

## EXERCISE 4: DYNAMIC SIMULATION OF RADINOCLIDE MIGRATION IN SOIL OF CROPLAND AND RESULTING DOSES TO FRAMER’S FAMILY

### 1. General description of problem

In this exercise we use NORMALYSA to simulate radiation exposure of reference persons (farmer’s family) resulting from agricultural works and consuming radioactively contaminated agricultural products from a contaminated cropland site. Exercise includes dynamic modelling of radionuclide redistribution in cropland soil due to vertical migration and uptake by crops.

#### 1.1 Contamination source term (contaminated site)

We consider a radioactively contaminated site that is used by a farmer’s family as a cropland to grow potatoes. The topsoil layer of site is contaminated by Cs-137 and Sr-90 (e.g., an area contaminated by radioactive fallout from the Chernobyl accident) (FIG 1).

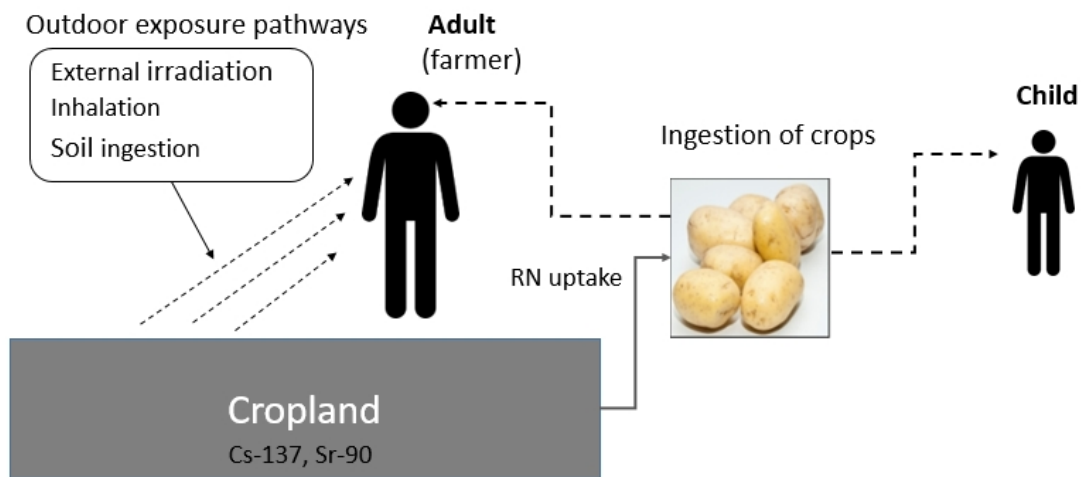


FIG 1. Illustrative scheme for exposure scenario in Exercise 4.

#### 1.2 Reference persons and exposure scenario

The reference persons for dose calculations are members of the farmer’s family (adult, child) who are using the contaminated site as a source of food.

It is assumed that adult (farmer) is exposed to radioactivity in the course of agricultural works at cropland site and due to consumption of radioactively contaminated products (potatoes) grown at the site. The farmer does not use any protective means during agricultural works (e.g., respirator).

The child is exposed to radioactivity only due to consumption of agricultural products.

The respective *exposure pathways* are listed in Table 1.

## NORMALYSA Tutorial

Table 1. Exposure pathways for members of farmer's family considered in Exercise 4.

Adult (Farmer)	Child
Exposure during agricultural works: <ul style="list-style-type: none"> <li>- external exposure;</li> <li>- inhalation of radioactive aerosols;</li> <li>- inadvertent ingestion of contaminated soil.</li> </ul> Consumptions of radioactively contaminated agricultural products	Consumptions of radioactively contaminated agricultural products

### 1.3 Calculation end-points

The calculation end-points for this exercise are the following parameters:

- Radionuclide concentrations (Cs-137 and Sr-90) in the topsoil layer,
- Gamma dose rate from the contaminated soil in cropland,
- Total annual effective doses received by reference persons for the described above exposure scenario.

Contributions of different exposure pathways to the total dose of reference persons (adult, child) shall be analysed.

The calculations shall be carried out for the time period of 100 years with the time step of 10 years.

## 2. Input data

The input data include characteristics and parameters of the cropland area (Table 2 - Table 3) and data on habits of reference persons (Table 4).

It should be pointed out that it is assumed that there is no soil erosion or bioturbation process for the modelled cropland site.

Table 2. Parameters of the cropland area.

Parameter	Value	Unit
Area of cropland	10000	m <sup>2</sup>
Height of the topsoil (rooting zone) layer	0.2	m
Height of the deep soil layer	0.5	m
Density of topsoil	1500	kg/m <sup>3</sup>
Density of deep soil layer	1700	kg/m <sup>3</sup>
Porosity of the topsoil layer	0.35	unitless
Porosity of the deep soil layer	0.25	unitless
Infiltration rate to soil (precipitation plus irrigation minus evapotranspiration rate)	0.2	m/year

Table 3. Parameters of the cropland area that are radionuclide-specific.

Radionuclide	Soil activity concentration (topsoil layer), Bq/kg	Distribution coefficient (Kd) for soil, m <sup>3</sup> /kg	Concentration ratio (CR) for potatoes, unitless
Cs-137	1500	0.5	0.05
Sr-90	700	0.05	0.8

Table 4. Habits of reference persons.

Parameter, unit	Adult	Child
Time spent in cropland, hours per year, hours	100	0
Fractional contribution of potatoes from cropland to yearly diet, %	80	50
Yearly ingestion of potatoes, kg/year	120	80

### 3. General description of implementation of problem in NORMALYSA

#### 3.1 Modules and modelling options used

To carry out calculations for the discussed above problem we will use the following modules of NORMALYSA:

- ‘Cropland’ module from ‘Receptors’ library to simulate radionuclide migration in soil of cropland area and radionuclide uptake by crops (potatoes),
- ‘Dose from occupancy outdoors’ from ‘Doses’=>‘Doses from occupancy’ library to simulate dose to adult (farmer) during agricultural works in cropland area,
- ‘Dose from ingestion of crops’ module from the ‘Doses’=>‘Doses from ingestion of different food types’ library to calculate internal doses to reference persons due to ingestion of contaminated agricultural products,
- To calculate the total dose received by reference person (external, internal exposure), the ‘Total Dose’ module will be used, that will carry out summing of doses calculated by respective dose modules.

#### Modelling options

When calculating radiation exposure in cropland area we will use modeling option allowing calculating ambient dose rate from radionuclide concentrations in soil and air.

### 3.2 NORMALYSA model structure and data exchanges between modules

The structure of NORMAYSA model for Exercise 4 in the form of block-scheme is shown in FIG 2.

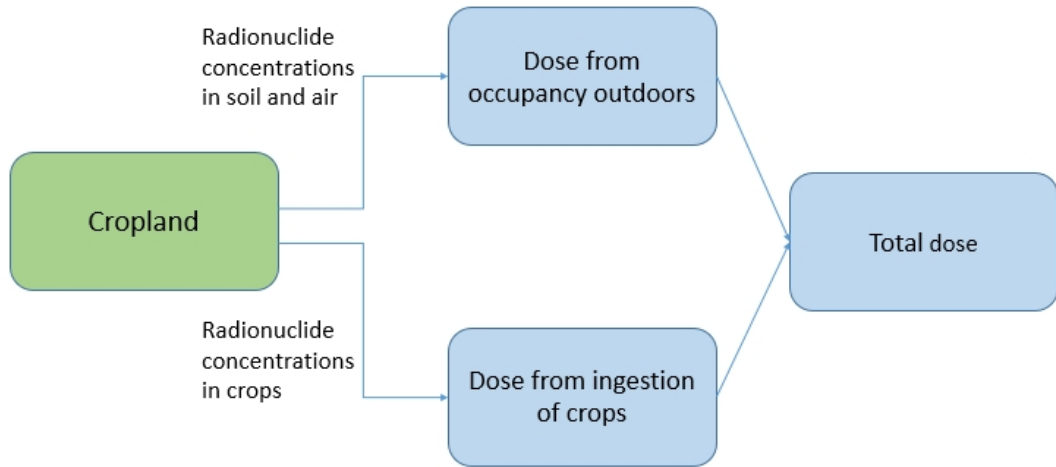


FIG 3. The structure of NORMAYSA model for Exercise 4.

### 3.3 General description of modelling steps

To solve the describe above problem using NORMALYSA, modeller needs to carry out the general sequence of steps shown in FIG 4. This is accomplished by going through different positions of the NORMALYSA main menu (shown to the left in the main software interface window).

The rationale of each NORMALYSA menu position (and respective modelling step) is briefly explained below.

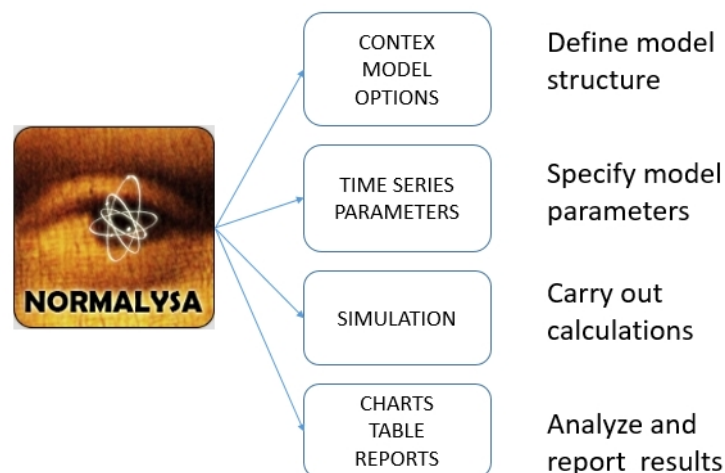


FIG 4. Sequence of modelling steps.

#### Setting the assessment context ('Context')

In this step, the NORMALYSA project file is created defining the simulation case. In particular, user specifies the name of the project file, and selects radionuclides to be included to the

simulation case. Modeler also has a possibility to activate or de-activate specific index lists relevant to modeled case such as, for example, 'Exposed Groups', 'Crop Types' included to simulation, etc. User can also manage here specific interface options, such as language of software interface and some other options.

### Defining the model ('Model')

This is the key step in setting up the modelling case, where user sets up the radioecological model. For composing the model, the Simulator supports classical "Interaction Matrix" interface and graphical "Block-Scheme" ("Graph") interface.

The radiocological model can be composed from modules included to libraries. User selects particular modules needed for his modelling case, and sets up data exchanges between modules.

### Specifying modelling options ('Options')

In this step, user specifies particular modelling options available in relevant modules used to setup the radioecological model.

### Specifying time-dependent input parameters in table format ('Time Series')

In case model includes time-dependent input parameters that need to be specified in table format, input of such parameters is carried out in this menu position.

### Entering model parameters ('Parameters')

In this menu, user has possibility to modify all model parameters.

The NORMALYSA modules are supplied with the default values of all model parameters. Some of these need not to be necessarily changed (for example, dose coefficients for dose assessment calculations). However, almost any model includes site-specific and/or modelling case specific parameters that will need to be specified by user.

### Running the simulation ('Simulation')

This menu allows user to set up simulation options (e.g., starting and ending times, specify output parameters, etc.), and eventually to run the model.

### Analysing results ('Tables' and 'Charts')

The Simulator menu includes two menu items for analysing simulation results: 'Charts' and 'Tables'. These menu items allow modeller to view data either in chart or table format. Simulation data can be also exported to MS Excel file format.

### Generating reports ('Reports')

This menu allows to generate automatically modelling report describing the simulation case, model used, input parameters, and simulation results. The report can be printed or exported to PDF format.

Additional information on user interface of NORMALYSA Simulator can be obtained from context sensitive '*Help Contents*' menu.

Below we will explain in detail how to carry out modelling operations for the considered exercise for the each specified above step (i.e., for the main menu positions).

## 4. Detailed description of composing and running the model in NORMALYSA

### 4.1 'Context' menu position

We start by defining the “context” for the model simulation, which includes defining the model name and selecting the list of radionuclides included in the simulation.

By default, the ‘Context’ window is shown in NORMALYSA when you open the tool.

1. Click the ‘New’ button in the context menu to create a new model file. Press the ‘Edit’ button to get access to the model description field (FIG 5).  
Give a name to the model (“Exercise 4”), fill in your name in the ‘Author’ field (optional) and type a short description of the exercise in the ‘Description’ field (optional).
2. In the context menu, click the ‘Save As’ button, then name and save the model file on an appropriate location in your computer.

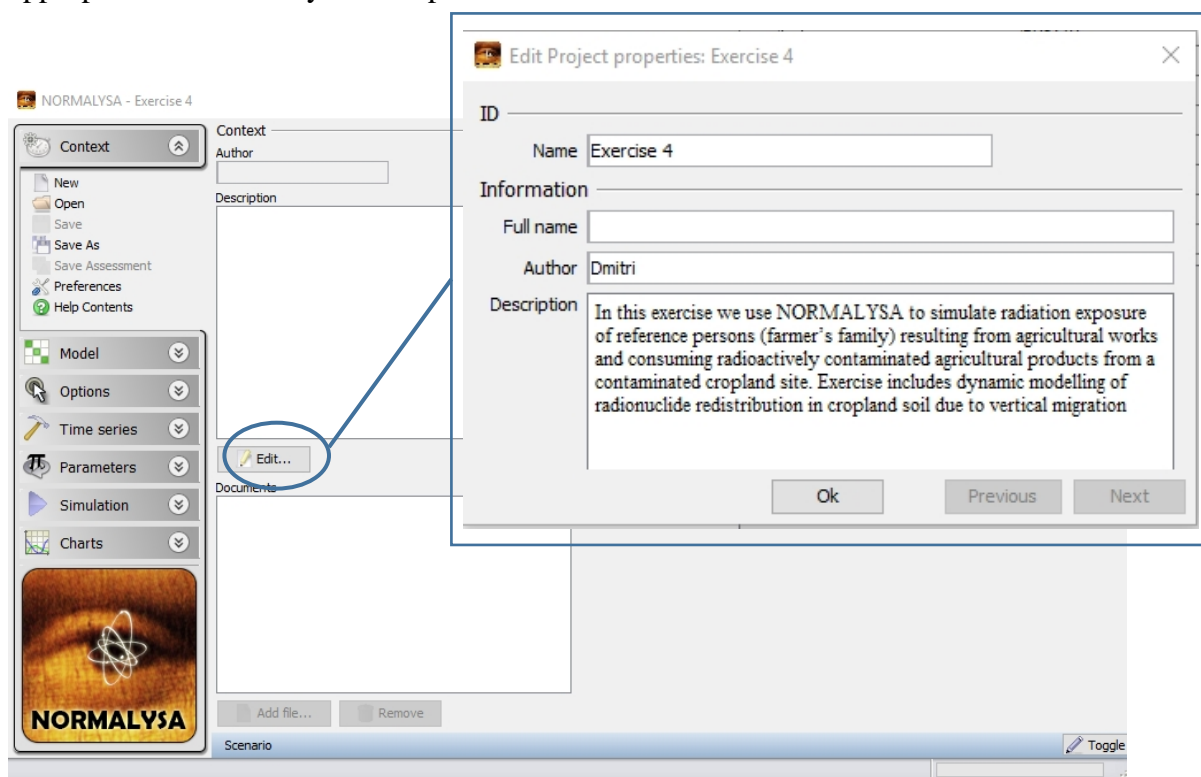


FIG 5. Editing ‘Project properties’ window.

List of ‘Contaminants’ (radionuclides) are shown on the right-hand side of the ‘Context’ window. When you create a new model, all radionuclides and decay chains are enabled by default.

We want to calculate doses from Cs-137 and Sr-90. To select these radionuclides first disable all radionuclides in the ‘Nuclides’ window. Then select Sr-90 and Cs-137 (FIG 6).

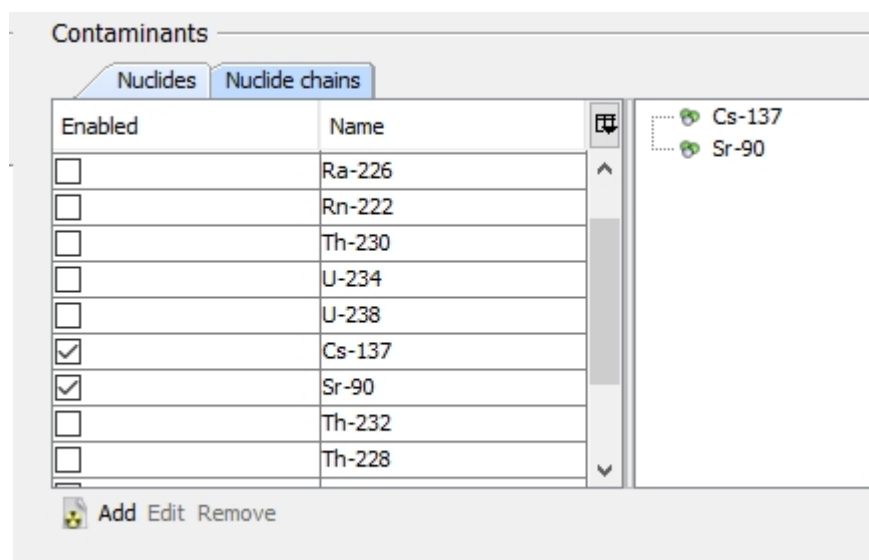


FIG 6. 'Contaminants' window with selected radionuclides.

## 4.2 'Model' menu position

Next, you will assemble the model. In this menu position, we will create the model by using the module library and “connectors” to exchange output and input data between the different modules.

Click on the 'Model' button in the menu to open the model window. NORMALYSA provides two means to visualize the model; either as a box diagram (graph) or as an interaction matrix. You can toggle between the two modes at any time by clicking on the tabs in the upper right corner of the 'Model' window (FIG 7). Next to the 'Graph' button (which is selected by default), you find the 'Matrix' button. Click on it to select the “matrix view”.

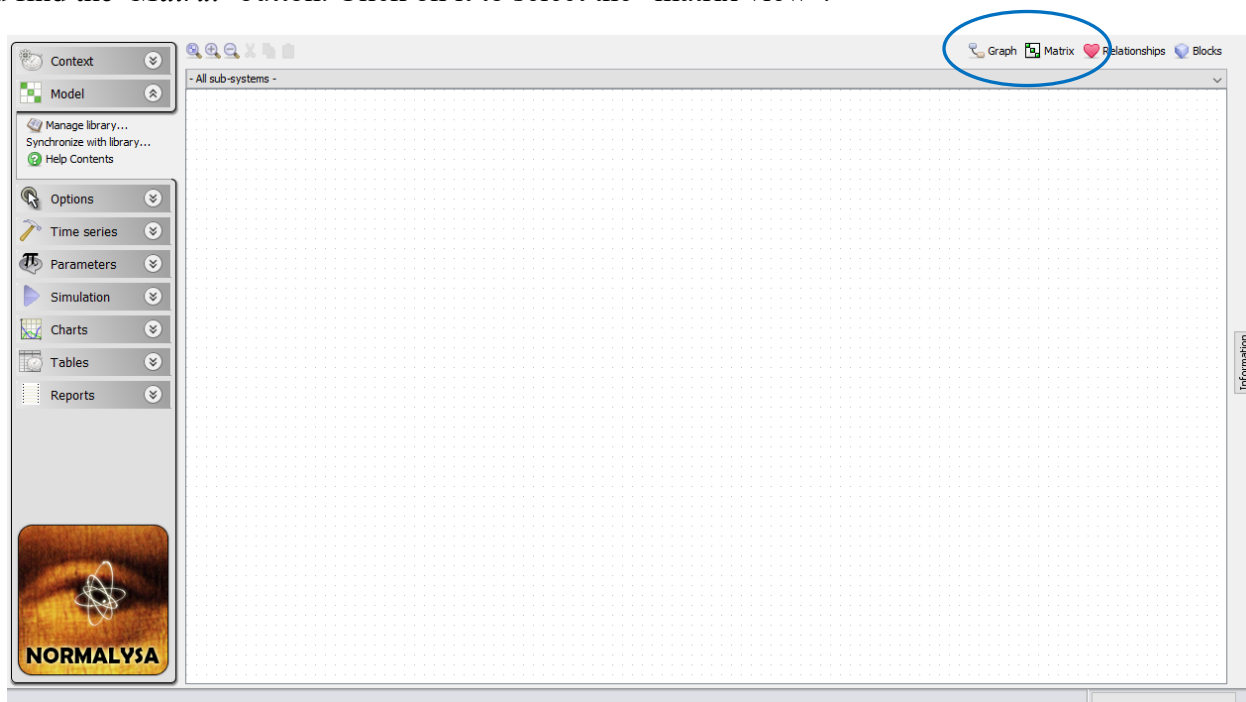


FIG 7. Tabs corresponding to different options ('Graph', 'Matrix') of model visualization.

## NORMALYSA Tutorial

Now we will compose the NORMALYSA model for Exercise 4 using the modules from respective libraries.

1. Right-click on an empty diagonal element in the matrix and choose ‘*Get from the library...*’ (or ‘*Add...*’) from the pop-up menu that appears. (Please note that to add more empty diagonal elements to the matrix you can right click with the mouse on a diagonal element and choose ‘*Insert Above*’ or ‘*Insert Below*’).
2. In the list of modules, select the ‘*Cropland*’ module from the ‘*Receptors*’ folder. You can read a short description of the selected model in the ‘*Description*’ field of ‘*Library*’ window (FIG 8).
3. Click ‘*Ok*’. You should now see the selected module as a “box” on the model area.
4. Right-click in the matrix and choose ‘*Insert Above*’ or ‘*Insert Below*’ to add new diagonal elements.
5. Repeat steps 1 – 4 to insert on the diagonal of the matrix the module ‘*Dose from occupancy outdoors*’ from ‘*Doses from occupancy*’ folder from ‘*Doses*’ library.
6. Repeat steps 1 – 4 to insert on the diagonal of the matrix the module ‘*Dose from ingestion of crops*’ from ‘*Doses from ingestion*’ folder from ‘*Doses*’ library.
7. Repeat steps 1 – 4 to insert the ‘*Total Dose*’ module.

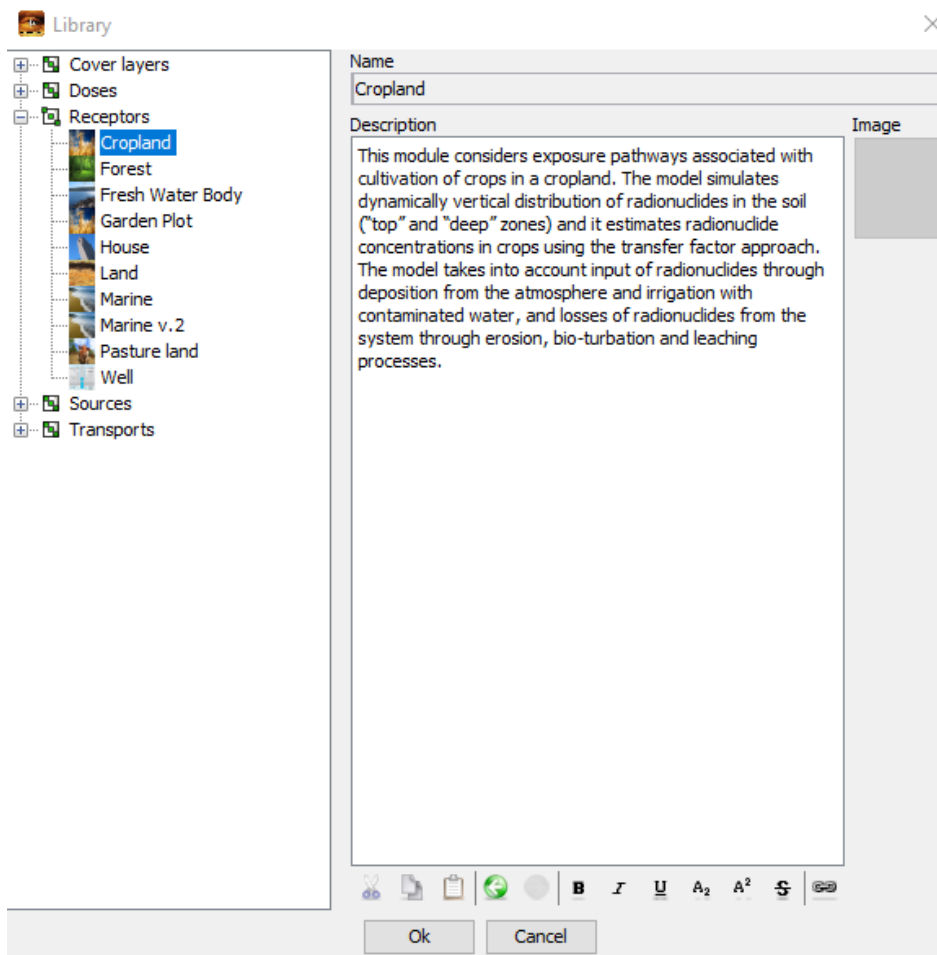


FIG 8. ‘*Library*’ window showing the explanatory text for the ‘*Cropland*’ module from the ‘*Receptors*’ library.

Now we need to connect individual modules in-between each other using “connector” blocks to exchange data. We need to connect the following pairs of modules (see block-scheme at FIG 3):



## NORMALYSA Tutorial

- ‘Cropland’ with ‘Dose from ingestion of crops’,
  - ‘Cropland’ with ‘Dose from occupancy outdoors’,
  - ‘Dose from ingestion of crops’ and ‘Total Dose’,
  - ‘Dose from occupancy outdoors’ and ‘Total Dose’.
1. To create a new “connector” block, right-click on the off-diagonal element of the matrix window projected (horizontally, vertically) on diagonal blocks that need to be connected, and chose ‘Connector’ from the pop-up menu (FIG 9).
  2. Repeat the process of connecting modules until your model will look as in FIG 10.

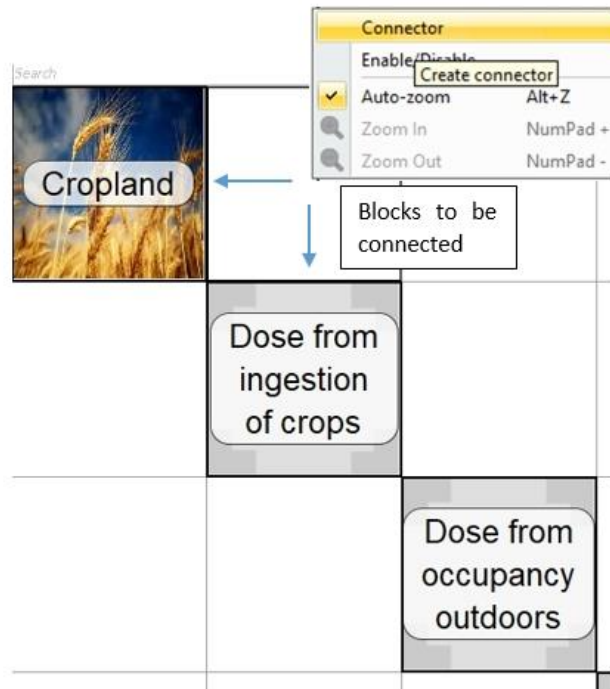


FIG 9. Connecting modules using “connector” blocks for data exchanges.

## NORMALYSA Tutorial

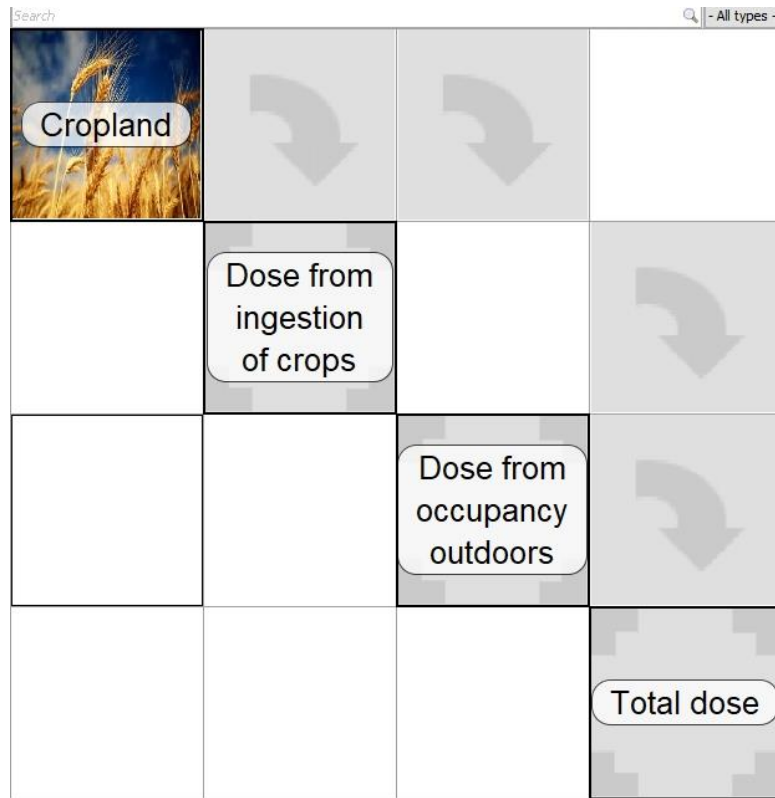


FIG 10. Full model for Exercise 4 including main modules and “connector” in ‘Matrix’ view.

Your next task is to tune the “connector” blocks in order to set proper data exchanges between modules. This process is described below.

1. Double click on the “connector” block between ‘Cropland’ and ‘Dose from ingestion of crops’ modules. The ‘*Edit Connector*’ window will be opened allowing to set up data exchanges between these modules (FIG 11). The left column of window lists the output parameters of the ‘Cropland’ module, while the right column lists the input parameters of the ‘Dose from ingestion of crops’ module. You have to match properly ‘output – input’ parameters between these two columns. The specific parameter can be selected by right-clicking the particular table cell, and selecting the need parameter from the drop-down list that appears.
2. You have to connect the following ‘output (left column) – input (right column)’ parameter pairs:

‘RN concentration in crops’ and ‘Concentration of radionuclide in crop (for respective crop type)’.

Please note that connected parameters need to have same units.

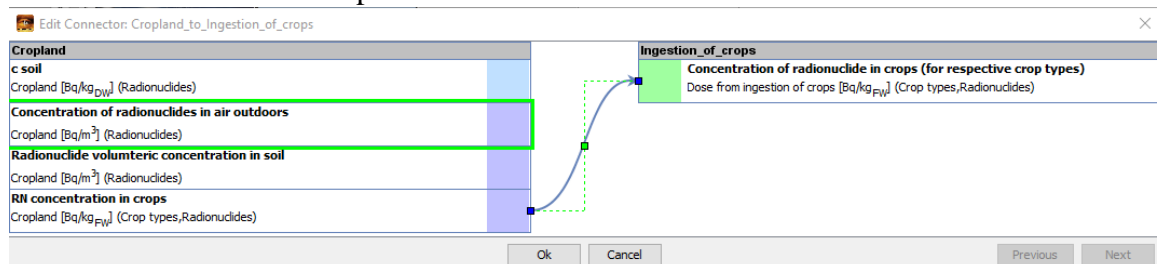


FIG 11. Using ‘*Edit Connector*’ window to set up data exchanges between modules.

## NORMALYSA Tutorial

3. Repeat similar operations for the “connector” block between ‘Cropland’ module and ‘Dose from occupancy outdoors’ module.
4. For these last modules you have to connect the following ‘output (left column) – input (right column)’ parameter pairs:
  - ‘*c soil*’ and ‘*Mass concentration of radionuclide in soil*’;
  - ‘*Radionuclide volumetric concentration in soil*’ and ‘*RN volumetric concentration in soil*’;
  - ‘*Concentration of radionuclides in air outdoors*’ and ‘*Concentration of radionuclide in outdoors air*’.
5. Repeat similar operations for the “connector” block between ‘Dose from ingestion of crops’ module and ‘Total Dose’ module.
6. For these last modules you have to connect the following ‘output (left column) – input (right column)’ parameter pairs:
  - ‘*Dose from ingestion of all cop types summed over all radionuclides*’ and ‘*Total dose from ingestion of food summed over all radionuclides*’;
7. Repeat similar operations for the “connector” block between ‘Dose from occupancy outdoors’ module and ‘Total Dose’ module.
8. For these last modules you have to connect the following ‘output (left column) – input (right column)’ parameter pairs:
  - ‘*Annual effective dose from external exposure outdoors summed over all radionuclides*’ and ‘*Total dose from external exposure summed over all radionuclides*’,
  - ‘*Dose from soil ingestion summed over all radionuclides*’ and ‘*Total dose from soil ingestion summed over all radionuclides*’,
  - ‘*Dose from inhalation outdoors summed over all radionuclides*’ and ‘*Total dose from inhalation summed over all radionuclides*’.

With the described above operations the setup of NORMALYSA model structure and data exchanges is completed.

Before leaving the ‘Model’ window, you can have a look at the NORMALYSA model that you have built in the ‘Matrix’ view (see FIG 10) and ‘Graph’ view (see FIG 12).

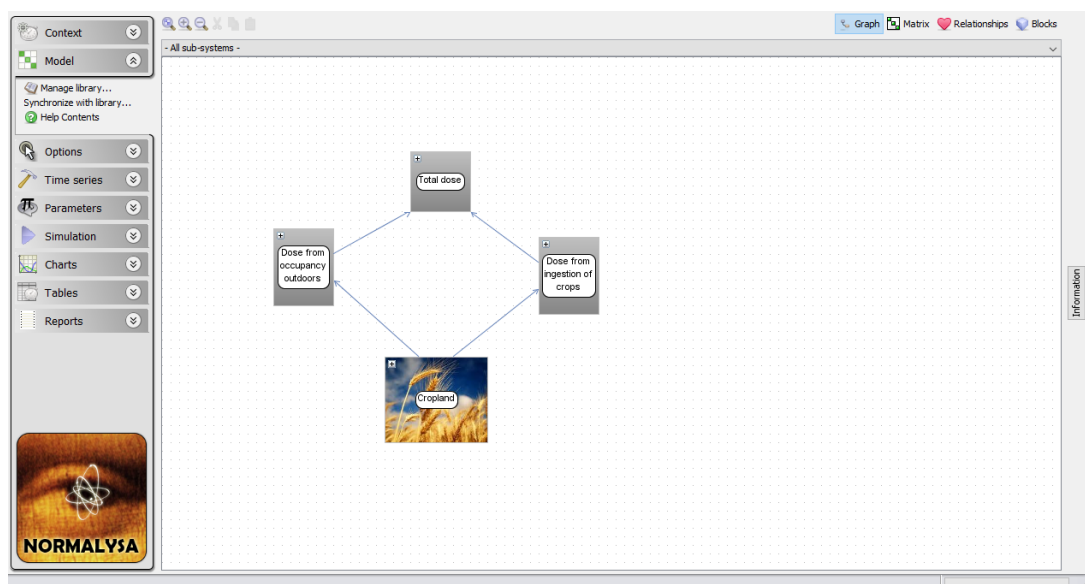


FIG 12. NORMALYSA model for Exercise 1a in the ‘Graph’ view.

## NORMALYSA Tutorial

When the NORMALYSA model is created using one or other combination of modules, a set of different “Indices” (or “index lists”) required by these modules is added automatically to the ‘Context’ window.

Now once we have set up the model, we need to re-iterate to the ‘Context’ window.

### Defining the ‘Exposed Groups’ index list

To inspect the “index lists” included to our model click on the ‘Context’ button in the main menu on the left side to re-open the respective window. The ‘Context’ window displays list of ‘Indices’ in the bottom right corner (see FIG 13).

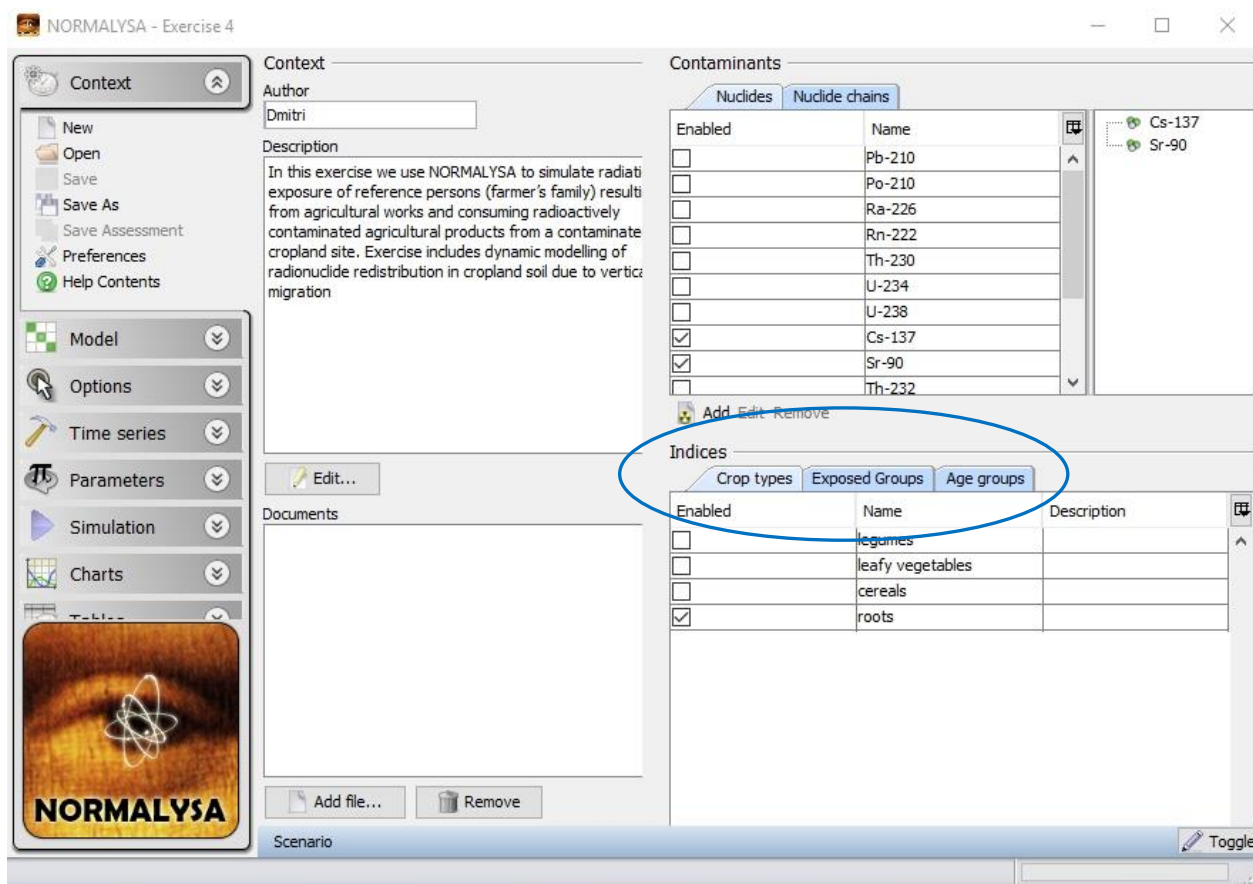


FIG 13. Viewing lists of ‘Indices’ of the newly created NORMALYSA model in ‘Context’ window.

Browse through the respective tabs to see which index lists have been added to NORMALYSA model. You will see three “index lists”: ‘Crop types’, ‘Exposed Groups’ and ‘Age Groups’. By default, all available entries in index lists are selected (activated).

In case of Exercise 4, we will need no to use ‘Exposed Groups’ index list to define age characteristics of reference person considered in this exercise.

1. Click the ‘Exposed Groups’ tab.
2. Rename the existing group “Reference person 1” to “Farmer”. By default, this reference person belongs to ‘Age Group’ category ‘Adults’. Do not change this last setting.
3. Rename the existing group “Reference person 2” to “Child”. By default, this reference person belongs to ‘Age Group’ category ‘Children’. Do not change this last setting.
4. Deselect the remaining reference person.

The result of adjustments of ‘Exposed Groups’ index list are shown in (FIG 14).

Indices			
Crop types			
Exposed Groups			
Age groups			
Enabled	Name	Description	Age groups
<input checked="" type="checkbox"/>	Farmer	Generic adult	Adults
<input checked="" type="checkbox"/>	Child	Generic child	Children
<input type="checkbox"/>	Reference person 3	Generic infant	Infants

FIG 14. Defining the ‘Exposed Groups’ index list.

**WARNING!**

The ‘Age groups’ index list cannot be changed in NORMALYSA. You can only assign respective age groups from this list to the reference persons listed in ‘Exposed Groups’ window.

Next we need to define ‘Crop types’ index list. In this exercise we are calculating doses due to ingestion of potatoes grown in cropland, which belong to the crop category ‘roots’. Therefore, you need to do the following:

1. Select ‘Crop types’ tab.
2. Tag (select) ‘roots’ crop category and deselect all other categories.

Indices		
Crop types		
Exposed Groups		
Age groups		
Enabled	Name	Description
<input type="checkbox"/>	legumes	
<input type="checkbox"/>	leafy vegetables	
<input type="checkbox"/>	cereals	
<input checked="" type="checkbox"/>	roots	

FIG 15. Defining the ‘Crop types’ index list.

4.3 ‘Options’ menu position

In some NORMALYSA modules you can choose among a number of different options for calculation of model variables (parameters). These options (if available) are accessed through the ‘Options’ button.

In case of this exercise, we need just to leave default selections of options for respective parameters.

One of these options states that radionuclide concentrations in soil of cropland are calculated dynamically using radionuclide migration model (rather than it is specified as a constant in time parameter, which is based on direct measurements) (FIG 16).

## NORMALYSA Tutorial

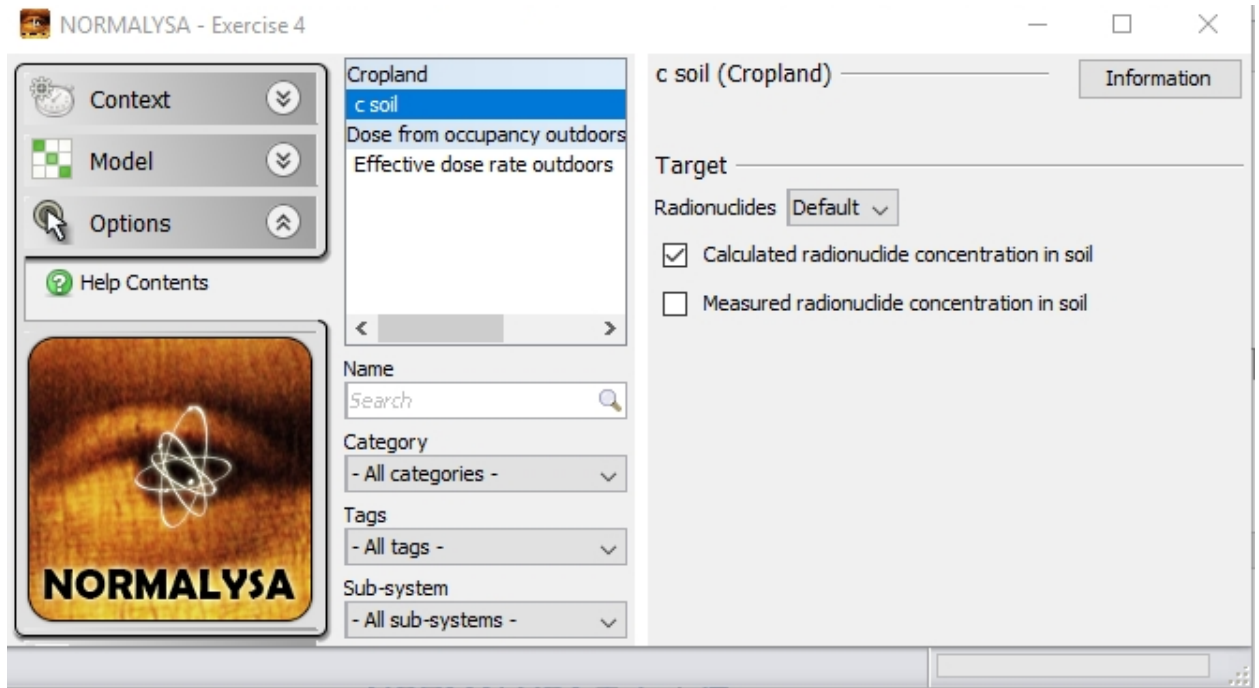


FIG 16. Modelling options for calculating soil concentration of radionuclides in ‘Cropland’ module.

The second modelling options is related to the module ‘Dose from occupancy outdoors’. The default value for this option states that the effective dose rate outdoors is calculated based on simulated radionuclides concentrations in soil and air (rather than it is specified as a constant in time parameter, which is based on direct measurements).

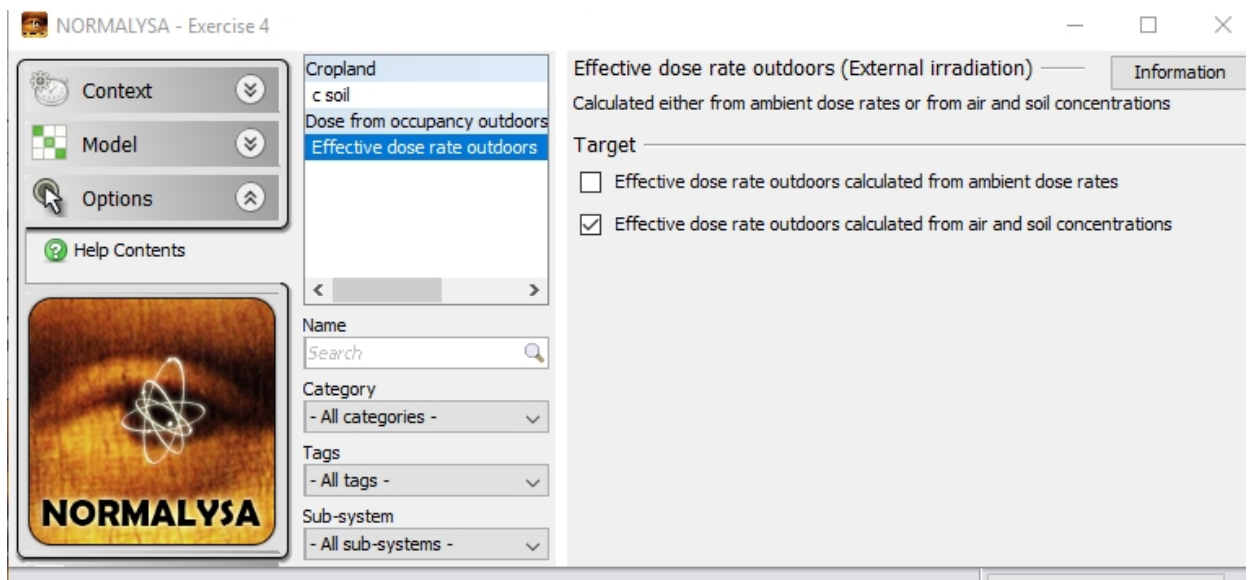


FIG 17. Modelling options for calculating effective external dose rate in ‘Dose from occupancy outdoors’ module.

### 4.4 ‘Time series’ menu positions

In the considered exercise, we do not need to make any inputs or adjustments in ‘Time series’ menu position.



### 4.5 'Parameters' menu position

Our next task is to define various model parameters. Open the '*Parameters*' window by clicking on the respective button in the main menu.

The '*Parameters*' window displays to the left all parameters needed by the model (FIG 18).

In the upper right part of the window, you see information on parameter that is currently selected. Click the button '*Information*' in the upper right corner to view parameter units and other relevant information.

In the bottom right part of the window the '*Data*' table is displayed, where you can view and edit parameter value. For some parameters you can use default values, but for some you may want to use values specific to your study, and these must be entered. When you input data be careful with parameter units.

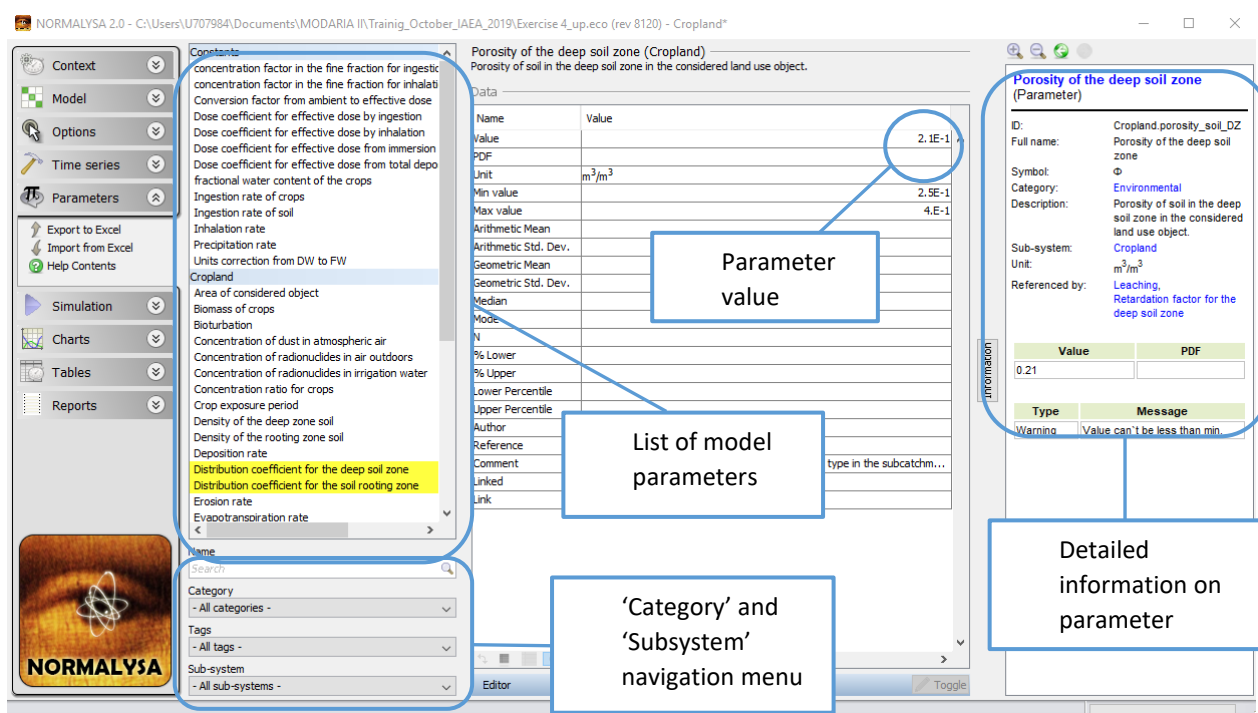


FIG 18. '*Parameters*' window.

You can use the controls in the left bottom corner of the window below the parameter list to search for specific parameters. The '*Category*' drop-down list allows you to display only parameters of a specific category. The '*Sub-system*' drop-down list allows you to display parameters only for a specific sub-system / module. (In our case these are: 'Cropland', 'Dose from ingestion of crops', 'Dose from occupancy outdoors', 'Total Dose', and 'Constants' block where various constants used in the model such as dose conversion coefficients, inhalation rate, etc. are compiled).

Before proceeding to entering parameter values, we need to carry out conversion of parameter units for some model parameters (see below).

Calculation of radionuclide initial deposition on cropland

The ‘Cropland’ module used in Exercise 4 requires as an input parameter ‘Initial deposition on cropland’ (*Dep\_Init*, expressed in Bq), that is initial activity inventory in the topsoil layer for the whole cropland system.

The following formula is used to calculate this parameter for respective radionuclides (Cs-137, Sr-90):

$$Dep\_Init = Area \times h\_soil\_RZ \times rho\_soil\_RZ \times C\_soil\_RZ,$$

Where *Area* (m<sup>2</sup>) is cropland area, *h\_soil\_RZ* (m) is height of topsoil layer, *rho\_soil\_RZ* (kg/m<sup>3</sup>) is density of topsoil layer, and *C\_soil\_RZ* (Bq/kg) is radionuclide-specific activity concentration in topsoil layer.

Conversion of units for time of exposure of reference persons

The ‘Dose from occupancy outdoors’ module used in Exercise 4 requires as an input parameter time of exposure of reference person expressed as ‘Fraction of the year that the reference person stays in a specific receptor’. Initially, time of exposure of farmer in cropland was provided in hours. So, we have to re-calculate this parameter to the needed unit.

The following formula is used to recalculate time of exposure from hours (*Time<sub>hours</sub>* = 100 hours/year) to corresponding time value expressed as a fraction of year (*Time<sub>fraction.year</sub>*):

$$Time_{fraction.year} = Time_{hours} / (24 \text{ hours/day} \times 365.25 \text{ days/year}) = 0.0114.$$

Data input for Exercise 4

For each of the parameter sets listed below carry out the following operations:

- Select the needed sub-system / module (e.g., ‘Cropland’, etc.)
- Select one-by-one each parameter in the list
- Enter the needed parameter value(s).

All needed parameter values are provided in Section 2 of this exercise. For convenience, these parameters are repeatedly presented below in Table 5 - Table 9 in accordance with the respective sub-systems (modules). If some parameter is not listed explicitly in tables below, this means that the default value of this parameter in NORMALYSA shall not be changed.

Table 5. Parameters of the sub-system ‘Cropland’

Parameter	Value	Unit
Area of considered object	10000	m <sup>2</sup>
Bioturbation	0	kg/(m <sup>2</sup> year)
Density of the deep zone soil	1700	kg/m <sup>3</sup>
Density of the rooting zone soil	1500	kg/m <sup>3</sup>
Erosion rate	0	kg/(m <sup>2</sup> year)
Evapotranspiration rate	0	m/year
Height of the deep soil zone	0.5	m
Height of the soil rooting zone	0.2	m
Irrigation rate of crops	0	m/year
Porosity of the deep soil zone	0.25	unitless
Porosity of the soil rooting zone	0.35	unitless



## NORMALYSA Tutorial

Table 6. Parameters of the ‘Cropland’ sub-system that are radionuclide-specific

Parameter	Unit	Cs-137	Sr-90
Concentration ratio of crops	Unitless	0.05	0.8
Distribution coefficient for the deep soil zone	m <sup>3</sup> /kg	0.5	0.05
Distribution coefficient for the dep soil zone	m <sup>3</sup> /kg	0.5	0.05
Initial deposition on cropland	Bq	4.5E9	2.1E9

Table 7. Parameters of the sub-system ‘Constants’

Parameter	Value	Unit
Precipitation rate	0.2	m/year

Table 8. Input parameter values for sub-system ‘Dose from ingestion of crops’

Parameter	Exposed Group	
	Farmer	Child
Fractional contribution crops from the cropland to the total ingestion of crops	0.8	0.5

Table 9. Input parameter values for sub-system ‘Dose from occupancy outdoors’

Parameter	Exposed Group	
	Farmer	Child
Fraction of the year that the reference person stays in a specific receptor	0.0114	0

### 4.6 ‘Simulation’ menu position

Now when we have composed the NORMALYSA model, and have defined input parameters, we are ready to carry out simulation.

Open the simulation window by clicking on the ‘*Simulation*’ button in the menu. This window allows you to adjust/change simulation settings and eventually to carry out the simulation.

The table in the bottom part of the window will display any errors and/or warnings (if present) – for instance if a value of some parameter is missing (is not defined) in the model. You cannot start a simulation if errors are shown in this table.

Before proceeding to calculations, we need to adjust simulation time settings and the list of output parameters.

Adjusting the simulation time settings

By default, simulation time is 100 years, so we keep this setting. However, we need to adjust the time step of the output to 10 years.

1. Click the ‘*Simulation Settings*’ sub-menu to the left. The ‘*General*’ tab of the ‘*Edit Simulation Settings*’ window will appear, that allows setting the overall simulation time and output times.
2. Check that the ‘*End time*’ is 100.0 (‘*Years*’) (FIG 19).
3. To adjust the output times, first press ‘*Remove*’ button at the right side of the ‘*Outputs*’ window to clear the default value of ‘*Time series*’ field.
4. Press ‘*Add*’ button at the right side of the ‘*Outputs*’ window, choose ‘*Linear*’ type of output in the menu that appears, and set ‘*N*’ parameter specifying the number of output times to “11” (see FIG 19). (The output time step is calculated as (‘*Start time*’ – ‘*End time*’)/(*N*-1)). Press ‘*Ok*’ button to close the window (s).

The ‘*Edit Simulation Settings*’ settings window with the adjusted simulation time/output parameters is shown in FIG 20.

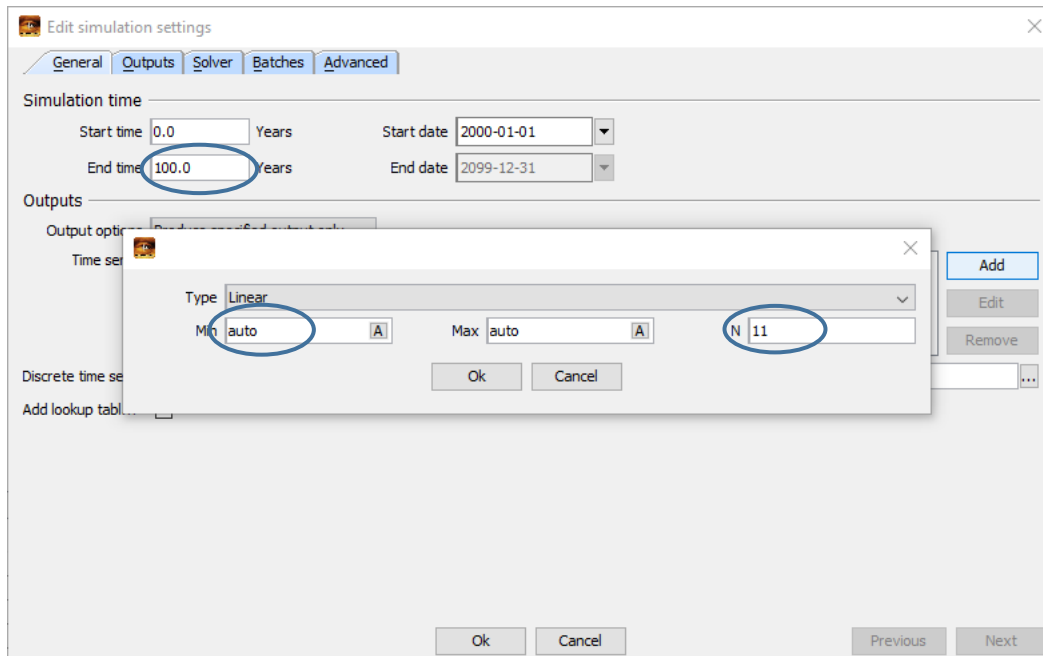


FIG 19. Adjusting of the ‘*Simulation time*’ and ‘*Outputs*’ parameters.

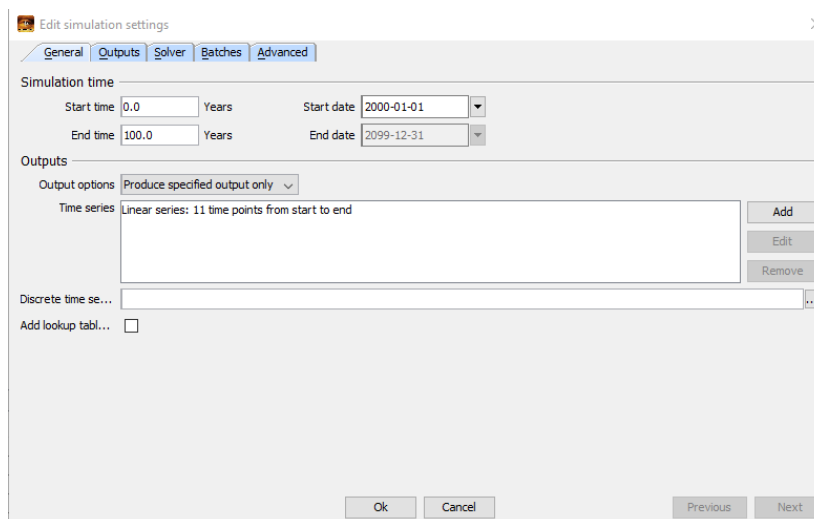



FIG 20. The resulting ‘*Simulation time*’ and ‘*Outputs*’ parameters settings.

### Adjusting the list of model outputs

Now we will adjust the list of NORMALYSA model outputs that will be included to the list of modeling results upon completion of simulation. (We need to do so as we are interested in a larger list compared to the default list of output parameters).

1. Click the ‘*Simulation Settings*’ sub-menu to the left, and choose ‘*Outputs*’ tab in the ‘*Edit Simulation Settings*’ window that appears. The window will be opened listing in the right sub-window model outputs. The left sub-window lists all other available model parameters. Output parameters are grouped according to respective sub-systems.
2. Click button  to clear the right window. Once this window is cleared, we will select from the respective sub-systems the outputs we are interested in.
3. Choose in the left window the ‘*Cropland*’ sub-system, select the ‘*RN concentration in soil*’ parameter, and click ‘>’ button.
4. Repeat the same operations with the following parameters from the ‘*Dose from ingestion of crops*’ sub-system: ‘*Dose from ingestion of all crop types for each radionuclide*’ and ‘*Dose from ingestion of all crop types summed over all radionuclides*’.
5. Repeat the same operations with the following parameters from the ‘*External irradiation - Dose from occupancy outdoors*’ folder from the ‘*Dose from occupancy outdoors*’ sub-system: ‘*Effective dose rate outdoors*’, ‘*Annual effective dose from external exposure outdoors*’.
6. Repeat the same operations with the following parameters from the ‘*Inhalation - Dose from occupancy outdoors*’ folder from the ‘*Dose from occupancy outdoors*’ sub-system: ‘*Dose from inhalation outdoors for each radionuclide*’, ‘*Dose from inhalation outdoors summed over all radionuclides*’.
7. Repeat the same operations with the following parameters from the ‘*Soil ingestion - Dose from occupancy outdoors*’ folder from the ‘*Dose from occupancy outdoors*’ sub-system: ‘*Dose from soil ingestion for each radionuclide*’, ‘*Dose from soil ingestion summed over all radionuclides*’.
8. Repeat the same operations with the following parameters from the ‘*Total Dose*’ sub-system: ‘*Total dose from all exposure pathways summed over all radionuclides*’.
9. The resulting ‘*Edit Simulation Settings*’ window with selected list of output parameters is shown in FIG 21. Press ‘*Ok*’ button to complete the process.

# NORMALYSA Tutorial

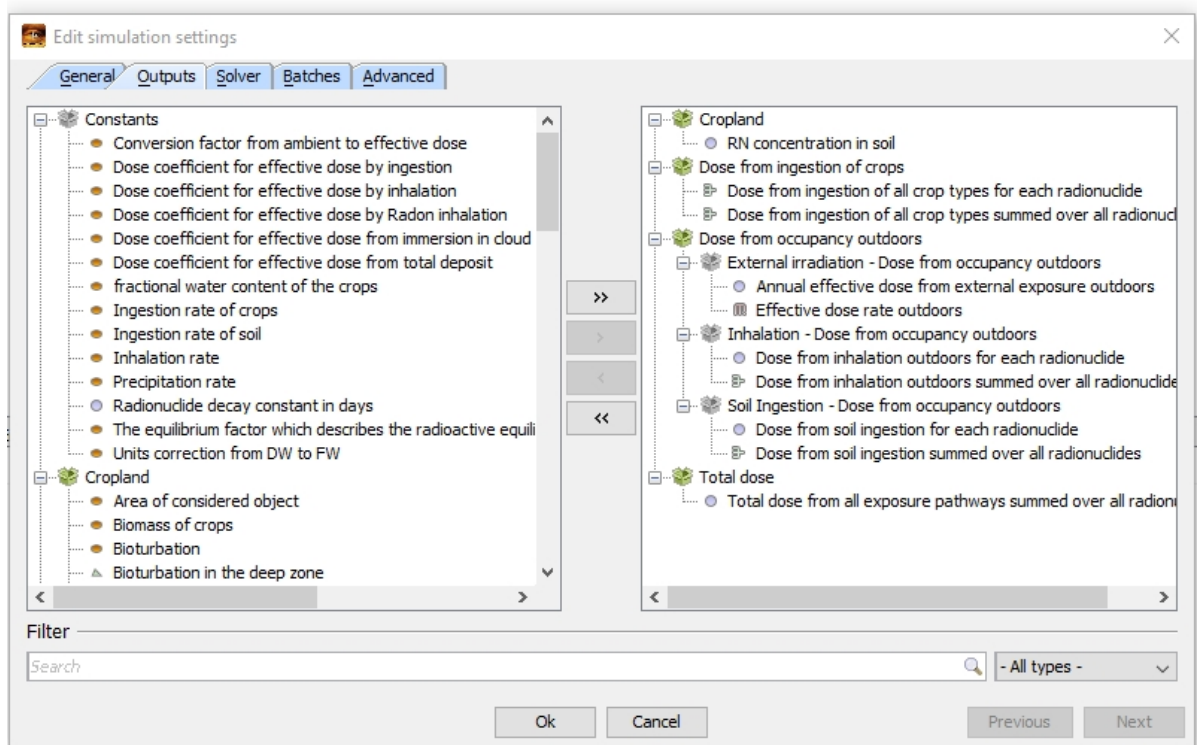


FIG 21. Adjusting the list of NORMALYSA model outputs.

## Running the model

Click the 'Run' button in the upper corner to perform the simulation (FIG 22).

The 'Information' window will display information on the progress of simulation process.

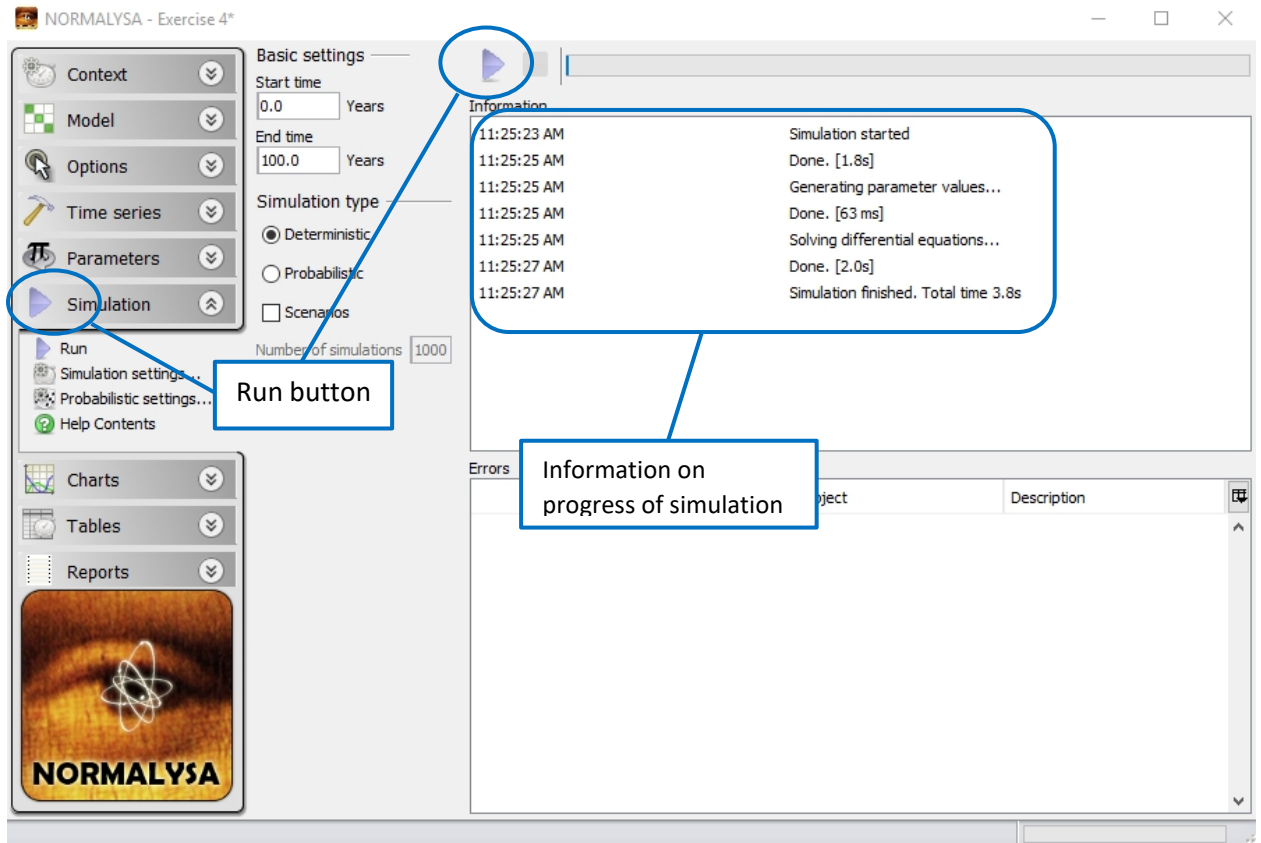


FIG 22. Running the NORMALYSA model.

## 4.7 Viewing simulation results

Simulation results can be viewed either in charts or in tables using the respective buttons of the main menu.

### Viewing simulation results in table format

To view results of the calculation in table format, open the respective window by clicking the 'Tables' button in the main menu to the left.

The available simulation results are listed in a sub-window immediately to the right from the main menu. Similarly to 'Parameters' window, you can use the controls below this window to search and filter out needed contents from the list of outputs.

The results are grouped in "folders" where the root folder has as a name the date and time of simulation.

To create a time table for the specific parameter(s) in the 'Quick View' window to the right, select the output parameter(s) of interest in the displayed tree of simulation results with the left mouse button. Several parameters can be selected by pressing and holding simultaneously the 'Ctrl' key on the keyboard. In case the selected parameter is dependent of an "index list" (such as 'Exposed groups', 'Crop Types' or 'Nuclides' index list), the needed entries of the index lists need to be tagged (the index lists corresponding to selected parameters appear below the window with simulation results).

For example, the following operations need to be carried out to display the table with the simulated radionuclide concentrations in topsoil (rooting zone) later of cropland.

1. Select with the left mouse button in the window of simulation results the output parameter '*RN concentration in soil*' inside the '*Cropland*' folder.
2. Tag '*All*' box (from the index list of nuclides) that will be displayed immediately below the window with the simulation results.
3. The time table displaying results of dose calculations for radionuclides (Cs-137, Sr-90) in soil will be shown in '*Quick View*' window (FIG 23).
4. You can make adjustments to the format of the displayed numerical values in the respective fields of '*Format*' window that appears immediately below the '*Quick View*' window.

Similar operations can be carried out to display in table format simulation results for doses to reference persons through different pathways from respective radionuclides (or total dose(s)). To do so, select the parameters of interest, and tagged needed boxes in the index list of nuclides and/or exposed groups that will appear below the window with the simulation results.

### Exporting data to Excel

In order to export table with simulation results to MS Excel, right click the 'Quick View' window displaying the needed table, and choose '*View in Excel*' from the pop-up menu that appears.

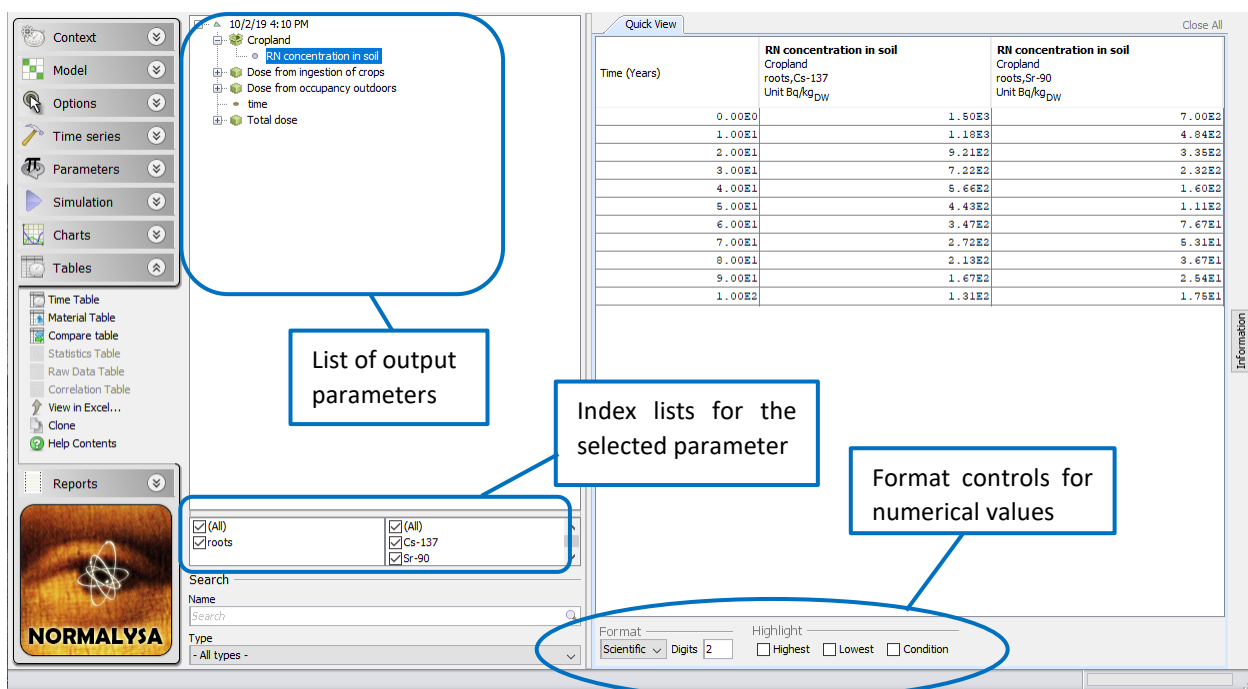


FIG 23. Displaying the table with the calculated radionuclide concentration in soil (in the rooting layer) in Exercise 4.

### Viewing simulation results in graphical (chart) format

To view results of the calculation in graphical format, open the respective window by clicking the 'Charts' button in the main menu to the left.

The operations needed to display charts are generally similar to displaying results in table format (see previous paragraph). To create a time graph for the specific parameter(s) in the 'Quick View' window to the right, the output parameter(s) of interest have to be selected in the displayed tree of simulation results with the left mouse button. Several parameters can be selected by pressing and holding simultaneously the 'Ctrl' key on the keyboard. In case the selected parameter is dependent of an "index list" (such as 'Exposed groups', 'Crop Types' or 'Nuclides' index list), the needed entries of the index lists need to be tagged. Some principal adjustments to the style and format the displayed chart can be made in the respective fields of 'Plot' window that appears immediately below the 'Quick View' window with the chart.

For example, the following operations need to be carried out to display the graph with the calculated annual effective doses to reference person 'Farmer' through different exposure pathways.

1. Select with the left mouse button in the window of simulation results the output parameter '*Dose from ingestion of all crop types summed over all radionuclides*' inside the '*Dose from ingestion of crops*' folder.
2. Press and hold 'Ctrl' key and select in a similar way the dose calculation results for other exposure pathways from the '*Dose from occupancy outdoors*' folder:
  - '*Annual effective dose from external exposure outdoors*' ,
  - '*Dose from inhalation outdoors summed over all radionuclides*'
  - '*Dose from soil ingestion summed over all radionuclides*' .

## NORMALYSA Tutorial

3. Tag 'Farmer' box in the index lists of exposed groups that will be displayed immediately below the window with the simulation results.
4. The time graph displaying dose calculation results of interest will be shown in 'Quick View' window.
5. Select the 'Bottom' option for legend location in 'Plot' window below the chart.'

The resulting time graph of radionuclide concentrations in well is shown in FIG 24.

Similar operations can be carried out to display other simulation results of interest.

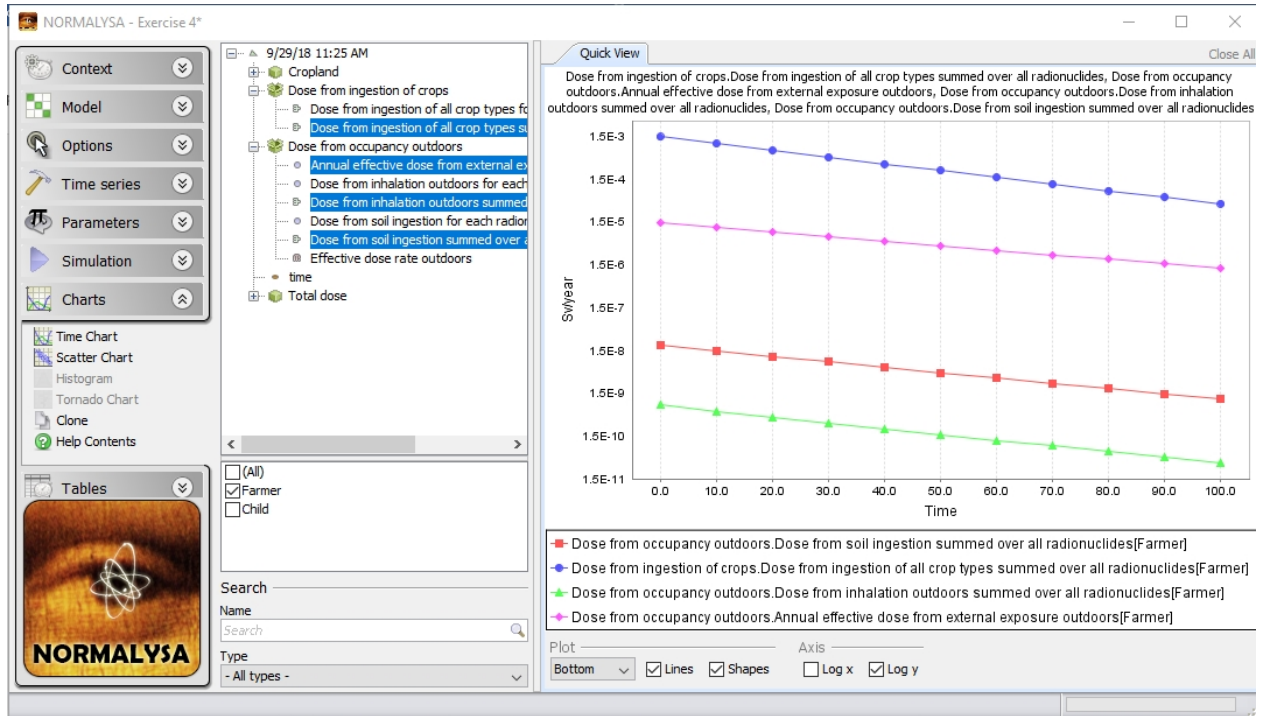


FIG 24. Displaying in chart format simulated doses through different exposure pathways to 'Farmer' reference individual for Exercise 4.



## 5. Results of exercise

This section lists simulation results in table format for exercise cross-checking purposes.

### 5.1 Radionuclide concentrations in the soil rooting zone layer

Simulation results for radionuclide concentrations in soil rooting zone layer are shown in Table 10. It can be seen that concentrations of both Cs-137 and Sr-90 decrease in time due to leaching by infiltration flow and radioactive decay. The Sr-90 concentration in soil decreases faster compared to Cs-137 because Sr-90 has smaller sorption distribution coefficient (Kd) value.

Table 10. Simulated radionuclide concentrations in soil rooting zone layer.

Time, years	Radionuclide concentration in soil, Bq/kg	
	Cs-137	Sr-90
0	1500.0	700.0
10	1175.4	484.3
20	921.1	335.1
30	721.8	231.8
40	565.6	160.3
50	443.2	110.9
60	347.3	76.7
70	272.1	53.1
80	213.2	36.7
90	167.0	25.4
100	130.9	17.5

### 5.2 Gamma dose rate from soil layer

Simulated gamma dose rate outdoors is shown in Table 11. Dose rate decreases in time due to radionuclide leaching from soil rooting zone by infiltration flow and radioactive decay.

Table 11. Effective dose rate outdoors, Sv/h

Time, years	Effective dose rate outdoors, Sv/h
0	1.4E-07
10	1.1E-07
20	8.6E-08
30	6.7E-08
40	5.2E-08
50	4.1E-08
60	3.2E-08
70	2.5E-08
80	2.0E-08
90	1.5E-08
100	1.2E-08

5.3 Doses to reference individuals through respective exposure pathways

Annual doses to ‘Farmer’ through respective exposure pathways are shown in Table 12. It can be seen that internal dose due to ingestion of crops by far dominate exposure through other pathways. Among pathways related to outdoor exposure due to farmer’s work in cropland, the external exposure is the main exposure pathway.

Annual doses to ‘Child’ due to ingestion of contaminated crops are shown in Table 13. It can be seen that doses are smaller compared to adult, which can be explained by smaller consumption rate of potatoes by child.

Doses to reference individuals decrease in time due to radionuclide concentrations decrease in the rooting zone layer, that is the source of exposure of farmer and the source of radionuclide uptake by potatoes.

Table 12. Simulated doses to farmer through various exposure pathways and total dose.

Time, years	Annual effective doses per pathway and total dose, Sv/y				
	Ingestion of crops	External exposure	Inhalation	Soil ingestion	Total dose
0	1.21E-04	1.39E-05	3.13E-09	3.90E-08	1.35E-04
10	8.43E-05	1.09E-05	2.27E-09	2.88E-08	9.52E-05
20	5.89E-05	8.55E-06	1.65E-09	2.13E-08	6.75E-05
30	4.12E-05	6.69E-06	1.20E-09	1.59E-08	4.79E-05
40	2.88E-05	5.24E-06	8.77E-10	1.18E-08	3.41E-05
50	2.02E-05	4.11E-06	6.44E-10	8.85E-09	2.43E-05
60	1.42E-05	3.22E-06	4.74E-10	6.65E-09	1.74E-05
70	9.98E-06	2.52E-06	3.51E-10	5.02E-09	1.25E-05
80	7.03E-06	1.97E-06	2.61E-10	3.79E-09	9.00E-06
90	4.97E-06	1.55E-06	1.94E-10	2.88E-09	6.52E-06
100	3.51E-06	1.21E-06	1.45E-10	2.19E-09	4.72E-06

Table 13. Simulated doses to child due to ingestion of crops.

Time, years	Dose from ingestion of crops, Sv/y
0	2.18E-04
10	1.51E-04
20	1.05E-04
30	7.28E-05
40	5.06E-05
50	3.52E-05
60	2.45E-05
70	1.70E-05
80	1.19E-05
90	8.28E-06
100	5.78E-06

## 6. Exercise for independent work

For the given above exercise, analyze contribution of different radionuclides (Cs-137, Sr-90) to various exposure pathways to reference individuals.

Answer the following question:

- Which radionuclide provides the largest contribution to internal exposure pathway (consumption of crops)?
- Which radionuclide provides the largest contribution to external exposure pathway (for farmer)?
- Which radionuclide provides the largest contribution to inhalation pathway (for farmer)?

Carry calculations to for scenario assuming that reference individuals in addition to potatoes are consuming cabbage (crop type '*Leafy Vegetables*') from the contaminated cropland. The yearly intake of cabbage for '*Adult*' category is 40 kg/year, and for '*Child*' it is 25 kg/year. The contributions of cropland to yearly diets of salad by reference individuals are same as for potatoes. For other model parameters related to growth and consumption of cabbage use default values of NORMALYSA for the crop type '*Leafy Vegetables*'. The time spent by farmer in cropland for agricultural works shall be increased to 120 hours.