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DEMONSTRATION OF A COMPUTER MODEL FOR RESIDUAL RADIOACTIVE MATERIAL GUIDELINES, RESRAD

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ABSTRACT

A computer model was developed to calculate residual radioactive material guidelines for the U.S. Department of Energy (DOE). This model, called RESRAD, can be run on an IBM or IBM-compatible microcomputer. Seven potential exposure pathways from contaminated soil are analyzed, including external radiation exposure and internal radiation exposure from inhalation and food ingestion. The RESRAD code has been applied to several DOE sites to derive soil cleanup guidelines. The experience gained indicates that a comprehensive set of site-specific hydrogeologic and geochemical input parameters must be used for a realistic pathway analysis. The RESRAD code is a useful tool; it is easy to run and very user-friendly.

INTRODUCTION

The U.S. Department of Energy (DOE) has established radiological protection guidelines for cleanup of residual radioactive material located at sites administered under its Formerly Utilized Sites Remedial Action Program (FUSRAP) and Surplus Facilities Management Program (SFMP).[1] The guidelines establish radionuclide concentrations or radioactivity levels that are acceptable if the site is to be used without radiological restrictions. Guidelines can be categorized as either (1) generic (or site-independent), i.e., taken from existing radiation protection standards, or (2) site-specific, i.e., derived from the basic dose limit (100 mrem/yr) using site-specific models and data. Generic guidelines for radium-226, radium-228, thorium-230, and thorium-232 are presented in Reference 1. For other radionuclides, procedures and data for deriving site-specific soil guidelines are provided in a report entitled *A Manual for Implementing Residual Radioactive Material Guidelines*.[2] These procedures and data are coded in a microcomputer model called RESRAD.

ENVIRONMENTAL PATHWAYS

The RESRAD model calculates the potential radiation doses resulting from seven potential exposure pathways: (1) direct exposure to external radiation from contaminated soil materials, (2) internal radiation from inhalation, (3) internal radiation from ingestion of plant foods grown on-site and irrigated with water drawn from an on-site well or pond, (4) internal radiation from ingestion of meat from livestock fed with fodder grown on-site and water drawn from an on-site well or pond, (5) internal radiation from ingestion of milk from livestock fed with fodder grown on-site and water drawn from an on-site well or pond, (6) internal radiation from ingestion of aquatic foods (fish) from a nearby pond, and (7) internal radiation from drinking water from an on-site well or pond. If certain pathways are considered to be negligible or not contributing to the total dose, they can be eliminated by setting certain parameters to zero in the RESRAD code.[2] The theoretical basis, calculational models, and data bases for RESRAD are described in detail in References 2 and 3.

PROGRAM DESCRIPTION AND REQUIREMENTS

The RESRAD model was developed for use on an IBM or IBM-compatible personal computer. The program is designed with various user-friendly features, including internal help files for information on input and output data, with an optional mouse to show default data values. A DOS 3.1 or equivalent operating system, a hard disk drive, and approximately 400K of memory are required to run RESRAD; a mathematics coprocessor is optional but highly recommended.

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RESRAD consists of two main programs, RESPC and RESMAIN. RESPC is a compiled Basic program (Microsoft QuickBASIC 4.5) that handles all user interaction with RESRAD, and RESMAIN is the Fortran code (Lahey F77L, Ver. 3.01) that does the actual computations and generates the output tables.

RESPC is loaded first (via RESRAD.BAT, NEXT.ORI, and NEXT.BAT). Within RESPC, the user may input selected site-specific data files, review and/or modify the parameters, save the data in a selected file, view and/or print selected results from the last RESMAIN computation, and run RESMAIN for a new computation. If RESMAIN is called, RESPC is reloaded automatically when RESMAIN completes, and the user may continue with any of the RESPC options.

To conserve memory, RESMAIN is organized with an overlay structure. The code is highly optimal in that no overlay is called a second time. PLINK86plus, Ver. 2.24, Phoenix Technologies Ltd., is the overlay linkage editor used.

MAIN MENU

The main menu (R010), as shown in Figure 1, is the starting point for using RESRAD. It is also the return point after completion of RESRAD's calculation phase. By selecting the major data and function categories, all input data and output reports are accessible from the main menu. To terminate RESRAD, press "Esc" while the main menu is on screen.

Instructions for interactive use of the code are provided in help files that can be displayed on the screen by pressing the "F1" or "F2" function key. Menu items are selected in the main menu (R010) by entering the appropriate item number and pressing "Enter." Items 1-9 display input forms on the screen, item 10 calculates results for the current set of parameters, and item 11 displays the output (summary or detailed report) from the last RESRAD run, or the user may view any selected ASCII file.

INPUT FORMS

Input data needed by RESRAD are accessible in a series of input forms. Figures 2-10 show the RESRAD input menus corresponding to items 1-9 on the main menu (see Figure 1). The input data shown on the input menus are the default data used in RESRAD. After an input form has been called for display, its input data can be reviewed and changed from the terminal. Pressing the "F10" function key will record all displayed entries and return control to the main menu. The changes made after an input form has been modified (but before it has been recorded) can be canceled by pressing the escape ("Esc") key. Recorded data are retained until changed again.

EXECUTION AND OUTPUT OPTIONS

When option 10 of the main menu is selected, RESRAD enters its RESMAIN computation and report generation phase. After RESMAIN execution is completed, the main menu (R010) will appear on the screen, and the user may continue with any of the options. However, the customary course will be to examine the output reports just generated via main menu option 11.

When option 11 is selected, the user is prompted to select for viewing the summary or detailed report from the last RESRAD run or any ASCII file. The last option is particularly

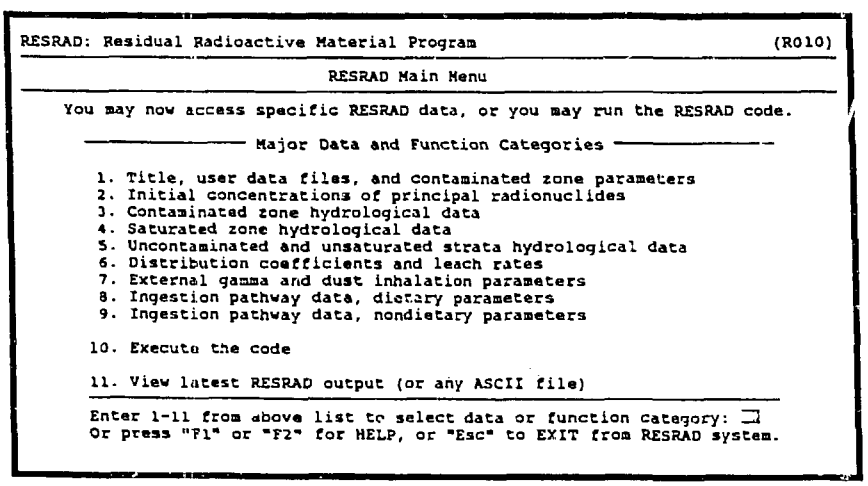

FIGURE 1 Main Menu for RESRAD

useful for examining saved output from a prior RESRAD run. It should be noted that it is not necessary to execute RESRAD (or, more strictly, RESMAIN) before using option 11. In general, SUMMARY.REP and DETAILED.REP files from the last RESRAD run will be available and may be examined at any time. However, if appropriate, the user will be warned that the report file may not match the current site-specific data file.

Summary Report

When the summary report option is selected, the first page (table of contents) of a multiple page summary report is displayed on the screen. The table of contents is shown in Figure 11. Subsequent report pages can be displayed by entering the page number and pressing either the "Enter" or "F10" function key. Pressing "Esc" will return to the main menu, R010. On-line help, primarily key strokes to aid in the page display, is available via the "F1" function key. Function keys "F7" and "F8" can be used to produce hard copy output.[2]

Detailed Report

When the detailed report option is selected, the first page (table of contents) of a multipage detailed report is displayed on the screen. A typical table of contents is shown in Figure 12. Individual report pages can be displayed and printed (or saved) in the same menner as for the summary output displays. The detailed displays present all of the intermediate calculation results. Users will not normally make use of these tables. The detailed data are used for verifying the code and can be useful for gaining insight into the transport mechanisms by enabling a more detailed investigation of the effect of parameter changes on pathway factors, environmental transport factors, and dose/source ratios for the different pathways.

DISCUSSION AND CONCLUSIONS

A computer program called RESRAD has been developed for DOE to calculate site-specific residual radioactive material guidelines for FUSRAP and SFMP sites. The code calculates potential radiation doses to individuals resulting from various potential exposure pathways. RESRAD is menu-driven with help files and built-in features to facilitate data manipulations. It is easy to install and can be run on an IBM or IBM-compatible microcomputer.

The RESRAD code has been applied to derive soil cleanup guidelines for several FUSRAP sites currently being decontaminated.[4-6] The code is a useful tool, easy to run, and very user-friendly.

ACKNOWLEDGMENT

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REFERENCES

1. U.S. Department of Energy, 1987, *U.S. Department of Energy Guidelines for Residual Radioactive Material at Formerly Utilized Sites Remedial Action Program and Remote Surplus Facilities Management Program Sites* (Revision 2, March 1987).

2. Gilbert, T.L., et al., 1989, *A Manual for Implementing Residual Radioactive Material Guidelines,* ANL/ES-160; DOE/CH/8901, prepared by Argonne National Laboratory for U.S. Department of Energy (June).

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4. Yu, C., J.M. Peterson, and Y.C. Yuan, 1988, *Derivation of Uranium and Cesium-137 Residual Radioactive Material Guidelines for the Niagara Falls Storage Site,* prepared by Argonne National Laboratory for U.S. Department of Energy (Aug.).

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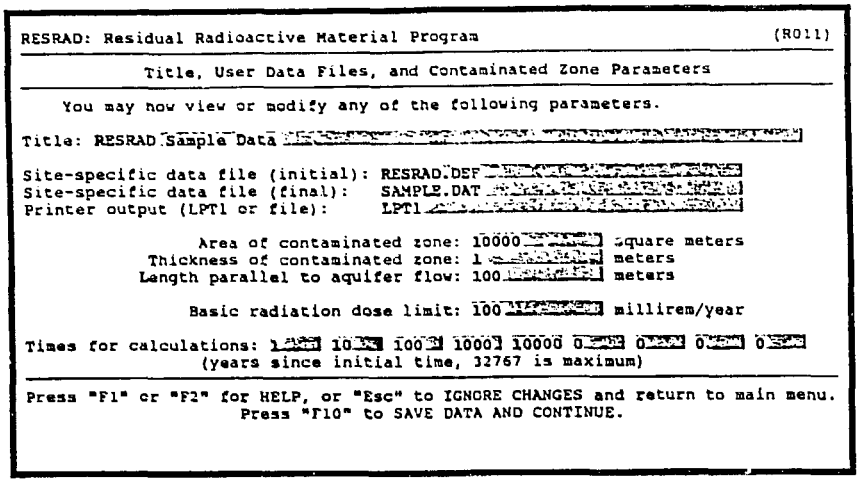

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RESRAD: Residual Radioactive Material Program                    (R011)

        Title, User Data Files, and Contaminated Zone Parameters

   You may now view or modify any of the following parameters.

Title: RESRAD Sample Data

Site-specific data file (initial): RESRAD.DEF
Site-specific data file (final):   SAMPLE.DAT
Printer output (LPT1 or file):     LPT1

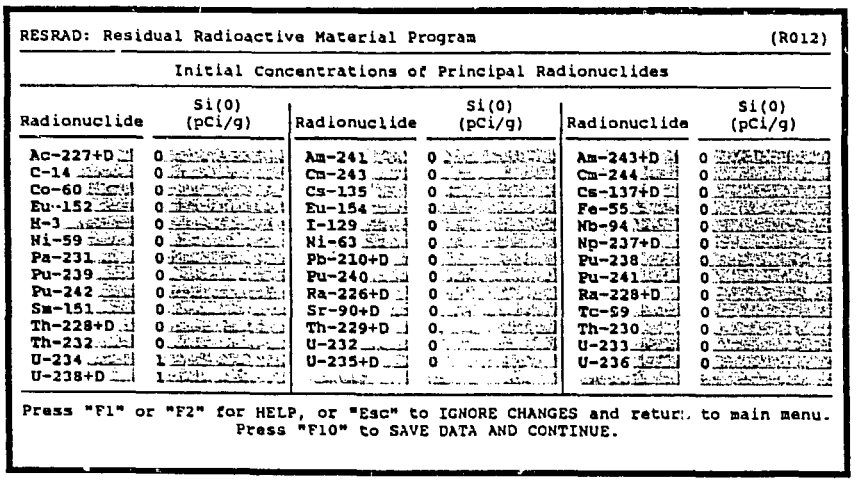
                Area of contaminated zone: 10000      square meters
              Thickness of contaminated zone: 1       meters
           Length parallel to aquifer flow: 100       meters

                Basic radiation dose limit: 100       millirem/year

Times for calculations: 1  10  100  1000  10000  0  0  0  0
                (years since initial time, 32767 is maximum)

Press "F1" or "F2" for HELP, or "Esc" to IGNORE CHANGES and return to main menu.
                Press "F10" to SAVE DATA AND CONTINUE.
```

FIGURE 2 Input Form R011 for Title, User Data Files, and Contaminated Zone Parameters



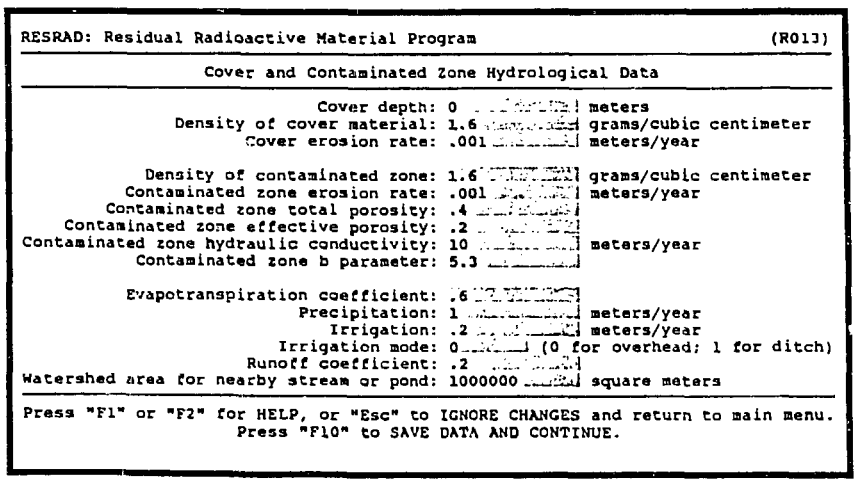
```
RESRAD: Residual Radioactive Material Program                    (R012)

        Initial Concentrations of Principal Radionuclides

Radionuclide  Si(0) (pCi/g)  Radionuclide  Si(0) (pCi/g)  Radionuclide  Si(0) (pCi/g)
Ac-227+D      0              Am-241        0              Am-243+D      0
C-14          0              Cm-243        0              Cm-244        0
Co-60         0              Cs-135        0              Cs-137+D      0
Eu-152        0              Eu-154        0              Fe-55         0
H-3           0              I-129         0              Nb-94         0
Ni-59         0              Ni-63         0              Np-237+D      0
Pa-231        0              Pb-210+D      0              Pu-238        0
Pu-239        0              Pu-240        0              Pu-241        0
Pu-242        0              Ra-226+D      0              Ra-228+D      0
Sm-151        0              Sr-90+D       0              Tc-99         0
Th-228+D      0              Th-229+D      0              Th-230        0
Th-232        0              U-232         0              U-233         0
U-234         1              U-235+D       0              U-236         0
U-238+D       1

Press "F1" or "F2" for HELP, or "Esc" to IGNORE CHANGES and return to main menu.
                Press "F10" to SAVE DATA AND CONTINUE.
```

FIGURE 3 Input Form R012 for Initial Concentrations of Principal Radionuclides



```
RESRAD: Residual Radioactive Material Program                    (R013)

        Cover and Contaminated Zone Hydrological Data

                          Cover depth: 0                meters
              Density of cover material: 1.6            grams/cubic centimeter
                  Cover erosion rate: .001              meters/year

          Density of contaminated zone: 1.6             grams/cubic centimeter
      Contaminated zone erosion rate: .001              meters/year
     Contaminated zone total porosity: .4
Contaminated zone effective porosity: .2
Contaminated zone hydraulic conductivity: 10            meters/year
        Contaminated zone b parameter: 5.3

          Evapotranspiration coefficient: .6
                       Precipitation: 1                 meters/year
                         Irrigation: .2                 meters/year
                    Irrigation mode: 0                  (0 for overhead; 1 for ditch)
                  Runoff coefficient: .2
Watershed area for nearby stream or pond: 1000000       square meters

Press "F1" or "F2" for HELP, or "Esc" to IGNORE CHANGES and return to main menu.
                Press "F10" to SAVE DATA AND CONTINUE.
```

FIGURE 4 Input Form R013 for Cover and Contaminated Zone Hydrological Data

```
RESRAD: Residual Radioactive Material Program                    (R014)

                Saturated Zone Hydrological Data

      You may now modify any of the following hydrological parameters.

            Density of saturated zone: 1.6      grams/cubic centimeters
          Saturated zone total porosity: .4
      Saturated zone effective porosity: .2
  Saturated zone hydraulic conductivity: 100    meters/year
      Saturated zone hydraulic gradient: .02
            Saturated zone b parameter: 5.3     (only if WTDR .NE. 0)

   Distance from surface to water table: 5      meters
          Water table drop rate (WTDR): .001    meters/year
               Well pump intake depth: 10       meters below water table

                Model for Water Transport Parameters

          Nondispersion or Mass-Balance: 0      (0 for ND, 1 for MB)
        Individual's use of groundwater: 150    m**3/year  (only if MB)

Press "F1" or "F2" for HELP, or "Esc" to IGNORE CHANGES and return to main menu.
                Press "F10" to SAVE DATA AND CONTINUE.
```

FIGURE 5 Input Form R014 for Saturated Zone Hydrological Data

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RESRAD: Residual Radioactive Material Program                    (R015)

        Uncontaminated and Unsaturated Zone Hydrological Data

      You may now modify the following hydrological parameters
      for the unsaturated zone below the contaminated zone.

      Set the thickness to > 0 to establish a stratum, or
      set the thickness = 0 to delete the stratum and erase all data.

                                        Unsaturated Strata
                                    1      2      3      4      5
                  Thickness (meters): 4
  Soil density (grams/cubic cm):      1.6
                 Total porosity:      .4
               Effective porosity:    .2
          Soil-specific b parameter:  5.3
Hydraulic conductivity (meters/year): 100

Press "F1" or "F2" for HELP, or "Esc" to IGNORE CHANGES and return to main menu.
                Press "F10" to SAVE DATA AND CONTINUE.
```

FIGURE 6 Input Form R015 for Uncontaminated and Unsaturated Zone Hydrological Data

```
RESRAD: Residual Radioactive Material Program                    (R016)

              Distribution Coefficients and Leach Rates

      You may now modify any of the following parameters.

                    Distribution Coefficients (cm**3/g)
                ("*" prefix on nuclide shows decay product only)

Zone            U-234  U-238  *Pb-210  *Ra-226  *Th-230
Contaminated    50     50     100      70       60000
Unsaturated 1   50     50     100      70       60000
"           2
"           3
"           4
"           5
Saturated       50     50     100      70       60000

Leach rates
(year**-1):     0      0      0        0        0

        Press "F5" (or "F6") to view previous (or next) 7 radionuclides.
Press "F1" or "F2" for HELP, or "Esc" to IGNORE CHANGES and return to main menu.
                Press "F10" to SAVE DATA AND CONTINUE.
```

FIGURE 7 Input Form R016 for Distribution Coefficients and Leach Rates

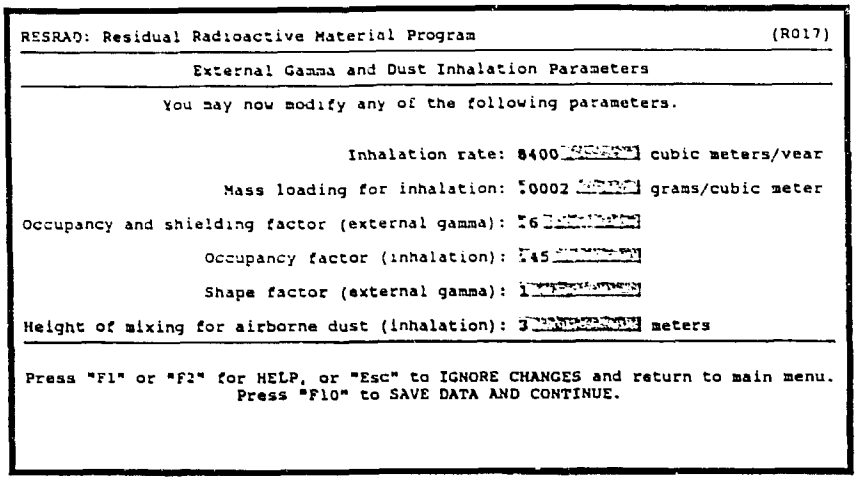

FIGURE 8 Input Form R017 for External Gamma and Dust Inhalation Parameters

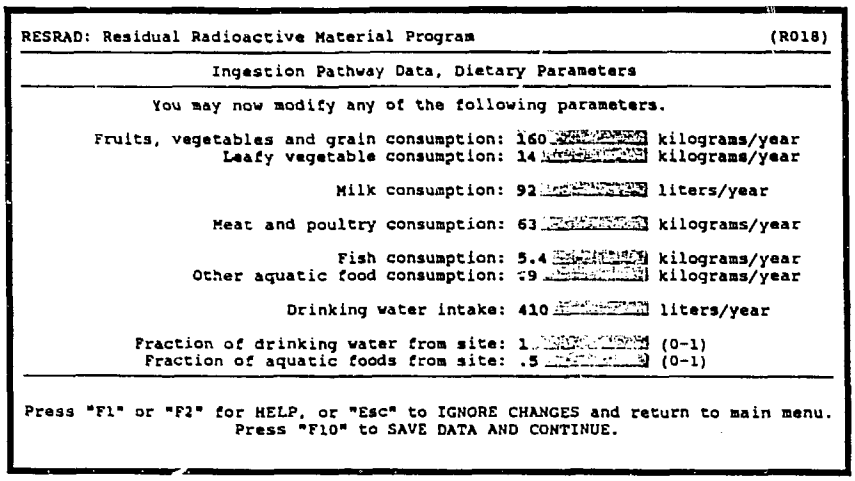

FIGURE 9 Input Form R018 for Ingestion Pathway, Dietary Parameters

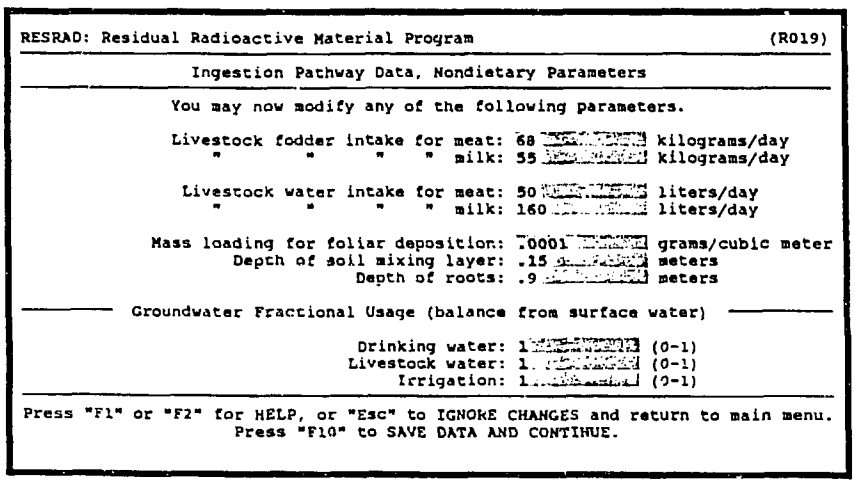

FIGURE 10 Input Form R019 for Ingestion Pathway, Nondietary Parameters

Table of Contents

Part I: Mixture Sums and Single Radionuclide Guidelines

FIGURE 11 Typical Table of Contents for Summary Report

Table of Contents

Part II: Source Terms, Factors, and Parameters for Individual Pathways

FIGURE 12 Typical Table of Contents for Detailed Report