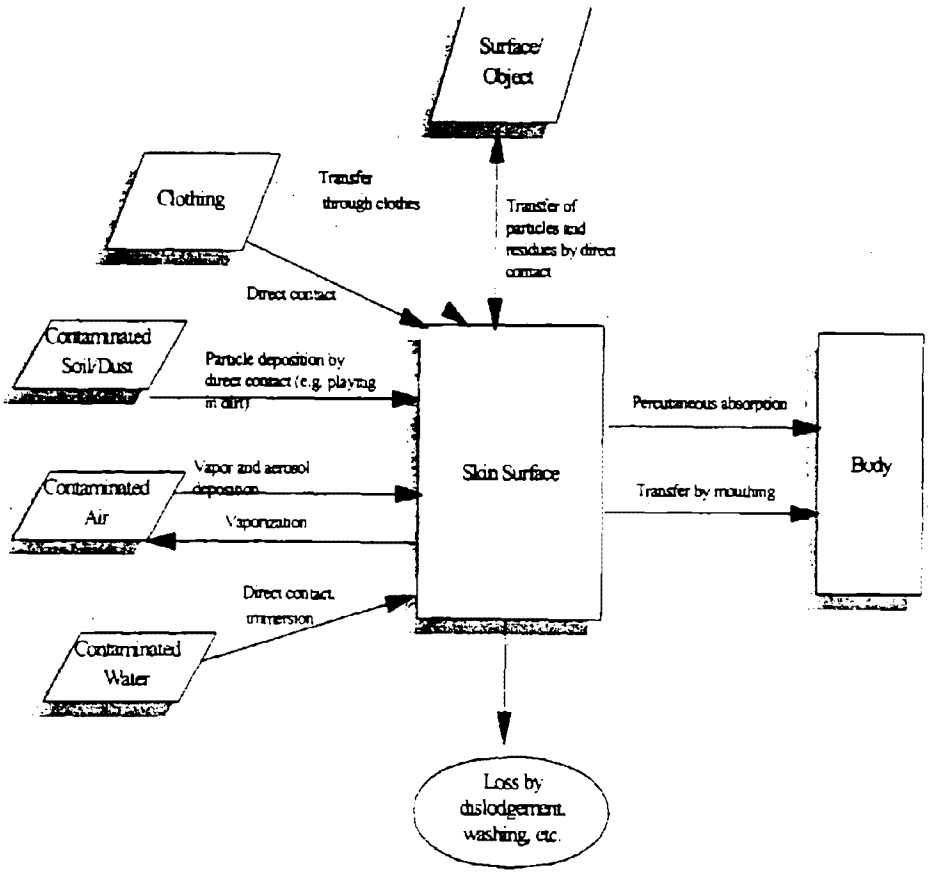

Figure 3: Mass Balance on Skin Surface

approach that is used. Two main approaches are currently used and these are discussed in general terms below.

1. Microactivity approach

In the microactivity approach, dermal and non-dietary ingestion exposure is explicitly modeled as a series of discrete transfers resulting from each contact with a contaminated surface. In this approach, the dermal or non-dietary ingestion exposure associated with a given microactivity or event (e.g., each time a child touches a given object) is quantified, as is the number of times during a day that each microactivity is performed.

$$E_{der}\ (mg/day) = C_{surf}\ (mg/cm^2) \times TF\ (unitless) \times SA\ (cm^2/event) \times EV\ (events/day) \quad (1)$$

Where E_{der} = dermal exposure associated with a given event (mg/day)
C_{surf} = total extractable contaminant loading on surface (mg/cm^2)
TF = fraction available for transfer from surface to skin (unitless)
SA = area of surface that is contacted (cm^2/event)
EV = event frequency (events/day)

The transfer factor, TF, can be further defined as:

$$TF\ (unitless) = TR\ (mg/cm^2) / C_{surf}\ (mg/cm^2) \quad (2)$$

Where TR = transferable surface residue, the mass of contaminant transferred to the skin or a skin surrogate per unit area of contacted surface (mg/cm^2)

The simple equation presented here does not account for variations in transfer efficiency or surface concentration with time and number of contacts. In addition, summation over all events during a given time period is required to predict dermal exposure for a given activity. Data required to use the microactivity assessment approach include measures of total extractable pesticide, transferable pesticide associated with a particular surface, and microactivity information.

2. Macroactivity approach

In the macroactivity approach, dermal and non-dietary ingestion exposure is modeled using empirically-derived transfer coefficients to lump the mass transfer associated with a series of contacts. The macroactivity approach has been used extensively to assess occupational exposure of agricultural workers, and has also been applied in a residential setting for adults performing choreographed reproducible activities. In this approach, the dermal and non-dietary ingestion exposure associated with a given macroactivity (e.g., playing in the yard) is measured and used to develop an activity-specific transfer coefficient.

$$E_{der}\ (mg/day) = ED\ (hr/day) \times TC_{der}(cm^2/hr) \times C_{surf}\ (mg/cm^2) \quad (3)$$

Where E_{der} = dermal exposure resulting from the completion of the activity on which the associated transfer coefficient is based (mg/day)
ED = exposure duration that represents the time spent involved in a specific activity as defined by the transfer coefficient (hr/day)
TC_{der} = dermal transfer coefficient (cm^2/hr)
C_{surf} = total extractable contaminant loading on surface (mg/cm^2)

The transfer coefficient, TC_{der}, provides a measure of dermal exposure resulting from contact with a contaminated surface while engaged in a specific activity. In equation 3, the transfer coefficient has been defined as follows.

$$TC_{der}\ (cm^2/hr) = E_{der}\ (mg/day)\ /[ED\ (hr/day) \times C_{surf}\ (mg/cm^2)] \quad (4)$$

By combining equations (1) and (3) and rearranging, the transfer coefficient can be related to the transfer factor in equation (1).

$$TC_{der}\ (cm^2/hr) = TF\ (unitless) \times SA\ (cm^2/event) \times [EV\ (events/day)\ /ED\ (hr/day)] \quad (5)$$

Equation (5) explicitly demonstrates that the transfer coefficient can be used to lump the uncertainty associated with the transfer efficiency, contact surface area, and contact events into one unknown factor. Dermal loading, exposure duration and aggregate surface loading data are required to develop the activity specific transfer coefficients. Once transfer coefficients are developed, exposure can be estimated by measuring surface loading and activity duration. The dermal transfer coefficient can also be defined in terms of the transferable surface residue. In that case, equation 3, as well as the input data, would need to be modified accordingly.

C. Dermal Exposure Research Questions (Appendix C)

A series of questions was developed using the conceptual model. The questions provide a framework for systematically reviewing the literature and evaluating the important factors for measuring and assessing children's exposures to pesticides via dermal contact with contaminated surfaces and objects as well as by non-dietary ingestion. The resulting information can be used as input to both assessment approaches.

D. Bibliography and Literature Summary Sheets

A thorough review of the dermal and non-dietary ingestion exposure literature was performed. Because several relevant reviews were identified for literature published prior to 1990, the emphasis of this review was on literature published from 1990 to date. Workshop participants reviewed this bibliography and provided the citations for any relevant literature and/or data that had not been included. The revised bibliography is presented in two parts (Appendix D). The first covers the peer-reviewed literature and the second covers U.S. Government reports and other Agency research products. In addition, many of the most significant references were read

and summarized according to the dermal exposure research questions. This summary is presented in Appendix E.

E. Working definitions of dislodgeable and transfer efficiency

In the course of conducting the literature survey and the workshop, it became apparent that there was some discrepancy in the way that individual researchers define the term **dislodgeable**. Researchers in the human exposure field currently use the term in two very different ways.

In the first, dislodgeable residue or dust is defined as the amount of residue or dust on a surface (e.g., carpet) that can be dislodged using extraction methods including HVS3 (e.g., U.S. EPA 1998a). Others define dislodgeability as the percent of the pesticide deposited on, or extracted from, a surface that is actually transferred to the skin (e.g., Camann, D., et al.,1996).

Therefore, for clarity in this report, we will avoid explicitly using the term dislodgeable. We will define the term **extractable surface loading** as the total amount of residue or dust on a surface that can be dislodged using extraction methods. Extractable surface loading is the quantity C_{surf} used in equations 1 and 3. Methods that are used to measure extractable loading include deposition coupons, HVS3, and some surface wipe techniques.

We will define **transferable surface residue** as the amount of residue or dust-bound residue on a surface that can be transferred from the surface to the skin or a skin surrogate (TR in equation 2). Methods such as hand press and PUF roller are used to measure transferable surface residues. **Transfer fraction** or **transfer efficiency** is then the ratio of transferable surface residue to extractable surface loading.

IV. General conclusions and recommendations

The workshop was organized into four breakout groups to cover the following topics: Pesticide concentrations in exposure media and scenarios for exposure, Microactivity approach for assessing dermal exposure, Macroactivity approach for assessing dermal exposure, and Procedures for generating exposure data for children

Each group was given specific questions to discuss and members were charged with identifying data gaps and recommending research needs for the group topic. Each group considered the specific objectives of the workshop. The EPA facilitators guided the group discussions to insure that time was allotted to each of the questions and to keep discussions focused on addressing the group charge. Toward the later part of the session, the group discussion was summarized by the facilitator and the rapporteur. The rapporteurs then presented highlights of the group discussions to all workshop participants. Breakout group summaries were prepared by the EPA facilitators based on group discussions and the rapporteurs' presentations. These summaries are presented below.

A final source of information was obtained from the group of external experts in the field of dermal and non-dietary ingestion exposure who were charged with reviewing the materials

prepared by EPA. Reviewers were also asked to identify the three most important research questions that must be addressed to better understand, quantify, and assess children's exposures to pesticides via dermal contact with contaminated surfaces. Finally, these experts reviewed the NERL bibliography and identified any relevant published materials that were not included.

One of the major issues that was discussed at length during the workshop involved the two assessment approaches (quantifying micro versus macro activity exposures). Workshop participants could not come to a consensus on which of the two approaches should be the focus of future research and exposure assessment activities. Rather it was recommended that both approaches for assessing dermal and non-dietary ingestion exposure be explored.

Research directed toward the **microactivity approach** will increase our fundamental understanding of the mechanistic factors influencing dermal and non-dietary ingestion exposures.

Unfortunately, the data requirements associated with the microactivity approach are extensive and the time and resources required to obtain sufficient data to perform reasonable exposure assessments may be significant.

The **macroactivity approach** affords the possibility of developing screening level exposure assessments in a shorter time frame and with fewer resources than would be required for the microactivity approach. However, the macroactivity approach was developed to assess occupational exposure in an agricultural setting where workers are engaged in similar activities and are exposed to relatively homogeneous environmental concentrations of pesticides. The feasibility of applying the macroactivity approach for the varied activities of infants and children in the heterogeneous residential or other indoor and outdoor environments needs to be studied. The macroactivity approach will only be useful if exposure can be adequately quantified by lumping children's activities into a relatively small number of macroactivities.

Based on all sources of information (the NERL literature review, the workshop breakout group discussions and summaries, and the expert review and input) the following significant dermal and non-dietary data collection and research needs were identified. Only general recommendations are summarized here. More specific research needs will be identified and prioritized in a research strategy that will be published in the peer reviewed literature.

A. Environmental Concentrations

Although significant work has been done on developing methods and on measuring pesticide concentrations in exposure media, more information is needed on the form of the pesticide contamination (residue or bound to house dust), the transferability of the pesticide, the distribution on surfaces throughout a residence, and the variations of these with time. A very significant data gap exists related to the patterns of pesticide use in the microenvironments where children spend the majority of their time. Detailed data are needed on the types of pesticides used and on the application practices both as a function of time and location.

B. Microactivity Exposure Assessment Approach

Very little data on age-specific microactivity patterns have been collected. The need for additional data in this area is significant. Information on the important microenvironments in which children spend time is needed. Once these have been identified, the significant microactivities occurring in the microenvironments need to be determined. Studies are also needed to identify and understand the significant mechanisms and parameters that determine the net transfer of pesticides from a surface to skin and from a surface or skin to the mouth.

C. Macroactivity Approach

The feasibility of using the macroactivity approach to assess children's exposures in a residential setting should be tested with existing data or a small-scale study before additional research priorities in this area are identified. As mentioned above, the macroactivity approach will only be useful if exposure can be adequately quantified by lumping children's activities into a relatively small number of macroactivities. The important macroactivities need to be identified.

D. Studies in Infants and Children

Both the microactivity and macroactivity exposure assessment approaches need to be confirmed. It is universally recognized that to do so, exposure estimates must be compared with biological measurements. Methods for biomonitoring in infants and young children need to be developed and improved.

V. Breakout group summaries

A. Breakout Group 1: Pesticide Concentrations in Exposure Media and Scenarios for Exposure

1. Charge

a. Identify and prioritize important scenarios

Several exposure scenario categories that need further study were identified. However, the Group did not attempt to numerically prioritize such scenarios. These include low-income housing scenarios, because some available data have suggested that low incomes are associated with higher exposures; daycare centers and other locations where very young children spend time have not been as well studied as have residences or school locations where older children spend their time. These exposure scenarios warrant further research, especially since FQPA identifies infants and children as targets for protection.

b. Determine what additional data and measurement methods are required to characterize exposure media concentrations and associated potential exposures for the most important scenarios

The Group recognized that many sampling and analysis methods exist for determining pesticide residue concentrations in a wide variety of media. The available methods are adequate for selected situations, but not for all conditions and pesticides of interest. In general, methods for

residue transfer efficiency are not as robust as those for media concentrations. Perhaps the greatest need in the area of transfer efficiency methods is to better understand the representativeness of the various methods for actual human exposure. Additional data are needed to allow better evaluation of all exposure pathways. Current data are inadequate except for initial approximations; hence, prioritization of scenarios cannot now be done rigorously.

2. *Answers to workgroup questions*

a. Availability of acceptable methods for measuring media concentrations of pesticide residues and their dislodgeability, transfer efficiency, and dermal loading

- For media concentrations, acceptable analytical methods are available for selected but not all situations of concern, and for most, but not all, pesticides.
- Transfer efficiency methods are also available, but are less robust than concentration methods; transfer efficiency test results are highly variable.
- Bioavailability of residues on skin is indeterminate (however, the charge to the Workshop and Group did not encompass this issue).

b. Additional work needed with current methods so that resulting data can be used for exposure assessment

- More study is needed on concentrations in media, changes in dermal loading over time, and residue migration and redistribution among phases and media including dust particles of various sizes.
- Studies are also needed to assess the transfer efficiency and relative bioavailability of residues as a function of age of the residues.
- Sensitivity of methods must be consistent across media. Methods for certain media may need improvement more than those for other media.
- Transfer efficiency methods are surrogates for residue transfer to human skin; the relationships among the various methods, and their representativeness for actual human exposure, are questionable and need more study.
- More studies are needed to be able to apportion the sources and exposure pathways.
- A better understanding of how to interpret dermal loading data is needed.
- A tape stripping method has been reported for evaluating contamination within different layers of skin. This method should be evaluated.
- A better understanding of the relationships between contact variables (pressure, duration, repeated contact, existing dermal loading, wetness, static press vs. smudge, etc.) and transfer of residues from surfaces to skin is needed.
- There is uncertainty about the efficiency of transfer of residues from skin (and other objects) to mouth in mouthing activities
- A broader range of pesticide ingredients and formulations should be studied.
- Correlation between air concentrations and dermal wipe residues was seen in some NHEXAS data; this relationship should be better understood.
- There is a need for an "NHANES for kids" study.

c. Adequacy of existing data to determine highest potential acute and chronic exposures
   - For acute exposure - data are currently inadequate except for preliminary estimates.
   - We need to better evaluate all exposure pathways.
   - For chronic exposure - relative importance of pathways is unknown.
   - There is a lack of knowledge about the distributions of residue concentrations to which the general population is exposed and the changes in these distributions over time.
   - Information on pesticide usage to determine acute exposures to children
   - Currently available information on pesticide usage is inadequate, especially for non-residential settings such as daycare centers. There are ongoing studies trying to address this question.
   - Some states and institutional users may have information which could be obtained about pesticide usage.
   - Usage patterns change over time.
   - Formulation vehicles and application methods are changing over time. These factors affect distribution, dislodgeability, and transfer efficiency.

d. Prioritize exposure scenarios
   - We need to better understand exposure scenarios for children living in low-income housing. These settings may be related to higher exposures.
   - Daycare centers and other exposure scenarios for very young children need more study.
   - The importance of many specific microactivities is not well understood.

3. *Additional Literature and Data Identified During Discussions*

a. Bob Krieger of UC-Riverside has data from a study of a family exposed after a fogger was used; chlorpyrifos metabolite was detected in urine for >30 days. However, these data are not reported in the peer reviewed literature. It is uncertain what the plans are to report these data.

b. A tape stripping method for determining residues at different layers or depths within the skin has been reported in the literature (Tsai et al., 1991; Chambin-Remoussenard et al., 1993).

c. S.C. Johnson Co. conducts usage surveys; perhaps some of their data could be obtained.

d. The Chemical Specialty Manufacturers Association (Jeff Driver of risksciences.com) has a task force study underway; this may be a source of useful information.

e. John Adgate at the University of Minnesota supervises a Master's student working on a thesis on household pesticide inventory data. Jim Quackenboss will obtain a copy of this data when it becomes available.

B. Breakout Group 2: Microactivity Approach for Assessing Dermal Exposure and Non-Dietary Ingestion

1. Charge

a. Evaluate the feasibility of a single event (microactivity) approach for assessing exposure

The feasibility of the microactivity approach for assessing dermal and non-dietary ingestion exposures is not yet known. Under this approach, knowledge about the frequency, duration, and location of a person's activities and contact with contaminated surfaces is combined with information on the transfer efficiency of a pollutant to assess exposure. Since dermal and non-dietary ingestion exposure to many pollutants occurs as a series of discrete transfers resulting from each contact with a contaminated surface, the microactivity approach would appear to offer the most realistic exposure assessment. However, implementing this approach requires a great deal of information about how children's activities affect their contact with surfaces over different time intervals and about the parameters associated with physical transfer of the pollutant from surface to skin, from skin to mouth, and from surface to mouth. Use of a microactivity approach will require much additional information about human activities and pollutant transfer coefficients. Collection of these data will be particularly important for young children since they are likely to have a much greater degree of dermal and non-dietary ingestion exposures resulting from their increased contact with potentially contaminated surfaces.

b. Identify and prioritize important exposure events

On a larger scale, acute dermal and non-dietary ingestion exposure to pesticides will be highest in locations where pesticides have been recently applied. Of particular importance are periods shortly after pesticide application in the places children spend most of their time: indoor residential, outdoor lawn, and daycare or school settings. These scenarios should receive the highest research priority. Due to the persistence of many pesticides in indoor environments, chronic dermal and non-dietary ingestion cannot be ruled out as an important exposure pathway for long-term exposures. Again, the children that spend a great deal of time at locations with a history of pesticide application are likely to be more highly exposed. To understand the relative importance of different exposure pathways for chronic exposure, inhalation and dietary intake data will be need to be collected or evaluated along with dermal and non-dietary ingestion exposure data .

On a micro-scale, there is not much information available to determine the most important individual exposure events. For example, it is not clear whether the cumulative dermal exposure that would result from playing on, or crawling over, a contaminated carpet leads to higher exposures than non-dietary ingestion of dust from the carpet. An order-of-magnitude assessment performed for chlorpyrifos using assumptions found in the Office of Pesticide Programs Standard Operating Procedures for Residential Exposure Assessments (Appendix F) provides a first approximation for prioritizing exposure pathways, and highlights the need for more information to prioritize the most important dermal and non-dietary ingestion exposure pathways for micro-scale events.

c. Additional measurement methods and data requirements

In many cases, existing methods are available and are being applied to gather data that could be used in the microactivity approach. Of particular interest are planned or ongoing studies involving videotaping and activity classifications for children. The monitored activities include children in indoor and outdoor residential settings and activities that could lead to contamination of food as it is consumed by children in home and daycare settings. Activity data derived from these planned studies, and additional data from new well-planned activity monitoring, will need to be organized and made available to researchers with an interest in the microactivity approach. In order to better understand the physical processes of contaminant transfers on a microscale level, additional data must be gathered through research. In particular, transfer factors must be measured for a variety of conditions, with a particular emphasis on conditions that are applicable to young children. Transfer efficiency data that are needed include factors from several different kinds of surfaces, for a range of contact pressures, moisture, and durations, and for a range of contaminants adsorbed to surfaces or on particles. Measurement methods that provide information about transfer efficiency of residues have been developed. More testing is needed to assess comparability of these methods and how well they represent actual transfer to skin and mouth.

2. *Answers to workgroup questions*

a. Advantages of the microactivity approach

- If the microscale activity and transfer parameters are well understood, the microactivity approach should provide dermal and non-dietary ingestion exposure estimates that are much closer to reality than estimates derived from more general approaches.
- Performing research to characterize the activity and transfer parameters will lead to an increased understanding of dermal and non-dietary ingestion exposure pathways, the factors influencing these exposures.
- Both mechanistic (event-by-event) and stochastic (activity and contact distribution) approaches and models can be supported using this approach.
- The microactivity approach requires an understanding of the mechanism that may lead to better characterization of dermal and non-dietary ingestion exposures for younger children.

b. Disadvantages of the microactivity approach

- This approach requires many more data points to characterize or measure exposures.
- Laboratory generation of activity and transfer data will be labor and data intensive, and field studies may also be more labor intensive in order to collect and process detailed activity information.
- The large number of parameters that are needed for modeled or measured exposures may cause increased variability in exposure estimates due to propagation of errors or improper classification of an important variable.

- Understanding single transfer events is very complex due to the wide variety of factors at work (surface area, pressure, moisture, surface type, residue type, etc.) and the short time scales for changes in these factors.

c. Events likely to result in significant exposures
   - Crawling is believed to be one of the most important exposure events due to long exposure times and the large surface area in contact with potentially contaminated surfaces.
   - Non-dietary ingestion resulting from hand-to-mouth activities is potentially very important due to the relatively large mass-transfer potential.
   - Object-to-mouth contact events may be very important due to the direct nature of ingestion and the possible increase in transfer efficiency resulting from saliva contact.
   - Contact with less absorbent surfaces will likely make residues or contaminated dusts more accessible for transfer during contact events.
   - Contaminated clothing may be important because the contact period may be greatly extended.
   - Indirect dietary ingestion exposure (contamination of foods during consumption) may be important because of the direct nature of ingestion and the potential for moisture and saliva increasing the mass transfer of residues.

d. Priority for method or data needs for the events
   - Research and data needs could not be prioritized based on existing data. In general, it is believed that these are all important events for cumulative exposures in children and that data are needed to characterize each event.

e. Temporal and spatial scales
   - Dermal and non-dietary ingestion will occur due to activities that result in contact with contaminated surfaces over time scales of seconds to minutes.
   - On a microscale, the sequence of events is probably important. For example, mass transfer to a hand after the child has put fingers in the mouth may be higher than for a dry hand for some residues. Residues transferred to the skin during one contact may be partially removed from a later contact. Also, residue transfer rates may decrease as repeated contacts are made with a contaminated surface.
   - Contact and residue transfer will be an ongoing process. It may be necessary to classify spatial scales in terms of specific locations (indoor home, lawn, daycare, school) based on the contaminants available for transfer and the specific kinds of activities performed by the child in those locations. It may be possible, from observational data, to classify contact scenarios or parameters for specific locations and to develop activity distributions for children in specific locations. This kind of classification may be built into a macroactivity approach.

f. Data that must be generated to characterize exposure events

- Activity
  - Time factors associated with specific activities (amount of time children spend playing outdoors, watching TV, etc.).
  - Microscale activity frequency and contact parameter data (surface area, pressure, static vs. smeared, wet vs. dry) are needed by location and age.
  - Video data (current collection in several studies) needs to be increased and consolidated.
  - Data needed should be a combination of National Human Activity Pattern Survey (NHAPS) data for general location distributions and video data for distributions of microscale activities within those locations.
- Transfer
  - Experiments are needed for existing methods to provide comparisons (hand wipe, rinse, PUF roller, etc.) and relation to actual exposure [highest priority].
  - Contact duration effects on transfer need to be characterized [second highest priority based on lack of existing data].
  - Wet vs. dry skin and saliva effects on transfer factors need to be measured.
  - Differences and magnitudes of transfer coefficients resulting from different contact factors (surface characteristics, contact surface, contact pressure, static vs. smeared contact, contact orientation) need additional data generation.
  - Negative transfers from skin (losses from the skin back to surfaces during contacts) need to be examined.

g. Methods needed to characterize events

- Videotaping on the appropriate scale to capture important contact events and parameters. Both laboratory and real-world data are needed.
- Biomechanical measurements are needed to better determine the appropriate measurement methods and testing procedures for contaminant transfers.
- Methods that are applied to children at several age ranges are necessary.
- Due to the difficulties in using children in testing methods involving toxic materials, a robotic approach might be considered.
- In general, well characterized methods for measuring surface (or dislodgeable residue) concentrations and residue transfers are needed to provide data for the microactivity approach .

h. Do acceptable models exist?

- The Stanford/Zartarian DERM model is based on the microactivity approach and includes temporal and spatial parameters. It can be used for simulations to evaluate or rank the important parameters and may serve as a starting point for

improved models based on new activity and transfer parameter data that become available.

- Models from EPA (the Residential Exposure Assessment Guideline Method 2.3.2 for example) and other researchers are available for estimating dermal exposures. In general, these models or guidelines do not allow input for all of the time and spatial scales and the multiple contact parameters needed to fully implement the microactivity approach for children. With additional data, it may be possible to revise or update these models if the most important exposure factors and parameters can be identified.
- Non-dietary ingestion parameters or components need to be included in existing models.
- A model for estimating indirect dietary ingestion exposures is currently under development (Berry, EPA) .

i. Confirmation of this exposure measurement approach

- Biomonitoring (urine or blood) is the best way to evaluate the measurement approach, but in order to be applied effectively the following is needed:
  - Absorption rates, metabolic pathways, and kinetics for the chemical of interest
  - A method for measurement of an appropriate biomarker
  - To select the sample collection timing based on the exposure timing and uptake and elimination kinetics
  - To account for other exposure pathways (inhalation, dietary)
- Biomonitoring results within an order of magnitude of estimated exposure may be adequate.
- Using a robot, modeled after a young child, may be an experimental approach worth examining due to the difficulty in performing controlled studies with children and potentially toxic chemicals.
- Could be used in pesticide-treated rooms, turf, etc. where child exposure would not be allowed.
- The robot would need to have the capability to mimic child activities and movements, contact pressures, and surface areas.
- The surface could be covered with material used as skin surrogate (i.e., cadaver skin, artificial skin, others).
- Would not provide information on non-dietary ingestion pathway .

3. Recommendations

It is suggested that these recommendations be carried out in the general order presented so that additional data gathering can focus on the most important needs.

a. Identify the most important pesticides for future study based on the likelihood of dermal contact by children (pesticides used in homes, on lawns, and in daycare or school settings) and potential toxicity.

b. Assess current data for defining activities for young children, including NHAPS and video analysis data for microscale activities in specific locations or situations. Identify the most important needs for additional data gathering for young children's activities . Identify the most important physical contact activities for additional laboratory study of transfer parameters.

c. Develop or refine models based on the microactivity approach. Perform sensitivity testing to identify the most important parameters for children's exposures.

d. Perform a critical evaluation of existing data and methods for dermal transfer parameters. Identify the most important parameters requiring laboratory data gathering needed to reduce the uncertainty in dermal exposure estimates for children. Perform laboratory measurements to define parameter ranges for the most important pesticides and transfer parameters.

e. Perform a critical evaluation of existing data and methods for non-dietary ingestion parameters. Identify the most important parameters requiring laboratory data gathering needed to reduce the uncertainty in dermal exposure estimates for children. Perform laboratory measurements to define parameter ranges for the most important pesticides and transfer parameters.

f. Conduct small-scale field studies for young children to determine if predicted exposures can be confirmed through the use of biomonitoring methods. Perform studies in locations likely to lead to the highest short-term (acute) exposures (i.e., homes or daycare centers where pesticides are routinely applied). Test measurement methods for surface measurements, contact parameters, and child activities that could be used in large scale studies of dermal and non-dietary ingestion exposures for young children .

C.. Breakout Group 3: Macroactivity Approach for Assessing Dermal Exposure

1. Charge

a. Feasibility of macroactivity approach for assessing exposure

The macroactivity approach has been used extensively to assess occupational exposure of agricultural workers. In an agricultural setting, data on worker dermal exposure (from dosimeters such as patches or cotton garments) and data on the amount of pesticide residue on plant foliage that is available for transfer to skin (dislodgeable foliar residue or DFR) are used to derive transfer coefficients. These transfer coefficients are thought to be activity and crop specific, but not pesticide specific. As a result, the transfer coefficients can be used with DFR measurements to estimate exposure to any given pesticide under the working and crop conditions for which the transfer coefficient was derived. The macroactivity approach has also been applied in a residential setting for adults performing choreographed reproducible activities. By studying a choreographed situation, the variability associated with natural human activities in a natural residential environment is minimized and transfer coefficients potentially representing a worst case exposure are derived. Use of this protocol requires confirmation to determine that the transfer coefficients are representative of high-end residential exposures to children .

Because the macroactivity approach was developed for use in the homogeneous agricultural work environment and residential studies have been limited to reproducible activities of adults, the feasibility of the macroactivity approach for assessing children's residential exposure to pesticides needs to be tested. The macroactivity approach may be more easily adapted for use in assessing children's exposures in outdoor residential environments than in indoor environments. In addition, use of this approach to assess non-dietary ingestion will require development of an additional transfer coefficient that is not currently considered for agricultural exposures.

b. Exposure activities

One advantage of the macroactivity approach is that identification of key activities may be less critical than with a microactivity approach. One potential method for implementing the macroactivity approach is to identify the most significant activities of infants and children and then collect data using simulated reproducible activities. Confirmation of the resulting transfer coefficients is then required to relate the results of the simulated exposures to real exposures. A second method is to collect data and develop a distribution of transfer coefficients for children in their natural environment. In this case the macroactivities are likely to be characterized by the microenvironment in which the activity takes place. For example, transfer coefficients would be derived for infants and children at home, at school, and outside. It is hypothesized that these transfer coefficients would be microenvironment and age specific. The need for additional breakdown of activities (e.g., active versus resting, by time spent in a given room in the house) would need to be tested. This second method was the focus of workgroup discussions.

c. Additional measurement methods and data requirements

In order to apply the macroactivity approach, a standard method for obtaining an aggregate measure of residential surface concentration will need to be developed. In addition, acceptable methods for monitoring exposure of infants and children will be required. Biological measurements will be needed to confirm results of the assessment approach. Data relating children's activities to dose would also be needed to identify key activities.

2. *Answers to Workgroup Questions*

a. Advantages of macroactivity approach

- Approach has been used successfully to assess occupational exposure to agricultural workers.
- Potentially lower data requirements over microactivity approach. Need to obtain aggregate measure of residential surface concentration and measure of exposure.
- Could provide useful (possibly screening level) assessment in less time.
- Fewer parameters may result in less correlation error.

b. Disadvantages of macroactivity approach

- Approach is not clearly feasible.
- Problems associated with exposing children.
- Unlike the agricultural environment, the residential environment is heterogeneous.
- Unlike occupational activity patterns, children's daily activities are heterogeneous.

c. Can we overcome disadvantages
   - Don't know
   - Recommend looking for test cases in existing data
     - Minnesota pesticide study
     - Environmental and exposure monitoring associated with the "1996 Methyl Parathion ATSDR Public Health Advisory"

d. Key activities
   - The general lack of data relating children's activities to dose, make this question difficult to address.
   - Key activities may be less critical with a macroactivity approach.

e. Temporal and spatial scales
   - Both temporal and spatial scales will be greater than for the microactivity approach.
   - Scales will be age specific.
   - Important time scales
     - Time between application and exposure
     - Time of loading (exposure)
     - Time until bathing
   - Important spatial scales
     - Microenvironment
     - Hands
     - Whole body

f. Data needs
   - Skin loading (dermal exposure)
   - Aggregate measure of surface concentration available for transfer to skin (comparable to DFR in agricultural assessments)
   - Exposure duration
   - Biological measurements of metabolites (dose)

g. Available methods
   - Overall method for using this approach is available from experience in agricultural exposure assessment.
   - Methods need to be developed for measurement of aggregate surface concentration
   - Methods for study of children or child surrogates

h. Confirmation of approach
   - Need child studies with environmental, skin loading, and dose data

3. *Recommendations*

a. Identify test cases in existing data to determine if application of the macroactivity approach for assessing dermal exposure is feasible.

b. Need agency standard for age group (or physiological development) breakdowns for use by all researchers.

4. *Additional literature and data identified during discussions*

a. EPA's National Center for Environmental Assessment (NCEA) has a group that is currently developing a standard for age-group breakdowns for children, 6 months to 21 years. Rob Elias chairs that group.

b. Literature and data from environmental and exposure monitoring associated with the "1996 Methyl Parathion ATSDR Public Health Advisory." EPA participants in this project may have included Drs. Elmer Akin, David Charters, J. Milt Clark, and Jon Rauscher. In this project extensive environmental monitoring was conducted and absorption was assessed using urinary biomarkers.

D. Breakout Group 4: Procedures for Generating Exposure Data for Children

1. *Charge*

a. Determine best approach for studying pesticide exposure to young children and infants. Determine what additional data and measurement methods are required to quantify dermal and non-dietary exposure of children

Consideration of approaches included both dermal exposure (contact) and non-dietary ingestion exposures. The age groups of concern, in terms of the need to determine (and document) if there are actually differences in exposures (and/or body burden), include infants and young children (e.g., 0-6 months, 6-12 months, and 1-3 years in age). Identification of the "best" approaches requires an appreciation of how these data will be used to conduct risk assessments, and to identify options for risk management which are both "safe" and "reasonable."

2. *Answers to Workgroup Questions*

a. Since you cannot intentionally expose children to pesticides or other toxic substance what are the approaches that can be used to generate the required data?

b. What are the advantages and disadvantages to these approaches?

Several approaches were discussed, and the advantages and limitations of each were identified:

- **Biomonitoring** was discussed at length as providing the "best" indicator of distributions of aggregate exposure.

  Advantages: Biomonitoring integrates all routes inhalation, ingestion, and dermal absorption) and incorporates all activity patterns (related to contact and uptake/intake). The biomarker measurements can be conducted with known

accuracy, and provide a "benchmark to judge" and/or a "foundation to develop" exposure (and dose) models and assessment practices.

Limitations: It may be difficult to collect urine samples from infants and young children. There is a need for reliable collection and analysis methods, accounting for possible interferences and difficulties in extraction of pesticidemetabolites from urine in diapers, and to determine or estimate (e.g., from weight) urine volumes. Some concerns have been expressed about the use of creatinine to adjust for the volume/concentration of urine with children. There are also difficulties in identifying the relative contribution of different routes and pathways (environments and sources), which indicates the need to make these measurements in conjunction with environmental and exposure monitoring. There must be reliable and sensitive methods available to analyze for the major metabolites of the target pesticide compounds. Interpretation of the relationship of the metabolite concentrations to exposures requires knowledge of pharmacokinetics and requires information (or involves assumptions) on the timing and routes of exposures (relative to experimental settings).

- **Environmental** (e.g., air, water, surfaces), **exposure** (air, dermal, diet), and **activity pattern** measurements should be made at the same time as biomonitoring. These may be done in focused (or "situational") studies (e.g., post-application), or in population probability-based surveys (stratified by usage), and/or under simulated (experimental/controlled) conditions.

  Advantages: This combination provides evidence of the "total" (aggregate) exposure under the conditions of study, as well as information to estimate/evaluate the relative contributions of each route, and the influence of activity patterns (e.g., diary reports and/or videography) on the frequency and magnitude of exposures .

  Limitations: These studies are usually only able to observe/measure concentrations and exposures in a limited number of locations. It is difficult, both in terms of cost and feasibility, to collect samples of environmental media concentrations from sites which are "representative" of those likely to be contacted by the study subject (e.g., stratification of air and surface concentrations and availability).

- **Passive dosimetry** (body suit, patches) can be used to measure/estimate dermal exposure under specific conditions and time periods (e.g., post-application).

  Advantage: The dosimeter can be calibrated to estimate the proportion of the suit/patch measurement (concentration/loading) that would be transferred to the skin, and the portion of this that would be absorbed (rate). Patches can be done in

conjunction with biomonitoring studies (without interfering with the exposure and absorption). It might be feasible to use patches with infants.

Limitations: The (structured) activities of adults then assumed to represent those of children (unstructured) as they relate to calculation and use of a transfer coefficient (cm2/hr). It can be difficult to extrapolate from patches to other skin surfaces, both in terms of differences in exposures and the transferability and retention of the patch relative to skin.

- **Fluorescent tracer** methods can be used with children.

  Advantages: this provide quantitative estimates of dermal exposure (qualitative for hand-to-mouth).

  Limitations: There may be some masking of surfaces; difficult to obtain measurements from cylindrical surfaces (e.g., arms and legs). Differences between the characteristics of the tracer and the target chemical may result in differences in the distribution of the materials in the home, and in transferability to the skin.

- **Dermal wash/rinse/wipe** methods can be conducted with children for easily accessible surfaces (e.g., hands). There were some concerns about the effects of different solvents (isopropyl alcohol) on extraction efficiency or sample stability.

  Advantages: This provides a measure of the dermal loading/concentration on the hands which is important for determining the potential for exposures associated with mouthing events. The hands are frequently uncovered and are the point of contact (exposure) with surfaces, so that a hand wipe/rinse is useful to say if there is evidence of any dermal exposures. In controlled studies, this can be used to assess recovery of residues from the skin.

  Limitations: The sample is usually taken at a single point in time, and provides an indication of the portion of the previous exposures which have not been absorbed (or removed from the skin). It is probably a better indicator of the environmental concentrations on surfaces contacted by the child than of the absorbed dose.

a. What type of data currently exist for children to evaluate dermal exposure methods or models? From NHEXAS, NHANES, other field studies?

There was only limited discussion of the currently available field studies. (Some of this had been discussed in a previous workshop on Activity Patterns). The Minnesota Children's Pesticide study (component of the NHEXAS study) provides concurrent biomonitoring, exposure (air, diet, dermal), environmental (air, water, soil/dust), and activity patterns (self-reporting, limited videography) for a sample of children, ages 3-12, selected with an emphasis on households with

more frequent indoor insecticide use. NHANES-III provides reference ranges for pesticide metabolites in adult urine samples (not intended to be a representative probability sample). Plans for NHANES-IV are to collect and analyze urine samples from children ages 6 and older.

b. What additional data are needed?

- Concurrent biomonitoring and exposure/environmental/ activity monitoring studies are needed for infants and young children. This requires some development of methods for:
  - Biomonitoring -- both laboratory and field sampling (i.e., for collection and analysis of urine samples);
  - Screening techniques which are reliable, sensitive, and low cost. For example, the identification of exposed populations to OP pesticides would be improved by improving the detection limits for alkyl phosphates (from ~25ppb to ~5 ppb).
- Realistic estimates of the ranges of aggregate exposure, as determined from biomarker data, are needed:
  - to provide risk managers with a determination of whether there is an immediate need to take actions to reduce exposures,
  - to determine if the current screening-level assessments (SOPs) are "realistic" in representing potential exposures in the aggregate, and
  - to provide a basis for developing and evaluating (validating) improved models of aggregate exposure (and dose).
- There is a need for more data on the activities/behaviors of infants (e.g., 0-6 months) and young children (e.g., crawling, 6-12 months).

c. Can we evaluate dermal models? What is the best way to do it?

- **Dermal exposure**. The basic information needed to develop and evaluate models of dermal exposure could be developed in experimental studies/settings. This allows one to control/modify the factors relating to exposures and focus on the dermal route.

  Advantages: This approach provides an understanding of the factors which influence dermal exposure.

  Disadvantages: There is a need to have marker compounds that can be safely used with children, since there are physical and flexibility differences between children and adults. There are possible adjustments that can be made for these differences when detailed biomechanics measurements can be collected for a sample of children and applied to the exposures of adults. Another approach suggested was the possibility of linking the activities of unexposed children to that of a robot in an exposure chamber.

- **Dermal dose**. Consideration of dermal exposure in the context of its contribution to aggregate exposure and risk also requires determination of the relative bioavailability and uptake/absorption of pesticides via the dermal route. A distinction was made between the potentially exposed surface area (total area of hand, ~400 cm2) relative to the likely contact area (~55 cm2) and the implication of this for dermal loading and mouthing-related ingestion (area of fingers < total hand). Information is needed on:
  - the transfer of materials from surfaces to the skin from repeated contacts (effects of increasing dermal loading and decreasing surface loadings);
  - extraction efficiency of the mouth (i.e., saliva and sucking/licking motion) for both residues and particles (with residues).
- **Indirect (non-dietary) ingestion**. There was some discussion of how to distinguish the contributions (to aggregate exposure) of dermal and ingestion routes. One approach is to identify a model compound which would have a different metabolic profile following oral and dermal dosing, and metabolites which could be measured in urine.

3. Recommendations

a. Perform biomonitoring studies to provide a realistic estimate of the distribution of aggregate "exposures" for children. These studies have immediate value in determining the likely ranges (including "high-end") of exposures which may be associated with pesticide use. For purposes of determining the relative contribution of different routes, pathways, contact activities, and sources to aggregate exposures it is important to include environmental and exposure monitoring (concurrent with biomonitoring). The major microenvironments of interest include residential (indoor/outdoor),daycare, and school settings (and possibly other locations where there is limited mobility, e.g., hospitals). The age groups of special concern include 0-6 month, 6-12 month, and 1-3 year old children. These studies could be done either as field studies or experimental studies. Field studies include both probability surveys and "opportunistic" studies following application events. Surveys may be stratified by usage and time, to provide adequate representation of the more "highly exposed" individuals and time-periods. Time-periods relevant to use-events include both the immediate post-application time frame and extend for two-to-three weeks thereafter. Experimental (controlled) studies conducted in test chambers, or outdoor locations, are useful to address mechanistic questions.

b. Exposure/dose models need to be simple, must be capable of representing "high end" exposures {highest priority need}, must be realistic (within some margin of error), and must specifically address children's acute and chronic exposure (age-related exposure, activity/behavior). Exposure models should be evaluated using biomonitoring measurements. An immediate need is to evaluate the acute exposures predicted by the EPA/OPP's current SOPs. These are a series of scenario-based "models" (set of default assumptions) for various types of residential pesticide applications. They were developed to meet a short term need, and were based on information that was currently available as a consensus (based on professional judgement). Major uncertainties in these include the frequency (and timing) of hand-to-mouth

activities, the use of transfer factor/coefficients for children, and the availability/transferability of residues from surfaces.

APPENDIX A

AGENDA

7:45	Registration
8:00	Introduction
	NERL dermal exposure research program
	Conceptual model for dermal exposure process and exposure assessment methodologies
	EPA literature review
	Charge to breakout groups
10:00	Breakout groups 1. Pesticide concentrations in exposure media and scenarios for exposure 2. Single event (microactivity) approach for assessing dermal exposure 3. Integrated activity (macroactivity) approach for assessing dermal exposure 4. Procedures for generating exposure data for children
12:00	Lunch
1:00	Breakout continued
2:30	Report on results of breakout discussions
4:00	Summarize most significant uncertainties and data gaps associated with use of measurements to assess dermal exposure
5:00	Adjourn

APPENDIX B

LIST OF PARTICIPANTS

Group 1	
Edwin Furtaw	EPA/ORD/NERL-LV (EPA Facilitator)
Marcia Nishioka*	Battelle - Columbus (Rapporteur)
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APPENDIX C

DERMAL EXPOSURE RESEARCH QUESTIONS

(focused on children's exposure to pesticides due to contact with contaminated surfaces)

Transfers from Source to Exposure Media

- What are the significant sources of pesticides on contaminated surfaces that lead to dermal exposure?
- What are the scenarios for transfer of contamination from the source to an environmental medium and then to a surface or object (e.g. track in)?
- What measurement methods and models are available to relate sources of contamination to contamination on surfaces and objects?

Exposure Media

- What are the concentrations on surfaces and objects (distinguish between total concentration and concentration available for transfer to skin)?
- What are the characteristics of the contamination (e.g. deposition form, physicochemical properties)? How do these characteristics vary with time?
- What are the characteristics of contaminated objects and surfaces?
- What methods and models are available to measure and predict contaminant concentrations on surface and objects?

Transfer from Exposure Media to Skin

- What are the major parameters that determine fraction and rate of mass transfer from the exposure media to skin?
- How do characteristics of the skin affect mass transfer?
- How do characteristics of contaminated objects and surfaces affect transfer?
- How do the characteristics of the contaminant and the material being transferred affect transfer?
- How does the type of contact affect mass transfer (contact pressure, motion, frequency, duration)?
- How do environmental conditions affect mass transfer?
- What methods and models are available to measure and predict mass transfer rates and transferable fraction?

- How can measurements of transferable fraction and mass transfer be used to estimate exposure?

Contact Activities

- Which objects and contact events contribute significantly to dermal exposure?
- What is the frequency and duration of sequential contacts between various skin surfaces and exposure media?
- What is the spatial distribution of contact events over the surface of the body?
- What activities contribute to removal of contaminant from the skin (e.g. hand washing, mouthing)?
- What are the activity patterns of susceptible subpopulations (children)?
- What methods are available for quantifying and characterizing (e.g., contact pressure and motion) contact activities?

Dermal Loading

- What are the mechanisms (pathways) by which chemicals can be loaded onto the skin surface? What are the important parameters for characterizing these pathways?
- What are the mechanisms by which chemicals can be lost from the skin surface (e.g., mouthing)? What are the important parameters for characterizing these losses?
- How can measurements of dermal loading be used to estimate exposure (applied dose)?
- How can the variation in dermal loading over time and body region be assessed?
- What measurement methods are available to assess the contaminant adhering to skin surfaces?
- What models are available to predict dermal loading and to relate dermal loading measurements to exposure?

Non-dietary Ingestion (mouthing of skin surfaces contaminated by contact with contaminated surfaces and objects, and direct mouthing of contaminated objects and surfaces)

- What activities are important for characterizing non-dietary ingestion of pesticides?
- What models and measurement methods are available to estimate and predict exposure to pesticides by non-dietary ingestion?

Dose/Uptake

- What are the major parameters that determine uptake of pesticide residues and residues bound to particles through skin?
- How do characteristics of the skin affect uptake?
- How do the characteristics of the contaminant affect uptake?
- How can biological monitoring be used to estimate dose due to dermal exposure?
- How can biological measurements be disaggregated to estimate exposure by route?
- What models are available to relate dermal loading of and exposure (applied dose) to particles and residues to uptake and absorbed dose?

APPENDIX D

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APPENDIX E

U.S. EPA SEPTEMBER 1998 DERMAL EXPOSURE WORKSHOP

SUMMARY OF LITERATURE REVIEW FOR MEASUREMENT METHODS AND RESULTS

Surface Measurements

- Extractable Residues
- Extractable Dust/Soil
- Transferable Residues
- Transferable Dust/Soil

Dermal Loading Measurements

- Dust/Soil Adhesion
- Whole Body Dosimeters and Hand Wipes

Non-Dietary Ingestion

Method	Results
Surface Measurements	
Extractable Residues Following Application	
Chenseng, 1998 The purpose of this study was to measure surface concentrations of chlorpyrifos following broadcast or aerosol applications. Deposition samples were collected by applying double-layer 12-ply cotton 7.6 x 7.6 cm gauze pads to randomly selected areas of carpet before application.	After broadcast treatment carpet deposition sample loadings ranged from 19.7 to 22.3 $\mu g/cm^2$; furniture deposition sample loadings ranged from 0.003 to 0.004 $\mu g/cm^2$. After aerosol treatment carpet deposition sample loadings ranged from 2.7 to 2.9 $\mu g/cm^2$; furniture deposition sample loadings ranged from 1.79 to 1.83 $\mu g/cm^2$; wall deposition sample loadings ranged from 0.06 to 0.09 $\mu g/cm^2$.
Fenske, 1991 Commercial broadcast application of chlorpyrifos (0.48 to 0.5% in aqueous solution) was performed at three residential and one office location. Deposition samples were collected on treated surfaces in three of the four study sites and on untreated surfaces for three of the four study sites. Deposition samples were collected on 100 cm^2 aluminum foil squares.	Mean deposition loadings measured on treated surfaces immediately after application ranged from 4.7 to 24 $\mu g/cm^2$ (mean 13.6 $\mu g/cm^2$) at one site; 1.2 to 5.1 $\mu g/cm^2$ (mean 3.2 $\mu g/cm^2$) at a second site; and 0.7 to 3.7 $\mu g/cm^2$ (mean 1.9 $\mu g/cm^2$) at a third site. The variability across sites, even when using similar application methods, shows the importance of measuring actual deposition for comparability across studies.
Nishioka, 1996 2,4-D and dicamba were professionally applied to lawn turf to examine dislodgeable residue, track-in, and temporal changes. Applied turf levels are reported here.	Turf levels of applied herbicides were 26.7 ± 10.0 mg/m^2 for 2,4-D and 1.7 ± 0.9 mg/m^2 for dicamba.
Ross, 1990 Home foggers were activated in hotel rooms with carpeted floors, most furniture removed, under controlled conditions of access and ventilation. Deposition samples were collected on the floor at four locations to measure chlorpyrifos and allethrin. Deposition samples were collected on 400 cm^2 aluminum sheets and on 12-ply gauze pads placed in dosimeters with 23.8 cm^2 exposed surface area.	Chlorpyrifos deposition measured on aluminum sheets ranged from 0.20 to 4.75 $\mu g/cm^2$ across the four different locations and six different treated rooms. The largest range within one room was 0.20 to 1.18 $\mu g/cm^2$ in opposite corners of the room. Chlorpyrifos deposition measured on gauze pads (placed next to the aluminum sheets) ranged from 0.47 to 4.75 $\mu g/cm^2$. The largest range within one room 0.47 to 4.75 $\mu g/cm^2$. Deposition rates measured with gauze pads were usually higher than rates measured with aluminum foil, with ratios ranging from 0.76 to 8.8; typically the ratio was near 1.5 to 2. Allethrin deposition ranged from 0.10 to 0.40 $\mu g/cm^2$ as measured with aluminum sheets, and from 0.14 to 0.31 $\mu g/cm^2$ measured with gauze pads.

Method	Results
Wright, 1984 This study measured deposition of chlorpyrifos and Diazinon following crack and crevice application. Tests were performed in 12 nonoccupied dormitory rooms. Aerosol or emulsion application of the pesticides at 0.5% or 1% concentrations were made with commercial application equipment into cracks and crevices to simulate treatment for cockroaches. Pie plates were placed on a table in the rooms during pesticide application and were immediately samples after the application was finished and one day post-application. Residues were measured by placing stainless steel and formica plates on a table in the center of the room. Plates were sampled, using the wipe procedure, to recover pesticide residue at selected post-application intervals. Wipe samples were collected from the stainless steel and formica plates using cotton balls saturated with 10 mL of isopropanol. Two wipe samples were collected from an 80 cm^2 area. Wipe samples were collected at 1,3,7,14, and 42 day intervals.	Diazinon was measured on the pie plates at 20 to 30 ng/cm^2 immediately after application and was not detected one day later. Chlorpyrifos was measured at 100 ng/cm^2 immediately after application; the loading decreased to 1 to 2 ng/cm^2 one day after application. No difference in deposition was observed between the aerosol and emulsion applications. Chlorpyrifos residues on the steel and formica plates ranged from 1,000 to 3,400 ng/cm^2 on the day of application, decreasing to 50 to 130 ng/cm^2 7 days post-application and 20 to 100 ng/cm^2 42 days post application. Diazinon residues ranged from 700 to 1,600 ng/cm^2 on the day of application, decreasing to 290 to 660 ng/cm^2 7 days post-application and 310 to 370 ng/cm^2 14 days post application
Camann and Harding, 1996 Broadcast application by professional pest control applicator; applied according to label instructions; ventilation for 2 hrs after. Extractable residue measured using deposition coupons collected on day of application.	Flooring / Active Ingred. / Floor Conc (ng/cm2) plush nylon carpet — Chlorpyrifos — 13,500 plush nylon carpet — Chlorpyrifos — 19,800 loop polyethy-ene carpet — Chlorpyrifos — 10,600 plush carpet (used) — Chlorpyrifos — 5,800; Piperonyl But. — 5,760; Pyrethrin I — 555 Sheet vinyl (new) — Chlorpyrifos — 8,000; Piperonyl But. — 7,600; Pyrethrin I — 1,200 Others also reported

Method	Results
Currie, 1990 -A commercial air sprayer was used to apply insecticides to the floors of seven offices (3 with carpet sprayed with Diazinon, three with carpet sprayed with chlorpyrifos, and one office with a vinyl floor sprayed with bendiocarb). -Air samples were collected prior to application, during application, and at intervals of up to 10 days post-application. -Surface deposition samples were collected by placing aluminum pans on the floor and at selected heights above the floor and removing them for extraction at intervals over the first 24 hours post-application. -Wipe samples were collected from the floor aluminum pans and from furniture in the offices at intervals of 1 - 2 hours, 24 hours, and 48 hours post-application. Two isopropanol-soaked gauze pads were used to wipe an area of 33 cm^2, with the pads drawn across the surface in both directions	Diazinon Results: -Deposition on aluminum plates ranged from 0.4 to 15 ng/cm^2. Concentrations on suspended plates generally had higher amounts 24 hr post-application than they did 1 - 2 hr post-application. -Wipe samples measured loadings ranging from 13 to 38 ng/cm^2. Chlorpyrifos Results: -Deposition on aluminum plates ranged from 0.24 to 3.16 ng/cm^2. Concentrations on suspended plates generally had higher amounts 24 hr post-application than they did 1 - 2 hr post-application. -Wipe samples measured loadings ranging from <0.3 to 5.9 ng/cm^2. Bendiocarb Results: -Deposition on aluminum plates ranged from 2.1 to 3.1 ng/cm^2. -Wipe samples measured loadings ranging from 11 to 25 ng/cm^2.

Method	Results
Extractable Dust/Soil	
Simcox, 1995 Pesticide levels found in the soil of agricultural homes was compared to nonagricultural homes. Soil samples were taken from children's outdoor play areas (26 cm x 26 cm). The top 0.5-1.0 cm of soil was taken and extracted to target four commonly used pesticides: phosmet, chlorpyrifos, azinophosmethyl, and ethyl parathion. The samples were sieved through 425 μm mesh and desiccated. The samples were then pre-wet with 400μL distilled water and 50 mL acetone, then sonicated. Household dust samples were collected with a HVS3 vacuum and extracted to target the same four pesticides. The target sample weight was 5 g ; samples were sieved through a 150 μm mesh sieve.	Organophosphorous pesticide concentrations in soil (mean, ng/g): azinophosmethyl: Ag families 60; Reference families <32 phosmet: Ag families 26; Reference families <7 chlorpyrifos: Ag families 17; Reference families 11 ethyl parathion: Ag families <34; Reference families <34 Organophosphorous pesticide concentrations in household dust (mean, ng/g) azinophosmethyl: Ag families 1870; Reference families 330 phosmet: Ag families 2080; Reference families 227 chlorpyrifos: Ag families 429; Reference families 168 ethyl parathion: Ag families 365; Reference families 76 Significantly higher levels of pesticides were found in the homes of agricultural families. Much higher levels were found in household dust (see below), where chemicals are not degraded or dispersed by environmental factors.
Bradman, 1997 This pilot study was to assess the level of pesticide contamination in rural children's home environments. Carpet dust was sampled with an HVS3; linoleum floors were sampled with a modified canister vacuum and hose. The carpet dust samples were passed through a 150 μm sieve and weighed. Bare floor dust samples were collected on a pre-weighed filter, which was re-weighed after sampling.	Diazinon was detected at four farmworker homes, with loading that ranged from 31-149 $\mu g/m^2$. This pesticide was detected in two non-farmworker homes, with loadings of <2$\mu g/m^2$ at the daycare center and up to 14$\mu g/m^2$ in the other home. Chlorpyrifos was detected in four farmworker homes and one non-farmworker home. The loading in the farmworker homes ranged from not detected to 14 $\mu g/m^2$. The loading in the non-farmworker home was up to 2 $\mu g/m^2$. Chlordane and t-nonachlor were detected in the daycare center and Fresno home at 1 to 3 ug/m3. Most other pesticides detected in housedust were well below 1 $\mu g/m^2$.

Method	Results
Budd, 1990 The purpose of this work was to field test the HVS2 to provide preliminary data on the amount and characteristics of dust in residences, the concentration of 30 pesticides in house dust, and to validate the methodology of the HVS2 in a nine-home pilot study. The surface loading was calculated by dividing the total mass of the pesticide by the area samples (ng/m^2)	An average of 11.8 target pesticides were identified in the floor dust in the nine sites. The highest concentrations in ng/m2 were found for o-phenylphenol (32,000), Diazinon (57,000), chlorpyrifos (190,000), chlordane (184,000), cis-permethrin (21,000), and trans-permethrin (26,000). The range across nine homes for a few of the 30 pesticides were: for chlorpyrifos 260 to 190,000 ng/m2; for chlordane 225 to 184,000 ng/m2; dieldrin 32 to 7400 ng/m2; for Diazinon 22 to 57,000 ng/m2; and for propoxur 460 to 42,000 ng/m2. The only relationship found with any physical or socioeconomic variables was between the number of pesticides and the age of the home.
Roberts and Ruby, 1989 (Method development) The high volume surface sampler (HVS2) was evaluated as a method to collect house dust (including semi-volatile organics). The goal was to have a known and reproducible removal rate of dust; relatively constant efficiency at different loadings of dust; similar size distribution of retained material which would stick to a child's skin/hand; and collect/extract the low and medium volatility organics expected to be found on dust particles. The HVS2 was tested with pesticide-inoculated dusts on three different surfaces at different surface loadings, with different static pressures.	The static pressure was found to be the best measure of appropriate height for the nozzle on carpets. When operated at the defined optimal settings, the fine materials (less than 150 μm) collected are approximately 6% of the total load of a standard test dust and 30% of the fine materials in the test dust. Collection efficiency on bare floors was greater than 90%. Did not evaluate size distribution of material which would stick to a child's hand.

Method	Results
Roberts, 1996 (Method development) This project involved testing three devices (HVF3, HVTS, BRMCS) in an attempt to find a reliable method for measuring dust on bare floors and upholstery. The collection efficiencies of three new devices were tested along with the accepted method of the High Volume Small Surface Sampler (HVS3). The new devices are the High Volume Tripod Sampler (HVTS), the High Volume Furniture Sampler (HVFS), and the Baltimore R&M Cyclone Sampler (BRMCS). The exposure media in this experiment were bare floors, upholstery, and rugs (plush and level loop). The dust loadings used in this study were 1) Bare floors: two loadings of 0.1 and 0.5 g/m^2 dust (from home vacuum cleaners) to represent light and heavy; applied to bare floor with a baker shaker. Dust was first sieved with a mesh screen so that the particles were <150 μm. 2) Upholstery: one gram of fine couch dust (two loadings of 2.5 and 5.6 g/m^2) was embedded in the face and vacuumed from the surface during testing.	Collection Efficiencies of the Dust Samplers: HVS3 — HVTS — HVFS — BRMCS bare floor: 85-87% — 84-85% — 84% — 85% rugs: plush: 67% — 62% — — 44% level loop: 69% — 66% — — 61% upholstery: velvet: NA — NA — 87-90% — 72% flat: NA — NA — 89-91% — 87% The four devices tested were equally effective in collecting house dust from bare floors. The HVFS was efficient in collecting dust from upholstery, and can be used alone or as an attachment to the HVS3. The HVTS and the BRMCS are lower in cost than the HVS3 but have limitations when used on rugs and upholstery.

Method	Results

Camann and Yau, 1998

Pesticides, PAHs, and PCBs were measured in dust samples collected from >140 Long Island homes of women enrolled in Breast Cancer Study. Carpet dust collected using the HVS3; <150 μm dust fraction extracted and analyzed.

		Concentrations (μg/g)		
	% Detected	50th Percentile	90th Percentile	Max
Aldrin	8	<0.03	<0.14	0.98
Atrazine	0	<0.02	<0.07	<0.30
Beta-BHC	0	<0.03	<0.75	<4.8
Alpha-chlordane	91	0.20	0.92	6.2
Gamma-chlordane	94	0.26	1.4	8.5
Dieldrin	24	<0.07	0.42	6.7
4,4'-DDD	19	<0.03	0.12	1.4
4,4'-DDE	62	0.04	0.23	0.86
4,4'-DDT	75	0.15	1.4	4.6
Heptachlor	44	<0.04	0.28	1.2
Heptachlor Epoxide	6	<0.02	<0.06	0.06
Hexachlorobenzene	1	<0.02	<0.06	0.31
Lindane	0	<0.03	<0.27	<7.6
Methoxychlor	71	0.26	2.4	31
trans-Nonachlor	85	0.13	0.63	4.3
Oxychlordane	1	<0.05	<0.48	0.11
		Chlordane Loadings (μg/m^2)		
Alpha-Chlordane		0.12	1.5	22
Gamma-Chlordane		0.18	1.9	31
Heptachlor		<0.03	0.28	7
trans-nonachlor		0.08	0.96	13

Data from the Long Island Study were compared to results from Childhood Leukemia Study (n=362) in nine midwestern states. Median pesticide dust concentrations were similar in both studies for most pesticides. The percentage of results above 0.1 μg/g was higher in Long Island for most pesticides. Maximum concentrations were higher in the midwest. Median loadings (μg/m^2) were about two times higher for most pesticides in the midwest homes.

Method	Results
Transferable Residues	
Geno, 1996 Hands are pressed onto aluminum foil spiked with pesticides. Foil allowed to dry.	Transfer efficiency from foil to hands of appox. 85% for chlorpyrifos and pyrethrin 1.
Gurunathan, 1998 Chlorpyrifos residues measured after pesticide application. Surface samples collected with LWW wipe method (filter material wetted with methanol and hexane, 5 passes over 100 cm^2). Plastic toys and plush toys extracted with hexane.	Surface wipes: One-wipe samples had peak of 43 ng/cm^2 on dresser top 36 h post-application with subsequent decrease over time. Multiple wipe samples increased through 72 h. Surface of plastic toys had mean residue of 11,500 ng/cm^2 with peak at 1 week post-application. Plush toys had mean residue of 15,000 ng/cm^2 with peak 2 weeks post-application. NOTE: Toy extraction method may not represent transferable residue.
Chenseng, 1998 The purpose of this study was to measure surface concentrations of chlorpyrifos following broadcast or aerosol applications. Surface wipe samples were collected with surgical gauze pads sprayed lightly two times with distilled water. An area of 100 cm^2 was wiped with 3 strokes. A second pad was used in the same area with the wipe performed at a 90° angle to the first wipe. Carpet and other surface samples were collected using this wipe procedure to measure transferable residue.	Transferable carpet residue measured after broadcast application was 143 to 186 ng/cm^2 one hour after application decreasing to 19 to 24 ng/cm^2 2 days post-application and 6 ng/cm^2 7 days post-application. Carpet residue measured after aerosol deposition was 98 to 131 ng/cm^2 one hour after application decreasing to 10 to 15 ng/cm^2 2 days post-application and 1 to 2 ng/cm^2 7days post-application. Differences in ventilation during the 7-day period did not produce large effects in dislodgeable residue.

Method	Results
Fenske, 1991 Commercial broadcast application of chlorpyrifos (0.48 to 0.5% in aqueous solution) was performed at three residential and one office location. Wipe samples were collected at eight times post-application. Three replicate samples were collected at each location to assess method and residue variability. Wipe sampling was performed using a modification of the OSHA procedure. Three strokes across a 100 cm^2 were made with a 7.5 x 7.5 cm surgical gauze pad, followed by three strokes with a second pad at a 90° angle to the direction of the first. At the first location, pads were sprayed lightly with distilled water prior to wiping, while in the remaining three sites the pads were sprayed with isopropanol.	Wipe samples collected from treated synthetic carpet at one location, under three sets of ventilation conditions, yielded surface loadings as follows: No Ventilation - Mean 1.6 $\mu g/cm^2$, range 0.07 to 3.6 $\mu g/cm^2$; CV 58% Doors Open - Mean 0.67 $\mu g/cm^2$, range 0.25 to 1.0 $\mu g/cm^2$; CV 40% Windows Open - Mean 0.71 $\mu g/cm^2$, range 0.13 to 1.8 $\mu g/cm^2$,CV64% Transferable residue on treated surfaces did not change substantially during the first 6 hr post-application, but decreased 30 to 40% within 24 hr post-application. Residues decreased from a mean of 690 to 280 ng/cm^2 in 24 hr in rooms with ventilation and from a mean of 1600 to 480 ng/cm^2 in 24 hr in rooms with no ventilation. Transferable residues on untreated surfaces increased during the 24 hours post application. Residues increased from a mean of 1.3 to 2.6 ng/cm^2 in 24 hr in rooms with ventilation and from a mean of 1.4 to 4.7 ng/cm^2 in 24 hr in rooms with no ventilation.
EPA, 1993 The objective was to determine the quantity of malathion transferred from carpet, painted sheetrock, and vinyl flooring onto skin or gloves. Aqueous malathion formulation was sprayed onto 3x3 cm patches of residential grade carpet, vinyl flooring, and painted sheetrock. Samples equilibrated for 1h. Either bare hand or hand with cotton glove was placed on treated surface. An inflatable cuff was used to apply even pressure for 15 sec. Malathion on bare hand extracted with isopropanol rinse. Malathion on glove extracted with acetonitrile.	Results: % transferred (SD) at 1h hand / Suit / Ratio(hand/glove) Carpet: 1.52(0.64) / 2.90 (3.42) / 0.94 (0.53) Vinyl Flooring: 0.18 (0.04) / 0.10 (0.03) / 2.06 (0.94) Painted Sheetrock: 0.03 (0.0) / 0.02 (0.0) / 1.82 (0.30)
Krieger, 1996 In this study a solution of disodium octaborate tetrahydrate (DOT) was applied to carpet at approximately 200 $\mu g/cm^2$ in an aqueous solution. Transferable residues were sampled using a California Dept. of Food and Agriculture (CDFA) roller method (roller over a cotton dosimeter with an area of 2,968 cm^2). The dosimeter was extracted with water.	Measurements of transferable residues made using the CDFA roller resulted in 0.15 ± 0.01 mg/L of boron in the water extract from carpet before treatment, 0.70 + 0.22 mg/L after treatment, and 0.22 ± 0.05 after study participants exercised on the carpet. [IF the roller dosimeter area is 2,968 cm^2, the applied amount of boron was 200 $\mu g/cm^2$, and if the amount of water used to extract the dosimeter was 1 L, then the approximate % transferrable for boron was in the range of 0.1% as measured with the CDFA method].

Method

Camann and Harding, 1996

This work compares the transfer efficiency of residues resulting from broadcast application of pesticides onto several floor surfaces. Included in the comparison were the Dow drag sled, the PUF roller, and the California cloth roller, and a human hand press. Samples were collected 2 h afer application. The hand wipe was performed with two 4"x4" dressing sponges, laced with 10mL isopropanol.

Results

Percent Mean Transfer of Dried Pesticide Residues (after broadcast application)

Flooring	Active Ingred	Floor Conc (ng/cm2)	Mean Transfer % Cloth roller	Drag Sled	PUF roller	Hand Press
plush nylon carpet	Chlorpyrifos	13,500	4.9	1.3	0.9	NT
plush nylon carpet	Chlorpyrifos	19,800	NT	0.40 dry 0.66 moist	0.26 dry 2.1 moist	NT
loop polyethy-ene carpet	Chlorpyrifos	10,600	2.7	1.7	1.5	NT
plush carpet (used)	Chlorpyrifos	5,800	NT	0.05	0.02	0.02
	Piperonyl But	5,760	NT	0.07	0.02	<0.005
	Pyrethrin I	555	NT	0.11	0.02	<0.01
sheet vinyl (new)	Chlorpyrifos	8,000	NT	13	5.5	1.8
	Piperonyl But	7,600	NT	12	4.7	2.2
	Pyrethrin I	1,200	NT	9	5.5	1.8

Experiments were also conducted to determine effect of # of passes, pass length, pressure and speed on the transfer efficiency of PUF roller and drag sled method. Results showed some variation in uptake although relationship was not linear.

Method	Results
Camman, 1996 Compared the transfer efficiencies of dry pesticide residues to hands moistened with human saliva, artificial saliva, or the surfactant dioctyl sulfosuccinate (DSS) -an 8 cm strip of palm (241 cm^2 area) on the testers' hand was wetted with 400 μL of fluid, and then pressed onto the carpet (after broadcast application of pesticide formulation) five times at 1 second and 1.0 psi each. -gauze dressings sponges were wetted with 10 mL of isopropanol for wiping, then placed in a container of 25 mL methanol. Wipe samples were cold-shake extracted with diethyl ether and n-hexane within 3 hours after collection. –source: the pesticide mixture was 0.25% chlorpyrifos, 0.025% pyrethrins, and 0.25% piperonyl butoxide in aqueous spray, applied to a 7 ft. x 12 ft. piece of carpet at a rate of 1 gallon per 1600 ft^2, 40 cm above test surface. Hand presses were made 5h, 1 day, and 2 days after application. -The authors compared their transfer efficiencies to those of dry hands, using values from a PUF roller and a drag sled obtained in a prior experiment.	Mean Transfer Efficiencies (Calculated as the mass transferred / carpet loading) Pyrethrin: DSS – 4.3% Human saliva – 4.8% Artificial saliva – 2.9% Dry hand (puf roller estimate) – 0.01% Dry hand (drag sled estimate) – 0.01% Chlorpyrifos: DSS 1.3% Human saliva – 1.1% Artificial saliva – 0.73% Dry hand (puf roller estimate) – 0.01% Dry hand (drag sled estimate) – 0.01% Piperonyl Butoxide DSS – 2.8% Human saliva - 2.8% Artificial saliva – 1.5% Dry hand (puf roller estimate) – 0.01% Dry hand (drag sled estimate) – 0.01% PUF roller used to estimate the transfer efficiency of a dry hand, about two orders of magnitude lower than the transfer efficiency of a wet hand.

Method	Results
Fortune, 1997 Performance of three transferable residue methods: the Dow drag sled, the PUF roller, and the California roller was performed by round-robin testing. Testers used the methods according to modified SOPs.	Sampling Precision Chlorpyrifos / Pyrethrin I / Piperonyl Butoxide PUF Roller 28.3% 45.7% 39.7% California Roller 27.1% 35.2% 29.7% Dow Drag Sled 23.5% 26.8% 25.8% Transfer Efficiency Chlorpyrifos / Pyrethrin I / Piperonyl Butoxide PUF Roller 1.4% 1.9% 1.8% California Roller 4.2% 4.2% 6.6% Dow Drag Sled 1.9% 2.1% 2.3% The authors conclude that reproducible and consistent data can be obtained for transferable residues on carpet using any of the three methods described. The subjective evaluations of the volunteers in the study consistently rank the California roller lower than the Dow sled or the PUF roller (including ease of training, cleanup, manipulations, time requirements, and assembly). Also, the high transfer efficiency of the California roller is thought to be less representative of actual human skin transfer efficiency.

Method	Results
EPA, 1998 (Laboratory and field methods establish a dermal transfer coeff...) Experiments were conducted to determine the quantity of malathion transferred from painted drywall, vinyl flooring, and nylon carpet to human skin surrogates, cotton suit material and polyurethane foam. Malathion was applied to coupons of painted drywall, carpet, and vinyl flooring by spray application of a technical grade malathion solution. Coupons were conditioned, transfer experiments were conducted at selected time intervals after application (0, 2,8, 24, 48, 72 h). Transferable residues were determined using the human hand and different skin surrogates (cotton suit material), PUF, pig skin, and cadaver skin. Transfer material was placed on coupon. An acrylic plate was placed on top, 80 mm Hg applied, held for 15 s. Exposed transfer materials were extracted with acetonitrile. Exposed hands were rinsed with isopropanol. Experiments were conducted to determine the dissipation rates of malathion residues from typical residential surfaces. Data were also generated on the effect of sampling methods on the amount of malathion recovered. Malathion as a chemical standard or as a commercial product was spiked (25 uL aliquots) onto coupons (usually 10 x 10 cm) of different material (cotton suit material, carpet, painted dry board, and vinyl flooring. Spiked coupons were equilibrated under controlled temperature and humidity conditions. Malathion remaining on the spike coupons at selected equilibration times was measured using a) wipes with cotton suit material wetted with acetonitrile - wipe extracted with acetonitrile; b) extractable residue method - coupons shaken with water surfactant solutions, aqueous solution extracted with methylene chloride. Analysis also conducted for malaxon as the major breakdown product of malathion.	% Transfer of Applied Malathion Measured Over 24 h After Application Transfer Material / Carpet / Painted Drywall / Vinyl Floor 2h / 24h / 0h / 24h / 2h / 24h Human Hands: 4.23% / 0.35% / 0.43% / 0.077% / 0.55% / 0.35% Pig Skin: 2.3%% / 0.054% / 0.99% / 0.015% / 0.46% / 0.025% Cotton Suit Material: 3.1% / 0.46% / 0.60% / 0.006% / 0.053% / 0.023% PUF: 2.83% / 0.55% / 0.22% / 0.031% / 0.39% / 0.10% Cadaver Skin: 1.1% / 0.22% / 0.17% / 0.014% / 0.13% / 0.26% NOTE: Sample materials were spiked in a way that may not be representative of how pesticides are applied to or transferred to surfaces in residential environments. No breakdown of malathion to malaxon observed. Wipe samples of carpet (26%), vinyl flooring (89%), and painted drywall (78%) did not quantitatively recover malathion. Recovery by extractable residue method, carpet (36%), painted drywall (19%), and vinyl flooring (25%) were generally lower than by the wipe method. All surfaces showed dissipation of malathion over a 72 h period – cotton suit material showed the slowest dissipation, humidity showed little effect, dissipation was highest at high temperatures. Different material showed different dissipation rates using the wipe vs the extractable residue method. Rate constants and half-lives were calculated for all conditions.

Method	Results
EPA, 1992 From literature review (Jurinski, 1984) surface wipe samples were collected on gauze pads.	Chlordane values of <0.1 to 39.8 $\mu g/m^2$.

Transferable Dust

Edwards, In Preparation A press sampler (EL sampler) was designed to collect surface dust samples representative of what would be transferred to the human hand during a single hand press. Housedust was allowed to settle on precleaned glass slides. The slides were analyzed with an Adherent Cell and Sorting (ACAS) interactive laser cytometer to determine particle size distribution. The slides were next sampled with either the EL sampler or a hand press. The EL sampler consists of a 10 x 15 cm extraction sheet loaded into a cassette. The sampler was pressed onto the collection surface for a period of five seconds, while all four legs of the sampler were in contact with the surface to ensure equal pressure. The hand press was performed in a similar manner–a pressure as close to 15 lb. was maintained for 5 seconds. Both the EL sheet and hand were extracted with 2-propanol and analyzed with GC/MS.	Cytometer analysis showed that both sampling methods removed 100% of the particles between 60-250 μm. In all size ranges, the amount of particles collected was very similar. Pesticide recoveries were both found to be very high and very similar, and the average collection efficiencies were also found to be very similar. Particle Removal Efficiencies 0 - 2.5 μm: Hand Press Test 68 %; EL Sampler 61% 2.5 - 10 μm: Hand Press Test -0.8 %; EL Sampler -64% 10 - 50 μm: Hand Press Test 35%; EL Sampler 56% 50 - 200 μm: Hand Press Test 100%; EL Sampler 100% Pesticide Collection Efficiency for Atrazine: Hand Press Test 43 %; EL Sampler 35% Diazinon: Hand Press Test 29 %; EL Sampler 31% Malathion: Hand Press Test 43%; EL Sampler 32% Chlorpyrifos: Hand Press Test 21%; EL Sampler 18%
Lewis, 1994 Several types of measurements of surface pesticide loadings were made in 9 homes with children. The HVS3 vacuum system was used to collect carpet dust samples, a PUF roller was used to sample carpet transferable residue, the investigator performed a hand press (area of 97 cm^2) on the carpet surface.	Mean results, all reported in $\mu g/m^2$ of carpet surface Chlorpyrifos: HVS3 1.3; PUF Roller 0.11; Hand Press 0.03 Chlordane: HVS3 4.5; PUF Roller 0.54; Hand Press 0.56 Heptachlor: HVS3 0.62; PUF Roller 0.05; Hand Press 0.02 Dieldrin: HVS3 0.12; PUF Roller 0.03; Hand Press <LOD PCP: HVS3 0.48; PUF Roller 0.03; Hand Press 0.02

Method	Results
Nishioka, 1996 Measurements were made for transferable turf residue after herbicide application using a PUF roller method. Measurements of residues in the homes resulting from track-in were made using the HVS3 vacuum and carpet PUF roller methods.	Transferable Herbicide Residues (ppm): Dicamba / 2,4-D Turf PUF roller: 1800 / 1000 Carpet Dust (HVS3): 58 / 32 Carpet (PUF): 6 / 3 Percent transfers: % turf transferables: 0.18 / 0.10 % transfer of turf trans. to dust: 3.2 / 3.2 % transfer of turf trans. to carpet: 0.35 / 0.32 The turf transferable levels were 0.1 - 0.2% of the turf application levels. This initial transferable residue as measured by the PUF is much higher than the transferable or total concentrations in the carpet, but there is a high correlation in their temporal profiles. Both types of carpet residues decrease more slowly than the turf residue. An increase in transferable residue was seen from 4-8 hours after application, speculated to be due to the further drying of the pesticide. There were dramatic decreases in residue after rainfalls, and decreases with time that are thought to be due to enhanced absorption/binding to turf.

Method	Results
Nishioka, 1997 Transport of lawn-applied pesticides into the home via track-in on shoes was measured. Lawns that had not previously been treated with pesticides were divided into 20 ft x 20 ft plots. Herbicide formulation applied: dicamba (1.7 mg/m^2); 2,4-D (26.7 mg/m^2); dicamba isomer (0.16 mg/m^2); granular chlorpyrifos (120 mg/m^2); spray chlorpyrifos (140 mg/m^2); chlorothalonil (970 mg/m^2). Carpeted track-in platforms were placed at one end of each lawn plot, and 1.5 g of a sieved residential house dust was applied and embedded (foil roller) in the carpet. Track-in was simulated when participants walked 20 times through the right and left sides of a given turf plot and stepped on the carpet . At the end of each experiment, each participant had walked in each lane of each carpet five times; residues from a total of 25 walks accumulated in each lane of carpet. The PUF roller was used to collect residues on turf (sampling rate of 40 cm/sec) and carpet (sampling rate of 17 cm/sec). The HVS3 was used for a controlled dust collection of areas that had been covered with tape during the experiment.	Relative Transfer of Pesticides from Turf Transfer ppm (%) Turf to PUF / Turf to Dust / Turf to Carpet Surface Dicamba spray: 1800 (0.18%) / 58 (3.2%) / 6.2 (0.35%) Dicamba isomer spray: 2700 (0.27%) / 80 (3.0%) / 3.0 (0.14%) 2,4-D spray: 1000 (0.10%) / 32 (3.2%) / 3.2 (0.32%) Chlorothalonil spray: 2100 (0.21%) / 42 (2.0%) / 6.1 (0.28%) Chlorpyrifos spray: 76 (0.008%) / 1.3 (1.6%) / 0.3 (0.26%) Chlorpyrifos granular: 45 (0.005%) / 8.0 (18%) / 0.2 (0.44%) Researchers also analyzed the temporal changes in pesticide levels in the turf and carpet. They demonstrated that track-in on shoes is a reasonable mechanism by which pesticides are carried into the home. Data showed that the track-in of residues occurred at 5-6 days after application, despite environmental conditions (rain and volatilization). They also showed that transferable residues were detectable up to 14 days after application.

Method	Results
Roberts, 1989 Tests were performed to determine if cotton gloves can be used to measure the quantity of transferable pesticide residue in carpets containing house dust with different pesticide concentrations. Reference carpet dust sections were prepared by first sieving house dust to obtain the <150 μm fraction, fortifying with target pesticides, and imbedding the dust into 0.5 m^2 plush nylon carpets. The gloves were worn over surgeon's powderless gloves by a 150 lb. technician. The technician's hand to carpet contact area was 322 cm^2. The cotton gloves were pressed into the carpet 100 times. The technician placed both hands flat onto the carpet and leaned from the shoulders over the hands for approximately 2 sec for each press	Chlorpyrifos, carbaryl, PCP, and propoxur were found in the unfortified dust at levels ranging from 3.4 to 80 ppm. Eleven other target pesticides were found at lower levels. Recovery of dieldrin and chlordane from fortified dust samples ranged from 93% to 162% after subtraction of the unfortified background. No detectable levels of pesticides were measured on a pair of unused gloves. Mean recovery efficiencies [a measure of the % transferrable] were determined using cotton gloves pressed into the carpets for carbaryl (0.34%), chlordane (1.02%), chlorpyrifos (1.03%), dieldrin (0.45%), and heptachlor (0.15%). The cotton glove press test could detect the presence of chlordane (at 4 ppm), dieldrin (at 3.4 ppm), chlorpyrifos (at 72 ppm), and carbaryl (at 40 ppm). It was not successful in detecting PCP (4.8 ppm), DDT (1.9 ppm), propoxur (3.4 ppm), and cis-permethrin (2.2 ppm) with the extraction method used.

Method	Results
Dust/Soil - Adhesion	
Duff, 1996 The purpose of this work was to measure dermal absorption for different skin soil loadings. Soils were loaded onto cadaver skin at 1 to 10 mg/cm^2. Radiolabeled lindane and 2,4-D was added to the soils. Amounts absorbed in the skin and through the skin were measured.	Mean % absorptions were 0.45 to 2.35% for lindane and 0.18 to 1.59% for 2,4-D. Percent of absorbed chemical will increase with decreasing soil load, providing that monolayer or greater skin coverage is maintained. As loadings decrease below the monolayer threshold, contact area and mass flux will decline leading to roughly constant % absorption. Many activities are likely to result in loadings of 1 mg/cm^2 or less, not providing complete monolayer coverage.
Kissel, 1996a The relationship between activities and dermal loading over time and body region were measured. Soil adhering to the subjects' skin was measured by washing exposed body parts in water, filtering these samples, and then weighing the desiccated samples. Pre-activity levels were found in the same manner. The mass recovered was converted to average skin loading using regression of the surface area of the respective body parts. A ratio of pre- to post-activity was also calculated. The data was compared to the current default soil loading range (set at 0.2 - 1.0 mg/cm^2 in 1992).	Post-activity hand, foot, arm, and leg data spanned the default range. In order of lowest mean loading to highest, the activity groups were Tae Kwon Do, soccer, groundskeepers, irrigation installers, rugby players, farmers, reed gatherers, and kids playing in the mud. Only the loadings for the kids playing in the mud clearly exceed the default range of 0.2 - 1.0 mg/cm^2. Observed hand loadings varied over five orders of magnitude (0.001 to 100 ng/cm2) and were dependent upon the type of activity. dermal exposure to soil appears to be episodic (daily periods of exposure to higher loading levels are likely to be less than 24 hours for most people).
EPA., 1992 From literature review of soil skin loading estimates for children	-CDC (1984) – 1 g/day for 0.75-1.5 years and 3.5-5 years; 10 g/day for 1.5-3.5 years -EPA (1984) - 0.5 mg/cm^2 -Lepow (1975) – 0.5 mg/cm^2 -Roels (1980) 159 mg/hand -Que-Hee (1985) – 0.2 mg/cm^2 Driver (1989) - 1.298 mg/cm^2 for particles < 150 μm; 0.946 mg/cm^2 for particles < 250 μm; 0.5821 mg/cm^2 for unsieved soils (1989) -Sedman (1989) - 1 g/day for 1-5 years

<table>
<tr><th>Method</th><th>Results</th></tr>
<tr><td><u>Kissel, 1996b</u>
The effect of particle size and moisture content of soils on the adherence of soils to skin was measured. Five soils were obtained locally, and analyzed by hydrometer (settling velocity) to determine composition (sand, silt, clay). Organic carbon contents were determined by combustion.
The hand press protocol involved placing hand palm-down in a pan of soil, gently agitating for 30 seconds, and then washing the hand (2% detergent solution) into a sample jar. Wash water was filtered through 37 mm glass fiber filters with a nominal pore size of 0.5 μm. Vacuum was applied by aspirator or pump. Filters were then oven dried overnight at 100°C, then cooled in a desiccator, and weighed.</td><td>With dry soil conditions (<2% moisture), adherence varied inversely with grain size. In wet soils (12-18% moisture), adherence generally varied directly with particle size. Effect of moisture on adherence of fine particles is inconsistent across soils, which may reflect differences in the surface characteristics of the various soils. Effects on larger particles are less variable. For whole soils (unfractionated), the adherence at moisture contents above 20% differed significantly from adherence at less than 10% moisture and adherence at 10-20 % moisture. Results from post-adherence sieving show a preferential selection of smaller sized particles under dry conditions. For each soil, under dry conditions, the relative proportion of sub-65 μm particles increases about 4-fold, while very little of the largest class adheres to skin. The sub-65 μm grains represent the largest single fraction of the sieved washed soil. A significant decline in the relative adherence of this size group is apparent under wet conditions. Increasing adherence of unsieved soils with increasing soil moisture appears to occur primarily as a result of the effect of moisture on adherence of larger size fractions.
<u>Mean Adherence (mg/cm²)</u>
<table><tr><th><u>Soil</u></th><th colspan="3"><u>Moisture</u></th></tr><tr><th></th><th><u><0.1 to 9%</u></th><th><u>10 to 19%</u></th><th><u>21 to 27%</u></th></tr><tr><td>211</td><td>0.33</td><td>3.09</td><td>5.88</td></tr><tr><td>CP</td><td>0.22</td><td>2.98</td><td>14.8</td></tr><tr><td>85</td><td>0.25</td><td>1.26</td><td>5.99</td></tr><tr><td>228</td><td>0.22</td><td>0.45</td><td>1.64</td></tr><tr><td>72</td><td>0.54</td><td>0.39</td><td>2.10</td></tr></table></td></tr>
<tr><td><u>Van Hemmen, 1995</u>
From a review of dermal exposure research literature was a report from Paustenbach, et al., 1992 estimating soil adhesion to skin.</td><td>A value of 0.5 mg/cm² adherence of soil was proposed as a reasonable estimate from contact with soils.</td></tr>
</table>

Method	Results
WA-023 (Rodes/Lewis), 1998 A dust deposition chamber that uniformly applies dust loadings typical of real indoor horizontal surfaces (30 to 50 ug/cm2) was developed. Dermal mass transfer rates of dust particles of known diameters were measured from smooth stainless steel surfaces, carpet, and vinyl flooring. Tests were performed with dry and moist hands, with synthetic saliva, and for direct and smudged contacts.	Actual contact areas are typically 30-40% of the entire hand projected area. A portion of the particles transferred from a contact surface to the skin are often transferred back to the contact surface in successive contacts, so that the mass transfer rate after 50 contact events may be only 20-30% of the rate for the first transfer. Transfer rates of dust particles (0-80 μm) from smooth stainless steel surfaces to dry skin range are 60 to 80%. Particle mass transfer rates from vinyl flooring are 20-40% less than from smooth stainless steel surfaces for 0-80 μm bulk dust. Preliminary dermal mass transfer rates for 0-80 μm particles from medium pile carpeting show dry skin transfer rates are typically <10% of those from smooth contact surfaces and that damp skin transfer rates are 2-3 times higher than dry skin rates. The presence of a "wet" synthetic saliva layer on the skin does not necessarily result in a greater mass transfer rate from stainless steel surfaces. Damp skin particle mass transfer rates from smooth surfaces are typically 20-40% less than dry skin rates for larger particles (40-80 μm), but somewhat higher than dry skin for 0-10 μm fine particles. Fine particles (0-10 μm) appear to transfer more readily from an uncharged contact surface to the skin than large particles or bulk dust.
Driver, 1989 Soil conditions (soil type, particle size, and organic content) affecting adherence to skin were assessed. Three soil particles sizes tested were <150 μm, <250 μm, and unsieved soil. Five different Virginia soils types were tested. -A known weight of soil was placed into a clean, tared plastic container. -Adult hands were placed into the soil for a 30 second contact period with constant agitation in the soil. -The weight of soil adhering to the skin was measured by weighing the plastic container after contact. -Hand surface area was estimated empirically from body weight and height.	The most important factor affecting adherence variability was particle size. Soil Adherence by Particle Size (mg/cm^2) Unsieved soil: 0.17 to 0.90; mean = 0.58 <250 μm: 0.80 to 1.23; mean = 0.95 <150 μm: was 0.76 to 1.85; mean = 1.40 Soil Adherence by Organic Content (mg/cm^2) 19% Organic: mean = 0.36 for unsieved soil and 0.79 for <150 μm. 1% Organic: mean = 0.60 mg/cm^2 for unsieved soil and 0.97 for <150 μm. **Note: included review of related studies with values for soil adherence ranging from 0.2 mg/cm2 to 0.9 (mg/cm^2).**

Method	Results
EPA, 1992 From literature review Driver et al. (1989) and Sedmen (1989) reviewed field studies of soil adherence to skin: Lepow et al. (1975) use tape stripping Roels et al. (1980) used nitric acid rinse (for lead) Hrager (1979)	Lepow: 0.5 mg/cm^2 Roels: 0.9 mg/cm^2 Harger: 1.45 mg/cm^2 for potting soil and 2.77 mg/cm^2 for kaolin dust
Whole body dosimeters	
EPA, 1998a Work was conducted to generate a dermal transfer coefficient for the crawling activity. This effort is based on the hypotheses that a dermal transfer coefficient can be used to extrapolate adult human test subject data to infants or children. It also assumes that accurate transfer coefficients can be developed using concurrently generated whole-body dosimetry, transferable residue data, and biomechanics data. This study used video analysis to establish the relationship between child contact activities and the uptake of dislodgeable surface residues. A broadcast application of a 0.5% solution of chlorpyrifos was made to carpet. Four hours after application, an adult test subject, wearing a whole-body dosimeter (cotton body suit, gloves, and socks), crawled on the treated carpet for approximately 2.5 minutes. After this activity, the dosimeter was removed, segmented to represent various body parts, and analyzed for pesticide residue uptake. Coupon samples on the carpet were used to measure chlorpyrifos deposition. The experiment was repeated 3x with the same adult subject. Biomechanical data were collected for # of contacts per body parts, duration of contact, average surface area making contact, average body part contact pressures; and contact surface areas for each part.	1. Chlorpyrifos deposition was 13.6 to 11.9 ug/cm2 for carpet. Extractable residues as measured by shaking with water/surfactant were 42, 58, and 44% of deposition rates. 2. Total exposure measured (hands, feet, shins, and knees) were 1,326 to 1665 ug. The mean exposure of the three replicates was not significantly different. In all cases, the left side had higher levels of chlorpyrifos. The transfer coefficient was 5854 cm2/h. 3. % transferred residue was 0.21% for left hand, 0.19% for right hand, 0.61% for left knee, and 0.45% for right knee. 4. A relationship between biomechanic activity and exposure (0.94 Spearman coefficient between pressure and exposure) was shown.

Method	Results
EPA, 1993 The objective was to determine the transfer of malathion from treated surfaces to a subject performing post-deposition activities. 1 h after spraying, an adult subject in full cotton body suit entered the room and began a series of 16 crawling and playing activities. Each activity was performed twice over a 32 minute period. After activities, the subject left the room, suit was removed, segmented by body part; separate body parts were extracted and analyzed individually. The study was conducted 3x.	Rear, feet, and hands showed the highest malathion levels. The overall mean amount of malathion found on the dosimeter garments across the three tests was 1875 μg. Amounts found on different body area segments ranged from 1.7 μg (left elbow) to 788 μg (pants, rear). Levels in second and third experiment were higher than the first. The surface was still wet during exposure, the body suit may have adsorbed higher concentrations.
Krieger, 1996 In this study a solution of disodium octaborate tetryhydrate (DOT) was applied to carpet at approximately 200 $\mu g/cm^2$ in an aqueous solution. Five volunteers wore whole-body dosimeter garments and performed a Jazzercise® routine to measure potential dermal transfer and 17 others wore only bathing suits. Urinary boron excretion was measured before and after the exposure. Each volunteer collected urine specimens over four-hour intervals starting the day before the exposure exercise event continuing through one day after their exercise exposure event.	Measurements of transfer of boron to the whole body dosimeters during the exercise routine were: Socks: mean 18 mg range 1 to 56 mg Gloves: mean 6 mg range 0 - 19 mg Union suits: mean 19 mg range 0 - 82 mg The large variability in whole body dosimeter results may reflect the distribution of DOT on different areas of the carpet and variation in the residual moisture in the carpet and carpet pad. For the 17 exposed volunteers, mean urine boron concentrations were: Day prior: 1.17 ± 0.63 mg/g of creatinine Day of event: 1.33 ± 0.68 mg/g of creatinine Day after: 1.31 ± 0.66 mg/g of creatinine For the 5 volunteers wearing the body dosimeters, and presumably unexposed, mean urine boron concentrations were: Day prior: 1.26 ± 0.42 mg/g of creatinine Day of event: 1.12 ± 0.36 mg/g of creatinine Day after: 1.26 ± 0.41 mg/g of creatinine In summary, it was concluded that there was no measurable dermal absorption or significant uptake of DOT.

Method	Results
Ross, 1990 Five volunteers wore dosimeter clothing during an exercise routine to measure dermal transfer in rooms treated with home foggers containing chlorpyrifos and allethrin. Volunteers went through a 20 min orchestrated Jazzercise® routine on specified floor locations. At specific time intervals, they changed dosimeter clothing and went through the same routine in a similarly treated room. Two experiments were performed at each of three time intervals (0, 6, and 12.5 hr) after fogger release and after a two hour unventilated and 30 minute ventilated reentry waiting period. Four types of clothing (cotton socks, cotton gloves, cotton shirts, and cotton tights) were worn as dosimeters of dermal transfer.	Accumulated residues on dosimeter clothing were measured for three times after reentry into the treated rooms; 0, 6, and 12 - 13 hr. Mean results for chlorpyrifos combining results for all five volunteers: Tights: 1190 to 1230 µg at 0 hr; 853 to 857 µg at 6 hr; 298 to 497 µg at 12 - 13 hr Shirts: 946 to 1043 µg at 0 hr; 557 to 664 µg at 6 hr; 274 to 319 µg at 12 - 13 hr Socks: 754 to 1020 µg at 0 hr; 563 to 706 µg at 6 hr; 268 to 381 µg at 12 - 13 hr Gloves: 459 to 570 µg at 0 hr; 320 to 372 µg at 6 hr; 117 to 163 µg at 12 -13 hr CV values ranged from approximately 22% to 82% across the five individuals for one test. Next, the pesticide concentration on the clothing (µg/cm²) was divided by the concentration measured on the floor to determine the percentage of applied pesticide transferred. Results were: Tights: 6.6% at 0 hr; 7.5% at 6 hr; 4.0% at 12 - 13 hr Shirts: 5.6% at 0 hr; 6.3% at 6 hr; 3.1% at 12 - 13 hr Socks: 32% at 0 hr; 33% at 6 hr; 20% at 12 - 13 hr Gloves: 14% at 0 hr; 14 % at 6 hr; 12% at 12 - 13 hr
Hand wipes	
Geno, 1996 At a time of 15 - 30 sec after hand contact with a surface fortified with pesticides, hands wiped with cellulose dressing sponge wetted with 2-propanol.	Handwipe efficiency of 104 ±11% for chlorpyrifos and 92 ± 28% for pyrethrin 1. Removal efficiencies for 29 other pesticides show most removal efficiencies are >70%.
Bradman, 1997 Handwipe samples were collected from 11 rural children. All hand surfaces were wiped 2x with gauze pads wetted with propanol.	Diazinon was detected (220 to 52 ng) on the hands of three of toddlers with the highest housdust loadings; chlorpyrifos was detected (100 to 20 ng) on the hands of the two toddlers that has the highest house dust loadings; all three resided in farmworker homes; no other compounds were detected.

Method	Results
EPA, 1993 The objective was to determine the precision, accuracy, recovery efficiency, and overall method quantitation limit for malathion on hand and forearm skin. 1 in^2 of each hand or forearm was spiked with aqueous malathion suspension, equilibrated for 15 min. Each hand was placed in a separate polyethylene bag with 250 mL of isopropanol. Bag was sealed tightly and hand shaken in bag for 30 s. Forearm swabbed with cotton pieces wetted with isopropanol.	Both methods gave quantitative recovery ranging from 97 to 120% with RSD of 1.2 to 26 %. The LOQ was 1ug/in^2.
Lewis, 1994 Several types of measurements of surface pesticide loadings were made in homes with children. Hand rinses were performed for 4 children using 2-propanol. Results from the hand rinses (assumed total hand surface area of 300 cm^2) were compared against results for three other methods including the HVS3 vacuum system used to collect carpet dust samples, a PUF roller used to sample carpet dislodgeable residue, and an investigator hand press (area of 97 cm^2) on the carpet surface.	Mean results, all reported in ng/cm^2 Child Hands / HVS3 / PUF Roller / Investigator Hand Press Chlorpyrifos (Home 1): 0.21 / 0.44 / 0.64 / 0.01 Dieldrin (Home 1): 0.01 / 0.04 / 0.05 / ND Chlordane (Home 2): 1.2 / 1.6 / 1.5 / 0.40 Heptachlor (Home 2): 0.32 / 0.42 / 0.43 / 0.10 Heptachlor (Home 3): 0.03 / 0.03 / 0.43 / 0.04 PCP (Home 2): 0.06 / 0.02 / 0.04 / 0.04 PCP(Home 4): 0.09 / 0.02 / 0.11 / ND

Method	Results
Yukanavage, 1997 Estimates of dermal (hand palm) loadings were derived primarily from applicator/occupational literature reports, of hand skin and glove measurements. Assumptions used in the derivation, many derived from the literature, included: -100% of the pesticide measured from hand rinse or gloved hand studies was deposited on the palmer hand surfaces. -Deposition was evenly distributed across fingers, thumbs, and palms of both hands. -Total surface area ranged from 73 to 1170 cm^2. A rounded value of 500 cm^2 is the area of one hand and 250 cm^2 is the palmer surface area of one hand. -Deposition rates (mg/h) may be converted to mass by multiplying by the collection duration since literature reports show is no correlation between the length of a collection period and establishment of a depositional steady state. -Gloves used to measure deposition may retain 5 times mor pesticide than skin. Hand rinses underestimate deposition. A factor of two was used to adjust glove data downward and a factor of two was used to adjust hand rinse data upward. -Using these assumptions, the palmer mass was calculated from: Palmer mass ($\mu g/250\ cm^2$) = [Exposure (μg/hands/h) x collection duration (min) x Adjustment (2 or 0.5)] 2 hands x 60 min/h	From literature reports of pesticide residues recovered from worker and applicator hands, the above equation was used to calculate palmar mass ranges. Ten of the 34 calculated palmar mass ranges are reported here, spanning the range of reported values: 1 to 4 $\mu g/250\ cm^2$ 6 to 24 $\mu g/250\ cm^2$ 27 to 172 $\mu g/250\ cm^2$ 310 to 1,085 $\mu g/250\ cm^2$ 800 to 2,000 $\mu g/250\ cm^2$ 750 to 31,000 $\mu g/250\ cm^2$ 1500 to 5,100 $\mu g/250\ cm^2$ 2000 to 5,000 $\mu g/250\ cm^2$ 3,900 to 14,000 $\mu g/250\ cm^2$ 4,900 to 31,000 $\mu g/250\ cm^2$

Method	Results
Non-Dietary Ingestion	
Hand or Object to Mouth	
Gurunathan, 1998 Measurement of toy and surface chlorpyrifos residues after application. Use of video activity data to estimate hand-to-mouth activity. Assuming 100% transfer for each touch and 365 contacts/hr, estimated oral dose calculated.	Estimated that an oral dose of 126 μg/kg/day would be experienced by a child one week after chlorpyrifos was applied.
Soil/dust ingestion	
Kissel, 1998 Hand-to-mouth transfer of soil was measured for adult subjects. The soil used was the sub 2mm fraction of a locally obtained, natural loamy sand, soil was autoclaved and stored at room temperature under foil; moisture content ranged from 0.8 to 1.6%. The experimental protocol consisted of 9 steps: 1) washing and drying the subject's hands; 2) loading one hand by pressing into a shallow pan (palm down, fingers spread); 3) mouthing three fingers above the first knuckle; 4) rinsing the mouth 3 times; 5) sucking the thumb; 6) rinsing the mouth 3 times; 7) licking the palm (3x); 8) rinsing the mouth 3 times; 9) washing the remainder of the soil from the hand. Initial soil loading on the hand was determined as mass lost from the pan. Wash water was filtered through 47-mm glass fiber filters with a nominal pore size of 0.5μm. The pre-weighed filters were oven dried overnight, cooled in a desiccator, and weighed. Surface area was calculated using correlations with height and weight	Mean mass transferred from hand to mouth was approximately 10 mg per event (thumb sucking 7.4%, finger mouthing 11.6%, palm licking 16.0%) with a range of 5.9 to 20.4 mg.. The mean percentage of total soil on the hand recovered from mouth was approximately 15% with a range of 6.2 to 23.7%. Soil mass transferred to mouth tends to vary directly with hand loading.
Stanek, 1997 Soil ingestion among adults was measured. Test subjects were fed soil tablets, and their total fecal output was collected for seven days. Estimates of the soil ingested were constructed using the trace element totals from the capsules.	Estimates indicate that the average adult ingests 10 mg soil/day, with an upper 95% value of 331 mg soil/day.

Method	Results
Calabrese, 1996 In this study, the authors addressed the large intertracer inconsistencies present in soil ingestion estimates. They theorized that the cause of the variability is differences in soil concentration between elements by particle size. The authors re-analyzed the soil ingested by children after it had been sieved to the smaller particle size of <250 μm. These new concentrations were then used to estimate soil ingestion, and the resulting estimates were compares with the original ones (<2mm). Soil samples were passed through a 250 μm sieve. The concentrations were estimated using inductively coupled plasma atomic emission spectroscopy (ICP-AES) for Al, Ti, and Si, and inductively coupled plasma mass spectroscopy (ICP-MS) for Ce, Nd, La, Y, and Zr.	The data for this experiment came from another study (Calabrese et al 1996), and included the total amount of trace elements from food and fecal samples for 62 children, as well as concentrations of trace elements estimated from soil samples collected in each child's yard. Distributions of soil ingestion estimates were reported for the children residing in Anaconda, Montana (n=62). Values presented included the minimum, 25%ile, median, 75%ile, 90%ile, 95%ile, and maximum. Only the mean and std are included in this summary. Tracer Specific Soil Ingestion (mg/day) Al: Mean = 1, Std = 90 Si: Mean = -19, Std = 64 Ti: Mean = -590, Std = 2606 Y: Mean = 38, Std = 116 Zr: Mean = -17, Std = 97
Calabrese, 1997a This study was designed to assess soil ingestion in children who were thought to display soil pica-like behavior based on retrospective parental observations. Food and fecal samples were collected from test subjects (described by their parents as displaying frequent soil pica behavior), as well as outdoor soil samples and indoor dust samples. The samples were assessed for three tracer elements: AL, Si, and Ti. Mass-balance estimates were calculated by subtracting the food amount from the trace element amount in feces, and then dividing this difference by the concentration of the trace element in either soil or dust.	Daily Median Soil and Dust Ingestion Rates (g/day) Mean: Soil Ingestion 0.135, Dust Ingestion 0.271 Median: Soil Ingestion 0.011, Dust Ingestion 0.017 Std: Soil Ingestion 0.278, Dust Ingestion 0.758 One of the 12 children showed soil pica behavior. The remaining children had soil ingestion estimates that were generally low, with median values under 40 mg/d for each tracer.

Method	Results
EPA, 1992 From EPA literature review, estimates of soil and dust ingestion for children.	-EPA (1984) – 100 mg/day -CDC (1989) – 10,000 mg/day for 1.5-3.5 year olds; 1,000 mg/day for 0.75-1.5 years and 3.5-5 years -Sedman (1989) – 590 mg/day -Hawley (1985) – 165 mg/day -LaGoy (1987) - 250 mg/day for 0-1 years and 6-11 years; 500 mg/day for 1-6 years - Calabrese (1987) – 200 mg/day average for children under 7 years -Clausing (1987) – 56 mg/day -Binder (1986) – 121-184 mg/day
Calabrese, 1997b In this report the authors examine potential acute exposures of children exhibiting pica behavior. The authors argue that instead of being a rare behavior confined to a small fraction of the population, pica behavior may be normal but relatively infrequent for most children in the general population. Ingestion dose values were calculated for 13 chemicals (at EPA soil screening levels) assuming pica soil ingestion rates of 5, 25, and 50 g/day. These estimated doses were then compared to reported values for human toxicity and lethality.	The authors estimate that 62% of all children will ingest >1 g of soil,, 42% of children will ingest >5 g, and 33% of children will ingest >10 g of soil on 1 - 2 days/year. Potential doses from pica behavior of soils with contaminants present at the EPA screening values were greater than reported lethal doses for cyanide, fluoride, phenol, and vanadium. Potential doses greater than reported human toxic doses were found for barium, cadmium, copper, lead, and nickel. Soil pica ingestion doses lower than reported toxic doses were found for antimony, arsenic, and naphthalene. Nonlethal toxic dose data were not found for pentachlorophenol. EPA derived soil screening values are based on chronic ingestion of 200 mg/day for soil, considered to be the upper 95th percentile for soil ingestion. However, contaminant levels that are safe for chronic exposure at this soil ingestion rate may result in acute toxicity for pica behavior if 5 to 50 g of soil is consumed at one time.

APPENDIX F: Chlorpyrifos Exposure Assessment

IMPORTANT PATHWAYS OF DERMAL ADSORPTION /NONDIETARY INGESTION FOR YOUNG CHILDREN IN THE HOME – Chlorpyrifos estimated from available literature data.

Used as a first pass to determine which routes and scenarios would give the highest exposure

Form	Contact Surface	Contact Type	Route	Assumptions	Estimated Exposure (ug/day)	Estimated Internal Dose (ug/day)
CHRONIC DERMAL EXPOSURE						
Dust	Carpet 5.0 ug/m2 - extractable surface concentration (HIPES, Fenske); 5% transferable (Rodes)	Hand	Ingestion	hand to surface contact - 0.035 m2 (EPA), 10 hand-to mouth per h (Freeman), 4 hour (½ EPA),50 % available once absorbed	0.35	0.18
		Body	Adsorption	****macroactivity approach** - 50% available for transfer, transfer coefficient 0.87 m2/h, 4 h, 1% dermal adsorption for pesticide not bound to particles	8.7	0.087
	Hard Surface 1.0 ug/m2 - extractable surface concentration (HIPES, extrapolate Nishioka) 50% transferable (Rodes, Edwards)	Hand	Ingestion	hand to surface contact - 0.035 m2, 10 hand-to mouth per h, 4 hour, 50% available once absorbed	0.7	0.35
		Body	Adsorption	****macroactivity approach** - 50% available for transfer, transfer coefficient 8.7 m2/h, 4 h, 1% dermal adsorption for pesticide not bound to particles	17.4	0.17

Form	Contact Surface	Contact Type	Route	Assumptions	Estimated Exposure (ug/day)	Estimated Internal Dose (ug/day)
Dust	2.0 ug/g (HIPES)	Food or hand-to-mouth	Ingestion	50 mg dust ingested per day (Calabrese), 50 % available once ingested	0.1	0.05

Form	Contact Surface	Contact Type	Route	Assumptions	Estimated Exposure (ug/day)	Estimated Internal Dose (ug/day)
ACUTE DERMAL EXPOSURE						
Residue	Carpet 75 mg/m2- extractable surface concentration (HIPES, SwRI) 0.2% transferable(SwRI)	Hand	Ingestion	hand to surface contact - 0.035 m2, 10 hand-to mouth per h, 4 hour, 50% available once ingested	210	105
				microactivity approach - contact area - 75 m2/hour, 4hour/day, 1% dermal adsorption	45,000	450
		Body	Adsorption	** **macroactivity approach** 50% available for transfer, transfer coefficient 0.87 m2/h, 4 h, 1% dermal adsorption,	130,500	1305
	Hard Surface 75 mg/m2- extractable surface concentration, 2% transferable (SwRI)	Hand	Ingestion	hand to surface contact - 0.035 m2, 10 hand-to mouth per h, 4 hour, 50% available once ingested	2100	1050
		Body	Adsorption	** **macroactivity approach** 50% available for transfer, transfer coefficient 8.7 m2/h, 4 h, 1% dermal adsorption,	1,305,000	13,500

Form	Contact Surface	Contact Type	Route	Assumptions	Estimated Exposure (ug/day)	Estimated Internal Dose (ug/day)
	HardToys 75 mg/m2 -extractable surface concentration. (Gurunathan), 2% transferable, assumed as above	Hand	Ingestion	hand to surface contact - 0.035 m2, 10 contacts/h; 4 h/day, 50% available once ingested	2100	1050
		Hand	Adsorption	hand to surface contact - 0.035 m2, 10 contacts/h; 4 h/day, 1% dermal adsorption,	42	21
		direct mouth	Ingestion	mouth to surface contact - - 0.0015m2, 10 contacts/h; 4 h/day, 50% dislodgeable, 50% available once ingested	2250	1125

Form	Contact Surface	Contact Type	Route	Assumptions	Estimated Exposure (ug/day)	Estimated Internal Dose (ug/day)
OTHER EXPOSURE ROUTES						
Food			Ingestion	3 ng/g; 500 g eaten; 50% available	1.5	0.75
Water			Ingestion	1 ng/g; 0.5 L; 100% available once ingested	0.5	0.5
Air			Inhalation	application day – 15 ug m3,; 10 m3 inhaled; 100% available	150	150
			Inhalation	14 days post application - 0.5 ug/m3; 10 m3 inhaled	5	5
			Inhalation	0.31 ug/m3 (NOPES) - 10m3 inhale	3.1	3.1
			Inhalation	1.6 ug/m3 (HIPES) - 14 days post application	16	16

microactivity approach
Exposure (ug/day) = extractable surface concentration (mg/m2) x fraction transferred x area of surface contact (m2/h) x h/day in activity
macroactivity approach (method used in OPP SOPs)
Exposure (ug/day) extractable surface concentration (mg/m2) x percent available to transfer x transfer coefficient* (m2/h) x h/day in activity

* transfer coefficient takes into account both fraction transferred and the contact area

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

A dermal and non-dietary ingestion exposure workshop was sponsored by U.S. EPA's National Exposure Research Laboratory (NERL) on September 17,1998. The purpose of this workshop was to gather information on the state-of-the-art in measuring and assessing children's exposures to pesticides via dermal contact with contaminated surfaces and objects as well as by non-dietary ingestion. Although the NERL human exposure research program covers exposure from source to dose, this workshop focused on characterizing concentrations of pesticides in the exposure media (on surface/object) and on quantifying the transfer of contaminants to the skin surface or mouth. The following report discusses the focus of the dermal exposure workshop, summarizes the workshop discussions and identifies research priorities based on a review of the literature, workshop discussions, and expert input.

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