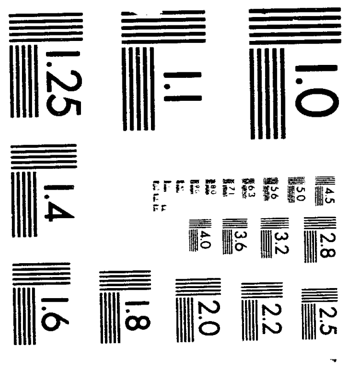

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MEPAS EXPOSURE MODEL UPDATES TO MEET CURRENT EPA GUIDANCE

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MEPAS EXPOSURE MODEL UPDATES TO MEET CURRENT EPA GUIDANCE[a]

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ABSTRACT

The Multimedia Environmental Pollutant Assessment System (MEPAS) is a software package developed for the U.S. Department of Energy (DOE) as a management tool to screen the many potential hazardous waste problems at DOE facilities across the country. The program considers both radioactive and chemical pollutants in estimating potential human health risks based on site- specific waste, environmental transport, and exposure characteristics. To support various DOE programs, recent modifications have been made to MEPAS to increase its applicability in analyzing the problems of mixed hazardous waste. Such analyses are needed to evaluate remediation options for mixed hazardous waste sites. This paper presents an overview of the MEPAS program and summarizes the current models used to translate environmental concentration values into projected intake by humans and, finally, into estimates of health risk. The recent modifications are described consistent with current EPA guidance for exposure and human health impact assessment.

INTRODUCTION

Evaluation of remediation options involves several criteria, including the potential reduction of health impacts to current and future populations. The Multimedia Environmental Pollutant Assessment System (MEPAS) is a software code developed for the U.S. Department of Energy (DOE) as a management tool to evaluate the health impacts from the many potential environmental problems complex-wide. Site-specific waste, environmental transport, and exposure characteristics are considered in estimating potential human health risks for radioactive and chemical pollutants. To support various DOE programs, recent modifications have been made to MEPAS to extend its use to risk assessment and increase its applicability in analyzing the problems of mixed hazardous waste. This paper presents an overview of the MEPAS code and describes the current models used to translate environmental concentration values into projected intake by humans and into estimates of health impacts consistent with current U.S. Environmental Protection Agency (EPA) guidance.

The MEPAS code includes models for groundwater, surface water, and atmospheric transport; these transport models may be used to estimate concentrations of pollutants at various points in the environment. Alternatively, concentrations may be defined by the user based on other measurements or results generated by other transport codes. The environmental concentrations are the starting point for the exposure-pathway and health-impact analyses. The new MEPAS exposure component allows detailed description of the potential exposure locations near a waste site. These locations may be represented by groundwater wells, river-water intake plants, aquatic recreational areas, agricultural production areas, measured media, measured direct radiation fields, or the general region within 50 miles of the site. The locations can also be defined to represent exposure of individuals or population groups. Contaminant concentrations defined at these locations are translated to daily intake rates of pollutants through twenty five exposure routes. Parameters for each pathway are defined by location to represent exposure to specific population groups, or individuals in a population group. For example, the intake rate of water may be defined as an average value for population exposure, or as a maximum value for individual exposures. Intakes of chemicals are expressed as a daily intake rate (mg/[kg-d]), and internal intakes of radionuclides and external radiation exposures are expressed as a total dose (rem). A health impact parameter for each pollutant is calculated using functions appropriate to the toxicity type defined for the pollutant (radionuclide, carcinogenic chemical, or non-carcinogenic chemical).

(a) Work supported by the U.S. Department of Energy under contract DE-AC06-76RLO 1830

The remainder of this paper describes the exposure pathway models and the models used to convert the daily intake rate or total dose to measures of human health impacts.

EXPOSURE PATHWAY MODELS

This section describes details of the exposure pathway models used in MEPAS. The exposure pathway analysis starts with pollutant concentrations in transport media and provides estimates of the average daily dose (chemicals) or total dose (radionuclides and radiation) to exposed individuals from contact with the transport medium or a secondary medium contaminated by the transport medium. The average daily dose or total dose is then used to estimate a measure of health impact appropriate to the type of pollutant considered, as described in the next section, on human health impact models. When appropriate, the individual health impact measure may be converted to a measure of health risk to the total population.

The transport pathways, transport media, exposure routes, media concentration units, and exposure pathways are given in Table 1 for the exposure pathways considered in MEPAS.

PLACE TABLE 1. HERE

The general equation for average daily dose, consistent with EPA (1) guidance for performing human exposure analysis in support of CERCLA activities is given by the following expression for intake of a chemical.

$$ADD_{pi} = C_{mi}\ IR_{pi} \left[\frac{EF_p\ ED_p}{BW_p\ AT_{pi}\ 365} \right] \qquad \text{(Eq. 1)}$$

where ADD_{pi} = average daily dose for pollutant i by exposure pathway p (mg/kg-d)

C_{mi} = concentration of pollutant i in medium m associated with exposure pathway p (units appropriate to the medium, pollutant, and exposure pathway)

IR_{pi} = rate of intake or contact with contaminated medium for the pollutant i and exposure pathway p (units of media volume or mass per day as appropriate to the medium, pollutant, and exposure pathway as per Table 1)

EF_p = exposure frequency for the exposure pathway (d/yr)

ED_p = exposure duration for the exposure pathway (yr)

BW_p = body weight of individuals exposed for the pathway (kg)

AT_{pi} = averaging time for the exposure pathway and pollutant (yr)

365 = unit conversion factor (d/yr)

The units of the product of concentration and intake rate ($C_{mi} \times IR_{pi}$) have units of mg/d. The units of the terms in the brackets have units of 1/kg. The factors in the bracket on the right of Equation 1 represent assumptions on the frequency and duration of the particular exposure scenario of interest. The averaging time is set to the exposure duration for non-carcinogenic chemicals and to 70 years for carcinogenic chemicals.

For exposure to radionuclides (internal and external exposure pathways), the total dose is evaluated as follows.

$$TD_{pi} = C_{mi}\ IR_{pi}\ DF_{pi}\ [EF_p\ ED_p] \qquad \text{(Eq. 2)}$$

where TD_{pi} = total dose for pollutant i by exposure pathway p (rem)

C_{mi} = concentration of pollutant i in medium m associated with exposure pathway p (units appropriate to the medium, pollutant, and exposure pathway)

IR_{pi} = rate of intake, contact with, or exposure to the contaminated medium for the pollutant and exposure pathway (units of media volume or mass per day as appropriate to the medium, pollutant, and exposure pathway as per Table 1)

DF_{pi} = dose conversion factor for intake of pollutant i by pathway p (units appropriate to the route of intake or exposure for pathway p)

and other terms are as previously defined. The units of the product of concentration, intake rate, and dose factor (C_{mi} x IR_{pi} x DF_{pi}) are rem/d. The units of the parameters in the brackets are days. Note that for radionuclides, the averaging time and body weight are not used to evaluate the average daily dose. The radiation dose conversion factors for internal exposures are defined for adults (70-kg reference man) and cannot be modified to be applicable to individuals in other age groups.

For the measured direct radiation exposure pathway, the average daily dose is evaluated as follows:

$$TD_p = D_{rf}\ IR_{pi}\ [EF_p\ ED_p] \qquad \text{(Eq. 3)}$$

where TD_p = total dose from exposure to a measured radiation field (rem)

D_{rf} = measured external dose rate (rem/d)

IR_p = modifying factor to account for time variation of radiation field as defined by the user (dimensionless)

and other terms are as previously defined.

Evaluation of the intake rate parameter, IR_{pi}, is specific to each exposure pathway. Expressions for intake rate for each of the 25 exposure pathways are given in the following discussion, ordered by intake route (ingestion, dermal contact, inhalation, and external radiation exposure) and by purpose of transport medium usage (domestic water, agricultural products, aquatic foods, water recreational activities, soil contact, air contact, external exposure, and measured radiation field exposure). The expressions are applicable to chemicals and radionuclides.

Drinking Water Ingestion

$$IR_{dw} = U_{dw} \qquad \text{(Eq. 4)}$$

where IR_{dw} is the effective daily intake rate for shower dermal contact (L/d) and U_{dw} is the water ingestion rate (L/d).

Optional corrections may be applied to account for removal of pollutant in the water treatment plant and for loss in transport through the water distribution system from the plant to the usage location (home).

Shower Water Dermal Contact

The effective daily intake rate for shower dermal contact is evaluated per unit concentration in domestic water, as follows:

$$IR_{sh} = I_{shi}\ A_{sh}\ F_{sh} \qquad \text{(Eq. 5)}$$

where IR_{sh} = effective daily intake rate for shower dermal contact (L/d)

I_{shi} = amount of pollutant i absorbed per shower per unit area of skin per unit concentration in water (mg/cm^2 per shower per mg/L, or pCi/cm^2 per shower per pCi/L)

A_{sh} = area of skin exposed while showering (cm^2)

F_{sh} = frequency of showering (showers/d)

The amount of pollutant absorbed per shower per unit area of skin is evaluated using the EPA (2) recommended models for dermal exposure.

Showering Inadvertent Ingestion

$$IR_{sg} = U_{sh}\ F_{sh}\ T_{sh} \qquad \text{(Eq. 6)}$$

where IR_{sg} = effective daily intake rate for inadvertent water ingestion while showering (L/d)

U_{sh} = rate of inadvertent water ingestion while showering (L/h)

F_{sh} = frequency of showering (showers/d)

T_{sh} = duration of a shower (h/shower)

Food Crop Ingestion

The intake of pollutants from ingestion of farm products is evaluated for initial contamination in irrigation water, air, and soil. For irrigation water contamination, the intake is as follows with the plant concentration normalized to the initial water concentration:

$$IR_{fpi} = C_{fpi}\ U_{fp} \qquad \text{(Eq. 7)}$$

where IR_{fpi} = effective daily intake rate of pollutant i for farm product ingestion (mg/d per mg/L or pCi/d per pCi/L)

C_{fpi} = concentration of pollutant i in farm product fp (mg/kg per mg/L or pCi/kg per pCi/L)

U_{fp} = daily intake rate of farm product fp (kg/d)

For deposition onto plants from air, the intake rate is evaluated with the plant concentration expressed normalized to the initial air concentration. The parameters are then defined as follows:

IR_{fpi} = effective daily intake rate of pollutant i for farm product ingestion (mg/d per mg/m^3 or pCi/d per pCi/m^3)

C_{fpi} = concentration of pollutant i in farm product fp per initial activity in air (mg/kg per mg/m^3 or pCi/kg per pCi/m^3)

For deposition onto soil with uptake by roots, the intake rate is evaluated with the plant concentration expressed normalized to the initial soil concentration. The parameters are then defined as follows:

IR_{fpi} = effective daily intake rate of pollutant i for farm product ingestion (mg/d per mg/m^2 or pCi/d per pCi/m^2)

C_{fpi} = concentration of pollutant i in farm product fp per initial activity deposited onto soil (mg/kg per mg/m^2 or pCi/kg per pCi/m^2)

Detailed descriptions of the models for estimation of the concentration of pollutants in plants is provided in Whelan et al. (3). The above equations are applicable to all farm products: leafy vegetables, other vegetables, meat, and milk (with units of milk expressed per liter instead of kg).

Aquatic Food Ingestion

The intake rate for aquatic food ingestion is evaluated as follows with the intake rate expressed per unit concentration in water:

$$IR_{afi} = U_{af}\, B_{afi} \qquad \text{(Eq. 8)}$$

where IR_{afi} = effective daily intake rate for pollutant i in aquatic food af via ingestion (mg/d per mg/L or pCi/d per pCi/L)

U_{af} = ingestion rate of aquatic food af (kg/d)

B_{afi} = bioaccumulation factor for aquatic food af and pollutant i (mg/kg per mg/L or pCi/kg per pCi/L)

This equation is applicable to both aquatic foods considered in MEPAS: fin fish and shellfish.

Swimming Water Ingestion

$$IR_{sw} = U_{sw}\, F_{sw}\, T_{sw} \qquad \text{(Eq. 9)}$$

where IR_{sw} = effective daily intake rate for inadvertent water ingestion while swimming (L/d)

U_{sw} = rate of inadvertent water ingestion while swimming (L/h)

F_{sw} = frequency of swimming events (events/d)

T_{sw} = duration of a swimming event (h/event)

Swimming Dermal Contact

The intake rate for dermal contact with water while swimming is evaluated per unit concentration of pollutant in water, as follows:

$$IR_{swi} = I_{swi} A_{sw} F_{sw} \qquad \text{(Eq. 10)}$$

where IR_{swi} = effective daily intake rate for pollutant i for swimming dermal contact (mg/d per mg/L or pCi/d per pCi/L)

I_{swi} = amount of pollutant i absorbed per swimming event per unit area of skin (mg/cm^2 per swim per mg/L, or pCi/cm^2 per swim per pCi/L)

A_{sw} = area of skin exposed while swimming (cm^2)

F_{sw} = frequency of swimming events (swim/d)

The amount of pollutant absorbed per swimming event per unit areas of skin is evaluated using the same EPA (2) recommended models as for dermal exposure while showering.

Shoreline Dermal Contact

The intake rate for dermal contact with shoreline sediment is evaluated per unit concentration of pollutant in water, as follows:

$$IR_{sdi} = I_{sdi} C_{sdi} A_{sd} F_{sd} \qquad \text{(Eq. 11)}$$

where IR_{sdi} = effective daily intake rate for pollutant i for shoreline sediment dermal contact (mg/d per mg/L or pCi/d per pCi/L)

I_{sdi} = amount of pollutant i absorbed per sediment contact event per unit area of skin (mg/cm^2 per event per mg/kg, or pCi/cm^2 per event per pCi/kg)

C_{sdi} = concentration of pollutant i in sediment per unit concentration in water from which sediment is contaminated (mg/kg per mg/L or pCi/kg per pCi/L)

A_{sd} = area of skin exposed during sediment contact (cm^2)

F_{sd} = frequency of sediment contact events (events/d)

The amount of pollutant absorbed per sediment event per unit areas of skin is evaluated using the EPA (2) recommended models for dermal exposure with soil. Details of the model to estimate sediment concentration from the surface water concentration are given by Whelan et al. (3).

Shoreline Sediment Ingestion

The intake rate for inadvertent ingestion of shoreline sediment is evaluated per unit concentration of pollutant in water, as follows:

$$IR_{shi} = U_{sd} C_{sdi} T_{sd} F_{sd} \qquad \text{(Eq. 12)}$$

where IR_{shi} = effective daily intake rate for shoreline sediment inadvertent ingestion (mg/d per mg/L or pCi/d per pCi/L)

U_{sd} = rate of inadvertent ingestion of sediment during shoreline contact events (kg/h)

T_{sd} = duration of a sediment contact event (h/event)

F_{sd} = frequency of sediment contact events (events/d)

Details of the model to estimate sediment concentration from the surface water concentration are given in Whelan et al. (3).

Soil Ingestion

The evaluation of the soil ingestion intake rate depends on the units defined for the soil concentration. For the measured soil pathway, the soil concentration is expressed per unit mass of soil and is evaluated as follows:

$$IR_{sl} = U_{sl} \qquad \text{(Eq. 13)}$$

where IR_{sl} = effective daily intake rate of soil (kg/d)

U_{sl} = rate of inadvertent ingestion of soil (kg/d)

For the atmospheric transport pathways, the soil concentration is expressed per unit area of soil receiving deposition, for which the intake rate is evaluated as follows:

$$IR_{sld} = \frac{U_{sl}}{t_{sl}\ p_{sl}} \qquad \text{(Eq. 14)}$$

where IR_{sl} = effective daily intake rate of soil by area (m^2/d)

U_{sl} = rate of inadvertent ingestion of soil (kg/d)

p_{sl} = areal density of soil (kg/m^2)

Soil Dermal Contact

The intake rate for dermal contact with soil is evaluated per unit concentration of pollutant in soil, as follows:

$$IR_{sli} = I_{sli}\ A_{sl}\ F_{sl} \qquad \text{(Eq. 15)}$$

where IR_{sli} = effective daily intake rate for soil contact (mg/d per mg/kg or pCi/d per pCi/kg)

I_{sli} = amount of pollutant i absorbed per soil contact event per unit area of skin normalized to unit concentration of pollutant in soil (mg/cm^2 per event per mg/kg, or pCi/cm^2 per event per pCi/kg)

A_{sl} = area of skin exposed during soil contact (cm^2)

F_{sl} = frequency of soil contact events (events/d)

The amount of pollutant absorbed per soil contact event per unit area of skin is evaluated using the EPA (2) recommended models for dermal exposure to soil. The above equation is based on soil concentrations expressed per unit mass of soil. When the soil concentration is based on unit area of soil, the normalization units are replaced with mg/m^2 or pCi/m^2 as appropriate for the pollutant.

Special Food Intake

$$IR_{fd} = U_{fd} \quad \text{(Eq. 16)}$$

where IR_{fd} is effective daily intake rate for food fd ingestion (kg/d) and U_{fd} is the daily intake rate of food fd (kg/d).

Indoor Inhalation of Volatile Pollutants

The intake rate for indoor inhalation of volatile pollutants is evaluated per unit concentration of pollutant in water, as follows.

$$IR_{ia} = U_{ia}\ C_{iai} \quad \text{(Eq. 17)}$$

where IR_{ia} = effective intake rate of air while indoors per unit concentration in domestic water (mg/d per mg/L or pCi/d per pCi/L)

U_{ia} = inhalation rate by individuals while indoors (m^3/d)

C_{iai} = concentration in indoor air per unit activity in domestic water as the source of volatile pollutants (mg/m^3 per mg/L or pCi/m^3 per pCi/L)

The indoor air concentration is estimated using the Andelman model (4) as recommended by EPA (5). This model accounts for transfer of volatile pollutants from domestic water to indoor air from showering and other uses of water by a factor of 0.5 L/m^3 (equal to C_{iai} in Equation 17). An alternate model is also available in MEPAS to account of inhalation of volatile pollutants while showering, as described by Whelan et al. (3).

Air Inhalation

$$IR_{ar} = U_{ar} \quad \text{(Eq. 18)}$$

where IR_{ar} is the effective daily intake rate from inhalation of airborne pollutant (m^3/d) and U_{ar} is the inhalation rate of air (m^3/d).

Inhalation of Resuspended Soil

The intake rate for inhalation of resuspended soil is evaluated per unit concentration of pollutant in soil, as follows:

$$IR_{rfi} = U_{ar}\ RF_i \quad \text{(Eq. 19)}$$

where IR_{rfi} = effective daily intake rate from inhalation of pollutants resuspended from soil (mg/d per mg/m^2 or pCi/d per pCi/m^2)

U_{ar} = inhalation rate of air (m^3/d)

RF_i = resuspension factor for pollutant i (mg/m^3 per mg/m^2 or pCi/m^3 per pCi/m^2)

Swimming External

The intake rate for external exposure while swimming is evaluated as follows:

$$IR_{swi} = T_{sw} F_{sw} \qquad \text{(Eq. 20)}$$

where IR_{swi} = effective daily external exposure rate from swimming in contaminated surface water (h/d)

T_{sw} = duration of a swimming event (h/event)

F_{sw} = frequency of swimming events (events/d)

Boating External

The intake rate for external exposure while boating is evaluated as follows:

$$IR_{bti} = SF_{bt} T_{bt} F_{bt} \qquad \text{(Eq. 21)}$$

where IR_{bti} = effective daily external exposure rate from boating in contaminated surface water (h/d)

SF_{bt} = shielding factor to relate boating external exposure to swimming external exposure (dimensionless)

T_{bt} = duration of a boating event (h/event)

F_{bt} = frequency of boating events (events/d)

Shoreline External

The intake rate for external exposure while on shoreline is evaluated normalized to unit concentration in water, as follows:

$$IR_{sxi} = SW\ C_{sdi}\ T_{sd}\ F_{sd} \qquad \text{(Eq. 22)}$$

where IR_{sxi} = effective external exposure rate for shoreline sediment external exposure per unit activity of a radionuclide in water from which sediment is contaminated (h/d per L/m^2)

SW = shore width factor (dimensionless)

C_{sdi} = concentration of pollutant i in sediment per unit concentration in water from which sediment is contaminated (pCi/m^2 per pCi/L)

T_{sd} = duration of a sediment contact event (h/event)

F_{sd} = frequency of sediment contact events (events/d)

Details of the model to estimate sediment concentration from the surface water concentration are given in Whelan et al. (3). The shore width factor (SW) accounts for reduction in dose rate because the shoreline is assumed to be narrower than the typical ground-plane exposure situation.

Soil External

$$IR_{sxi} = T_{sl} \qquad \text{(Eq. 23)}$$

where IR_{sxi} = effective external exposuure rate for soil external exposure (h/d)

T_{sl} = daily exposure time to contaminated soil (h/d)

When the soil concentration is given in units of pCi/kg soil, the concentration must be converted to units of pCi/m^2 by multiplying by an assumed soil thickness and soil density.

Air External

The intake rate for external exposure to contaminated air is evaluated normalized to unit concentration in air, as follows:

$$IR_{axi} = T_{ar} \qquad \text{(Eq. 24)}$$

where IR_{axi} = effective external exposure rate for submersion in contaminated air (h/d)

T_{ar} = daily exposure time to the contaminated air (h/d)

Measured Direct Radiation

The intake rate for exposure to measured radiation fields is evaluated as follows:

$$IR_{dr} = T_{dr} \qquad \text{(Eq. 25)}$$

where IR_{dr} is the effective daily exposure to the measured radiation field (h/d) and T_{dr} is the daily exposure duration to the measured radiation field (h/d).

HUMAN HEALTH IMPACT MODELS

The daily intake and dose rates are used to estimate health impacts for each of the defined pollutants, usage locations, and exposure pathways. A health-impact parameter for each pollutant is calculated using functions appropriate to the toxicity response defined for the pollutant (radionuclide, carcinogenic chemical, or non-carcinogenic chemical). Health impacts from radionuclides and radiation are expressed as the lifetime risk of cancer (fatalities or total incidence). The health impact for carcinogenic chemicals is the lifetime risk of cancer (total tumor incidence) as defined by EPA cancer potency factors (6,7). Health impacts for non-carcinogenic chemicals are defined as a hazard index, which is the ratio of the daily intake to a reference dose as defined by the EPA (6,7) for inhalation and ingestion. Dermal exposures are expressed as equivalent oral intakes, as recommended by EPA (1).

The risk of cancer incidence to an individual from chemical intakes is evaluated as follows:

$$R_{pi} = ADD_{pi}\, SF_{pi} \qquad \text{(Eq. 26)}$$

where R_{pi} = risk of cancer incidence for individuals exposed via pathway p to pollutant i (risk/lifetime)

ADD_{pi} = average daily dose for pollutant i by exposure pathway p (mg/kg/d)

SF_{pi} = cancer slope factor (potency factor) for intake of pollutant i by pathway p (risk per mg/kg/d)

The slope factors are defined in EPA's Integrated Risk Information System (6) and in Health Effects Assessment Summary Tables (7) for inhalation and ingestion intakes. The values used in Eq. 26 must be selected for the intake route appropriate for the exposure pathway being evaluated.

The risk of cancer incidence to an individual from radionuclide intakes is evaluated as follows:

$$R_{pti} = TD_{pi}\ HE_t \qquad \text{(Eq. 27)}$$

where R_{pti} = risk of cancer incidence for individuals exposed via pathway p to pollutant i (risk/lifetime)

TD_{pi} = total dose for radionuclide i by exposure pathway p (rem)

HE_t = total cancer incidence conversion factor (risk/rem)

The risk of cancer fatality to an individual from radionuclide intakes is evaluated as follows:

$$R_{pfi} = TD_{pi}\ HE_f \qquad \text{(Eq. 28)}$$

where R_{pfi} = risk of fatal cancer for individuals exposed via pathway p to pollutant i (risk/lifetime)

HE_f = fatal cancer incidence conversion factor (risk/rem)

and other terms are as defined above. Equations 27 and 28 also apply for the measured direct radiation field exposure pathway.

A measure of the health risk to populations is evaluated by multiplying the individual health risk by the population exposed. When several populations are exposed, or when more than one exposure pathway is included, the total population health risk is evaluated as the sum of the health risks for every pathway and population.

The health impact measure for exposure to non-carcinogenic chemicals is the hazard quotient or hazard index. This parameter is evaluated as the ratio of the estimated intake to the reference dose for the pollutant and intake route of interest, as follows:

$$HI_{pi} = \frac{ADD_{pi}}{RfD_{pi}} \qquad \text{(Eq. 29)}$$

where HI_{pi} = hazard index for pathway p and pollutant i (dimensionless)

ADD_{pi} = average daily intake rate of pollutant i by pathway p (mg/kg/d)

RfD_{pi} = reference dose for intake of pollutant i by pathway p (mg/kg/d)

The reference doses are defined by EPA (6,7) for ingestion and inhalation intakes. The reference dose is a level of exposure that is unlikely to impact health of individuals exposed at that level. The hazard index values may be summed over exposure pathways (as appropriate to the exposure scenario being defined) to obtain a hazard quotient for the pollutant. There are no meaningful measures of population health impact for non-carcinogenic chemicals.

The models described in this paper are consistent with current EPA guidance for exposure and human health impact assessments. The primary change necessary to MEPAS to incorporate the features of these models has been addition of user options to modify the basic exposure parameters (body weight, exposure duration, and intake rates) and addition of specific EPA models for dermal contact and indoor air inhalation. The user now has the option to establish a pre-defined set of default parameter values that can be accessed for all analyses. This pre-defined default parameter file can be established to represent any appropriate regulatory analysis.

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TABLE 1. Transport and Exposure Pathway Summary

Transport Pathway	Contaminated Medium	Concentration Units	Exposure Route	Exposure Pathways
Groundwater	Water at well location	mg/L or pCi/L	Ingestion	Drinking water
			Ingestion	Water while showering
			Dermal	Shower water contact
			Inhalation	Air while showering
	Water at intake for agricultural production	mg/L or pCi/L	Ingestion	Leafy vegetable
			Ingestion	Other vegetables
			Ingestion	Meat
			Ingestion	Milk
Surface water	Water at domestic intake location	mg/L or pCi/L	Ingestion	Drinking water
			Ingestion	Water while showering
			Dermal	Shower water contact
			Inhalation	Air while showering
	Water at recreational use location	mg/L or pCi/L	Ingestion	Water while swimming
			Ingestion	Sediment from shoreline
			Dermal	Swimming water contact
			Dermal	Shoreline sediment contact
			External	Water while swimming
			External	Water while boating
			External	Shoreline sediment
	Water at intake for agricultural production	mg/L or pCi/L	Ingestion	Leafy vegetable
			Ingestion	Other vegetables
			Ingestion	Meat
			Ingestion	Milk
	Water at aquatic food production location	mg/L or pCi/L	Ingestion	Fin fish
			Ingestion	Shellfish
Atmospheric	Air at location of people	mg/m^3 or pCi/m^3	Inhalation	Air
			External	Submersion in air
	Soil at location of people	mg/m^2 or pCi/m^2	Ingestion	Soil
			Dermal	Soil contact

TABLE 1. (contd)

Transport Pathway	Contaminated Medium	Concentration Units	Exposure Route	Exposure Pathways
			Inhalation External	Soil resuspension Soil
	Air at location of agricultural production	mg/m^3 or pCi/m^3	Ingestion Ingestion Ingestion Ingestion	Leafy vegetables Other vegetables Meat Milk
	Soil at location of agricultural production	mg/m^2 or pCi/m^2	Ingestion Ingestion Ingestion Ingestion	Leafy vegetables Other vegetables Meat Milk
Measured soil	Soil at location of people	mg/kg or pCi/kg	Ingestion Dermal Inhalation External	Soil Soil contact Soil suspension Soil
Measured foods	Food eaten by people	mg/kg, mg/L, pCi/kg, or pCi/L	Ingestion	Food
Direct radiation	Radiation dose rate at location of people	rad/h	External	Radiation exposure

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