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Updating the Multipathway Exposure Health Risk Assessment Computer Program

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

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Updating the Multipathway Exposure Health Risk Assessment Computer Program

Final Report

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ACKNOWLEDGMENTS

Model improvements and the revised user's guide have been prepared by Vicente J. Garza, who at the time this work started was a Ph.D. candidate in the Civil and Environmental Engineering Department at the University of California, Davis. The modifications to the HRA program were made in consultation with the project investigators and the ARB and OEHHA staff. The work here represents part of a joint effort between Lawrence Livermore National Laboratory (LLNL) and the University of California, Davis (UCD), to address scientific problems related to risk assessment through the LLNL-UCD Risk Sciences Program. This report was submitted in fulfillment of ARB Interagency Agreement No. 92-318, "Updating the Multipathway Exposure Assessment Computer Program", by the University of California, Davis under the sponsorship of the California Air Resources Board. Work will be completed by February 28, 1994.

ABSTRACT

This report describes the process and results of a project to improve the Health Risk Assessment (HRA) computer program. The major scientific objectives of this project were to evaluate the existing program in order to identify changes that can increase the capability, efficiency, and flexibility of the program: to modify the program so as to incorporate these changes; and to modify the algorithms and intermedia transfer factors as directed by the Office of Environmental Health Hazard Assessment (OEHHA) and the Air Resources Board. Several modifications were implemented to make HRA 2.0 faster and more efficient than HRA 1.1. As a result, calculation algorithms are now more efficient, the calculation time has been reduced, and some temporary files have been eliminated. There are a number of changes in HRA 2.0 that make the program more user friendly and flexible relative to HRA 1.1. Creating, editing, and viewing the input files has been improved. Viewing reports on screen has also been improved. All changes to the HRA program were made in consultation with ARB and OEHHA staff. A summary comparison of HRA to the CAirTOX model is provided as extra information. This comparison for the arsenic and TCDD releases to air reveals that there are a number of similarities and some significant differences in the exposures predicted by these two multipathway models.

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INTRODUCTION

This report describes the process and results of a project to improve the Health Risk Assessment (HRA) computer program developed by the State of California Air Resources Board (ARB) and Office of Environmental Health Hazard Assessment (OEHHA). The major scientific objectives of this project were to evaluate the existing program in order to identify changes that can increase the capability, efficiency, and flexibility of the program; to modify the program so as to incorporate these changes; and to update the exposure and risk assessment factors built into the program to make these factors consistent with recent findings in the scientific literature. All changes to the HRA program were made in consultation with ARB and OEHHA staff.

The ARB has developed the HRA computer program to carry out multiple pathway exposure assessments for toxic chemicals released to air. The HRA program assists the evaluation of health risk associated with toxic chemical emissions to air and allows users to assess the potential for exposure to air emissions through inhalation as well as non-inhalation exposure routes. The program has been used to carry out risk assessments for facilities subject to the California Air Toxics "Hot-Spots" Program and for municipal waste incinerators and medical wastes incinerators. The program can calculate cancer risk and cancer burden and hazard indices for non-cancer health effects. The program requires as input atmospheric dispersion modeling results for the air shed in the vicinity of the facility being assessed.

This report describes six tasks performed at the University of California, Davis under the auspices of the University of California (UC) Risk-Science Program and funded by the ARB. These tasks supported the further development and implementation of the HRA program and scientifically-based efforts to characterize exposure and risk. These tasks were (1) incorporate current health risk data, (2) revise the program language and structure so that future changes to the program are easier to implement, (3) evaluate the existing program to identify changes that enhance both the flexibility and usability of the program and then implement these changes, (4) make provisions for direct reading of dispersion model outputs into the program, (5) update the user's guide for the program to reflect implemented changes (6) to modify the program, as directed by OEHHA and ARB, to include new exposure assessment algorithms and intermedia transfer factors. All changes to the HRA program were made in consultation with ARB and OEHHA staff.

Background

For toxic substances released to air, the principal elements of the risk assessment process have been defined by the National Research Council, U.S. National Academy of Sciences (NRC, 1983) and consist of hazard identification, exposure assessment, dose-response assessment, and risk characterization. The goal of the HRA program is to integrate existing dose-response data with exposure models in order to characterize risk. The exposure assessment component as implemented in HRA can be further divided into three subtasks, one dealing with the analysis of the source terms of toxic emissions to air, the second involving analysis of the transport and transformation of those substances in environmental media, and the third dealing with human contacts with these contaminated media.

Transport and Transformation

Substances in outdoor (or ambient) air are dispersed by atmospheric advection and diffusion. The volume and mass of the air compartment is defined by the area of the contaminated landscape and the mixing height of the lower atmosphere. Meteorological parameters have an overwhelming influence on the behavior of contaminants in the lower atmosphere. Among them, wind parameters (direction, velocity, and turbulence) and thermal properties (stability) are the most important. The standard models for estimating the time and spatial distribution of point sources of contamination in the atmosphere are the Gaussian statistical solutions of the atmospheric diffusion equation. These models are obtained from solution of the classical differential equation for time-dependent diffusion in three dimensions. Pasquill (1961) has discussed the physical basis, analytical solutions, and the use of these equations. Turner (1970) and Hanna et al. (1982) have compiled workbooks on applications of these solutions to air pollution problems, including the application of the Gaussian models to area and line sources. There are numerous computer programs available and many papers describing algorithms for assessing the dispersion of point, line, and volume air pollution sources.

Multiple Pathway Exposure Assessment

A multiple pathway exposure analysis begins with the effort, through models or measurements, to obtain contaminant concentrations for ambient air (gas and particle phases), surface water, surface soil, and root-zone soil in the vicinity of the release site. The exposure assessment process consists of relating contaminant concentrations in these environmental media to contaminant concentrations in the media with which a human population has contact (personal air, tap water, foods, household dusts and soils, etc.). The average daily dose is the product of the exposure concentrations in these contact media and an intake or uptake factor that relates the concentrations to the distributions of potential dose within the population. Methods and assumptions used to develop multiple pathway exposure models at toxic chemical release sites are described by McKone and Daniels (1990). Listed in Table 1 are the potential interactions among environmental

media, exposure media, and exposure routes that have been identified in efforts to date. Not all of these interactions are included in the current HRA model.

The concentrations in air, water and soil used for an exposure assessment are those measured or estimated to be available in these environmental media at the nearest receptor point to the source (e.g., the toxic hot spot). When an environmental concentration is assumed constant over time, the population-averaged potential dose (for ingestion or inhalation routes) or absorbed dose (for dermal contact) is expressed as an average daily dose rate (ADD), in mg/kg-d,

$$ADD = \frac{C_i}{C_k} \times \frac{IU_i}{BW} \times \frac{EF \times ED}{AT} \times C_k \qquad (1)$$

In this expression $[C_i/C_k]$ is the inter-media transfer factor, which expresses the ratio of contaminant concentration in the *exposure* medium *i* (i.e., personal air, tap water, milk, soil, etc.) to the concentration in an environmental medium *k* (ambient-air gases, ambient-air particles, surface soil, root-zone soil, surface water, and ground water) and *[IUi/BW]* is the intake or uptake factor per unit body weight associated with exposure medium *i*. For exposure through the inhalation or ingestion route, *[IUi/BW]* is defined as the intake rate per unit body weight of the exposure medium such as m^3(air)/kg-d, L(milk)/kg-d, or kg(soil)/kg-d. For exposure through the dermal route, *[IUi/BW]* is replaced by *UFi*, the uptake factor per unit body weight and per unit initial concentration in the applied medium (L(water)/kg-d or kg(soil)/kg-d). In addition, *EF* is the exposure frequency for the exposed population, in days per year; *ED* is the exposure duration for the exposed population, in years; *AT* is the averaging time for the exposed population, in days; and C_k is the contaminant concentration in environmental medium *k*. When concentrations are not constant over time then Eq. 1 becomes time-dependent.

MATERIALS AND METHODS

As noted in the introduction, this project had six tasks. In this section we describe the methods used to address the problems posed by each of these tasks.

Table 1. Matrix of exposure pathways linking environmental media, exposure scenarios, and exposure routes for toxic emissions to air.

Exposure Routes	MEDIA		
	Air (gases and particles)	**Soil** (surface & root-zone)	**Surface Water**
Inhalation	• Inhalation of gases and particles in outdoor air • Inhalation of gases and particles transferred from outdoor air to indoor air	• Inhalation of soil vapors that migrate to indoor air • Inhalation of soil particles transferred to indoor air	• Indoor inhalation of contaminants transferred from tap water
Ingestion	• Ingestion of fruits, vegetables, and grains contaminated by transfer of atmospheric chemicals to plant tissues • Ingestion of meat, milk, and eggs contaminated by transfer of contaminants from air to plants to animals • Ingestion of meat, milk, and eggs contaminated through inhalation by animals • Ingestion of mother's milk	• Human soil ingestion • Ingestion of fruits, vegetables, and grains contaminated by transfer from soil • Ingestion of meat, milk, and eggs contaminated by transfer from soil to plants to animals • Ingestion of meat, milk, and eggs contaminated through soil ingestion by animals • Ingestion of mother's milk	• Ingestion of tap water • Ingestion of irrigated fruits, vegetables, and grains • Ingestion of meat, milk, and eggs from animals consuming contaminated water • Ingestion of fish and seafood • Ingestion of surface water during swimming or other water recreation • Ingestion of mother's milk
Dermal contact	(not considered)	• Dermal contact with soil	• Dermal contact in baths and showers • Dermal contact while swimming

Task 1 - Update the Health Effects Data File

The health effects data set required as input for the HRA program consists of cancer potencies (or unit risk factors) and reference exposure levels. In carrying out this task, we organized the current health effects data provided to us by OEHHA and ARB to include

updates to the existing data and to put this data in a form that can be input easily to the revised HRA model.

Task 2 - Revise Program Language and Structure

The goal of this task was to revise the program language and structure so that current and future changes to the program are easier to carry out. In order to achieve this goal, we examined program languages other than BASIC as the preferred language for this program. In consultation with the ARB staff, we determined that the most appropriate language for HRA 2.0 is the Pascal language, which makes possible much better graphics displays. HRA 1.1 was first translated into Pascal and then verified and validated against the BASIC version before we proceeded to make any further modifications.

Task 3 - An Evaluation and Implementation of Modifications to Make the Program More Flexible and User Friendly

We evaluated the existing program to identify changes that enhance both the flexibility and "user-friendliness" of the program and then implemented these changes. As part of this task we provided a brief written discussion of our evaluation to ARB staff and made recommendations for changes that would increase both the flexibility and user friendliness of the program. Specifically, we explored ways of including windows, menus, and graphic outputs to enhance the user friendliness of the program; we evaluated ways of making the structure of the program more modular in order to make it more flexible and allow for easy modification, such as the addition of new exposure algorithms. The results of our analysis were presented to the ARB staff in a meeting held on September 30, 1993. After the ARB staff had an opportunity to review the recommendations made in this written discussion, we implemented the recommended modifications to the program.

Task 4 - Direct Reading of Dispersion Modeling Outputs

In order to increase the utility of the HRA program, we had proposed to modify the HRA 1.1 program so that tables of X/Q produced by an air dispersion program could be loaded directly into the HRA program. However, during meetings with the ARB, we were encouraged not to pursue this issue. As a result, we have not designed the program to accept X/Q automatically in any particular format, but the program structure allows this capability to be added easily in the future.

Task 5 - Update the User's Guide

The modifications described above have altered the program to the point that the existing user's guide is out of date. Thus, as part of this effort, we revised the User's Guide so that it reflects the changes made to the program.

Task 6 - Modifications for New Exposure Assessment Algorithms and Intermedia Transfer Factors

The goal of this task was to modify the algorithms and transfer factors at the direction of ARB and OEHHA. We considered revised algorithms and food-chain exposure scenarios, breast-milk exposure to infants, and air-to-water system transfers. A summary comparison of HRA to the CAirTOX model is provided as extra information. This comparison was not part of the contract and is provided here for consideration when updating the HRA program in the future.

The University of California, Lawrence Livermore National Laboratory (LLNL) has carried out an effort to improve the current mathematical models used to estimate the relationship of chemical concentrations in air to concentrations in the air, soil, water, and food with which human populations have contact. The prototype algorithms from that effort have been incorporated into a spreadsheet program called CAirTOX. The algorithms are described in detail in an LLNL-issued report (McKone, 1993a), which has been delivered to both the Stationary Sources Branch of the ARB and the Office of Environmental Health Hazard Assessment.

CAirTOX was developed as a spreadsheet model to assist in making exposure calculations for stationary contaminant sources to air. CAirTOX follows an approach that has been incorporated into the CalTOX model, which was developed for the California Department of Toxic Substances Control (McKone, 1993b, 1993c, 1993d). With CAirTOX, we can address how contaminants released to an air basin can lead to contamination of soil, food, surface water, and sediments. The modeling effort includes a multimedia transport and transformation model, exposure scenario models, and efforts to quantify uncertainty in multimedia, multiple-pathway exposure assessments. The seven-compartment structure used in CAirTOX is illustrated in Figure 1. The seven CAirTOX compartments are (1) air, (2) ground-surface soil, (3) root-zone soil, (4) plant leaves, (5) plant roots, (6) surface water, and (7) sediments. In contrast to many models used for assessing environmental fate, CAirTOX imposes conservation of mass on the contaminated landscape unit. In addition, the model accounts systematically for gains and losses in each compartment and for the whole system in concert.

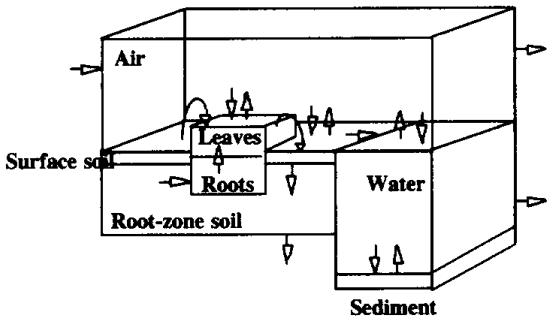

Figure 1. Mass exchange processes modeled in a seven compartment environmental transport model.

RESULTS

In the six subsections below, the results of this project are described according to the tasks identified in the *Materials and Methods* section.

Task 1 - Update the Health Effects Data File

We placed the health effects data in a form that is compatible with the new (HRA 2.0) version of the program. Both the 1992 and 1993 versions of the health effects data can be used by HRA 2.0 and were supplied by the ARB. As requested by the ARB, only the 1992 data will be included in the distribution disk of HRA 2.0. We created a program to edit the database. The program will only be available to ARB staff and not distributed with HRA 2.0.

Task 2 - Revise Program Language and Structure

Several modifications, which are transparent to the user, make HRA 2.0 faster and more efficient than HRA 1.1. Calculation algorithms are now more efficient. The calculation time has been reduced. Some temporary files have been eliminated. Redundant code has been eliminated by eliminating redundant variables and by developing subroutines for common repetitive tasks.

The bioavailability of each substance, which is an entry in the pollutant data file, is now initialized to 1 instead of 0. This change leads to more efficient code.

The format of input files has been changed from text files to binary files. Therefore the user must now use the HRA 2.0 program to edit or create input files.

The executable program for HRA 2.0 is comparable in size to HRA 1.1. Memory requirements are approximately the same. In the new version, memory requirements depend in part on the size of the input files. HRA 2.0 requires approximately 200K of memory for the sample analyses included in the distribution disk.

Task 3 - An Evaluation and Implementation of Modifications to Make the Program More Flexible and User Friendly

There are a number of changes in HRA 2.0 that make the program more user friendly and flexible relative to HRA 1.1.

Creating, editing, and viewing the input files has been improved. Viewing reports on screen has also been improved. The user is now presented with an index corresponding to the analysis that was performed. In this way the user can select the section of the report/file that he/she wants to see. When the user decides to save the report to a file

using HRA 2.0, two files are created. One with an extension .RPT, which is a regular text file and one with an extension .BIN, which is a binary file used by the HRA 2.0 to view a previously saved report using the "View/Print Files" menu.

On-line help has been added to the program. The file containing the on-line help is named HRA93.HLP.

The form of the input files required to run an analysis has been changed. The files are no longer text files. As a result of this change, the input files can only be created and edited with the HRA 2.0 program. This change increases the consistency and security of program execution.

Ranges for numeric values for inputs are now provided to the user who is constructing input files for HRA 2.0. This change helps the user in avoiding incorrect or non-plausible values for inputs and helps to reduce the likelihood that the program will crash.

In HRA 1.1, chronic exposures by routes other than inhalation (i.e., ingestion and dermal uptake) were reported along with the individual cancer risk results. However, since chronic dermal and ingestion exposures can be associated non-cancer endpoints, this system was confusing. In HRA 2.0, chronic exposures by ingestion and dermal routes are reported in a separate menu that applies to both cancer and non-cancer health effects. This revision is illustrated in Figure 2 below.

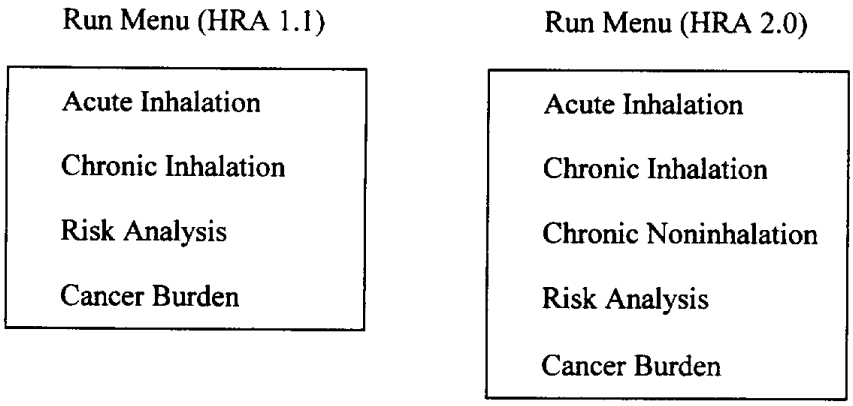

Figure 2. Differences between the *Run Menu* in HRA 1.1 and HRA 2.0

Task 4 - Direct Reading of Dispersion Modeling Outputs

We have retained the option of allowing the user to manually enter the X/Q values as is done in the HRA 1.1.

Task 5 - Update the User's Guide

A revised User's Guide for HRA 2.0 has been prepared. A copy of the User's Guide is included as an appendix to this report.

Task 6 - Modifications for New Exposure Assessment Algorithms and Intermedia Transfer Factors

At the ARB and OEHHA's direction, no modifications were made to the multipathway algorithms and the intermedia transfer factors.

DISCUSSION

Risk assessment is a quantitative evaluation of information on potential health hazards of environmental contaminants and the extent of human exposure to these contaminants. As applied to toxic chemical emissions to air, risk assessment involves four interrelated steps. These are (1) determination of source concentrations or emission characteristics, (2) exposure assessment, (3) toxicity assessment, and (4) risk characterization. These steps can be carried out with assistance from analytical models in order to estimate the potential risk associated with existing and future releases. HRA 2.0 has been developed as a computational model to assist in making these types of calculations.

At best, mathematical models only approximate real systems, and therefore their predictions are inherently uncertain. In evaluating the reliability of risk assessment models two questions must be asked, (1) how large is the uncertainty in the model predictions and (2) how much confidence can be placed in the results? To address these questions, exposure and risk should be presented so that uncertainty in risk and exposure can be characterized by expectation (mean) and spread (variance). Ultimately, there is a need to include both a sensitivity analysis and a variance propagation analysis to determine the reliability of the risk estimates and to identify which components of the analysis limit overall reliability.

The HRA model should not be considered finished simply because it has moved from version 1.1 to version 2.0. To maintain the scientific defensibility of this model, there is a need to constantly audit its relationship to what is in the current literature, to guidance of the U.S. EPA, and to the practices of other California agencies.

One of the most significant issues in the HRA model that should ultimately be addressed is the inherent lack of reliability associated with both measured data and models used to determine intermedia transfer factors (ITFs). There are a number of ITFs used in HRA—steady-state bioconcentration factors for plant root concentrations relative to soil concentration, plant leaf concentration relative to air concentration, and fish concentration relative to water or sediment concentrations; steady-state biotransfer factors for milk or dairy-product concentration relative to contaminant intake by cattle; meat concentration relative to contaminant intake by animals; egg concentration relative to contaminant intake by chickens; and breast milk concentrations relative to contaminant intake by mothers; and contaminant biodegradation factors in soil.

Overall variance in quantitative estimates of ITFs comes from several factors including (1) variability among experiments; (2) our ignorance regarding the process of metabolism and chemical partitioning; and (3) the reliability with which we can measure both the outcome (biotransfer or partition factor) and the explanatory variable (e.g., K_{ow}). It is likely that the lack of reliability for determining these ITFs can be a major contribution to the overall variance in the exposure estimates of HRA. The results of

HRA will be more credible, if the variance in these values is clearly stated and the impact of these variances on the final estimates of risk is assessed. At a minimum, this can be done by listing the estimation error or the experimental variance associated with the ITF parameters when these values or their estimation equations are listed in tables. This is certainly something to consider in future versions of the model.

The HRA model accounts for deposition primarily as a physical process that can be represented with the equivalent of a velocity. It has been demonstrated in the scientific literature that this approach is valid for particles and chemicals attached to particles, such as metals, radionuclides, speciated organic and inorganic compounds, and polar and non-polar nonionic compounds with extremely low vapor pressure. However, for nonionic, non-polar, semivolatile organic compounds simple deposition is clearly not the only process by which contaminants are transferred from air to soil and plant surfaces. These latter compounds are often transferred from air to lipid (i.e. plant leaves) and to organic-carbon (i.e., soil) surfaces by a mass transfer process that is governed by chemical potential and by mass transfer resistance. It is often not possible to use a simple deposition model for these chemicals.

Summary Comparison of CAirTOX and HRA with Examples

A summary comparison of HRA to the CAirTOX model is provided as extra information. This comparison was not part of the contract and is provided here for consideration when updating the HRA program in the future. Listed in Table 2 are the potential interactions among environmental media, exposure media, and exposure routes that were listed in Table 1 and addressed in the proposed CAirTOX model. CAirTOX is intended to expand on the approach used in HRA. In order to make clear the differences in exposure pathways used in these two models, we shaded in Table 2 those exposure pathways included only in CAirTOX. The unshaded listings are exposure pathways included in both models.

Another way to compare CAirTOX and HRA is to consider how the quantitative results of the models differ for specific chemicals. This type of comparison is described in an LLNL-issued report (McKone, 1993a), which has been delivered to both the Stationary Sources Branch of the ARB and the Office of Environmental Health Hazard Assessment. This comparison is repeated here because it has relevance to the issue of future model revisions. This comparison gives us a sense of which excluded exposure pathways are significant and should be considered for inclusion in a future version of HRA. Tables 3 and 4 list potential doses by route and pathway predicted by HRA and CAirTOX using similar landscape characteristics and chemical properties for dioxins and furans (TCDD) and inorganic arsenic. In this simulation the air concentration was fixed at 10^{-9} mg/m^3 for TCDD and 10^{-3} mg/m^3 for arsenic.

In comparing these results, we note that

(1) the inhalation doses are comparable for both chemicals;

(2) surface-water ingestion doses are similar between the two models for arsenic but not for TCDD;

(3) for both arsenic and TCDD, CAirTOX predicts higher potential doses for homegrown produce than HRA;

(4) for TCDD predictions of doses through meat are comparable and predictions of doses through milk differ by roughly a factor of 3 between the two models;

(5) for arsenic, predictions of doses through meat are roughly a factor of 3 higher in CAirTOX and predictions of doses through milk are roughly a factor of 5 higher in CAirTOX;

Table 2. Matrix of exposure pathways used in CAirTOX and HRA to link environmental media, exposure scenarios, and exposure routes. Those pathways included only in CAirTOX are shaded and those included in both HRA and CAirTOX are not shaded.

Exposure Routes	MEDIA		
	Air (gases and particles)	**Soil** (surface & root-zone)	**Surface Water**
Inhalation	• Inhalation of gases and particles in outdoor air • Inhalation of gases and particles transferred from outdoor air to indoor air	• **Inhalation of soil vapors that migrate to indoor air** • **Inhalation of soil particles transferred to indoor air**	• **Indoor inhalation of contaminants transferred from tap water**
Ingestion	• Ingestion of fruits, vegetables, and grains contaminated by transfer of atmospheric chemicals to plant tissues • Ingestion of meat, milk, and eggs contaminated by transfer of contaminants from air to plants to animals • Ingestion of meat, milk, and eggs contaminated through inhalation by animals • Ingestion of mother's milk	• Human soil ingestion • Ingestion of fruits, vegetables, and grains contaminated by transfer from soil • Ingestion of meat, milk, and eggs contaminated by transfer from soil to plants to animals • Ingestion of meat, milk, and eggs contaminated through soil ingestion by animals • Ingestion of mother's milk	• Ingestion of tap water • **Ingestion of irrigated fruits, vegetables, and grains** • Ingestion of meat, milk, and eggs from animals consuming contaminated water • Ingestion of fish and seafood • **Ingestion of surface water during swimming or other water recreation** • **Ingestion of mother's milk**
Dermal contact	(not considered)	• Dermal contact with soil	• **Dermal contact in baths and showers** • **Dermal contact while swimming**

(6) for TCDD, predictions of doses through fish are a factor of 16 higher in HRA than in CAirTOX (this is due primarily to the modeling of particle deposition in CAirTOX and the absence of this modeling in HRA);

(7) for arsenic, predictions of doses through fish are a factor of 1000 higher in CAirTOX than in HRA (this is due primarily to the modeling of particle runoff in CAirTOX and the absence of this modeling in HRA);

Table 3. Comparison of potential doses (mg/kg-d) to TCDD predicted by HRA and CAirTOX under similar conditions and with an air concentration of 10^{-12} mg/m^3.

	HRA	CAirTOX
Inhalation	2.8×10^{-13}	3.5×10^{-13}
Ingestion:		
Water	2.2×10^{-12}	7.0×10^{-15}
Exposed produce	--	9.5×10^{-11}
Unexposed produce	--	8.4×10^{-14}
Garden products	5.7×10^{-13}	--
Meat	1.6×10^{-11}	2.3×10^{-11}
Milk	1.9×10^{-11}	7.0×10^{-11}
Eggs	n/a	6.0×10^{-13}
Fish	1.1×10^{-11}	6.7×10^{-13}
Soil	2.1×10^{-13}	4.2×10^{-15}
Total Ingestion	4.9×10^{-11}	1.9×10^{-10}
Dermal Uptake	2.0×10^{-13}	2.6×10^{-12}
Breast Milk	3.6×10^{-13}	2.0×10^{-11}
Dose Sum	5.0×10^{-11}	2.1×10^{-10}

(8) for both chemicals, soil-ingestion exposure is roughly a factor of 100 higher in HRA relative to CAirTOX;

(9) dermal uptake of TCDD is comparable in the two models and, for arsenic, a factor of 10 higher in CAirTOX;

(10) predicted breast milk dose to TCDD is 100 times higher in CAirTOX than in HRA (this is due primarily to the inclusion of more pathways for transferring contaminants form soil and food to human breast milk in CAirTOX); and

(11) the total dose predicted from all pathways differs between the two models by roughly a factor of 5 or less for both compounds.

Table 4. Comparison of potential doses (mg/kg-d) to arsenic predicted by HRA and CAirTOX under similar conditions and with an air concentration of 10^{-6} mg/m^3.

	HRA	CAirTOX
Inhalation	2.8×10^{-7}	3.6×10^{-7}
Ingestion:		
Water	5.0×10^{-6}	1.0×10^{-5}
Exposed produce	--	1.0×10^{-5}
Unexposed produce	--	2.2×10^{-5}
Garden products	1.5×10^{-6}	--
Meat	2.0×10^{-7}	6.4×10^{-7}
Milk	7.7×10^{-8}	4.2×10^{-7}
Eggs	n/a	1.1×10^{-8}
Fish	9.4×10^{-9}	1.0×10^{-5}
Soil	1.3×10^{-6}	2.5×10^{-8}
Total Ingestion	8.1×10^{-6}	5.2×10^{-5}
Dermal Uptake	2.8×10^{-8}	2.1×10^{-7}
Breast Milk	n/a	2.2×10^{-9}
Dose Sum	8.1×10^{-6}	5.3×10^{-5}

SUMMARY AND CONCLUSIONS

This report describes six tasks performed at the University of California, Davis under the auspices of the University of California (UC) Risk Science Program and funded by the ARB. These tasks supported the further development and implementation of the HRA program and scientifically-based efforts to characterize exposure and risk. These tasks were (1) incorporate more current health risk data, (2) revise the program language and structure so that future changes to the program are easier to carry out, (3) evaluate the existing program to identify changes that enhance both the flexibility and "user-friendliness" of the program and then implement these changes, (4) modify the program to allow for the direct reading of dispersion modeling outputs, (5) update the user's guide for the program, (6) modify the program, as directed by OEHHA and ARB, to include new exposure assessment algorithms and intermedia transfer factors.

Several modifications make HRA 2.0 faster and more efficient than HRA 1.1. Calculation algorithms are now more efficient. The calculation time has been reduced. Some temporary files have been eliminated. Redundant code has been eliminated by eliminating redundant variables and by developing subroutines for common repetitive tasks. The format of input files has been changed from text files to binary files, with the result that the loading of data has been accelerated substantially, but the files are still not accessible to the average end user. The executable program for HRA 2.0 is smaller than the executable for HRA 1.1.

There are a number of changes in HRA 2.0 that make the program more user friendly and flexible relative to HRA 1.1. Creating, editing, and viewing the input files has been improved. Viewing reports on screen has also been improved. Ranges of numeric values for inputs are now provided to the user who is constructing input files for HRA 2.0. This change helps the user in avoiding incorrect or non-plausible values for inputs and helps to reduce the likelihood that the program will crash.

A revised user's guide for HRA 2.0 is in preparation. Because it is still undergoing revisions, a final copy is not included with this draft final report. A copy of the user's guide will be included as an appendix in the actual final report.

A summary comparison of HRA to the CAirTOX model is provided as extra information. This comparison was not part of the contract and is provided here for consideration when updating the HRA program in the future. Summary Comparison of CAirTOX and HRA for the arsenic and TCDD releases to air reveals that there are a number of similarities and some significant differences in the exposures predicted by these two multipathway models. Interestingly, the total dose predicted by the two models for the two compounds do not differ as significantly as the exposure by specific pathways. This comparison does not imply that there are any significant errors in either model but reveals the need to compare and reconcile model differences as part of the process for updating either model.

Intermedia transfer factors (ITFs)—such as the biotransfer factors in milk, meat, eggs, breast milk, etc.—are derived from either controlled experiments or more often from statistical estimation equations and their exact values are often highly uncertain. The implication of such large uncertainties needs to be addressed in any future revisions of the HRA model.

RECOMMENDATIONS

Much effort has been expended in this project to modify and improve the HRA model. As a result, we believe that the HRA 2.0 has some significant advantages over its predecessor, the HRA 1.1 model. Nonetheless, the HRA 2.0 model should not be considered the ending point in the process for assessing health risks from toxic chemical emissions to air. Instead it is a stepping stone in an evolving process of model development. In participating in this process, we have made a number of observations regarding what might be the appropriate next steps in this process. We share these observations in this section as a set of recommendations. Our recommendations involve four issues. First, we believe that the work presented here is most useful if it is viewed as part of a continuing effort to develop multimedia exposure/risk models and verify, validate and reconcile these models with other similar models and with actual data wherever possible. Second, there is a continuing need for better graphic displays of the outputs of the HRA results. Third, the large uncertainties associated with the types of indirect pathways included in HRA demands a more explicit treatment of uncertainties. Finally, the ultimate reliability of the HRA model is strongly linked to the precision of inputs, particularly the intermedia transfer factors. More work needs to be done to define and reduce the uncertainties in these factors.

Continuing Verification, Validation, and Reconciliation

An exposure assessment can be carried out through modeling, sampling, or some modeling/sampling combination. Ultimately this characterization provides a set of static pictures used to characterize a dynamic world. Unless these "pictures" can be guided by an appropriate theoretical framework, they are of little value unless we have a very large set of "pictures". The HRA model should strive to maximize the amount of information obtained from each "picture". This can be accomplished through an iterative process of models and samples. In such a system, the HRA model is used initially to characterize exposure and must serve as a repository for much of the current knowledge of environmental pollution and exposure processes. Measurements of exposure concentration and markers of dose together with the results of other models should be used in selected cases to audit the HRA exposure characterizations.

In order to validate the quantitative estimates of exposure produce by HRA, these estimates should be compared to measured concentrations and predictions by other models. The comparison to measured values should be carried out for at least three chemical species: (1) a ubiquitous widely used industrial organic solvent with high vapor pressure and low solubility, (2) a widely used non-industrial organic chemical, such as a pesticide, with low vapor pressure and very low solubility, and (3) a metal such as arsenic or lead. Regional concentration data as well as data collected at specific sites should be used to evaluate model predictions.

More Graphic Display Results

The major objective of the HRA is to provide risk managers and other decision makers with a more complete picture of both how potential human exposure comes about and how precisely it can be quantified for toxic chemical emissions to air. The risk communication process can be expedited when the exposure and risk information is presented in a graphic manner. The continuing evolution of personal computers makes graphic results much easier to distribute. Further improvements to the HRA model should take advantage of these graphic capabilities.

The HRA exposure model provides methods for integrating multiple-exposure routes from multiple-environmental media in a way that relates concentrations of toxic chemicals to potential total human dose from toxic chemical emissions to air. These types of diagrams allow the decision maker to make both route-to-route and medium-specific comparisons of total potential doses from multiple environmental media. Well-organized graphics would allow the decision maker to better determine a strategy for reducing exposure and risk from toxic chemical emissions to air.

Confronting Uncertainties

In reality there are many sources of uncertainty and variability in the process of human health-risk assessment. Many of these uncertainties and variabilities are not reducible. Effective policies are possible under conditions of uncertainty, but such policies must take the uncertainty into account. There is a well-developed theory of decision making under uncertainty, which is described in several texts. One often used method for addressing uncertainty in risk assessments is the compounding of upper bound estimates in order to make decisions based on a highly conservative estimate of exposure and risk. Such an approach is contrary to the principles of decision making under uncertainty. This latter approach leaves the decision maker with no flexibility to address margins of error; to consider reducible versus irreducible uncertainty; to separate individual variability from true scientific uncertainty; or to consider benefits, costs, and comparable risks in the decision making process.

The principles of decision making under uncertainty are not necessarily complex. Often the principles of such decision making are simply common sense. But in any issue involving uncertainty, it is important to consider a variety of plausible hypotheses about the world; consider a variety of possible strategies for meeting our goals; favor actions that are robust to uncertainties; favor actions that are informative; probe and experiment; monitor results; update assessments and modify policy accordingly and favor actions that are reversible (Ludwig et al., 1993).

In order to make HRA consistent with such an approach, it needs to be modified so that both sensitivity and uncertainty analyses are incorporated directly into the model operation. Parameter values used in HRA should eventually be described in terms of mean values and some measure of variation in place of plausible upper values. Then

model outputs could be described in terms of the confidence intervals associated with model predictions.

At minimum, an uncertainty propagation method, such as Monte Carlo, should be used to characterize the impact of the potentially large uncertainties in the estimates of biotransfer factors and other ITFs on the precision of estimates of exposure within the population.

Better Characterization of Intermedia Transfer Factors

Many intermedia transfer parameters (such as K_{oc}, vapor pressure, soil-erosion rates, and biotransfer factors, etc.) are based on empirical estimation techniques. These types of empirical estimation equations often have very large estimation errors—a geometric standard deviation of as much as an order of magnitude is common. In order to determine the reliability of the HRA results there is need to determine how these empirical estimation techniques limit the precision of the transport and uptake models. There are two approaches for determining the impact of these estimation errors on model reliability-(1) validation studies that compare model predictions to the measured relationship between emissions and concentrations and (2) sensitivity/uncertainty analyses that identify critical links between estimation errors and model precision. Both activities need to be a continuing part of the development process for the HRA program.

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