DEVELOPMENT OF HEALTH CRITERIA FOR SCHOOL SITE RISK ASSESSMENT PURSUANT TO HEALTH AND SAFETY CODE 901(f):

GUIDANCE FOR ASSESSING EXPOSURES AND HEALTH RISKS AT EXISTING AND PROPOSED SCHOOL SITES

FINAL DRAFT REPORT

December 2002

Integrated Risk Assessment Section
Office of Environmental Health Hazard Assessment
California Environmental Protection Agency

Development of Health Criteria for School Site Risk Assessment Pursuant To Health and Safety Code 901(f): Guidance for assessing exposures and health risks at existing and proposed school sites

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Executive Summary

This draft guidance document was prepared to comply with California Health and Safety Code Section 901(f), which requires OEHHA to develop and publish a guidance document for use by the Department of Toxic Substances Control and other state and local environmental and public health agencies to assess exposures and health risks at existing and proposed school sites. It presents methodology for estimating exposure of school users to toxic chemicals found as contaminants at existing and proposed school sites, and the health risks from those exposures. It incorporates exposure factors unique to the school environment, and considers the activity patterns of children from birth through age 18, and of adult school employees.

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Introduction and Purpose

Section 901(f) of the California Health and Safety Code states that: "On or before December 31, 2002, the Office (of Environmental Health Hazard Assessment, OEHHA) shall publish a guidance document, for use by the California Department of Toxic Substances Control (DTSC) and other state and local environmental and public health agencies to assess exposures and health risks at existing and proposed school sites. The guidance document shall include, but not be limited to, all of the following:

(A) Appropriate child-specific routes of exposure unique to the school environment, in addition to those in existing exposure assessment models.

(B) Appropriate available child-specific numerical health effects guidance values and plans for the development of additional child-specific numerical health effects guidance values.

(C) The identification of uncertainties in the risk assessment guidance and those actions that should be taken to address those uncertainties."

Pursuant to HSC§901(f)(A) and (C), OEHHA is proposing these guidelines for multimedia, multipathway, risk assessment at existing and proposed school sites. HSC§901(f)(B) is addressed in a separate document (OEHHA, 2002a).

Need for Guidance

Children differ from adults anatomically, physiologically, and behaviorally in ways that may affect their exposure to environmental contaminants. For example, on a body weight basis, children require more oxygen, food, and water, and have a higher skin surface area than adults. Children's activities are different. Children are in a period continuous change as they move from infancy through puberty and into adulthood. Most previous guidance has focused on residential or occupational scenarios, and has treated childhood as a homogeneous life stage. This guidance addresses the differences between children and adults, and between the school setting and other settings.

Scope of Guidance

As required by the legislation, this guidance is intended to support assessment of chemical exposures and health risks at existing and proposed school sites, to characterize uncertainty in assessing exposure and risk in the school setting, and to suggest which areas are most in need of further research.

Mathematical models can be used to predict exposures and risks to specified groups of people from chemicals in specified environmental media under defined conditions. This guidance lays out a modeling approach to predicting exposures and risks to preschoolers, students, teachers and other school personnel, and their offspring, from chemicals in the soil, shallow ground water, and air at the school site. In a separate document (OEHHA, 2002) OEHHA describes a spreadsheet adaptation of this model. The Schoolscreeen spreadsheet is optional, and the user retains the responsibility to ensure that the model parameters including toxicity parameters are current and correct. The model is applicable to most chemicals, the notable exception being lead. OEHHA suggests the use of the DTSC Lead Risk Assessment Spreadsheet for assessment of exposure to lead at school sites.

The model is designed to support a tiered approach to assessment of risk. It can be used in screening mode, with default input values and all pathways included (tier 1). It also accommodates user-supplied site-specific input parameters and/or elimination of pathways that are not appropriate for a given site (tier 2). Use of this guidance in tier 1 or tier 2 mode should be discussed with and approved by DTSC or other regulatory programs for which the risk assessment is being conducted. In some cases, it may be appropriate to add in additional sources of chemicals in the environment. For example there may be off-site emissions that may impact on-site concentrations. OEHHA suggests that users document and justify all departures from default conditions so that reviewers can duplicate the modeling conditions and verify the result. This guidance specifies toxicity criteria that should be used in assessing risk and hazard.

Exposures to chemicals in building materials and furnishings and chemicals used in schools are beyond the scope of this guidance. This guidance only addresses risk assessment for schools, and it does not include project specific guidance such as selection of chemicals of potential concern, determination of appropriate exposure point concentrations, and site characterization, including sampling and analyses plans or strategies. In addition, this guidance does not provide risk management application or decision-making criteria. For information regarding the application of this document to regulatory programs, contact DTSC or other agencies that may utilize this guidance as a part of their regulatory program.

Schools Conceptual Site Model

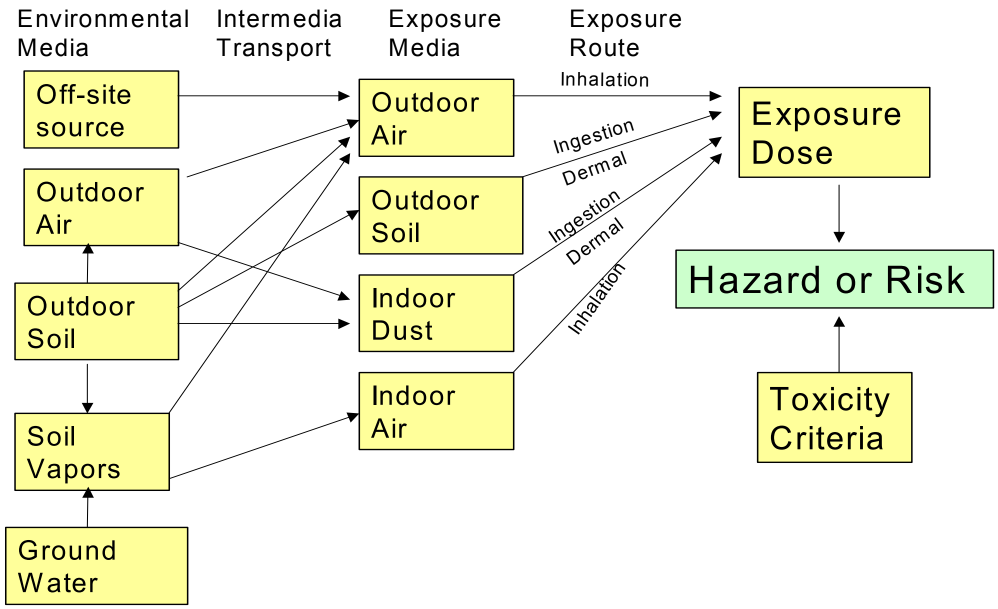
A conceptual site model includes the contaminated environmental media, the movement of the chemicals within and between environmental compartments (intermedia transfers), the concentration of the chemical(s) in various personal exposure media, exposure pathways and routes, exposed populations, and the amount of the chemical(s) taken into the body. These movements and concentrations may be described by a series of mathematical relationships. This guidance proposes a series of such mathematical relationships, which are described below.

As depicted in Figure 1, this model considers contaminated soil and shallow ground water as primary source media. Contaminated soil can be an exposure medium (by ingestion or dermal contact) and can be a source for transfer into other compartments. Chemical can vaporize from soil into indoor or outdoor air or it can be entrained into the suspended particle phase. As a default, soil is treated as the source of suspended particulate matter, but a measured on-site concentration in particulate matter may replace the calculated value. By this means, total particle-bound contaminants from off-site and on-site sources can be included. Vapors can be inhaled indoors or outdoors. Soil can be transported indoors, where it becomes a component of interior dust. Exposure to this dust can be by ingestion or dermal contact.

This guidance does not link ground water to drinking water. Instead, measured drinking water concentrations are supplied by the assessor. Ground water is treated as a source for chemicals that may vaporize and contribute to soil vapors. However, a measured value for a volatile chemical in soil vapor may be substituted for the value estimated from soil and ground water concentrations.

Hazard quotients and incremental risks are estimated for each chemical; then the hazard quotients and incremental risks associated with the individual chemicals are added to arrive at the total hazard index and total risk. If the total hazard index does not exceed one, then it may be assumed that the non-cancer toxic effects are unlikely and further analysis of non-cancer effects is not necessary. If the total hazard index exceeds one, it may be useful to separate chemicals by target organ and/or mode of action and add the hazard quotients of only those chemicals that are likely to act in an additive manner. This target organ/mode of action analysis should be documented.

Figure 1: Conceptual Site Model



Potentially Exposed Sub-populations at Schools

With the exception of pregnant or nursing women, genders are not separated. The following school sub-populations are addressed by the model:

1) Students from kindergarten through high school

2) Staff

3) Pregnant or nursing women

4) Pre-schoolers aged one through four

5) Nursing infants less than one year of age in day care at the school site whose mothers are students or staff.

Other groups that may use or visit the school facilities, such as parents, other visitors, and members of the general community are not explicitly considered. Since their visits would be less frequent than the students and staff, their long-term average exposure would be less than that of the groups listed above. Also, it would be possible to assess exposure of nursing infants who did not spend time at the school site, but whose mothers were students or staff. However, these children would be exposed less than infants described above (group #5).

Potential Exposure Media at Schools

The model addresses potential contamination of the following media:

a) Soil - Soil is often the primary environmental medium to be contaminated when toxic materials are spilled or dumped. Students and others at school sites may be exposed to soil on the campus. Bare dirt may cover a portion of the campus area. Playgrounds and athletic fields may have patches of bare dirt. Even paved areas may contain a layer of soil.

b) Dust - Interior surfaces including floors, desks, shelves, and windowsills, may accumulate a layer of dust between cleanings. This dust may come from multiple sources, including tracked-in or blown-in outdoor soil.

c) Air - Air may contain vapor-phase and/or particulate contaminants. The multiple sources of vapors and particles may include on-site and off-site sources. The model estimates indoor and outdoor concentrations of pollutants in the particulate or vapor phases based on concentrations in soil and/or ground water. Air may also be contaminated by vapor- or particle-phase pollutants originating off-site. Depending on program requirements, these contamination sources can be added to on-site emissions or measured directly.

Other potential exposure media

Drinking water for schools is usually supplied by a regulated municipal water supply, and therefore not site-related. Even in the unusual case that an on-site well would be used to supply potable water, the water thus produced would be regulated as a public water supply. Therefore, OEHHA recommends excluding the drinking water pathway from the schools exposure model.

OEHHA is aware that increasing numbers of schools are emphasizing gardening in the curriculum, and initially considered including food grown in the site soil as an exposure pathway, however, a variety of simulations using an array of chemicals representing various chemical classes including volatile organic chemicals, lipophilic organic chemicals, and heavy metals showed that the food pathway never contributed as much as 1% of the total risk or hazard, even assuming up to 5% of the diet being site-grown produce. Therefore, OEHHA recommends excluding the food pathway from the schools exposure model.

Exposure Pathways

Exposure pathways can be direct or indirect. A direct exposure pathway consists of a contaminated environmental medium and an exposure route by which the contaminated medium contacts and enters the body (e.g. ingestion of contaminated soil, pathway 1 in Table 1). An indirect exposure pathway consists of a contaminated environmental medium, one or more transfers between environmental media and ultimately an exposure medium, and an exposure route by which the exposure medium contacts and enters the body (e.g. transfer of chemicals from contaminated soil to indoor dust and ingestion of indoor dust, pathway 3 in Table 1).

Table 1: Exposure Pathways

Path-way	Source medium	Environmental medium	Exposure medium	Exposure Route	Infants 0-1	All others
1	Soil	Soil	Soil	Ingestion		X
2	Soil	Soil	Soil	Dermal contact		X
3	Soil	Soil	Dust	Ingestion		X
4	Soil	Soil	Dust	Dermal contact		X

5	Soil	PM_{10}	Outdoor Air	Inhalation	X	X
6	Soil	PM_{10}	Indoor Air	Inhalation	X	X
7a	Soil	Soil vapor*	Indoor Air	Inhalation	X	X
7b	Ground water	Soil vapor*	Indoor Air	Inhalation	X	X
8	Soil	Soil vapor	Outdoor Air	Inhalation	X	X
9	Offsite source	Vapors	Outdoor Air	Inhalation	X	X
10	Offsite source	PM_{10}	Outdoor Air	Inhalation	X	X
11		Mother's dose	Human milk	Ingestion	X	

* A representative measured concentration in soil vapor may be substituted for the model-based estimate.

Exposure Pathway Equations

Figure 1 depicts the movements of contaminants into and between environmental and exposure media. These movements and the resulting exposures may be described by a series of mathematical relationships. This model includes up to eleven pathways by which school users could be exposed to chemicals at the school site. Each pathway can be represented by an equation which describes a concentration in the source medium, up to two transfer constants that relate the concentration in the source medium to a concentration in an intermediate or exposure medium, and a contact rate that describes the daily intake of, or contact with, the exposure medium. When the exposure pathway is direct (i.e. the environmental medium and the exposure medium are the same, such as ingestion of outdoor soil), then no transfer constants are required. The daily dose associated with each of these pathways is estimated as follows:

1. Ingestion of outdoor soil: $D = C_S * I_S * A_I * F_S * F_O / BW$, where:
   - D = Pathway-specific daily dose of contaminant (µg/kg/day)
   - C_S = Concentration of contaminant in soil (µg/g)
   - I_S = daily soil/dust ingestion (g/day)
   - A_I = route absorption factor (unitless)
   - F_S = fraction of daily soil/dust ingestion and dermal contact that occurs at school (unitless)
   - F_{O} = fraction of daily soil/dust ingestion and dermal contact that occurs outdoors (unitless)
   - BW = age-specific body weight (kg)

2. Dermal contact with outdoor soil: $D = C_S * A_D * F_S * F_O * D_S$ where
   - D = Pathway-specific daily dose of contaminant (µg/kg/day)
   - C_S = Concentration of contaminant in soil (µg/g)
   - A_D = route-specific absorption factor (unitless)
   - F_S = fraction of daily soil/dust ingestion and dermal contact that occurs at school (unitless)
   - F_{O} = fraction of daily soil/dust ingestion and dermal contact that occurs outdoors (unitless)
   - D_S = Daily dermal contact with soil/dust (g/kg/day) = $\sum(A_{BP} * L_{BP})$, where
   - A_{BP} = body-part-specific area (cm^2/kg)
   - L_{BP} = body-part-specific skin loading (g/cm^2/day)

3. Migration of chemicals from outdoor soil to indoor dust; ingestion of indoor dust:
   $D = C_S * TF_{SD} * I_S * A_I * F_S * F_I / BW$; where

D = Pathway-specific daily dose of contaminant (µg/kg/day)
C_S = Concentration of contaminant in soil (µg/g)
TF_{SD} = Transfer factor from soil to indoor dust (unitless)
I_S = daily soil/dust ingestion (g/day)
A_I = route absorption factor (unitless)
F_S = fraction of daily soil/dust ingestion that occurs at school (unitless)
F_I = fraction of school soil/dust ingestion that occurs indoors (unitless)
BW = age-specific body weight (kg)

4. Migration of chemicals from outdoor soil to indoor dust; dermal contact with indoor dust:
$D = C_S * TF_{SD} * A_D * F_S * F_I * D_S$ where
D = Pathway-specific daily dose of contaminant (µg/kg/day)
C_S = Concentration of contaminant in soil (µg/g)
TF_{SD} = Transfer factor from soil to indoor dust (unitless)
A_D = route-specific absorption factor (unitless)
F_S = fraction of daily soil/dust contact that occurs at school (unitless)
F_I = fraction of daily soil/dust ingestion that occurs indoors (unitless)
D_S = Daily dermal contact with soil/dust (g/kg/day) = $\sum(A_{BP} * L_{BP})$, where
A_{BP} = body-part-specific area (cm^2/kg)
L_{BP} = body-part-specific skin loading (g/cm^2)

5. Suspension of soil particles in outdoor air; inhalation of suspended particulate matter (PM_{10}) in outdoor air:
$D = C_S * TF_{PM/S} * PM_{10} * B_O * T_O * A_{In}$, where
D = Pathway-specific daily dose of contaminant (µg/kg/day)
PM_{10} = Concentration of PM_{10} in outdoor air (g_{PM}/L_{air})
B_O = Body-weight-normalized breathing rate outdoors (L/min/kg)
T_O = Time outdoors at school daily (min/day)
A_{In} = route-specific absorption factor (unitless)
C_S = Concentration of contaminant in soil (µg/g)
$TF_{PM/S}$ = Ratio of the concentration of contaminant in outdoor PM_{10} to the concentration of contaminant in soil (unitless) A representative measured value for concentration of a chemical in outdoor PM_{10} may replace the value estimated from soil data; in that case the equation becomes: $D = C_{PM10} * PM_{10} * B_O * T_O * A_{In}$, where
C_{PM10} = Measured concentration in PM_{10}

6. Movement of suspended particulate matter (PM_{10}) from outdoor air to indoor air; inhalation of PM_{10} in indoor air:
$D = C_S * TF_{PM/S} * TF_{I/O} * S_F * B_I * T_I * A_{In}$, where
D = Pathway-specific daily dose of contaminant (µg/kg/day)
C_S = Concentration of contaminant in soil (µg/g)
S_F = Respirable particle load for indoor air (g_{PM}/L_{air})
B_I = Weight-normalized breathing rate indoors (L/min/kg)
T_I = Time indoors at school daily (min/day)
A_{In} = route-specific absorption factor (unitless)
$TF_{PM/S}$ = Ratio of the concentration of contaminant in outdoor PM_{10} to the concentration of contaminant in soil (unitless)

$TF_{I/O}$ = Ratio of the concentration of contaminant in indoor PM_{10} to the concentration of contaminant in outdoor PM_{10} (unitless)

7a. Vaporization of volatile chemicals from the soil; penetration of vapors into building interior; inhalation of vapors mixed with indoor air:

$D = C_S * \alpha * VC_S * B_I * T_I * A_{In}$, where:

D = Pathway-specific daily dose of contaminant (µg/kg/day)

C_S = Concentration of contaminant in soil (µg/g)

α = Ratio of chemical concentration in indoor air to that in soil vapor (unitless)

VC_S = Volatilization constant from soil (g_{soil}/L_{vapor})

B_I = Weight-normalized breathing rate indoors (L/min/kg)

T_I = Time indoors at school daily (min/day)

A_{In} = route-specific absorption factor (unitless)

A measured soil vapor concentration may be used in place of the value estimated from soil matrix data; in that case the equation becomes:

$D = C_{SV} * \alpha * B_I * T_I * A_{In,}$ where:

C_{SV} = concentration in soil vapor (µg/L) and 7a and 7b collapse into a single pathway 7. The decision as to which one to use should be made in consultation with the lead agency for the project.

7b. Vaporization of volatile chemicals from shallow ground water; penetration of vapors into building interior; inhalation of vapors mixed with indoor air:

$D = C_{GW} * \alpha * VC_{GW} * B_I * T_I * A_{In}$, where:

D = Pathway-specific daily dose of contaminant (µg/kg/day)

C_{GW} = Concentration of contaminant in ground water (µg/ml)

α = Ratio of chemical concentration in indoor air to that in soil vapor (unitless)

VC_{GW} = Volatilization constant from ground water (ml_{water}/L_{vapor})

B_I = Weight-normalized breathing rate indoors (L/min/kg)

T_I = Time indoors at school daily (min/day)

A_{In} = route-specific absorption factor (unitless)

A measured soil vapor concentration may be used in place of the value estimated from ground water data; in that case the equation becomes:

$D = C_{SV} * \alpha * B_I * T_I * A_{In,}$ where

C_{SV} = concentration in soil vapor (µg/L), and 7a and 7b collapse into a single pathway 7. The decision as to which one to use should be made in consultation with the lead agency for the project.

8. Inhalation of chemicals vaporized from outdoor soil:

$D = C_S * 1/VF * B_O * T_O * A_{In}$, where:

D = Pathway-specific daily dose of contaminant (µg/kg/day)

C_S = Concentration of contaminant in soil (µg/g)

1/VF = Inverse of the Volatilization Factor (ratio of concentration in air to concentration in soil)(g_{soil}/L_{air})

B_o = Weight-normalized breathing rate outdoors (L/min/kg)

T_o = Time outdoors at school daily (min/day)

A_{In} = route-specific absorption factor (unitless)

9. Inhalation of contaminants in vapors that originate off-site:

$D = C_A * (B_I * T_I + B_O * T_O) * A_{In}$, where

D = Pathway-specific daily dose of contaminant (µg/kg/day)

C_A = Concentration of contaminant vapor in site air (µg/L)

B_I = Weight-normalized breathing rate indoors (L/min/kg)
T_I = Time indoors at school daily (min/day)
B_O = Weight-normalized breathing rate outdoors (L/min/kg)
T_O = Time outdoors at school daily (min/day)
A_{In} = route-specific absorption factor (unitless)
This pathway accommodates modeled on-site concentrations from off-site sources. It is independent of (and therefore added to) modeled on-site concentrations. However, representative on-site concentrations measured under conditions that would capture contaminants originating both off-site and on-site, should include the contribution from both sources and therefore would replace modeled concentrations based on on- and off-site sources. This pathway may be inappropriate for some programs.

10. Inhalation of contaminants in suspended particles that originate off-site.
$D = C_A * (B_I * T_I + B_O * T_O) * A_{In}$, where
D = Pathway-specific daily dose of contaminant (µg/kg/day)
C_A = Concentration of particulate contaminant in site air (µg/L)
B_I = Weight-normalized breathing rate indoors (L/min/kg)
T_I = Time indoors at school daily (min/day)
B_O = Weight-normalized breathing rate outdoors (L/min/kg)
T_O = Time outdoors at school daily (min/day)
A_{In} = route-specific absorption factor (unitless)
This pathway accommodates modeled on-site concentrations from off-site sources. It is independent of (and therefore added to) modeled on-site concentrations. However, representative on-site concentrations measured under conditions that would capture contaminants originating both off-site and on-site, should include the contribution from both sources and therefore would replace modeled concentrations based on on- and off-site sources. This pathway may be inappropriate for some programs.

11. Ingestion on contaminants in breast milk (only for infants up to one year old)
$D = C_{BM} * I_{BM} * A_I$, where
D = Pathway-specific daily dose of contaminant (µg/kg/day)
C_{BM} = Contaminant concentration in breast milk (µg/g), estimated as:
$0.0000002 * K_{OW}$ * maternal dose (mg/day of contaminant)
I_{BM} = Age-specific, weight normalized daily breast milk ingestion (g/kg/day)
A_I = route-specific absorption factor (unitless)

Each of these equations gives a pathway-specific daily dose of the chemical in question. The pathway-specific daily dose is converted to an annual average daily dose by multiplying by the fraction of annual exposure days (EF/365). The pathway-specific annual average daily dose is divided by the route-specific reference dose (RfD) to arrive at the pathway-specific hazard quotient (HQ). The pathway-specific HQs are added to give the chemical-specific HQ. In a screening analysis, the chemical-specific HQs for each chemical are added to give the Hazard Index. In a more detailed (tier 2) analysis, target organs and mechanisms of toxic action may be considered in determining the appropriateness of adding the HQs for individual chemicals.

To compute cancer risk, the pathway-specific annual average daily dose is converted to a pathway-specific lifetime average daily dose by multiplying by the fraction of a lifetime represented by each exposure scenario (ED/AT, i.e. 1/70 of a lifetime for each year of exposure). The pathway-specific lifetime average daily dose is multiplied by the route-specific cancer potency factor to obtain the risk for that pathway. The pathway-specific risks for relevant pathways are added to give the chemical-specific risk. Finally the chemical-specific risks for each chemical are added to give the total cancer risk. Annual risks may be added for a series of years to obtain the total risk for that period.

The pathway equations above require numerical values or parameters, which can be divided into "intermedia transfer constants" and "exposure factors", which are described below and summarized in a table at the end of each section:

Intermedia Transfer Constants

When the environmental medium and the exposure medium are not the same, an intermedia transfer constant is involved. Transfer constants describe the relationship between the concentration of a chemical in one compartment and the concentration of the chemical in another compartment, or, in some cases, the concentration of one medium in another, such as the amount of suspended particulate matter in the air. Some indirect pathways – such as vaporization of soil contaminants and movement of the vapors into indoor spaces – involve two or more intermedia transfer constants. Some transfer constants are chemical-specific; others are general.

Transfer factor from soil to indoor dust (TF_{SD}) is the ratio of the concentration of a chemical in the dust on surfaces inside the school building(s) to its concentration in outdoor soil from the schoolyard. This is important because dust on indoor surfaces may be a significant source of exposure to chemicals originating in soil and transported to the building's interior through open doors and windows, HVAC systems, building infiltration, and on shoes, clothing, and objects carried into the rooms. OEHHA recommends a default value of one (1).

Transfer factor from soil to outdoor particulate matter ($TF_{PM/S}$) is the ratio of the concentration of contaminant in outdoor PM_{10} to the concentration of contaminant in outdoor soil from the schoolyard. This is important because students and other school users may inhale suspended respirable particles in the outdoor air. OEHHA recommends a conservative default value of one (1). If samples of outdoor PM_{10} are collected and analyzed, this transfer constant is not needed.

Concentration of site-related particulate material less than 10 microns in diameter in outdoor air (PM_{10}). OEHHA recommends a default value of 1.8 E-9 g PM/L (1.8 $\mu g/m^3$). This value is based on the EPA Soil Screening Levels document (EPA, 1996).

Transfer factor from outdoor particulate matter to indoor particulate matter ($TF_{I/O}$) is the ratio of the concentration of a chemical in indoor PM_{10} to its concentration in outdoor PM_{10} at the school. This is important because students and other school users may inhale suspended respirable particles in the indoor air. OEHHA recommends a default value of one, implying that indoor and outdoor suspended particulate matter are equivalent with respect to chemical contaminant concentration.

Respirable particle load for indoor air (S_F) is the concentration (in g_{PM}/L_{air}) of particulate material less than 10 microns in diameter in indoor air. OEHHA recommends a default value of 1.8E-9 g PM/L (1.8 $\mu g/m^3$). This assumes that indoor PM levels are the same as outdoor PM levels.

Soil vapor to Indoor air (α) is the unitless ratio of the concentration of a chemical in indoor air to its concentration in soil vapor. It is a dilution factor for vapors moving from relatively confined spaces in soil pores to the better-ventilated building interior. OEHHA recommends the use of the Johnson and Ettinger model to estimate a value for this parameter. The model may be used in screening mode with default parameters. Site-specific parameters may be used when justified.

Volatilization constant from soil (VC_S) is the ratio of the concentration of a chemical in soil vapor to its concentration in the soil matrix. This ratio, in $\mu g/L_{vapor}/(\mu g/g_{soil})$, depends on the physical and chemical properties of the chemical, and on the properties of the soil. OEHHA recommends the Johnson and Ettinger screening model (EPA, 2000 (2)) to estimate this value.

Volatilization constant from ground water (VC_{GW}) is the ratio of the concentration of a chemical in soil vapor to its concentration in shallow ground water. This ratio, in $\mu g/L_{vapor}/(\mu g/ml_{water})$, depends on the physical and chemical properties of the chemical, and on the properties of the soil. OEHHA recommends the Johnson and Ettinger screening model (EPA, 2000 (2)) to estimate this value.

Volatilization factor (VF) is the ratio of the concentration of a chemical in soil to its concentration in outdoor breathing zone air. To calculate VF, OEHHA recommends the use of chemical-specific parameters and the equations in EPA's Soil Screening Guidance (EPA, 1996) with one modification: to better represent the possible contaminated area on a school site, EPA's default high-end value of Q/C of 68.8 for a 0.5-acre contaminated site is adjusted to 41.24, corresponding to a 10-acre contaminated site.

Table 2: Transfer Constants

Factor	Units	Value
TF_{SD}	**Unitless**	**1**
$TF_{PM/S}$	**Unitless**	**1**
PM_{10}	**g PM/L**	**1.8 E-9**
$TF_{I/O}$	**Unitless**	**1**
S_F	**g PM/L**	**1.8 E-9**
α	**Unitless**	**Chemical-specific**
VC_S	**$\mu g/L_{vapor}/(\mu g/g_{soil})$**	**Chemical-specific**
VC_{GW}	**$\mu g/L_{vapor}/(\mu g/ml_{water})$**	**Chemical-specific**
VF	**$\mu g/L_{air}/(\mu g/g_{soil})$**	**Chemical-specific**

Exposure Parameters

Most existing risk assessment guidance is focused on multi-year residential or occupational exposure scenarios. Exposure parameters given in existing guidance are generally long-term averages. This guidance is specifically aimed at school populations, including students, teachers and other staff, and users of on-site day care. Children are rapidly changing anatomically, physiologically and behaviorally. Thus, we recommend a set of exposure parameters for each year until age 18. We believe that it is useful to evaluate the exposure of growing children on a year-by-year basis for several reasons:
(1) Some chemicals may exhibit age-specific toxicity. OEHHA is currently evaluating this aspect, and may publish age-specific toxicity criteria in the near future. Age-specific toxicity criteria should be paired with corresponding age-specific exposure estimates, to the extent possible.
(2) If the exposure parameters are given on a year-by-year basis, model users can aggregate the years in a manner that best supports the risk management process. Conversely, if OEHHA were to recommend exposure parameters that were averaged over some period of years, that averaging period might not match the proposed land use scenario, and it would be difficult to change the averaging period to match the exposure scenario.

The principal sources of data for this guidance were the Technical Support Document for Exposure Assessment and Stochastic Analysis (OEHHA, 2000), the draft Children's Exposure Factors Handbook (EPA, 2000), and the Exposure Factors Handbook (EPA, 1997). When more than one value was available for an exposure parameter, preference was given to values that were reported in a way that conformed to the assessment methodology, such as age-specific or short age intervals, and values reported as a function of body weight. This avoided or reduced the need to interpolate or extrapolate data and to convert data to appropriate units using uncertain conversion factors. When percentile estimates were available, preference was given to the ninetieth percentile. Where data were considered equally appropriate for the analysis, preference was given to OEHHA values. Consideration was given to entering the data as distributions rather than as point estimates, but distributions were not available for several critical parameters. This approach will be considered in future revisions.

This guidance includes the following parameters. Recommended values are summarized in Table 3, at the end of this section:

Soil Ingestion (I_S) is the estimated total daily inadvertent soil and dust ingestion. Geophagia or soil pica is not addressed in this document. EPA (2000, Table 5-21) estimated total daily soil and dust ingestion by children 1-6 years of age as 100 mg/day mean, with 400 mg/day as an upper end, adding that 200 mg/day may be taken as a conservative estimate of the mean. EPA (1997) recommended a value of 50 mg/day for adults. OEHHA (2000, page 4-15) recommends default values of 200 mg/day for children 1 - 6, and 100 mg/day for everyone over the age of 6. The estimated daily soil ingestion rates at school, shown in the last column of the table below, are based on OEHHA recommendations.

Age (years)	EPA mean (mg/day)	EPA upper end (mg/day)	**Recommended value (mg/day)**
<1			**0**
1-6	100	400	**200**
>6	50		**100**

Fraction at school (F_S) is the estimated fraction of total daily soil and dust ingestion and dermal contact that occurs at school. It calculated as the total time at school (indoors plus outdoors) divided by 16 hours per day. This is based on the assumptions that soil and dust ingestion and dermal contact are proportional to time spent at a given locale, that soil and dust ingestion occur only during waking hours, which comprise 16 hours per day.

Soil adherence to skin = $\sum(A_{BP} * L_{BP})$, where A_{BP} = body-part-specific area (cm^2/kg, see below) and L_{BP} = body-part-specific skin loading (g/cm^2/day). EPA (2000) recommends the data of Kissel et al. (1996, 1998) and Holmes et al (1996) as a basis for estimating body-part- and activity-specific soil skin loading. OEHHA considers these data to be the best available because they are based on real-world exposures to young children in day-care centers, (daycare kids #1a, 1b, 2, and 3) an exposure setting similar to that being assessed. The children ranged in age from 1 to 6.5 years and included 17 boys and 4 girls (groups 1a and 1b were the same children, measured in the morning and afternoon). They wore long pants (16) or shorts (5), long sleeves (7) or short sleeves (14), and mostly low socks and shoes, but 5 were barefoot. Exposure times ranged from 3.5 to 8 hours, with no obvious correlation between time and dermal loading. These data are limited by low numbers of children, high inter-individual variability, limited age range and the need to match their activities with those being assessed.

The estimated mass of soil or dust adhering to a unit area of skin was estimated on a body-part-specific basis. Geometric means ranged from 0.02 to 0.09 mg/cm^2 (see table below). Although this reference does not provide values for the head and trunk, these body parts are likely to be contaminated by soil at rates less than or similar to the legs. Therefore, OEHHA recommends a value of 0.02 mg/cm^2 for the head and trunk. A "fraction exposed" term is not used, since the studies were based on entire body parts irrespective of whether they were partially clothed or not.

Data from other groups of children were available. The indoor kids (3 to 13 years of age) and tae kwon do participants (8 to 42 years) playing on a carpeted surface for 1.5 to 2 hours generally had lower dermal exposures to soil than the daycare kids; 9 to 14-year-old kids playing in mud for 10 to 20 minutes had much higher dermal exposures (2 – 3 logs); while 13 to 15 year-olds playing soccer on grass and bare earth for 40 minutes had a soil exposure that was generally similar to the daycare kids. The daycare data were preferentially used for young children because the setting was most similar to the school setting.

Skin Surface area (A_{BP} = body-part-specific area, cm^2/kg) As stated above, EPA (2000) recommends using body-part- and activity-specific soil skin loading rates. In order to do this, skin surface area needs to be calculated on a body-part-specific basis. Data on fractional area of various body parts are found in Table 8-3 (EPA, 2000). Age-specific body surface area data are found in tables 8-1 and 8-2 (EPA, 2000). Table 8-4 (EPA, 2000) supplies surface-area to body weight ratios, but these are pooled for ages 2.1 to 19 years. Since it is apparent from analyzing the data in Tables 8-1, 8-2 and 11-1 (EPA, 2000) that surface-area-to-body-weight ratios change markedly with age, OEHHA recommends using the age-specific data in Tables 8-1, 8-2, and 8-3 to calculate these ratios. A sample calculation (for a 1-year-old child) is given in the table below.

Body part	Fraction of Body[a]	Total skin Area[b] cm^2/kg	Fractional Area[c] cm^2/kg	Skin Loading[d] g/cm^2	Skin Loading[e] g/kg
Head	**16.5%**	**641**	**105.8**	**0.000020**[f]	**0.0021**
Trunk	**35.5%**	**641**	**227.6**	**0.000020**[f]	**0.0044**
Arms	**13.0%**	**641**	**83.3**	**0.000023**	**0.0019**
Hands	**5.7%**	**641**	**36.4**	**0.000092**	**0.0034**
Legs	**23.1%**	**641**	**148.1**	**0.000020**	**0.0029**
Feet	**6.3%**	**641**	**40.2**	**0.000065**	**0.0026**
Total	**100%**		**641**		**0.0173**

a EPA, 2000, Table 8-3

b Estimated from EPA, 2000, Tables 8-1, 8-2, and 11-2. Recommended values are age-specific means of boys and girls.

c Calculated as the product of column 2 times column 3

d EPA, 2000, Table 8-13

e Calculated as the product of column 4 times column 5. Assumes that the school children will be clothed similarly to those in the study (see EPA, 2000, Table 8-12).

f There are no data for trunk and head. OEHHA suggests that the value for the legs, i.e. 0.02, be adopted for the head and trunk.

Fraction outdoors (F_O) is the estimated fraction of the daily school-related dermal and ingested soil/dust exposure that is acquired outdoors. This is calculated as the time spent outdoors divided by the time spent outdoors plus the time spent indoors (see below). The implicit assumption is that indoor and outdoor exposure are proportional to time spent in those environments. This fraction is significant only if the concentration of a contaminant in indoor dust differs from its concentration in outdoor soil.

Body weight (BW) for children up to 3 years old is from EPA, 2000, Table 11-1. The 50th percentile values for boys and girls within each year of age were averaged to obtain a representative value. E.g. the body weight for one-year-olds is the average of male and female 50th percentile values at 12, 18, and 24 months. Body weights for children older than 3 years are the means for boys and girls at the beginning and end of each age interval from Table 11-2 (EPA, 2000). E.g. the body weight estimate for four-year-olds is the average of male and female means (including clothing) at 4 and 5 years. Mid-range values for body weight are recommended because this parameter appears only in the denominator of the soil ingestion and dermal contact equations, and since the numerators are thought to be conservative estimates of these parameters, it would be excessively conservative to use a low-end body weight. Estimated body weights for various ages are given below and in Table 3:

Age (years)	Weight (kg)		Age (years)	Weight (kg)
0-1	7.04		9-10	33.90
1-2	11.08		10-11	38.70
2-3	13.29		11-12	43.20
3-4	16.35		12-13	47.85
4-5	18.55		13-14	53.20
5-6	21.15		14-15	57.05
6-7	23.75		15-16	60.35
7-8	26.50		16-17	62.90
8-9	29.80		17-18	64.15

Exposure time, outdoors (T_O) is the 75th percentile age-specific daily outdoor exposure time shown below (along with 50th and 95th percentile values for comparison) (EPA, 2000, Table 9-40). The data are based on national activity pattern survey data, and are weighted according to gender, age, race employment status, region, season, etc, to represent the U.S. population (Tsang and Klepis, 1996). OEHHA recommends the seventy-fifth percentile values (in bold below) because when 75th percentile values for time indoors at school and for time outdoors at school are added, the combined time at school ranks at the 95th to 99th percentile for total time spent at school (EPA, 2000, Table 9-34). Table 9-40 may overestimate actual time spent outdoors on school grounds because it includes some time spent at playgrounds. However, in some instances playground time may be spent at the school grounds. Data for infants <1 are not available, so the values for 1-year-olds are recommended as a surrogate.

	MINUTES SPENT OUTDOORS AT SCHOOL PER SCHOOL DAY		
Age	50th percentile	**75th percentile**	95th percentile
1-4	65	**140**	175
5-11	60	**120**	220

12-18	55	**105**	225

Exposure time, indoors (T_I) is the 75th percentile age-specific daily indoor exposure time shown below (along with 50th and 95th percentile values for comparison) (EPA, 2000, Table 9-39). OEHHA recommends seventy-fifth percentile values (in bold below) because when 75th percentile values for time indoors at school and for time outdoors at school are added, the combined time at school ranks at the 95th to 99th percentile for total time spent at school (EPA, 2000, Table 9-34). Data for infants less than 1 year of age are not available, so the values for 1-year-olds are recommended as a surrogate.

	MINUTES SPENT INDOORS AT SCHOOL PER SCHOOL DAY		
Age	50th percentile	**75th percentile**	95th percentile
1-4	269	**500**	595
5-11	403	**445**	565
12-18	420	**450**	565

Breathing rate, outdoors (B_O) the estimated breathing rate for outdoor school activities like walking and running were estimated form the data of Wiley, et al in OEHHA, 2000, p. 3-27. This Guidance recommends using an average of the ventilation rates for moderate activity (0.6 L/min-kg) and for heavy activity (0.9 L/min-kg), i.e. 0.75 L/min-kg for all ages. In the Wiley, et al. report, the moderate activity category includes, outdoor play, outdoor leisure, and golf, while the heavy activity category contains activity descriptors such as walking and active sports. The recommendation to use an average of the ventilation rates for moderate and heavy activity is based on the fact that both sets of descriptors were deemed consistent with outdoor activities at school.

Breathing rate, indoors (B_I) the estimated breathing rate for indoor school activities, were estimated from the data of Wiley, et al (in OEHHA, 2000, p. 3-25 to 3-26). The light activity category contained activity descriptions compatible with indoor activities at school, such as eating, talking, reading, and homework. The moderate activity category also contained some activity descriptions, such as indoor play, compatible with indoor activities at school, particularly for younger children. Therefore we recommend using an average of the ventilation rates for moderate activity (0.6 L/min-kg) and for light activity (0.3 L/min-kg), i.e. 0.45 L/min-kg, for children up through age 5. For older children the light activity ventilation rate of 0.3 L/min-kg for indoor activities is recommended, since their more vigorous activities typically take place outdoors.

Exposure frequency (EF) is the estimated number of days students or other school users attend school annually. The recommended default value for a 9-month school year is 180 days, the standard school-year length in California. For year-round schooling, (i.e. a standard 9-month school year plus summer school) a value of 223 days may be used. This value is based on the assumption that a student attending year-round school has 12 holidays plus five weeks off annually.

Breast milk intake (I_{BM}) This Guidance recommends a daily breast milk ingestion of 130 g/kg/day for the first 12 months of life (OEHHA, 2000, Table 5.13, 90th percentile).

Breast milk concentration (C_{BM}) of organic chemicals is estimated as 0.0000002 * K_{OW} (octanol/water partition coefficient) * maternal dose (mg/day). Maternal dose is the calculated annual average daily dose for pregnant or lactating women (µg/kg/day) * body weight (kg)* 0.001 mg/µg) (DTSC, 1994)

Fraction absorbed, inhalation (A_{In}) is the chemical-specific ratio of the total dose of a chemical absorbed through the respiratory tract to the total amount of the chemical inhaled. In the absence of data to support an alternative value, a default value of one should be used.

Fraction absorbed, ingestion (AI) is the chemical-specific ratio of the total dose of a chemical absorbed through the gastro-intestinal tract to the total amount of the chemical ingested. In the absence of data to support an alternative value, a default value of one should be used.

Fraction absorbed, dermal (A_D) is the chemical-specific ratio of the total dose of a chemical absorbed through the skin to the total amount of the chemical that is adsorbed onto the skin. Suggested values in the following table are from (DTSC, 1994) Table 2. page A-6):

Compound Class	Absorption fraction
Chlorinated insecticides	0.05
Polynuclear aromatic hydrocarbons, polychlorinated biphenyls	0.15
Organophosphates, pentachlorophenol	0.25
Polychlorinated dibenzo-p-dioxins and dibenzofurans	0.03
Other organic chemicals	0.1
Cadmium	0.001
Arsenic	0.03
Other metals and complexed cyanides	0.01
Free cyanide	0.1

Lifetime Exposure Fraction (ED/AT) is the fraction of a lifetime represented by each exposure scenario. It enters into the calculation of cancer risk but not the calculation of the hazard index. Exposures need to be adjusted according to the lifetime exposure fraction because while cancer potency factors are based on lifetime exposure, this model estimates school-related exposure and risk for a series of one-year intervals beginning at birth. Since exposures differ from year to year, risks for each year are unique. For single-year scenarios, ED/AT is 1/70 or 0.014. For staff, the exposure duration is 25 years, standard occupational exposure duration. Annual and/or multi-year risks may be added to obtain the aggregate risk for any multi-year period.

Table 3: Summary of Recommended Exposure Parameters

		Recommended values for age																			
Parameter	Units	<1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	Preg-lac.	Staff
Soil Ingestion[a]	mg/day	0	200	200	200	200	200	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Fraction at school[b]	unitless	0.67	0.67	0.67	0.67	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58
Fraction outdoors[c]	unitless	0.22	0.22	0.22	0.22	0.22	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.11
Body weight[d]	Kg	7.04	11.1	13.3	16.4	18.6	21.2	23.8	26.5	29.8	33.9	38.7	42.3	47.9	53.2	57.1	60.4	62.9	64.2	64.2	70
Surface area, head[e]	Cm^2/kg	117	106	63	55	54	50	47	45	42	38	33	29	25	28	26	23	21	20	20	20
Loading rate, head[f]	g/cm^2	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5
Surface area, trunk[e]	Cm^2/kg	229	228	171	128	122	124	126	122	116	107	104	101	99	91	91	89	87	85	82	85
Loading rate, trunk[f]	g/cm^2	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5
Surface area, arms[e]	Cm^2/kg	88	83	53	58	54	50	47	45	42	39	39	39	39	34	34	35	35	47	45	47
Loading rate, arms[f]	g/cm^2	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5
Surface area, hands[e]	Cm^2/kg	34	36	24	24	22	19	17	17	17	17	16	16	15	14	15	15	15	14	13	14
Loading rate, hands[f]	g/cm^2	9e-5	9e-5	9e-5	9e-5	9e-5	9e-5	9e-5	9e-5	9e-5	9e-5	9e-5	9e-5	9e-5	9e-5	9e-5	9e-5	9e-5	9e-5	9e-5	9e-5
Surface area, legs[e]	Cm^2/kg	132	148	103	108	108	102	98	97	95	90	89	88	87	89	90	90	90	82	79	82
Loading rate, legs[f]	g/cm^2	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5	2e-5
Surface area, feet[e]	Cm^2/kg	42	40	32	29	28	26	25	25	25	24	23	21	20	22	21	20	19	19	19	19
Loading rate, feet[f]	g/cm^2	7e-5	7e-5	7e-5	7e-5	7e-5	7e-5	7e-5	7e-5	7e-5	7e-5	7e-5	7e-5	7e-5	7e-5	7e-5	7e-5	7e-5	7e-5	7e-5	7e-5
Breathing rate, outdoors[g]	L/min-kg	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.7
Exposure time, outdoors[h]	min/day	140	140	140	140	140	120	120	120	120	120	120	120	105	105	105	105	105	105	105	60
Breathing rate, indoors[i]	L/min-kg	0.45	0.45	0.45	0.45	0.45	0.45	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Exposure time, indoors[i]	min/day	500	500	500	500	500	445	445	445	445	445	445	445	450	450	450	450	450	450	450	480
Exposure frequency[n]	days/yr	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	
Exp. freq. (year-round)[o]	days/yr	223	223	223	223	223	223	223	223	223	223	223	223	223	223	223	223	223	223	223	250
Breast milk intake[p]	g/kg/day	130	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Exposure duration[q]	Years	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	25
Averaging time[r]	Years	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70

[a] The estimated total daily inadvertent soil and dust ingestion, based on OEHHA 2000, page 4-15. Geophagia or soil pica is not addressed in this document.
[b] Fraction of daily soil and dust ingestion and dermal loading that occurs at school, based on the number of hours at school daily divided by 16. OEHHA recommends default values of 0.67 for infants <1 and 0.563 (9 of 16 hours daily) for staff.
[c] Fraction of daily site-related dermal and ingested soil/dust load that is acquired outdoors. Calculated as the time spent outdoors divided by the time spent outdoors plus the time spent indoors.

[d] Body weight data for children up to 3 years old were taken from EPA, 2000: Table 11-1 (50th percentile; mean of boys and girls). For older children, values were taken from Table 11-2, the mean for boys and girls and the average of the beginning and end of the interval.
[e] EPA, 2000, Table 8-13 (Assumes that the school children will be clothed similarly to those in the study; see EPA, 2000, Table 8-12).
[f] Estimated from EPA, 2000, Tables 8-1, 8-2 and 8-3 OEHHA suggests that the value for the legs, i.e. 0.02, be adopted for the head and trunk
[g] Based on (OEHHA, 2000, p. 3-27).
[h] Based on 75th percentile values from EPA, 2000, Tables 9-39 and 9-40. Since data for adult staff are not available, OEHHA recommends a default value of 60 minutes daily
[i] OEHHA recommends a value of 0.45 L/min-kg for children up through age 5, and a value of 0.3 L/min-kg for older children and adults based on (OEHHA, 2000, p. 3-25 to 3.26).
[j] Based on 75th percentile values from EPA, 2000, Tables 9-39 and 9-40. Since data for adult staff are not available, OEHHA recommends a default value of 480 minutes daily.
[n] The recommended default value for a 9-month school year is 180 days, the standard school-year length in California.
[o] For year-round schooling, a value of 223 days may be used.
[p] Based on (OEHHA, 2000, Table 5.13, 90th percentile).
[q] Exposure Duration is the number of consecutive years of exposure represented by the exposure scenario under evaluation.
[S] OEHHA recommends a default value of 70 years.

Chemicals of Concern

Chemicals of concern should be determined in consultation with the lead regulatory agency on the project. Suggested guidance includes DTSC, 1994, section 2.4.6.7.

Exposure Point Concentration

Exposure point concentration should be determined in consultation with the lead regulatory agency on the project. Suggested guidance includes DTSC, 1992, Chapter 2.

Toxicity Criteria

OEHHA cancer potency values and reference exposure levels, which are available at (http://www.oehha.ca.gov/risk/ChemicalDB/index.asp) should be preferentially used. When OEHHA criteria are not available, U.S. EPA criteria found in the Integrated Risk Information System (IRIS) database (http://www.epa.gov/iriswebp/iris/index.html) should be used when available. If criteria for a given chemical are not available either from OEHHA or in IRIS, criteria from other published sources or may be used, subject to approval by the reviewing agency.

Risk Calculation

Hazard quotients and incremental risks from all exposure pathways are estimated and summed for each chemical. The hazard quotients and incremental risks for the individual chemicals are then added to calculate the total hazard index and total risk. For screening assessment, the default assumption is that hazards posed by individual chemicals are additive. Some non-cancer toxic effects of individual chemicals are unlikely to be additive. In those cases, a statement to that effect, with documentation based on target organ and/or mode of action, should be included.

Following the methodology described herein will produce age-specific estimates of hazard and risk. In order to calculate the risk for a multi-year period, the risks for individual years must be added. Hazards are not usually considered to be additive from year to year (i.e. the chemical exerts its full effect of within one year).

Sensitivity Analysis

The calculated risk or hazard may be relatively sensitive or insensitive to changes in various input parameters. This relative sensitivity was investigated by changing the input parameters one at a time and measuring the effect on the risk or hazard. The change in the risk or hazard divided by the change in the input parameter is termed the *local sensitivity*. The local sensitivity is dependent on how the parameter is mathematically related to the result. However, it can change, depending on other inputs. For example if soil were the only contaminated medium, the model would be very sensitive to changes in the soil ingestion rate. But if ground water were the principal contaminated environmental medium, the model would be relatively insensitive to changes in the soil ingestion rate. The local sensitivity is also heavily influenced by the properties of the contaminant. For example, risk from volatile chemicals is sensitive to changes in breathing rate and hours spent indoors daily, while risk from non-volatile chemicals is relatively insensitive to changes in these parameters.

For this analysis, representative conditions were selected. The only inputs were 0.15 mg/kg of the chemical in soil and 0.1 μg/L in shallow ground water. The following table shows the results of the analysis for 1-2-year-olds. The ratio of change in output/change in input has been converted to percentages, i.e. a 1:1 ratio would be shown as 100%. Some parameters (e.g. those that appear in the denominator) change the output in the opposite direction; these are shown as negative percentages. Four chemicals were selected to represent a range of physical and chemical characteristics. They include a volatile chemical, a relatively non-volatile lipophilic organic chemical, a metal and a metal that is carcinogenic by inhalation but not by ingestion. Each chemical was evaluated based on its most sensitive endpoint: For the first three the most sensitive endpoint was carcinogenicity; for the fourth, non-carcinogenic toxicity was limiting.

Table 4: Sensitivity Analysis*

	Vinyl chloride	DDT	Cadmium	Chromium VI	Maximum
Indoor dust/outdoor soil	0.10%	74.00%	77.34%	77.29%	77.34%
Outdoor PM10/outdoor soil	0.00%	0.00%	0.00%	0.000%	0.000%
Outdoor PM10	0.00%	0.00%	0.00%	0.000%	0.000%
Indoor PM10/outdoor PM10	0.00%	0.00%	0.00%	0.000%	0.000%
Indoor PM10	0.00%	0.00%	0.00%	0.000%	0.000%
Indoor vapor/Soil vapor, J&E	93.90%	3.00%	0.00%	0.000%	93.900%
Koc	-0.028%	0.00%	0.00%	0.000%	-0.028%
H	0.000%	0.00%	0.00%	0.000%	0.000%
Fraction absorbed, resp	97.30%	4.10%	0.00%	0.000%	97.30%
Fraction absorbed, ingest	0.20%	94.90%	99.19%	99.40%	99.40%
Fraction absorbed, dermal	2.50%	1.20%	1.05%	0.73%	2.500%
Soil vapor/soil matrix	91.10%	0.00%	0.00%	0.00%	91.10%
Soil vapor/groundwater	2.90%	3.00%	0.00%	0.00%	3.00%
Volatilization Factor	-5.40%	-1.00%	0.00%	0.00%	-5.40%
Soil Ingestion	0.20%	93.20%	98.50%	98.74%	98.74%
Fraction at school	0.20%	94.40%	98.50%	98.74%	98.74%
Surface area	0.00%	0.80%	0.81%	0.567%	0.81%
Fraction outdoors	0.00%	0.50%	0.54%	0.38%	0.54%
Body weight	-0.20%	-85.80%	-89.54%	-89.77%	-89.77%
Breathing rate, outdoors	3.40%	1.60%	0.00%	0.00%	3.40%
Exposure time, outdoors	3.40%	1.50%	0.41%	0.29%	3.40%
Exposure time, indoors	93.90%	2.60%	-0.39%	-0.27%	93.90%
Breathing rate, indoors	93.90%	3.00%	0.00%	0.00%	93.90%
Exposure frequency	100.00%	100.00%	100.00%	100.00%	100.00%
Exposure duration	100.00%	100.00%	100.00%	0.000%	100.00%
Averaging time	-90.90%	-90.90%	-90.90%	0.00%	0.00%
area fraction Head	0.00%	0.30%	0.07%	-0.044%	0.30%
area fraction Trunk	0.00%	0.10%	0.15%	-0.076%	0.15%
area fraction Arms	0.00%	0.00%	0.06%	-0.050%	0.062%
area fraction Hands	0.00%	0.10%	0.11%	0.052%	0.11%
area fraction Legs	0.00%	0.10%	0.09%	-0.019%	0.10%

area fraction Feet	0.00%	0.10%	0.08%	0.027%	0.10%
loading Head	0.00%	0.30%	0.07%	0.069%	0.30%
loading Trunk	0.00%	0.10%	0.15%	0.15%	0.15%
loading Arms	0.00%	0.00%	0.06%	0.062%	0.062%
loading Hands	0.00%	0.10%	0.11%	0.109%	0.11%
loading Legs	0.00%	0.10%	0.09%	0.094%	0.10%
loading Feet	0.00%	0.10%	0.08%	0.084%	0.10%
Reference Dose	0.00%	0.00%	0.00%	100.00%	100.00%
Cancer potency	100.00%	100.00%	100.00%	0.00%	100.00%

* The ratio of the change in risk or hazard to the change in the input parameter.

The total sensitivity of a model to changes in a given parameter is the product of the local sensitivity to changes in that parameter and the total range of that parameter. Therefore, if either the local sensitivity or the range of variation is very small, variability in that parameter is unlikely to have appreciable impact on risk or hazard. For example if a parameter had a local sensitivity of less than 1%, a 10-fold error in the parameter value would change the hazard or risk by less than 10%. A change of less than 10% is not likely to change the result expressed to one significant figure. Risk assessors generally acknowledge that their results are good to only one significant figure at best. Therefore, the analysis of parameter uncertainty below is focused on those with 1% or greater local sensitivity.

Uncertainty Analysis

Model Uncertainty

In time-dependent models, concentrations, flow rates, and dose rates change with time. Time-independent models like the one described herein assume that conditions are at equilibrium and do not change over time. They do not account for source depletion. This could result in overestimating risk, particularly if multi-year exposures are considered.

This model does not consider all possible transport mechanisms or all possible factors affecting environmental fate and transport of environmental contaminants. For example, it does not consider transport of soil contaminants to ground water, transfer from soil or air into edible plants, or redeposition of particulate matter. However, the authors believe it considers the principal determinants of chemical exposures at schools.

Exposure Pathway Uncertainty

This model does not consider all possible exposure pathways. For example, crops could be grown in site soil and/or contaminated ground water could be used to irrigate site-grown crops, thereby transferring contaminants to produce eaten by students. Also inhalation of volatile chemicals while showering is not included. The contribution of these pathways to the overall risk or hazard is minimal. The drinking water pathway is not considered based on the assumption that the source of drinking water at schools is regulated by local authorities.

Parameter Uncertainty

In addition to a unique exposure scenario, exposure assessment for schools requires a unique set of exposure parameters. For example, building parameters, and age distribution and activity patterns of the school users differ from typical residential, recreational, and occupational settings. As discussed above, under the heading "Sensitivity Analysis", parameters with a local sensitivity of 1% or greater and those that have an unusual level of uncertainty are the primary focus of this discussion.

Transfer factor from soil to indoor dust (TF_{SD})

Interior dust is an important exposure medium in school site exposure assessment because students typically spend much of their time at school in classrooms and other indoor areas. The fraction of dust that comes from site soil is poorly characterized, but significant, inasmuch as other sources of interior dust are less affected by site selection. This parameter is a good candidate for further study because it has a high parameter uncertainty and high local sensitivity (77%). The uncertainty, which is in both directions, is under investigation in a collaborative effort among the California Air Resources Board, the California Department of Health Services, the California Department of Toxic Substances Control, OEHHA, and the Research Triangle Institute.

Soil vapor to Indoor air (α)

The ratio of chemical concentration in indoor air to that in soil vapor parameter (alpha) is a good candidate for further study because it has a high parameter uncertainty and high local sensitivity for some chemicals (up to 94%). Site-specific factors such as operation of the HVAC system (positive or negative pressure, ventilation rates, etc.), type of foundation, and use of doors and windows will substantially affect alpha. OEHHA has no current plans for research to reduce the uncertainty in this parameter. The uncertainty is in both directions.

Volatilization constant from soil (VC_S)
The ratio of the contaminant concentration in soil vapor to that in soil matrix depends on the physical and chemical properties of the chemical, as well as soil properties. This ratio, in $\mu g/L_{vapor}/(\mu g/g_{soil}$, has a high local sensitivity (up to 91% for volatile chemicals) and is relatively uncertain. However, the uncertainty can be partially offset by sampling soil vapors in addition to soil matrix. Since there is no reason to believe that $\mathbf{VC_S}$ would be different in a school environment than in other environments, OEHHA recommends the Johnson and Ettinger model (EPA, 2000 (2)) to estimate this value.

Volatilization constant from ground water (VC_{GW})
The ratio of the contaminant concentration in soil vapor to that in shallow groundwater depends on the physical and chemical properties of the chemical, as well as soil properties. This ratio, in $\mu g/L_{vapor}/(\mu g/ml_{water}$, has a moderate local sensitivity (up to 3% for volatile chemicals) and is relatively uncertain. However, the uncertainty can be partially offset by sampling soil vapors in addition to ground water. Since there is no reason to believe that it would be different in a school environment than in other environments, OEHHA recommends the Johnson and Ettinger model (EPA, 2000 (2)) to estimate this value.

Volatilization factor (VF)
The volatilization factor has a moderate local sensitivity – up to 5.4%. It is based on a well-reviewed document. However, OEHHA recommends adjusting the contaminated area to 10 acres (compared to the default value of 0.5 acres) to more closely reflect the size of a school site. This reduces VF by approximately 40%, which increases the atmospheric concentration by about 67%, since atmospheric concentration is a function of 1/VF.

Soil Ingestion (I_S)
Soil and dust ingestion is a good candidate for further study because it has a high parameter uncertainty and high local sensitivity (up to 99%). U.S. EPA has estimated soil/dust ingestion by children and adults, and these values are widely applied in the residential setting. There are no estimates specific to the school environment; however, some of the data, collected in day care facilities, may be relevant to a school environment. Basic research in the area of soil and dust ingestion in schools is beyond the scope of this project. Since the recommended value is equivalent to U.S EPA's conservative estimate of central tendency, we believe that the model is unlikely to underestimate soil ingestion for most children and adults. However a few children at the upper end of the distribution may ingest more soil than the 200 mg/day default.

Fraction at School (F_S)
The fraction of the daily soil ingestion and dermal contact that occurs at school is another parameter with a high local sensitivity (up to 99%). The recommended values are based on the estimated fraction of the waking hours that are spent at school, and the assumption that these exposure pathways are proportional to time spent in an environment (i.e., that soil ingestion and dermal contact do not occur preferentially at school or at home). The uncertainty is in both directions, but the maximum underestimate is less than two-fold, since the recommended values range from 58 to 67% and the true value could not exceed 100%.

Body weight
Body weight has a high local sensitivity (up to -90%) for chemicals whose exposure is primarily by soil ingestion. This is because soil ingestion (unlike breathing rate) is not normalized to body weight in this model. The negative sign indicates that risk decreases as body weight increases.

Exposure Time and Breathing Rate, Outdoors and Indoors
The outdoor exposure time and breathing rate have a moderate local sensitivity (up to 3.4% for volatile chemicals). The indoor exposure time and breathing rate have a high local sensitivity (up to 94% for volatile chemicals). The recommended parameter values are based on recent studies involving 52 children ranging in age from 3 to 12 years and another 160 children and adults from age 6 to 77 (OEHHA, 2000, p. 3-8 to 3-13). Ideally, school children would be observed to establish daily patterns of indoor and outdoor activities, with breathing rates assigned to each activity. However, these observations are not available for children in a school environment, so we assigned average breathing rates for indoor and outdoor activities. Detailed observations of pre-school and school children of various ages could help to reduce the uncertainty in these parameters. However, even with more data, variation between schools and between individuals is likely to be considerable, and inferences would still have to be made concerning which measured respiration rates correspond to the observed activities.

Discussion of Total Exposure time
There is significant uncertainty in the exposure time per day and per year. The sum of the recommended 75th percentile exposure times indoors and outdoors is 555 to 620 minutes per day. California law requires a minimum of 50,400 minutes of instructional time per year for grades 1-8. Based on a typical 180-day schedule, this translates to 280 minutes per day. Even allowing another 90 minutes for lunch, recesses, and/or between-class time brings the total to 370 minutes, considerably less than the recommended 75th percentile estimates. Part of the difference could be explained by other time spent at school such as participation in before- or after-school activities. Surveys focused specifically on the school environment could help to narrow this range of uncertainty.

Exposure frequency

Exposure frequency has a high local sensitivity (100%) because this value enters into every calculation of risk and hazard. While it is not particularly uncertain, it is quite variable, ranging from the minimum days per year required by law to a maximum for a student, staff member, or day-care child who attends the school year-round.

Lifetime Exposure Fraction (ED/AT)

Lifetime Exposure Fraction is the fraction of a lifetime represented by each exposure scenario. It does not enter into the calculation of hazard index, but applies only to carcinogens. Exposure duration has a local sensitivity of 100% for carcinogenicity. Averaging time (in effect, the expected life span) has a high local sensitivity (-91%) but has a relatively low uncertainty and is a widely applied value. It enters into the calculation of cancer risk but not the calculation of the hazard index. Exposures need to be adjusted according to the lifetime exposure fraction because while cancer potency factors are based on lifetime exposure, this model estimates school-related exposure and risk for a series of one-year intervals beginning at birth. This involves interpolation and therefore introduces uncertainty. Since exposures differ from year to year, risks for each year are unique. For single-year scenarios, ED/AT is 1/70 or 0.014. Because the risks are calculated on a year-by-year basis, annual risks may be added to obtain the aggregate risk for any multi-year period.

Even though there is ample precedent for the use of cancer potency factors based on lifetime exposure to evaluate risks from less-than-lifetime exposures, there is a legitimate question as to whether risks due to short-term exposures should be estimated using lifetime cancer potencies and be compared to lifetime risk benchmarks. On one hand, because exposures at school sites are changing from year to year, and because they may be for shorter time periods than residential or occupational exposures, it may be beneficial to assess risks on a single year- or short multi-year basis. On the other hand, assessment of risks over longer periods would involve less interpolation from lifetime studies, thereby reducing the uncertainty involved in this interpolation. In a separate project, OEHHA is evaluating the effect of short-term exposures to carcinogens early in life. If this leads to the future development of age-specific cancer potency factors, then it would be appropriate to assess exposure for time periods that correspond to the age-specific cancer potency factors.

Reference Dose (RfD)

Reference dose has a high local sensitivity (100% for non-carcinogenic effects). The uncertainty varies from minimal (when the RfD is based on data from sensitive humans) to considerable (when multiple uncertainty factors are involved such as when the RfD is based on laboratory animals and/or inadequate studies). The need for reference doses reflecting the potentially greater sensitivity of children to toxic effects of some chemicals is under evaluation by OEHHA.

Cancer Potency

Cancer potency has a high local sensitivity (100% for carcinogenic effects). The uncertainty varies from moderate (when the potency is based on human cancer incidence data) to high (when extrapolated from high-dose rodent data). There is additional uncertainty in extrapolating carcinogenic potency determined in a full lifetime study to less-than-lifetime exposure scenarios. The typical approach is to assume linearity, i.e. half the exposure is equivalent to half the risk. However, there is evidence that less-than-lifetime exposure of some carcinogens to children and infants may be more potent in inducing cancer than the same exposure later in life. Methodology to evaluate carcinogenic potency of early-in-life exposures is the subject of an ongoing OEHHA project.

Fraction absorbed, resp, Fraction absorbed, ingest

The fraction absorbed by the respiratory and ingestion routes has a high local sensitivity (up to 99%). The recommended default value of one implies that absorption is the same in the exposure situation as in the study(s) that are the basis for the toxicity criteria, an assumption widely accepted in the risk assessment community. In reality, the rats may have been fed or dosed with the test chemical mixed into a vehicle that enhances absorption compared to the form to which humans will be exposed. Conversely, the rats may have been exposed to a poorly absorbed form while humans are exposed to a readily absorbed form, though this seems less likely. Route-specific absorption is an important issue for inter-route extrapolation. The uncertainty is in both directions but is not likely to exceed a two- or three-fold error, since most compounds are readily absorbed the gastro-intestinal or the respiratory mucosa. OEHHA has no current plans for research on these parameters.

Fraction absorbed, dermal

Although the fraction absorbed by the dermal route has a moderate local sensitivity (up to 2.5%), it is potentially an important parameter because data on chronic toxicity or carcinogenicity by the dermal route are generally not available and therefore inter-route extrapolation is the rule. Current estimates, based on models and experiments using laboratory animals and cadaver skin, are relatively uncertain for some chemicals. However, there is no reason to believe that dermal uptake would be different in a school environment than in other exposure scenarios, and OEHHA has no current plans for dermal uptake research. The uncertainty is in both directions.

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