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DEVELOPING RESRAD-BASELINE FOR ENVIRONMENTAL BASELINE RISK ASSESSMENT[1]

ABSTRACT

RESRAD-BASELINE is a computer code developed at Argonne National Laboratory for the U.S. Department of Energy (DOE) to perform both radiological and chemical risk assessments. The code implements the baseline risk assessment guidance of the U.S. Environmental Protection Agency (EPA 1989). The computer code calculates (1) radiation doses and cancer risks from exposure to radioactive materials, and (2) hazard indexes and cancer risks from exposure to noncarcinogenic and carcinogenic chemicals, respectively. The user can enter measured or predicted environmental media concentrations from the graphic interface and can simulate different exposure scenarios by selecting the appropriate pathways and modifying the exposure parameters. The database used by RESRAD-BASELINE includes dose conversion factors and slope factors for radionuclides and toxicity information and properties for chemicals. The user can modify the database for use in the calculation. Sensitivity analysis can be performed while running the computer code to examine the influence of the input parameters. Use of RESRAD-BASELINE for risk analysis is easy, fast, and cost-saving. Furthermore, it ensures consistency in methodology for both radiological and chemical risk analyses.

INTRODUCTION

Baseline risk assessment methodology is applied in several stages of waste management and remediation activities: to set cleanup priorities for different sites by comparing site-specific risks, to set preliminary remediation goals, and to evaluate human health risks associated with

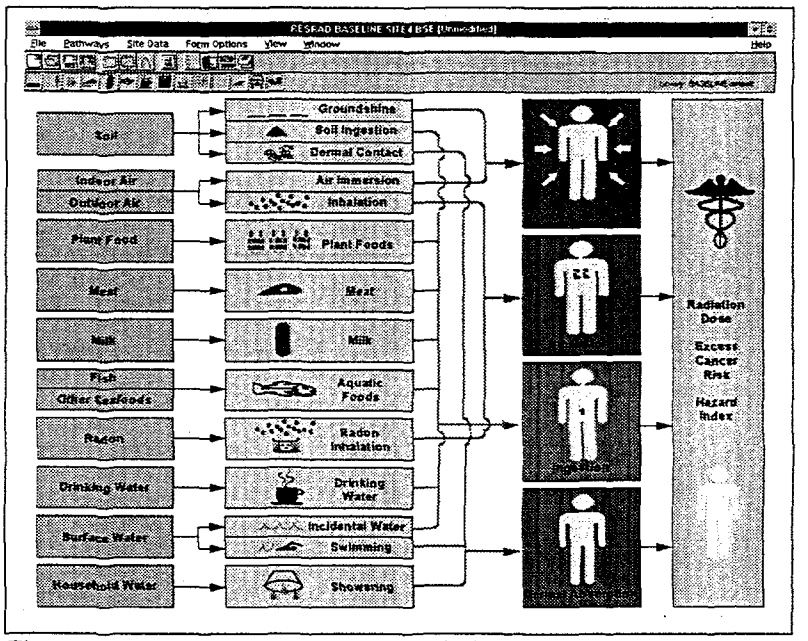

Figure 1 Main menu and graphic window

[1] Work supported by the U.S. Department of Energy, Assistant Secretary for Environmental Restoration and Waste Management and Assistant Secretary for Environment, Safety, and Health, under contract W-31-109-Eng-38.

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remediation alternatives. Because the number of contaminants, potential exposure pathways, and land use scenarios could be substantial, a computer code is needed to mechanize the calculation and reduce cost and effort.

RESRAD-BASELINE was developed to calculate human health risks with environmental media concentrations and exposure parameters. It was designed for Windows™ application. The user interface consists of a main menu and graphic window (see Figure 1) and numerous subwindows to set up the exposure scenario for analysis. The user can enter the input parameters through interaction with the various windows and their options. The input parameters are then collected and stored in an ASCII text file following the FORTRAN NAMELIST format. This ASCII file is then used for input to a FORTRAN calculation program. After the calculation is completed, the user can view, print, or save the calculational results to an ASCII file. The results can also be copied to another Windows™ application or converted to a Microsoft Excel spreadsheet.

EXPOSURE PATHWAYS CONSIDERED BY RESRAD-BASELINE

Fourteen exposure pathways are considered by RESRAD-BASELINE. For both radionuclides and chemicals, the pathways are inhalation; ingestion of plant, meat, milk, aquatic foods, soil, and drinking water; and incidental ingestion of water while swimming. Additional pathways for radionculides are inhalation of radon and external radiation from soil and from air immersion. Dermal absorption is a much more significant pathway for chemicals and is considered only for chemicals from swimming, showering, and soil contact.

METHODOLOGY AND INPUT PARAMETERS USED BY RESRAD-BASELINE

The methodology used in the RESRAD-BASELINE code follows the EPA's guidance on Human Health Evaluation for Superfund (EPA 1989). Intake/uptake quantities (in units of mg/kg/day for chemicals and pCi/yr for radionuclides) are calculated for different exposure pathways (except for external radiation pathways) using the corresponding environmental media concentrations and exposure parameters. The quantities are then used to characterize health risks by use of dose conversion factors and toxicity values from the database.

Environmental media concentrations that can be entered into the code are concentrations in soil (pCi/g for radionuclides and mg/kg for chemicals) used for groundshine, soil ingestion, and dermal absorption from soil contact pathways; indoor and outdoor air concentrations (pCi/m^3 for radionuclides and mg/m^3 for chemicals) used for inhalation and air immersion pathways; concentrations in plant food (pCi/kg for radionuclides and mg/kg for chemicals) used for the plant ingestion pathway; concentration in meat (pCi/kg for radionculides and mg/kg for

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chemicals) used for the meat ingestion pathway; concentration in milk (pCi/L for radionuclides and mg/L for chemicals) used for the milk ingestion pathway; concentration in fish and other seafood (pCi/kg for radionuclides and mg/kg for chemicals) used for the aquatic food ingestion pathway; concentration in drinking water (pCi/L for radionuclides and mg/L for chemicals) used for the drinking water ingestion pathway; concentration in surface water (pCi/L for radionuclides and mg/L for chemicals) used for incidental water ingestion while swimming and dermal absorption from swimming pathways; concentration in household water (mg/L for chemicals) used for the dermal absorption from showering pathway; and indoor and outdoor concentrations (pCi/m^3) of radon and radon progeny for the radon inhalation pathway.

For ingestion pathways, the exposure parameters are the ingestion rates (kg/day or g/day or L/day), contamination fractions, exposure frequencies (days/yr), and exposure duration (yr). The average body weight is used to normalize the intake quantities for chemicals, and the average life span is used to calculate life-time average intake quantities. For the soil ingestion pathway, two ingestion rates, two average body weights, and two exposure durations are used to quantify intake rates for young children and adults. Consideration of two-stage exposure for the soil ingestion pathway is consistent with the EPA's guidance because young children tend to ingest more soil but weigh less than adults.

The inhalation pathways use indoor and outdoor inhalation rates (m^3/day), time fraction spent outdoors, exposure frequency, exposure duration, and the indoor and outdoor air concentrations to calculate the intake rates. Indoor and outdoor concentrations and indoor and outdoor inhalation rates can be of different values. This feature provides flexibility to consider the variation in contaminant partitioning provided by a building and the different activity patterns an individual may exhibit while indoors and outdoors. The radon-222 and radon-220 concentrations can be entered directly from the interface. Their progeny concentrations can be specified by entering the measured values or by using equilibrium fractions for RESRAD-BASELINE to calculate the concentration values. Radiation doses for radon inhalation are calculated by using the accumulated exposure in terms of working level month (WLM) and then converting the WLM to effective dose equivalent (EDE) (Yu et al. 1993).

For dermal absorption pathways, exposure parameters include contamination fractions, exposure frequencies, skin surface areas (cm^2), soil-to-skin adherence factor (mg/cm^2-event), and event durations (minutes per event for showering and hours per event for swimming and soil contact). Because the amount of dermal uptake is time- and contaminant-dependent, two chemical properties are also used to calculate the uptake quantities: dermal permeability coefficient (cm/h) and absorption fraction for soil contact. These factors are not input parameters, but are stored in the database used by RESRAD-BASELINE. Alternatively, these

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two parameters can be calculated by the code with the molecular weight (g/mole), Henry's law constant (atm-m^3/mole), molecular diffusivity (cm^2/s), octanol/water partition coefficient (Kow), and organic carbon partition coefficient parameters stored in the database, and the organic carbon content of soil, which is an input parameter. The mathematical model used to quantify dermal uptake of contaminants was obtained from the EPA's guidance on dermal exposure assessment (EPA 1992a).

To calculate external radiation doses from groundshine and air immersion, the exposure parameters needed are time fraction spent outdoors and exposure frequency. For the groundshine exposure pathway, the shielding factor and the thickness (m) and density (g/cm^3) of contaminated soil are used to adjust the dose conversion factors [(mrem/yr)/(pCi/cm^3)]. The shielding factor accounts for the attenuation of external radiation provided by a building. The dose conversion factors are the radiation doses incurred by an individual per exposure from a contaminated zone of infinite depth and lateral extent with a density of 1.6 g/cm^3.

DATABASE USED BY RESRAD-BASELINE

The database for RESRAD-BASELINE currently contains 84 radionuclides and 151 chemicals, including organic and inorganic materials, and some metals. Additional radionuclides and chemicals may be added in the future. RESRAD-BASELINE allows users to modify the database used in the calculation. Dose conversion factors and slope factors for radionuclides, toxicity information (slope factors and reference doses) for chemicals, and chemical properties (dermal permeabilities, absorption fractions, Henry's law constants, molecular diffusivities, organic carbon partition coefficients, and octanol/water partition coefficients) can be accessed and modified from the input windows. RESRAD-BASELINE will then generate a separate database with the user's modifications for use in calculating human health risks.

Default dose conversion factors (DCFs) for groundshine and air immersion were obtained from EPA Federal Guidance Report No. 12 (EPA 1993b). DCFs for ingestion and inhalation were obtained from Federal Guidance Report No. 11 (EPA 1988). Two radiological cancer risks are calculated: one using the slope factors, which are defined as the best estimated life-time average excess cancer incidence risk per exposure, and the other using a dose-to-risk conversion factor (risk/mrem). The dose-to-risk conversion factor can be modified from the input window for health risk factors. The default value is 7.6×10^{-7} risk/mrem (EPA 1994b). Slope factors for groundshine, inhalation, and ingestion were obtained primarily from the EPA's Health Evaluation Assessment Summary Tables (HEAST) (EPA 1994a), with some calculated using the default DCFs and dose-to-risk conversion factor and some taken from the EPA report *Estimating Radiogenic Cancer Risks* (EPA 1994b). The DCFs and slope factors, except those for radon,

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used in the RESRAD-BASELINE database are accumulated values that include short-lived progeny. The short-lived progeny are assumed to be in secular equilibrium with the parent radionuclides and have half-lives of less than 6 months. For radon, the individual slope factors for parent and progeny are used.

Toxicity information for chemicals is used to calculate hazard indexes (using reference doses) for noncarcinogens and cancer risks (using slope factors) for carcinogens. The default values were obtained from the EPA's Integrated Risk Information Systems (IRIS) (EPA 1992b) and HEAST. The inhalation slope factors [$(mg/kg\text{-}day)^{-1}$] were converted from inhalation unit risks [$(\mu g/m^3)^{-1}$] by assuming an inhalation rate of 20 m^3/day and an average body weight of 70 kg. The inhalation reference doses (mg/kg-day) were converted from inhalation reference concentrations (mg/m^3) by assuming the same inhalation rate and body weight. For reference doses, the uncertainty factors incorporated in deriving the values are shown in the input window and are printed in the output text report. For slope factors, the cancer classes that were assigned to the chemicals are shown and printed. The uncertainty factors and cancer classes are only for the user's information and are not used in the calculations.

SENSITIVITY ANALYSIS

A useful feature of the RESRAD-BASELINE code is its ability to perform sensitivity analyses for most input parameters. Parameters to be subjected to sensitivity analysis can be selected directly from the data input windows, and the analyses are then performed automatically during the calculations. Results of the sensitivity analysis are output in the text report after those for the base data.

USER INTERFACE FOR RESRAD-BASELINE

RESRAD-BASELINE was developed as a Windows™ application with a graphical interface written in Visual BASIC™. The user interface includes a main graphic window, a button bar, a pathway bar, a variable message bar, and a menu bar. The main graphic window provides a schematic representation of the exposure pathways (Figure 1) used by RESRAD-BASELINE to calculate human health risks. The graphic also provides the user with a convenient way to view and/or change data. By clicking on any box on the graphic, the user can display a window containing all of the data pertaining to the selected portion of the graphic. Multiple windows can be displayed at once, and the data can be modified and saved. Figures 2 through 4 show typical windows that can be opened when clicking on different columns of the main graphic window. Figure 2 shows the source media window that is opened when clicking on the first column of the graphic. It allows the user to select contaminants and enter their

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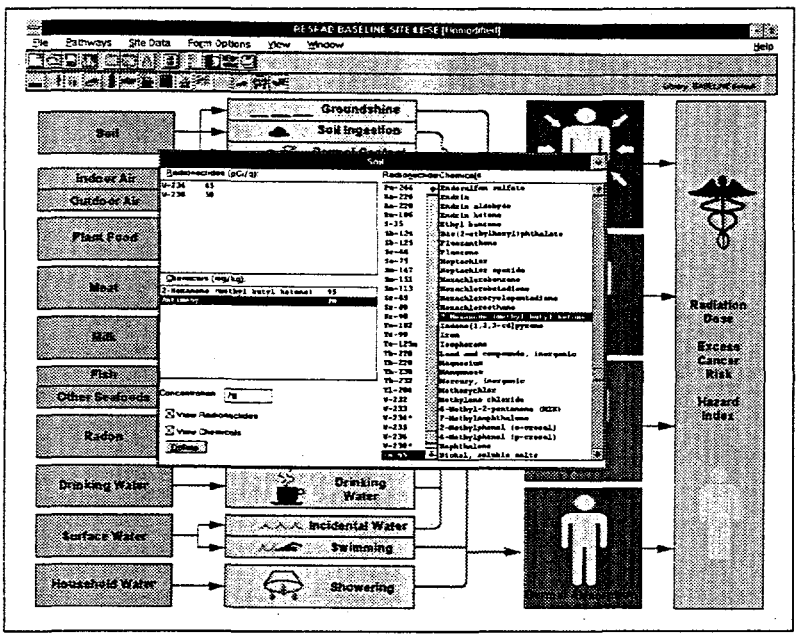

Figure 2 Source media window

concentrations. Figure 3 shows the environmental pathways window that allows the user to enter the corresponding exposure parameters for a specific pathway. This window can be opened by clicking on the second column of the graphic. Figure 4 shows two windows that can be accessed by clicking on the third column of the graphic. The first window allows the user to select a specific contaminant. After a contaminant is selected, the second window will appear so that the user can modify the health risk factors and properties for the contaminant.

In addition to permitting the use of the main graphic window for data entry, RESRAD-BASELINE allows the user to enter data by using the menu bar. The menu bar provides options for file management, pathway selection, site-specific data entry, form operation, viewing files and selection made by the user, and accessing on-line help. By choosing "Site Data" from the menu options, the user is able to enter or modify environmental media concentrations and exposure parameters. The exposure parameters are grouped in a different way than that used by the graphic window. In the main graphic window, parameters are grouped by specific pathway. In the "Site Data" menu option, similar parameters are grouped across all pathways. This provides the user with flexibility for reviewing and assigning exposure parameters.

Pathways can be selected or suppressed with the pathway bar or the menu option. The user cannot open the corresponding environmental pathways window from the graphic interface if a pathway is suppressed and, if using the menu option for data entry, cannot modify the corresponding parameters for the suppressed pathway.

The button bar includes several buttons to reset parameters (to default values); open/save files; run RESRAD-BASELINE calculations; save/cancel changes (to the current input form); select parameters for sensitivity analysis; view output; and toggle the graphic interface, sensitivity analysis summary, pathways bar, and variable message bar. The exposure pathways window can

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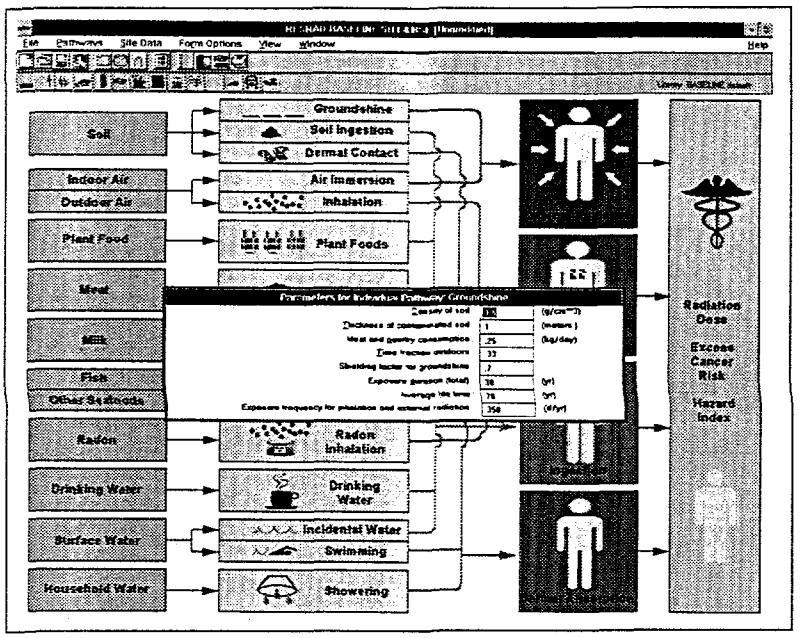

Figure 3 Environmental pathways window

be saved by using the "Save Changes" button or by pressing the "F10" key. It can be closed without saving any changes by using the "Cancel Changes" button or by pressing the "Esc" key. The variable message bar is located at the bottom of the screen. It provides one line of information for the highlighted input parameter in the exposure pathways window and includes a brief description of the parameter, the default value, and the upper and lower bound values. More detailed information for each highlighted parameter can be obtained by selecting "Help" from the menu bar.

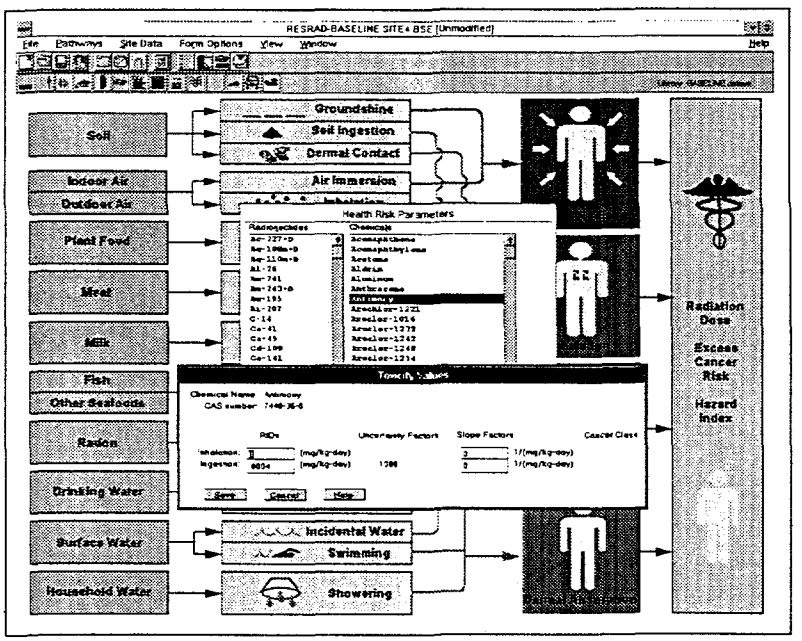

Figure 4 Health risk window

Results can be viewed immediately after calculation is completed or later by either selecting the "View" option from the menu bar or by pressing the corresponding key from the button bar. While viewing the calculation results, the user can select a particular portion for viewing, printing, copying to another Windows™ application, or converting to a Microsoft Excel spreadsheet. The results can also be saved to an ASCII file. The user can select the font size of characters for use in viewing and printing the results.

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RESRAD-BASELINE OUTPUT

After the calculation is completed, RESRAD-BASELINE generates a text report file that can be viewed directly from the interface window, printed, or copied to another file. The text report file includes a table of contents (Figure 5) to help users locate and access specific portions of the report. The body of the report starts with a list of dose conversion factors and slope factors for radionuclides (if one or more radionuclides are selected), followed by a list of toxicity values and chemical properties (if one or more chemicals are selected), then a summary of the site-specific input parameters, a summary of pathway selections, the chemical abstract service (CAS) numbers for chemicals, and the calculational results. The default values and the values actually used in the calculation for the database parameters and the site-specific input parameters are listed.

Calculational results using base data are listed in the text report, followed by results for any sensitivity analyses performed. For each input parameter under sensitivity analysis, all tables are repeated twice listing results obtained by using the two new values for the studied parameter. Calculational results listed for radionculides are amount of intake quantities, dose components and their fractional contribution to the total dose for individual radionuclides and pathways, cancer risk components and fractions obtained by using the risk conversion factor, and cancer risks components and fractions obtained by using the slope factors. For chemicals, the listed results are the amount of intake quantities, hazard index components and fractions for noncarcinogenic effects, and cancer risk components and fractions for carcinogenic effects. These tables can be used to identify the dominant exposure pathways and contaminants.

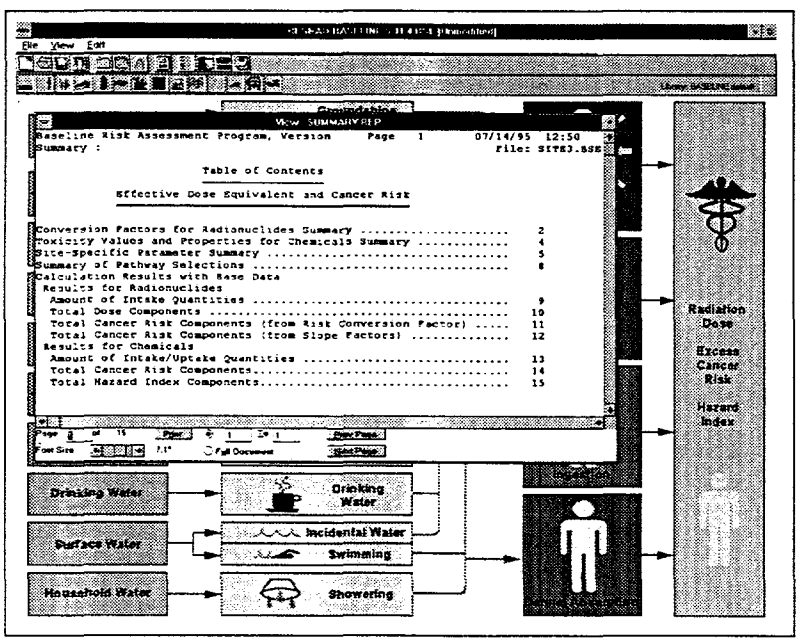

Figure 5 View windows with table of contents

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CONCLUSIONS

RESRAD-BASELINE is a useful tool for implementing the baseline risk assessment methodology for risk analyses. The code was developed for Windows™ application and uses a graphic window, a menu bar, a button bar, a variable message bar, and a pathway bar to assist the user in entering data, running the code, viewing the results, and operating the code. The interface design is very flexible and provides for different needs of the user. On-line help and instructions are available throughout the operation. The exposure pathways can be selected and input parameters tailored to reflect different exposure scenarios. Both radiological and chemical risks can be assessed at the same time with consistent methodology. Since the baseline risk assessment methodology is applied broadly at different stages of environmental remediation and waste management activities, using RESRAD-BASELINE to assist risk analyses will provide considerable savings in time and cost.

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