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Project Summary

RAETRAD Version 3.1 User Manual

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This report is a user's manual for the RAETRAD (RAdon Emanation and TRAnsport into Dwellings) computer code. RAETRAD is a two-dimensional numerical model to simulate radon (^{222}Rn) entry and accumulation in houses from its calculated generation in soils, floor slabs, and footings and its movement by diffusion and advection through soil and concrete pores and openings. User input defines nominal house size and foundation parameters, concrete properties, and soil properties, including their distributions of radium (^{226}Ra), moisture, and related properties.

RAETRAD is installed automatically and operated on common personal computers. It includes a graphical user interface with interactive queries to assist the user in defining model problems. Default values typical of the properties of common soil textural classes and concretes are provided to assist in generic definitions of unknown parameters. Separate input files are created for each problem and can be analyzed in batch mode or individually. Six sample problems are provided with the program diskette to verify proper installation and operation of the software.

This Project Summary was developed by EPA's Air and Energy Engineering Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Radiation doses from indoor radon decay products are a significant cause of lung cancer and are the dominant source of natural radiation exposure in the U.S. population. Indoor radon comes mainly from decay of naturally occurring radium in underlying soils, although contributions from water, building materials, outdoor air, and other sources are sometimes important. Indoor radon levels are difficult to predict; however, long-term average levels can be estimated by mathematical models, which simulate the complex processes of radon generation, transport, and indoor entry using soil and house parameters.

The RAETRAD model was developed to provide simple but detailed simulations of radon generation in soils and foundation structures and entry into indoor environments. It represents slab-on-grade houses of different sizes and shapes on soils with any distribution of radon sources, physical properties, water contents, and gas transport properties. It was developed in part under the Florida Radon Research Program (FRRP), co-sponsored by the Florida Department of Community Affairs and the U.S. Environmental Protection Agency (EPA). It has been used in the FRRP to characterize the effects of foundation soil and fill properties on indoor radon entry, to characterize the modes of radon entry, to characterize soil radon potentials for mapping of their geographic distributions, to develop simplified lumped-parameter models, and to support development of radon-protective building construction standards.

RAETRAD is particularly useful for addressing questions such as how strong and how close to a house can a radon source be for particular soil and ground water conditions without excessively elevating indoor radon levels. This information is important for planning and regulating soil excavation and replacement at radium-contaminated sites and also in regulating building construction in areas with high-radium strata or with fill soils of higher or lower radium concentration. Version 3.1 of the RAETRAD computer code extends many of its previous capabilities and operates on personal computer systems.

Model House Configuration

RAETRAD represents the house floor, foundation, and vicinity soils by two-dimensional arrays of properties for use in finite-difference calculations. The arrays are oriented vertically and horizontally as shown in Figure 1. The house is rectangular, with user-specified dimensions, and is represented with its floor slab, cracks, footings, and foundation soils in elliptical-cylindrical geometry to utilize efficient two-dimensional finite-difference calculations. The elliptical-cylindrical symmetry considers the aspect ratio (length/width) of the rectangular house to represent it more accurately than conventional, circular-cylindrical or two-dimensional Cartesian geometries.

RAETRAD can analyze either simple or relatively complex problems, depending on the amount of information available to characterize the house and its foundation soils. It is designed to represent as many discrete regions as desired (e.g., concrete slab, footings, fill soil, and foundation soil layers). Each region is assumed to be homogeneous and may consist of one or more contiguous numerical mesh units. For each defined region, individual values are defined for the radium concentration, radon emanation coefficient, density, porosity, water content, radon diffusion coefficient, air permeability, radon adsorption coefficient, and anisotropies of the diffusion and permeability coefficients. User-specified radon concentrations and air pressures are applied as boundary conditions at the top of the floor slab and on the outdoor soil surface.

The differential equations describing pressure-driven air flow and radon generation, decay, and transport (both diffusive and advective) are solved separately in RAETRAD. This provides the steady-state air pressure and velocity fields from the first solution as input for calculating the advective component of transport in obtaining the second solution for the radon equations. Multiphase radon equations are used to include moisture effects in the calculations. For both equations, coefficients defined by the properties of each mesh unit are arranged into matrices that are solved directly without iteration.

Operating Environment and Installation

RAETRAD is designed for use in the Microsoft Windows® 3.1 environment on an IBM®-compatible personal computer system. The system ideally should be equipped with a math co-processor and a VGA color monitor and graphics system and should have at least 3 Mbytes of unused random access memory (RAM). RAETRAD will prompt the user if any of these conditions are not satisfied but can proceed anyway at the user's option. Printed output is formatted for a 132 character-per-line printer.

An installation program *install* is included on the RAETRAD Version 3.1 diskette. The installation program creates a RAETRAD subdirectory when started from the Windows® File Menu. It also loads the RAETRAD files into the subdirectory and creates a RAETRAD program group and icon for use in the Windows® desktop display.

Getting Started

Upon startup, RAETRAD displays five main menu options. The *INPUT FILES* option is used to create, modify, and delete RAETRAD input files. The *RAETRAD ANALYSIS* option lists all input files listed on the input subdirectory for selection of those to be analyzed. Up to 30 files can be selected for batch analysis. The *RAETRAD RESULTS* option lists all output files on the output subdirectory for detailed or summary viewing on the screen or for printout. The *I/O PATHS* option allows specification of subdirectory locations for data (input and output) files separate from the RAETRAD system files. The *EXIT* option is used to end the RAETRAD session.

The *I/O PATHS* option should be selected upon initial startup to define data and system subdirectories. They need not be redefined in subsequent sessions except to rename the subdirectories. Input file names are appended to a .RAE extension, and corresponding output files have a .OTn extension, where n is a version number to distinguish multiple analyses of a file with the same name.

Input and output files for six sample problems are furnished with the RAETRAD Version 3.1 diskette to verify program installation and operation. The sample files can be analyzed from Option 2 (*RAETRAD ANALYSIS*).

Creating Input Files

A detailed user dialogue is furnished for creating new input files under the *INPUT FILES* menu. The dialogue is guided by a graphical display of a house and up to 17 soil and concrete classes for parameter selection. Default values, displayed with most data queries, are selected by pressing <ENTER> without additional input. The <ESC> key allows the user to back up to readdress the previous question.

General parameters are defined first, including the maximum soil depth to be analyzed and its radial extent and mesh unit size. House parameters are defined next, including the height of the indoor volume, the width and length of the rectangular house, and its ventilation rate, indoor air pressure, and indoor radon concentration. The specified indoor radon concentration is only a numerical boundary condition and has little effect on the resulting calculated indoor radon concentration.

Floor slab parameters are specified next, including concrete thickness, radium concentration, bulk density, radon emanation coefficient, porosity, and material type. The material type selects a set of default parameters (accessible in the RAETRAD.SYS file) for succeeding queries about water content, radon transport constants, and adsorption. Outdoor air pressure and radon boundary conditions are defined next, followed by detailed definition of soil layers. For each layer, the thickness and number of vertical mesh units are defined, followed by radium concentration, density, emanation coefficient, porosity, and material type. The default soil properties stored in the RAETRAD.SYS file are based on soil moistures at -30 kPa matric potential and empirical correlations of radon diffusion coefficients and air permeability with soil properties.

The dimensions of the foundation footing and stem wall are defined next, along with their radium concentration, density, emanation coefficient, porosity, and material type parameters. The fill soil thickness is then defined, followed by the location, distribution, and properties of floor cracks and penetration openings. The openings may be defined to go into the house or to an external vent and may have alternative pressure and radon boundary conditions to those specified for the house. Many of the chosen parameters are displayed graphically on the screen, and all are finally saved in the input file under the chosen file name. Input files can be altered with the *Modify/Review* option and can also be manipulated outside the Windows® environment with the DOS editor.

Processing Files and Managing Output

The *RAETRAD ANALYSIS* option displays all input (.RAE) files for user selection. It then queries for disk storage or printed output and whether to include detailed air pressure and radon concentration arrays in the output. The RAETRAD calculations are then started, displaying on the screen the name of the current file being processed. Upon completion, the program returns to the main menu for further instructions.

The *RAETRAD RESULTS* option permits viewing of either the *Summary Output* or *Detailed Output* on the screen. Different sections are located using positioning keys. The option is also given to print output to a previously initialized printer with 132-character line width.

Sample Problems

The six sample problems utilize a 28.4 x 54.3 ft (8.7 x 16.6 m) slab-on-grade house with 1 ft (0.3 m) of fill soil and a stem wall that penetrates 2 ft (0.6 m) below grade. Indoor air pressure and radon boundary conditions are -2.4 Pa and 2 pCi/L, respectively, and outdoor values are zero. The floor slab has different openings in the different problems. For Problem 1, the slab has a 1-cm wide perimeter crack. For Problem 2, it has the same perimeter crack plus two utility penetrations (100 cm^2 each) near the center. For Problem 3, it has the same perimeter crack plus two passive, external subslab vents (100 cm^2 each) at -5 Pa pressure. For Problem 4, it has only the passive subslab vents without the perimeter crack. For Problem 5, it has only the subslab vents, but at -20 Pa pressure. For Problem 6, it has the perimeter crack plus the two subslab vents at -20 Pa pressure.

The indoor radon concentrations computed for Problems 1, 2, and 3 are similar (2.75, 2.79, and 2.75 pCi/L, respectively), indicating dominance by the perimeter crack. Subslab ventilation (Problem 6) only slightly reduced the indoor concentration. Eliminating the perimeter crack in Problem 4 reduced the indoor radon level to 0.7 pCi/L, and adding more suction pressure (Problem 5) made little additional difference. These results apply only to the sample problems and can be very different with different house and soil properties and configurations.

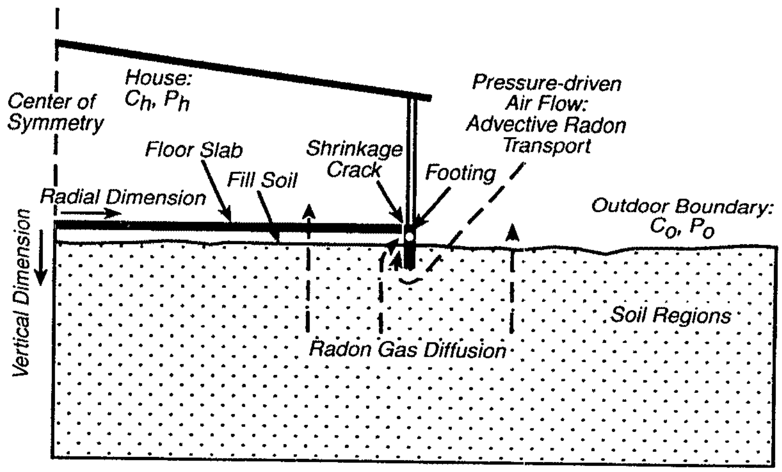

Figure 1. *Two-dimensional grid and boundaries used to define house and soil regions for air and radon entry calculations.*

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The complete report, entitled "RAETRAD Version 3.1 User Manual," consists of a paper copy and a diskette. The paper copy (Order No. PB95-139689) and the diskette (Order No. PB95-501995) are priced as a package for $140.00 (cost subject to change) and will be available only from

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