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RAMISW — SOFTWARE FOR MODELLING MIGRATION OF RADIONUCLIDES IN SOIL

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Аннотация

Работа посвящена описанию компьютерной реализации конвективно--диффузионной модели вертикальной миграции радионуклидов в почве. Приведено полное описание и руководсво по использованию программы RamisW for Windows. В качестве наглядного примера работы программы выбраны реальные данные Чернобыльских выпадений.

Kanevski M., Koptelova N., Demyanov V. RamisW — SOFTWARE FOR MODELLING MIGRATION OF RADIONUCLIDES IN SOIL. Preprint IBRAE-97-13. Moscow. Nuclear Safety Institute. July 1997. 21 p. — Refs.: 6 items.

Abstract

The work includes description and a User's Guide for RamisW software for Windows for modelling radionuclide migration in soil. RamisW is a computer realization of advection-diffusion model of vertical migration of radionuclides in soil. User's guide is accompanied by a detailed case study based on data from the Chernobyl fallout.

RamisW — Software for Modelling Migration of Radionuclides in Soil

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1 Introduction

1.1 What is RAMISW?

Ramisw for Windows was developed at Nuclear Safety Institute (IBRAE RAS).

While modelling vertical migration of radionuclides, convection and diffusion are usually taken into consideration, as these processes determine the migration rate. The equation of convective diffusion is used in the **RAMISW** computer model, describing migration of radionuclides in soil. The **RamisW** model is a computer code for calculation of vertical migration of radionuclides in soil, which is based on the diffusion - convection model.

The main functions of the program are:

- inputting initial data either manually or from a database;
- calculation of radionuclide concentration in soil for different layers after momentary contamination of localities;
- viewing numerical and graphic results;
- saving results as ASCII and dBase files.

Note Current ***RamisW*** version is still under development, and some other tools may be included in the next version.

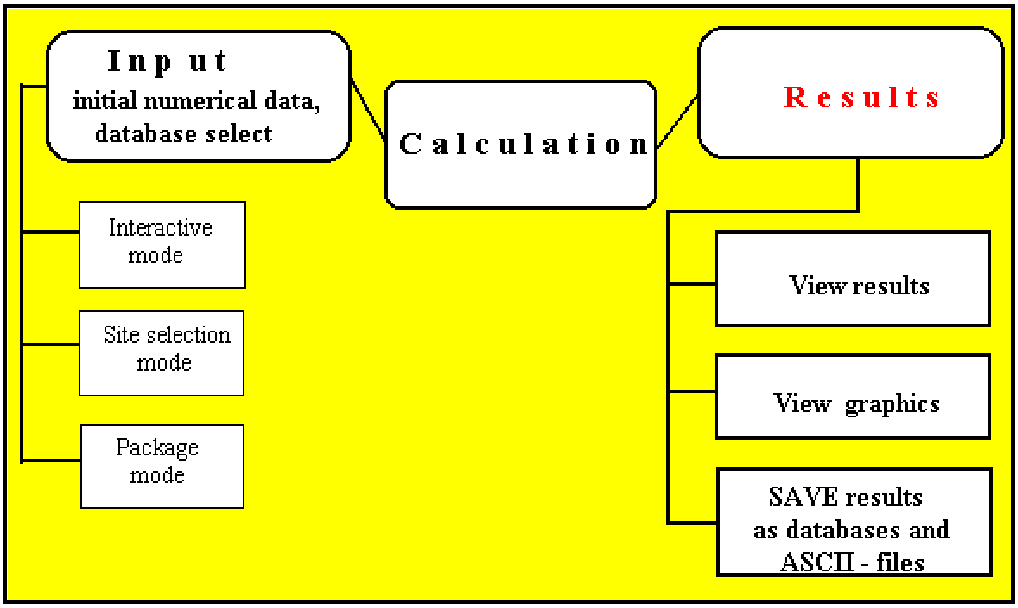


Fig.1. Structure of RamisW program.

1.2 Installation

System requirements	Hardware requirements for the computer to run ***RamisW*** are as follows: IBM or IBM compatible PC, main processor 386 or higher, co-processor installed The 32-bit version of RamisW can be run only under 32-bit operating systems such as Microsoft Windows 95.
Disk space	One should have enough free space on the hard disk - approximately 4.5 MB for executable modules plus some extra memory to suit the size of your database files.
Files	SETUP.EXE installs the 32-bit version of RAMISW.
	To run ***RamisW,*** just click its icon in the Windows'95 Start menu

1.3 Computer Language

RamisW software has been created, using *Visual Basic 4.0*.

2 Program Structure

The program structure can be represented as a menu system. Users can refer to the main menu which consists of the following options: **File, View, Save, Windows, Property, Help** and **Operating mode** status bar with **Interactive** mode radio button, **Site selection** mode radio button, and **Package** mode radio button (see Fig.2).

Fig.2 Main Menu

2.1 File Option

File option — The **File** option includes the following sub-options: **Open model database set** and **Exit.**

Open model database set — This option opens a model database of the dBase type and uses **Open model database set** dialogue for choosing the directory with model databases.

<u>External databases</u> — <u>Model-independent (external) databases containing regional information are as follows</u>:

`br_cs.dbf` - contains data on surface contamination by caesium in 1986 and soil types in localities of the Bryansk Region;

`br_sr.dbf` - contains data on surface contamination by strontium in 1986 and soil types in localities of the Bryansk Region;

`br_r.dbf` - contains climatic data for the Bryansk Region as well as SITE, RAIN_JAN, RAIN_FEB, RAIN_MAR, RAIN_APR, RAIN_MAY, RIN_JUN, RAIN_JUL, RAIN_AUG, RAIN_SEP, RAIN_OCT, RAIN_NOV, RAIN_DEC, RAIN_YEAR fields. The SITE field contains names of the stations while the rest contain numeric values of precipitation in January, February, etc.

<u>Internal databases</u> — <u>Model-dependent databases are the following:</u>

`rad_cat.dbf` - contains half-decay times of seven radionuclides. It includes **NAME** and **DECAY_TIME** fields. The first one is the list of radionuclides, and the second one contains respective half-decay times.

`soil.dbf` - contains soil parameters. It includes the following fields: **SOIL_TYPE** (type of soil), **MEAN_HUM** (mean humidity), **APP_DEN** (apparent density of soil), **M_F_VELOS** (mean flow velocity), **DIFF_COEFF** (coefficient of diffusion). Records in the database contain values of the above quantities for each type of soil.

`soil_kdc.dbf` - contains coefficients of radionuclide distribution, depending on soil type. It comprises **SOIL_TYPE**, **CS**, and **SR** fields. The first one contains the list of soil types while the second and third ones contain numerical values of the partition coefficients by different soil types. .

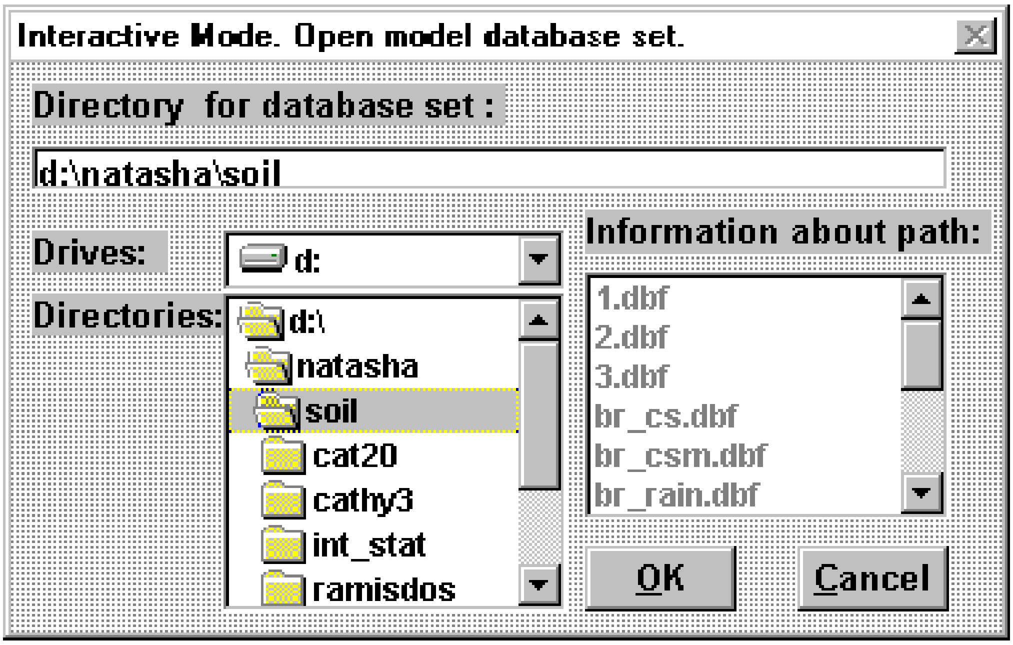


Fig.3. Open database set dialogue box.

Using user's — The program was designed so, that all of the databases used in it could be easily replaced by *own data* others. For this purpose, the user can readily rename available databases in accordance with the manual, taking external databases names from it. If this way is undesirable, insignificant intervention of the programmer is required

Exit Exit command closes all forms that contain data from the current operating mode. It closes also model databases and provides quitting.

2.2 View Option

The **View** option consists of two sub-menus: **Current Session** and **From File.**

Current session The **View** | **Current session** option allows to view any current **Results files** and loads the **Open results file** dialogue box.

From File The **View | From File** option (see Fig.4) makes possible to view any **Results file** created during any other code operation session in the **Main results** window.

Open results file dialogue box Allows to select the name of **Results file** (see Fig.5) and view it in the **Main results** window.

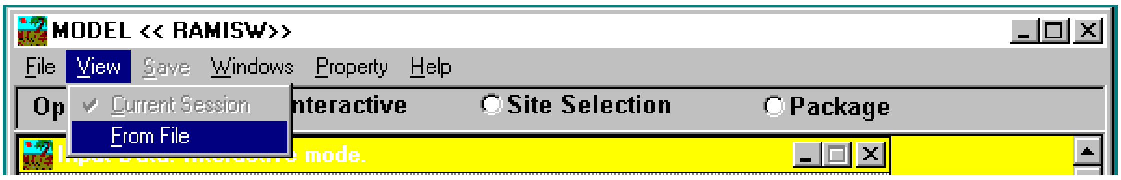


Fig.4. ***Main menu | View | From file.***

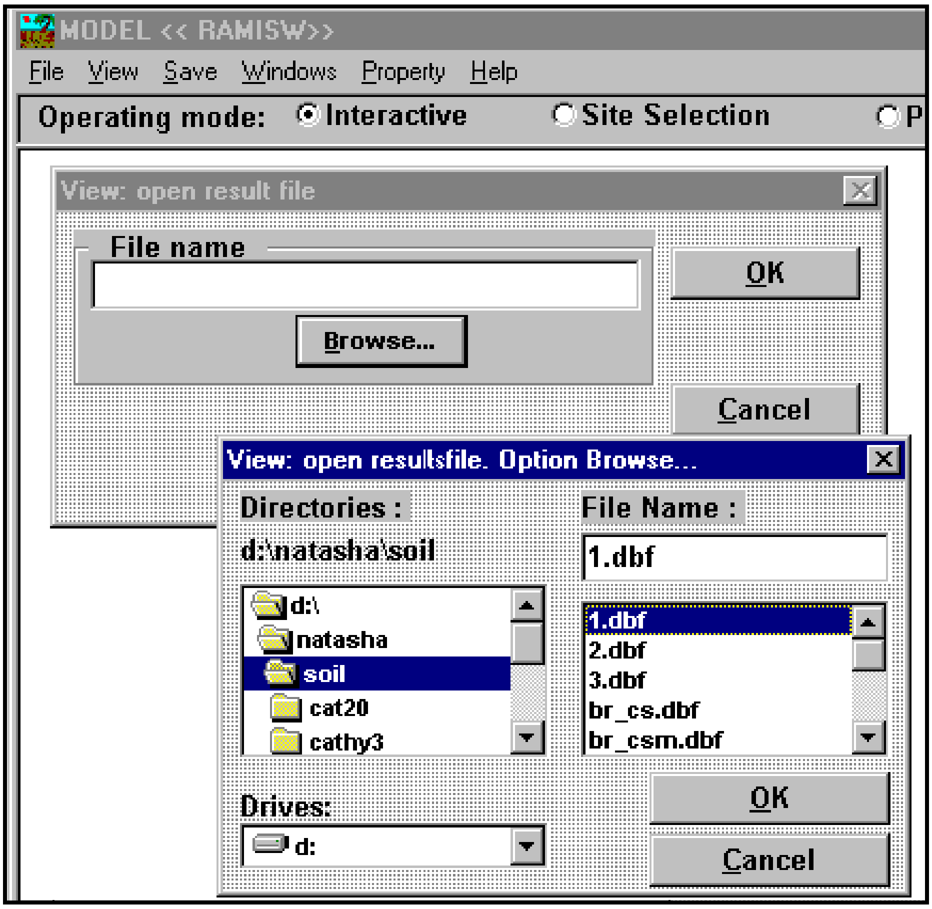


Fig.5. Open result file dialogue box.

Main results window Contains a heading with some initial data and a results table (see fig. 14,15). In the main results window, there is presented some reference information, read from the initial data input window: radionuclide, name of the field with initial surface contamination, total rainfall amount, migration duration, month of migration beginning. The user can see detailed representation of the solution.

Results file (Results database) Its detailed description is given below in section *2.7.3.3. Results databases and ASCII-files.*

2.3 Save Option

Main Menu | Save option Allows to save calculated results of the current session (**Results File**) as dBase (database) and ASCII files. Description of **Results File** is given below in section *2.7.3.3. Results databases and ASCII-files.*

User can save the current calculation in the **Main results** window or save any **Results File** of the current session in **Main Menu,** if the option is enable.

In the **Interactive** mode and **Site selection** mode, specifying the results file name in the **Save Results As...** dialogue box is sufficient for saving (see Fig.6).

In the **Package** mode, the user should first choose names of the fields to be saved. For this purpose, the user should employ the **Fields selection** dialogue box, and only after that appears **Save Results As...** dialogue box.

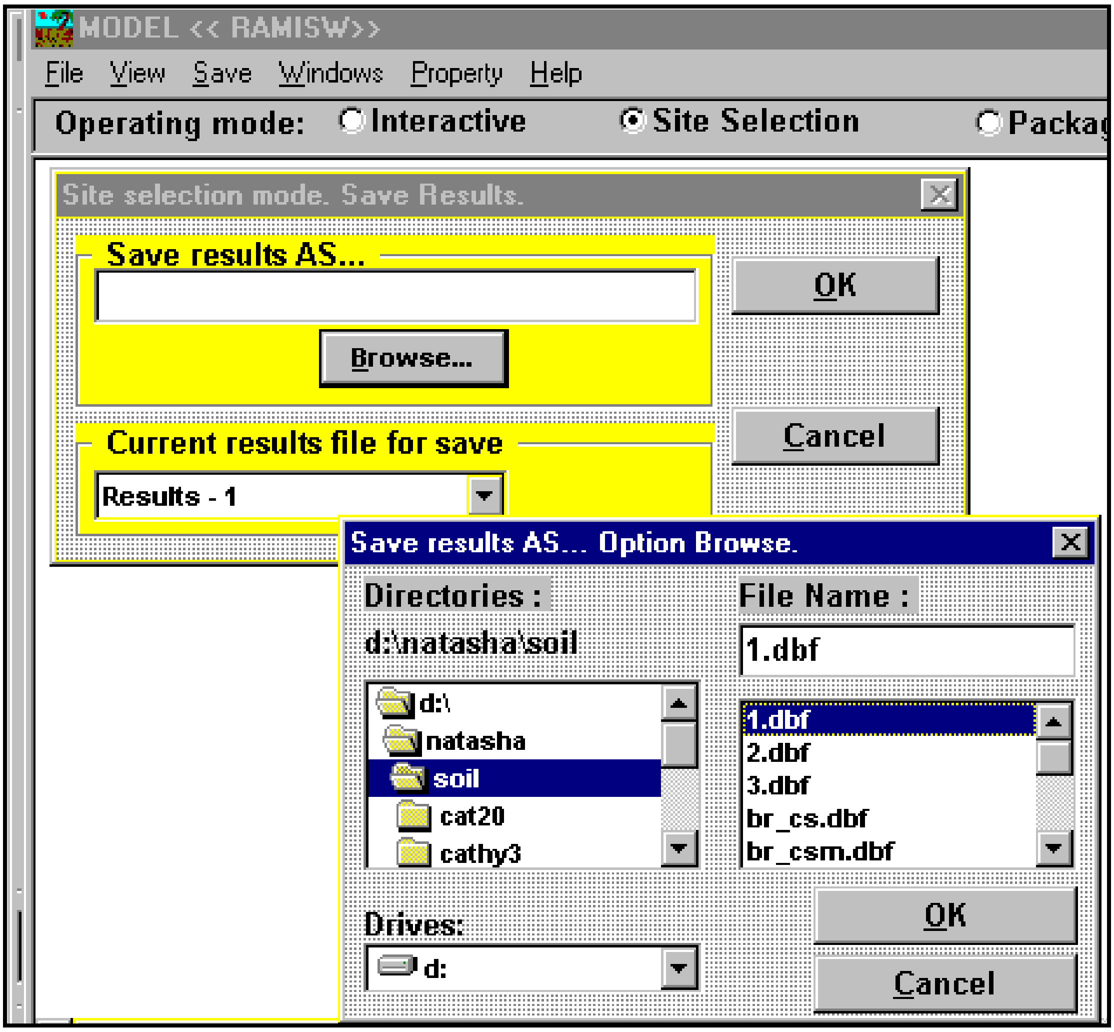


Fig.6.Dialog box: save results file as .

Save Results Allows to specify the results file name.

As... dialogue box

Fields selection dialogue box — To save results in the package mode, the program offers to choose the names of fields to be included in the results file. A dialogue box with two list boxes is presented on the screen. The first one (left) contains the list of all inputted and calculated fields. The second box (right) is used for moving there the names of the fields that will be saved in the results database. Fields selection/deselection is made by pressing Enter or left mouse button on the field. Therefore, the user himself can determine the results file structure (see Fig.7). The **Recalculate co-ordinates** option is intended for recalculation of the co-ordinates.

Recalculate co-ordinates option — If the initial database includes fields with names XGRAD, XMIN, XSEC and YGRAD, YMIN, YSEC which must contain by default the geographical co-ordinates of an inhabited locality in the form of integers, the co-ordinates will be recalculated. They will be presented as real numbers and written in two new fields named XGRADNEW and YGRADNEW.

Note — This option is active in the **Main Menu,** if there are some buffer files of performed calculations on the disk.

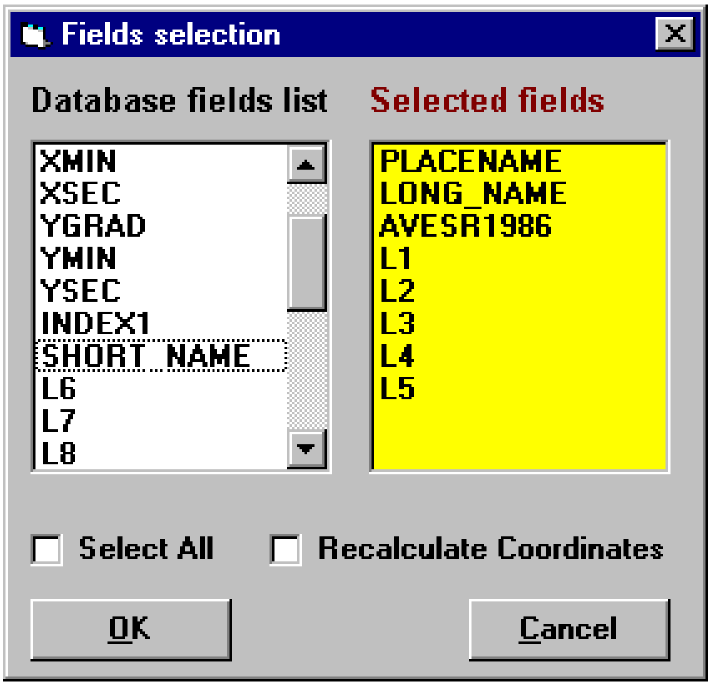


Fig.7. Fields Selection dialogue box.

2.4 Window Option

The **Windows** option arranges all active windows. Options of this menu allow arranging all secondary windows.

2.5 Property Option

Main Menu | Property option — Calls the **Maximum number of rows** dialogue box (see Fig.8).

Maximum number of rows dialogue box — Makes possible to change the maximum number of rows to be loaded in the grid in the **Main results** window. This refers only to the Package mode. Using the number of rows to be loaded is due to the fact, that the time required to load the **Main results** window may be too long, when processing voluminous databases.

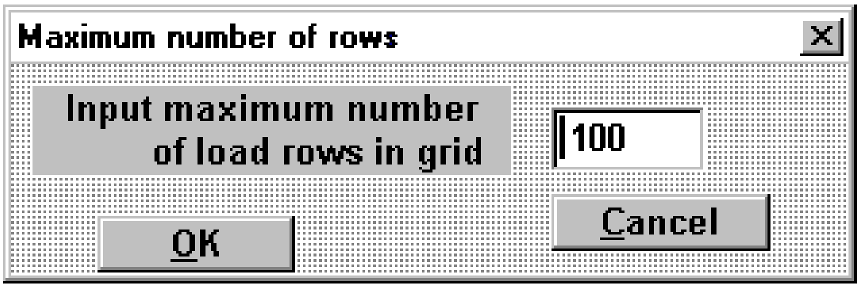


Fig.8. Input maximum load rows for Main results window.

2.6 Help Option

The **Help** option consists of two sub-menus: the **About** option and the **Program Help** option**.**

2.7 Operating Mode

Operating mode status bar	Consists of three radio buttons: **Interactive** mode, **Site Selection** mode, and **Package** mode. By means of these commands, the user can close all forms and model databases related to the current operating mode. All the modes are intended for calculating radionuclide concentration in soil for different layers after momentary contamination of different localities. <u>The user's operation session consists of three phases</u>: • inputting initial data, choosing required databases; • calculation; • results presentation.

2.7.1 Inputting Data, Choosing Databases

Inputting **initial data**, choosing required databases	All parameters necessary for calculations are specified by default. If other values of parameters are available, they can be edited in the **Input initial data** window of **Interactive** (default values being saved), **Site selection,** and **Package** modes.
Input initial data window	There are some differences for these three modes. Therefore, we will give separate descriptions of these forms (i.e., **Input initial data** window in the **Interactive**, **Site selection**, and **Package** modes).

2.7.1.1. Inputting initial data, Interactive mode

Interactive mode	The **Input initial data** window allows the user to choose several parameters for subsequent concentration calculation
Radionuclide	The necessary radionuclide must be chosen from the radionuclide list box. The list includes all radionuclides from the **NAME** field of the RAD_CAT.dbf database.
Decay time	The value is chosen from the **DECAY_TIME** field of the (RAD_CAT.dbf) model database to suit the nuclide chosen.
Soil type	Is to be chosen from the soil type list box. The list includes all soil types from the SOIL_TYPE field of the SOIL.DBF model database.

Soil parameters In accordance with the **soil type** chosen, the values of **apparent density, mean humidity, mean flow velocity, diffusion coefficient** are found in the SOIL.DBF model database.

Partition coefficient Must fit the **soil type** and **radionuclide.** Also found in the SOIL_KD.DBF database.

Total rainfall amount The total water layer cumulated during the migration lapse (in [cm]).

Migration Depth The depth of the soil layer under calculation (in [cm]).

Migration Duration The time of radionuclide migration (in [month]).

Soil Layer Thickness Specifies the points for which the calculated results must be outputted. The **Soil Layer Thickness** is related with the **Migration Depth**, namely**, Soil Layer Thickness** = **Migration Depth / Soil Number**.

Initial surface contamination The user is offered to input the **initial surface contamination** value in any of two possible units displayed in the window: [kBq/m] or [Ci/km]. If this value is specified in one of them, it will be recalculated to the other.

Note If necessary, the user can change from the keyboard the data displayed in the **Input initial data** window.

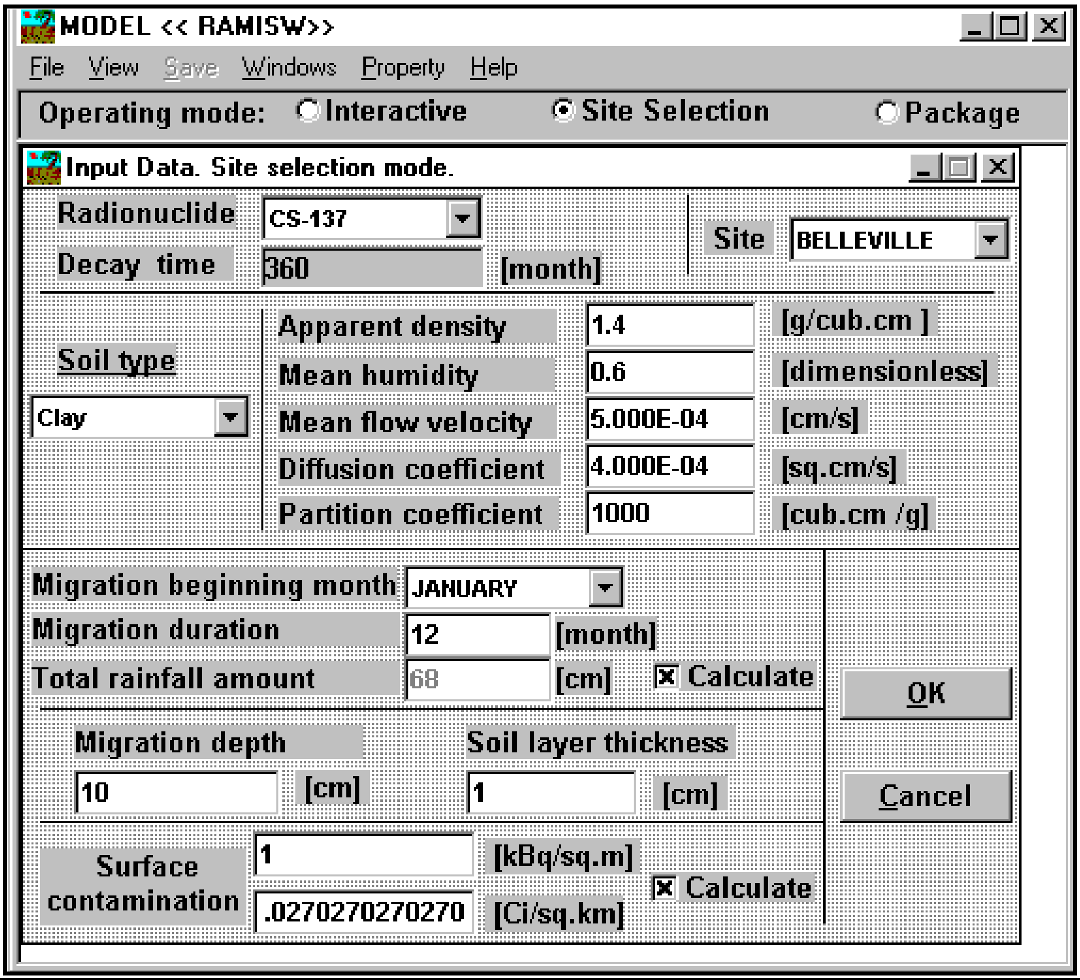


Fig.9. Input initial data window. Interactive mode.

2.7.1.2. Inputting initial data, Site selection mode

SITE SELECTION mode

The **Input initial data** window provides not only the same input functions of the **Interactive** mode **Input initial data** window, but also offers the number of additional opportunities (see fig. 10).

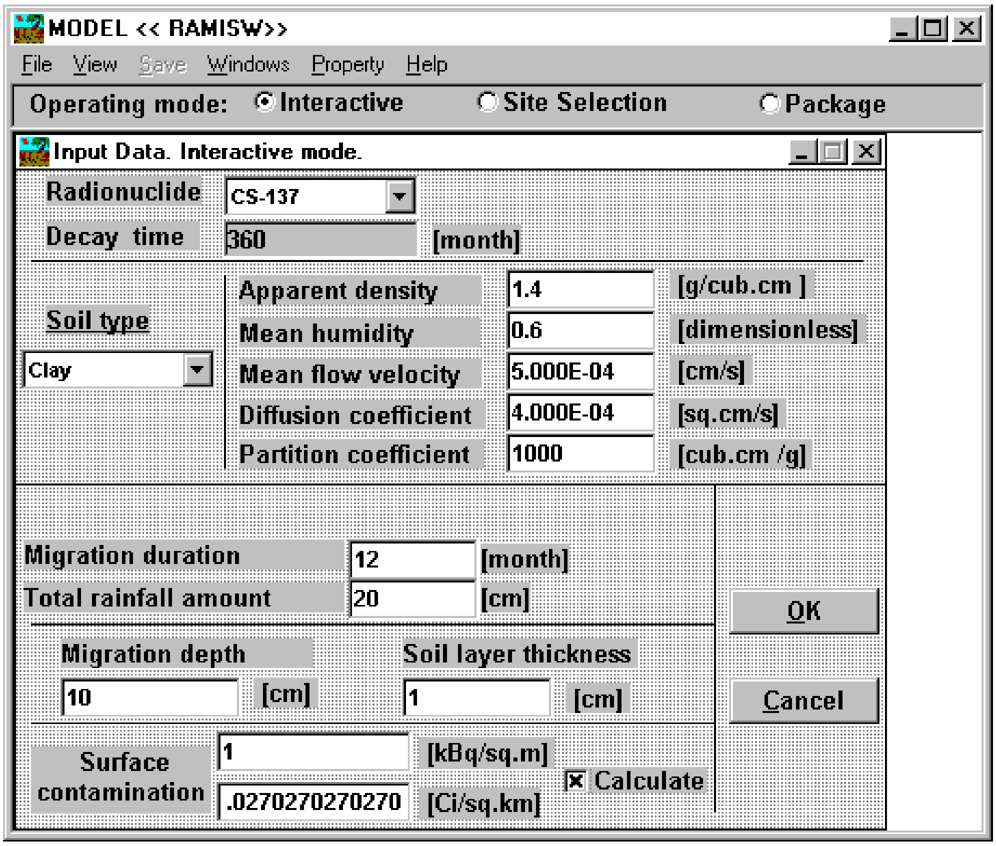


Fig.10. Inputting initial data. The ***Site selection*** *mode.*

Site

Once the necessary radionuclide and half-decay time are chosen, the power plant list box is offered to choose the necessary **Site**. The list includes the names of sites from the **SITE** field of the `SOLCONT.dbf` database.

OTHER site

Once the site chosen, the user can input manually the data on monthly precipitation rate. The precipitation data displayed in the **Input rain for site 'other'** dialogue box is saved and appended to the `SOLCONT.dbf` database.

Input rain for site 'other' dialogue box

Allows inputting a new site name (**Input site name**) and the monthly amount of rainfall in this region during a year, as well the total precipitation per year (see Fig.11).

Migration parameters

- Month of migration beginning
- Migration duration
- Total rainfall amount

Total rainfall amount

Is calculated by the code, using data from the climatic database. The data needed for this calculation is as follows: **month of migration beginning**, **monthly precipitation data** and **migration duration**.

Monthly precipitation data

For any of the sites, the code finds the corresponding database (`SOLCONT.dbf`) where data on precipitation is stored and picks up the information required for subsequent calculation of the water layer thickness (**Total rainfall amount)**.

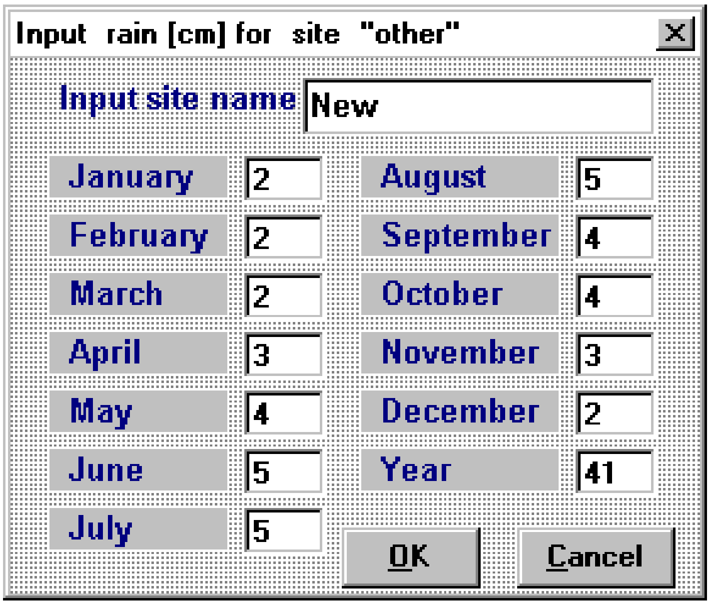


Fig.11. Inputting climatic data for ‘OTHER’ site.

Month of migration beginning — Is chosen from the list box. The items in the list box are names of months.

Migration duration — Is inputted manually.

Note — Notice that, to provide the proper operation of this module, the climatic database should comprise the following fields: SITE, RAIN_JAN, RAIN_FEB, RAIN_MAR, RAIN_APR, RAIN_MAY, RIN_JUN, RAIN_JUL, RAIN_AUG, RAIN_SEP, RAIN_OCT, RAIN_NOV, RAIN_DEC, RAIN_YEAR (in the **Site Selection** mode, it is `SITERAIN.dbf`, in the **Package** mode for the Bryansk Region, `BR_RAIN.dbf`).

2.7.1.3. Inputting initial data, Package mode

Contamination Database name — First, the name of a **contamination database** is offered to be selected in the **Input initial data** window.

This computer model enables to process, in the **Package** mode, any databases containing data on surface contamination by arbitrary radionuclides. Among actual contamination databases processed with the help of the **RamisW** model are that on radionuclides contamination of the Briansk Region of the Russian Federation as well as some bases on contamination of the Briansk Region by caesium (`BR_CS.dbf`) and strontium (`BR_SR.dbf`).

The database should contain complete information about localities of the region under consideration.

The database must contain the following information on inhabited localities of a chosen region: indispensable fields of the database are those with data on contamination (there may be a few fields with information on contamination in different years or months) and soil composition for each inhabited locality. The desirable fields are those containing a locality's soil type and its name (PLACENAME).

Contamination field name — Is chosen from the fields list box. The list includes all text-type field names from the **Contamination Database.**

Soil Type field name	Is chosen from the soil type field name list box. The list includes all text-type field names from the **Contamination Database.**
Climate database name	Is chosen from the database list box. The list includes all dBase-file names from the current directory.
Note	The user himself must check that the field name corresponds to the field contents. Otherwise, some unpredictable errors may occur.
Radionuclide	A Radionuclide and its half-life are to be defined first. For example, working with the database on the Briansk Region, the user selects the contamination field thus defining radionuclide and, consequently, its half-life. They are displayed in the window without any other effort of the user. For any other database, the user should enter a radionuclide name manually. To do this, the radionuclides list box is proposed (the `RAD_CAT.dbf` database is used).
Decay constant	With a radionuclide selected, the code searches respective **Decay** constant (in months) and displays it on the **Input initial data** window.
Migration parameters	The next step is to input the migration variables: • Vertical migration depth (in [cm]), • Migration beginning month, • Migration duration (in months), • Total rainfall amount (in [cm]). The **Vertical migration depth** and the **Migration duration** are inputted manually. The **Migration beginning month** is chosen from the list box which contains all months.
Total Rainfall Amount	Is calculated by the code as described above in the description of the **Site selection**, **Input initial data** window.
Note	Once a soil profile consisting of a definite number of layers is considered, this number must be specified. In this version of the code, the number of layers is constant and equal to 10. In case the data input is incorrect, the user can cancel further steps and resume inputting.
Soil parameters	**Soil parameters** : • Apparent density (in [g/cub.cm]), • Mean humidity (dimensionless value), • Mean flow velocity (in [cm/sec]), • Diffusion coefficient (in [sq.cm/sec]) are in the `SOIL.DBF` database. Values of the soil parameters read from the database appear in the **Input initial data** window. It is assumed that the thicknesses of layers in the vertical soil profile are the same, and the profile can be characterised by constant parameters of flow velocity and diffusion coefficient. Some additional soil parameters are required for calculation. In order to select this parameters only once for each type of soil, the code first sorts records by all available soil types. As a result of this operation, all records of the initial database are grouped in conformity with their soil type. The database thus formed permits to perform calculation for one type of soil in numerous localities.
Partition Coefficient	In the `SOIL_KDC.DBF` database, the code finds the **partition coefficient** ([cub.cm/g]) corresponding to selected soil type and radionuclide and also displays it in the **Input initial data window**.
Note	In accordance with the soil type chosen, **soil parameters** and the **partition coefficient** is chosen solely by the code!

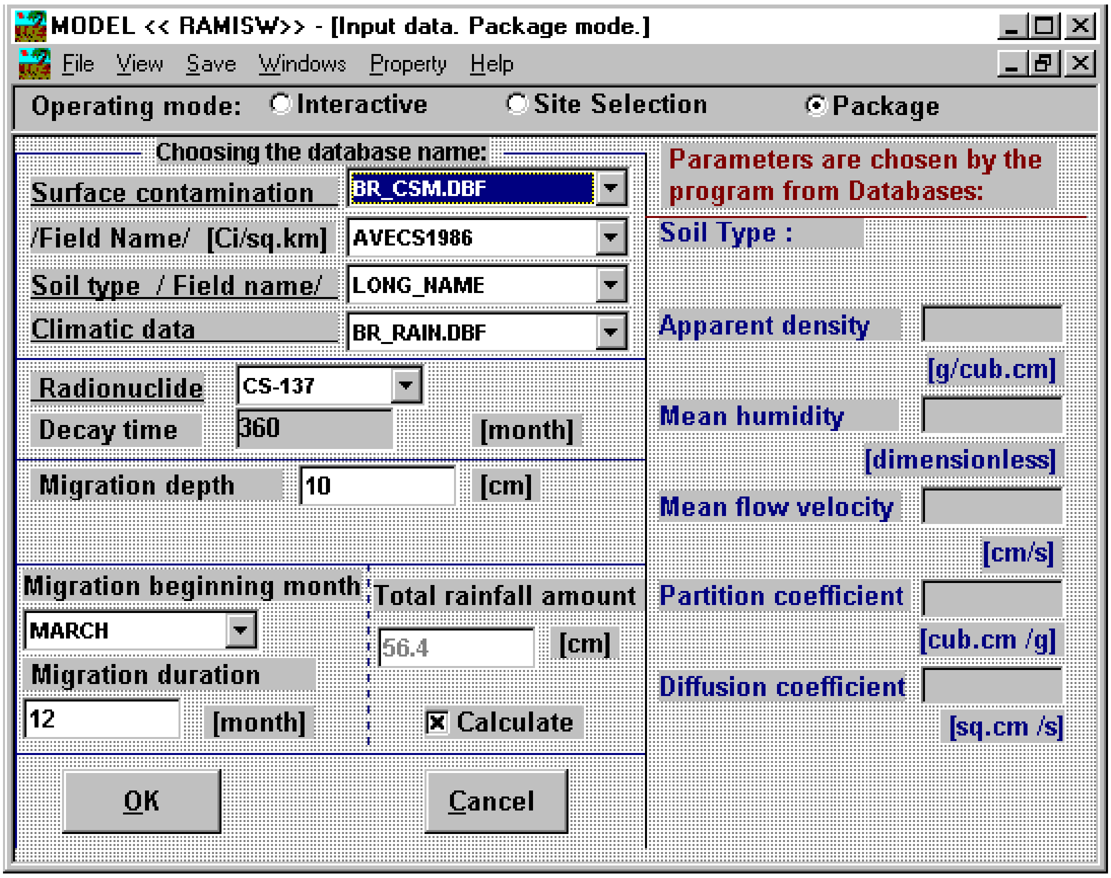
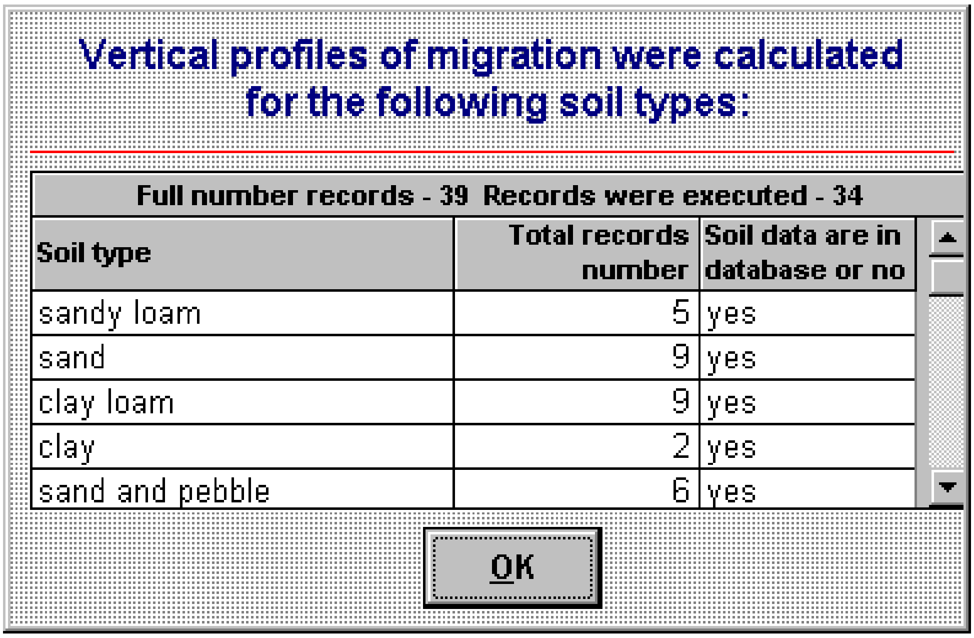


Fig.12. Inputting initial data. Package mode

2.7.2 Calculation

Diffusion-Convection Equation	Calculation of vertical migration of radionuclides in soil is based on the diffusion-convection model. See below (section **3. Equations and mathematical methods**).
Interactive Mode, **Selected Site** Mode	In the **Interactive** mode and **Selected site** mode, calculation is performed for a momentary contamination of one surface point with specified soil type and climatic data and the **diffusion-convection equation** is solved only once.
Package Mode	In the case of the **package** mode, calculation of concentrations in vertical soil layers after momentary surface contamination is executed for a large set of localities with different soil types. In such a situation, to increase the speed of algorithm operation, one first has to group data in soil types. Since the climatic data under the supported problem formulation are identical for all space points, the diffusion-convection equation for an initial contamination of 1 Cu/km^2 is first solved. Further, the result value must be multiplied by the value of initial contamination in each locality with constant soil type.



Soil type	Total records number	Soil data are in database or no
sandy loam	5	yes
sand	9	yes
clay loam	9	yes
clay	2	yes
sand and pebble	6	yes

Fig.13. Summary table. Upon finishing the calculations in Package mode, a summary table appears on the screen, indicating the total number of: (1) records in the initial database, (2) records involved in calculations, and (3) records related to each type of soil.

2.7.3 Representation of results

2.7.3.1 View results

Main Results window

A description of this window is given above (in the **View** option of 2.2 section).

2.7.3.2 Graphic results

Graphic option

Only for the **package mode**: the graphic dialogue box allows to view results in graphic form in the user's results form. The user can choose five place names from the placename list box and view three-dimensional bar graphs and line graphs. In one dialogue box, only 5 plots can be constructed!

2.7.3.3 Results databases and ASCII-files

Database and **ASCII- file** in **Interactive** mode, **Site Selection** mode

For Interactive mode, Site Selection mode the text file has the following structure. Detailed information about calculated variants is collected in the first string) of an ASCII-file:

1) file name; 2) contamination field name; 3) radionuclide; 4) migration depth (cm); 5) migration beginning month; 6) migration. Then the numerical array of results out of the same chosen fields follows (see example 1).

The database contains only a results array (see Example 2). Note that in the **Interactive** and **Site selection** modes calculation results are written to a file with a constant structure, i.e. that with a constant number of definite fields, which are INTERVAL ([cm]) - Soil layers, Radionuclide concentrations in soil layers, [Bq/kg]; Radionuclide concentrations in soil layers, [Ci/kg]; Cumulative sum.

Example 1. Example of ASCII-file:

Model : 60 [month]
Calculate mode :Interactive mode
Radionuclide : CS 137
Decay time : 360 [month]
Type of soil : Clay
Apparent density : 1.4 [g/cm**3]
Mean humidity : .0005[dimensionless]
Mean flow velocity : .6 [cm/sek]
Diffusion coefficient : .0004[cm**2/sek]
Partition coefficient : 10000 [cm**3/g]
Migration depth : 12 [cm]
Migration duration : 2 [month]
Total water layer : 2 [cm]
Calculated step : 2 [cm]
Surface contamination : 100 [kBq/m]

Interval [cm]	Activity [Bq/kg dry soil]	Activity [nCi/kg dry soil]	Activity %	Cumulated sum [Bq/kg dry soil]
0	3557.44765	96.14723	99.99285	99.99285
2	.25431	.00687	.00714	100
4	0	0	0	100
6	0	0	0	100
8	0	0	0	100
10	0	0	0	100
12	0	0	0	100

Example 2: Example of results database:

Interval	Bqkg	nCikg	Ppp	Sum
0	3557.44765	96.14723	99.99285	99.99285
2	.25431	.00687	.00714	100
4	0	0	0	100
6	0	0	0	100
8	0	0	0	100
10	0	0	0	100
12	0	0	0	100

Database and **ASCII- file**, **Package** Mode

The text file has the following structure. Detailed information about calculated variants is collected in the title (first string) of an ASCII-file:

1) file name; 2) contamination field name; 3) radionuclide; 4) migration depth (cm); 5) migration beginning month; 6) migration. Then the numerical array of results out of the same chosen fields follows.

In the **package** mode, when creating the result database (**Results file**), twenty fields are added to initial database. These are fields with: results on the calculated activity for each layer (the number of layers is constant and equal to 10) as well as on the cumulative sum for each layer.

The names of displayed table fields are as follows:

Calculation indicator, name of the field with initial surface contamination, ‘Soil type’ field name, and other fields from the initial database, followed by 10 fields with the calculated activities for 1st,2nd,...10th layer ([Bq/kg]), 10 fields with the cumulative sums ([%]).

Example3. Example of ASCII-file:

When saving **Results File** in **Fields Selection** dialogue box fields MARKER, AVECS1986, L1, L2, L3, L4, L5 were chosen.

RESTMP2 - package mode:AVECS1986,CS-137 migration- 10cm,MARCH, 12month; rainfall- 56.4cm step- 1cm

7

MARKER

AVECS1986

L1

L2

L3

L4

L5

4	0.07	156.26874	11.90267	0.45637	0.01174	0.00022
14	0.3	669.72317	51.01143	1.95591	0.05032	0.00097
22	0.67	1495.71507	113.92552	4.36821	0.11239	0.00218
23	0.7	1562.68739	119.02667	4.5638	0.11742	0.00228
39	16.6	37058.01514	2822.63238	108.22718	2.78462	0.05408
3	0.07	155.30317	12.79863	0.5318	0.01482	0.00031
13	0.29	643.39886	53.02288	2.20319	0.06142	0.00129
16	0.46	1020.56371	84.10527	3.49472	0.09743	0.00204
20	0.48	1064.93604	87.76202	3.64666	0.10166	0.00213
21	0.57	1264.61155	104.21739	4.33041	0.12073	0.00253
24	0.93	2063.31358	170.03891	7.06541	0.19698	0.00414
26	0.93	2063.31358	170.03891	7.06541	0.19698	0.00414
29	0.93999	2085.47756	171.86545	7.1413	0.1991	0.00418
31	0.95	2107.68592	173.69566	7.21735	0.20122	0.00423
1	0.06	144.17678	10.33611	0.37751	0.00929	0.00017
7	0.11	264.32409	18.94953	0.6921	0.01703	0.00031
12	0.26	624.76603	44.7898	1.63589	0.04025	0.00074
18	0.46	1105.35528	79.2435	2.89427	0.07122	0.00132
19	0.47	1129.38474	80.96618	2.95718	0.07273	0.00135
25	0.93	2234.74003	160.20968	5.85145	0.14391	0.00268
28	0.93999	2258.74546	161.93064	5.91431	0.14554	0.00271
32	0.95	2282.79895	163.65505	5.97729	0.14709	0.00273
33	2	4805.89253	344.53694	12.58377	0.30966	0.00576
2	0.06	144.21486	10.2844	0.37461	0.0092	0.00017
15	0.41	985.46822	70.27676	2.55987	0.06297	0.00117
5	0.08	158.13739	11.50491	0.42189	0.01038	0.00019
8	0.13	256.97326	18.69547	0.68558	0.01686	0.00031
27	0.93999	1858.09455	135.1812	4.95723	0.12196	0.00226
30	0.93999	1858.09455	135.1812	4.95723	0.12196	0.00226
37	7.8	15418.3953	1121.72826	41.13486	1.01206	0.01878
38	13.5	26685.6843	1941.45277	71.19495	1.75164	0.03251
10	0.22	487.78892	40.45793	1.69396	0.04764	0.00101
11	0.24	1140.7521	468.1788	105.002	16.18704	1.90433
36	5.05	24003.3253	9851.2623	2209.42	340.6023	40.07023

Example 4. Example of Database:

Fields names: MARKER, AVECS1986, L1, L2, L3, L4, L5.
The contents of records coincides fully with values in the numerical array, Example 3.

Note Note that the database name differs from that of the ASCII-file only in extension (DBF and TXT respectively).

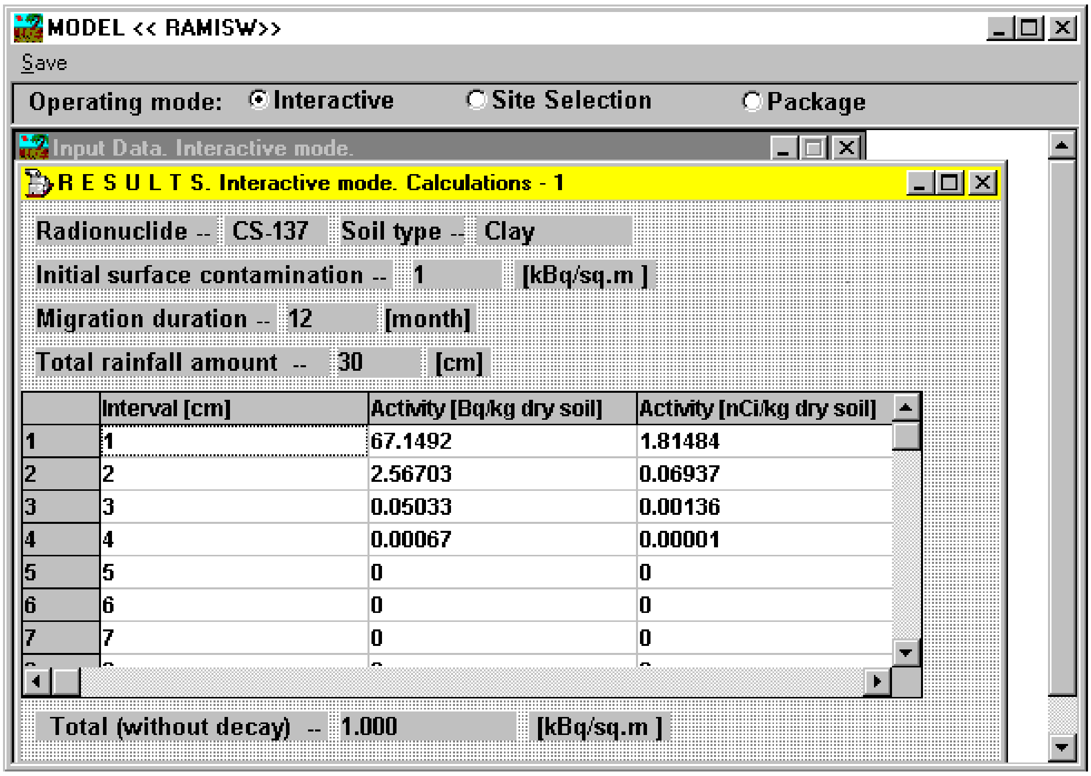


Fig.14. Main results window for interactive mode

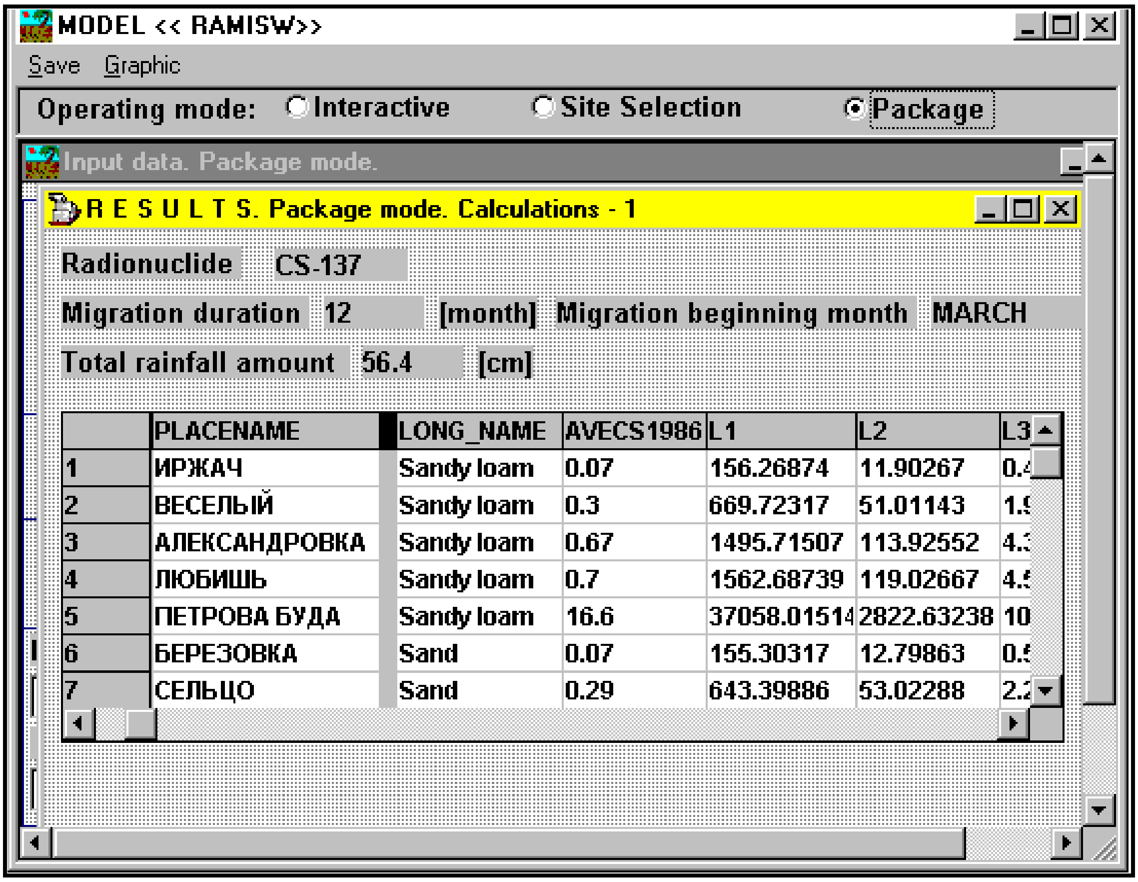


*Fig.15. **Main results** window for package mode*

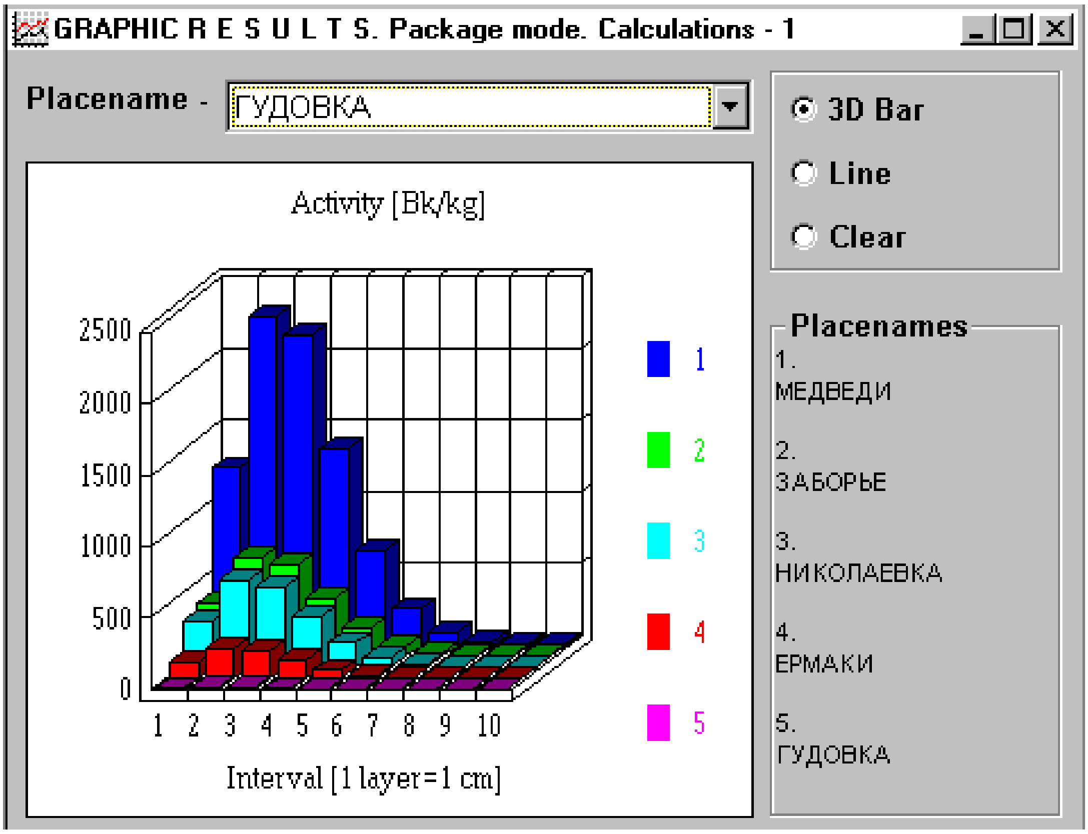


Fig.16. 3-D graphic results for package mode

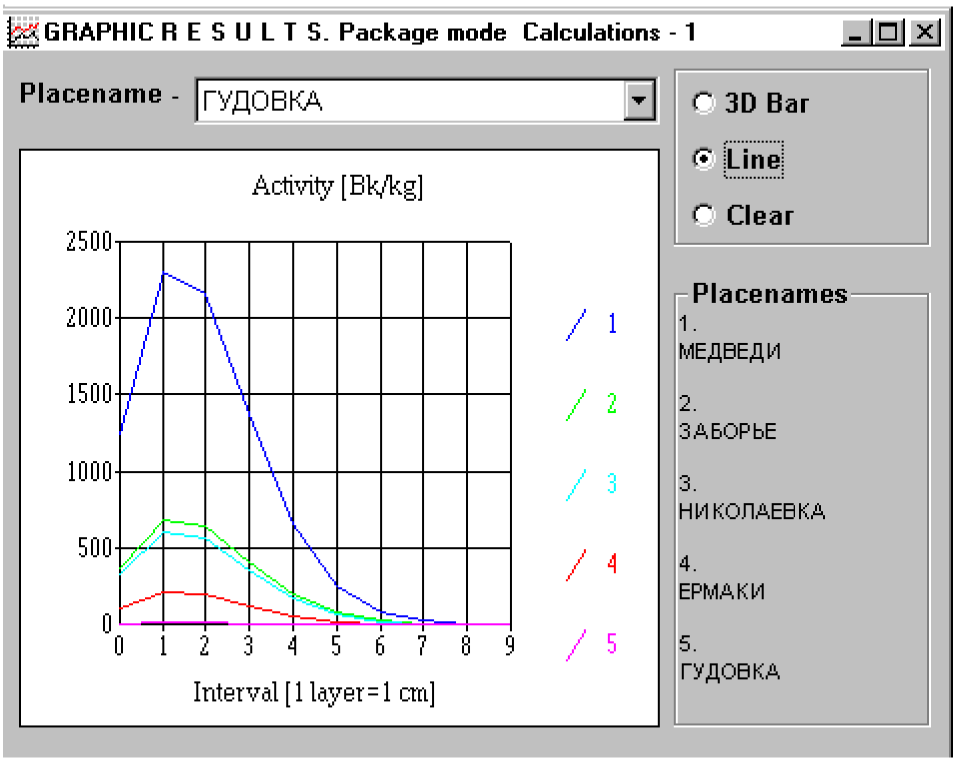


Fig.17. Line graphic results for package mode

3 Equations and mathematical methods

To solve the diffusion-convection equation, a dimensional explicit finite difference method is used. A continuous area under consideration is replaced by a set of equidistant isolated points, i.e. a grid, and the equation solution is sought at these points (grid nodes). The derivatives included into the equations are approximated by finite differences. And the solution to the equation in partial derivatives reduces to that of a system of algebraic equations.

3.1 Equation of advection diffusion

When modelling vertical migration of radionuclides, advection and diffusion are usually taken into consideration because of their determining the velocity of this process. Equation of advection diffusion is used in **RAMISW** describing radionuclides migration in soil:

$$\theta\frac{\partial C}{\partial t}+\rho\frac{\partial S}{\partial t}=D\theta\frac{\partial^2 C}{\partial z^2}-u\theta\frac{\partial C}{\partial z}$$
$$S=k_d C, z\geq 0, 0\leq t\leq T_{\max} \tag{1}$$

where *C*- radionuclide concentration in liquid fraction (Bq/l),
S - radionuclide concentration in solid fraction (Bq/ kg of dry soil),
θ - relative humidity,
r - mean apparent density (g/cub.cm),
u - mean flow velocity (cm/ sec),
D - diffusion coefficient (sq.cm/sec),
k_d - coefficient of radionuclide distribution (cub.cm/g),
z - depth (cm).

To make this equation feasible it is necessary to add initial and boundary conditions.
Initial conditions will be:

$$C(z, t_0)=f(z), \quad z\geq 0. \tag{2}$$

Boundary conditions at infinity:

$$C(z, t)=0, \quad z\to\infty, 0\leq t\leq T_{\max}. \tag{3}$$

The conditions of boundary line ‘atmosphere – soil’ will be considered as a given flow of radionuclides through the boundary surface of media.

$$D\frac{\partial^2 C}{\partial z}(0,t)-uC(0,t)=0, 0\leq t\leq T_{\max} \tag{4}$$

In order to take into account the radioactive decay, the obtained solution of equation is multiplied by $e^{-\lambda T_{\max}}$ $, where \lambda$ is the radioactive decay constant.

Eq. (1) with initial and boundary conditions (2)-(4) are rather general and are used widely for developing both analytical and numerical models.

3.2 Spatial and temporal analogue of the diffusion/convection equation

To solve this equation, a finite-difference method is employed in our paper. For this purpose, the continuous region under consideration is replaced for a plurality of isolated points, i.e., a grid, and the solution to the equation is determined at these points (grid nodes). The derivatives forming part of the equations are approximated by finite differences and solving the equation in partial derivatives reduces to that of the system of algebraic equations.

In the region being considered, a grid uniform in the spatial variable (*z*) and time variable (*t*) is introduced: ($Z_n=nh$, where $h=Z_{max} / N=const$, $n=0,...,N$) and ($t_j=jt$, where $t = T_{max} / J=const, j=0,...,J$).

To approximate the initial equation, we shall use a relatively well-known method of ‘ahead in time’ differences and central spatial differences. For this purpose, we will employ a three-point spatial template and a two-point time one:

Let us add initial conditions to the equation:

$$C_j^0 = \tilde{N}(z_j, 0) = f(z_j) = f_j,$$

where:

$f_j = \dfrac{Init}{(\dfrac{\theta}{K_d} + \rho) \cdot h}$ ($h=z_{j+1}-z_j$, Init - initial surface contamination) approximates $f(z)$ at points z_j, $j=0,...,J$.

Boundary conditions in the infinity:

$$C(z_j, t_\partial)=0, \quad z \rightarrow \infty, 0 \leq j \leq J,$$

and those at the interface:

$$\frac{D}{U} \cdot \frac{C^n{}_1 - C^n{}_0}{h} - C^n{}_0 = 0, \qquad n=0,...,N.$$

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