PNNL-16164

Pacific Northwest
National Laboratory
Operated by Battelle for the
U.S. Department of Energy

Multimedia Environmental Pollutant Assessment System (MEPAS): Human Health Impact Module Description

D. L. Strenge
M. A. Smith

October 2006

Prepared for
Engineer Research and Development Center
U.S. Army Corps of Engineers
Vicksburg, MS
under Contract DE-AC05-76RL01830

DISCLAIMER

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-ACO5-76RL01830

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information,
P.O. Box 62, Oak Ridge, TN 37831-0062;
ph: (865) 576-8401
fax: (865) 576 5728
email: reports@adonis.osti.gov

Available to the public from the National Technical Information Service,
U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161
ph: (800) 553-6847
fax: (703) 605-6900
email: orders@nits.fedworld.gov
online ordering: http://www.ntis.gov/ordering.htm

PNNL-16164

Multimedia Environmental Pollutant Assessment System (MEPAS): Human Health Impact Module Description

D. L. Strenge
M. A. Smith

October 2006

Prepared for
Engineer Research and Development Center
U.S. Army Corps of Engineers
Vicksburg, MS
under Contract DE-AC05-76RL01830

Pacific Northwest National Laboratory
Richland, Washington 99352

Summary

This report represents one of the three documents that have been derived from the original Multimedia Environmental Pollutant Assessment System (MEPAS) Exposure Pathway and Human Health Impact Assessment document (Strenge and Chamberlain 1995) and describes the receptor intake pathway module.

MEPAS is a physics-based environmental analysis code that integrates source-term, transport, and exposure models for endpoints such as concentration, dose, or risk. Developed by Pacific Northwest National Laboratory,[(a)] MEPAS is designed for site-specific assessments using readily available information. Endpoints are computed for chemical and radioactive pollutants. This system has wide applicability to a range of environmental problems using air, groundwater, surface-water, overland, and exposure models. With this system, a user can simulate release from the source, transport through air, groundwater, surface water, or overland, and transfer through food chains and exposure pathways to the exposed individual or population. Whenever available and appropriate, U.S. Environmental Protection Agency guidance and models were used to facilitate compatibility and acceptance.

Although based on relatively standard transport and exposure computation approaches, the unique feature of MEPAS is that these approaches are integrated into a single system. The use of a single system provides a consistent basis for evaluating health impacts for a large number of problems and sites. Implemented on a desktop computer, a user-friendly shell allows the user to define the problem, input the required data, and execute the appropriate models. This document describes mathematical formulations used in the MEPAS human-health-impact assessment. The human-health-impact analysis starts with pollutant intake values for an exposure medium and estimates a measure of health impact appropriate to the type of pollutant and exposure pathway considered.

Reference

Strenge DL, and PJ Chamberlain. 1995. *Multimedia Environmental Pollutant Assessment System (MEPAS): Exposure Pathway and Human Health Impact Assessment Models.* PNL-10523, Pacific Northwest Laboratory, Richland, WA.

(a) Pacific Northwest Laboratory is operated for the U.S. Department of Energy by Battelle under Contract DE-AC05-76RL01830.

Acronyms

EPA	U.S. Environmental Protection Agency
MEPAS	Multimedia Environmental Pollutant Assessment System
PNNL	Pacific Northwest National Laboratory

Acknowledgments

The authors express appreciation to the Pacific Northwest National Laboratory's (PNNL's) Bruce Napier for technical review and Wayne Cosby for technical editing of the report. Appreciation is also expressed for equation editing to PNNL's Crystal Briones and NaTasha Stoker.

Contents

1.0 Introduction

This report represents one of the three documents that have been derived from the original Multimedia Environmental Pollutant Assessment System (MEPAS) Exposure Pathway and Human Health Impact Assessment document (Strenge and Chamberlain 1995) and describes the receptor intake pathway module.

The human-health-impact module uses the receptor intake results obtained from the receptor intake module and estimates a measure of health impact appropriate to the type of pollutant and exposure pathway considered. For chemical pollutants, the human-health-impact module estimates the health impacts from the average daily intake rate. Both carcinogenic and non-carcinogenic impacts are included. For radionuclide pollutants, the health impacts are estimated from the total lifetime intake of the radionuclide. For radiation doses, the health impacts are estimated from the total lifetime dose.

The estimation of health impacts is described in the following sections.

2.0 Radiation and Radionuclide Health Impacts

Health impacts from exposure to radiation and radionuclides are expressed as the risk of developing cancer or as the lifetime radiation dose. The lifetime risk may be reported as the lifetime risk of total cancer incidence, as cancer fatalities, or as cancer incidence plus severe hereditary effects. Two methods are available to estimate the risk of cancer incidences: using health-effects conversion factors and U.S. Environmental Protection Agency (EPA) slope factors. These methods are described in the following section.

2.1 Lifetime Cancer Risk: Health Effects Conversion Factors

The radiation dose calculated for each of the radionuclide intake and direct radiation-exposure pathways are as lifetime dose (Sv) from intake or exposure over the exposure duration for the given exposure pathway. The risk of cancer from exposure at the lifetime dose is estimated using health-effects conversion factors. The lifetime fatal cancer risk is estimated as follows:

$$R_{fkki} = HE_f D_{kki} DF_{ri} \tag{2.1}$$

where R_{fkki} = risk of developing fatal cancer from the lifetime exposure for pathway kk and radionuclide i (risk/lifetime)
HE_f = fatal cancer lifetime risk, health-effects conversion factor (risk per Sv)
D_{kki} = total lifetime intake for pathway kk and radionuclide i (Bq)
DF_{ri} = dose conversion factor for radionuclide i and intake route, r (Sv/Bq).

The dose conversion factor used corresponds to the intake route for the particular exposure pathway represented by the subscript kk. Dose conversion factors are available in MEPAS for ingestion, inhalation, and dermal-intake routes.

The lifetime total cancer incidence risk is estimated as follows:

$$R_{tkki} = HE_t D_{kki} DF_{ri} \tag{2.2}$$

where R_{tkki} = total risk of developing cancer from lifetime exposure for pathway kk and radionuclide i (risk/lifetime)
HE_t = total cancer lifetime risk health effects conversion factor (risk per Sv)
D_{kki} = total lifetime intake for pathway kk and radionuclide i (Bq)
DF_{ri} = dose conversion factor for radionuclide i and intake route, r (Sv/Bq).

The risk from developing cancer and severe hereditary effects is estimated as follows:

$$R_{hkki} = HE_h D_{kki} DF_{ri} \tag{2.3}$$

where R_{hkki} = total risk of developing cancer and severe hereditary effects from lifetime exposure for pathway kk and radionuclide i (risk/lifetime)
HE_h = total cancer lifetime risk health effects conversion factor (risk per Bq)
D_{kki} = total lifetime intake for pathway kk and radionuclide i (Bq)
DF_{ri} = dose conversion factor for radionuclide i and intake route r (Sv/Bq).

2.2 Lifetime Cancer Risk: EPA Slope Factors

EPA has developed slope factors for exposure to radionuclides via inhalation, ingestion, and external direct radiation from contamination on a ground plane. This method may be used only to estimate lifetime risk of cancer incidence because the slope factors are specific to total cancer incidence. The slope factors are intended to be used to convert from radionuclide intake expressed as pCi ingested or inhaled to lifetime cancer incidence risk. Factors are also given for exposure to contaminated ground surfaces expressed as risk/yr per pCi/g soil. Slope factors are not given for dermal absorption or external exposure from air submersion or water immersion.

The ingestion slope factors are defined for their intake media: water, food and soil. The correct ingestion factor must be applied to each ingestion pathway based on the intake medium type.

In the following equations, it is assumed that the slope factors have been converted to units of Bq (1 Bq = 27 pCi). For ingestion exposures, the EPA slope factors may be applied as follows to the lifetime ingestion radiation doses generated as described in the exposure pathway section:

$$R_{tkki} = D_{kki} SF_{gi} \tag{2.4}$$

where R_{tkki} is the total risk of developing cancer from the lifetime exposure for ingestion pathway kk and radionuclide i (risk/lifetime), D_{kki} is the lifetime intake of radionuclide i for ingestion pathway kk (Bq), and SF_{gi} is the cancer ingestion slope factor for incidence lifetime risk for radionuclide i for the ingestion intake type for the pathways with food or soil (risk per Bq ingested)

For inhalation exposures, the EPA slope factors may be applied as follows to the lifetime inhalation radiation doses generated as described in the exposure pathways section:

$$R_{tkki} = D_{kki} SF_{hi} \tag{2.5}$$

where R_{tkki} is the total risk of developing cancer from the lifetime exposure for inhalation pathway kk and radionuclide i (risk/lifetime), D_{kki} is the lifetime intake of radionuclide i for inhalation pathway kk (Bq), and SF_{hi} is the cancer incidence lifetime risk inhalation slope factor for radionuclide i (risk per Bq inhaled).

For external exposures to soil, the EPA external slope factors may be applied as follows to the lifetime external radiation dose generated as described in the exposure pathway section.

$$R_{tkki} = D_{kki} SF_{si} 10^{-3} \tag{2.6}$$

where R_{tkki} = total risk of developing cancer from the lifetime exposure for external-soil pathway kk and radionuclide i (risk/lifetime)

D_{kki} = effective average soil or sediment concentration of radionuclide i for external pathway kk (Bq/kg)

SF_{si} = cancer-incidence external slope factor for exposure to contaminated ground (risk/yr per Bq/g soil)

10^{-3} = units conversion factor (kg/g).

2.3 Lifetime Radiation Dose

Another output of the MEPAS human-health-impacts module is the lifetime radiation dose received by the exposed individual. This output is estimated using dose conversion factors for the specific exposure pathways.

For ingestion pathways, the lifetime radiation dose is calculated using the total lifetime intake and the ingestion dose conversion factor, as follows.

$$D_{tkki} = D_{kki} DF_{gi} \tag{2.7}$$

where D_{tkki} is the total radiation dose for pathway kk and radionuclide i (Sv), D_{kki} is the total lifetime intake for pathway kk and radionuclide i (Bq), and DF_{gi} is the dose conversion factor for radionuclide i and the ingestion intake route (Sv/Bq).

For inhalation pathways, the lifetime radiation dose is calculated using the total lifetime intake and the inhalation dose conversion factor, as follows.

$$D_{tkki} = D_{kki} DF_{hi} \tag{2.8}$$

where D_{tkki} is the total radiation dose for pathway kk and radionuclide i (Sv), D_{kki} is the total lifetime intake for pathway kk and radionuclide i (Bq), and DF_{hi} is the dose conversion factor for radionuclide i and the inhalation intake route (Sv/Bq).

The lifetime dose from external exposure to soil is evaluated as follows.

$$D_{tdei} = D_{dei} DE_{gi} \frac{10^{-6} 10^{3}}{t_{dd} \rho_{dd}} ED_{dei} 8766 \tag{2.9}$$

where D_{tdei} = total lifetime dose for radionuclide pollutant i from external exposure to soil (Sv)
D_{dei} = average soil concentration for the soil external pathway from radionuclide i (Bq/kg)
DE_{gi} = dose conversion factor for external exposure to radionuclides on a ground plane for radionuclide i (Sv/h per Bq/m^2)
ED_{dei} = exposure duration for the soil external pathway (yr)
8766 = units conversion factor (h/yr)
10^{-6} = units conversion factor (m^3/cm^3)
10^3 = units conversion factor (g/kg)
t_{dd} = thickness of shoreline sediments (m)
ρ_{dd} = density of shoreline sediments (g/cm^3).

The lifetime dose from external exposure to shoreline sediment is evaluated similarly, as follows.

$$D_{tssi} = D_{ssi} DE_{gi} \frac{10^{-6}10^{3}}{t_{ss}\rho_{ss}} ED_{ssi} 8766 \tag{2.10}$$

where D_{tssi} = total lifetime dose for radionuclide pollutant i from external exposure to shoreline sediment (Sv)
D_{ssi} = average shoreline sediment concentration for the soil external pathway from radionuclide i (Bq/kg)
DE_{gi} = dose conversion factor for external exposure to radionuclides on a ground plane for radionuclide i (Sv/h per Bq/m^2)
ED_{ssi} = exposure duration for the shoreline sediment external pathway (yr)
8766 = units conversion factor (h/yr)
10^{-6} = units conversion factor (m^3/cm^3)
10^3 = units conversion factor (g/kg)
t_{ss} = thickness of shoreline sediments (m)
ρ_{ss} = density of shoreline sediments (g/cm^3).

The lifetime dose from external exposure to air is evaluated as follows.

$$D_{taei} = D_{aei} DE_{ai} ED_{aei} 8766 \tag{2.11}$$

where D_{taei} = total lifetime dose for the air external pathway from radionuclide i (Sv)
D_{aei} = average air concentration for the air external pathway from radionuclide i (Bq/m^3)
DE_{ai} = dose conversion factor for external exposure to airborne radionuclide i (Sv/h per Bq/m^3)
ED_{aei} = exposure duration for the air external pathway (yr)
8766 = units conversion factor (h/yr).

The total lifetime dose from swimming in contaminated water is evaluated as follows.

$$D_{twei} = D_{wei} DE_{wi} ED_{wi} 8766 \tag{2.12}$$

where D_{twei} = total lifetime dose for radionuclide pollutant i from swimming in contaminated surface water (Sv)
D_{wei} = average water concentration of radionuclide i for swimming in contaminated surface water (Bq/L)
DE_{wi} = dose conversion factor for immersion in contaminated water for radionuclide i (Sv/h per Bq/L)
ED_{wi} = exposure duration for the swimming pathway (yr)
8766 = units conversion factor (h/yr).

The total lifetime dose from boating on contaminated water is evaluated as follows.

$$D_{tbei} = \frac{D_{bei} DE_{wi} ED_{bi} 8766}{2} \tag{2.13}$$

where D_{tbei} = total lifetime dose for radionuclide pollutant i from boating in contaminated surface water (Sv)
D_{bei} = average water concentration of radionuclide i for boating on contaminated surface water (Bq/L)
DE_{wi} = dose conversion factor for immersion in contaminated water for radionuclide i (Sv/h per Bq/L)
ED_{bi} = exposure duration for the boating pathway (yr)
8766 = units conversion factor (h/yr)
2 = geometry correction factor for boating relative to swimming (dimensionless).

3.0 Carcinogenic Chemical Health Impacts

The lifetime risk of total cancer incidence is estimated using EPA slope factors for chemical carcinogens for inhalation- and ingestion pathways. The EPA slope factors give the lifetime cancer incidence risk per average daily dose. For ingestion exposures, the lifetime cancer incidence risk is evaluated as follows:

$$R_{tkki} = D_{kki} SF_{gi} \tag{3.1}$$

where R_{tkki} is the risk of developing cancer from the lifetime exposure for ingestion pathway kk and chemical pollutant i (risk/lifetime), D_{kki} is the average daily ingestion intake for exposure pathway kk for chemical pollutant i (mg/kg/d), and SF_{gi} is the ingestion slope factor for cancer incidence risk for chemical pollutant i (risk per mg/kg/d ingestion intake).

Inhalation lifetime cancer incidence risk is evaluated similarly, as follows:

$$R_{tkki} = D_{kki} SF_{hi} \tag{3.2}$$

where R_{tkki} is the risk of developing cancer from the lifetime exposure for inhalation pathway kk and chemical pollutant i (risk/lifetime), D_{kki} is the average daily inhalation intake for exposure pathway kk for chemical pollutant i (mg/kg/d), and SF_{hi} is the inhalation slope factor for cancer incidence risk for chemical pollutant i (risk per mg/kg/d inhalation intake).

When inhalation unit risk factors are available for a chemical, the lifetime cancer risk from inhalation may be calculated using the average daily air concentration in place of the average daily inhalation intake rate, as follows.

$$R_{tkki} = C_{kki} / UC_{hi} \tag{3.3}$$

where R_{tkki} is the risk of developing cancer from the lifetime exposure for inhalation pathway kk and chemical pollutant i (risk/lifetime), C_{kki} is the average daily air concentration for exposure pathway kk for chemical pollutant i (mg/m^3), and UC_{hi} is the inhalation unit risk concentration for cancer incidence risk for chemical pollutant i (risk per mg/m^3 inhalation intake).

Dermal exposures are evaluated as equivalent ingestion intakes by dividing the dermal intake by the absorption fraction for the GI tract, as follows.

$$Intake_{Ingestion} = \frac{Intake_{Dermal}}{f_{1i}} \tag{3.4}$$

where f_{li} is the fraction of pollutant i absorbed in passing through the GI tract following ingestion (dimensionless).

The equivalent ingestion intake is then used in Equation (3.1) to determine the risk for the dermal pathway.

4.0 Non-Carcinogenic Chemical Health Impacts

The health impacts for exposure to noncarcinogenic chemicals are expressed as a hazard quotient. The hazard quotient is the ratio of the average daily dose to the reference dose. The reference dose represents a level that is believed to be safe for members of the general population. Exposure at this level will result in a hazard quotient of 1.0. The hazard quotient for ingestion pathways is evaluated as follows:

$$HQ_{gkki} = \frac{D_{kki}}{RfD_{gi}} \tag{4.1}$$

where HQ_{gkki} is the hazard quotient for ingestion pathway kk for noncarcinogenic chemical pollutant i (dimensionless), D_{kki} is the average daily dose for ingestion pathway kk for noncarcinogenic chemical pollutant i (mg/kg/d), and RfD_{gi} is the ingestion reference dose for noncarcinogenic chemical pollutant i (mg/kg/d).

The hazard quotient for inhalation pathways can be written similarly, as follows:

$$HQ_{hkki} = \frac{D_{kki}}{RfD_{hi}} \tag{4.2}$$

where HQ_{hkki} is the hazard quotient for inhalation pathway kk for noncarcinogenic chemical pollutant i (dimensionless), D_{kki} is the average daily dose for inhalation pathway kk for noncarcinogenic chemical pollutant i (mg/kg/d), and RfD_{hi} is the inhalation reference dose for noncarcinogenic chemical pollutant i (mg/kg/d).

When inhalation reference concentration values are available for a chemical, the hazard quotient from inhalation may be calculated using the average daily air concentration in place of the average daily inhalation intake rate, as follows.

$$HQ_{tkki} = C_{kki} / RC_{hi} \tag{4.3}$$

where HQ_{hkki} is the hazard quotient for inhalation pathway kk for noncarcinogenic chemical pollutant i (dimensionless), C_{kki} is the average daily air concentration for exposure pathway kk for chemical pollutant i (mg/m^3), and RC_{hi} is the inhalation reference concentration for chemical pollutant i (mg/m^3).

Dermal exposures are treated as equivalent ingestion exposures as described in Section 3.0.

When hazard quotient values are added across exposure pathways or pollutants, the resulting sum is referred to as a hazard index.

5.0 Conclusions

This document describes mathematical formulations used in the MEPAS human-health-impact assessment. The human-health-impact analysis starts with pollutant intake values for an exposure medium and estimates a measure of health impact appropriate to the type of pollutant and exposure pathway considered. Endpoints include cancer-incidence and hazard-quotient values for exposure to chemicals and radiation dose and cancer incidence for exposure to radiation and radionuclides. Developed by Pacific Northwest National Laboratory, MEPAS is designed for site-specific assessments using readily available information. Endpoints are computed for chemical and radioactive pollutants. This system has wide applicability to a range of environmental problems using air, groundwater, surface-water, overland, and exposure models. With this system, a user can simulate release from the source, transport through air, groundwater, surface water, or overland, and transfer through food chains and exposure pathways to the exposed individual or population.